Optimal placement of distributed generation using firefly algorithm

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Abstract. Optimal placement of Distributed Generation (DG) is an important activity for distribution network operator to operate the network with more optimal in terms of real power losses (RPL). In this paper, a meta-heuristic algorithm called firefly algorithm has been used find optimal location and size of DG units based on RPL. The proposed approach is implemented on IEEE 15 bus and PG & E 69 bus distribution systems in MATLAB environment. Based on simulation results, it has been observed that firefly algorithm is performing well to identify optimal location and size with minimum RPL.

Keywords. Distributed Generation, Firefly Algorithm, Real power losses, Bio-inspired algorithms.

1. Introduction

Distributed generation (DG) penetration into the distribution network is increasingly growing due to some benefits including reducing real power losses (RPL), improvement of voltage profile, government schemes to reduce global warming, increasing reinforcement horizon, and reliability improvement [1]. Appropriate location and size for each DG unit to integrate into the distribution network is required else it will cause a negative impact on the above parameters.

Many researchers are working optimal placement of DG problem with various conventional and meta-heuristic algorithms by considering various objective functions as listed in Table1. All the literature works presented in Table 1 provides great contribution towards optimal placement of DG units using meta-heuristic algorithms. However, these have some limitations like premature convergence and results are not guaranteed.

In this paper, the optimization problem i.e. optimal placement of DG in terms of position and generation capacity is mathematically modeled by considering minimization of RPL as an objective function and the constraints are voltage limits and thermal limit of the feeders. A meta-heuristic
algorithm called "firefly algorithm" has been used solve this constrained optimization problem. Backward and forward sweep load flow method [16] has been used to do distribution network load flow analysis as it uses full use of the distribution network ladder system, good convergence characteristics and required less memory space [17].

Table 1. Literature report DG units placement

| Reference | Test System | Objectives             | Algorithm |
|-----------|-------------|------------------------|-----------|
| [2]       | 6,14,30     | Optimize power losses  | GA        |
| [3]       | 33,69       | Optimize power losses  | GA        |
| [4]       | 69          | Optimize power losses  | GA        |
| [5]       | 33          | Optimize power losses  | GA        |
| [6]       | 16,37       | Optimize power losses  | GA        |
| [7]       | 69          | Optimize power losses  | GA        |
| [8]       | 69          | Optimize power losses  | PSO       |
| [9]       | 30          | Optimize power losses  | PSO       |
| [10]      | 13,33       | Multiple objectives    | ACO       |
| [11]      | 69          | Optimize voltage limit | ABC       |
| [12]      | 33,69       | Optimize DG capacity   | HS        |
| [13]      | 6,14,30     | Optimize DG capacity   | PH        |
| [14]      | 31          | Optimize power losses  | PH        |
| [15]      | 11/0.4kV    | Optimize reliability   | MCS       |

The remainder of the paper was structured as follows: Section 2 outlines the problem formulation, Section 3 presents the simulation findings of the suggested approach and Section 4 summarizes the conclusions of this paper.

2. Methodology
The mathematical modeling of an objective function of the studying optimization problem is presented in equation (1) and the subjected constraints are shown in equation (2).

\[
\text{Maximize Brightness} = \frac{1}{1 + p_{\text{loss}}} \quad (1)
\]

\[
\begin{align*}
V_{\text{min}} & \leq V_i \leq V_{\text{max}} \\
l_i & \leq I_i \leq I_{\text{max}} \\
p_{g,\text{min}} & \leq P_g \leq p_{g,\text{max}} \\
2 & \leq loc \leq n
\end{align*} \quad (2)
\]

2.1. Firefly Algorithm
Current classical algorithms have drawbacks, such as a highly receptive initial stage, and frequently converge to a local optimal solution. Bio-inspired algorithms have been developed to solve these particular problems [18, 19, 20, 21]. Firefly Algorithm (FA) [22] was one of the bio-inspired algorithms that evolved based on Fireflies swarming behavior. Fireflies are moving towards the more brighter firefly. Brightness of the firefly has been evaluated based on objective function value and the amount of attraction depends on brightness and distance between fireflies. The step by step procedure for firefly algorithm is presented in Algorithm 1.
Algorithm 1 Firefly Algorithm for DG placement

Inputs
1: Read n, \( P_{h_{\text{max}}} = 1 \text{MW}, P_{h_{\text{min}}} = 0, n_{DG} = 2 \)
2: Set epochs = 100, \( \gamma = 1, \beta_0 = 1, \alpha = 0.2, \text{pop} = 40 \)

Steps
1: Initialize fireflies \([X]\) randomly \(<\text{firefly}[X] = [\text{loc}(DG1), \text{loc}(DG2), \text{Size}(DG1), \text{Size}(DG2)]\>
2: Find RPL for each firefly
3: Find brightness for each firefly using equation (1)
4: Set iteration \( t = 1 \)
5: Set firefly \( i = 1 \)
6: Set firefly \( j = 1 \)
7: while \( t \leq \text{epochs} \) do
8: while \( i \leq \text{pop} \) do
9: while \( j \leq \text{pop} \) do
10: Compute \( r = \sqrt{\sum_{f=1}^{4} (X[i,f] - [j,f])^2} \)
11: if Brightness\((X[i]) < \text{Brightness}(X[j])\) then
12: \( X' [i] = X[i] + \beta_0 \times e^{-\gamma r^2} \times (X[j] - X[i]) + \alpha \times (\text{rand} - 0.5) \)
13: Impose boundary limits
14: Find brightness for firefly "i" using equation (1)
15: if \( \text{Brightness}(X'[i]) \geq \text{Brightness}(X[i]) \) then
16: Set \( X[i] = X'[i] \)
17: end if
18: end if
19: \( j = j + 1 \)
20: end while
21: \( i = i + 1 \)
22: end while
23: \( X_{\text{best}} = X_{\text{best}} + \alpha \times \text{rand} \) Exploitation
24: \( t = t + 1 \)
25: end while

3. Results and discussion
The proposed method was implemented on IEEE 15 and PG & E 69 bus distribution test systems for optimally placing two DG units with 0.9 lagging power factor having maximum capacity 1MW each under MATLAB environment [23]. IEEE 15 and PG & E 69 bus distribution test systems data are drawn from [24].

3.1. Performance of firefly algorithm in stochastic environment
The proposed firefly algorithm is simulated 10 times to classify the position and generation potential of DG units. Out of the 10 best simulations in terms of the minimal RPL, the position and generation power of the DG units shall be considered. Interpretation of the proposed approach is observed in probabilistic framework is presented in Table 2. From the Table 2, it has been observed that standard deviation is almost near to zero that shows less uncertainty in the solution given by firefly algorithm. Convergence characteristics of firefly algorithm on the discussing problem i.e. optimal placement of DG units for IEEE 15 and PG & E 69 bus distribution test systems are presented in Figure 1. From the Figure 1, can visualize the uncertainty in solution provided by firefly algorithm.
3.2. Optimal location and capacity for DG units

The optimal position and capacity for the two DG units for IEEE 15 and PG& E 69 bus distribution test systems are presented in Table 3. From the Table 3, it has been observed that IEEE 15 bus distribution network will operate with minimum RPL i.e. 13.6 kW if two DG units with 386kW and 1MW generation capacity connected at bus 9 and 3 respectively. Similarly PG& E 69 bus distribution network will operate with minimum RPL i.e. 43.8 kW if two DG units with 566kW and 855kW generation capacity connected at bus 63 and 61 respectively.

| Parameter                     | PG & E 69 | IEEE 15 |
|-------------------------------|-----------|---------|
| DG1 location                  | 63        | 9       |
| DG2 location                  | 61        | 3       |
| DG1 size (kW)                 | 566       | 386     |
| DG2 size (kW)                 | 1000      | 855     |
| RPL (kW)                      | 43.8      | 13.6    |
| Base case loss (kW)           | 221.8     | 60.1    |

Table 2. Stochastic behaviour of FA

| Simulation | Real Power Losses (MW) PG & E 69 | IEEE 15 |
|------------|-----------------------------------|---------|
| 1          | 0.081                             | 0.014   |
| 2          | 0.059                             | 0.016   |
| 3          | 0.068                             | 0.016   |
| 4          | 0.081                             | 0.015   |
| 5          | 0.07                              | 0.014   |
| 6          | 0.044                             | 0.015   |
| 7          | 0.048                             | 0.016   |
| 8          | 0.057                             | 0.018   |
| 9          | 0.084                             | 0.014   |
| 10         | 0.063                             | 0.014   |
| Min.       | 0.044                             | 0.014   |
| Max.       | 0.084                             | 0.018   |
| Mean       | 0.065                             | 0.015   |
| Std.       | 0.014                             | 0.0012  |

Figure 1. Converging characteristics

(a) IEEE 15 Bus Test System: Convergence characteristics
(b) PG& E 69 Bus Test System: Convergence characteristics

Table 3. Optimal location and size of DG units
3.3. Voltage profile comparison
Voltage profile in base case and with DG unit for both IEEE 15 bus and PG&E 69 bus distribution systems is presented in Figure 2. From the Figure 2, it has been observed that voltage profile for both test systems is improved with DG units.

![Voltage profile comparison](image)

Figure 2. Voltage profile

3.4. Comparative analysis
The proposed firefly algorithm based approach for DG placement optimization problem is validated by comparing with genetic algorithm [25] in stochastic environment as shown in Table 4.

| Simulation | FA     | GA[25] |
|------------|--------|--------|
| 1          | 0.081  | 0.0784 |
| 2          | 0.059  | 0.0461 |
| 3          | 0.068  | 0.0689 |
| 4          | 0.081  | 0.0951 |
| 5          | 0.07   | 0.0469 |
| 6          | 0.044  | 0.0743 |
| 7          | 0.048  | 0.0722 |
| 8          | 0.057  | 0.0723 |
| 9          | 0.084  | 0.0732 |
| 10         | 0.063  | 0.0588 |
| Min.       | 0.044  | 0.0461 |
| Max.       | 0.084  | 0.0951 |
| Mean       | 0.065  | 0.0686 |
| Std.       | 0.014  | 0.0147 |

Comparative analysis between Genetic Algorithm (GA)[25] and the proposed approach is presented in terms of converging characteristics is presented in Figure 3. From Figure 3, it has been observed that the proposed approach reaches better solution. GA is trapped by some suboptimal point even though it is converging fast comparing to firefly algorithm.
Figure 3. Comparison between GA [25] and proposed approach in terms of converging characteristics

4. Conclusions
Distributed generation integration into the distribution system is increasing rapidly due to some technical, economical and environmental advantages. This integration will provide positive impact if it is installed at proper location else leads negative impact on the system. There is a need of designing an efficient algorithm to integrate DG units to distribution system.

In this article, firefly algorithm was used to solve the optimum DG placement optimization problem on the basis of the RPL reduction that was subjected to constraints such as the voltage limits and thermal limits of the feeders. The suggested approach is tested by comparing with the genetic algorithm in the probabilistic framework. Firefly algorithm reaches more near to global optimum solution comparing to genetic algorithm. IEEE 15 and PG&E 69 bus test systems have been used to simulate the proposed approach.

The discussed DG optimal placement problem can be extended by considering the objectives like emission reduction, maximize reliability and reinforcement horizon.

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