ALLOCATING GAS-FIRED DGs CONSIDERING NATURAL GAS SYSTEM CONSTRAINTS

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ABSTRACT

This paper proposes a method for power system expansion planning with sizing of gas-fired distributed generation units, considering natural gas system constraints. The proposed model allocates gas-fired distributed generation units and determines the capacity of them. Furthermore, the lines and substations that should be expanded are addressed. The objective function of the optimization problem is the total construction and operation costs, and a combinatorial fast method, is utilized to solve it. The method is employing CLA-PSO to be suitable for large scale systems.

1. INTRODUCTION

Natural gas is increasingly used as an appropriate fuel for electricity generation because of many advantages including availability, low environment negative impacts and being more economical in comparison to other fossil fuels in many countries.

Gas-fired power plants provide a close integration of natural gas and power systems. Gas system affects the security and economics of power system. From the security point of view, pipeline contingencies, loss of pressure, lack of storage or gas supply disruptions may lead to forced outages of gas-fired units [1]. As a result, interdependency of the natural gas and power systems is an important task.

Since the problem is complex and nonconvex, a common algorithm can't solve it. Although combination of PSO and backward algorithm can be used to solve such problems, it is not appropriate for large scale systems. The proposed method is employing CLA-PSO to be suitable for large scale systems.

In this paper, the natural gas system equations are presented. The problem constraints, objective function and the utilized optimization algorithm are discussed in the next parts. Finally, the proposed approach is implemented on Zanjan subtransmission system in Iran.

2. NATURAL GAS SYSTEM MODELING

The natural gas network can be modeled with steady state and dynamic equations [2]. The steady state equations of the gas transmission system are presented in the following subsections. Variables and indices are presented in Appendix I.

2.1 Main components of the natural gas network

Fig. 1 shows the main components of the gas transmission and distribution system from the source to the loads, including supplier nodes, distribution pipelines, storage components, compressors and loads.

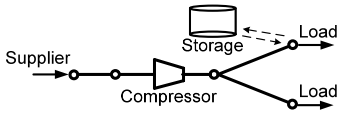

Fig. 1:Natural gas network elements

2.1.1 Supplier and load nodes in natural gas system

The source and load nodes are shown as gas injector with positive and negative signs, respectively. The injection of the supplier nodes should be in a limited range as follows:

$$S_k^{\min} \le S_{k,d} \le S_k^{\max} \qquad (1)$$

The other constraint, which should not be violated in each node, is the gas pressure as follows:

$$\pi_k^{\min} \le \pi_{k,d} \le \pi_k^{\max} \qquad (2)$$

2.1.2 Gas pipelines model

Similar to power system, where power transmission is related to adjacent buses voltages and power line parameters, gas transmission is driven by different gas pressures and is affected by some parameters including pipelines length, operating pressure and temperature, gas type, altitude change over the transmission path and pipelines friction [3]. Gas flow between x and y nodes can be determined as follows:

$$\begin{cases} f_{xy,d}^2 = C_{xy}^2(\pi_{x,d}^2 - \pi_{y,d}^2) \times Sgn(\pi_{x,d} - \pi_{y,d}) \\ Sgn(\pi_{x,d} - \pi_{y,d}) = \{ \begin{matrix} 1 & \pi_{x.d} \ge \pi_{y.d} \\ -1 & \pi_{x,d} \le \pi_{y,d} \end{matrix} \end{cases} \qquad (3)$$

where C_{xy} is the pipeline constant, which depends on temperature, length, diameter, friction and flowed gas type and $f_{xy,d}$ is Gas flow through node x to y in load level d [kcf/h].

Each gas pipeline has a capacity which can be obtained as follows:

$$\left| f_{xy,d} \right| \le f_{xy}^{\max} \qquad (4)$$

2.1.3 Gas storage

In contrast to electricity, gas can be stored in a considerable amount in low load condition to be used in peak load [2].

Gas storage facilities are categorized by their operation parameters and capacity to balance gas transmission [4]. Gas storage constraints are as follows:

$$VS_r^{\min} \le VS_{r,d} \le VS_r^{\max} \qquad (5)$$

2.1.4 Compressors model

Compressors are used to compensate gas pressure loss in pipelines. Gas flow in compressor shown in Fig. 1 can be achieved as follows:

$$f_{xy} = \frac{H_m}{k_{m_2} - k_{m_1}\left[\dfrac{\max(\pi_x,\pi_y)}{\min(\pi_x,\pi_y)}\right]^{\alpha_m}} Sgn(\pi_x - \pi_y) \quad (6)$$

where k_{m_1}, k_{m_2} and α_m are the experimental parameters, which are related to the compressor design [2] and H_m is power of compressor m. Compressors also consume natural gas for its operation, which its value is shown with LC_m and can be calculated as follows:

$$LC_m = \alpha_m H_m^2 + \beta_m H_m + \gamma_m \qquad (7)$$

2.2 Gas System Load Flow Equations

Nodes gas pressure and pipelines flow can be determined with gas system load flow. To formulate steady state gas load flow, nodal balance equations are utilized [2]. Eq. (8) shows that the input and output gas of a node are equal.

$$S_{k,d} + \sum_y f_{xy,d} = \sum_y f_{yx.d} + D_{k,D} \quad \forall y \in \{1..NGN\} \quad (8)$$

Substituting (3) and (6) in (8), a nonlinear system equation can be obtained, which can determine all gas pressures and pipelines flow.

3. OPTIMIZATION PROBLEM

This section aims to present the optimization problem.

3.1 Objective Function

The optimization problem objective function can be formulated as follows:

$$TC=GIC+LEC+SEC+GFC+BPC+LOC+GMEC \qquad (9)$$

As seen in (9), the costs can be categorized in seven categories as follows:

3.1.1 Generation Initial Cost (GIC)

This term of the objective function includes the cost of DG units construction, which can be calculated as follows:

$$GIC = \sum_{i=1}^{i=NS} C_i^{gi} \times P_i^{gi} \qquad (10)$$

where C_i^{gi} is the construction cost of 1 MW DG in substation i with P_i^{gi} capacity.

3.1.2 Line and Substation Expansion Cost (LEC)

The cost of adding new lines and substations should be considered as follows:

$$LEC = \sum_{j=1}^{j=NL} C_j^{le} \times n_j^{le} \qquad (11)$$

$$SEC = \sum_{i=1}^{i=NS} C_i^{se} \times P_i^{se} \qquad (12)$$

3.1.4 Gas Network Modification and Expansion Cost (GMEC)

The gas network should be expanded to support DGs natural gas consumption:

$$GMEC = \sum_{y=1}^{y=PT} C_y^{me} \times n_y^{me} \qquad (13)$$

where n_y^{me} is required length of pipeline type y to expansion or modification gas network and C_j^{le} is cost of 1km pipeline type y.

3.1.5 Gas Fuel Cost (GFC)

The fuel of natural gas-fired DGs is provided from the gas network with the cost of:

$$GFC = \sum_{i=1}^{i=NS} \sum_{t=1}^{t=T} \sum_{d=1}^{d=ll} C_{i,d}^{gf} \times \beta^t \times DG_{i,d} \qquad (14)$$

where $C_{i,d}^{gf}$ is the fuel cost of generator installed at substation i in load level d.

It should be noted that generator fuel cost is an operation cost, which should be paid during operation period so it should be converted to present value with the factor of $\beta = \frac{1}{1+Dis}$ for each year.

3.1.6 Bought power Cost (BPC)

The bought power cost can be calculated as follows:

$$BPC = \sum_{i=1}^{i=NS^*} \sum_{t=1}^{t=T} \sum_{d=1}^{d=ll} C_{i,d}^{bp} \times \beta^t \times P_{i,d}^{Pb} \qquad (15)$$

4. OPTIMIZATION ALGORITHM

The optimization problem presented in section 3 is nonlinear and complicated with a variety of constraints. This paper combines algorithms, i.e. backward, Cellular Learning Automata (CLA) and Particle Swarm

Optimization (PSO) to solve the optimization problem and utilizes Newton-Raphson for gas load flow.

4.1 CLA-PSO Algorithm

PSO is a population based parallel searching algorithm, which begins with a set of random results and then find the optimal result by searching among the updated particles location. In this paper a version of PSO is utilized which is a combination of Cellular Learning Automata (CLA) and continuous PSO [5]. Running PSO and CLA-PSO on the objective function separately, has shown that CLA-PSO is so faster and PSO may not be able to solve some large systems.

4.2 Backward Algorithm

In this paper, an innovative backward algorithm is utilized. Evaluating this method on Garver test system in [6] illustrated results of proposed method is matched absolute optimal results. Also this method is explained in [7].

4.3 Newton-Raphson Algorithm

So far, various methods are utilized in gas load flow, including linearization [8] and Newton-Raphson [9] methods. Newton-Raphson method is used in this paper to obtain gas load flow.

Fig. 2 shows the flowchart of power system expansion planning by DGs in subtransmission system level considering natural gas system.

5. RESULTS AND DISCUSSION

Zanjan in Iran power system is used to evaluate the implementation of the proposed approach. A standard 5 nodes gas network is utilized in this paper[2].

Three approaches are investigated in this paper as follows:

Approach 1: All the demanded load is supplied from the transmission system and no DG is supposed to be installed.

Approach 2: DG units installation is considered as well as buying electric power form transmission system. The capacity of each source are determined. The gas system constraints are neglected in this approach.

Approach 3: in addition to approach 2, gas system constraints is also taken into account.

A comparison between the three approaches is presented in Table 1. Furthermore, the optimization result for approach 3 is illustrated in Fig. 3.

It can be seen that although DGs installation requires high initial cost, the low operation costs during operation period cause the total cost of the approach 2 to be less than approach 1. Furthermore, neglecting gas system constraints in approach 2 caused to add extra gas network Modification Cost to GMEC, while in approach 3 GMEC only contains

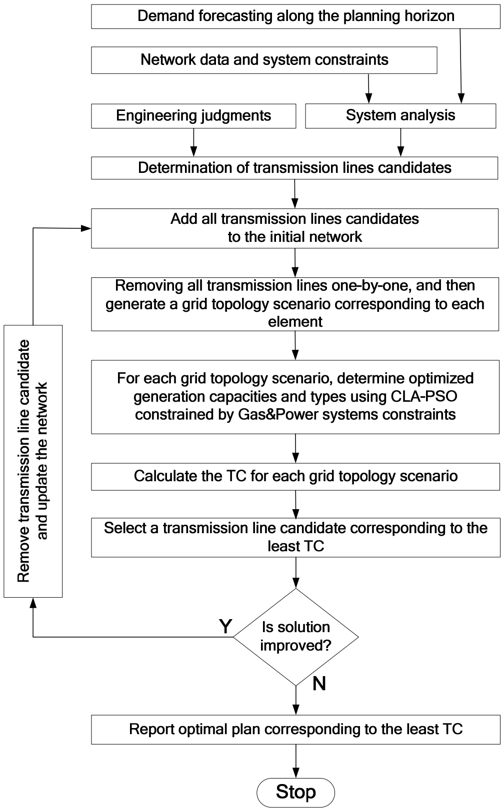

Fig. 2. Optimization problem flowchart

TABLE 1. Costs in the three defined approaches

	Cost (1000$)		
	Approach 1	**Approach 2**	**Approach 3**
Bought Power	6344171	0	0
DG Installation	0	589130	935300
Gas Network Modification and Expansion	0	62781	10103
Fuel	0	921589	619331
Line Expansion	58194	6998	5288
Substation Expansion	2400	800	1600
Losses	41389	4823	8410
Total	6446154	1586121	1580032

6. CONCLUSION

Gas-fired DGs provide a close integration of natural gas and power systems. Gas system affects the security and economics of power system. This paper proposed a method for power system expansion planning with sizing of gas-fired distributed generation units, considering natural gas system constraints. Since the problem is complex and nonconvex, an appropriate algorithm has to be utilized for large scale systems.

The implementation of the proposed approach on Zanjan power system shows that for optimal and practical such planning, the gas system should be considered.

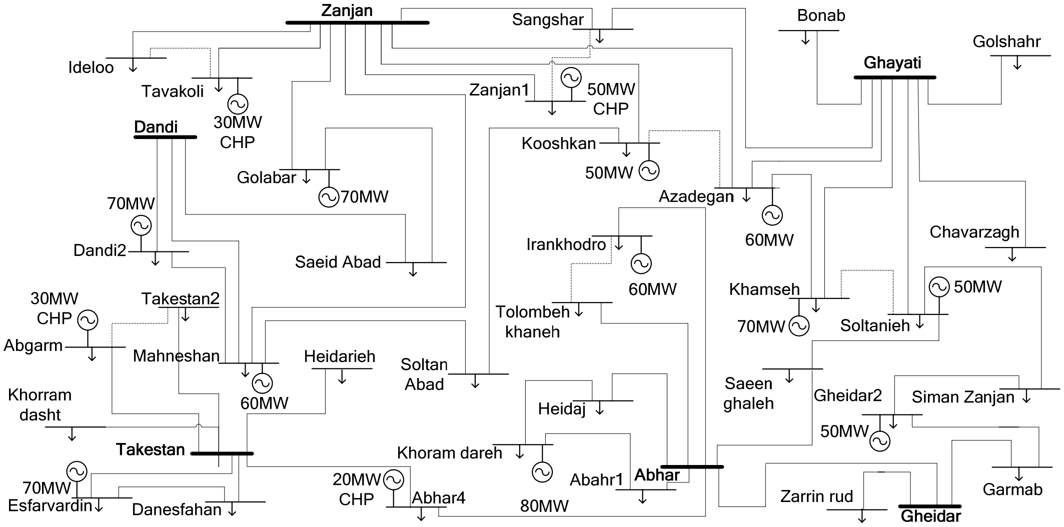

Fig. 3: The optimal result of Allocating Gas-fired DGs Considering Natural Gas System Constraints (approach 3)

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Appendix I. Indices and Variables

NS: Number of subtransmission system substations.
NS*: Number of substations connected to transmission system.
NL: Number of total present and candidate corridors.
NGN: Number ofgas nodes.
ll: Number of load levels.
T: Planning horizon [year].
i: Substation index.
j: Corridor index.
d: Load level index.
t: Year index.
k: Gas node index.
C_i^{gi} : initial cost of DG unit in substation i [\$/MW]
C_j^{le} : Cost of construction transmission line in corridor j [\$].
C_i^{se} : Cost of substation i expansion [\$].
$C_{i,d}^{bp}$: Cost of buying power in substation i and load level d [\$/MWh].
$C_{i,d}^{gf}$: Cost of Generation fuel in node i and load level d [\$.h/MBtu].
P_i^{gi} : Capacity of DG installed in substation i [MW].
n_j^{le} : Number of transmission lines in corridor j.
P_i^{se} : Extended capacity of substation i [MW].
$DG_{i,d}$: Fuel consumption of DG in substation i and load level d [MBtu/h].
$P_{i,d}^{Pb}$:Bought energy from transmission system through substation i in load level d along 1 year[MWh].
$S_{k,d}$: Gas injection of node d in gas load level k [kcf/h].
$\pi_{k,d}$: Gas pressure of node k in load level d [Psig].
$f_{xy,d}$: Gas flow through node x to y in load level d [kcf/h].
C_{xy} : Constant of pipeline between nodes x and y.
$VS_{r,d}$: Gas volume of reservoir r in load level d [kcf].
H_m: Power of compressor m.
Dis: Annual discount rating (%).