DETERMINING OPTIMAL CAPACITY OF DISTRIBUTED GENERATION UNITS IN MULTIPLE ENERGY CONVERSION CENTERS CONSIDERING LOAD UNCERTAINTY USING ACO AND PSO ALGORITHMS

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Capacity of Distribute Generation (DG) unit vary from several kilo watts to tens of Megawatts; it is used to generate electrical energy close to consumers. If these units are connected to the grid, the grid is affected in many aspects including reduction of losses of the network, improvement in voltage profile and increase in network reliability. Inappropriate placement of DG units increases losses, generation and transmission costs. Therefore, optimization methods are required for placement of these units in the grid; thus, number of DG units, installation location and their capacities should be determined such that grid loss is reduced as much as possible under grid constraints. In this project, Ant Colony Optimization and Particle Swarm Optimization algorithms are used to solve the problem. After extracting flowchart of this method for optimal placement of DG units, computer programs are formulated and implemented on a standard IEEE 33-bus radial grid and obtained results are compared; their advantages and disadvantages are suggested. Obtained results indicate voltage profile and reduce network losses.

Keywords: DG units, optimal placement, reducing network losses, voltage profile, increasing network reliability

1. Introduction

Today, political and economic critics and problems like limited fuel resources, environmental concerns, and overcrowding, economic growth are all worldwide issues which have involved scientists to figure out proper approaches for solving energy problems in the world. Fortunately, most countries of the world have understood importance of different energy resources especially renewable energies in providing current and future needs; thus, they have conducted extensive researches and investments on developing utilization of these infinite resources.

Energy, is a basic requirement for economic development and providing welfare for human. Currently, energy consumption throughout the world is 10

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milliard raw petroleum per year and it is predicted that these numbers will increase to 12 and 14 milliard tons. These numbers indicate [1-4] that energy consumption in the next century would be very huge. All renewable energies take more responsibility in providing energy every day. These resources promise to respond both basic problems of fossil fuels. Renewable energies are basically compatible with nature; there is no end for them, because they are renewable. Other features of these resources include being distributed and extended all throughout the world; requiring lower technologies, makes renewable energies more attractive especially for developing countries; thus, in international policies, especially United Nation's plans, a special role is given to renewable energy resources [2].

Statistics indicate that the most important factor in destroying and polluting environment is generation, conversion and consumption of different types of energy; while, not only energy consumption will not remain at a constant level, but predictions indicate that their consumption will increase to about 7000 dollars in 2020 which is 75% more than what it was in 1980; this is due to population increase, tending towards welfare and increase in gross per capita production [5].

Proper utilization of DG resources might be an effective approach to resolve problems like high loss, low power quality and density in power systems. Connection of DG units with suitable placement in the grid, is followed by various effects which include increasing reliability of the grid, reducing losses, improving voltage profile, reducing transmission and distribution costs and improving power quality parameters including voltage imbalance. One of the most important issues in DG studies in placement and determining their capacity. This issue is important because through proper determination of these qualities, energy generation cost and grid loss can be reduced. Recent developments in renewable resources technology, increase in demand and requiring clean and cheap energy has attracted attentions to DG. In case, placement of DG units in power system is done properly, system becomes stable, reliability is increased, losses are reduced and final generation cost is reduced.

Electricity quality word has found many applications in industrial countries and electrical industry. The above discussion covers many of the existing distortions. Issues which are covered by electricity quality are not necessarily new concepts, but what is new, is efforts of engineers for collecting these issues and putting them in specific patterns. In other words, a new look to existing distortions in power systems has emerged as a new concept which is important to be studied in these systems [6]. On the other hand, considering problems caused by unfavorable quality of electricity, using proper methods for improving quality sounds necessary which requires proper and new solutions. Therefore, in order to find suitable methods, electricity quality problems and concepts should be well understood; this is possible when these concepts are well defined and evaluated. Power quality in electrical grids is a more complete concept of stability and preparedness which means that what quality does the consumer receive. Power quality is affected by following factors:

- Flickr
- Harmonics
- Voltage Imbalance

Two points can be inferred from effects of imbalance on power quality in voltage imbalance in industries. For instance, electricity companies have defined power quality equal to reliability. Instead, manufacturers of electrical equipment define power quality as proper performance of equipment based on supply characteristics [7]. But, what is used as power quality in this research is any problem which changes voltage, current or frequency, disrupts equipment or improper performance of equipment.

In general, only voltage quality in a power system can be controlled and there is no proper control over currents drawn by different loads. Therefore, standards in industrial countries specify allowed range of voltage sources. AC electricity grids are designed such that they operate in a sine voltage with specific frequency and amplitude. Any considerable deviation in amplitude, frequency is an electricity quality problem.

2. Problems caused by Voltage and Current Imbalance

Voltage and current imbalance: voltage generated in balanced three-phase power systems is a sine with equal amplitudes and each phase has 120 electrical degrees' difference with the other phase. A three-phase system is said to be imbalanced if amplitude or angle difference of phase voltages are not equal. Imbalance includes inequality in amplitudes and electrical angle difference of main frequency of phases. Imbalance can be divided to three following categories:

- Imbalance in voltage vectors of the basic frequency
- Imbalance in phase angle of voltage vectors of the basic frequency
- Imbalanced harmonic distortion between phases

In order to categorize imbalance factors, structural and performance factors can be mentioned.

Structural factors of the grid indicate structure and configuration of the grid. In many cases, asymmetric configuration of a system makes it unbalanced. One of structural factors which creates imbalance, geometrical asymmetry in line impedances and cables as a result of imperfect transposition of lines, asymmetry in wiring of transformers, open triangle or open star transformer banks (these links convert zero component of voltage of primary system to a negative component in secondary), worn out fuses and capacitive banks can be mentioned.

Second imbalance factor which is the main factor of this phenomenon is performance and unbalanced loads. Imbalance caused by structural factors is mainly negligible and solvable. What increases imbalance problems is performance factors including single-phase, two-phase and three-phase loads like electric arc furnaces and unbalanced equipment like links with high impedance like loose contacts and worn out contactors, unbalanced number of turns in windings of inductive motors or imbalance caused by incorrect repair and imbalance in rotor and stator of these motors. In addition, incorrect performance of power factor correction devices and single-phase to ground connection error can be mentioned. Eliminating imbalance caused by grid performance is difficult due to the following reasons:

- Existence of household, commercial and industrial single-phase loads [8]
- Continuous changes in power consumption of the grid as a result of changes in large industrial loads
- In addition, ASDs are nonlinear due to presence of diode rectifiers; if they are single-phase, they draw non-sine currents which creates harmonic distortions if the grid [9].

Costs caused by voltage and current imbalance: in distribution networks, asymmetry of load and phases is obvious which occupies capacity of lines, increase losses, increases voltage drop and imposes financial losses. It is clear that occupied line capacity reduces level of power which can be received from the line; since, electricity companies should respond power demanded by consumers, they have to construct a new like which imposes extensive costs on these companies.

On the other hand, as losses increase and voltage drop increases, current level at consumer side also increase which increases losses at consumer sides especially motor loads. Increase in loss power of loads reduces efficiency and lifetime of equipment which consequently increases losses. In [5], optimization is performed through birds' meta-heuristic method aiming to reduce losses for a distribution system in the presence of DG resources. Authors of [10] have employed Ants Colony Optimization algorithm to obtain number of required DGs for a specific period and utilizing this grid during this time through changing load aiming to minimize investment costs and utilizing DG and buying electricity from the grid. In [11], analytical method and mathematical model are used to select optimal location for installing DG in order to reduce losses.

3. Methodology

In order to utilize DG resources optimally, DG resources should be located at most proper points of the grid considering technical and economic constraints.

In general, any energy generation in relatively low capacities which is performed at consumption location or close to it, neglecting the technology employed for generation, is considered a type of distributed generation. In distribution section, input power is distributed such that system losses are minimum and quality of power delivered to consumer is acceptable; therefore, conventional structure has three main properties:

- Existence of major production centers
- Transmitting power to consumption centers using high voltage and transmission network
- Distributing transmission power at consumption centers

Ant Colony Optimization algorithm (ACO) is known as ants colony algorithm and ant colony optimization in Iran; it is one of the well-known evolutionary optimization algorithms. Shortest path, with higher pheromone is more probable to be selected. In initial uses of ACO, it was concluded that an elitism strategy like GA might improve efficiency of the algorithm.

Among applications of ACO, optimization of problems which require finding the shortest path, can be mentioned:

Intra-city and inter-city routing

- Routing between posts of high voltage distribution networks
- Routing in computer networks.

How can ants algorithm guarantee convergence to optimal solution? Answer lies in the point that if parameters of the algorithm like coefficients C_1, C_2 and w are not adjusted correctly, convergence of the solution towards optimal solution is not guaranteed. Therefore, searching solution tends towards local optimum and converges at that point. Local optimum is the point at which solution is the best solution around itself but it is not the best solution among all solutions. In order to resolve this problem, several researchers have proposed optimization solutions including improved ants algorithm entitled as particle swarm algorithm with ants' guaranteed convergence.

In fact, using DG units have various effects, where this project aims to achieve two mentioned impacts. Placement is an optimization problem to solve which, an optimization method should be used. There are various method for solving optimization problems where some of them find the relative optimal point like linear and nonlinear planning, gradient methods and … and others try to find the absolute optimum, like evolutionary methods, simulated annealing and etc. these methods have their own advantages and disadvantages. In this project, ants algorithm is chosen among optimization methods. Choosing ants algorithm as optimization method is due to: ability to achieve absolute optimum or a point close to optimum, not requiring side calculations and not having convergence problems. Several methods have been proposed for solving placement problem. Some of these methods are based on relative optimization methods. Since optimization methods used in these algorithms are relative, during search procedure, one might be trapped in local optimums; thus, absolute optimization methods should be used. Using ants algorithm in optimization of power networks has attracted attentions of researchers in recent years. To this end, ants algorithm is used for optimizing distribution grids including DG, placement and determining capacity of DGs in distribution networks.

3.1. Modeling Load Uncertainty in Placement of DG Resources

In this study, as mentioned before, main purpose is to place and determine optimal capacity of DG units which is challenging in radial distribution grids; one of the most important challenges is voltage drop in some buses and non-smoothness of voltage profile which results in losses. On the other hand, uncertainty in behavior of loads is also considered as a challenge; in other words, load changes in distribution network might affect placement and determination of optimal capacity, significantly.

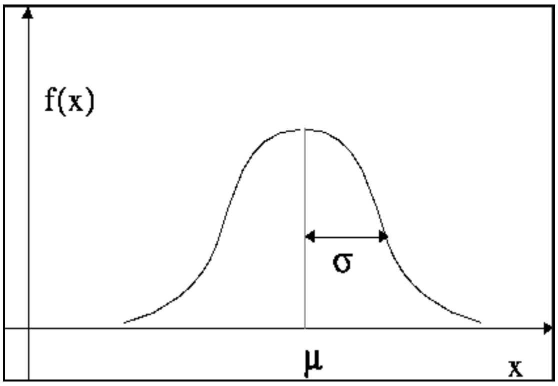

Fig.1 Normal probability density function

To this end, various researches have proposed various methods for modeling load changes randomly among which load modeling using fuzzy method, load modeling using monte-carlo method and etc can be mentioned, where each one has its own advantages and disadvantages. Purpose of this study is to model uncertain behavior of load through a meta-heuristic method and offer most optimal configuration for installing DG units and their capacity based on the proposed model. In this method, random variables are estimated as power consumption of each bus according to Gaussian probability distribution which can model uncertainty nature in power consumption of loads. For this purpose, a specific power is considered for each consumer based on normal probability distribution function (PDF) with assumed mean and variance; solution is searched based on these data. Considering the following figure, bell shape normal PDF with mean μ (based on power consumption at the corresponding bus) and variance

σ^2 (based on previous load consumption data of the corresponding bus) is assumed for each bus. This function can be obtained using the following approximate relationship for normal PDF.

$$f(x;\mu,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2/(2\sigma^2)}, x \in R \quad (1)$$

This assumption becomes feasible using randn(μ,σ^2) in powerflow.m of MATLAB and replacing it with unity power at each bus.

4. Simulation

In this simulation, a power grid model is required to provide ability of applying considered optimization algorithm in MATLAB. Considered model should meet the following conditions:

- Connection matrix of buses in the grid
- maximum power of each DG
- possibility of creating and installing what type of DG on which buses
- matrix of branches and topology of the grid
- cost of installing each DG per MW
- constraints on voltage of buses and current of lines in the network

Therefore, using grid model, it is time to start simulation to find the most optimum solution considering constraints of 33-bus model.

4.1. Objective Function of the Optimization Algorithm

As known, most important part of an optimization problem is selecting the proper objective function for the optimizer. When objective function is comprised of several parts, this issue becomes more important. In fact, this study aims to find the most optimal voltage profile and install DGs with minimum cost, simultaneously.

On the other hand, since measurement unit of these two are different, both should be normalized in terms of total loss and total cost of installing DGs; which maps both variables from two spaces with different measurement units to a common domain; thus, linear operations can be performed on them.

Objective function is comprised of two weighted parts where the first part is the lost power divided by total generated power and second part is cost of installing DGs divided by total cost of installing all possible DGs on buses. On the other, by weighting each part, importance of each part is determined. For instance, if reducing losses is more important than cost of installing DGs, $W_1>W_2$ should be chosen. But in order to guarantee convergence of objective function towards most optimum solution, by applying penalties to improper solutions, most optimal solution is achieved faster. There are different types of penalties; here, a hybrid penalty is used such that solution of each cost is multiplied by penalty function.

Penalty for each solution indicates that it is improper or it has exceeded determined ranges for effective parameters of the solution like current, voltage and penalty function is considered as follows:

$$\mathbf{V} = (\boldsymbol{\alpha} + \boldsymbol{\beta} \times \mathbf{Violation}) \tag{2}$$

Where α and β are penalty coefficients, violation is the amount of violation of the solution from the determined space by constraints and V is the penalty function. Therefore, by multiplying this function by the main objective function, objective is obtained. In fact, α and β weight each penalty.

In other words, innovative idea which can be proposed for modeling optimization problems is to limit the objective function using penalty coefficients; employing penalty coefficients means getting the algorithm far from searching undesired solutions (defined by constraints of the problem) and guiding it towards the objective function. For this purpose, problem constraints are applied as penalties with different weights and if the algorithm selects solutions in this margin, cost of objective function is increased.

4.2. Modeling the Objective Function

In order to model the objective function, since cost of pollution caused by greenhouse gases is an important factor in maximum utilization from DG units, thus, it is required to model and evaluate the objective function with and without cost of pollution caused by greenhouse gases.

4.2.1. Modeling the Problem without considering Cost of Greenhouse Gases

Simulated objective function is as follows:

$$TotalCost = \min\{\left(w_1 \times \sum_{i=1}^{n} \frac{|V_i - V_r|}{V_r} + w_2 \times \sum \frac{DGIns}{C_m S_m}\right) + (\alpha + \beta \times \text{violation})\} \tag{3}$$

Where final cost function is described with TotalCost.

As it can be seen, the objective function is comprised of two main parts. First part is associated to losses and second part is associated to cost of installing DG units. On the other hand, in order to add non-similar values like cost, power and voltage in a function, it is required to normalize values to their own unit. Another part is also defined as penalty which is defined as follows:

$$violation = \alpha \times V_L + \beta \times V_u + \gamma \times P_{res} \tag{4}$$

- *Optimal Placement of DGs in a 33-bus Grid*

In order to employ the mentioned model, matrices and vectors should be defined in MATLAB, using which evolutionary algorithm finds the most optimal solution by applying a proper objective function.

Therefore, considering the above discussion, following steps are performed in MATLAB:

Step 1: creating a model of standard IEEE 33-bus grid using matrices

Step 2: creating different constraints on system characteristics to make the created model more real

Step 3: creating random solutions and calculating violation of solutions from solution space

Step 4: applying random solution to the objective function and penalty function for calculating cost of each solution

Step 5: comparing solutions and finding least cost among all searched methods

Step 6: representing output solution as which type of DG can be utilized on which bus with how much of the maximum power

In the 33-bus model, a matrix is defined for determining impedance parameters corresponding to each branch of the network as shown in Table 1.

In which rows show branches and columns show number of transmitting buses, number of receiving buses, number of branches which connect buses, ohmic resistance and corresponding inductance of the grid.

Above matrix represents the following 33-bus grid (Figure 2). As can be seen in this figure, buses 2 to 33 are PQ buses and bus 1 is the slack bus; after optimal placement of DGs, buses on which DGs are installed are converted to PV buses. Information of generated and consumed power of each bus is given in Table 1. Current constraint and voltage constraint are considered for each line and bus, respectively; voltage of each bus should vary between 0.8 to 1.2 per unit and any violation from this range, penalizes the solution. Maximum power and cost for installing each DG are also determined.

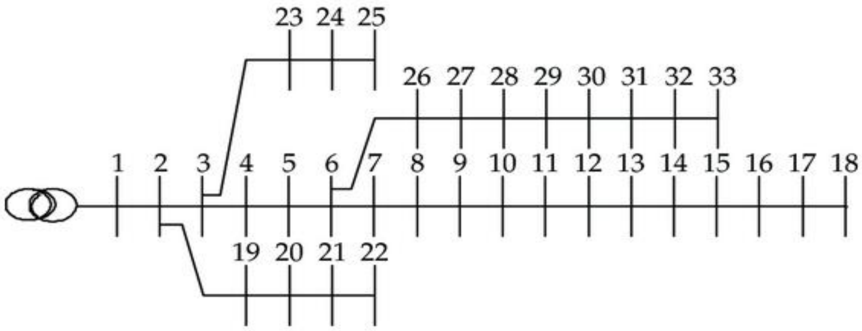

Fig.2 standard IEEE-33 bus test system

Each variable in the optimization algorithm represents position of particles which is comprised of three main parts:

- *Determining buses on which DG is installed (33 variables for 33 buses)*
- *Determining type of DGs installed on buses determined at step 1 or previous step (33 variables for 33 buses)*
- *Determining operating range of each DG installed at 2. (33 variables for 33 buses).*

Indeed, it should be noted that results are obtained from simulation of a grid with arbitrary model in which cost of installing each MW of solar DG units and CHP is considered as in Table 2. Therefore, as an application, model of the network can be changed as a n-bus model for which most optimal location for installing DGs in each practical and impractical grid can be found. Thus, by performing simulations on this model and considering the constraints of a standard IEEE 33-bus grid, results are obtained as in Table 3. It should be noted that despite there is the possibility of installing DG on some buses, the optimization algorithm has determined that it is better not to install DG on those buses. After performing simulation, not only type of DGs installed on each bus is determined, bus also required rate for each DG is also determined.

This simulation is selected for 100 iterations and 10 particles (number of output data of the function (NFE) would be 1000); it can be seen in Figure 2 that as the optimization algorithm is executed, the objective function is minimized. In this algorithm, voltage of different buses is determined first through performing power flow (voltage profile) and loss index is also obtained. Then, algorithm investigates power flow equations through offering random solutions from power generated by DGs at the points of the grid at which DGs can be installed; installation cost is determined by determining installation location, type of the unit and its generated power. Then, voltage of each bus is determined by performing power flow one again and this loop continues until design cost and power loss of the algorithm are balanced.

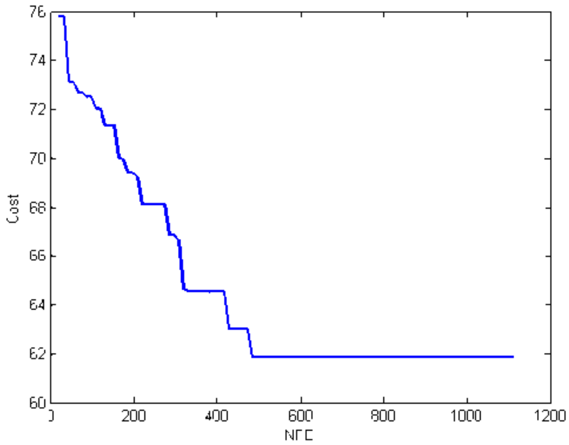

Fig.3 Cost function of the Grid in the Absence of DG resources

4.2.2. Voltage Profile of the Grid in the Absence of DG resources

Objective function is improving voltage profile of the grid; in fact, in order to improve voltage profile, network losses are introduced to the optimization problem directly and the objective is realized through minimizing them. Thus, one the measures which can represent efficiency of the proposed model well is voltage profile model; in the following, cases before installing DGs and after installing DGs are compared. In situation, where DG resources are not used for obtaining the objective and the grid is utilized conventionally, voltage profile for the 33-bus network is as shown in Figure 4.

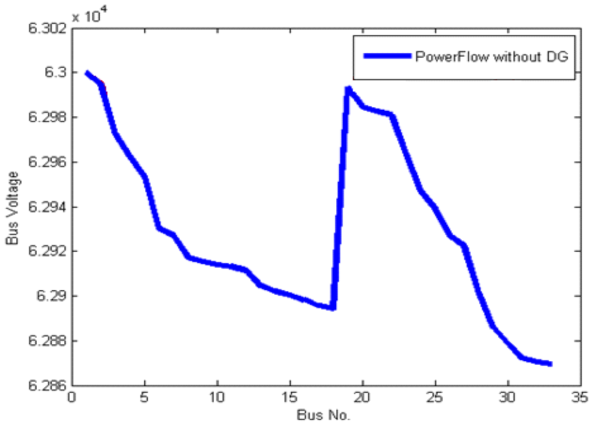

Fig.4. Voltage Profile of the Grid in the Absence of DG resources

As can be seen, in situation where power flow is performed for the grid in the absence of DGs, voltage profile would be non-smooth which reduces voltage stability margin of the grid.

4.2.3. Voltage Profile in the presence of DGs

After optimizing objective function and placement of DGs in the grid, voltage profile is presented as in Figure 5. As can be seen, voltage profile is improved after installing DG units and this improves voltage stability margin of the network. Voltage profile is improved due to presence of DGs and compensating voltage drops at buses.

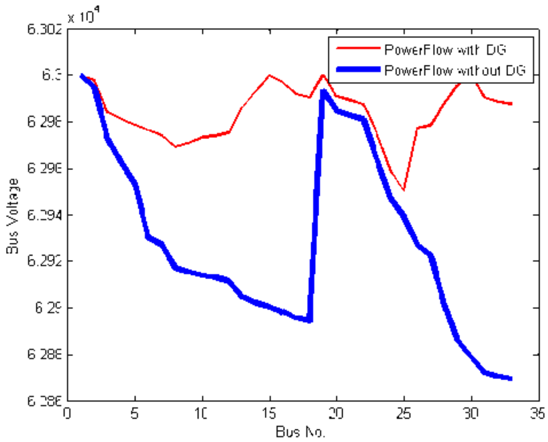

Fig.5. Voltage profile of the grid (without considering cost of pollution using ACO Algorithm)

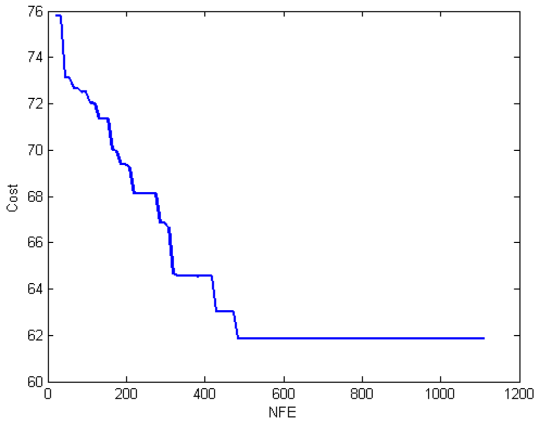

Fig.6. Cost function diagram (without considering cost of pollution using ACO Algorithm)

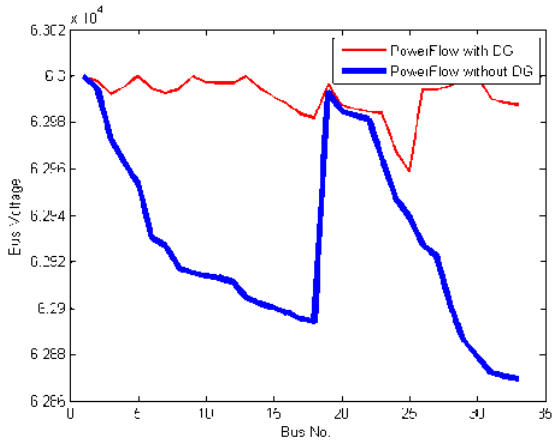

Fig.7. Voltage profile of the grid (without considering cost of pollution using PSO Algorithm)

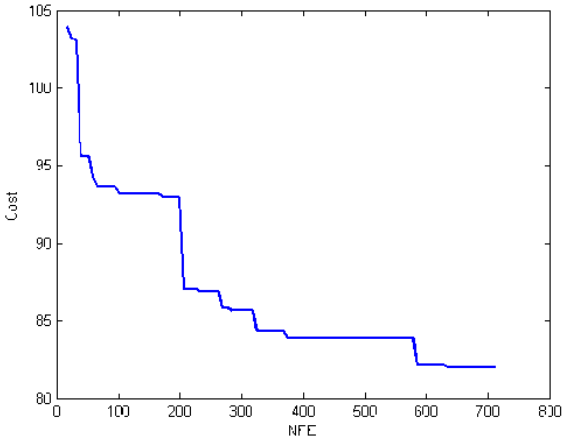

Fig.8 Cost function diagram (without considering cost of pollution using PSO Algorithm)

4.2.4 Modeling the Problem considering Greenhouse Gases

Simulated objective function is as follows:

$$Cost = \min\{w_1 \times \sum_{i=1}^{n} \frac{|V_i - V_r|}{V_r} + w_2 \times \sum \frac{DGIns}{C_m S_m} + w_3 \times \sum \frac{S_d - S_{DG}}{S_d}\}$$

Where final cost function is obtained by adding penalties to the above cost and Sm is maximum power of buses, C_m is maximum cost of generating each MW of DG, V_i is voltage of *ith* bus, V_r is the nominal voltage, S_d is total demanded power, S_{DG} is total power generated by DG units.

In fact, for defining each objective function and adding pollution cost to it, total generation cost by fossil units is calculated through minimizing which, pollution cost is reduced significantly. It should be mentioned that in this research, for evaluating losses, an index, voltage violation from 1 per unit voltage is defined which can be a proper index for evaluating losses.

4.2.5 Simulation Results considering Cost of Pollution caused by Greenhouse Gases

Similar to previous case, this case is also simulated and the results are given in Table 4. In this study, optimal placement of DGs is simulated in two cases and it has been shown that when air pollution is considered, results differ a little with results of the first case. Considering Figure 7 and comparing it with Figure 5, it can be seen that when cost of pollution caused by fossil units is not considered, voltage profile would be smoother; in other words, cost of losses would be less, while considering this constraint, increases non-smoothness of the voltage profile. Cost of losses considering the defined relationship for voltage violation would be 41% and 65% for ants algorithm and PSO, respectively.

On the other hand, by investigating the results obtained in Table 4, it can be seen that since purpose is to reduce power bought from fossil units, power received from DG units has increased extensively; consequently, cost of buying form DGs has increased.

It should be noted that Ants algorithm has shown its performance in solving the problem; because Ants algorithm has shown similar performance in optimal placement of DGs with and without considering cost of pollution caused by fossil units; it has searched the desirable solution for the problem. Since performance of this algorithm is inherently similar to PSO, these algorithms are compared in Figure 8; comparison between behavior and final optimized value by these algorithms can be seen well; this comparison shows that Ants algorithm has reached a more optimal value faster than PSO which reduces processes for simulations.

Finally, comparing figures 8 and 4 shows that when cost of pollution caused by fossil units is considered, optimized final cost is more than the case where this constraint is not considered; in other words, in this situation, final cost is increased because the algorithm looks for solutions which are closer to solution of the problem to the practical problem.

5. Conclusion

One of the most important issues in power systems is using DG resources adapted to the main system. Due to stochastic nature of DG systems, designers should use such resources in power systems, carefully. Thus, we decided to solve power flow problem by considering a power system modeled in MATLAB and applying one of the strongest meta-heuristic evolutionary algorithms to obtain minimum losses in the presence of DG resources. In simulations, Ants algorithm and PSO are used and most optimal location for installing DGs on a 33-bus grid are found. In future, this optimization can be performed on a real power system to compare the results with theory. Since, in practice, other parameters are involved in optimization problem, this problem is not investigated here.

Other suggestions for future works include making the problem dynamic such that optimization is performed dynamically through considering power of DG resources to be variable and power taken from each DG is determined instantaneously. Moreover, in order to investigate the problem comprehensively, it is desirable to involve other DG units in solving the problem. It should be mentioned that this can decreases computer processes significantly. Finally, involving other parameters like system reliability in solving placement problem, might make the simulation response much close to practical model.

Table 1

Information of generated and consumed power of each bus (in MW)

BUS	1	2	3	4	5	6	7	8	9	10	11
P	3.8	0.1	0.09	0.12	0.06	0.06	0.2	0.2	0.06	0.06	0.045
Q	2.4	0.06	0.04	0.08	0.03	0.02	0.1	0.1	0.02	0.02	0.03
BUS	12	13	14	15	16	17	18	19	20	21	22
P	0.06	0.06	0.12	0.06	0.06	0.06	0.09	0.09	0.09	0.09	0.09
Q	0.035	0.035	0.08	0.01	0.02	0.02	0.04	0.04	0.04	0.04	0.04
BUS	23	24	25	26	27	28	29	30	31	32	33
P	0.09	0.42	0.42	0.06	0.06	0.06	0.12	0.2	0.15	0.21	0.06
Q	0.05	0.2	0.2	0.025	0.025	0.02	0.07	0.6	0.07	0.1	0.04

Table 2

Cost of installing each MW of solar DG units and CHP

BUS	1	2	3	4	5	6	7	8	9
Cost(Million$)	1000	1000	1000	1000	4.4064	1000	1000	1000	7.6673
BUS	10	11	12	13	14	15	16	17	18
Cost(Million$)	1000	1000	1000	3.0143	1000	5.9708	1000	1000	1000
BUS	19	20	21	22	23	24	25	26	27
Cost(Million$)	4.7166	1000	1000	1000	1000	1000	1000	1000	1000
BUS	28	29	30	31	32	33			
Cost(Million$)	1000	1000	6.5465	1000	1000	1000			

Table 3

The simulation results of optimal location of DGs

Bus number with distributed generation unit	DG Type	Installed capacity(MW)
5	Solar	1.12
13	CHP	1.54
15	CHP	7.62

Table 4

The simulation results of DGs with considering cost of pollution

Bus number	Type of DG	Installed capacity(MW)
5	Solar	6.173
13	CHP	6.204
19	Solar	6.192
30	CHP	6.204

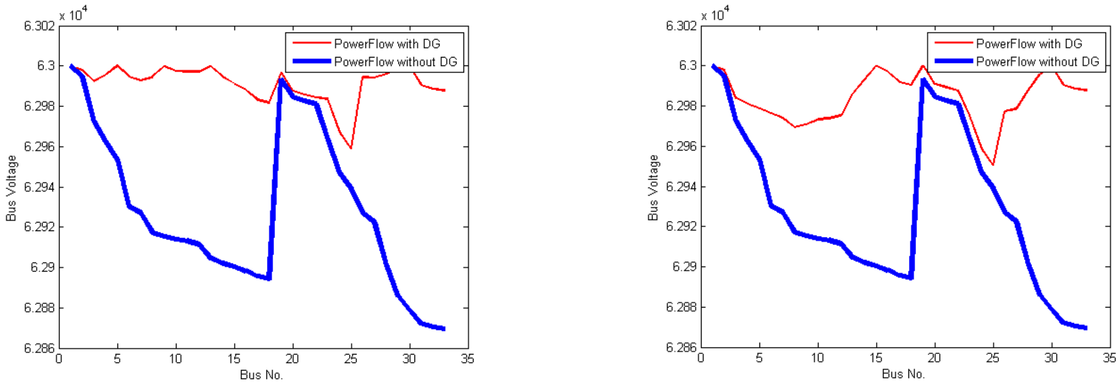

Fig.9 Voltage profile of the grid (without considering cost of pollution using ACO (right) and PSO (Left) Algorithms)

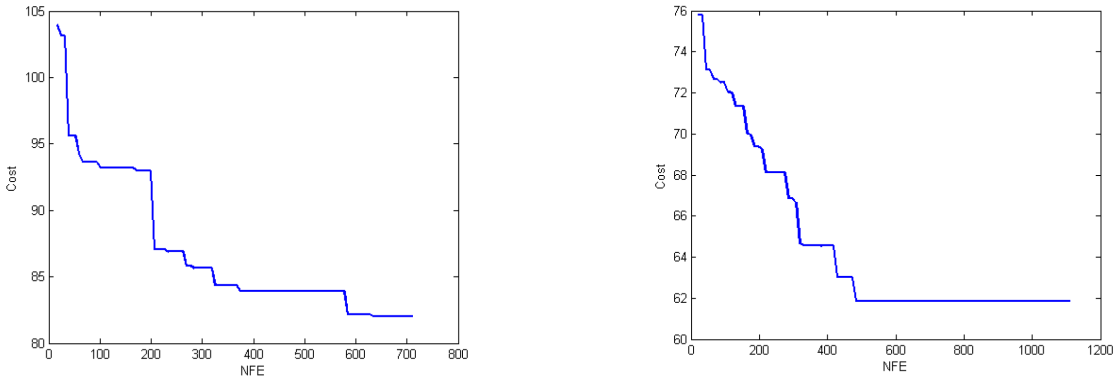

Fig.10. Cost function diagram (without considering cost of pollution using ACO (right) and PSO (Left) Algorithms)

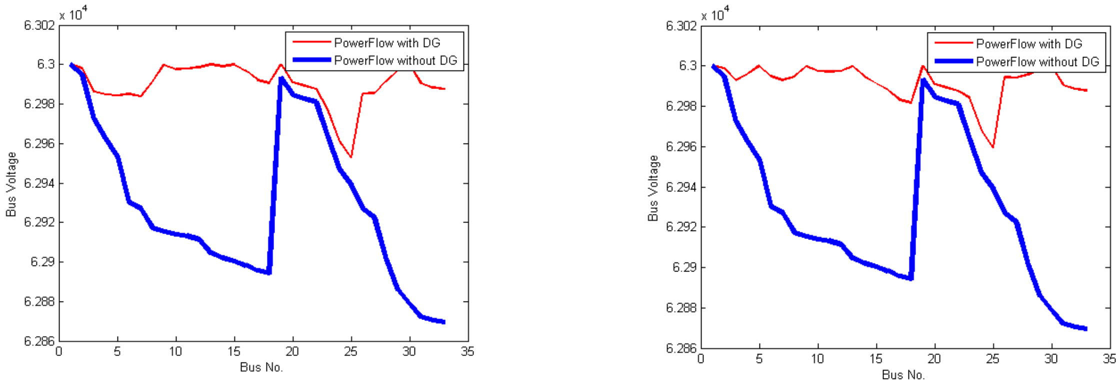

Fig.11 Voltage profile of the grid (with considering cost of pollution using ACO (right) and PSO (Left) Algorithms)

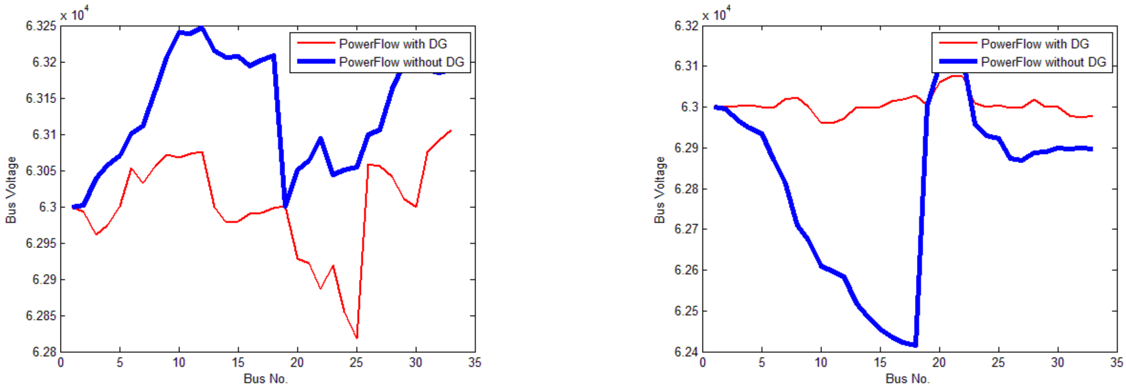

Fig.12 Voltage profile of the grid with considering cost of pollution using PSO Algorithm (The variance is equal to one (on the right) and the variance is greater than one (on the left))

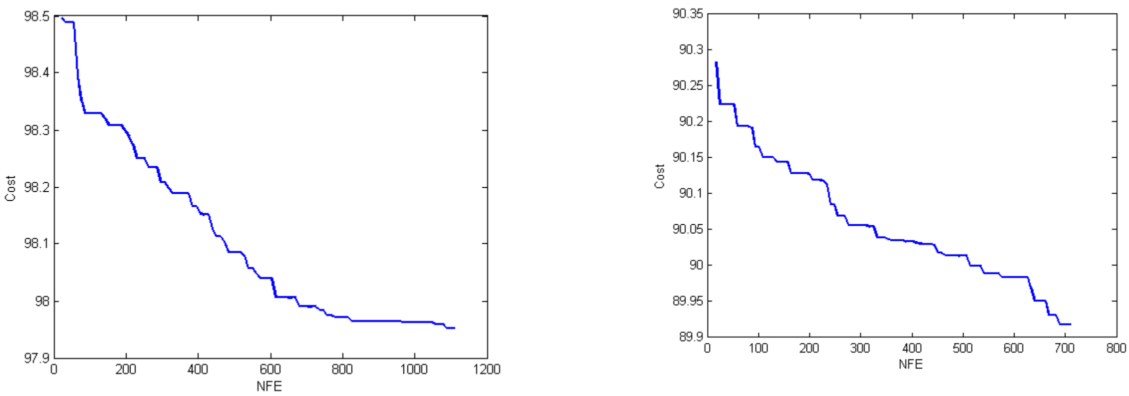

Fig.13 Cost function of the grid (with considering cost of pollution using ACO (right) and PSO (Left) Algorithms)

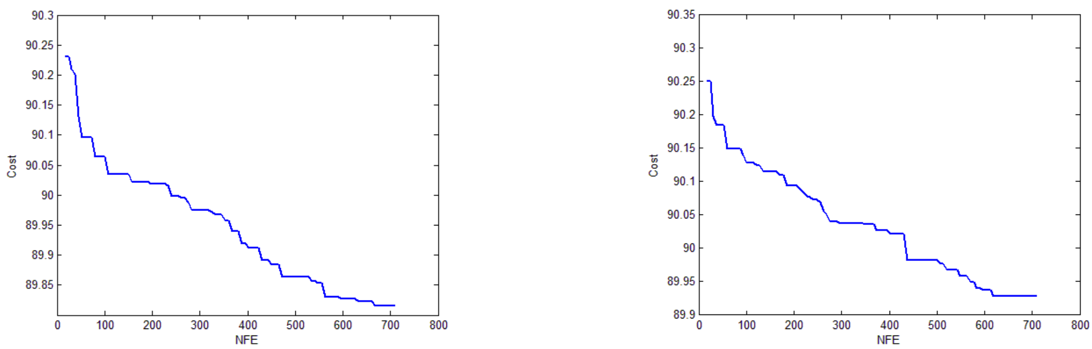

Fig.14 Cost function of the grid with considering cost of pollution using PSO Algorithm (The variance is equal to one (on the right) and the variance is greater than one (on the left))

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