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Abstract. This paper addresses the Line Pack Management of the "GZ1 Hassi R'mell-Arzew" gas pipeline. For a gas pipeline system, the decision-making on the gas line pack management scenarios usually involves a delicate balance between minimization of the fuel consumption in the compression stations and maximizing gas line pack. In order to select an acceptable Line Pack Management of Gas Pipeline scenario from these two angles for "GZ1 Hassi R'mell-Arzew" gas pipeline, the idea of multi-objective decision-making has been introduced. The first step in developing this approach is the derivation of a numerical method to analyze the flow through the pipeline under transient isothermal conditions. In this paper, the solver NSGA-II of the modeFRONTIER, coupled with a matlab program was used for solving the multi-objective problem.

1. Introduction

This work is concerned with the minimization of energy cost for gas pipeline under transient conditions. The purpose of the work (Dupont and Rachford) [1] was to develop a mathematical programming approach to reducing fuel cost in long gas transmission lines with time varying demands. They use descent method together with Lagrange Multipliers to solve given non linear problem. An algorithm described in [2] based on sequential quadratic programming and takes account of the structure of the pipe flow equations by means of a reduced gradient technique which eliminates most of the variables from the quadratic sub-problem. Goldberg [3] solved the Wong's problem in the framework of the genetic algorithms. The GA method is a biologically inspired optimization and search technique developed by Holland [4]. Chebouba et al. [5] applied an ant optimisation algorithm to a linear system. In this paper, a genetic algorithm (NSGA II) [6] is used to solve a bi-objective problem.

2. Transient Flow in Pipeline Systems

The pipeleg is the most important component of the system because it defines the major dynamic characteristics. Isothermal unidirectional flow is usually assumed when modeling the flow of gas through a pipeleg, they result in the following equations, and the equation of continuity is

$$\frac{\partial m}{\partial x}+\frac{\partial(\rho A)}{\partial t}=0 \qquad (1)$$

The equation of motion is the transient form, accounting for the change of parameters in time:

$$\frac{\partial p}{\partial x} + \rho g \sin\alpha + \frac{\lambda v^2 \rho}{2d} + \rho \frac{\partial v}{\partial t} = 0 \tag{2}$$

The equation of state for a gas flow regarded as isothermal is,

$$\frac{p}{\rho} = z \frac{R}{M} T$$

the number of fundamental equations reduces to three and equation may be written in the simpler form

$$\frac{p}{\rho} = B^2 \tag{3}$$

Where B is the isothermal speed of sound, Equations (1) and (3) imply

$$F_1 = \frac{B^2 \partial m}{A \partial x} + \frac{\partial p}{\partial t} = 0 \tag{4}$$

where mass flow is $m = \rho A v = \frac{p}{B^2} A v$

By equations (2) and (3), and the above definition of m,

$$F_2 = \frac{1 \partial p^2}{2 \partial x} + \frac{p \partial m}{A \partial t} + \frac{p^2 g}{B^2} \sin\alpha + \frac{\lambda B^2 m^2}{2dA^2} = 0 \tag{5}$$

We transform the system of partial differential equations into one of algebraic equations by the method of finite differences as performed in the implicit method [7].

4. Compressor Unit and Stations

4.1. Single centrifugal compressor unit

The primal quantities related to a centrifugal compressor unit are inlet volumetric flow rate Q, speed S, adiabatic head H, and adiabatic efficiency η. The relationship among these quantities can be well described by the following equations:

$$S = -B_H Q + \left((B_H Q)^2 - 4A_H \left(C_H Q^2 - (H/9.81) \right)^{0.5} \right) / (2A_H) \tag{6}$$

$$\eta = (C_E (Q/S)^2 + B_E (Q/S) + A_E)/100 \tag{7}$$

where A_H, B_H, C_H, A_E, B_E, and C_E are constants which depend on the compressor unit and are typically estimated by applying the least squares method to a set of collected data of the quantities Q, S, H, and η. Since, the preferred variables from the pipeline modeling perspective are mass flow rate m, suction pressure p_s and discharge pressure p_d, the relationships between (H,Q) and (m,p_s,p_d) are the following:

$$H = \frac{Z_s R T_s}{\omega} \left[\left(\frac{p_d}{p_s} \right)^{\omega} - 1 \right] \tag{8}$$

$$Q = Z_s R T_s \frac{m}{p_s} \frac{1}{n} \tag{9}$$

where $\omega = \frac{\gamma - 1}{\gamma}$, the specific heat ratio γ, the gas compressibility factor at suction conditions Z_s, and the gas constant R, are positive parameters. n is an integer number which represents the number of compressor to put in service.

5. Objective functions

5.1 Total power Minimization

To find out how to run the compressor station so as to achieve a given value *(m/n,p_s,p_d)*, we proceed to map that point back to the original operating space by first computing H and Q from equations (8) and (9), respectively, and then solving for S and η in equations (6) and (7), respectively.
The power w consumed by a compressor station is given by

$$W = \frac{mH}{\eta\eta_m}$$

where η_m is a mechanical efficiency.

The functional to be minimized is the total power consumed by the system when it operates during the time period [t=0 t=tp] and is expressed over such time period as follows:

$$W_{Total} = \sum_{t=0}^{t=tp} \left(\frac{m_t H_t}{\eta_t \eta_m} \right)$$

5.2. Line pack maximization

The key consideration in pipeline operations is line pack, which is defined as the volume of natural gas between the compressor discharge pressure and the customer end-point delivery pressure. Gas pipelines not only serve as transportation links between producer and consumer, but they also represent potential storage units for safety stocks.

Moreover, adequate line pack allows pipeline operators to handle short-term fluctuations in demand and supply properly. On the other hand, when the line pack level is high, the energy consumption might be unnecessarily high. Total line pack maximization is expressed as follows [8]:

$$Maximise\ (LP_{TOT}) = \sum_{t=0}^{t=tp} 7.855\ 10^{-7} \left(\frac{T_{SC}}{P_{SC}} \right) \left(\frac{P_{avg(t)}}{Z_{avg(t)} T} \right) D^2\ L$$

7. SOFTWARE

All these equations were integrated in a computer program, built in matlab. This program was used for hydraulic modeling of the pipeline systems

On the other hand, for the optimization part, we use, in this work, the genetic algorithm optimization software NSGA II [6] available in modeFRONTIER by ESTECO [9].

modeFRONTIER allows optimization analysis to be achieved to changing the values assigned to the input variables of Matlab software. The output from matlab software can then be described as the objectives and constraints of the problem.

8. Application

In this case, we consider the last pipeleg of the pipeline. The initial conditions can be characterized as the steady state studied in the last section. The principal parameters used for the last pipeleg of the gas pipeline Hassi R'Mel- Arzew (Algeria) are listed in table 1.

Table 1

Length of the pipeleg (km)	Diameter (m)	gas constant J/(kg-°k)	contract pressure (bar)	Time horizon (h)	Step time (h)	Mass flow equation at load (kg/s)
110	0.990	435	42	24	1.5	300*(1-0.7*sin((2*3.14*t/3600)))

As with any meta heuristics, many parameters need to be set to have a good performance of NSGA II algorithm. The model performance was tested against variations of cross probability and mutation probability. A value of 0.3 for cross probability and one of 0.1 for mutation probability seem to be the best choice for our problem.

The calculations of simulation were realized by means of programs made in Matlab. We have determined, for a period of 24 hours, the discharge pressures, compressor speed and adiabatic head in the last compressor station which is directly connected with the point of delivery. This solution represents the optimal programming run of this station on a forecast of consumption over a period of 24 hours. We have chosen sixteen 1.5-h times steps. The results, for the minimum of power used by turbo compressors, are listed in tables 2 and 3. We can notice from table 3, that the pressure at delivery point never drops below the contract pressure (42 bars).

Table 2

Time step	Discharge pressure in bars	**Time step**	Discharge pressure in bars
Time step 1	57.35	Time step 9	55.9
Time step 2	65.39	Time step 10	65.01
Time step 3	55.9	Time step 11	56.1
Time step 4	66.57	Time step 12	64.9
Time step 5	56.24	Time step 13	55.86
Time step 6	64.52	Time step 14	65.98
Time step 7	56.96	Time step 15	61.55
Time step 8	66.04	Time step 16	55.86

Table 3

Time step	Pressure at delivery point in bars	**Time step**	Pressure at delivery point in bars
Time step 1	45.51	Time step 9	42.02
Time step 2	42.03	Time step 10	42.26
Time step 3	42.00	Time step 11	43.06
Time step 4	42.51	Time step 12	42.00
Time step 5	42.05	Time step 13	44.36
Time step 6	42.06	Time step 14	42.09
Time step 7	42.88	Time step 15	42.27
Time step 8	43.74	Time step 16	42.03

10. Conclusion

The objectives, in this paper, were to maximize the system line pack as the first, and to minimize total power as the second objective function. Also, since there was approximately a direct relation between the power consumed and CO2 emission, the Pareto points with minimum power resulted in minimum carbon dioxide emission and vice versa. At the end, we can provide a decision aid tool to operators of gas pipeline networks for making appropriate decision to determine discharge pressures and number of turbo compressors to put in service. In the future, to improve these results, we plan to use a hybrid method combining the genetic algorithm optimization software NSGA II and a local search.

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