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Research Article

OPTIMAL INTEGRATION OF DISTRIBUTED GENERATION IN RADIAL DISTRIBUTION SYSTEM USING PARTICLE SWARM OPTIMIZATION TECHNIQUE

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ABSTRACT

Fossil fuel depletion, electricity demand increment, and environmental degradation shift the power system network to adopt distributed generation (DG) at local distribution system. The optimal integration of distributed generation witnesses many benefits such as reduce power losses, increase voltage profile and stability of the system etc. However, the non-optimal integration may deteriorate the existing operation. Therefore, this paper presents the methodology to optimally integrate the distributed generation in the radial distribution system. The main aim is to reduce the power losses and improve the voltage profile using particle swarm optimization technique. The proposed technique is implied on benchmark IEEE 69 bus system. The proposed technique is also compared with many optimization algorithms. The overall results show that the proposed method gives better results as compared to other literature algorithms.

Keywords: power loss reduction; particle swarm optimization; distributed generation.

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1. INTRODUCTION

Among many technical challenges, the power loss reduction and voltage profile, improvement remain the essential aspects in the radial distribution system [1-3]. It is due to fact that the distribution system poses high resistance to reactance ratio, which engenders more power losses and voltage drop as compared to the transmission system [4]. Besides, the maximum penetration of renewable generation will increase more power losses as compared to existing one. The voltage control devices in traditional distribution system work in a sense that the voltage magnitude will decrease along the feeder, as starting from the substation to the customer's end. However, the integration of DG deviates the distribution system from one-direction to bidirectional and it is expected that power may flow in reverse direction and cause the voltage magnitude and voltage stability to overshoot or undershoot over the safe limit. Therefore, the power loss minimization and voltage profile improvement are very important factors for power quality and stability of distribution system.

In literature, many optimization algorithms such as analytical methods, heuristic methods, and meta-heuristic methods have been incorporated for optimal DG integration. Among them, the analytical expressions are not capable to handle the large and complex system [5]. Many heuristics and meta-heuristic optimization algorithms have also been proposed. These algorithms includes genetic algorithm (GA) [6], bat algorithm (BA) [7], artificial bee colony optimization algorithm (ABC) [8], back-tracking and fuzzy expert [9], bacterial foraging optimization algorithm (BFOA) [10, 11], big-bang big crunch method [12] and imperialist competitive algorithm GA [13]. The overall aim is to optimally integrate the distributed generation in the distribution system, so that maximum remuneration in terms of power loss reduction and voltage profile improvement can be obtained. However, in this paper, a new methodology is presented to optimally integrate the distributed generation using particle swarm optimization method.

Moreover, the rest of paper is organized as Section 2, presents the problem formulation, Section 3 presents the particle swarm optimization method, Section 4 shows the results and discussion and Section 5 concludes the research outcomes.

2. PROBLEM STATEMENT

In this paper main objective is set as minimization of real power loss of the radial distribution system with following constraints. The power loss, voltage, and other parameters are found using backward forward load flow analysis, detail given in [20]. The objective function can be mathematically described as in Equation (1).

$$Min\ f = min\ (P_{loss}) \qquad (1)$$

where Ploss is the active power losses of the radial bus system.

2.1 Constraints

The equality and inequality constraints are given in Equation (2) – Equation (5).

a. Equality Constraints

The bus real and reactive power is limited to:

$$P_{DG,M} = P_{loss} + \sum P_{D,M} \qquad (2)$$

$$Q_{DG,M} = Q_{loss} + \sum Q_{D,M} \qquad (3)$$

where PDG,M, and QDG,M are the real and reactive power injection by DG at bus M. ∑ PD,M and ∑ QD,M is the total real and reactive power at bus M. According to these constraints, the real and reactive power injection at bus M must be equal to actual real power demand at that node and power losses of that node.

b. Inequality Constraints:

Position of DG:

$$2 \leq DG_{position} \leq N_{buses} \qquad (4)$$

Voltage at load bus:

$$V_{min} \leq V \leq V_{max} \qquad (5)$$

V_{min} and V_{max} are minimum and maximum voltage at bus *M*.

3. PARTICLE SWARM OPTIMIZATION TECHNIQUE

The optimal integration of distributed generation in the radial distribution system is carried out using particle swarm optimization method. The PSO algorithm is a stochastic optimization technique introduced by [23]. This algorithm is basically inspired by social behavior of living things such as birds flocking and fish schooling. This algorithm works in a sense that supposes v and s in search space are the velocity and position of the particle. Each particle in the whole population (or swarm) moves to words its best position with velocity v. Each particle's velocity closes to pbest and gbest is calculated by Equation (6). Each particle's current position is updated by Equation (7). The complete flow chart of the proposed method is given in Figure 1.

$$v_{id}^{k+1} = \omega \times v_{id}^{k} + c_1 \times rand() \times \left(pbest_{id} - v_{id}^{k} \right) + c_2 \times rand() \times \left(gbest_{d} - v_{id}^{k} \right) \quad (6)$$

$$S_{id}^{k+1} = S_{id}^{k} + v_{id}^{k+1}, i = 1, 2, \ldots..n, \; d = 1, 2 \ldots, m \quad (7)$$

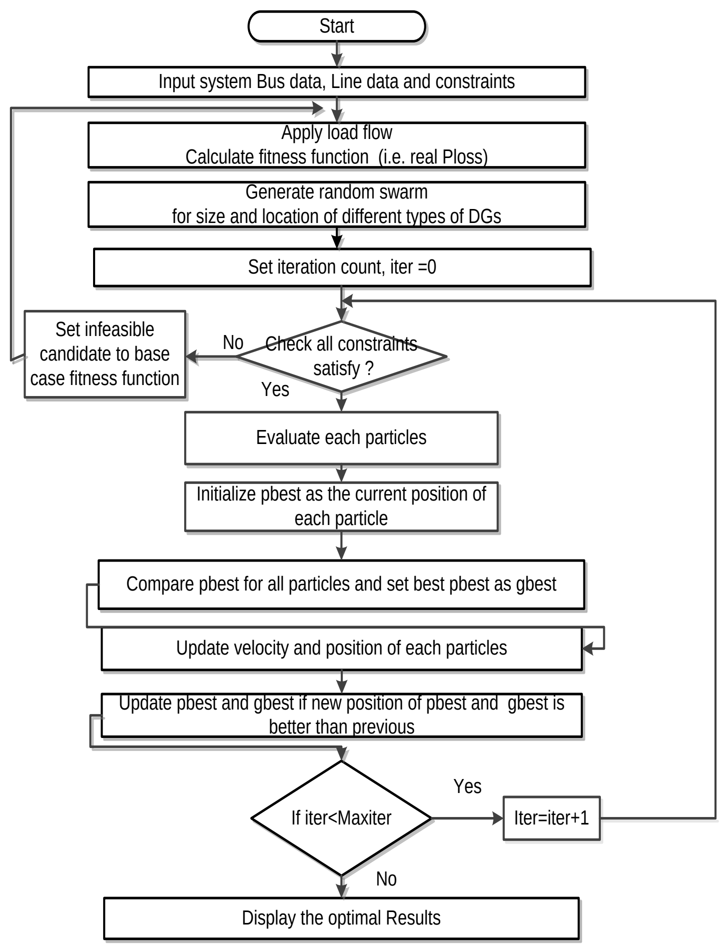

Fig. 1. Flow chart for optimal DG configuration using single objective PSO optimization method

4. RESULTS AND DISCUSSION

To evaluate the performance of the proposed method, in this paper three case studies are performed. Case study 1, the only active power DGs are introduced, whereas in case study 2, only reactive power DGs are connected. Case study 3 representing both type of DGs i.e. simultaneous placement of active and reactive power DG. Furthermore, in each case study, one to three number of DG units were connected to realize the optimal efficiency. All three case studies are implemented on benchmark IEEE 69 bus system. Figure 2 shows the one-line diagram of IEEE 69 bus system.

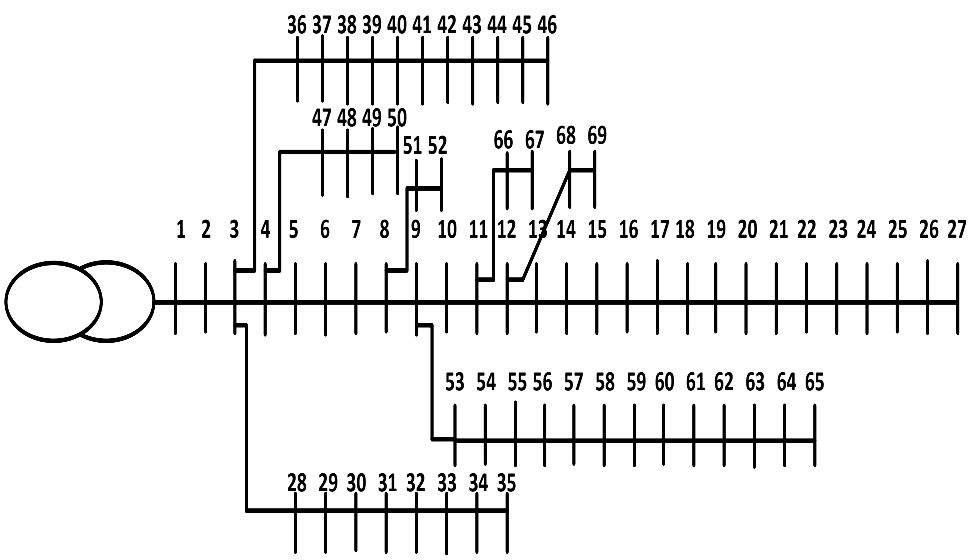

Fig. 2. IEEE 69 radial distribution system

The total real and reactive power demand is 3802 kW and 2694 kVAr respectively. The bus and line parameters are taken from [24-25]. The base case power losses, DG types and numbers and optimal location and size are mentioned in Table 1.

Table 1. Location and size for IEEE 69 bus with objective function values

DG type	DG Nos	DG location	DG size (MW)	Ploss (kW)	Ploss Reduction (%)
Base case	--	--	--	224.78	--
Type-1	1 DG	61	1.8695	83.171	63.01
	2DG	18,61	0.54113,1.7893	71.600	68.16
	3 DG	18,11,60	0.3772,0.4910,1.7245	69.400	69.14
Type-2	1 DG	61	1.86956	152.00	32.41
	2 DG	61,15	1.1878,0.3525	146.80	32.72
	3 DG	61,22,11	1.3029,0.2495,0.3836	145.30	35.39
Type-3	1-1 DG(P)	61	1.82826	23.20	89.68
	1-1 DG(Q)	61	1.24681		
	2-2 DG(P)	61,24	1.70834,0.47481	13.40	94.04
	2-2 DG(Q)	69,61	0.035124,1.44839		
	3-3 DG(P)	68,24,61	0.7251,0.100,1.6593	12.40	94.48
	3-3 DG(Q)	69,02,63	0.5834,1.5876,1.01653		

It can be seen that with maximum (3) number of DG integration of type-1, type-2, and type-3, the power loss is improved up to 69.14 percent, 35.39 percent and 94.48 percent respectively. Similarly, in this case, it can be concluded that the results with the integration of type-III DG gives better performance as compared to type-I and type II. Moreover, Table 2 presents the comparisons of one, two and three number of DG unit (s) of type-I, with other optimization algorithm such as MTLBO [14] and with ACO-ABC [15].

Table 2. Comparison of PSO optimization algorithm for IEEE 69 bus with one parameter (using only type-1 DG)

No. of DGs	Method	DG location	DG size (MW)	Total DG capacity (MW)	Ploss
1 DG	Proposed Algorithm	61	1.86956	1.8695	83.171
	ACO-ABC [15]	61	1.87260	1.8726	83.189
	MTLBO [14]	61	1.81970	1.8197	83.323
2 DGs	Proposed algorithm	18	0.5411	2.330	71.60
		61	1.7893		
	ACO-ABC [15]	18	0.5309	2.3127	71.657
		61	1.7818		
	MTLBO [14]	17	0.5197	2.2517	71.776
		61	1.7320		
3 DGs	Proposed algorithm	18	0.3772	2.5927	69.400
		11	0.4910		
		61	1.7245		
	ACO-ABC [15]	11	0.5597	2.6224	69.429
		21	0.3468		
		61	1.7159		
	MTLBO [14]	11	0.4938	2.5447	69.539
		18	0.3720		
		61	1.6725		

It can be observed that with the use of 1 DG unit, the placement of DGs by both algorithms ACO-ABC [15] and MTLBO [14] is same. However, the size of DG is different. The analysis further states that the proposed method gives better result in loss reduction and DG capacity compared to ACO - ABC [15] and MTLBO [14] algorithms. Similarly for 2 DG units and 3 DG units, the performance of proposed algorithm is better in terms of loss reduction. Moreover, the voltage profile is the main parameter of the radial distribution system. The voltage profile of each node defines the performance of the system. Optimal placement and sizing of DG increase the voltage profile of each bus of the system. The results of both parameters for IEEE 33 bus are depicted in Table 3.

Table 3. The voltage profile for IEEE 69 bus system

DG Type	**DG Nos**	**Voltage (p.u)**		**Rise (%)**
		Min	Max	
	Base case	0.9090 @ 65	1.00 @ 1	
Type-1 DG	1 DG	0.9778 @ 65	1.00 @ 1 & 2	7.03
	2 DG	0.9782 @ 65	1.00 @ 1 & 2	7.07
	3 DG	0.9789 @ 65	1.00 @ 1,2 & 3	7.14
Type-2 DG	1 DG	0.9303 @ 65	1.00 @ 1	2.28
	2 DG	0.9309 @ 65	1.00 @ 1	2.35
	3 DG	0.9399 @ 65	1.00 @ 1	3.28
Type-3 DG	1 DG	0.9960 @ 65	1.00 @ 1,2,3,28 & 36	8.73
	2 DG	0.9976 @ 65	1.00 @ 1, 2, 3, 28 & 36	8.88
	3 DG	0.9984 @ 65	1.00 @ 1,2,3,4,28 & 36	8.95

The base case voltage profile values for IEEE 69 bus is 0.9090 p.u at bus 65 before installing the DG. However, it can be seen that with the installation of type-1 DG, the voltage profile can be improved up to 0.9789 p.u. which is 7.14 percent. With the installation of type-2 DG it can be improved up to 0.9399 p.u which is 3.28 percent and with the installation of type-3 DG, it can be improved up to 0.9984 p.u which is 8.95 percent respectively. Moreover, this paper is set for optimization of power loss minimization and it is worth noting in Figure 3, and 4 that the proposed method satisfies the voltage constraints for each bus of the system.

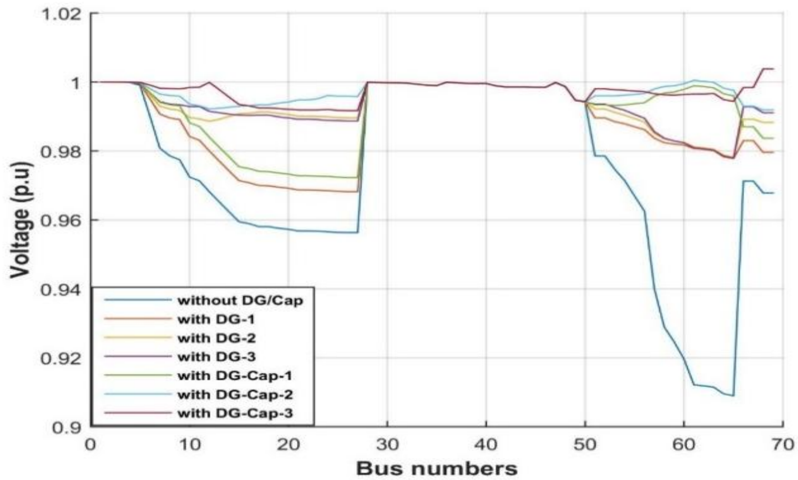

Fig. 3. Voltage profile for 69 bus with type-II & type-III DG

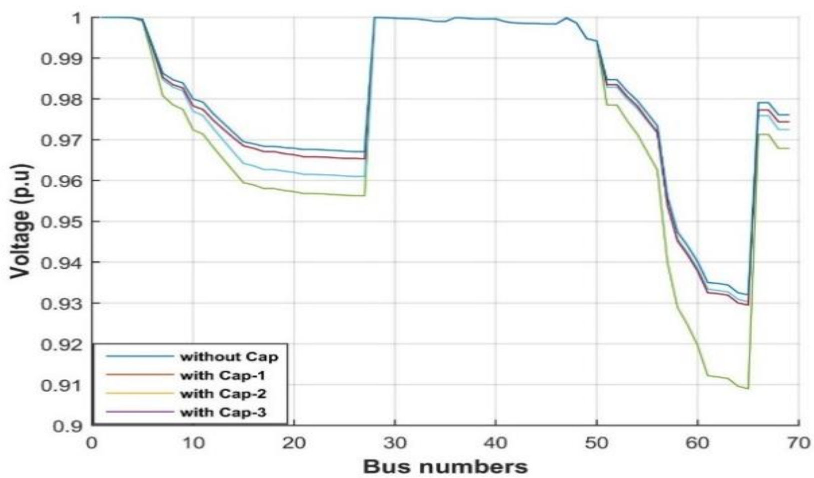

Fig. 4. Voltage profile for 69 bus with type-II

Before adding the distributed generation sources in both IEEE IEEE 69 bus system, the substation bus has highest voltage profile as 1.00 p.u. However, bus 65 has lowest voltage profile. After integrating DG, it can be seen that the type-1 and type 3 (active power and the combination of active power with capacitor) increase more voltage as compared to only type-2 DG. The overall analysis shows that the voltage profile of this proposed methodology for optimal placement and sizing is better as compared to many algorithms as cited in this paper.

5. CONCLUSION

This paper presents the power loss reduction in radial distribution system using particle swarm optimization method. Three different types of distributed generation along with one to three numbers of DG units were used to realize the actual performance of the distribution system. The proposed methodology is tested on benchmark IEEE 69 bus system. The overall result concludes that the proposed methodology is giving better results as compared to other literature algorithm which is cited in this paper. Moreover, the type-3, simultaneous placement, and sizing of active power and reactive power DG have more effective as compared to type-1 and type-2. Furthermore, the proposed methodology has also satisfied the voltage constraints, which is a very important factor for the distribution system.

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