OPTIMAL ALLOCATION OF DISTRIBUTED GENERATIONS IN RADIAL DISTRIBUTION SYSTEMS USING IDE ALGORITHMS

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Abstract

Recently distributed generations (DGs) have been integrating into the distribution networks. The size and location of DGs have important impacts on the system indices; real power losses reduction and voltage profile improvement, reliability improvement. In this research, improved DE algorithm is used for optimum allocation of DGs in radial distribution networks. The goal of this paper is to minimize power losses and improve voltage profile by the least possible injected power from DGs. To assess different iDE algorithm capabilities, simulations carried out on two IEEE 33-bus and 69-bus standard radial distribution systems.

***Index Terms*— Improved differential evolutionary algorithm, distributed generation, radial distribution systems, real power losses, voltage profile.**

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I. INTRODUCTION

Distributed Generations (DGs) are remarked usually as the generation of electricity by using small generators which are located in power distribution systems or the power load centers which are fed. The reasons for implementation of DGs have been motivated because of the different factors such as recent advances in small and efficient generation technologies, increasing interests in the environmental issues, postponing investment on new power transmission and distribution systems, and the need for more flexible and reliable electric power systems [1-3].

Many potential benefits of DGs depend on the size and site of DGs. Thus, there have been different techniques for optimal placement of DGs. To solve the DG allocation optimization problem, a mixed integer linear program was formulated. The objective function was to optimal determination of the DG [4]. Tabu Search-based method was proposed to determine the optimum solution for the DG placement problem; however, this technique has some drawbacks such as being time-consuming algorithm in addition that it is trapped in local minima [5]. An analytical expression was introduced for finding optimum size and power factor of four types of DG units. DG units are sized to reach the highest real power loss reduction in distribution networks [6]. In Ref. [7], Artificial Bee Colony (ABC) algorithm was used to find the optimum DG size, power factor, and location for minimization of the total system real power loss. A multi-objective optimization algorithm was proposed in [8], its objectives consist of minimization of costs, emission and power losses of distribution system and voltage profile improvement. This multi-objective optimization was solved by the modified Honey Bee Mating Optimization (HBMO) algorithm. Genetic Algorithm (GA)-based technique with Optimal Power Flow (OPF) calculations were utilized to determine the optimum size and location of DG units installed on the system for minimization of the cost of active and reactive power generation. Similar to TS, the GA is a time-consuming method, although it can reach near-global solutions [9].

Particle Swarm Optimization (PSO) algorithm is another optimization technique motivated by social behavior of animals such as bird flocking and fish schooling introduced first by Kennedy and Eberhart [10]. PSO and its various branches have been utilized in many power system optimization problems [11]. Differential Evolution (DE) is a simple while powerful Evolutionary Algorithm (EA) for global optimization which was introduced by Price and Storn, it has gradually become more popular and has been used in many practical cases, mainly because it has demonstrated good convergence properties and is principally easy to understand [12, 13]. In this paper, an improved DE (iDE) technique is utilized for optimal DG allocation.

Rest of the paper is organized as follows: Section II presents problem formulation and objective function. iDE Techniques for finding optimal sizes and locations of various DG sizes are included and referred in Section III. Results and Discussion of optimum DG placement on two IEEE 33-bus and 69-bus radial distribution systems are addressed in Section IV. Finally, conclusions are summarized in Section V.

II. PROBLEM FORMULATION

For solving DG allocation problem, first a power flow method should be used. The goal of a power flow calculation is obtaining complete voltage angles and magnitudes information for each bus in a power system. In this paper, power flow calculation which is forward-backward (fw-bw) method is also necessary to obtain the variation of power and voltage when some DGs are installed into the system.

A. Objective Function

Mathematically, the objective function is formulated to minimize the total real power losses as Eq. (1).

Minimize O.F.

$$O.F. = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij}(P_iP_j + Q_iQ_j) + B_{ij}(Q_iP_j - P_iQ_j) \qquad (1)$$

where, $A_{ij} = \dfrac{R_{ij}cos(\delta_i - \delta_j)}{V_iV_j}$, $B_{ij} = \dfrac{R_{ij}sin(\delta_i - \delta_j)}{V_iV_j}$

P_i and Q_i are real and reactive power injection in bus *i*. R_{ij} is the resistance between *i*th and *j*th bus. V_i and δ_i are the voltage magnitude and angle of *i*th bus. V_j and δ_j are the voltage magnitude and angle of *j*th bus.

B. Problem Constraints

In this paper, optimization problem is solved subject to several problem constraints which are given further.

Load balance: For each bus, to meet demand and supply the following equations should be satisfied.

$$P_{Slack} + \sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L$$

(2) *Voltage limits:* For each bus, there should be an upper and lower voltage bounds.

$$|V_i|^{min} \leq |V_i| \leq |V_i|^{max} \quad (3)$$

$|V_i|^{min}$=0.95 p.u. and $|V_i|^{max}$=1.05 p.u.

Active and reactive power limits of DG: To size DGs, there should be a range of available DG size.

$$Q_{DGi}^{min} \leq Q_{DGi} \leq Q_{DGi}^{max}$$
$$P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{max} \quad (4)$$

Real power loss limits: It is obvious that Total Real Power Loss should be decreased after DG installation.

$$\sum Loss_k(withDG) \leq \sum Loss_k(withoutDG) \quad (5)$$

III. OPTIMIZATION ALGORITHMS: IDE

The reason why we chose DE is for its good convergence properties. It has only a few control parameters kept fixed throughout the entire evolutionary process [14].

In general, DE algorithm has five stages. Fig. 1 shows structure of the algorithm [15].

Initialization: This algorithm is a population based algorithm, for this, initial population is produced as Eq. (6).

$$\overline{Z}_{i,k}^{G} = \overline{Z}_{L}^{MIN} + rand \times (\overline{Z}_{L}^{MAX} - \overline{Z}_{L}^{MIN})$$
$$i \in [1,P],\ L \in [1,V] \quad (6)$$

To start optimization process. Dimensions of DE algorithm depend on the size of population *P*, and variable *V*.

Where, Z_L^{MIN} and Z_L^{MAX} are lower and upper boundaries, respectively, selected based on the type of problem. *rand* produces a value in [0,1], randomly.

Mutation: The initialized population is mutated using Eq. (7). Mutation operator helps algorithm to escape from local minima. For this, three vectors are randomly selected from initial population called Z_1, Z_2 and Z_3. Main criterion in production of mutated matrix is scaling factor, *F*, which is selected from [0, 2]. The impact of 2nd and 3rd selected vectors, Z_2 and Z_3, in mutation process are controlled by *F*,

$$\overline{Z}_{m,i}^{G+1} = \overline{Z}_1^G + F(\overline{Z}_2^G - \overline{Z}_3^G) \quad (7)$$

Crossover: By crossover operator, prior population (parent) is composed and then produces next population (children). Crossover operator is not applied on all population, and applying criteria is Crossover Rate, *CR*. This parameter has a real value in [0, 1]. If crossover rate is more than a random value, vectors from mutation step are selected; otherwise, selection is performed from initial population,

$$\overline{Z}_{c,ji}^G = \begin{cases} \overline{Z}_i^{G+1} & if\ \alpha_j \le CR\ or\ j=\gamma \\ \overline{Z}_i^G & otherwise \end{cases},\ i=1,\dots,P;\ j=1,\dots,V \quad (8)$$

where, α_j and γ are chosen randomly from $[1,\dots,V]$.

Selection: In this stage, the algorithm uses selection operator to select optimal solution. In other words, selection operator decides between initial matrix, Z_i, and crossover matrix, Z_{ji}. If related solution of crossover vector, $f(Z_{c,i}{}^G)$, is less or equal to solution corresponding to initial population, $f(Z_i{}^G)$, crossover vector is selected which is shows in Eq. (9),

$$\overline{Z}_i^{G+1} = \begin{cases} \overline{Z}_{c,i}^G & if\ f(\overline{Z}_{c,i}^G) \le f(\overline{Z}_i^G) \\ \overline{Z}_i^G & otherwise \end{cases}\ i=1,\dots,P \quad (9)$$

Termination Criteria: To terminate algorithm, there are two techniques; reaching optimal solution and finishing iteration number. In optimization problem, second criterion is used.

```
import values of population size, generation, variable number.
 while termination criteria is satisfied
  {
    for i=1 to NP; i++
     {
       selection three vector from population randomly;
          U_i(mut)^(G) = U_a^(G) + SF(U_b^(G) - U_c^(G))
          for j=1 to VN; j++
           {
             if rand(0,1)<CR
                U_ji(cross)=U_(mut)
             else
                U_ji(cross)=U_ji
           } % End of crossover operator
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```
%start selection operator
if f(U_i(cross)) ≤ f(U_i)
  U_i = U_i(cross)
else
  U_i = U_i
% End for selection operator
}
} %End while
```

Fig. 1. Structure of simple DE algorithm

IV. RESULTS AND DISCUSSION

iDE aalgorithm has been implemented in the MATLAB software for optimal sitting and sizing of DGs and tested on two standard IEEE 33-bus and 69-bus radial distribution systems.

A. IEEE 33-bus radial distribution system

The first system is a radial distribution system with the total load of 3.72 MW, 2.3 *MVar*, 33 bus and 32 branches, the real power losses in the system is 210.98 *kW* while the reactive power losses is at 143 *kVar* [16].

For single-DG placement, it was assumed that maximum DG size is less/equal to 1250 *kW* (Table 1). As it can be seen from results in Table 1, the minimum real power loss is achieved by iDE algorithm. The maximum real power loss reduction by iDE is at 39.70% in comparison to the case without DG installation. However, this solution not leads to the best voltage profile because the main purpose is to minimize real power loss. PSO has better results for voltage profile, since it propose a DG near the lowest bus voltage (bus 18).

TABLE I. SINGLE DG PLACEMENT RESULTS IN IEEE 33-BUS SYSTEM

Technique	DG Installation		Power Loss		Bus Voltage	
	Total Size (kW)	*@ bus*	*Value (kW)*	*Decline (%)*	*Min. (p.u.)*	*Mean (p.u.)*
Without DG	-	-	210.98	-	0.9038	0.9453
PSO	1210	13	129.53	38.60	0.9348	0.9712
iDE	1212	8	127.17	39.70	0.9349	0.9635

For double and triple-DG placement it was assumed that maximum DG size is less/equal to 2000 *kW* (Table 2). The minimum real power loss is achieved again using iDE algorithm which the reduction is at 54.53% in comparison to the case without any DG installation. It is obvious that the more the DG size and DG number, the more is the benefits.

TABLE II. DOUBLE-DG PLACEMENT RESULTS IN IEEE 33-BUS SYSTEM

Technique	DG Installation		Power Loss		Bus Voltage	
	Size (kW)	*@ bus*	*Value (kW)*	*Decline (%)*	*Min. (p.u.)*	*Mean (p.u.)*
Without DG	-	-	210.98	-	0.9038	0.9453
PSO	550	15	106.24	49.64	0.9467	0.9667
	621	30				
iDE	1227	13	95.93	54.53	0.9651	0.9819
	738	32				

Studying results in Table 3 reveals that iDe could gain better results compared to the PSO technique in real power loss reduction, by reducing real power loss to 56.13%. In addition, iDE could improve voltage profile better than the PSO technique. It should be mentioned that the size and number of DGs are very important in power loss reduction, and in particular for voltage profile improvement.

TABLE III. TRIPLE-DG PLACEMENT RESULTS IN IEEE 33-BUS SYSTEM

Technique	DG Installation		Power Loss		Bus Voltage	
	Size (kW)	*@ bus*	*Value (kW)*	*Decline (%)*	*Min. (p.u.)*	*Mean (p.u.)*
Without DG	-	-	210.98	-	0.9038	0.9453
PSO	846	16	94.02	55.43	0.9528	0.9758
	384	26				
	499	30				
iDE	681	10	92.55	56.13	0.9654	0.9829
	600	18				
	719	31				

B. IEEE 69-bus radial distribution system

The second test system is the IEEE 69-bus radial distribution system with the total load of 3.80

MW and 2.69 *MVar*. Data for this system are as in [16]. Results are furnished in Table 4 which is evaluated for three DG units placement.

The optimum results for each DE technique are obtained with population size of 30, after 30 runs, CR=0.1 and for power factor of 0.85 lagging (Table 4).

TABLE IV. SINGLE DG PLACEMENT RESULTS IN IEEE 69-BUS SYSTEM

Technique	DG Installation		Power Loss		Bus Voltage	
	Size (kW)	***@ bus***	***Value (kW)***	***Decline (%)***	***Min. (p.u.)***	***Mean (p.u.)***
Without DG	-	-	224.89	-	0.9092	0.9734
iDE	603	17	117.16	47.90	0.9402	0.9874
	634	52				
	662	60				
PSO	842	6	125.86	44.03	0.9405	0.9812
	901	59				
	601	63				

As it can be seen from Table IV, the DE technique can obtain acceptable results compared to PSO technique. This is because DE techniques have good convergence properties. All of the three DE techniques reduced real power losses more than 40% with DG sizes less than 2000 *kW*. While, PSO techniques do this with more DG sizes.

V. CONCLUSIONS

In this paper improved DE technique was employed for optimal sitting and sizing of the DGs. It is obvious that both PSO and DE techniques have reached acceptable results, and because of good convergence properties, iDE technique could reach better results.

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