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Optimum Allocation of Distributed Generation using PSO: IEEE Test Case Studies Evaluation

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Abstract

Distributed Generation (DG) integration and renewable energy utilization in distribution networks have become more attractive as one of the promising ways in the transition of existing grid to advance future distribution network. In power system, especially in distribution network, DGs are able to reduce the total power losses which have significant impact on environmental pollution. In distribution network, DGs need to be optimally situated to avoid any unwanted risks such as voltage rise and losses increment. This paper aimed to perform the optimum allocation of integrated DG that resulted in the best possible operation of distribution network. In this paper, objective function was considered as an integer and discrete problem that was formulated with different objective functions and constraints. This paper proposed Particle Swarm Optimization (PSO) to ascertain the minimum value of the defined objective functions. The IEEE 37 bus test system was examined as a test case to demonstrate the effectiveness of the proposed approach on the total power losses reduction and voltage profile improvement.

Keywords: DG Allocation, Distribution Network Planning, PSO.

INTRODUCTION

Distributed Generations (DGs) are small generators that are often integrated into the distribution network, providing the electricity locally to load customers [1]. DG impact on distribution networks is important and needs to be well acknowledged to avoid any unwanted risks. An optimal allocation of DGs can help to reduce network losses and improve network performance. Recent studies show that 13% of total generated powers are lost at distribution level [2] and can be reduced by installing DGs if optimally placed and sized. Energy losses can also be reduced by a suitable selection of DG [3].

The high penetration level of DG in distribution network can influence the power system with voltage and power losses increment. Therefore, voltage improvement is one of the major issues that needs to be addressed [4] by allocating adequate DG. The technologies adopted in DG comprise small gas turbines, micro-turbines, fuel cells, wind and solar energy, biomass, small hydro-power etc. [1]-[6]. In distribution systems, DGs can provide benefits for the consumers as well as for the utilities, more especially in grids where the central generations are impracticable or where there are deficiencies in the transmission and distribution system [7]. The main reasons for the increasingly widespread use of DG can be summed up as follows [8]-[10]. In the process of placement of DG, several factors need to be considered, such as the technology to be used, the number and the capacity of the units, the optimal location, and the type of network connection. However, in order to maximize benefits, solution techniques for DG deployment should be obtained using optimization methods because, installing DG units at non-optimal places and in inappropriate sizes may cause system power losses and cost increment. Moreover, installing DG units is not straight forward, thus, the placement and sizing of DG units should be carefully selected.

Researchers focus on heuristic techniques that tend to find a good solution to a complex combinatorial problem within a rational time. Singh et al. [10] asserted that the constant load models have determined the effect of different load and sensitivity to voltage and frequency. Authors [11] have used an analytical method for optimal DG allocation. This method is based on the equivalent current injection that uses the bus injection to branch current (BIBC) and branch current to bus voltage (BCBV) matrices which is developed and broadly achieved for the load flow analysis of the distribution systems which causes reduction on the search space.

In [12], a dynamic programming application is performed for DG location in terms of loss reduction and voltage improvement. Many researchers have used evolutionary methods for finding the optimal DG placement [13]–[15]. In a study [15], an adaptive-weight PSO (APSO) algorithm is used to place multiple DG units, but the objective is to minimize only the real power loss of the system. In [16], DG units are placed at the most sensitive buses to voltage collapse. The units have the same capacity and are placed one by one. An analytical method is utilized to determine the optimum location–size pair of a DG unit in order to minimize only the line losses of the power system. In [13], GA based algorithm is presented to locate multiple DG units to minimize a cost function including the system losses and service interruption costs. The optimization procedure is formulated using only voltage profile indices, and then the effect of introducing DG units on the line losses is analysed. In [17] a multi-objective formulation for the siting and sizing of DG resources into existing distribution networks has been proposed. Figure 1 shows the importance of DG Integration to the power distribution network.

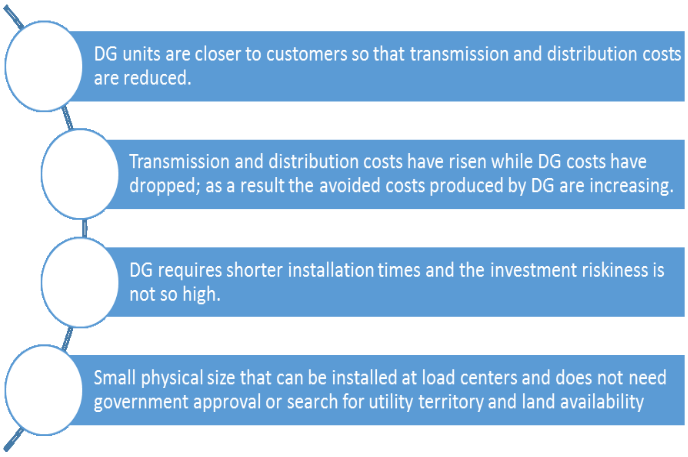

Figure 1: DG importance in future power distribution network

METHODOLOGY

Particle swarm optimization (PSO) theory has been developed through a simulation of simplified social models. PSO is an optimization method established by Kennedy and Eberhart in 1995, inspired by social compartment of bird flocking or fish schooling [18]. PSO is considered as one the recent developments in combinatorial meta-heuristic optimization which is a population-based stochastic search algorithm [19]-[20] basing on a simple concept. It works in two steps, calculating the particle velocity and updating its position. Therefore, the computation time is short, and little memory is required. The process of PSO algorithm in finding optimal values follows the work of this animal society. PSO consists of a swarm of particles, where particle represents a potential solution. Recently, there are several modifications from the original PSO. In order to accelerate the achievement of the best conditions. The development will provide new advantages and also resolve the diversity of problems. One of the weaknesses of PSO algorithm is that sometimes optimum solutions will converge into the local area of the search space. This phenomena is called local minima. This paper has utilized modified-PSO algorithm that improves mutation features on the percentage of population of the particles. The mutation on population may help to avoid local minima phenomena. In other words mutation can improve PSO algorithm in terms of preventing to converge locally and find an optimum solution.

Figure 2 shows the PSO algorithm that has been proposed in this paper for optimum DG allocation. The algorithm was initialized with PSO initial parameters such as maximum iteration, population size, and mutation rate. A test case was modelled and power flow calculation performed using OpenDSS engine. The random solutions were generated in population loop and evaluated in order to find the best initial random solution for PSO main loop. The mutation operator was performed once the PSO iterated in locally. The best global result of the algorithm is the optimum solution with minimum power losses and best possible voltage profile.

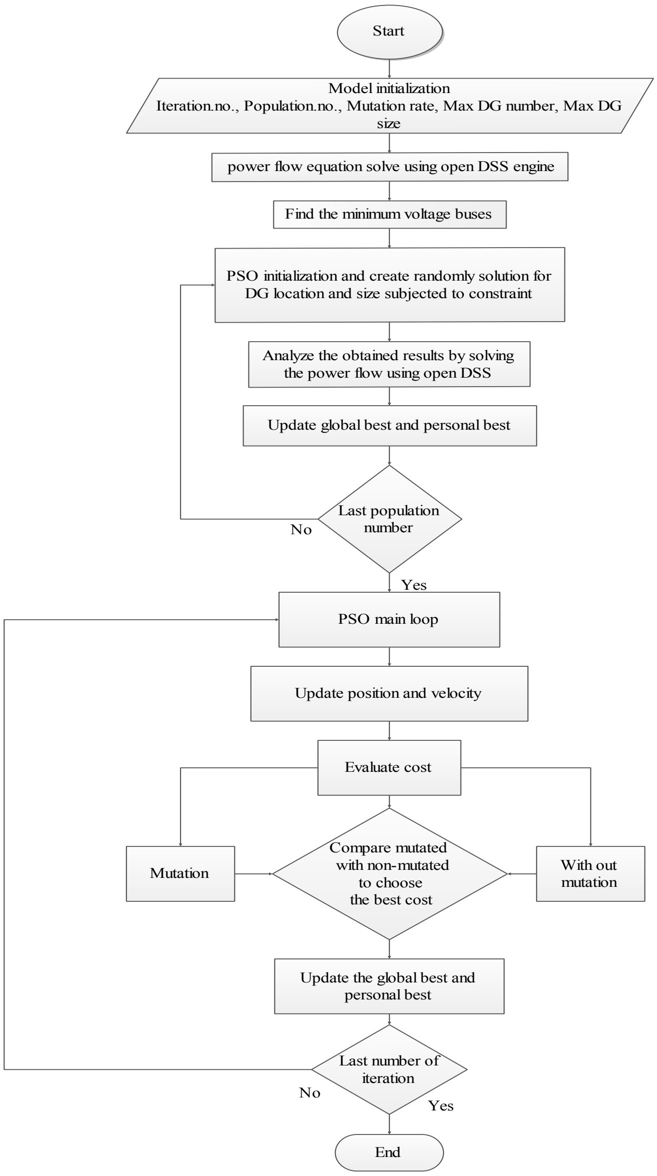

Figure 2: PSO methodology

a. Impacts of DGs on Voltage Drop

Due to the small ratio of X to R in distribution networks and the radial structure of these grids, the impact of DGs on distribution network voltage is significant. By considering this issue, the voltage drop for the network can be written as follows [3], [21], [22]:

$$\Delta V = V_1 - V_2 = (R + jX)I \qquad (1)$$

$$I = \frac{P - jQ}{V_2^*} \qquad (2)$$

$$|\Delta V|^2 = \frac{(RP+XQ)^2 + (RP-XQ)^2}{V_2^2} \approx \frac{(RP+XQ)^2}{V_2^2} \quad (3)$$

where, ΔV is the line voltage drop, R+jX is the line impedance, Q is the reactive power, P is the active power, V1 & V2 and I, are the Bus 1 and 2 voltage amplitude and the current flow through the line, respectively. The above equations should be considered as one of the constraints of the optimization problem. This constraint can be considered as penalty factor into the objective function. The transformer tap positions can be influenced by voltage improvement in distribution networks which is important for voltage regulation.

Once the voltage at secondary terminal of transformer has improved as close as possible to one per unit, the tap position steps can be situated in initial position. This act can gives more opportunity to voltage regulation by tap changer and will increase the lifecycle of transformers that would be cost effective [23]. Hence, the voltage improvement through allocating DG units into the distribution network will cause more flexibility of transformer tap changer to regulate the voltage.

b. Objective Function Formulation and Case Study Assessment

This study has performed three different scenarios assessment with objective functions in order to find the optimum placement and sizing of DG into an IEEE 37 buses test network as shown in Figure 3. This test network has been utilized in this paper in order to demonstrate the functionality of the proposed algorithm to find the optimum placement and sizing of the DG. The objective function and constraints are formulated in three deferent scenarios. DG placement and sizing has significant impacts on the total network losses and voltage profile in distribution networks. In this regards, three types of scenarios have been elaborated in this paper as follows:

a) Minimization of total power losses and voltage profile improvement without any constraints for maximum DG size and numbers:

Min;

$$OF = \alpha.Losses + \beta.V_{violation} \quad (4)$$

b) Minimization of total power losses and voltage profile improvement with maximum number of DG number and without DG size constraints:

Min;

$$OF = \alpha.Losses + \beta.V_{violation} + \gamma.DG_{Number}Violation \quad (5)$$

c) Minimization of total power losses and voltage profile improvement with maximum numbers and sizes of DG:

Min;

$$OF = \alpha.Losses + \beta.V_{violation} + \gamma.DG_{Number}Violation + \lambda.DG_{Size}Violation \quad (6)$$

$$DG_{Number}Violation = MAX(0,(N_{DG} - Max_{DG})) \quad (7)$$

$$DG_{Size}Violation = MAX(0,(\sum DG^{i}{}_{Sizes} - Max_{Total\,DG})) \quad (8)$$

Where all of the objective functions are subject to the following constraints:

Bus voltage $V_i^{\min} \le V_i^t \le V_i^{\max}$ (9)

Current feeders $I_{fi} \le I_{fi}^{rated}$ (10)

DG units are considered as constant output generation with unit power factor and there are a few initial assumptions of the DG sizes and constraints which are specified as follows:

- Maximum number of DG;
  - Scenario #1, 37 units (all nodes)
  - Scenario #2, 9 units
  - Scenario #3, 9 units
- Maximum Size of total DG units;
  - Scenario #1, not limited
  - Scenario #2, not limited
  - Scenario #3, 1500kW
- Minimum size of each unit is 100 KW
- Maximum size of each unit is 1MW
- Voltage constraint ($0.95 \leqslant V_{node} \leqslant 1.05$)

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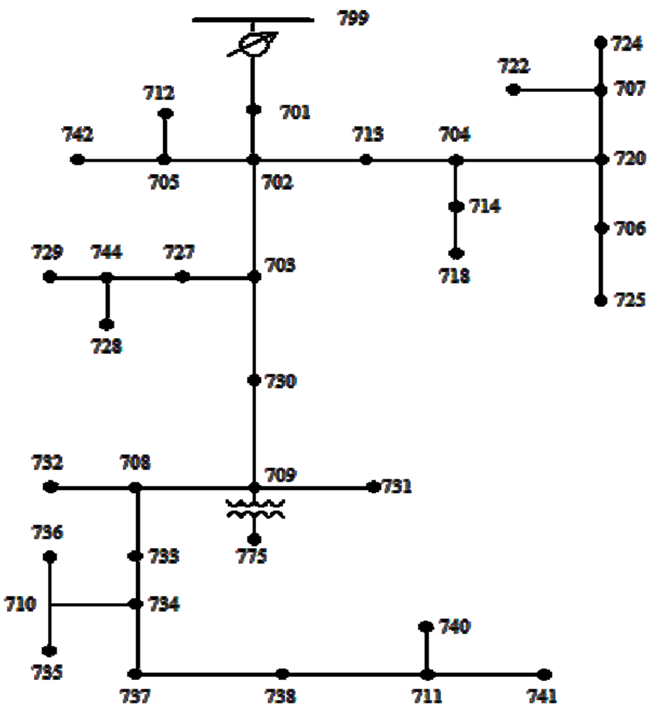

Figure 3: IEEE 37 node test network

RESULTS AND DISCUSSION

Table 1 shows the comparison of IEEE 37 nodes standard case were three types of scenarios are designed for DG allocation. All of the scenarios for optimum allocation of DG resulted in the total power losses reduction and voltage profile improvement. The scenario #1 integrated 16 DG units with 2700kW total generation which resulted in the significant losses reduction about 50% with 30.68kW power losses compared to the standard case which was 60.56kW. In scenario #2, the DG integration was limited to 9 units which have concluded to 2650kW total DG generation with 31.55kW power losses. In other words, scenario #2 has chosen the larger size of DG units in order to minimize the power losses by integrating only 9 DG units. In scenario #3, the number of DG units and size of the total DG generation were limited to 9 units and 1500kW, respectively. As shown in Table 1, the scenario #3 had acceptable total power loss reductions 47.79kW compared to the standard case. It should be noted that in all of the scenarios, the voltage profiles has been controlled within IEEE standard range (0.95< V_{node} <1.05) as shown in Figures 4-7. In addition, the voltage profile has been improved after the DG integration. The comparison of total power losses between standard case and all scenarios is shown in Figure 8. It indicates the power losses per elements of networks, before and after the DG integration.

Table 1: The comparison table between standard case and three scenarios of DGs allocation

	Standard case	After optimum DGs allocation		
		Scenario #1	Scenario #2	Scenario #3
Total Losses[kW]	60.56	30.68	31.55	47.799
Min.voltage[p.u.]	0.971	0.993	0.994	0.988
Max.voltage[p.u.]	1.039	1.029	1.030	1.0313
Numbers of DG units	No DG units	Bus701: 700KW Bus 705: 200KW Bus 713: 150 KW Bus 703: 150 KW Bus 706: 100KW Bus 722: 200 KW Bus 708: 200 KW Bus 731: 100 KW Bus 736: 100 KW Bus 741: 100 KW Bus718: 100 KW Bus 734: 150KW Bus 737: 100 KW Bus 738: 150 KW Bus 728: 100 KW Bus729: 100 KW	Bus 701: 750KW Bus 702: 200 KW Bus 727: 350KW Bus 704 : 250 KW Bus 706: 100 KW Bus 722: 250 KW Bus 732: 150 KW Bus 735: 200 KW Bus 738: 400 KW	Bus 742: 100 KW Bus 733: 300 KW Bus 731: 150 KW Bus 735: 100 KW Bus 740: 150 KW Bus 718: 100 KW Bus 734: 200 KW Bus 738: 200 KW Bus 728: 200 KW
Total		16 DG units 2700 KW	9 DG units 2650 KW	9 DG units 1500 KW

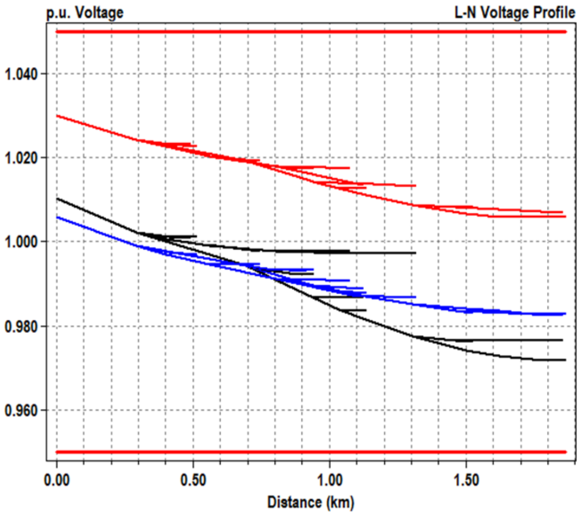

Figure 4:Voltage drop in distance before DG integration

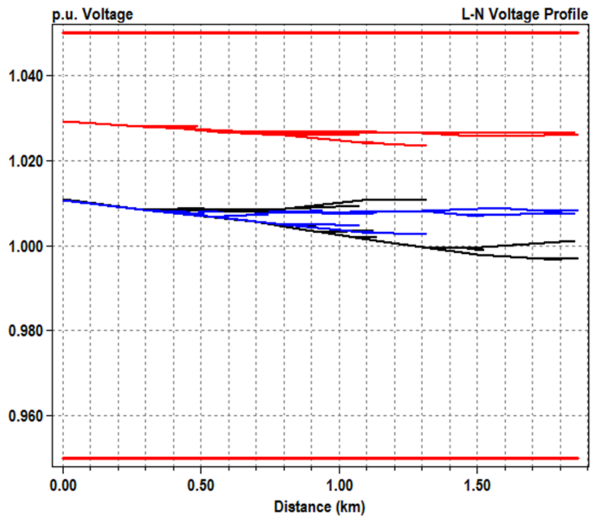

Figure 5:Voltage drop in distance for scenarios #1

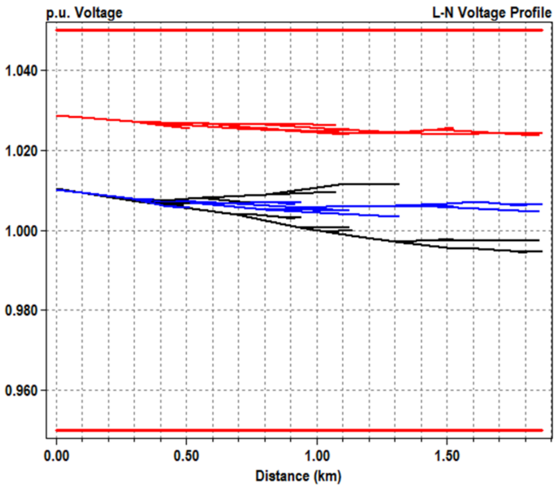

Figure 6:Voltage drop in distance for scenarios #2

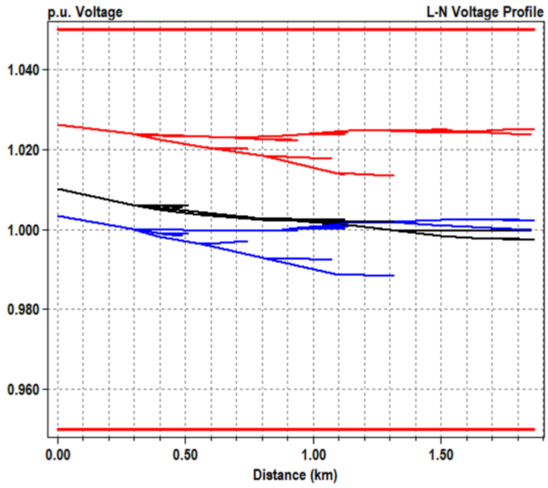

Figure 7:Voltage drop in distance for scenarios #3

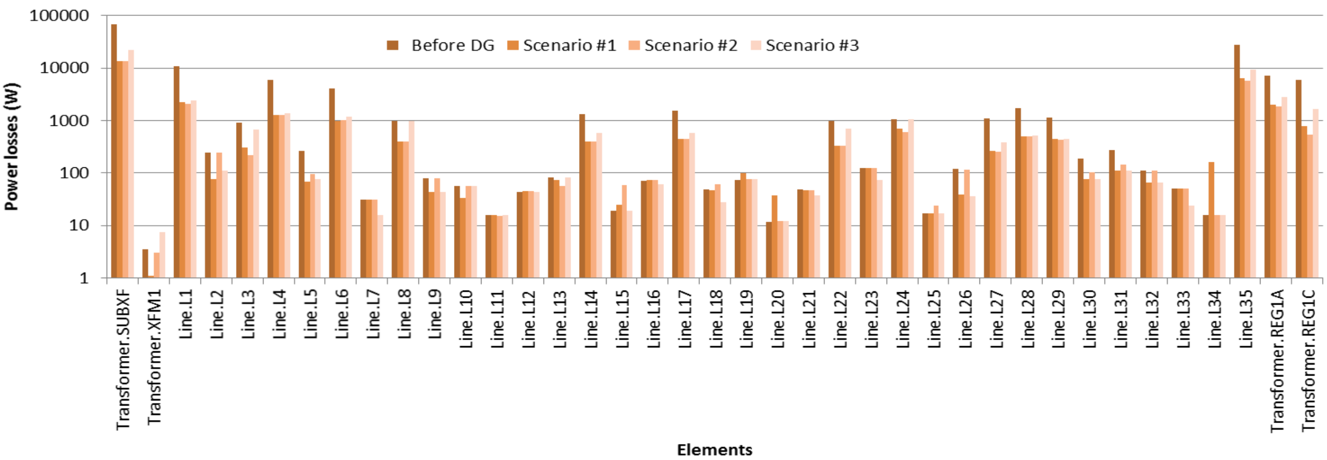

Figure 8: Power losses comparison for DG allocation before and after scenarios

CONCLUSION

In this paper, three different scenarios for DGs allocation have been applied in order to study the impacts of these units on network performance. The Particle Swarm Optimization (PSO) has been utilized in this paper in order to solve the objective functions of optimum DGs allocation in distribution network. The results show that the total power losses can be minimized significantly by allocating the optimum size of DG in the optimum placement. Moreover, the limitations of DG number and size have been determined as constraints of the objective function and the results show that the constraints could be optimally applied. In addition, the voltage profile of the network has been improved and power losses significantly reduced. In short, using DG units in distribution networks is one the proper solutions in future distribution network planning in order to improve the network performance provided, DG units are allocated adequately. More studies need to be conducted on DG and their impacts on distribution networks.

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