Metaheuristic Techniques based Optimal Placement and Sizing of Multiple Distributed Generations in Radial Distribution System

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***Abstract*—In this paper, Meta-heuristic techniques were employed for optimal placement and sizing of multiple Distributed Generations (DGs) in a Radial Distribution System (RDS) to mitigate the losses and voltage deviations. In this study, Genetic Algorithm (GA), Shuffled Frog Leap Algorithm (SFLA) and Jaya Algorithm (JAYA) were applied on a standard IEEE 33 bus test system. It was observed from the test results simulated under MATLAB environment that Jaya Algorithm outperformed GA and SFLA for optimal placement and sizing of multiple DGs to mitigate the losses and voltage deviations.**

***Index Terms*—Genetic Algorithm (GA), Shuffled Frog Leap Algorithm (SFLA), Jaya Algorithm (JAYA), Distributed Generations (DGs), Radial Distribution System (RDS).**

NOMENCLATURE

δ_i i_{th} bus voltage angle
δ_j j_{th} bus voltage angle
θ_{ij} Admittance angle between buses i and j
C_{Time} Computational Time in seconds
Ch_{length} Chromosome length
DG_{loc} Location of DG
DG_{size} Size of DG
E_i i_{th} bus voltage
E_j j_{th} bus voltage
E_{max} Maximum bus voltage
E_{min} Minimum bus voltage
f_1 Total loss index
f_2 Voltage deviation index
I_{max} Maximum line current
I_{min} Minimum line current
k Line number
L_{wdg} Losses with DGs
L_{wodg} Losses without DGs
$min(F)$ Minimization of Objective function
N_b Number of buses
N_{dg} Number of DGs
N_{frogs} Number of frogs
N_{mem} Number of memeplexes
P_c Probability of crossover
P_{DG} Active power generation of DG
P_{DG}^{max} Maximum active power generation of DG
P_{DG}^{min} Minimum active power generation of DG
P_{di} Real power demand of i_{th} bus
P_e Probability of elitism
P_{gi} Real power generation of i_{th} bus
P_{load} Active power load
P_m Probability of mutation
P_{size} Population size
Q_{di} Reactive power demand of i_{th} bus
Q_{gi} Reactive power generation of i_{th} bus
r_1, r_2 Random value between (0,1)
S_{ij} Complex power loss of a line between buses i and j
S_{ji} Complex power loss of a line between buses j and i
S_{loss} Total complex power loss of the system
VD_{wdg} Voltage deviation with DGs
VD_{wodg} Voltage deviation without DGs
w_1 Weight factor of loss index
w_2 Weight factor for Voltage deviation index
X_i Initial population
$X_i^{'}$ Updated population
X_i^{best} Best value of i_{th} population
X_i^{worst} Worst value of i_{th} population
Y_{ij} Admittance of line between buses i and j

I. INTRODUCTION

Integration of DGs into the grid has enabled the planning of electrical power system expansion sustainable and easy availability of power supply to remote areas, which are deprived of quality power. The depletion of Conventional energy sources like Coal, Gas and Oil has motivated the planners to increase generation of renewable energy sources which are inexhaustible and pollution free [1]. The Integration of DGs into the grid has increased stability, reduced losses and therefore operating costs and enabled efficient and eco-friendly availability of power in remote areas [2]. DGs are available in both non-renewable energy based (Diesel, Natural gas. etc) and renewable energy based technologies. Renewable DGs such as Wind, Solar, Hydro and Biomass. etc have become popular because of reduced gas emissions [3]. Distributed power generations address several issues like high peak load demand, high Transmission and Distribution (TD) losses, supply to inaccessible areas, rural electrification, improved power reliability and quality, better energy and demand management and finally optimal use of grid assets [4].

The Principal objective of DGs installation into the Distribution System is to find the optimal placement and sizing of DGs so as to reduce power losses and costs as well voltage profile improvement at critical buses there by improving reliability of the system [5]. There are a significant number of nature inspired algorithms like Genetic Algorithm [6], Particle Swarm Optimization [7], Analytical methods [8], Simulated annealing and Shuffled Frog Leap Algorithm [14] which have been proposed for optimal allocation of DGs for efficient transmission of power to consumers. There is ample scope for improvement of DGs allocation by employing nature inspired algorithms. Nature Inspired Algorithms have higher potential to solve Complex optimization problems like Optimal allocation and sizing of DGs in comparison with conventional methods to get global optimal solution.

In this paper, Meta-heuristic algorithms have been employed to study the optimal placement and sizing of Multiple DGs into the radial distribution systems for minimization of losses and voltage deviations. Meta-heuristic algorithms such as GA, SFLA and Jaya have been applied on IEEE 33 bus Radial Distribution System [16] for mitigating the losses and voltage deviations. In the absence of DGs, the losses computed by utilizing the forward backward distribution load flow [17] method in the IEEE 33 bus RDS are considered base case losses.

This paper is organized in four sections: Problem Formulation for DGs location and size is presented in Section II. Meta-heuristic Algorithms such as Genetic Algorithm, Shuffled Frog Leap Algorithm, Jaya Algorithms are explained in Section III. In Section IV Simulation results on IEEE 33 Bus Radial distribution system based on Meta-heuristic algorithms are discussed and the results were compared with the performance of other algorithms. Finally the conclusions and scope for further research are elaborated in Section V.

II. PROBLEM FORMULATION

The aim of this paper is to find the optimal placement and sizing of multiple DGs in RDS by mitigating losses and voltage deviations. The objective function expression is shown in equation 1.

$$min(F) = w_1 f_1 + w_2 f_2 \quad (1)$$

The objective function for formulating the problem is as follows

1) Initially run the base case load flow for the distribution system to calculate the total losses before placement and sizing of DGs into the system. Calculate losses after placement and sizing of DGs. The loss index (f_1) is defined as the ratio between the losses with DGs and without DGs as shown in equation 2.

$$f_1 = \frac{L_{wdg}}{L_{wodg}} \quad (2)$$

2) The voltage deviation index (f_2) is defined as the ratio between the voltage deviation with DGs and without DGs as shown in equation 3.

$$f_2 = \frac{VD_{wdg}}{VD_{wodg}} \quad (3)$$

The above cited objective function (1) is subject to the following equality and inequality constraints.

$$P_{gi} - P_{di} - \sum_{j=1}^{N_b} |E_i||E_j|Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (4)$$

$$Q_{gi} - Q_{di} - \sum_{j=1}^{N_b} |E_i||E_j|Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (5)$$

$$E_{min} \leq E \leq E_{max} \quad (6)$$

$$I_{min} \leq I \leq I_{max} \quad (7)$$

$$P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max} \quad (8)$$

III. META-HEURISTIC TECHNIQUES

Optimization problems have been solved using Classical methods like Gradient method, Newtons method, linear programming, Quadratic programming etc. However these techniques have difficulty in attaining the global optimal value due to a large number of control variables and discrete search space. Meta-heuristic Techniques have been gaining popularity in recent times as alternative approaches to solving such complex problems.

A. Genetic Algorithm (GA)

GA is an Evolutionary algorithm [6] which is inspired by nature. Genetic Algorithm is applied to Optimization problems. Generate randomly a population of binary strings. Calculate the fitness of each string in the population. Create offspring's through reproduction, cross-over and mutation operation. Evaluate the new strings and calculate the fitness for each string (chromosome). If the search goal is achieved, or an allowable generation is attained, return the best chromosome as the solution otherwise create off springs until the search goal is achieved.

Algorithm 1 : GA for the formulated problem

1. Read Radial Distribution System data (Line data, Bus Data), GA parameters and DGs parameters.
2. Run the base case Load flow without DGs.
a) Compute the total line losses using equation 9

$$S_{loss}(k) = S_{ij}(k) + S_{ij}(k) \tag{9}$$

b) Compute the voltage deviations using equation 10

$$VD_{wodg}(i) = abs(\frac{E(i) - E(1)}{E(1)}) \tag{10}$$

3. Generate Random Initial Population.
4. Start Iteration count
5. Decode the chromosomes into decimal values
6. Normalize the decoded values with defined limits of variables
$([DG_{loc}(1)....DG_{loc(N_{dg})} DG_{size(1)}....DG_{size(N_{dg})}])$
7. Compute the system losses with new parameters obtained
a) Update P_{load} using equation 11 and run the load flow

$$P_{load}(DG_{loc}(N_{dg})) = P_{load}(DG_{loc}(N_{dg})) - DG_{size}(N_{dg}) \tag{11}$$

b) Compute total loss in the system using equation 9.
c) Compute maximum voltage deviation in the system using equation 10.
d) Define index for both objectives.
8. Compute the fitness function value for all chromosomes using equation 12

$$fitness(i) = \frac{1}{1 + f_1 + f_2} \tag{12}$$

9. Sort the population according to fitness value in descending order.
10. Perform Elitism operator
11. Perform Crossover to obtain the remaining chromosomes using Roulette Wheel technique.
12. Perform Mutation Operator
13. Transfer the newly obtained chromosomes to the next generation.
14. Repeat the procedure for maximum number of iterations.
15. First element of the sorted population is the required solution.
16. Decode, normalize and run load flow based on the obtained solution. Calculate losses and voltage deviations.

B. Shuffled Frog Leap Algorithm (SFLA)

Shuffled Frog Leap Algorithm (SFLA) [14] is a real coded population based meta-heuristic optimization method. It mimics the mimetic evolution of a group of frogs when seeking location that has the maximum amount of available food. It is based on the evolution of memes carried out by interactive individuals and a global exchange of information between / among themselves. It combines the benefits of local search tool and mixing information from Parallel Local Searches to move toward a global solution.

C. Jaya Algorithm (JAYA)

Jaya Algorithm is a simple and powerful global optimization algorithm [12] applied to the benchmark function of constraint and unconstrained problems successfully. Here, the solution can be obtained for a given problem moving towards the best solution by avoiding the worst solution. This algorithm requires only few control parameters and does not need any other algorithm specific control parameters which require extensive tuning before conducting the actual computational experiments. Jaya algorithm is also simple to understand.

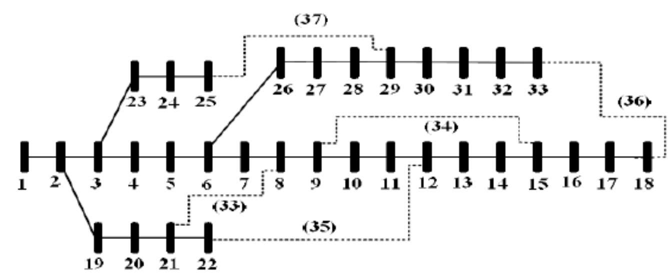

Fig. 1. IEEE 33 bus Radial Distribution System [16].

TABLE I
PARAMETERS

Algorithm Parameters		
GA	SFLA	JAYA
$P_{size} = 20$	$N_{frogs} = 20$	$P_{size} = 30$
$Ch_{length} = 8$	$N_{mem} = 4$	..
$P_e = 0.1, P_c = 0.8, P_m = 0.05$	..	..

IV. SIMULATION RESULTS

MATLAB-R2017a [18] software was utilized on a personal computer with Intel (R) core i5 processor of 4GB RAM for implementation of the proposed methods on IEEE 33 bus RDS. The data pertaining to IEEE 33 bus RDS can be accessed at [16] and the single line diagram of RDS without DGs is shown in Figure 1. Meta-heuristic algorithms are used for the Optimal placement and sizing of Multiple DGs under MATLAB environment. The total losses and voltage deviations in the test system can be minimized by integrating the DGs into the system. It can be inferred from the simulation results that JAYA algorithm is more efficient in comparison with GA and SFLA.

Algorithm 2 : SFLA for the formulated problem

1. Read Radial Distribution System data (Line data, Bus Data), SFLA parameters and DGs parameters.
2. Run the base case Load flow without DGs.
a) Compute the total line losses using equation 9
b) Compute the voltage deviations using equation 10
3. Generate Random Initial Population.
4. Start Iteration count
5. Normalize the values with defined limits of variables ($[DG_{loc}(1)....DG_{loc}(N_{dg})DG_{size}(1)....DG_{size}(N_{dg})]$)
6. Compute the system losses with new parameters
a) Update P_{load} using equation 11 and run the load flow
b) Compute total loss in the system using equation 9.
c) Compute maximum voltage deviation in the system using equation 10.
d) Define index for both objectives.
7. Compute the fitness function values for all frogs using equation 12
8. Sort the population according to fitness value in descending order as shown in below matrix

$$\begin{bmatrix} DG_{loc1}^{1} & .... & DG_{loc1}^{n} & DG_{size1}^{1} & ... & DG_{size1}^{n} \\ : & : & : & : & & \\ DG_{locm}^{1} & .... & DG_{locm}^{n} & DG_{sizem}^{1} & ... & DG_{sizem}^{n} \end{bmatrix}$$

9. Divide the population into 'M' number of memeplexes such that last solution of each memeplex is the best in the memeplex. Let us say memeplex 1 (M1) and has a population of 5

$$M1 = \begin{bmatrix} DG_{loc1}^{1} & .... & DG_{loc1}^{n} & DG_{size1}^{1} & ... & DG_{size1}^{n} \\ : & : & : & : & & \\ DG_{loc5}^{1} & .... & DG_{loc5}^{n} & DG_{size5}^{1} & ... & DG_{size5}^{n} \end{bmatrix}$$

10. Update each solution of the memeplexes w.r.t. to best solution in same memeplex;

$$New_{solution} = Old_{solution} + (local_{best} - Old_{solution}) * rand; \tag{13}$$

Now compute the fitness value. If new fitness value is greater than old fitness value then accept the new solution otherwise update the solution using equation 14

$$New_{solution} = Old_{solution} + (global_{best} - Old_{solution}) * rand; \tag{14}$$

If suitable solution is not found, then generate random solution.
11. Merge all memeplexes to form one population and sort according to fitness in descending order.
12. Repeat the procedure for maximum number of iterations.
13. Final solution of the population is the best solution.
14. Update P_{load} according to global best and run load flow
15. Compute losses and voltage deviations and compare with the losses and voltage deviations without DGs.

Algorithm 3 : JAYA algorithm for the formulated problem

1. Read Radial Distribution System data (Line data, Bus Data), JAYA parameters and DGs parameters.
2. Run the base case Load flow without DGs.
a) Compute the total line losses using equation 9
b) Calculate the voltage deviations using equation 10
3. Generate Random Initial Population.
4. Start Iteration count
5. Define the limits of DGs variables ($[DG_{loc}(1)....DG_{loc}(N_{dg})DG_{size}(1)....DGsize(N_{dg})]$)
6. Compute the system losses with new parameters values.
a) Update P_{load} using equation 11 and run the load flow
b) Compute total loss in the system using equation 9.
c) Compute maximum voltage deviation in the system using equation 10.
d) Define index for both objectives.
7. Compute the fitness function values for all population using equation 12
8. Evaluate the best and worst solutions based on the fitness values.
9. Update all solutions by using the best and worst solutions using equation 15

$$X_i^{'} = X_i + r_1 * (X_i^{best} - |X_i|) + r_2 * (X_i^{worst} - |X_i|) \tag{15}$$

10. If updated solution is better than the initial solution, then consider it as new solution; otherwise consider the initial solution.
11. Repeat the procedure till the maximum number of iterations.
12. Compute losses and voltage deviations with the new best solution. Compare it with the losses and voltage deviations without DGs.

TABLE II
COMPARISON OF LOSSES BASED ON DG_{size} AND $DG_{location}$ USING GA

N_{dg}	***1***	***2***	***3***
DG_{loc}	***12***	***31, 13***	***31, 26, 16***
$DG_{size}(MW)$	***1***	***1, 1***	***0.9725, 1, 0.6588***
$L_{wodg}(p.u)$	***0.2131***	***0.2131***	***0.2131***
$L_{wdg}(p.u)$	***0.1554***	***0.1073***	***0.0997***
$C_{Time}(Sec)$	***8.002***	***8.615***	***8.947***

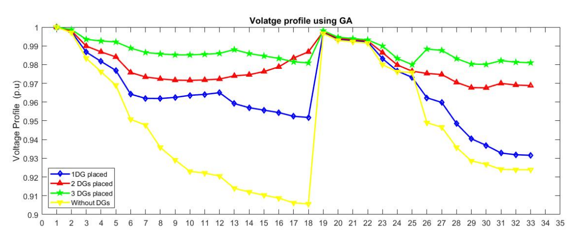

Fig. 2. Plot of Voltage profiles with integration of DGs using GA

The algorithm parameters are listed in Table I. Jaya algorithm has fewer parameters when compared to GA and SFLA. The analysis of results cited in Table II reveals that losses are minimized by integration of multiple DGs into the system using GA. The maximum voltage deviation value before integrating DGs is 0.0808 p.u. If we integrate one DG into the system the voltage deviation decreased to 0.0684 p.u. Similarly, if we integrate two DGs and three DGs, then the maximum voltage deviation decreased to 0.02297 p.u and 0.0204 p.u respectively. The voltage profiles plot with integration of DGs using GA is pictorially represented in Figure 2.

TABLE III
COMPARISON OF LOSSES BASED ON DG_{size} AND $DG_{location}$ USING SFLA

N_{dg}	***1***	***2***	***3***
DG_{loc}	***12***	***30, 12***	***15, 24, 30***
$DG_{size}(MW)$	***0.99***	***0.978, 0.970***	***0.756, 0.918, 0.855***
$L_{wodg}(p.u)$	***0.2131***	***0.2131***	***0.2131***
$L_{wdg}(p.u)$	***0.1554***	***0.1050***	***0.09072***
$C_{Time}(Sec)$	***13.03***	***16.35***	***15.74***

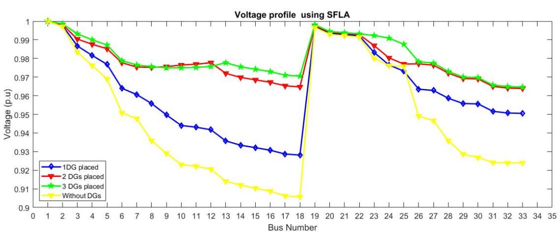

Fig. 3. Plot of Voltage profiles with integration of DGs using SFLA

The simulated results cited in Table III reveal the effect of DG integration on losses using SFLA. The maximum voltage deviation value before integrating DGs is 0.0808 p.u. If we integrate one DG into the system the voltage deviation decreases to 0.0684 p.u. Similarly, if we integrate two DGs and three DGs, then the maximum voltage deviation decreased to 0.0382 p.u and 0.0206 p.u respectively. The voltage profiles plot with integration of DGs using SFLA is pictorially represented in Figure 3.

TABLE IV
COMPARISON OF LOSSES BASED ON DG_{size} AND $DG_{location}$ USING JAYA ALGORITHM

N_{dg}	***1***	***2***	***3***
DG_{loc}	***12***	***30, 13***	***31, 24, 16***
$DG_{size}(MW)$	***1***	***0.98, 0.98***	***0.85, 1, 0.92***
$L_{wodg}(p.u)$	***0.2131***	***0.2131***	***0.2131***
$L_{wdg}(p.u)$	***0.1554***	***0.1050***	***0.0904***
$C_{Time}(Sec)$	***8.050***	***8.516***	***8.890***

Table IV represents the simulated results obtained using Jaya algorithm. If we integrate one DG into the system the voltage deviation decreased from 0.0808 p.u to 0.0584 p.u.

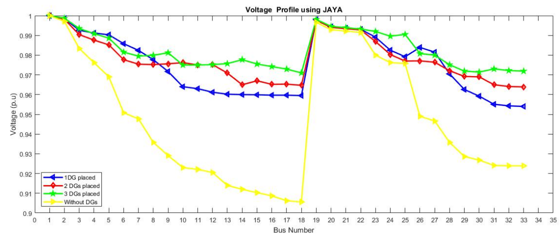

Fig. 4. Plot of Voltage profiles with integration of DGs using JAYA

Similarly, if we integrate two DGs and three DGs, the maximum voltage deviation decreased to 0.0277 p.u and 0.0203 p.u respectively. The voltage profile plot with DGs using Jaya algorithm is as shown in Figure 4. Table V shows the

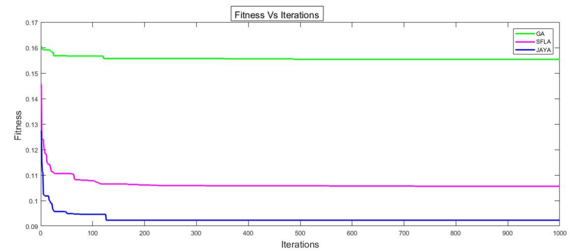

Fig. 5. Convergence plot of GA, SFLA and JAYA Algorithms

comparison of the losses and voltage deviations of GA, SFLA and Jaya algorithms. The Convergence plot of GA, SFLA and JAYA algorithms represented in Figure 5. It is clear that Jaya algorithm outperformed GA and SFLA for optimal location and sizing of multiple DGs integration into RDS.

TABLE V
LOSS AND VOLTAGE DEVIATIONS COMPARISION OF GA,SFLA AND JAYA ALGORITHMS

N_{dg}	**Losses (p.u)**			
	Without DG	***1 DG***	***2 DGs***	***3 DGs***
GA	***0.2131***	***0.1554***	***0.1073***	***0.0997***
$SFLA$	***0.2131***	***0.1554***	***0.1050***	***0.09072***
$JAYA$	***0.2131***	***0.1554***	***0.1050***	***0.0904***
N_{dg}	**Voltage deviations (p.u)**			
	Without DG	***1 DG***	***2 DGs***	***3 DGs***
GA	***0.0808***	***0.0684***	***0.02297***	***0.0204***
$SFLA$	***0.0808***	***0.0684***	***0.0382***	***0.0206***
$JAYA$	***0.0808***	***0.0584***	***0.0277***	***0.0203***

V. CONCLUSIONS

This paper investigated the impact of GA,SFLA and JAYA algorithms for multiple DG placement and sizing in radial distribution system for reduction of total losses and Voltage deviations. If we integrate multiple DGs into the system, the losses and voltage deviations are minimized. Meta-heuristic algorithms are effective in terms of saving power and improving voltage profile. However, among these Jaya Algorithm performs well compared to the SFLA and GA in terms of losses, voltage deviations and computation time. There is further chance of achieving better result by selecting a proper mix of DG technologies based on local condition and optimizing algorithms in future. In future the impact of meta-heuristic algorithms can be studied by considering multiple objectives, DGs with uncertainties and Network reconfiguration into the Distribution systems from small scale systems to very big systems. To explore this further, the impact of DGs on protection due to the uncertain behaviour of DG's such as renewable energy sources and the cost of protection may be considered in the formulation of the objective function.

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