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Power Loss and Voltage Deviation Reduction in Radial Distribution Systems Using Optimum Allocation of Distributed Generations

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Abstract: This study addresses distributed generation allocation for power loss and voltage deviation reductions in distribution systems. To reach the mentioned benefits determining the optimal capacity and location of the DGs is important. Since problem formulation includes several individual objectives, hence an optimization algorithm i.e., Improved Particle Swarm Optimization (IPSO) algorithm is used to allocate muli-DG units in radial distribution systems. To verify the effectiveness of the proposed algorithm in finding best solutions, IEEE 33 bus standard system and a 22 bus practical system of Tehran City are selected. Simulation results indicate the efficacy of the proposed algorithm in DG sizing and sitting.

Key words: Distributed generation, improved particle swarm optimization algorithm, voltage deviation, power loss, radial distribution system

INTRODUCTION

DG penetration into distribution systems has been increased in the world. The major reasons can be the liberalization of electricity markets, constraints on building new transmission and distribution lines and environmental concerns (Singh and Misra, 2007; Ackermann *et al*., 2001). Technological advances in small and effective generators, power electronics and energy saving devices for transient backup have also accelerated the integration of DG into electric power distribution networks (Marwali *et al*., 2007).

It is clear that any loss reduction is profitable to distribution utilities and also for customers. Power loss reduction is therefore the most important factor which should be considered in planning and operation of DGs (Singh and Verma, 2009; Ochoa *et al*., 2008). For instance, multi-objective index for performance calculation of distribution systems for single-DG size and location planning has been proposed (Singh and Verma, 2009). For this analysis, the active and reactive power losses receive significant weights of 0.40 and 0.20 respectively. The current capacity receives a weight of 0.25, leaving the behavior of voltage profile at 0.15. Also, providing high reliability for the customers is of great importance.

In a radial distribution feeder, depending on the technology, DG units can deliver a portion of total real and/or reactive power to loads so that the feeder current reduces from the source to the location of DG units. However, it has been indicated that if DG units are inappropriately allocated and sized, the reverse power flow from larger DG units can lead to higher system losses (Acharya *et al*., 2006; Atwa *et al*., 2010). Hence, to minimize losses, it is of great importance to find the best location and size of the DG units.

Optimization techniques are extensively utilized for the best sizing and sitting of DG units. There are many approaches for deciding the optimum size and location of DG units in distribution systems. The optimum locations of DG were determined in the distribution network (Thong *et al*., 2007; Gandomkar *et al*., 2005; Keane and O'Malley, 2006).

In some research, the optimum location and size of a single DG unit is determined, while in others the optimum locations and sizes of multiple DG units are determined (Al Hajri *et al*., 2007; El-Khattam *et al*., 2009). A Particle Swarm Optimization (PSO) algorithm was introduced to determine the optimum size and location of a single DG unit for minimizing the real power losses of the system. PSO was used to place multiple DG units with non-unity power factor, but the objective was to minimize only the real power loss of the system (AlHajri *et al*., 2007).

In this paper for optimum sizing and sitting of multi-DG units, an improved branch of PSO will be used. PSO which first was introduced by Kennedy and Eberhart (1995) is one of the modern population based heuristic algorithms. It has a flexible and well-balanced mechanism to enhance the global and local exploration abilities in many fields (Shayeghi *et al*., 2010; Zebardast *et al*., 2011;

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Robinson *et al*., 2004; Yang *et al*., 2007), will be utilized and obtained results will be compared with that of have been reached using new and advanced techniques.

The improved algorithm is used for power loss reduction and reliability enhancement. In section two, problem formulation is given. In section three the optimization algorithm is introduced and in section four simulation results and discussion are put. Finally, in section five a conclusion will be given.

METHODOLOGY

Problem formulation: The main goal of the proposed algorithm is to determine the optimum location and size of DG units by minimizing different functions related to study aims as a unified objective function. In this study, following three goals are pursued. The goals are loss reduction, reliability improvement and achieving the formers with the minimum DG size. These individual objectives should be composed with constraints to obtain the proper objective functions. The overall objective function composing constraints and goals is as:

$$\begin{aligned} &Minimize \quad J = \sum_{m=1}^{3} k_m . J_m \\ &k_m \in [0,1] \quad = \sum_{m=1}^{3} k_m = 1 \end{aligned} \tag{1}$$

where, k_m are weighting factors assigned to each objectives which in this study are considered K_1 = 0.40, K_2 = 0.35, K_3 = 0.25 for power loss, reliability and DG size, respectively.

Power loss: Power loss in distribution system is as the most important objective. Here, power loss will be one of the individual objectives given by:

$$\begin{aligned} &P_L = \sum_{i=l}^{n}\sum_{j=l}^{n} A_{ij}\left(P_i P_j + Q_i Q_j\right) + B_{ij}\left(Q_i P_j + P_i Q_j\right) \\ &J_1 = \frac{P_{loss,i}}{P_{loss,base}} \end{aligned} \tag{2}$$

In which,

$$A_{ij} = \frac{R_{ij}\cos\left(\delta_i - \delta_j\right)}{V_i V_j}, B_{ij} = \frac{R_{ij}\sin\left(\delta_i - \delta_j\right)}{V_i V_j}$$

Here,
$P_{loss,I}$ = value of P_{loss} for *ith* particle after DG installation and $P_{loss,base}$ is initial $P_{loss.}$

Reliability of costumers: Reliability of customers is included in objective function as Expected Energy Not Supplied (EENS):

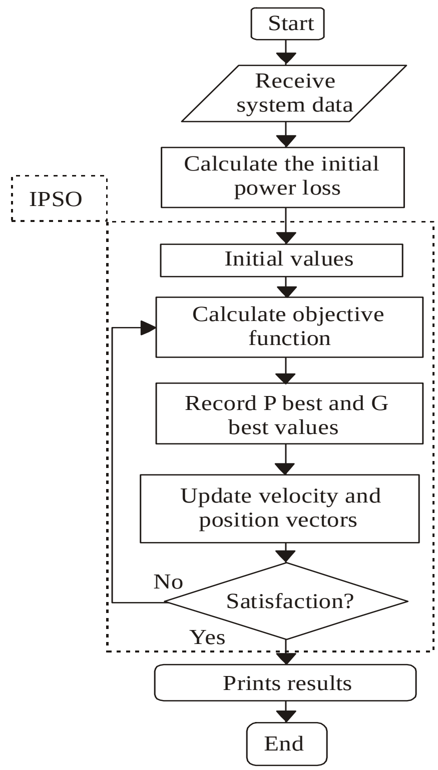

Fig. 1: The problem solving procedure using the proposed algorithm

$$\begin{aligned} &EENS = \sum_{i=1}^{N_p} EENS_i = \sum_{i=1}^{N_p} L_i \sum_{i=1}^{N_c} ri_j \, \lambda i_j \\ &J_2 = \frac{EENS_i}{EENS_{base}} \end{aligned} \tag{3}$$

N_c = Elements which their interruptions result in failure
N_p = Total number of network load points
λ_{ij} = Failure rate of *jth* costumer as the interruption in *ith* element
r_{ij} = Average repair time
L_i = Average loads of *ith* load point
$EENS_i$ = Expected energy not supplied for *ith* particle after DG installation
$EENS_{base}$ = Expected energy not supplied before DG installation

Figure 1 illustrates the implemented methodology for DG allocation.

DG installation cost: To allocate minimum DGs on optimization, DG size (or cost) is considered as another objective as:

$$J_3 = \frac{\sum_{j=1}^{m} P_{DGi,j}}{\sum_{j=1}^{N_p} P_{load,j}} \quad (4)$$

P_{DGi} = Installed power in *jth* bus for *ith* particle
m = Number of suggested DGs
$P_{load,j}$ = Active power of *ith* load point

Problem constraints: There are some constrains and in problem solving as follows:

Power balance:

$$P_{Slack} + \sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L \quad (5)$$

Active and reactive power limitations of DG:

$$\begin{aligned} Q_{DGi}^{\min} \le Q_{DGi} \le Q_{DGi}^{\max} \\ P_{DGi}^{\min} \le P_{DGi} \le P_{DGi}^{\max} \end{aligned} \quad (6)$$

Power loss limitations:

$$\sum Loss_k\,(withDG) \le \sum Loss_k\,(withoutDG) \quad (7)$$

Bus voltage limitations:

$$\left|V_i\right|^{\min} \le \left|V_i\right| \le \left|V_i\right|^{\max} \quad (8)$$

Bus current limitations:

$$\left|I_i\right| \le \left|I_i\right|^{\max} \quad (9)$$

Optimization algorithm:

Standard PSO: PSO is a population-based intelligent searching algorithm. It has excellent performance in searching for the global optimum. PSO resembles the social behavior of birds or fish when they find food together in a field.

The performance of this evolutionary algorithm is based on the intelligent movement of each particle and collaboration of the swarm. The improved standard version of PSO, in this study, such that each particle starts from a random location and searches the space with its own best knowledge and the swarm's best experience. The search rule can be expressed by simple equations with respect to the position vector $X_i = [x_{i1}, \ldots, x_{in}]$ and the velocity vector $Vi = [v_{i1}, \ldots, v_{in}]$ in the *n*-dimensional search space as:

$$\begin{aligned} v_i^{k+1} = \omega v_i^k + c_1 r_1\left(XPbest_i^k - X_i^k\right) + \\ + c_2 r_2\left(XGbest^k - X_i^k\right) \end{aligned} \quad (10)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1},\ i = 1, 2..., n \quad (11)$$

$$\omega = \omega_{\max} - \frac{\omega - \omega_{\max}}{iter_{\max}} \times iter \quad (12)$$

where, i, k and $iter_{max}$ are the particle, the iteration index and the number of total iterations, respectively; v_i^k and x_i^k are the velocity and position vectors of particle i at iteration k, respectively; ω is no more a constant value rather for which $\omega \geq 0$ is defined as inertia weight factor. Empirical studies of PSO with inertia weight have shown that a relatively large ω have more global search ability while a relatively small ω results in a faster convergence; c_1 and c_2 are individual and swarm acceleration constants, respectively set to 2.0; r_1 and r_2 are random numbers in [0, 1]; and $Pbest_i^k$ and $Gbest^k$ are the best positions that particle i has achieved so far based on its own experience and the swarm's best experience, respectively.

Power loss and reliability calculation: To calculate the power loss, common backward forward (Bw-Fw) power flow is utilized, also, for the customers' reliability, EENS is calculated. So to do this, just a breaker is used after source for both test systems and there is no other protection device such as fuses, reclosers and etc.

NUMERICAL RESULTS

In this study, four DG types; 500, 750, 1000 and 1500 kW was the available size of DGs in this paper. The proposed methodology is tested on IEEE 33 bus radial distribution system and a 22 bus practical system.

IEEE 33 bus radial distribution system: This test system is depicted in Fig. 2 (Kashem *et al*., 2000).

Table 1 presents the results of the optimal sizes and locations of DG units by various techniques (Hung *et al*., 2011; Padma Lalitha *et al*., 2010; Falaghi and Haghifam, 2004). For multiple DG units, improved PSO achieves a loss reduction of 65.00% in comparison to the without DG installation while the best of the other techniques i.e., Improved Analytical method could just enhance (IA) at 61.50%. Also for the Bus voltage this algorithm could increase the voltage min. and mean about 0.7 and 0.4 in per unit which are considerable values.

In general, for this system, improved PSO method can leads to an optimum or near optimum solution for multiple DG units. It should be noted that for comparison

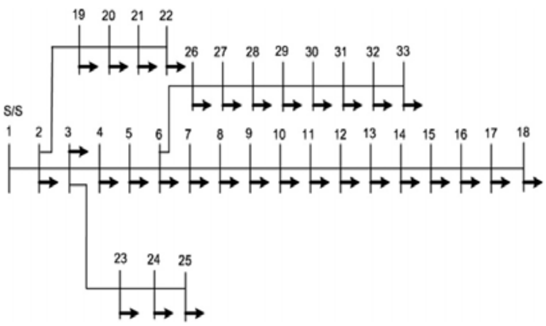

Fig. 2: IEEE 33 bus test system

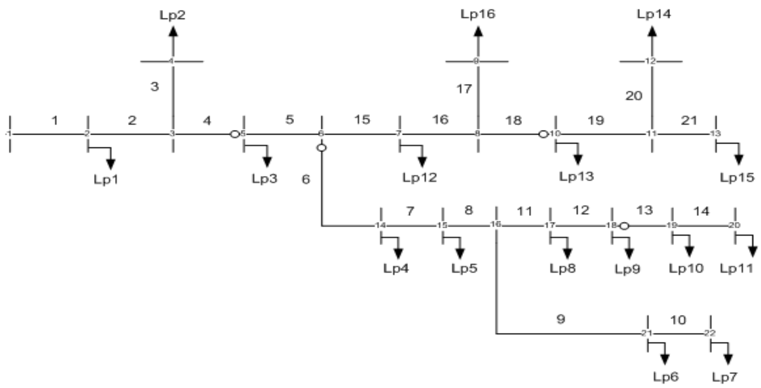

Fig. 3: 22-bus practical system

Table 1: DG placement by various techniques for 33-bus system

	DG installation			Bus voltage (p.u.)	
Technique	@ bus	Size (kW)	Ploss (kW)	Min	Mean
Without DG	-	-	211.20	0.9037	0.9430
ABC algorithm	(6)(15)	2500	89.96	0.9510	0.9696
PSO	(8)(15)(32)	2000	88.99	0.9534	0.9717
LSF	(18)(25)(33)	2430	85.07	-	-
IA	(6)(12)(31)	2520	81.05	-	-
Improved PSO	(8)(16)(24)(32)	3000	75.39	0.9812	0.9893

Table 2:DG placement by various techniquesforAfsarie-Tehran 22 bus system

	DG installation			Bus voltage (p.u.)	
Technique	@ bus	Size (kW)	Ploss (kW)	Min	Mean
Without DG	-	-	168.76	0.8869	0.9131
PSO	(13)(18)	1250	50.00	0.9535	0.9625
Improved PSO	(12)(17)	1500	44.54	0.9632	0.9700

on power loss, although DG sizes are slightly more for the used techniques however this could be neglected for the achieved benefits.

33 Bus practical system (Falaghi and Haghifam, 2004): Single line diagram of the system is shown in Fig. 3, other required data are in study of Falaghi and Haghifam (2004). Table 2 presents the results of the optimal sizes and locations of DG units. For multiple DG units, improved PSO achieves a loss reduction of 74.00 and 11.00% compared without DG and standard PSO, respectively. Also, bus voltage values increased significantly, i.e., improved PSO could raise the Mean value about 0.06 in per unit. About reliability, the values of EENS were 40000, 24983 and 18975 in *kWh/yr* for no DG, PSO and DAPSO, respectively. The improvements were 52.56 and 24.04% with improved PSO in comparison to without DG and PSO.

For reliability evaluation, simulation results show that the EENS values, as an index of reliability, were 14532 (kWh/year), 10689 (kWh/year) and 9038 (kWh/year) for no DG, PSO method and improved PSO method, respectively. It can be inferred that improved PSO method could increase about 15.5 and 38% the reliability of the costumers supply in comparison to the no DG and PSO method.

CONCLUSION

In this study, power loss and reliability analysis was performed using improved PSO method for multiple DG allocation. This method is improved and developed standard PSO for finding the size of different DG sizes and the best location for DG allocation. The number of DG units from the appropriate sizes and locations can reduce the losses to a considerable amount. Given the choice, DG(s) should be allocated to enjoy other benefits as well such as loss reduction. In this study, impact of DGs sitting and sizing on power loss and reliability were evaluated.

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