Placement of DGs in Distribution Network with Considering Protection Coordination Limits

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Received: August 2014 Revised: December 2014 Accepted: January 2015

ABSTRACT:
The use of Distributed Generation (DG) units as small power generation units in distribution networks has received increasing attention during recent years. Distributed generation applications are growing due to environmental and economic issues, technological improvements, and privatization of power systems. Distributed generation application, however, has negative effects in protection coordination. Due to penetration of DG disturbs the radial nature of conventional distribution networks. Therefore, protection coordination will be changed in some cases, and in some other cases it will be lost. This paper proposes a Genetic Algorithm (GA) technique for the optimal placement of DG units in the distribution systems with considering protection coordination limits.

KEYWORDS: Distributed Generation, placement, loss reduction, protection, Genetic Algorithm, short circuit level.

1. INTRODUCTION
Distributed generation is concerned with small generating units installed in strategic points of the distribution or sub-transmission systems and close to load centers. DG can be used in an isolated way, supplying the consumer’s local demand, or in an integrated way, supplying energy to the remaining of the electric system. In distribution systems, DG can provide benefits for the consumers as well as for the utilities, especially in sites where the central generation is impracticable or where there are deficiencies in the transmission system. DG may also be named as Embedded Generation or Distributed Energy Resources (DER) [1].

Generally, DG impacts on distribution system depend on several factors such as DG location, technology and capacity as well as the mode of DG operation with network. Application of DG in distribution networks can lead to considerable reliability enhancement, peak shaving, loss reduction and power cost saving. In contrast, power quality issue, islanding operation and voltage control problems are among troublesome impacts of DG application. The impact of DG on system operation depends highly on DG location in the distribution system such that installing DG on improper locations would lead to increase in energy loss and loading of distribution feeders. For this reason, an optimization method must be used to find optimal DG location considering the costs and benefits of DG application to the customers and the utility [2].

There are many approaches for placing DGs in distribution system, Ahmadigorji et al. [2] presents an optimization method to determine optimal DG placement, based on a cost/worth analysis approach. This method considers technical and economical factors such as energy loss, load point reliability indices and DG costs, and particularly, portability of DG. In [3] and [4], respectively a genetic algorithm and Particle Swarm Optimization (PSO) approach, has been used for allocating DGs in distribution systems in order to loss reduction, voltage profile improvement, environmental effects, installation and exploitation and maintenance expenses and costs of load prediction of each bus. The studies in [5]-[7] utilized GA for the allocation of DG units in the distribution system to minimize loss and voltage profile improvement. In [8] multi-objective formulation as a nonlinear programming (NLP) is proposed for optimal placement and sizing of DG units. Objective functions include minimising the number of DGs and power losses as well as maximising voltage stability margin formulated as a function of decision variables. The work in [9] and [10] respectively presented a multi-objective
formulation based on a pso and Ga for reliability improvement and loss reduction. In [11] the authors developed a methodology to optimally allocate DG capacity on the distribution network though Different types of the DG for minimising the power loss of the system. Author of [12] in order to placement of DG units have used modified shuffled frog leaping algorithm (MSFLA) method to loss reduction and voltage profile improvement. In [13] analytical approach to find the optimal size of DG has been proposed, to loss reduction. In [14] the authors determine the optimal placement of DG and capacitor by the applications of PSO technique to minimize the real power loss. Duong Hung et al.[15] presents a methodology for the integration of dispatchable and non-dispatchable renewable distributed generation units for minimizing annual energy losses.

Most previous studies concentrated on improving several parameters but the impact of installed DG units on coordination of protection devices in distribution networks is ignored. For this reason, In this paper the proposed method to keep the coordination of protection devices are presented and discussed.

2. PROTECTION PROBLEMS

Since distribution network in directly connected to the consumer, its optimum protection can play an important role in reducing loss of electricity, increasing reliability and augmenting the efficient lifetime of devices.

Connection of small generators to distribution grids is not new at all. But in the recent past the number of small generators has been increased rapidly and the effect on distribution grid operation has become noticeable. Concerns have arisen if the distribution system including distributed generation is still protected properly. Some of these distinguished difficulties are as [16]:

i) false tripping of feeders
ii) nuisance tripping of protective devices
iii) blinding of protection
iv) increase or decrease of fault levels with connection and disconnection of DERs
v) unwanted islanding
vi) prevention of automatic reclosing
vii) unsynchronised reclosing

The most important negative effects of the DG on the protection system of the distribution network will be reviewed in the following sub-sections [17].

2.1. Impact of DG installation on short circuit level

Short circuit level description is based on impact of fault on power and current. This description is criterion factor for increasing definition in fault and current. Fault level can be formulated simply in p.u as below:

\[ I_f = \frac{1}{|Z_{th}|} \] (1)

In this equation, \( I \) is fault current and \( Z_{th} \) is Thevenin impedance seen by bus i in p.u. In distributed network the fault current level is commonly 10–15 p.u that 1 p.u is nominal current. Installing DG causes to placing an impedance in parallel with a part of network, therefore the impedance seen at fault location is reduced. DG size increment is tantamount with reduction in equivalent DG impedance. Therefore by increasing the DG size, the fault current level increases as well [18]. Furthermore, presence of DG in a radial distribution network, in which all the currents are flowed from the source to the consumers, may change the current direction in some lines.

2.2. Blinding of protection

In this case the grid contribution to the total fault current will be reduced because of the contribution of distributed generation which shown in Fig. 1. Due to this reduction it is possible that the short-circuit stays undetected because the grid contribution to the short circuit current never reaches the pickup current of the feeder relay. Overcurrent relays as well as directional relays and reclosers their operation on detecting an abnormal current. Hence, all protective systems based on these protection devices can suffer malfunctioning because of the reduced grid contribution. This mechanism is called blinding of protection.

Fig. 1. Short-circuit current contribution of both grid and DG-unit

2.3. False tripping

False tripping, also known as sympathetic tripping, is possible when a generator which is installed on a feeder, contributes to the fault in an adjacent feeder connected to the same substation. The generator contribution to the fault current can exceed the pick-up level of the overcurrent protection which can lead to a trip of the healthy feeder before the actual fault is cleared. In Fig. 2 the principle of false tripping is shown schematically.

When selectivity cannot be reached by changing the protection settings the application of directional overcurrent protection can solve the problem. However, directional protection is slower, more expensive and usually not the standard solution of grid operators.
2.4. Recloser problems

Protection of overhead distribution feeders with automatic reclosers is a very efficient way to protect against temporary disturbances and minimize the number of supply interruptions. Because of the coordination between the reclosers and the lateral fuses, permanent faults are cleared in a selective way. Connection of DG to these type of feeders causes several protection problems at the same time. First of all, the fault current detection by the recloser is affected by the generator contribution and can lead to a detection problem. Secondly, the coordination between reclosers or fuse and recloser can be lost which directly causes selectivity problems. This is explained in more detail with the feeders shown in Fig. 3.

As shown in Fig. 4 the fuse and recloser are coordinated such that there is selective fault clearing for the fault currents $I_{k,\text{min}} < I_{\text{fault}} < I_{k,\text{max}}$. For the situation in Fig. 4 the coordination between the fuse and recloser is lost when $I_{k,\text{tot}} > I_{k,\text{max}}$. In that case the curve of the fuse is under the curve of the recloser and the fuse clears the fault before the recloser operates. Hence, temporary faults will be cleared permanently and lead to unnecessary interruptions.

Besides detection problems and lost of coordination DG also causes unsynchronized reclosing. During the recloser’s dead time a part of the feeder is disconnected from the main system to allow the arc to deionize. The connected generator tends to keep the disconnected feeder part energized and maintains the arc at the fault-location. Hence the temporary fault becomes permanent. Moreover, due to unbalance between load and generation the generators will drift away from synchronism with respect to the main grid which results in an unsynchronized reclosing action. This can seriously damage the generator and causes high currents and voltages in neighboring grids.

2.5. Concerns of unintentional islanding

Islanding also known as loss of mains or loss of grid, is formed when a part of the distribution network that connected with a DG/DGs becomes electrically isolated from the utility supply but continue to be energized by the DG for supplying power to the loads. Unintentional islanding is the state that one or more DG units unintentionally continue energizing a section of distribution network when the network loses supply. The system can be exposed to hazards and risks particularly when it is not being designed to support it. Several related issues regarding unintentional islanding are as, power quality, out of synchronism closure, grounding or earthing, protection systems on the islanded system are unlikely to be coordinated, personal safety [19].

3. OPTIMAL DISTRIBUTED GENERATION SIZING AND PLACEMENT

The installation of Distributed Generation (DG) units is becoming more prominent in distribution systems due to their overall positive impacts on power networks. Some major advantages of integrated DGs include reducing power losses, improving voltage profiles, reducing emission impacts and improving power quality. Because of these benefits, utility companies have started to change their electric infrastructure to adapt to the introduction of DGs in their distribution systems. Nonetheless, in order to maximize benefits, solution techniques for DG deployment should be obtained using optimization methods, since installing DG units at non-optimal places and in inappropriate sizes may cause an increase in system power losses and costs. Moreover, installing DG units is not straightforward, and thus the placement and sizing of DG units should be carefully addressed.

Solution techniques for DG deployment can be obtained via optimization methods in order to maximize DG benefits. Various optimization techniques have been used by several researchers for finding the optimal sizing and its optimal locations.
Such optimization methods can be classified into analytical methods such as “2/3 rule” [20] and heuristic methods such as Genetic Algorithm, Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), etc., or into single and multi-objective, based on the number of objectives. The major objective of DG placement techniques used in the literature is to minimize power system losses. However, other objectives, like improving the voltage profile and reliability and maximizing DG capacity and cost minimization have also been considered [21].

3.1. Problem formulation

An optimization problem can be mathematically defined as the minimization or maximization of a function (called the objective function) while satisfying a number of equality and/or inequality constraints on its variables. The general optimization problem can be formulated as:

\[ \text{Min/Max: } f(x) \]
\[ \text{subject to: } \begin{align*} h_i(x) &= 0, & i &= 1, 2, \ldots, n \\ g_j(x) &\leq 0, & j &= 1, 2, \ldots, m \end{align*} \]

Where \( f(x) \) is the objective function, a function of \( x \) that we want to maximize or minimize. \( h(x), g(x) \) are the vectors of equality and inequality constraints that the unknowns must satisfy. \( X \) is the vector of \( n \) decision or unknown variables and \( x = [x_1, x_2, \ldots, x_n] \).

This kind of optimization is called a single-optimization problem, since \( f(x) \) is only one objective function. On the other hand, a multi-objective optimization concerns the minimization of a vector of objectives, while satisfying a number of equality and inequality constraints or bounds. The multi-objective optimization problem can be mathematically formulated as follows:

minimize: \( F(x) = [f_1(x), f_2(x), \ldots, f_k(x)] \) \hspace{1cm} (3)

Where \( F(x) \) is a vector of \( k \) objective functions.

3.2. Constraints

The objective function is minimized subject to various operational constraints to satisfy the electrical requirements for the distribution network and constraints on DG operation. These constraints are discussed as follows:

Power Balance Constraints: Power balance is given by nonlinear power flow equations, which state that the sum of complex power flows at each bus in the distribution system injected into a bus minus the power flows extracted from the bus should equal zero.

\[ P_{DGi} - P_{Di} - \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\delta_i - \delta_j - \phi_{ij}) = 0 \] \hspace{1cm} (4)

Where \( P_{DGi} \) and \( P_{Di} \) are active power delivered by DG at bus \( i \) and active power demand at bus \( i \). \( |V_i| \) is the magnitude of the \( ij \)-th element of the admittance matrix. \( \phi_{ij} \) is the angle of the \( ij \)-th element of the admittance matrix and \( NB \) is the total number of buses.

Power Flow Constraints: The power flow constraint is used to ensure that they do not approach their thermal limits. The following constraint checks for the absolute power flow both at the sending and receiving ends of a particular line to be within the upper limit of the line.

\[ S_{ij} \leq S_{ij}^{\max} \] \hspace{1cm} (6)
\[ |S_{ij}| \leq S_{ij}^{\max} \] \hspace{1cm} (7)

Where \( S_{ij}^{\max} \) is apparent power maximum allowable for branch \( ij \), and \( S_{ij} \) is apparent power flow transmitted from bus \( i \) to bus \( j \).

Generation Capacity Constraints: Limiting the DG size so as not to exceed the power supplied by the substation and the output power of each DG unit is constrained by lower and upper limits.

\[ \sum_{i=1}^{n_{DG}} (P_{DGi} + jQ_{DGi}) \leq P_{SS} + jQ_{SS} \] \hspace{1cm} (8)
\[ P_{DGi}^{\min} \leq P_{DGi} \leq P_{DGi}^{\max} \] \hspace{1cm} (9)

Where \( P_{DGi}^{\min} \) and \( P_{DGi}^{\max} \) are the minimum and maximum operating outputs of unit \( i \), respectively. \( P_{SS} \) and \( Q_{SS} \) are active and reactive power delivered by substation, respectively.

Bus voltage limit: Bus voltage magnitudes and phase angles of the radial distribution system are to be bounded between maximum and minimum values, imposed by a system operator. The boundary constraint can be expressed as follows:

\[ |V_i^{\min}| \leq |V_i| \leq |V_i^{\max}| \] \hspace{1cm} (10)
\[ \delta_i^{\min} \leq \delta_i \leq \delta_i^{\max} \] \hspace{1cm} (11)

Where \( |V_i^{\min}| \), \( |V_i^{\max}| \), \( \delta_i^{\min} \) and \( \delta_i^{\max} \) are the lower and upper bounds of the bus voltage \( |V_i| \) and the bus voltage angle \( \delta_i \), respectively.

In addition, constraints can be soft or hard. The constraint is considered hard, if could not have been violated. On the centrally, the constraint is considered soft if the algorithm violated some constraints to find the best answers. Since electrical companies are interested in installing DG resources while undertaking
the least costs and changes all the constraints are assumed to be hard constraints and must not be violated [22].

4. GENETIC ALGORITHM TECHNIQUE

The Genetic Algorithms are employed to designate optimization algorithms that perform a kind of approximate global search such that:
(i) They rely on the information obtained by the evaluation of several points in the search space. Each “current point” is called an individual, and the set of “current point” is called the population. The algorithm keeps this set of “current points”, instead of keeping a single “current point” as would be the case of in most optimization algorithms.
(ii) The population converges to a problem optimum through sequential applications, at each iteration, of genetic operators [23].

The GA process starts with a random population of chromosomes, which represent all possible solution of a problem that are considered candidate solutions. The size of the population depends on the size and the nature of the problem. The positions of each chromosome are encoded as characters or numbers and could be referred to as genes. Then according to the desired solution an evaluation function is used to calculate the goodness of each chromosome known as “Fitness Function”. Two basic operators, crossover and mutation, are used to simulate the natural reproduction and mutation of species during evaluation. The main aim of crossover is to search the parameter space and it is the most important operator in GA. The crossover operator takes two strings from the old population and exchanges the next segment of their structures to form the offspring. The function of mutation is used to prevent the loss of the information. Mutation can keep the population more diverse so that it alters a string locally to create a better string. Once the new proportion is completed, the program will continue to generate new population. The iteration can be stopped while no further significant change of the solution occurs or when the specified number of iteration is reached [24].

5. SAMPLE CASE STUDY

The proposed method has been applied and simulated on a sample 38- bus network. The single line diagram of the network is illustrated in Fig. 5. Candidate DG bus locations are determined by detailed planning analysis including technical, environmental and economic studies [10], which is assumed as an input and are beyond the scope of the work presented in this paper. The candidate buses selected in the presented case study are totally arbitrary and are located as shown in Fig. 5. The system data is available in [25].

Where one relay is added at the beginning of the main feeder, one recloser at bus 7 and 3 fuses are added at the beginning of each lateral feeder at bus 2, 3 and 6 respectively, also one fuse is added at bus 11. It should be noted that the specified destination function can be generalized to be used for all distribution networks with any number of buses and any protection device.

5.1. Objective function of proposed method

The proposed purpose of this paper is described by the following.

Objective function:

\[
\text{Minimize: } \sum Cost_{p_i} + Cost_{q_i} + Cost_{DG}
\]  

Where \( P_i \), \( Q_i \) are annual active power loss and annual reactive power loss, respectively.

To calculate the cost of loss, first load flow is carried out in DIGSILENT software and then the results are used to calculate the losses and ultimately they are multiplied by the loss price. DG cost includes primary cost and exploitation and maintenance costs, which is defined as follows:

\[
Cost_{DG} = a + bP\left(\$/kW\right)
\]  

Where \( P \) is the nominal active power of DG. Also, \( a \) and \( b \) are calculated using the following formula:

\[
a = \frac{\text{Capital Cost}($/kW) \times \text{Capacity}(kW) \times G}{\text{Life Time (Year)} \times 365 \times 24 \times LF}\left(\$/kW\right)
\]  

\[
b = \text{Fuel Cost}($/kW) + \text{O&M Cost}($/kW)
\]

Where \( G \) is the annual rate of interest and LF is the load coefficient of DG. In this study, these values are considered equal to unity.

In this study, there load levels (light, medium and
heavy load) are considered for annual load duration curve for determination of size and location of DG which presented in Fig. 6.

![Fig. 6. Annual load duration curve](image)

Technical constraints of the network includes, constraint of the voltage level of the buses, Line current constraint and Coordination criteria between protection device. Technical constraints of the DG includes, the penetration level of DG resources and constraint power factor of the DG units, also size of DG. The constraints in the optimization process are shown in Table 1.

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Model</th>
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<tbody>
<tr>
<td>Line current</td>
<td>$</td>
</tr>
<tr>
<td>Bus voltage</td>
<td>$</td>
</tr>
<tr>
<td>DG penetration</td>
<td>$</td>
</tr>
<tr>
<td>CC: Rec-Rel</td>
<td>$OT_{Rel}(I_{MF}) &gt; TAT(I_{MF}) + 0.2$</td>
</tr>
<tr>
<td>CC: Fuse-Rel</td>
<td>$OT_{Rel}(I_{MF}) &gt; MCT_{Fuse}(I_{MF}) + 0.35$</td>
</tr>
<tr>
<td>CC: Fuse-Fuse</td>
<td>$MCT_{Fuse}(P,I_{MF}) &lt; 0.75 \times MMT_{Fuse}(B,I_{MF})$</td>
</tr>
<tr>
<td>CC: Fuse-Rec</td>
<td>$OT_{Rec}(B,F,I_{MF}) &lt; 0.75 \times MCT_{Fuse}(P,I_{MF})$ $OT_{Rec}(B,D,I_{MF}) &gt; TCT_{Fuse}(P,I_{MF})$</td>
</tr>
</tbody>
</table>

5.2. Proposed algorithm

Proposed method has been developed in Digsilent and MATLAB environments. First of all In MATLAB environment the initial population is generated randomly and this population send to Digsilent. In Digsilent environment for each chromosome as a solution using load flow and short circuit calculation the Objective function value is calculated. After applying the obtained locations and places to DG resources, their technical and operational constraints are checked. Some of solutions are not satisfied the system and DG constraints, these solutions are called infeasible solutions. Infeasible solutions are eliminated with penalty strategy. Then this value sent to MATLAB. In MATLAB environment the results are sorted according to the lowest value and the minimum value is stored as the best result. When the maximum iteration of the algorithm is reached the algorithm is stopped, then the best solution is chose as a final solution. Otherwise using selection, crossover and mutation operators the new population is generated, by repeating this procedure the best solution is obtained. The flowchart of simulation is presented in Fig. 7.

5.3. Simulation results

According to the simulation results, all the objectives of installing DG resources are satisfied, using the proposed algorithm. It can be observed from the Fig. 8-Fig. 12. The optimal locations of DG units with the corresponding sizes as shown in Table 2, also applied to test the network and the results are discussed.
next. Total loss of the network, before and after installing DG units is shown in Fig. 8. As it is shown the total power loss of the network is reduced 31.44, after installing DG units.

<table>
<thead>
<tr>
<th>Table 2: optimal results</th>
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<tbody>
<tr>
<td>size</td>
</tr>
<tr>
<td>1-MW</td>
</tr>
<tr>
<td>0.9-MW</td>
</tr>
</tbody>
</table>

Fig. 9 illustrates the voltage profile of the distribution network, before and after installing DG resources. As it is obvious, the voltage profile is improved and voltages of all the buses are in the allowable range, after installing DG units.

To check the fuse-recloser coordination in the presence of DGs, as the most critical condition, three-phase fault is applied at 1% of line 12. Therefore, by considering the constraint of coordination criteria, the coordination of fuse-recloser would certainly be keep after installing DG units, as shown in Fig. 10. It can be seen from Fig. 10 that the fault current value for fault on line12 is within the coordination range, the recloser–fuse coordination is considered to be acceptable, because in coordination range the recloser fast curve operates in less time than the time sufficient to damage the fuse for a temporary fault also the fuse only operate for a permanent fault on the lateral feeder, recloser slow curve also provides back up to fuse.

Also Fig. 11 and Fig. 12 illustrates the current of line in normal state and short-circuit level of the distribution buses (3-phase short circuit), before and after installing DG units, respectively. It is clear from Fig. 11 that the line current approximately in all the
lines decreases after installing DG units. The biggest value of decreases is for the line 1, 2 (closer to slack bus), the current value of this line decreases from 115 Ampere to 78, and from 100 to 67 Ampere, respectively after installing DG units. As it is clear from Fig. 12, the short circuit level of all buses increases after installing DG resources but this increase has not any protection problem in the network.

6. CONCLUSIONS
Using distributed generation can have positive and negative impact on the distribution networks. Installation place and units capacity are some important issues that should be taken into consideration to obtain maximum efficiency. For example selecting an inappropriate place and capacity of DG resources, brings about the increase of short circuit current, then mis-coordination is occur between protection device. Placement of the DG units in large distribution systems is a complex combinatorial optimization problem. Genetic algorithms offer a powerful approach to these optimization problems. This paper presented a Genetic Algorithm to identify the optimal placement of DG units. Unlike the previous works on intelligent DG placement which all consider just a few parameters to be optimized; the proposed method uses all possible significant parameters into account to be formulated and optimized.

REFERENCES


