Optimum Distributed Generation Location, Type, and Penetration for Radial Distribution Networks

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Abstract

This paper studies the effect of implementing distributed generation (DG) units into radial distribution systems to optimize the electrical performance of the network. The IEEE 13 bus radial test feeder was chosen as an example for radial distribution networks. The DG units are categorized by the type of power generated, which are apparent power (P+jQ) and active power (P only). The optimization process uses two techniques, the first is the generalized reduced gradient (GRG) and the second is the genetic algorithm (GA). The paper studied and compared the impact of implementing both categories of DG units, using both optimization techniques on the electrical performance of the radial distribution system, from three points of view; the overall system losses, the bus voltage, the generation costs. Graphs are presented to show the effect of varying the penetration level (i.e. DG size) with each point of view separately, in addition to a comparison between the performance of GRG and GA. Finally the DG units with apparent power generation are preferred from the three points of view. And the GA performance is better with larger number of variables.

Keywords: Distributed Generation (DG), IEEE 13 bus system, radial distribution, genetic algorithms.

1. Introduction

In the last few years, electrical distribution networks experiences tremendous increase in power demand from the local customers connected to the network. This is due to, either increase in the number of the connected customers and/or due to increase in the social welfare. So the network has to meet this demand increase and secure sufficient power for all the customers. This is done either by increasing the power network capabilities (i.e. implementing more power units) which means deferring of cable sizes, medium voltage
switchgear, protection devices settings, etc.; or by installing small generators to the distribution network, connected to the customer side of the meter. Hence the term distributed generator (DG) was introduced. The last solution leads to increase of the deregulation of the networks and also has many proponents who claim that implementing DG units leads to the decrease in power losses, enhance voltage profile, decrease the generation cost and - last but not least – delay the deferring the of the existed substations (Víctor et al., 2006; Kashem et al., 2006; Peter et al, 2000).

One of the most important factors affecting the choice of DG type is the technology used in producing electric power from the DG unit. It may be from photovoltaic, wind turbines or CHP units (combined heat and power) (Víctor et al., 2006). Also another factor affecting the decision of choosing of the DG is the penetration percentage of DG in the distributed system (Víctor et al., 2006; 2006; Peter et al, 2000; Celli and Pilo, 2002).

2. LITERATURE REVIEW

Several studies have been done on using genetic algorithms to solve the problem of optimal placement of DG unit(s) in radial distribution system. Sedighizadeh and Rezazadeh (2008); Raj and Goswami, (2009) used the genetic algorithms as an optimization technique to find the best location to install the DG unit; and the number of the units that should be used; because the wrong placement will lead to lose all the advantages of the added DG unit(s).

Kashem et al., 2006) proposed the adding DG units with certain size and location as a solution to decrease the overall system losses in distribution systems. Begović et al. (2001) investigated the impact of renewable energy DG unit; also the work used Monte Carlo simulation to find the proper penetration level. And as the penetration level was chosen properly, the more enhancements added to the system performance.

This paper studies the impact of implementing single DG unit on the electrical performance of the IEEE 13 bus radial test feeder. The DG unit is added to the PQ buses with several penetration levels. The used units are categorized into units generating apparent power; and units generates active power. The system performance is studied from three points of view, first, overall system losses; second, bus voltage; third, generation cost. The optimization is done on the generation cost function using two optimization techniques GRG and GA. The simulation of the IEEE 13 bus system and the optimization techniques are done using the MATLAB® software.

The presented graphs show the effect of varying the penetration level with each point of view separately, in addition to a comparison between the performance of GRG and GA. This study recommends the implementation of the DG units with apparent power generation. Also, using GA with large number of variables (adding more than one DG unit) to get the benefits that the GA offers, otherwise, the performance of any optimization technique will be satisfactory.

3. Optimization Algorithms

Optimization is the art of choosing the best solution(s) from a set of different alternative
that maximize the benefits in the problem under study. The optimum solution is not always
the least point - on the curve describing the problem - it may be the maximum; it depends on
the nature of the problem.

The optimization techniques could be divided into two main categories:

a) Conventional methods: like generalized reduced gradient (GRG).

b) Artificial Intelligence methods: like genetic algorithm (GA).

Both methods were used in this study to find the optimal solution for the proposed
objective function (mentioned in the section III). This section provides a quick overview on
how each technique work.

3.1 Generalized Reduced Gradient

This optimization technique converts the constrained problem to an unconstrained one
using direct substitution. It belongs to a family of techniques called the reduced gradient
methods. The algorithm has dummy variables (non-basic) besides the original variables
(basic). First step, building derivative matrix (B) contains the derivatives (d) of the function
with respect to each variable. After the first iteration, the algorithm modifies the values of the
initial guess using parameter (α) which is a parameter of the line along the reduced gradient.
After each iteration the variables values are updated until the algorithm reaches a satisfactory
value from the point of view of the operator. This technique depends on evaluating function
derivative which may be, in some problems, hard to be found or calculated (Ralph, 1986).

3.2 Genetic Algorithms

This optimization technique inspires the human genes. The algorithm codes the possible
solutions for the problem in a form of bit strings called individual and the bits forming the
string called genes. Then the algorithm forms mating pool which contains all the strings and
applies three operators in order to optimize the function, these operators are: selection,
crossover, and mutation (Sivanandam and Deepa, 2008; Haupt& Haupt).

Selection: This operator is used to choose the best individuals in the mating pool based on
their fitness values (as the individual fitness increases, the more likely to be selected). The
method that was used in this study was stochastic uniform selection due to its ability to
provide zero bias and minimum spread in the selection of the individuals forming the mating
pool.

Crossover: This operator is used to enhance the fitness value of the individuals. The
selected value of crossover probability was 0.8.

Mutation: This operator helps in recovering the lost traits due to the crossover operator.
The selected value of mutation probability was 0.2.

Elitism: It is not a GA operator, it more likely a selection method. It was used to ensure
the survival of the "super individuals" (individuals with the highest fitness value) to the next
generation without passing by the stage of crossover and mutation. The selected individuals
are called elite children.
The objective function, that both optimization algorithms used to find its optimal solution, was formulated as a polynomial function contained the sum of all operating costs (initial, running, and maintenance) of each generator in the each system. The function used to express the overall operating cost was:

\[
(a + b \times P_g + c \times P_{DG}^2) + (G_{DG} + b_{DG} \times P_{DG} + c_{DG} \times P_{DG}^2)
\]  

(1)

Where \(a, b, c\) are cost factors for each generator

\(P_g\) : the output power from the maingenerator

\(P_{DG}\) : the output power from the added DG unit

4. System Modeling

4.1 Network Model (IEEE 13 bus Radial System)

The system under study was the IEEE 13 bus radial test feeder shown in figure 3. The test feeder contains single generator located at bus #1. The buses were connected in a radial way, thus it was considered as a radial distribution system operates under 11/0.4 kV level. Table 1 shows the data of the test feeder.
Table iDATA OF THE IEEE 13 BUS RADIAL TEST FEEDER

<table>
<thead>
<tr>
<th>Point of comparison</th>
<th>IEEE 13 bus (bus numbers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slack Bus</td>
<td>1</td>
</tr>
<tr>
<td>PV Buses</td>
<td>2</td>
</tr>
<tr>
<td>PQ Buses</td>
<td>3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13</td>
</tr>
<tr>
<td>Number of Loads</td>
<td>8</td>
</tr>
<tr>
<td>Number Tie Lines</td>
<td>13</td>
</tr>
</tbody>
</table>

Figure 3: IEEE 13 bus radial test feeder

4.2 DG Implementation

The aim from this research was to implement a DG unit, with different penetration levels, to PQ buses, in order to study the impact of this implementation on the distribution network. The goal was to optimize the network operation by minimizing both overall network losses, generation costs and to enhance the bus voltage profile. The DG penetration level was chosen according to the following equation:

DG penetration level = capacity factor × Overall system capacity

DG penetration level: it is the size of the chosen DG unit regardless the technology it uses to generate either apparent electrical power or active electrical power.

The capacity factor: is a factor chosen by the operator. It was chosen to range from 0.01 to 0.2 with a step of 0.01.

Overall system capacity: it is the sum of the maximum generated power of the already existing units.

There are three classifications of DG units. The first is according to the type of the fuel used (which can be renewable and nonrenewable). The second classification is according that these units are dispatchable or non dispatchable (generated power is/isn't function in the power network needs). The last classification, used in this study, is done according to the
output electrical power (which can be apparent “active & reactive” or active only).

4.3 Proposed Algorithm

The optimization was done on equation (2) to study the variation of the penetration level of the implemented DG unit, on the system using both optimization techniques. The GRG was used first to decide the best location, type, and penetration level for the implemented DG unit, following the hereunder procedure:

a) Study the system under normal operating conditions and check that the system is operating in the feasible region where all constraints are satisfied.

b) Implement the DG unit at each bus with different penetration level (from 1% to 20%). Then record for each bus and each penetration level: overall system losses, bus voltage and generation cost.

c) For each bus draw graphs showing the change in values of overall system losses, bus voltage and the generation costs (each in a separate graph) versus the penetration level of the added DG unit. Then the optimization was done once more, following the same procedure, using GA. Finally, the best obtained results of GRG and GA were graphed.

5. Simulation Results

5.1 Implementing one DG unit with Apparent Power Generation:

In the presented simulation results the best performance of the optimization technique was dependent on the point of view. As for the overall system losses and generation costs, the best values were the least; while for the bus voltage, the best values were the highest. In other words, the best optimization technique was not, always, the one got the least values. The presented graphs in this section showed sample from the obtained graphs (i.e. only presenting the best obtained simulation results). The GRG showed that bus #8 was the best place to implement a DG unit, while GA showed that bus # 9 would be the best place to place the unit. The overall losses kept decreasing within the penetration margin of the added DG unit. Figure 4 and figure 5 showed a comparison between the performances of GRG and GA from the overall system losses point of view.

![Figure 4. Effect of DG unit implementation on overall system losses (bus 8)](image1)

![Figure 5. Effect of DG unit implementation on overall system losses (bus 9)](image2)
Figures 6 and 7, shows another comparison between GRG and GA performances, this is from the bus voltage point of view.

On the contrary from the overall losses graphs, there were limitations on the penetration level; as after 14% penetration level the bus voltage starts to deteriorate.

Figure 8 and Figure 9 show the optimization techniques that either bus #8 or bus #9 (with slight differences) would be suitable for implementing a DG unit without any limitations on the penetration level. And as the overall system losses decreased, the effect of the quadratic term in equation (2) becomes small thus leading to make the generation cost curve a bit linear.

After finishing this phase from the study, all the studied busses in IEEE 13 bus test feeder showed similar performance from the three points of view. Now the decision of choosing the optimum bus would be subject to another constraints (like the availability to install the unit in this bus or another), which was outside the scope of this study. Thus after taking the decision; the system planner/operator, should take a look on all the above three points of view to choose carefully the size of the DG unit. As both overall losses curve and generation cost curve showed that any penetration level would be ok, while the bus voltage curve gives a limitation.
To compare the overall performance of both GRG and GA from the three points of view, the best results at each system bus was chosen to be graphed, each in separate figure.

In figure 10 the GA performance was better all over the simulation process than the performance of GRG.

Figure 10: Overall system losses “best values” comparison (GRG vs. GA)

In figure 11 the performances of both GRG and GA were mutual, as none of them got the “all best” values all over the simulation process. In figure 12 the performances of both GRG and GA were comparable, as both got almost the same “best values”.

Figure 11: Voltage bus “best values” comparison (GRG vs. GA)

Figure 12: Generation cost “best values” comparison (GRG vs. GA)

B. Implementing One DG with Active Power Generation

In this section the DG unit type was different from that used in previous section, as it generated only active power. This time both GRG and GA agreed to choose bus #9 to be the ideal bus to implement the DG unit without any restrictions on the penetration level.

In figure 13 although the overall system losses were decreasing (for both GRG and GA) but it were still higher than any that have been obtained in the previous section. In figure 14
the enhancement in the bus voltage was not obvious for the GRG and little for GA, compared to the previous section.

![Figure 13: Effect of DG unit implementation on overall system losses (bus 9)](image1)

![Figure 14: Effect of DG unit implementation on bus voltage (bus 9)](image2)

The following figures 16, 17 and 18; showed a comparison between the overall performance of both GRG and GA from three points of view. The performance of GA was better than the GRG, all over the simulation process, from the three points of view.

![Figure 16: Overall system losses “best values” comparison (GRG vs. GA)](image3)

![Figure 17: Voltage bus “best values” comparison (GRG vs. GA)](image4)

![Figure 18: Generation cost “best values” comparison (GRG vs. GA)](image5)
Conclusion

This paper addressed the problem associated with the implementation of DG units into radial distribution systems, as a proposed solution to stop the deterioration and to enhance the electrical performance of the network. The IEEE 13 bus radial test feeder was chosen to simulate a radial distribution feeder. After constructing the mathematical model of the system, a single DG unit was added to each PQ bus, with different penetration levels (i.e. size) that ranges from 1% to 20% of the total generated power by the already existing generator located at bus #1. The DG unit was categorized by the kind of generated power, which was apparent power (P+jQ) or active power (P only). The optimization was done using two techniques; the generalized reduced gradient (GRG) and the genetic algorithm (GA). There were three points of view to evaluate the electrical performance of the radial system under study. First point was, the overall system losses; second, the bus voltage; third, the generation costs (including fuel, maintenance and operation costs). The paper studied and compared the impact of implementing both types of DG units, using both optimization techniques on the electrical performance of the radial distribution system, from three points of view.

The implementation of DG units into radial networks should be planned carefully, otherwise the implemented DG unit (regardless the penetration level or the output power) would cause more deterioration in the electrical performance of the network. So, the selected unit with proper penetration level, type, and location would deliver power to the nearby loads. The injected power from the added unit would be subtracted from the output of the main substation, thus stopping a portion of the already spreading power in the network (before the addition of the unit) from flowing again. This had two benefits: first, increasing of the spinning reserve of the main substation leading to increase the possibility of supplying more loads in the future; second, the system losses was decreased and the generation cost also decreased accordingly. Also, it was shown that units generating apparent power caused a remarkable enhancement in bus voltage performance, and decreased both the overall system losses and the generation costs compared to units that generated active power only.

Concerning the optimization techniques used in this study; GA showed competitive performance compared to GRG, either in one to one comparison or in overall comparison. The GA was able to find better values to the variables in equation 2, more than that found by GRG, leading to getting less overall system losses, enhanced bus voltage values and less generation costs. Some presented graphs showed comparable performance, and sometimes the GRG results superior that of GA. The reason of this referred to the limited number of variable (only two generators). Generally, as the number of variables increased the superiority of GA became clearer.
References


