Abstract

Today, with advances in semiconductor technology and the ability to interface and power electronic converters and also the desires and motivations of economic and environmental another option has occurred to increase the capacity for network engineers and power systems planners. Size and place selection (planning) of distributed generation is the optimization problem that to solve it should get help from one of the optimization methods. In this paper, two methods to determine the size and location of distributed generation (DG) units are presented in distribution system. Four objective functions include, cost, power loss, voltage profile and environmental attributes are intended. The proposed algorithms are tasted on the 34-bus radial system. The results show that voltage profile and power loss improve with proposed solution.

Keywords: Distributed Generation (DG), Multi-objective Optimization Algoritm, Multi Objective Particle Swarm Optimization (MOPSO), Non-dominated Sorting Genetic Algorithm (NSGA)

1. Introduction

Expansion of large cities, increasing demand for electricity, use of renewable sources of electricity market, the high cost of creating a new electrical grid, spatial problems for them and many other issues is common using of Distributed Generation (DG) in the consumer. In ref imperialist competitive algorithm is used for optimal multiple DGs placement and sizing in a distribution system.

2. Objective Functions

There are four objective functions in this paper that are optimized concurrently. A multi objective optimization problem is generally as follows:

\[
\text{Minimize: } F(x) = \{f_1(x), f_2(x), \ldots, f_m(x)\} \tag{1}
\]

Subject to: \(g_i(x) \geq a_i, \quad i=1, 2, \ldots, q\),

\(h_j(x) \geq b_j, \quad j=1, 2, r\).

Where there are q inequality and r equality constraints and \(x = [x_1, x_2, \ldots, x_n]\) is the vector of n design variables. \(f_1\) is the cost function, \(f_2\) is voltage profile, \(f_3\) and \(f_4\) are the power loss and the environmental functions, respectively.

2.1 Cost Function (\(f_1\))

Network cost during the planning period include:

1) Investment cost of DG units, the assumption is that these units can be installed and put into operation the first year. In other words, installation and commissioning period is assumed neglibegle.
2) The cost of buying electricity from the grid during the planning period.
3) The cost of electrical energy produced by DG which include fuel costs, operation and maintenance.

Thus the cost function with above factors as follows:
Two Methods for Size Selection of DG Units in Distribution Networks

\[ f_1 = \sum_{i=1}^{\text{usedDGs}} \left( IC_i \times \frac{T}{\text{Lifetime}_i} \right) \]  \hspace{1cm} (2)

\[ \sum_{t=0}^{T} \left[ \left( P_{\text{grid}} \times C_{\text{grid}} \right) + (O \& M + \text{Feul}) \times \text{Cap}_{DG} \right] \times 8750 \]

Where \( IC_i \) is investment costs (buying and installation) distributed generation units, \( P_{\text{grid}} \) is delivered Power to the distribution system network in \( T \)t year, \( C_{\text{grid}} \) is unit price of electricity bought from grid, \( \text{Cap}_{DG} \) is vector capacity of of the used DG in distribution system, \( T \) is the length of planning period and \( \text{Lifetime}_i \) is lifetime of \( i \)th DG.

2.2 Voltage Profile \( (f_2) \)

One of the most significant problems in the distribution network is improper voltage profiles. Because the voltage is the main parameters in terms of the quality of services provided by electricity companies. The voltage profiles calculated as follows:

\[ f_2 = \sum_{i=1}^{m} \frac{V_i - V_b}{V_b} \]  \hspace{1cm} (3)

Where \( m \) is number of buses.

2.3 Power Loss \( (f_3) \)

Two important parameters in calculating the losses are line resistance and currents. The total real power losses can be calculated as:

\[ f_3 = P_{\text{loss}} = \sum_{k=1}^{n} I_k^2 R_k \]  \hspace{1cm} (4)

Where, \( n \) is number of branches and \( I_k \) and \( R_k \) are the magnitude of current and the resistance of the branch \( k \), respectively.

2.4 Environmental Function \( (f_4) \)

Today, with the increasing demand for electric energy production and increasing the awareness of environmental pollutions, reducing these pollutants is important. In this paper considering the following objective function, we want to minimize the annual amount of pollutant gas emissions. The main pollutant gases and \( a_i \) (emission rate of pollutant gases) are in Table 2:

\[ f_4 = \sum_{i=\text{Tech}} \text{Cap}_{DG,i} \times a_i \times 8760 \]  \hspace{1cm} (5)

3. Constraints

In this paper, These constraints are considered.

\[ \sum_{j=1}^{m} P_{DG,j} = \sum_{j=1}^{m} P_{D,j} + P_{Loss} \]  \hspace{1cm} (6)

\[ \sum_{j=1}^{m} Q_{DG,j} = \sum_{j=1}^{m} Q_{D,j} + Q_{Loss} \]  \hspace{1cm} (7)

\[ |P_{DG,\text{min}}| \leq |P_{DG,j}| \leq |P_{DG,\text{max}}| \]  \hspace{1cm} (8)

\[ |Q_{DG,\text{min}}| \leq |Q_{DG,j}| \leq |Q_{DG,\text{max}}| \]  \hspace{1cm} (9)

\[ |V_{j,\text{min}}| \leq |V_j| \leq |V_{j,\text{max}}| \]  \hspace{1cm} (10)

4. Proposed Approaches

The evolutionary algorithms presented in this paper are designed to effectively and efficiently solve multi objective problems from the DG planning. In this paper, two methods are proposed.

4.1 Non-dominated Sorting Genetic Algorithm (NSGA-II)

This algorithm is one of the most powerful evolutionary optimization algorithm. NSGA-II algorithm steps are as follows:

1) Generate the initial population.
2) Study population was produced from the perspective of defined objective functions.
3) Apply the non-dominated sorting.
4) Calculate the crowding distance.
5) Selection of parents for reproduction.
6) The mutation and crossover
4.2 Multi Objective Particle Swarm Optimization

This algorithm is a generalization of pso algorithm for solving multi-objective optimization problems. MOPSO algorithm steps are as follows:

1) Create the initial population.
2) Separate the dominated members of the population and saving them on the Rep.
3) tabulating the purpose of discovery.
4) Every piece chooses a leader of the members from the Rep. and makes his move.
5) Best personal memory of each particle is updated.
6) The dominated members of the current population is added to the Rep.
7) Delete the Non-dominant members Rep.
8) If the number of Rep. is more than determined capacity, Additional members are removed.
9) If the termination conditions are not fulfilled, come back to 3 otherwise the end.

4.3 Best Compromise Solution

To find the best solution we find the membership function for each function but before that we need to find $F_i^{\text{min}}$ and $F_i^{\text{max}}$. Membership function is obtained from the following equation. The technique based on fuzzy set theory and the value range for each objective function is $1 \sim 0$.

$$U_i = \begin{cases} 
1 & F_i = F_i^{\text{min}} \\
F_i^{\text{max}} - F_i^{\text{min}} & F_i^{\text{min}} < F_i \leq F_i^{\text{max}} \\
0 & F_i = F_i^{\text{max}}
\end{cases}$$  \hspace{1cm} (11)

$u^k$ is the corresponding membership function for the solution k and is calculated as follows:

$$u^k = \frac{\sum_{i=1}^{\text{NO}} u_i^k}{\sum_{k=1}^{\text{M}} \sum_{i=1}^{\text{NO}} u_i^k}$$  \hspace{1cm} (12)

Where, NO is number of objectives and M is number of Pareto solutions. The maximum member ship function is the best compromise solution.

5. Numerical Results

The proposed planning framework was implemented in the MATLAB environment and applied to the IEEE 34-node distribution test system (Figure 1). The distribution test system has a total load of 1.769 MW + 1.044 MVAR.

In this paper, the following assumptions are considered:

1) Distributed generations do not have the capability of generating reactive power and are modeled as the negative active loads in the load points.
2) Planned duration is 5 years and DG units just can be installed in the first year and exploit.
3) The lifetime of all the units is considered 10 years.

Six conventional DG technologies and their parameters are expressed in the following (Table 1). To determine the set of non-dominated solutions, the NSGA algorithm is executed using the parameters (Table 2). The emission rates of DG technologies are presented (Table 3). Figure 2 is technology, location and size of DG units in the optimal planning scheme in the NSGA-II and Figure 3 show the result of the MOPSO algorithm.

Solution number 298 was selected as the best planning scheme among the non-dominated solutions in the NSGA-II algorithm (Table 5). The values of the cost function, voltage profile, Power loss and environmental objective functions in this scheme are 6.81M$, 0.1277%, 0.2382 M$, and 4.94M$, respectively. Solution number 191 was selected as the best planning scheme among the non-dominated solutions in the MOPSO algorithm (Table 6). The best solution of two methods is same. The values of the cost function, voltage profile, power loss and environmental objective functions without DG and the best proposed solution (Table 7).
Table 1. Parameters of DG technologies

| Number | Type             | Size (KW) | O&M+F ($/KW) | DG Capital Cost |
|--------|------------------|-----------|--------------|-----------------|
| DG1    | Diesel Engine    | 450       | 4.5          | 500             |
| DG2    | Gas Turbine      | 550       | 4            | 1000            |
| DG3    | Micro-Turbine    | 600       | 5            | 1500            |
| DG4    | Fuel Cell        | 600       | 5            | 3500            |
| DG5    | Wind Turbine     | 150       | 1            | 4500            |
| DG6    | Photovoltaic     | 200       | 0.5          | 5000            |

Table 2. Parameters of the NSGA-II algorithm

| Parameter          | Value     | Parameter          | Value     |
|--------------------|-----------|--------------------|-----------|
| Population         | 350       | Generation (gmax)  | 350       |
| Crossover          | 0.7       | Mutation           | 0.15      |

Table 3. Emission rate of pollutant gases (kg/kWh)*

| Tech. | Emission rate of pollutant gases (kg/kWh) |
|-------|------------------------------------------|
|       | $CO_2$ | NOx  | $SO_2$ | $CO$  | PM10 |
| DE    | 0.65   | 4.483| 0.093  | 1.275 | 0.16 |
| GT    | 0.63   | 0.236| 0.002  | 0.144 | 0.016|
| MT    | 0.72   | 0.091| 0.002  | 0.247 | 0.018|
| FC    | 0.46   | 0.006| 0.012  | 0.002 | 0    |
| WT    | 0      | 0    | 0      | 0     | 0    |
| PV    | 0      | 0    | 0      | 0     | 0    |

The parameters of the MOPSO algorithm are presented (Table 4).

Table 4. Parameters of the MOPSO algorithm

| Parameter   | Value | Parameter              | Value |
|-------------|-------|------------------------|-------|
| Population  | 350   | Repository             | 400   |
| Crossover   | 0.7   | Maximum Number of      | 600   |
|             |       | Iterations             |       |

Figures 4 and 6 show voltage profile and power loss, respectively without DG and for the best proposed solution in 1st year. Figures 5, 7 are in 5th year.

6. Conclusions

In this paper, two methods for finding a suitable location and size of DGs were presented. Four objective functions including cost, voltage profile, power loss and environmental function were optimized concurrently. The proposed methods were applied to the IEEE 34-bus distribution system. The results showed that voltage profile and power loss were improved with proposed solution.
Figure 2. Technology, location and size of DG units in the NSGA-II algorithm.

Figure 3. Technology, location and size of DG units in the MOPSO algorithm.

Figure 4. Voltage profile without DG and the best proposed solution for 1st year.

Figure 5. Voltage profile without DG and the best proposed solution for 5th year.

Table 5. Ranking of the planning schemes according to the values of the normalized membership functions.

| Scheme no. | Rank | Normalized membership function ($\times 10^{-2}$) | Normalized objective function value | Actual objective function value |
|-----------|------|-----------------------------------------------|-----------------------------------|--------------------------------|
| 298       | 1    | 3.29                                         | 0.4865                           | 0.4865                          |
| 288       | 2    | 3.25                                         | 0.4863                           | 0.4863                          |
| 214       | 3    | 3.22                                         | 0.4862                           | 0.4862                          |

| Scheme no. | Rank | Normalized membership function ($\times 10^{-2}$) | Normalized objective function value | Actual objective function value |
|-----------|------|-----------------------------------------------|-----------------------------------|--------------------------------|
| 298       | 1    | 3.29                                         | 0.4865                           | 0.4865                          |
| 288       | 2    | 3.25                                         | 0.4863                           | 0.4863                          |
| 214       | 3    | 3.22                                         | 0.4862                           | 0.4862                          |
### Table 6. Ranking of the planning schemes according to the values of the normalized membership functions

| Scheme no. | Actual objective function value | Normalized objective function value | Actual rank | Normalized rank
|------------|---------------------------------|-------------------------------------|-------------|----------------|
| 1         | 6.81 | 0.1277 | 1 | 2 |
| 2         | 6.81 | 0.1276 | 1 | 2 |
| 3         | 6.81 | 0.1281 | 1 | 2 |

### Table 7. The values of the functions without DG and the best proposed solution

| Functions | Without DG | The best solution of NSGA-II | The best solution of MOPSO |
|-----------|------------|-------------------------------|-----------------------------|
| Cost (M$) | 6.159      | 6.81                          | 6.81                        |
| Voltage profile (%) | 0.3523 | 0.1277                         | 0.1277                      |
| Power loss (M$) | 0.902    | 0.2382                         | 0.2382                      |
| Environmental function (M$) | 0 | 4.94                           | 4.94                        |

![Figure 6. Power loss without DG and the best proposed solution for 1st year.](image)

![Figure 7. Power loss without DG and the best proposed solution for 5th year.](image)
7. References

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