USE OF GAS-FIRED CO-GENERATION SOURCES IN 20 K.V DISTRIBUTION GRIDS FROM THE PERSPECTIVE OF DISTRIBUTION SERVICE COMPANY BY THE GROUP SEARCH OPTIMIZER ALGORITHM

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Abstract: The use of Gas-fired co-generation sources has been widely adopted in the electrical grids in Iran and many other countries across the world over the past few years. In this paper, the problem of locating and determining the capacity of co-generation sources has been studied from the perspective of a distribution service company. The Company is the investor of the project. The main objective is to reduce the operational cost of the electrical grids during a year. Constrains of the electrical grids and the distributed generation sources have been taken into account in modeling the problem. To solve the problem group search optimizer algorithm has been used. To do the numerical analysis a 20 kv distribution service grid has been used. The results show that operating costs reduce if distributed generation sources are used in the grids. The income from heat recovery and the amount of loss reduction in the grid are significant.

Keywords: Group search optimizer, Distributed generation sources, Gas-fired co-generation sources

1. Introduction

Nowadays power industry restructuring and energy market segmenting have made the economic parameters very important. Accordingly distribution companies are looking for better ways to increase their income and to decrease their costs. Construction of new distribution stations and feeders incur high costs. Therefore the companies prefer to delay investment on them. However, gas-fired co-generation sources have drawn a lot of attention as an important research topic over the recent years. A great deal of studies have been carried out on the issue: Estimation of the location and size of distributed generation units in distribution systems with different load models as a multi-objective optimization for DG units programming [1], the analytical approach of the reliability evaluation of the DG based on operation mode [2], determination of optimal operating strategy for DG by considering the hourly reliability worth[3] and reliability benefits of DG on heavily loaded feeders[4]. In this study SAIDI Reliability Criterion has been used to evaluate the reliability.

A method for evaluating the reliability based on structural analysis and distribution of system in a DG has been reported in [5]. Different analytical methods such as two- thirds method for determination of the optimal location and size of DGs in distribution systems have also been reported in [6].

In general, to determine an optimal plan for CHP development in a grid, various factors such as technical constraints of the n grid, characteristics of gas-fired units, environmental effects, economic analysis and many other factors should be considered. The most important needed parameters are time, location and the capacity. They can be studied from the view point of an investor, a distribution services company or a user. Furthermore, distribution co- generation sources can be provided by various institutions.

In the present article the use of co-generation sources in grid has been studied from the perspective of a distribution service company. To solve the problem group search optimizer algorithm has been used. The algorithm for modeling has been adopted from [7].Here the question of the development of co-generation units has been studied in the perspective a service company which is in charge of the operation of a distribution grid. This company can be either a public or private distribution company in the operation of a power grid of an industrial estate.

2. Method

The main purpose of this study is to propose an appropriate plan for the development of small- scale generators in distribution grids. To determine an optimal plan, the following parameters should be considered:

- The optimal location of generators installation
- The optimal capacity of generators.

To make the task simple other parameters are ignored. In the present study, the distribution service company is the proprietor of the co-generations generators. Therefore, the costs of the installation and operation of co-generators should be considered in the problem.

Optimal capacity and optimal location of the installation of distributed generation sources are the main variables which are defined as follows.

$$X=\begin{bmatrix} P_{DG} \\ bus_{DG} \end{bmatrix} \quad (1)$$

P_{DG}: capacity of DG

bus $_{DG}$: location of DG installation

2.1. Annual Costs

Generally annual costs include grid costs and co-generation sources costs which can be of the following subsections:

2.1.1. The Cost of Investment on CHP

It is actually a coefficient of installed capacity per megawatt (MW) which is defined as: (to make the equation simple, the interest rate has not been considered)

$$f_{inst} = \frac{c_{inst}.DG_{cap}}{DG - life} \quad (2)$$

F_{inst}: The installation cost of distribution generation sources per Rls./year

C_{inst}: Investment cost rate for installing distribution generation sources per Rls./MW

DG_{cap}: installed capacity in the grid per MW.

DG-life: lifespan of DG per year.

2.1.2. Fuel Costs of CHP

After the DG installation in the grid, fuel cost will be added to the equation. This is formulated as:

$$f_{fuel} = \left(\frac{DG_{cap}}{\eta_e.b}\right).c_{gas}.h \quad (3)$$

The parentheses shows gas consumption amount by the generator per hour.

F_{fuel}: Fuel cost of all the distributed generation sources installed in the grid per Rls.

C_{gas}: Fuel consumption rate by distributed generation sources per Rls/M^3

h: time duration of CHP operation in one year per(hour).

b: thermal value of gas in grid per ($\frac{K_{wh}}{m^3}$)

The Cost of Repair and Maintenance of CHP

$$f_{main} = C_{main} \times E_{turb} \quad (4)$$

2.1.3. The Cost of Grid Losses

It is computed by multiplying the amount of wasted energy in the grid by the price of bought energy.

$$f_{loss} = C_e.E_{loss} \quad (5)$$

To compute the amount of wasted energy in the grid first AC load-flow and the current of the lines have been computed. Then, the grid losses in one year are expressed by as:

$$E_{loss} = h.\frac{1}{2}\sum_{i=1}^{nbus}\sum_{\substack{j=1 \\ i\neq j}}^{nbus} R_{ij}.\left[I_{ij}\right]^2 \quad (6)$$

R_{ij}: line resistance between i , j buses(pu).

I_{ij}: line current between i , j buses(pu).

2.1.4. The Cost of Power Purchase from the National Power Grid

The distribution services Companies cannot meet all the needs of their customers by the installed generators. Therefore they should buy their extra needed energy from the power market. The equation **(7)** shows how to compute power purchase cost from the power market:

$$f_e = \sum_{i=1}^{nbus} c_e.(PL_i - PDG_i) \quad (7)$$

The parameters are defined as follows:
F_e: the cost of buying power from the grid per Rls.
Nbus: the number of buses in grid
C_e: the price of buying power from grid per Rls/ MWh
PL_i: the Load of i bus per (MW)
PDG_i: the installed capacity in i bus per (MW)

2.1.5. Income from the Heat Recovery

The amount of heat produced by co-generation generators is computed based on the amount of saved gas. To do so the following equation is used:

$$r_w = c_w.W_r \quad (8)$$

W_r: the amount of recovered heat from generator is computed as:

$$W_r = MIN\left\{\frac{DG_{cap}.\eta_w}{\eta_e.b}, P_w\right\} \quad (9)$$

η_w : Thermal efficiency of generator
η_e : Electrical efficiency of generator
ρ_w : Local thermal load in the place of generator instalation

2.2. The Objective Function

In the previous section, some terms have been proposed to estimate the incomes and expenses of the service companies. To compute the annual income and costs the following equation can be formulated:

$$cost = f_{inst} + f_{loss} + f_{main} + f_{pur} - r_w \quad (10)$$

2.3. Constraints of the Question

They include technical constraints of the grid and of the distributed generation sources that can be defined as:

2.3.1. Equality Constraints of of Power Flow

These constraints should be established for each year and can be formulated as follow:

$$Q_{Gi} - Q_{li} = \sum_{i=1}^{n-bus} V_i V_j (G_{ij} sin\theta_{ij} - B_{ij} cos\theta_{ij})$$

$$P_{Gi} - P_{Li} = \sum_{i=1}^{n-bus} V_i V_j \left(G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij}\right) \quad (11)$$

Where the parameters are defined as:
Q_{Gi}: Total reactive power production in i bus (pu)
Q_{Li}: Total reactive power of load in i bus (pu)
P_{Gi}: Total active power production in i bus(pu)
P_{Li}: Total active power of load in i bus (pu)
G_{ij}: The real part of line admittance between i , j buses (pu)
B_{ij}: the imaginary part of line admittance between i , j buses (pu)
θij:The angle of line admittance between i , j buses (rad)
V_i: the voltage of i bus (pu)

2.3.2. The Constraint of Grid Voltage

$$V^{min} \leq V_n \leq V^{max} \quad (12)$$

2.3.3. The Constraint of Limited Line Capacity

$$|f_{ij}| \leq F_{ij}^{max} \quad (13)$$

2.3.4. Constraint of the Limitation of Total DG Capacity Installed in the Grid

The installed capacity in the grid should not be more than the grid load and should not inject power into the upstream grid. For this reason, the following constrain is added to the problem. At this constrain the total installed capacity in the grid is 80 %(maximum) of pick load of the grid.

$$\sum_i DG_{cap_i} \leq 0.8P_D \quad (14)$$

Group search optimizer algorithm is used to solve the problem. This algorithm has been cited in reference [7]. It is a minimization algorithm, therefore the objective function can be defined as:

$$f = {}^{cost}/_{primary - cost} \quad (15)$$

In this equation "cost" refers to the cost of grid operation after the use of DG generators and "primary-cost" refers to the operation costs before the use of DG generators in the grid. Accordingly, if the obtained objective function is lower than one, there will be reduction in costs. It means the smaller the obtained number; the higher the operation cost reduction will be.

2.4. Group search optimizer Algorithm

Group search optimizer **(GSO)** algorithm has been inspired from animal behavior especially from their searching behavior. This is used to solve the continuous optimization problems. It was first used by He et al in 2006 [9]. It was precisely formulated in [10] and compared with genetic and PSO algorithms.

In Group search optimizer algorithm the participants are referred to as "Group" and every single participant as a "member". Three different members have been determined in every step including: 1-producer 2-scrounger and 3-ranger. In each step, a member who has the best fitting has been selected as producer; scroungers are those who go after producers and use the sources found by them, rangers have been roamed in searching space. Generally, algorithm is based on determining producer in each repetition. After that, producer searches around in its present place. If it finds a better place it will move there; otherwise, it changes its angle of view and searches for answer.

If no better answer is found after some repetitions, the producer remains in its first place and turns to its primitive angel of view in its first repetition. Then, about 80% of the members are selected as scrounger and do the process of scrounging. The rest does ranger process.

The following chart shows group search optimizer algorithm completely.

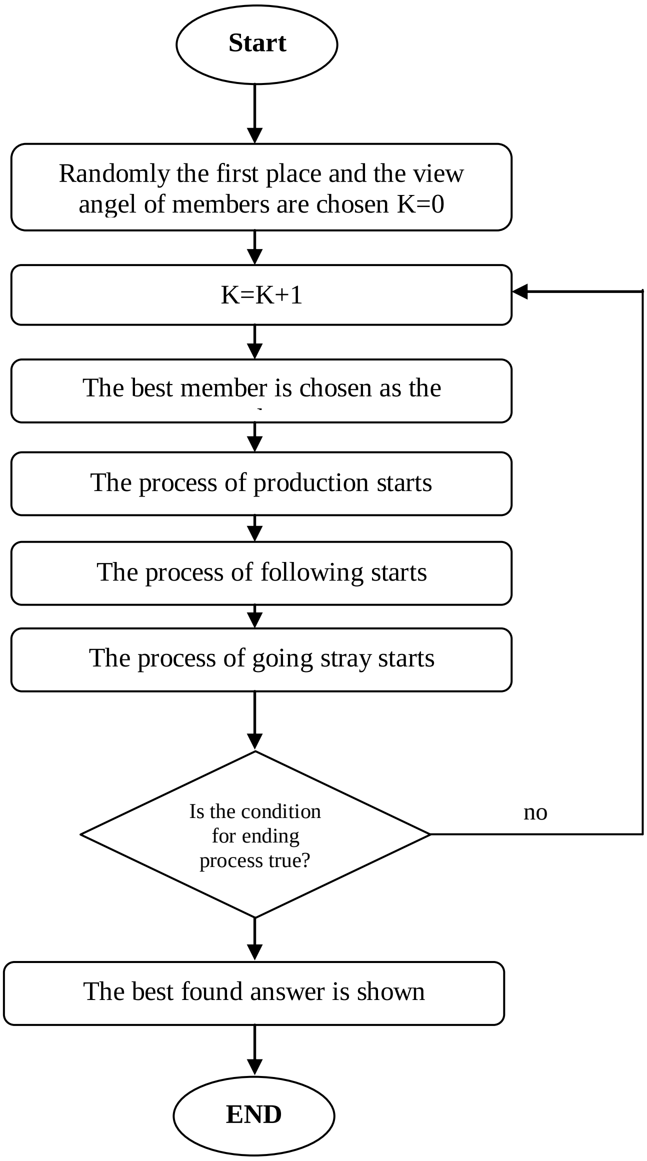

Figure1- An algorithm for GSO

3-Results

The purpose of this study has been to reduce operating costs in DGs during one year.

To achieve this goal a 20 KV distribution substation with 3 feeders in Isfehan (Dehaghan) have been chosen. The load pick of the grid is about 400A in 20kv. To simulate the power factor of all loads have been take to be 0.8 phase lag. There are 397 distribution transformers in the grid.

The single-line diagrams of distribution substation have been shown in the following figure.

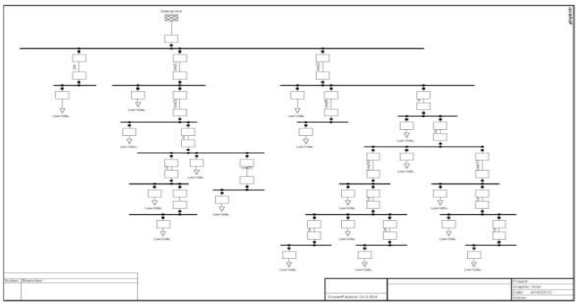

Figure 2- Single- line Diagram of the Grid

The following table shows the characteristics of buses and the related lines in a grid.

Table1- characteristics of the grid load

bus number	MW	MVAR	MW thermal
1	11.1	8.3	0
2	1.5	1.2	0
3	0.3	0.3	0
4	0.9	0.6	1.5
5	0.6	0.5	0
6	0.9	0.7	1.75
7	0.6	0.5	0
8	0.5	0.4	1
9	1.1	0.8	0
10	0.5	0.4	1.3
11	0.7	0.5	0
12	0.4	0.3	0
13	0.3	0.2	0
14	0.2	0.2	0
15	0.4	0.3	0
16	0.8	0.6	1.5
17	0.5	0.4	0
18	0.4	0.3	0
19	0.5	0.4	0

Table2- characteristics of grid line

First bus	Second bus	Length(KM)	R(Ω)	X(Ω)	Fmax (MW)
1	2	9	2.44	2.22	12
1	3	15	4.07	3.70	12
3	4	5	1.36	1.23	10
4	5	2	0.54	0.49	10
5	6	10	2.71	2.46	10
6	7	12	3.25	2.96	10
5	9	3	0.81	0.74	10
1	14	4	1.08	0.99	12
14	15	2	0.54	0.49	10
14	16	3	0.81	0.74	10
16	12	1	0.27	0.25	10
12	11	1	0.27	0.25	10
11	10	8	2.17	1.97	10
10	8	4	1.08	0.99	10
12	13	3	0.81	0.74	10
13	17	2	0.54	0.49	10
17	19	1	0.27	0.25	10
17	18	3	0.81	0.74	10

Table3- parameter of GSO algorithm

Number of repetition	Number of population	Range of distributed generation capacity	Primary angles
100	100	$[50kw - 2000kw]$	$\pi/4$

The following table shows the parameters which are required to solve the problem

Table4: The parameters required to solve the problem

$C_o(Rls)$	$C_{gas}(Rls/(m^3))$	$C_{R\&D}(Rls/(MW-year))$
0	700	300000000
$C_{inst}(Rls/MW)$	η_w	H(hour)
100000000	0.45	8760
$V^{min}(pu)$	$V^{max}(pu)$	$DG\_life\ (year)$
0.95	1.05	10
$C_e\left(Rls/MW_h\right)$	η_e	$b\left(\frac{kwh}{m^3}\right)$
800	0.4	9.6

Table5 shows the optimal plan. As mentioned above, 6 buses have been chosen to install distributed generation sources.

Finally; by installation of 8868 K.W. Capacity in the grid the operating of grid has been recovered.

Table5: the optimal plan consists of capacity and location of the installation of the co-generation sources in the grid.

Number of bus	(KW) capacity
4	1788
6	1944
10	1432
8	976
16	1597
TOTAL CAPACITY=8868	

Table6: Comparison of costs of operation before and after DG installation

	Before DG installation	After DG installation
losses	18669.3	5067.8
Income from heat recovery	0.0	4503.2
Electricity purchase from the grid	155577.6	101356.7
The initial investment	0.0	7737.0
Maintenance	0.0	2321.1
fuel	0.0	12355.0
total	174246.9	128837.7

As can be seen the costs for operating the grid has been decreased. The following figure shows the amount of decreasing compared to initial state

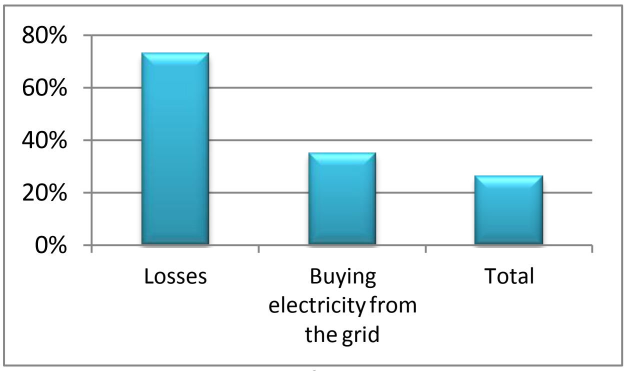

Figure 3: the decrease of costs in the grid in percent

Figure 4 shows the grid voltage before and after connecting the sources to the grid.

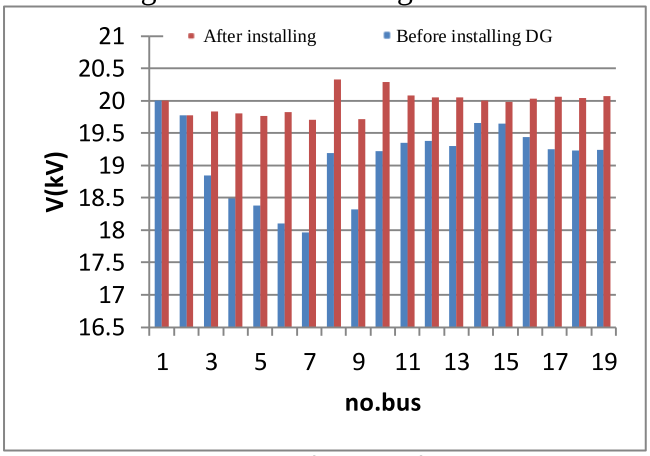

Figure4: Grid voltage before and after connecting the sources to the grid

As it has been shown by entering the cogeneration sources into the grid the voltage have been increased. In this study the cogeneration sources has been model as PQ by the power factor of 0.85 in post- phase.

The following figure shows the loading scale of the lines of the grid. As can be seen in the transmitted power has decreased due to local generation in the grid. This is a positive point which leads to the release of grid capacity and can respond to to the growth of the load.

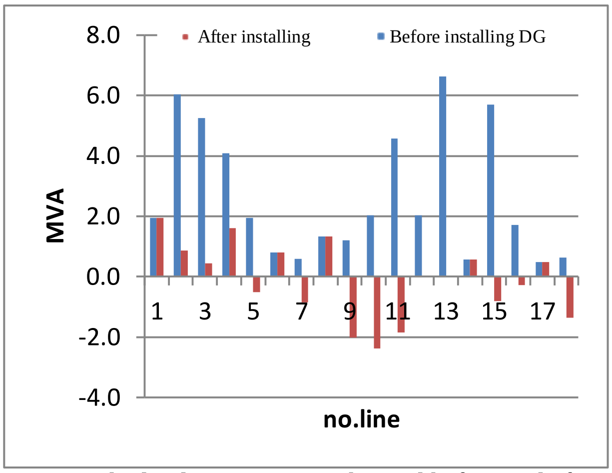

Figure 5: the loading amount in the grid before and after connecting the sources

The following figures show the percentages of costs in both states.

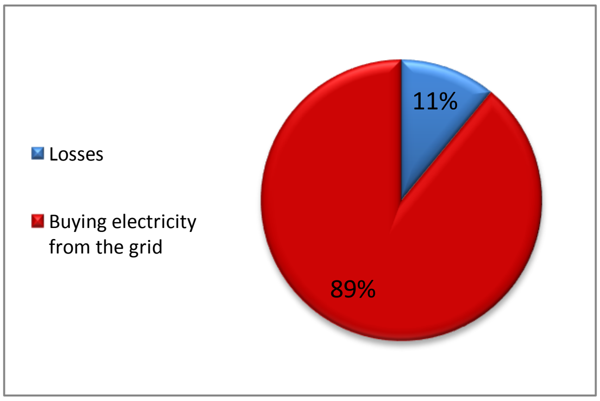

Figure 6: Division of costs in the initial state

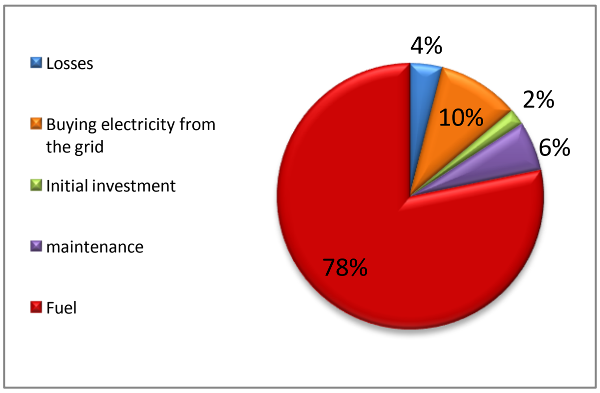

Figure 7: The division of costs after the installation of cogeneration resources

As can be seen the highest cost in both states is related to the power purchase from the grid. After connecting the distributed generation sources about 79% of the costs is for purchasing power from the grid. This suggests that the amount of capacity Installed on the grid can be increased further. However, since the amount of thermal load is limited in the grid. Therefore the chosen capacities should be limited. If the thermal load in the grid increases the possibility of heat recovery also goes up. Therefore the increase of capacities of cogeneration ounces would seem justifiable.

Figure 8 shows the convergence of algorithm in 100 repetitions. As mentioned before, the algorithm has reached to its optimal answer in repetition of 53.

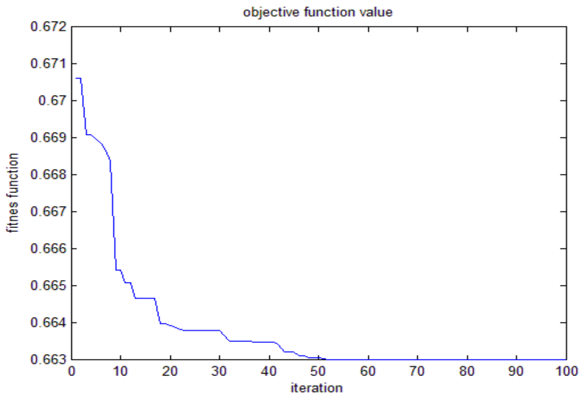

Figure 8- The graph of algorithm convergence

4-Conclusion:

In the present study an attempt has been made to investigate the use of gas-fired co-generation sources on 20 KV distribution grids from the perspective of a distribution service company. The results reveal that the use of distributed generation sources has a significant effect on the decrease of operation costs if it would be feasible to recover heat. Accordingly distributed generation sources have less efficiency in the grids with low heat consumption. Other advantages of the use of gas-fired co-generation sources in distribution grids are voltage increase and load decrease in grid lines.

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