Tuning of the Pressure Equation in the Natural Gas Transmission Network

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ABSTRACT
The best and most economical way of transportation of natural gas in immense scale and for a long time is pipeline.
In this paper a small portion of the natural gas transmission networks in Iran has been analyzed, Part of the main export pipeline with some branch to Local consumers.
From the perspective of a manager or engineer of Gas industry, Gas distribution network is a set of parameters; the most important parameter is pressure at any point of gas network. Engineering Software estimates the pressures based on the pressure equation; these equations have always some errors, sometimes the error is a too much as far as could be cause serious problems in gas distribution. In general gas equation is Connection between flow pressure pipelines; based on temperature, roughness, compressibility factor, density gas pipeline specifications and environmental changes. In this research we have tried to adapt the amount of pressure based on Roughness values changes.

Recently, several statistical techniques are used to solve such problems, in this study, the genetic algorithm is used. Along with error correction it has time saving compared to the analytical methods.
Tuning process in this network System error can be reduced by up to 8 times in first step and it can be insignificant if the strong computer Processor or sufficient time be available.

General Terms
D - pipe internal diameter
L - length
P - pressure
Q - actual flow rate
T - temperature
Z - gas compressibility factor
η - compressor adiabatic efficiency

Keywords
Gas transmission, Pipeline, Optimization, Pressure equation, NG behavior simulation, Statistical calculations, Tuning

1. INTRODUCTION
Gas, as a result of the storage difficulties, needs to be transported immediately to its destination after production from a reservoir. There are a number of options for transporting natural gas energy from oil and gas fields to market (Rojey et al., 1997; Thomas and Dawe, 2003). These include pipelines, liquefied natural gas (LNG), compressed natural gas (CNG), gas to solids (GTS), i.e., hydrates, gas to power (GTP), i.e., electricity, and gas to liquids (GTL), with a wide range of possible products, including clean fuels, plastic precursors, or methanol and gas to commodity (GTC), such as aluminum, glass, cement, or iron [4].

Gas Network Management
Gas network management Means: setting the pressure and input Equipment's power; so that doesn't accrue any pressure drop or abnormal pressure in the network. The manager tool for this purpose is dispatching, Dispatching is a set of tools and software which Connect between the equipment and engineers. Equipment generally has little specified error value that will be negligible by calibration; but softwares are more challenging, this will be discussed in following.

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 Equation (11-1) (Uhl, 1965, Schroeder, 2001)[4]:

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

Where Q_{sc} is standard gas flow rate, measured at base temperature and pressure, ft^3/day;

Pipelines are usually not horizontal; however, as long as the slope is not too great, a correction for the static head of fluid (H_c) may be incorporated into Equation (11-1) as follows (Schroeder, 2001) [4].

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

Error definition
Based on the review Of Data taken from network measurement system Significant amount of error is 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 during the history by provided newer Equations.

Sources of Error
Perhaps the first question that comes to mind is: "Why no equation does not really accurate answer"

The answer is pipelines condition and what will happen in feature is ambiguous. Such as:

1 - Aging the pipes; this factor is influenced by many parameters (such as temperature tubes per minute, precise amounts of alloy composition, metallurgy metal tube sex, gas ...)

2 – Environment; Temperature and weather forecast for the next few days Is an approximate so Temperature and weather exact forecasting for over than 30 years is impossible

The only way in this issue is using statistical optimization for fixing the Equations which used in softwares.

Such corrections are common in developed countries, for example (in 2012), ATMOS International Limited has carried out extensive research on the Subsea Pipeline Models [3].

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.

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2. **NETWORK** SIMULATION

Studied Network in The paper is a branched network (Figure 4) Simulation codes have written Based on the traditional equations (in this study AGA are chosen)

In this study the temperature changes are ignored, the reason for this is: a) pipelines are buried b) Attempts to correct the equation only Based on the roughness is modification

Most common Equations

In order to construct a pipeline from a conventional equation for gas transmission network this is used in most National Iranian Gas Company's software:

AGA

The AGA fully turbulent is the most frequently recommended and widely used equation L high-pressure, high-flow-rate systems for medium- to large-diameter pipelines. It predicts both flow and pressure drop with a high degree of accuracy, especially if the effective roughness values used in the equation have been measured accurately [1].

The AGA folly turbulent equation has the following form in Imperial Units.

Where:

Q_b = gas flow rate at base conditions, SCF/D

Tb = temperature at base condition, 520 °R

Pb = pressure at base condition, 14.7 psia

$$Q_b = 38.774\left(\frac{T_b}{P_b}\right)D^{2.5}\left(\frac{{P_1}^2 - {P_2}^2 - E}{GT_{ave}Z_{ave}L}\right)^{0.5}\left(4log\frac{3.7D}{Ke}\right)$$

Where the transmission factor is defined using the Nikuradse equation [1]:

$$\sqrt{\frac{1}{f}} = 4log\frac{3.7D}{Ke}$$

Optimization

The most important part optimization is determining objective function, the Strategies for Process and finding disputed part of the equations (This is usually one of the pipelines specifications).

First the pipeline equation is considered:

$$Q_b = 38.774\left(\frac{T_b}{P_b}\right)D^{2.5}\left(\frac{{P_1}^2 - {P_2}^2 - E}{GT_{ave}Z_{ave}L}\right)^{0.5}\left(4log\frac{3.7D}{Ke}\right)$$

Almost every one of the parameters in the equation can be taken into account as an objective function but there are some issues that should be considered and no one can decide without thorough review of the pipeline and Mastering in instruments on pipelines. Flow (Q) and pressure (P) are connected and both can be the objective, p has some Advantages (1. It can be measured easily 2.it can be measured exact 3. Pressure has very common units and in most time it is psi)

Eventually there is no Fundamental difference but pressure has some advantages so pressure was considered as the objective function.

The equation can be rewriting as below:

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

Rewritten in terms of the pressure is not necessary, but it is better understanding of dependencies and Sensitivity analysis.

After passage of time will be two sets of data:

1 - Series pressures calculated in software

2 - Series of reports of pressure measurement systems

Genetic Algorithm

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution [2].

At each step, the genetic algorithm uses the current population to create the children that make up the next generation.

GA in MATLAB

One of the most practical software for academic Semi-industrial research in chemical engineering is MATLAB.

In this study codes was written in MATLAB based on AGA equation.

For optimization of the problem 'Optimization Toolbox (Optimtool)'was used.

In this study, the population was in the range of 200 to 1000 (of course to find the range population 10 to 50,000 was tested and this area has the fastest response) the range of change is between 10to 10000 micro inch, fitness scaling was rank, migration was forward, and no hybrid function and the crossover was Heuristic (returns a child that lies on the line containing the two parents).

Heuristic crossover [2]:

Child = parent2 + R * (parent1 - parent2)

In the optimization fitness function was Ke (roughness value), the number of variables was n umber of pipes and the objective function was sum of squared differences ($\Sigma(P_i^2 - P'^2_i)$).

3. RESULT

The case was a real sample of gas transmission pipelines in Iran. It's the Part of a major pipeline that has branches in several small towns.

This analysis has been based on AGA and Colebrook-White equation. In this paper, the error is:

$E = P_{out}(AGA)$ or P_{out}(Colebrook-White) - P_{out}(measurement)

Programming is done in the objective function (which should be minimized):

$O.F = \Sigma|[P_i^2(\text{measurement}) - P_i^2(\text{Calculation})]|$

Accurate modeling was performed assuming isothermal network model based on roughness values, default values are provided in table 1.

As can be seen in Table in 6 points in a network is the destination of the parameters, there are some significant errors. These errors are related to the timing and conditions provided there is no pressure equation and Claimed to have provided with no errors equation.

But this is not an insoluble problem. One of the best solutions is uses of optimization process; this means that pressure equations of pipelines to be corrected periodically so that in the next period they will predict the best possible answer.

Only a very limited number of studies based on genetic algorithm optimization process can give satisfactory results (table 2).

Although these results may not be perfect, but the error reduction about 20% by only spend a few minutes, is acceptable. Optimization success rate in this case is a bit difficult, it does not mean it is better or not (definitely is improved), but the success rate is discussed. The reason for this lack is measurable indicators for each section of the pipeline.

Of course, in this part of the network, Optimization criterion is Pressure-tail, in small cities entrance.

By examining the results of the network optimization in limited points limited, for all points results obtained. If the results of these points were not in the objective function no is evaluated (table 3).

As there is a huge difference between the endpoint was not reached until after there is a change.

In The text the Point to zero (without change) are presented as the ultimate optimization.

Total 1. error in steps of optimization (GA)

Mode	default	Preliminary	slight
Total error	125.69	103.9904	85.42134

medium	Final	Ultimate
48.75652	16.22369	-0.02324

Reaching to the Ultimate point takes tenfold time more than reaching to final point from an economic perspective10 times more for the upgrade successful factor from 87% to 100% is often not justified (justified if there is plenty of time).

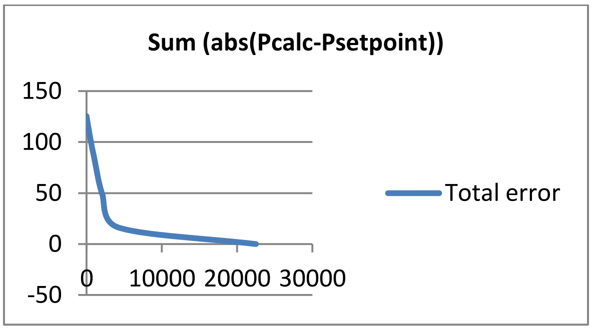


Figure 1: Total absolute error

If the kinds of errors are Contemplate, Can be found that there is generally a positive error, which means the default used roughness Increased over time. This is more evident in the main pipeline; Due to the large diameter main pipeline is expected to be less effective over time, while there is The effect is not only less ,But sometimes equal to or greater!

The reasons that can be noted: Pipes are older or using worse alloy or material in this pipe.

If we change the optimization and remove the previous limits the following answers Will achieved:

If answers of two sets are compared:

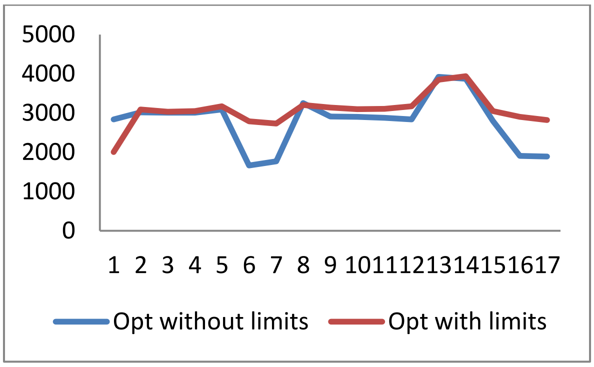
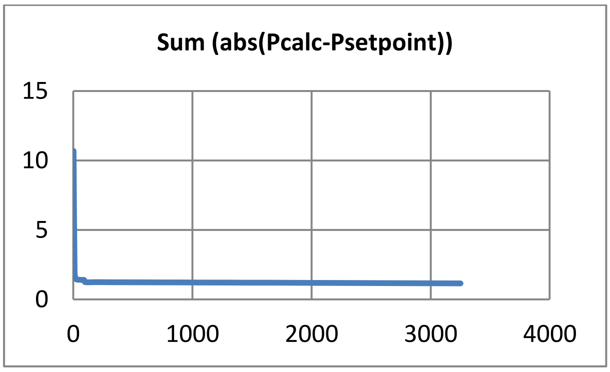


Figure 2: The effect of Range restrictions on Optimization

Both answers are good answers of pressure. But by a short review on roughness values can be found the limitations are reasonable.

Because the passage of time always increase the pipe's roughness; roughness should be much greater; its compliance in limited mode.

Now if the results of the optimization period 1 be considered for network optimization in second and other period following differences are observed:



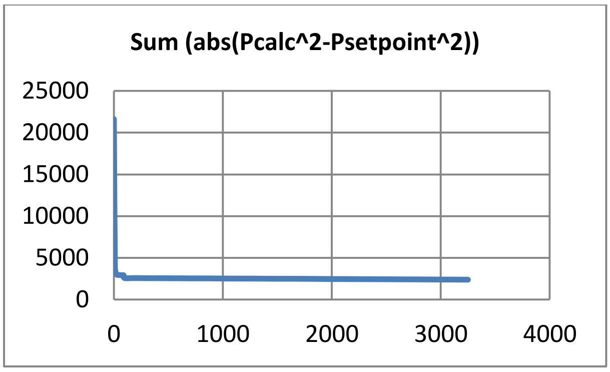


Figure 3: GA with initial value

By insert the Optimized values from period 1 for period 2, (network flows and pressures have changed), rate to achieve response will increase in 1000times.

Time saving

In this study, the genetic algorithms are used to optimize this method is a statistical method that can be used to optimize the most simulated process.

Response rate in this way is much higher, if the number of computations performed in two modes:

1 - Calculate all modes and search

2 - Genetic Algorithm

Are Considered:

1)

$(\text{Number of pixels})^{\text{No of points}} = (500)^{17} = 7.629394*10^{45}$

2)

(Number of pixels)*(generation) = 500*25000 = 12500000

In this case, the optimization process by Central Processing Unit: Intel(R) Core2Due @ 2.8GHz take About 10 hours.

By A rule of thumb if the number of computations put measure of the speed, the first method will take about Thousands of years.

Usually in a genetic algorithm Analysis is about one or more controversial variables. In this study, roughness is selected

The reason for this choice is more ambiguous than other variables; for pipeline the variable range is between 500 and 5000; this limit is good estimate for common metal pipes.

4. CONCLUSIONS

From the perspective of, Gas distribution network management there are two important parameters:

- The quantity of gas transmission networks
- Quality services to gas consumers

Software used in the gas industry uses certain pressure equations. The average of the errors are acceptable, But these errors over time due to environmental influences and aging network increases for satisfying the Two parameters the equations are required which Have high accuracy And don't lose accuracy over time.

Tuning of these equations based on statistical algorithms significantly increase the accuracy, There will be the exact quantity Also quality of service to consumers' increases that means pressure drop and Gas lost won't happen and of course there is no abnormally high pressure in the network.

5. REFERENCES

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TABLES

Table 2. default value errors

Default Value	Exact Value	Error
1069.127		
1030.482		
990.6736		
949.197	934.318	14.878
1059.937		
1051.636		
1051.33	1050.020	1.309
887.1947	861.396	25.798
1046.629		
1031.204		
1015.033		
1003.845		
893.691		
763.3859	705.879	57.506
997.5334		
997.2169	983.954	13.262
996.6532	983.716	12.937

Table 3. preliminary GA errors

Preliminary optimization	Exact Value	Error
1069.015		
1029.528		
988.7827		
946.3142	934.318	11.996
1059.647		
1051.179		
1050.87	1050.020	0.849
879.8802	861.396	18.484
1046.247		
1030.72		
1014.447		
1003.14		
889.321		
753.9875	705.879	48.108
996.7163		
996.388	983.954	12.433
995.8338	983.716	12.117

Table 4. Errors in all points

Full optimization	Exact Value	Error
1070.114	1070	-0.11391
1069.751	1069.65	-0.10123
1069.776	1069.73	-0.04643
1069.81	1069.81	2.42E-05
1061.979	1061.82	-0.15858
1061.935	1061.78	-0.15483
1061.933	1061.63	-0.30262
1057.367	1057.62	0.253078
1046.228	1045.41	-0.81751
1027.582	1026.49	-1.09171

1007.935	1007.02	-0.91514
994.7845	994.085	-0.69947
991.4283	990.617	-0.81126
983.1795	983.183	0.003468
986.9607	986.481	-0.47972
987.4716	986.948	-0.52359
985.8225	985.903	0.080533

Table 5: Network point's Optimization steps

default	Preliminary	slight	medium	Final	Ultimate
1069.127	1069.015	1069.015	1069.015	1069.015	1069.015
1030.482	1029.528	1028.794	1027.216	1025.773	1025.563
990.6736	988.7827	987.2276	984.1648	981.1257	981.1376
949.197	946.3142	943.9261	939.0506	934.3113	934.3145
1059.937	1059.647	1059.466	1059.086	1058.693	1056.892
1051.636	1051.179	1050.861	1050.199	1049.573	1050.389
1051.33	1050.87	1050.547	1049.877	1049.24	1050.02
887.1947	879.8802	873.9576	862.4927	861.3779	861.3955
1046.629	1046.247	1045.969	1045.415	1044.747	1041.736
1031.204	1030.72	1030.348	1029.622	1028.678	1024.377
1015.033	1014.447	1013.988	1013.067	1011.837	1006.246
1003.845	1003.14	1002.585	1001.453	999.9492	993.0712
893.691	889.321	885.4802	878.043	867.8756	865.0481
763.3859	753.9875	745.3714	728.3594	705.8812	705.8774
997.5334	996.7163	996.0633	994.7559	992.9933	984.6143
997.2169	996.388	995.7236	994.394	992.5984	983.9525
996.6532	995.8338	995.1784	993.8664	992.0981	983.7004

Table 6: Optimization steps errors

default	Preliminary	slight	medium	Final	Ultimate
14.878	11.9962	9.608062	4.732585	-0.0067	-0.00352
1.309	0.849737	0.527292	-0.14348	-0.78026	-0.00042
25.798	18.48423	12.56157	1.096664	-0.01805	-0.00051
57.506	48.1085	39.49243	22.48041	0.002222	-0.00164
13.262	12.43395	11.76957	10.43996	8.644374	-0.00151
12.937	12.11778	11.46242	10.15038	8.382099	-0.01564

Table 7. Effect of limitation on Optimization

Opt with limits Ke	Opt with limits P	Opt without limits Ke	Opt without limits P
1999.999	1069.015	2836.071	1068.612
3083.882	1025.773	3016.396	1025.564
3034.309	981.1257	3009.534	980.9971
3050.491	934.3113	3006.186	934.318
3166.716	1058.693	3086.413	1058.34
2788.353	1049.573	1659.718	1050.164
2726.875	1049.24	1762.662	1049.859
3202.212	861.3779	3252.615	861.3958
3139.119	1044.747	2907.505	1044.481
3095.388	1028.678	2898.511	1028.486
3103.28	1011.837	2872.147	1011.738
3168.153	999.9492	2830.94	999.9902
3844.971	867.8756	3916.265	867.3197
3936.774	705.8812	3871.271	705.876

3047.901	992.9933	2797.468	993.1423
2899.194	992.5984	1901.784	992.8162
2814.347	992.0981	1885.312	992.2571

FIGURES

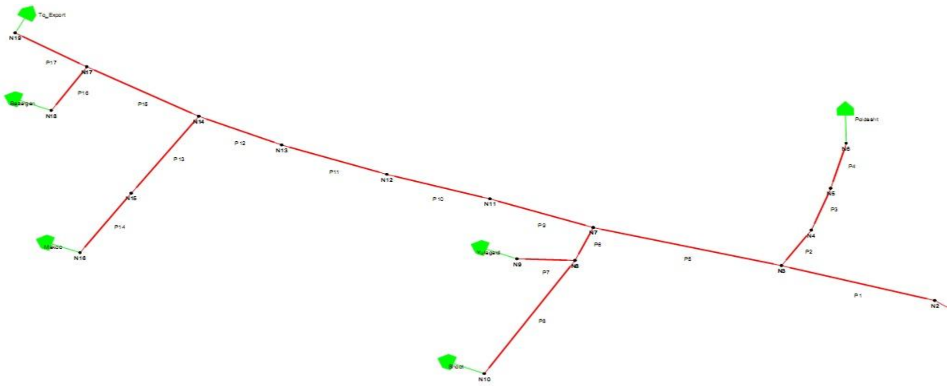

Figure 4: Studied network

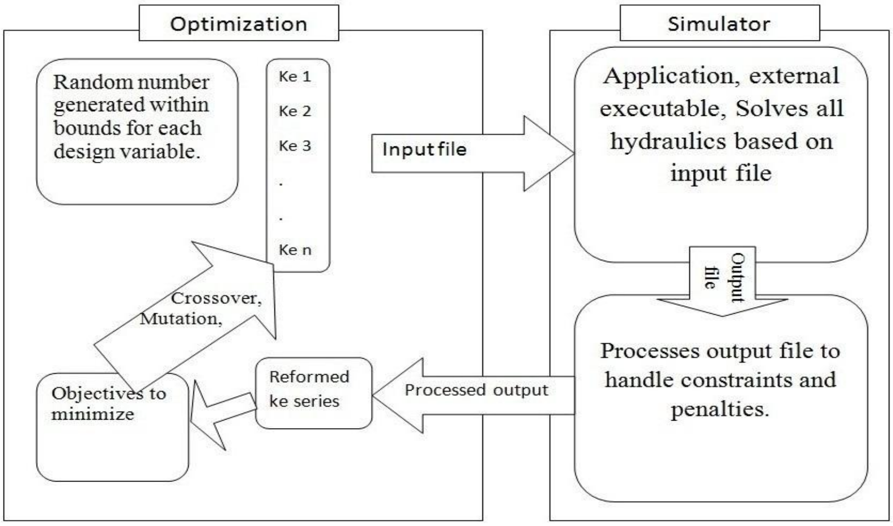

Figure 5: Data flow chart of interaction

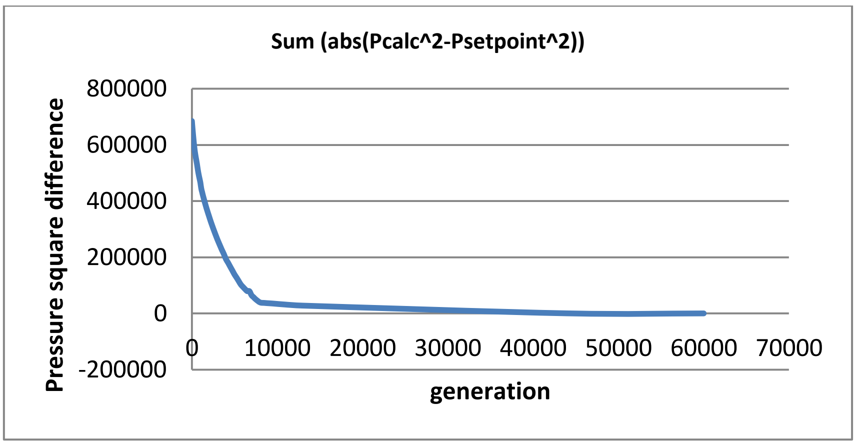

Figure 6: Optimization graph

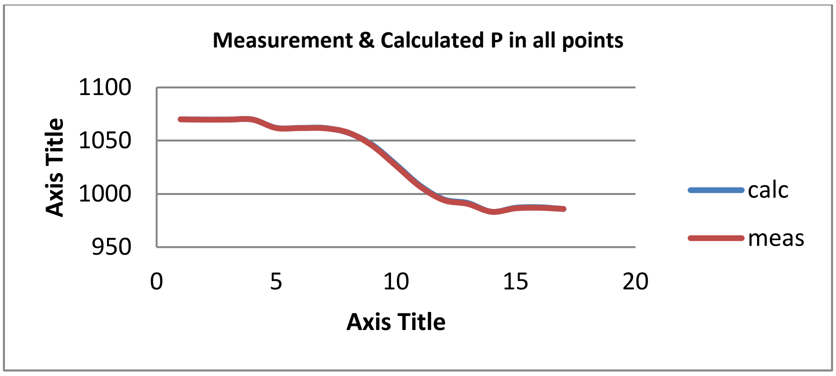

Figure 7: Measurement & Calculated P in all points of network