Minimization of Power Losses With Different Types of DGs Using CSA

Anand Kumar Pandey*,†, Sujatha K S*, Sheeraz Kirmani**

*Department of Electrical and Electronics Engineering, JSS Academy of Technical Education, C-20/1, Sector-62, Noida, India
** Department of Electrical Engineering, Faculty of Engineering & Technology, Aligarh Muslim University, Aligarh-202002, India

(anandkrpandey@jssaten.ac.in, sujathaks@jssaten.ac.in, sheerazkirmani@gmail.com)

† Corresponding Author; Anand Kumar Pandey, JSS Academy of technical education, Noida-201301, India, Tel: +91 7838434833, anandkrpandey@jssaten.ac.in

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Abstract: Proper allocation of DGs in distribution network is important from all the aspects like technical, economical and environmental. In this paper, Crow search algorithm (CSA) technique has been proposed to find the optimal size and location of multiple DGs of different types to reduce the active power loss of the distribution network (DN). The proposed method has only two parameters to be tuned while other metaheuristic optimization methods discussed in the literature have more than two tunings parameter. Parameter tuning plays a very important role to reach the global optimal value. The proposed method is tested on 33 bus and 69 bus test system and the obtained result is compared with improved analytical (IA) and particle swarm optimization (PSO) method. The proposed method gives better results compared to existing PSO and IA methods.

Keywords: Distributed Generation, Crow search algorithm, Power System optimization

1. Introduction

The growth of any country is determined by the per capita consumption of energy. In developing countries energy crisis is a main concern for the economic growth. Mainly, there are two types of energy available on the earth. One is called conventional energy and other is known as nonconventional or renewable energy. Because of the limited availability and disadvantages of conventional energy resources, renewable energy sources (RES) are getting popular. Renewable energy sources like solar, wind geothermal and biomass are abundantly and freely available in the nature. These sources are used either in off grid mode or on grid mode. RES such as solar energy is getting day by day popular because of the ease of technology and policy implementation. The conversion of energy from the solar is based on the photoelectric effect. It is most widely used technology all over the world. By using the solar panels solar energy is converted to DC electricity. Output electrical energy produced from the solar photovoltaic (SPV) module depends on the several factors some of them are mounting of the modules whether it is fixed or mounted or inclined, local climatic condition, solar radiation approaching on the surface. The renewable energy resources are becoming a boon to the developing world where the necessity of electrical energy is increasing day by day. There are many types of renewable energy resources among them the solar energy is the superlative. Though photovoltaic (PV) cell has some limitations of high capitation cost, lower conversion efficiency, partial shading and seasonal energy production, it has seized the attention of many researchers because of its special virtues. The special virtues include costless source and maintenance free system. These systems are also pollution free that is environmental contamination is reduced to the minimum of zero percentage. The gap between PV power generation and the load demand is fulfilled by using batteries. Solar, biomass, wind, geothermal i.e. renewable energy sources have negligible impact on the green house gas emissions and these are known as Distributed generation (DG) sources. In literature DGs are mainly classified in four categories depending on the terminal characteristics:

Type-1 DG: It is Capable of injecting only real power (P) to the system...
Type-2 DG: It is capable of injecting only reactive power (Q) to the system.

Type-3 DG: It is capable of injecting P and Q both to the system.

Type-4 DG: It is capable of injecting P and taking Q from the system.

The high incursion of DG resources on the distribution network has started many challenges to distribution network such as increasing losses, voltage fluctuation and low voltage stability etc.[1]. The high penetration of DG on distribution network can have either positive or negative impact depending on the operating uniqueness and the DG characteristics. Poor voltage profile and power loss is the main concern in developing countries; therefore it becomes necessary to place the DGs of appropriate size at optimal location.

Different optimization algorithm has been reported in the literature. In [2] authors has proposed one of the accurate technique, Particle swarm optimization (PSO) to allocate the different types of DGs in distribution network but this method has four settings parameters to run the algorithm. [3] Discusses about the allocation of DG using Genetic algorithm (GA) method, this method has six settings parameters and only type-1 DG is discussed. In [4, 5] authors have presented crow search optimization (CSO) algorithm for allocation of DG which has two settings parameters but only type-1 DG is considered for the study. Paper [6] presents parameter independent Teaching learning based optimization (TLBO) algorithm to find the optimal allocation of DG, this method discusses about the type-1 DGs only. In all the papers [7-13] authors have proposed different optimization methods for allocation of DG but none of the author have proposed allocation for all the types of DG and all the methods have more than two settings parameters. Paper [25-29] discusses about the CSA method and other concepts to find the allocation of solar PV but it is limited to the one location only. Setting parameters of the algorithm play a very important role in optimization. It is very difficult to set parameters for global optimal solution. This paper contributes CSA method for all the types of DG allocation which has only two settings parameters and easy to tune for global optimal value. CSA method has been given by Alireza Askarzadah [14]. This algorithm has been used in many areas [15-18] which proves the superiority of the algorithm. The optimal location and sizing of DG in radial distribution systems using CSA for all the types of DGs has not been reported in literature till now which motivates to develop CSA method to determine the location and size of DG. The Results is compared with other technique which proves the superiority of CSA. The remaining sections are as follows: Section 2 discusses about problem formulation Section 3 proposed methodology section 4 test systems and result in the last Section 5 we discuss about the conclusion.

2. Problem Formulation:

Finding the optimal allocation of DG in DN is a constrained nonlinear optimization problem. Where the size of the DG is a continuous variable and location of the DG is a discrete variable. In this work the Bus-injection to branch-current (BIBC) and branch-current to bus-voltage (BCBV) method of load flow analysis is used for the study purpose and the details about BIBC and BCBV is given in[19].

2.1 Objective Function

Power loss ($P_L$) of the radial distribution network is considered for the optimization subject to the constraints.

$$\min(P_L) = \min \left( \sum_{i=1}^{n} \frac{P_i^2 + Q_i^2}{V_i^2} \right) R_i$$

Where $P_i$ and $Q_i$ are active and reactive power flow of the branch i respectively. $R_i$: Resistance of the branch i, $V_i$: voltage of the bus i and n; total number of buses of the system

2.2 Constraints:

i. The size of the DG varies between minimum value ($DG_{i_{min}}$) of zero and maximum value ($DG_{i_{max}}$) of 100 percent of total load of the system as the case may be

$$DG_{i_{min}} \leq DG_{i} \leq DG_{i_{max}}$$

ii. Voltage at each bus should be within permissible limit i.e. ±0.05.

$$0.95p.u. \leq V_i \leq 1.05 p.u.$$ (3)

iii. Power flow equations should match.

$$P_j = |V_j| \sum_{k=1}^{n} |V_k| |Y_{jk}| \sin(\delta_j - \delta_k - \theta_{jk})$$ (4)

$$Q_j = - |V_j| \sum_{k=1}^{n} |V_k| |Y_{jk}| \cos(\delta_j - \delta_k - \theta_{jk})$$ (5)

$$P_j = P_{Dgj} - P_{Dij}$$

$$Q_j = Q_{Dgj} - Q_{Dij}$$ (6)

Where $V_k$ is voltage at bus k, $Y_{jk}$ and $\theta_{jk}$: admittance magnitude and angle between bus j and k respectively, $\delta_j$: phase angle of bus j, $\delta_k$: phase angle of bus k.

3. Proposed Methodology:

Crow search algorithm has been implemented to get the optimal allocation of all types of DGs, BIBC and BCBV method has been used to determine the required objective. Brief explanation of the CSA is given in the following sections:

3.1 CSA technique:

CSA is a nature inspired population based meta-heuristic optimization algorithm given by Alireza Askarzadah in the year 2016 to solve the constrained engineering optimization problem. If we compare the performance of CSA with other intelligent optimization methods the solution obtained by CSA is better [14]. This method has been implemented to find the optimal sizing and location of the DG system. The crows are the most
intelligent birds in nature. Ratio of brain and body of crow the algorithm is rooted in the cleverness behavior of the crows. The evolutionary process is given as hiding and recovery of extra food. The crow flock and optimization process have many similarities. In crow flock each crow hides their surplus food to certain place (hiding place) of environment and retrieves the food from that place when it is desired. Other crows of the flock chase each other to steal the superior food but it is not an simple task since if a crow knows that one more crow is following it goes to another place to make fool. From optimization point of view Crows are searchers, Environment is the search space, each position is feasible solution, quality of food is fitness function and the best food is global solution of optimization problem [14].

Mathematically, the position of crow in a d-dimensional search space is defined by a vector

$$X_{\text{iter}} = [x_1^{\text{iter}}, x_2^{\text{iter}}, \ldots, x_d^{\text{iter}}]; j = 1, 2, \ldots, N & \text{iter} = 1, 2, \ldots, \text{iter}_{\text{max}}$$  \hspace{1cm} (7)

Each crow has its hiding place (memory) and memory of crow in a d-dimensional search space is defined by a vector

$$m_{\text{iter}} = [m_1^{\text{iter}}, m_2^{\text{iter}}, \ldots, m_d^{\text{iter}}]; j = 1, 2, \ldots, N & \text{iter} = 1, 2, \ldots, \text{iter}_{\text{max}}$$  \hspace{1cm} (8)

where $$m_{\text{iter}}$$ is the position of hiding place of crow j and best position of crow j obtained so far.

Let us suppose crow i want to follow crow j for better food source in this scenario two cases are possible:

Case1: Crow j is unaware that crow i is following and in this case crow i will reach to the hiding position of crow j. The new position of crow i is given by:

$$X_{\text{iter}+1} = X_{\text{iter}} + r_i \times f^{\text{iter}} \times (m_{\text{iter}} - X_{\text{iter}})$$  \hspace{1cm} (9)

Where $$X_{\text{iter}+1}$$ is the modified position of the crow i; $$r_i$$ a random number with uniform distribution between 0 and 1; $$f^{\text{iter}}$$ flight length of crow i at iteration iter; $$A P^{\text{iter}}$$ awareness probability of crow j at iteration iter.

Case2: Crow j knows that crow i is following to make him fool he will update to some random position in the search space.

Both cases can be written as:

$$X_{\text{iter}+1} = \begin{cases} X_{\text{iter}} + r_i \times f^{\text{iter}} \times (m_{\text{iter}} - X_{\text{iter}}), & r_j > AP^{\text{iter}} \\ \text{a random position, otherwise} \end{cases}$$  \hspace{1cm} (10)

After each iteration, the position and memory of crows are updated. The size of DG is taken between 0 to 100 percent of the total load (continuous) of the system. In CSA algorithm the maximum number of iteration and population size of the crows are fixed. The initial position and memory of the ith crow has been considered as $$X_i$$ and $$m_i$$ respectively and they are given by eqn. (7) and (8).

is very good comparing to other birds. The motivation of

3.2 CSA approach for location and sizing of DG

The CSA approach used for solving the optimal placement and size of multiple DGs of different types to minimize the active power loss takes the following steps:

Step1: Input the flock size (N), Number of decision variable (d), maximum number of iterations, flight length and awareness probability.

Step2: Initialize the position and memory of the crows. For the flock size N and decision variable d the size of the search space i.e. crow position and position of the food i.e. memory matrix is $$N \times d$$.

$$\text{Crows position(X)} = \begin{bmatrix} x_1^1 & x_1^2 & \ldots & x_1^d \\ x_2^1 & x_2^2 & \ldots & x_2^d \\ \vdots & \vdots & \ddots & \vdots \\ x_N^1 & x_N^2 & \ldots & x_N^d \end{bmatrix}$$  \hspace{1cm} (11)

$$\text{Memory (m)} = \begin{bmatrix} m_1^1 & m_1^2 & \ldots & m_1^d \\ m_2^1 & m_2^2 & \ldots & m_2^d \\ \vdots & \vdots & \ddots & \vdots \\ m_N^1 & m_N^2 & \ldots & m_N^d \end{bmatrix}$$  \hspace{1cm} (12)

Table 1: Size of the search space in different cases

<table>
<thead>
<tr>
<th>Type of system</th>
<th>Number of DG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DG</td>
<td>2 DG</td>
</tr>
<tr>
<td>Type-1</td>
<td>$$N \times 2$$</td>
</tr>
<tr>
<td>Type-2</td>
<td>$$N \times 2$$</td>
</tr>
<tr>
<td>Type-3</td>
<td>$$N \times 3$$</td>
</tr>
</tbody>
</table>

The location is an integer value initialized between 2 to 33 (for 33-bus system) and 2 to 69 (for 69-bus system) while size is a continuous value initialized between 1 to 100 (for both 33 and 69 bus systems). Initially the value of m is equal to X, because crows have no experience in starting.

Step 3: Calculate the active power loss (fitness function) for each crow position using BIBC and BCBV method of load flow analysis. This step is required to check the quality position of each crow.

Step 4: Generate new position of the crows in the search space which is obtained by eq. (10) and check the boundary violations given in eq. (2) and (3).

Step 5: Calculate the fitness function for each crow position (generated in step 4) using BIBC and BCBV method and find the fitness value for each position.

Step 6: If the fitness function value of the new position is better than fitness function value of the memorized position the crow updates it’s memory by the new position otherwise remain in previous position. Crow updates their memory as follows:
reduction in loss and statistical
4.1.2
obtained from CSA methods give equal or better result
the
method. The statistics of the CSA method shows
is less compare to PSO method but it is more than IA
but it is better than IA while DG size obtained from CSA
is compared with PSO
optimal locations are 13, 24, 30.

4. Test Systems and result:
Two different test systems and three different types of
different types of DGs are Type-I, Type-2, and Type-3. This method is implemented
in Matlab version 2017 a. The CSA parameters selected
for solving the optimization are: N =100, Maximum
number of iteration (itermax) =500, Flight length (fl) =0.2,
Awareness probability (AP) =2.5 and 50 independent runs
[14]. These values are selected on experience basis for
better result and convergence. Bus 1 is considered as the
reference bus. From economical point of view maximum
number of DG taken is three. Statistical analysis of each
system is carried out to check the robustness of the
algorithm.

4.1 33-bus system:
IEEE-33 bus system is taken for the study purpose.
Active power, reactive power and total load power of the
system is 3.72 MW, 2.33 MVAr and 4.4 MVA respectively[20]. This system has 32 numbers of branches and 33
numbers of buses. The base loss of the system is 210.96
KW.

4.1.1 Type-I DG placement
Table 2 shows the optimal location and size of multiple
DGs by CSA approach. For single DG system, optimal
size of the DG is 2.59 MW and optimal location is 6 and
for two DG system, total optimal size of the DG is 2.01
MW and optimal locations are 13, 30. For three DG
system, total optimal size of the DG is 2.83 MW and
optimal locations are 13, 24, 30. The result obtained from
the CSA is compared with PSO [21] and fast analytical
method (IA) [22]. For single DG, Table 2 shows better
result than IA. The size of DG obtained from CSA is better
compare to PSO and IA method. For 2 DG units, power
loss reduction and DG size by CSA and PSO is same but it
is better than IA method. For 3 DG units, power loss
reduction of CSA and PSO method is approximately same
but it is better than IA while DG size obtained from CSA
is less compare to PSO method but it is more than IA
method. The statistical data of the CSA method shows
robustness of the method for type-I system. Table 8 shows
the voltage characteristics of the system. Therefore result
obtained from CSA methods give equal or better result
compare to PSO and IA method.

4.1.2 Type-II DG placement
Table 3 shows the optimal location, size, power loss,
reduction in loss and statistical data of multiple DGs
placed in the system. From the table 3 maximum and
minimum percentage reduction loss of the system is 28.26
and 34.47 respectively. Minimum reduction is obtained for
single DG placement while maximum is for 3 DG. The
minimum and maximum voltage variation is 0.9319 p.u.
and 1 p.u. respectively. Statistical data shows the
robustness of the proposed method for type-2 system. As
DG inserted in the system increases, power loss of the
system decreases and percentage system power loss
increases.

4.1.3 Type-III DG placement
Optimal location, size, and power factor of multiple DG
placement for type-3 system is obtained in table 4 and
corresponding voltage profile in table 8. Result from the
proposed method is compared with PSO[21] and IA[22]
method. For single DG placement optimal size, location,
DG size and percentage reduction in loss for proposed
method is approximately same as PSO and IA method. For
position of two and three DG in the system result from the
CSA method gives improved performance than IA but
lower performance than PSO method.

4.2 69-bus system:
The second system is a 69-bus system having active power
load of 3.80 MW, reactive power load of 2.70 KVAR and
total load of 4.7 MVA [23]. Total branches and buses in
the system is 68 and 69 respectively. 50 independent runs
are performed to study the statistics of the algorithm for
different type of DGs. The base case loss of the system is
225 kW.

4.2.1 Type-I DG placement
Optimal location, size, power loss, percentage reduction
in loss and statistical analysis of multiple DGs are obtained
and given in table 5. From the results maximum and
minimum percentage reduction in loss is 68.41 and 62.62
respectively. Maximum and minimum voltage is 0.9806
p.u. and 1 p.u. respectively. It is found that optimal
location and size obtained from the proposed method is
same as PSO but reduction in loss obtained from the CSA
method is better than PSO.

4.2.2 Type-II DG placement
Table 6 shows different values obtained using CSA
optimization method. Maximum and minimum percentage
reduction in loss is obtained as 32.44 and 34.87
respectively. Maximum and minimum voltage is obtained
as 1 p.u. and 0.9329 p.u. respectively. As the number of
DG inserted in the system increases reduction in loss
increases and power loss decreases.

4.2.3 Type-III DG placement
Optimal location, size, power loss, reduction in loss and
statistics of multiple DGs are obtained using CSA
optimization method and it is given in table 7. Table 7
gives maximum and minimum percentage reduction in loss
as 89.71 and 97.9 respectively. Voltage profile of the
system lies between 0.9723 to 1 p.u. respectively. Result
from the proposed technique is compared with PSO method. This method gives equal result as PSO.

Flow chart for the location and sizing of DG:

![Flow chart](image-url)
Table 2: Optimal values for Type-1 System

<table>
<thead>
<tr>
<th>No. of DG</th>
<th>Method</th>
<th>Optimal location</th>
<th>Optimal size MW</th>
<th>Total DG Size MW</th>
<th>Power Loss (kW)</th>
<th>Reduction in loss (%)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DG</td>
<td>CSA</td>
<td>6</td>
<td>2.58</td>
<td>2.58</td>
<td>111.03</td>
<td>47.38</td>
<td>111.03</td>
</tr>
<tr>
<td></td>
<td>IA[22]</td>
<td>6</td>
<td>2.60</td>
<td>2.60</td>
<td>111.10</td>
<td>47.38</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>PSO[24]</td>
<td>6</td>
<td>2.59</td>
<td>2.59</td>
<td>111.03</td>
<td>47.38</td>
<td>NA</td>
</tr>
<tr>
<td>2 DG</td>
<td>CSA</td>
<td>13 13</td>
<td>0.85 1.16</td>
<td>2.01</td>
<td>87.17</td>
<td>58.69</td>
<td>87.167</td>
</tr>
<tr>
<td></td>
<td>IA[22]</td>
<td>6 14</td>
<td>1.80 0.72</td>
<td>2.52</td>
<td>91.63</td>
<td>56.61</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>PSO[24]</td>
<td>13 30</td>
<td>0.85 1.16</td>
<td>2.01</td>
<td>87.17</td>
<td>58.69</td>
<td>NA</td>
</tr>
<tr>
<td>3 DG</td>
<td>CSA</td>
<td>13 24 30</td>
<td>0.76 1.03 1.04</td>
<td>2.83</td>
<td>72.79</td>
<td>65.46</td>
<td>72.79</td>
</tr>
<tr>
<td></td>
<td>IA[22]</td>
<td>6 12 31</td>
<td>0.90 0.90 0.72</td>
<td>2.52</td>
<td>81.05</td>
<td>61.62</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>PSO[24]</td>
<td>14 24 30</td>
<td>0.77 1.09 1.07</td>
<td>2.93</td>
<td>72.79</td>
<td>65.50</td>
<td>NA</td>
</tr>
</tbody>
</table>

Table 3: Optimal values for Type-2 System

<table>
<thead>
<tr>
<th>No. of DG</th>
<th>Optimal Location (Bus No.) &amp; Optimal Size (MVar)</th>
<th>Total DG Size MVar</th>
<th>Power Loss (kW)</th>
<th>Reduction in loss (%)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DG</td>
<td>30</td>
<td>1.26</td>
<td>1.26</td>
<td>151.38</td>
<td>28.26</td>
</tr>
<tr>
<td>2 DG</td>
<td>12 30</td>
<td>0.47 1.06</td>
<td>1.53</td>
<td>141.84</td>
<td>32.78</td>
</tr>
<tr>
<td>3 DG</td>
<td>13 24 30</td>
<td>0.39 0.54 1.04</td>
<td>1.97</td>
<td>138.27</td>
<td>34.47</td>
</tr>
</tbody>
</table>
### Table 4: Optimal values for Type-3 System

<table>
<thead>
<tr>
<th>No. of DG's</th>
<th>Method</th>
<th>Optimal Location</th>
<th>Optimal Size MVA</th>
<th>Optimal Size MVA</th>
<th>Total MVA</th>
<th>Power Loss (kW)</th>
<th>Reduction in loss (%)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DG</td>
<td>CSA</td>
<td>6</td>
<td>3.107</td>
<td>0.82</td>
<td>3.107</td>
<td>67.87</td>
<td>67.85</td>
<td>67.87, 67.87, 67.87, 2.36e-06</td>
</tr>
<tr>
<td></td>
<td>IA[22]</td>
<td>6</td>
<td>3.107</td>
<td>0.82</td>
<td>3.107</td>
<td>67.9</td>
<td>67.82</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>PSO[21]</td>
<td>6</td>
<td>3.035</td>
<td>0.82</td>
<td>3.035</td>
<td>67.9</td>
<td>67.82</td>
<td>NA</td>
</tr>
<tr>
<td>2 DG</td>
<td>CSA</td>
<td>13</td>
<td>0.93</td>
<td>1.557</td>
<td>0.90</td>
<td>2.487</td>
<td>28.51</td>
<td>28.51, 28.90, 28.56, 0.013852</td>
</tr>
<tr>
<td></td>
<td>IA[22]</td>
<td>6</td>
<td>2.195</td>
<td>1.098</td>
<td>0.82</td>
<td>3.293</td>
<td>44.39</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>PSO[21]</td>
<td>13</td>
<td>0.914</td>
<td>1.535</td>
<td>0.82</td>
<td>2.449</td>
<td>28.6</td>
<td>NA</td>
</tr>
<tr>
<td>3 DG</td>
<td>CSA</td>
<td>14</td>
<td>0.439</td>
<td>0.632</td>
<td>0.779</td>
<td>3.514</td>
<td>11.77</td>
<td>11.77, 14.48, 12.92, 0.23042</td>
</tr>
<tr>
<td></td>
<td>IA[22]</td>
<td>6</td>
<td>1.098</td>
<td>0.768</td>
<td>0.82</td>
<td>2.964</td>
<td>67.87</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>PSO[21]</td>
<td>13</td>
<td>0.863</td>
<td>1.188</td>
<td>0.91</td>
<td>3.482</td>
<td>67.9</td>
<td>NA</td>
</tr>
</tbody>
</table>

### Table 5: Optimal values for Type-1 System

<table>
<thead>
<tr>
<th>No. of DG</th>
<th>Method</th>
<th>Optimal Location</th>
<th>Optimal Size (MW)</th>
<th>Total DG Size (MW)</th>
<th>Power Loss (kW)</th>
<th>Reduction in loss (%)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DG</td>
<td>CSA</td>
<td>61</td>
<td>1.82</td>
<td>1.82</td>
<td>83.19</td>
<td>63.03</td>
<td>83.19, 83.19, 83.19, 1.56e-08</td>
</tr>
<tr>
<td></td>
<td>PSO[24]</td>
<td>61</td>
<td>1.87</td>
<td>1.87</td>
<td>83.37</td>
<td>63.01</td>
<td>NA</td>
</tr>
<tr>
<td>2 DG</td>
<td>CSA</td>
<td>17</td>
<td>0.52</td>
<td>1.77</td>
<td>2.29</td>
<td>71.66</td>
<td>71.66, 71.7, 71.66, 5.65e-03</td>
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<tr>
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<td>PSO[24]</td>
<td>17</td>
<td>1.78</td>
<td>0.53</td>
<td>2.31</td>
<td>71.68</td>
<td>NA</td>
</tr>
<tr>
<td>3 DG</td>
<td>CSA</td>
<td>11</td>
<td>0.50</td>
<td>0.39, 1.72</td>
<td>2.61</td>
<td>69.42</td>
<td>69.42, 71.32, 69.97, 2.74e-02</td>
</tr>
<tr>
<td></td>
<td>PSO[24]</td>
<td>11</td>
<td>0.46</td>
<td>0.44, 1.70</td>
<td>2.60</td>
<td>69.54</td>
<td>NA</td>
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</tbody>
</table>
Table 6: Optimal values for Type-2 System

<table>
<thead>
<tr>
<th>No. of DG</th>
<th>Optimal Location</th>
<th>Optimal Size (MVAr)</th>
<th>Total DG Size MVAr</th>
<th>Power Loss (kW)</th>
<th>Reduction in loss (%)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DG</td>
<td>61</td>
<td>1.328</td>
<td>1.328</td>
<td>152.01</td>
<td>32.44</td>
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<td>152.01</td>
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<td></td>
<td></td>
<td>152.01</td>
</tr>
<tr>
<td>2 DG</td>
<td>17 61</td>
<td>0.36 1.273</td>
<td>1.633</td>
<td>147.85</td>
<td>34.29</td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>147.85</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>147.87</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td>147.85</td>
</tr>
<tr>
<td>3 DG</td>
<td>11 20 61</td>
<td>0.397 0.233 1.244</td>
<td>1.874</td>
<td>146.54</td>
<td>34.87</td>
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</tr>
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<td></td>
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<td>146.54</td>
</tr>
<tr>
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<td>146.68</td>
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Table 7: Optimal values for Type-3 System

<table>
<thead>
<tr>
<th>No. of DG's</th>
<th>Method</th>
<th>Optimal location</th>
<th>Optimal Size MVA</th>
<th>Optimal power factor</th>
<th>Total Size MVA</th>
<th>Power Loss (kW)</th>
<th>Reduction in loss (%)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DG</td>
<td>CSA</td>
<td>61</td>
<td>2.24</td>
<td>0.81</td>
<td>2.24</td>
<td>23.15</td>
<td>89.7</td>
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<tr>
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<td>PSO[21]</td>
<td>61</td>
<td>2.22</td>
<td>0.81</td>
<td>2.22</td>
<td>23.20</td>
<td>89.7</td>
<td>NA</td>
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<tr>
<td>2 DG</td>
<td>CSA</td>
<td>18 61</td>
<td>0.63 2.14</td>
<td>0.84 0.81</td>
<td>2.77</td>
<td>7.21</td>
<td>96.8</td>
<td>7.21</td>
</tr>
<tr>
<td></td>
<td>PSO[21]</td>
<td>17 61</td>
<td>0.63 2.13</td>
<td>0.82 0.81</td>
<td>2.76</td>
<td>7.20</td>
<td>96.8</td>
<td>NA</td>
</tr>
<tr>
<td>3 DG</td>
<td>CSA</td>
<td>11 22 61</td>
<td>0.59 0.42 2.06</td>
<td>0.93 0.76 0.81</td>
<td>3.07</td>
<td>4.51</td>
<td>98</td>
<td>4.51</td>
</tr>
<tr>
<td></td>
<td>PSO[21]</td>
<td>11 18 61</td>
<td>0.60 0.46 2.06</td>
<td>0.83 0.81 0.81</td>
<td>3.12</td>
<td>4.61</td>
<td>97.9</td>
<td>NA</td>
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</tbody>
</table>

5. Conclusion:
A new optimization technique to solve the optimal allocation of multiple DGs of different types for minimization of active power loss in distribution network is discussed in this paper. Proposed scheme is implemented on 33 and 69 bus system. The obtained result is compared with existing methods like PSO and IA method. It is seen that for all type of DG proposed method gives better result than IA method and roughly equal result to PSO method. This method is easy to implement compare to PSO method as it has only 2 parameters while PSO has 4 parameters to control. If parameters are not controlled properly it will lead to local optimal value. To check the robustness of the method Statistical data has been analyzed. This paper implements single objective function taking constant load to find the solution. In future multi-objective function and time varying load and generation can be taken into consideration for finding the solution. Researchers and planners may find this study useful by implementing it.
**Fig. 2:** Power loss vs. type of DG for 3 DG system in 33-bus system

**Fig. 3:** Power loss vs. type of DG for 3 DG system in 66-bus system

**Fig. 4:** Convergence characteristics for three DG, type-1, 33-bus system
**Fig. 5:** Convergence characteristics for three DG, type-2, 33-bus system

**Fig. 6:** Convergence characteristics for three DG, type-3, 33-bus system

**Fig. 7:** Convergence characteristics for three DG, type-1, 69-bus system
Table 8: Voltage profile for 33-bus system

<table>
<thead>
<tr>
<th>DG Type</th>
<th>Minimum voltage</th>
<th>Bus No.</th>
<th>Maximum voltage</th>
<th>Bus No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No DG</td>
<td>0.9038</td>
<td>18</td>
<td>1.0000</td>
<td>1</td>
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<tr>
<td>Type-1</td>
<td>0.9581</td>
<td>33</td>
<td>1.0000</td>
<td>1</td>
</tr>
<tr>
<td>Type-2</td>
<td>0.9289</td>
<td>18</td>
<td>1.0000</td>
<td>1</td>
</tr>
<tr>
<td>Type-3</td>
<td>0.9940</td>
<td>22</td>
<td>1.0091</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 9: Voltage Profile for 69-bus system

<table>
<thead>
<tr>
<th>DG Type</th>
<th>Minimum voltage</th>
<th>Bus No.</th>
<th>Maximum voltage</th>
<th>Bus No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No DG</td>
<td>0.9092</td>
<td>65</td>
<td>1.0000</td>
<td>1</td>
</tr>
<tr>
<td>Type-1</td>
<td>0.9783</td>
<td>1</td>
<td>1.0000</td>
<td>1</td>
</tr>
<tr>
<td>Type-2</td>
<td>0.9329</td>
<td>65</td>
<td>1.0000</td>
<td>1</td>
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<td>Type-3</td>
<td>0.9904</td>
<td>27</td>
<td>1.0000</td>
<td>1</td>
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References


