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Optimal Placement of DGs in Distribution System including Different Load Models for Loss Reduction using Genetic Algorithm

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Abstract

Distributed generation (DG) sources are becoming more prominent in distribution systems due to the incremental demands for electrical energy. Locations and capacities of DG sources have great impacts on the system losses in a distribution network. This paper presents a study aimed for optimally determining the size and location of distributed generation units in distribution systems with different load models. The objective is to minimize network power losses. The impacts of DG model on locating and sizing of DG are also presented considering different voltage dependent load models. Also, different types of customers such as industrial, residential, and commercial loads are considered for load modeling. The optimization problem has been solved using genetic algorithm. For simulation purpose, this algorithm has been executed on 33-bus and 69-bus test systems. Results show that type of DG modeling and load modeling has considerable effect on determination of the optimum siting and sizing of DGs. Also, DGs installation in optimum size and location has considerable effect on loss reduction and voltage improvement of distribution system.

Keywords: *Distributed Generation, Load Model, Genetic Algorithm, Loss Reduction*

1. Introduction

Loss reduction in distribution system is one of the main goals of power utilities. Specially, with the impending deregulated environment, electric utilities are seeking new technologies to provide cheap power with suitable reliability and power quality because of retail competitive structure. There are various methods for loss reduction such as capacitor placement, high voltage distribution system, conductor grading, network reconfiguration and installation of distributed generation (DG). Distributed generation can be understood as the production of electricity by small generators located in the distribution network or near the loads they are attending [1]. One of the recent most remarkable techniques for loss reduction is DG placement in distribution systems. Since DG units generate power locally to fulfill customers demand, appropriate sizing and sitting of DG can drastically reduce power losses in the distribution systems [2].

Optimal placement of DG for loss reduction has been investigated in many references using various classical and/or modern optimization methods. In [3-5] DG allocation has been formulated analytically. Other methods which were used for solving the problem are as follows: a combination of tabu search and genetic algorithms [6], particle swarm optimization [7], a combination of genetic algorithm and particle swarm optimization [8], heuristic approach [9], honey bee mating optimization (HBMO) [10] and a sequential quadratic programming upon the level of power losses and DG cost compatibility of different generation [10]. However, the load was modeled as constant power sinks, i.e. independent from feeder voltage magnitude.

The reminder of the paper is organized as follows: The models of DG and the voltage dependent load models are discussed in section 2. The problem formulation is presented in Section 3. The proposed algorithm is described in section 4. Simulation results are presented in Section 5 and finally some relevant conclusions are given in Section 6.

2. Modeling of DG and Load

In order to simplify the model of DG in power flow analysis, in this paper, DG is modeled as follows:

DG in Type-I: Distributed generators that supply only constant active power to the network without consuming any reactive power. Such DGs can be modeled as negative constant active power load in the load flow analysis.

DG in Type-II: The DG technologies such as micro-turbine and fuel cell with ac-dc converters are considered to be able to supply both of active and reactive power to the distribution system. These DGs are implemented as negative power loads, i.e. PQ node types. in load flow analysis.

Practical voltage-dependent load models, i.e., residential, industrial, and commercial ones, have been adopted for investigations. The load models can be mathematically expressed as [11]:

$$P_i = P_{oi}\left(\frac{V_i}{V_{oi}}\right)^{\alpha} \qquad (1)$$

$$Q_i = Q_{oi}\left(\frac{V_i}{V_{oi}}\right)^{\beta} \qquad (2)$$

Where V_i is the voltage at bus i, V_{oi} is the nominal operating voltage at bus i, P_i and Q_i are active and reactive power for load point i with bus voltage of V_i, respectively, P_{oi} and Q_{oi} are the active and reactive power for load point i with bus voltage of V_{oi}, respectively, and α and β are the exponents of real and reactive power formulations, respectively. In the constant load model conventionally used in power flow studies, α and β are assumed to be zero. The values of the active and reactive exponents used in this paper for industrial, residential, and commercial loads are given in Table 1 [11].

In practical situations, loads are mixtures of different load types, depending on the nature of the area being supplied. Therefore, in this study, three different types of load consisting of residential, industrial, and commercial loads are considered, in which every bus of the system has one type of load. On the other hand, load of distribution system varies in different season of year. Therefore, in this paper, load condition is considered in three stages as low level for summer night period, medium level for summer day and winter night periods and also peak load level for winter day period. Assumed load levels in different periods of the year are shown in Figure 1 [11].

Table 1. Typical load types and exponent values

Season	Load type	Day		Night	
		α	β	α	β
Summer	Residential	0.72	2.96	0.92	4.04
	Commercial	1.25	3.50	0.99	3.95
	Industrial	0.18	6.00	0.18	6.00
Winter	Residential	1.04	4.19	1.30	4.38
	Commercial	1.50	3.15	1.51	3.40
	Industrial	0.18	6.00	0.18	6.00

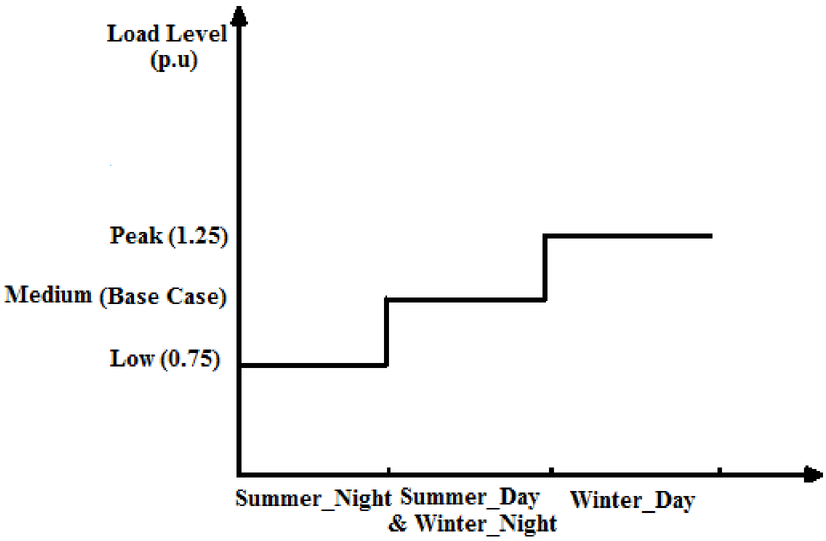

Figure 1. Load level in different period of the year

3. Problem Formulation

The DG optimal placement and sizing problem is formulated as one of the mixed types of nonlinear optimization problems with continuous and discrete variables. The objective function considered in this paper is to find the best combinations of DG rating and placement for a given number of DGs that optimally minimize the total power losses of radial distribution system network.

3.1 The Objective Function

The final goal of the optimization problem is to minimize the power losses of the network. The objective function can be mathematically expressed as:

$$f = \min S_{T,Loss} \quad (3)$$

The power losses equation can be written in the following form:

$$S_{T,Loss} = \sqrt{P_{T,Loss}^2 + Q_{T,Loss}^2} \quad (4)$$

Where $S_{T,Loss}$ the is total power loss, and $P_{T,Loss}$ and $Q_{T,Loss}$ are total active and reactive power loss in the system, respectively.

3.2 Power Losses

Generally, distribution systems are fed at one point and have a radial structure. The load flow equations of radial distribution network are computed by forward/backward method, because of its low memory requirements, computational efficiency and robust convergence characteristic. The active and reactive power loss of the line section connecting between buses i and i+1 may be computed as:

$$P_{Loss}(i, i+1) = R_{i,i+1}\, I_{i,i+1}^2 \qquad (5)$$

$$Q_{Loss}(i, i+1) = X_{i,i+1}\, I_{i,i+1}^2 \qquad (6)$$

Where $I_{i,i+1}$ is the magnitude of the current of the line section connecting between buses, i and i+1, $R_{i,i+1}$ and $X_{i,i+1}$ are resistance and reactance of the line section connecting between buses i and i+1, respectively. Also, $P_{Loss}(i, i+1)$ and $Q_{Loss}(i, i+1)$ are active and reactive power loss of the line section connecting between buses i and i+1, respectively.

The total active and reactive power loss of the feeders in the system are determined by summing up the losses of all line sections of the feeder, which is given as:

$$P_{T,Loss} = \sum_{i=0}^{NB-1} P_{Loss}\,(i, i+1) \qquad (7)$$

$$Q_{T,Loss} = \sum_{i=0}^{NB-1} Q_{Loss}\,(i, i+1) \qquad (8)$$

Where $P_{T,Loss}$ and $Q_{T,Loss}$ are the total active and reactive power loss of the feeders in the system, respectively.

3.3 The constraint considered for the objective function

The following constraints are considered in the optimization problem using genetic algorithm.

3.3.1 Voltage limits

In this paper, the following optimization constraint is used for the voltage magnitude of each bus:

$$V_{i,min} < V_i < V_{i,max} \qquad (9)$$

Where $V_{i,min}$ and $V_{i,max}$ are the lower and upper voltage limits, respectively. Also, V_i is the voltage magnitude at bus i.

3.3.2 Capacity of feeders

Maximum power flow of network feeders is limited to the power carrying capacity of conductors.

$$S_i < S_{i,max} \qquad (10)$$

Where, S_i is the power flow at feeder i and $S_{i,max}$ is the maximum power flow at feeder i.

3.3.3 DG technical constraints

As DG capacity is inherently limited by the energy resources at any given location, it is necessary to constrain capacity between the maximum and the minimum levels.

$$P_{g,min} < P_g < P_{g,max} \qquad (11)$$

$$Q_{g,min} < Q_g < Q_{g,max} \quad (12)$$

Where $P_{g,max}$ and $P_{g,min}$ are the maximum and minimum active output power of DG, respectively. Also $Q_{g,max}$ and $Q_{g,min}$ are the maximum and minimum reactive output power of DG, respectively.

4. Genetic Algorithm

A Genetic Algorithm (GA) is a programming technique that mimics biological evolution as a problem solving strategy based on Darwinian's principle of evolution and survival of fittest to optimize a population of candidate solutions towards fitness [12]. GA utilizes an evolution and natural selection that uses a data structure like chromosomes and evolve the chromosomes, using selection, crossover, and mutation operators. The process starts with a random population of chromosomes, which is considered as candidate solutions. For each solution, size–location pairs of the DG units introduced to the system are chosen within technical limits of locations and sizes of the DG units. Each solution must satisfy the operational constraints represented by Eqs. (9)–(12). If one of these constraints is violated, such a solution is rejected [12].
The size of the population depends on the size and the nature of the problem. The positions of each chromosome are encoded as characters or numbers and could be referred to as genes. Then according to the desired solution, an evaluation function, known as “Fitness Function”, is used to calculate the goodness of each chromosome. Two basic operators, crossover and mutation, are used to simulate the natural reproduction and mutation of species during evolution. The main aim of crossover is to search the solution space and it is the most important operator in GA. As it can be seen in Figure 2, the crossover operator takes two strings from the old population (parents) and exchanges some segments of their structures to form the offspring (children).

The function of mutation is used to prevent the loss of the information. Mutation can keep the population more diverse so that it alters a string locally to create a better string. Once the new proportion is completed, the program will continue to generate new populations. The iterative process can be stopped while no further significant change of the fitness occurs or when the specified number of iteration is reached. The Selection of chromosomes for survival and combination is biased towards the fittest chromosomes. A GA generally has four components. A population of individuals represents a possible solution. A fitness function which is an evaluation function by which we can tell if an individual is a good solution or not. A selection function decides how to pick good individuals from the current population for creating the next generation. Genetic operators such as crossover and mutation explore new regions of search space while keeping some of the current information at the same time [12].

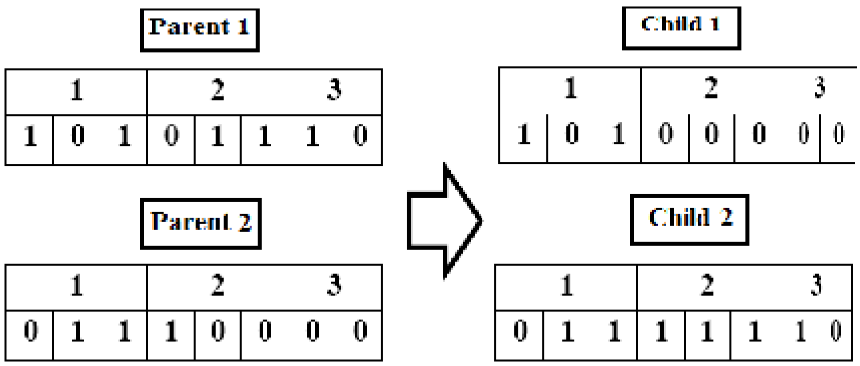

Figure 2. Crossover operation

Coding of the solution is very important aspect of a correct implementation of the GA to achieve the results. In this paper, structure of each chromosome coding is shown in Figure 3.

Location of DG	Size DG

Figure 3. Chromosome encoding

As it has been shown, the chromosome is composed of two main sections. First section contains the optimal location for DG installation and second section, whose structure is shown in Figure 4. contains the best size of DG, which, in turn, consists of two main sections.

Active output power of DG	Reactive output power of DG

Figure 4. Structure of second section

In this paper, roulette wheel selection, which chooses parents by simulating a roulette wheel with different sized slots, each proportional to the fitness of one individual, is chosen. For the crossover operation, the one point and scattered crossover mechanisms were tested in this study. The one point crossover mechanism exchanges the genetic information in the two selected parents based on a single position which is determined at random. The mutation mechanism used in this study implied generating a random gene number and flipping the bit found at that position.

The population size affects the efficiency and performance of the algorithm. If the population size is too small, the solution domain will not be adequately searched and thus will result in poor performance. On the other hand, if the population size is too large, although a better searching process is achieved but the execution time and the storage requirement is increased considerably. In practice, the proper number of population size is obtained experimentally. In this paper, mutation probability and crossover probability set as 0.2 and 0.8, respectively. The number of the initial population is selected 20 and 40 for 33-bus and 69-bus systems, respectively. The maximum number of iterations is selected 400. The flowchart of GA is presented in Figure 5.

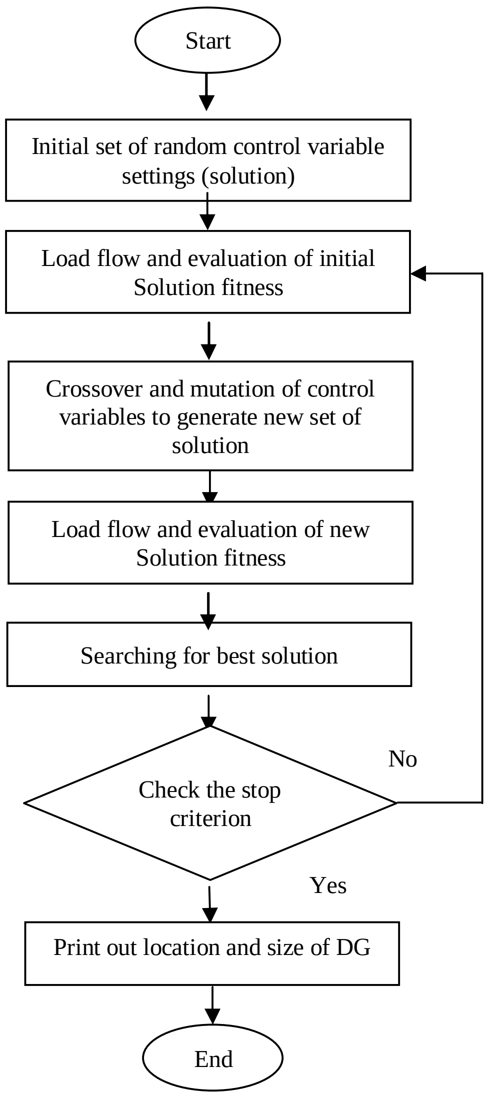

Figure 5. Flowchart of Genetic Algorithm for placement problem

5. Simulation Results and Analysis

The proposed algorithm is tested on two 33-bus [13] and 69-bus test systems [14]. The first bus is considered as the feeder of electric power from the generation/transmission network (slack bus). The remaining buses of the distribution system are considered for the placement of DG unit. The real and reactive loads were modeled as voltage dependent load models with considering different load levels. Active and reactive power loss and bus voltage magnitude are determined by implementation of backward/forward load flow algorithm for optimal sitting and sizing of DGs for installation in the test systems. In this paper for the optimization problem, the following cases were considered to validate the proposed approach:

Case 1: Optimal size and location of a DG unit in type- I in distribution network is determined to minimize the objective function given by equation (3).

Case 2: Two DG units in type-I are placed to minimize the objective function.

Case 3: Optimal placement and sizing of a DG unit in type-II is determined to minimize the objective function.

Case 4: Two DG units in type-II are placed to minimize the objective function.

5.1 33 Bus radial distribution system

The first test system is a radial system with the total load of 3.72 MW, 2.3 MVar in the base case, 33 buses and 32 branches as it is shown in Figure 6[13].

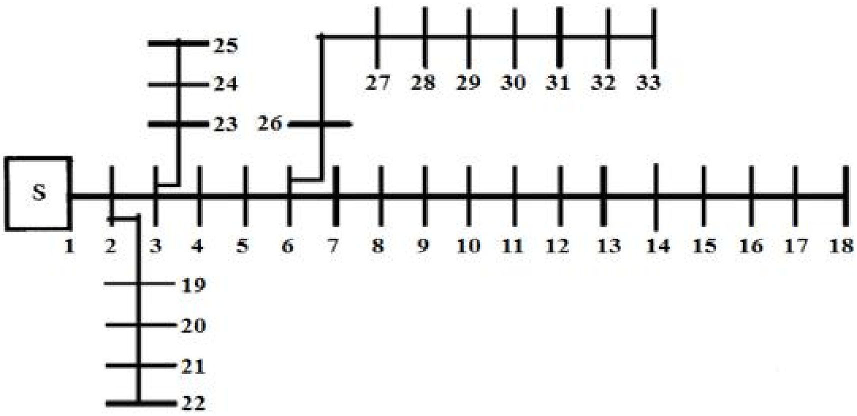

Figure 6. Single line diagram of a 33-bus radial distribution system

Tables 2 and 3 show results of DGs placement on 33-bus test system for each of the four mentioned cases. Table 2 shows the best place and size for units DGs for these cases determined by genetic algorithm. Also, table 3 shows active and reactive power loss reduction using DG installation for the cases.

Table 2. Optimum size and location of DGs in 33-bus test system for different cases

Different Cases		Location	Size
Case 1	DG in Type-I	Bus 10	1114 kW
Case 2	DG in Type-II	Bus 30	958 kW
			278.86 kVar
Case 3	DG in Type-I	Bus 3	922.97 kW
	DG in Type-I	Bus 30	970.39 kW
Case 4	DG in Type-II	Bus 8	732.02 kW
			15.875 kVar
	DG in Type-II	Bus 30	649.31 kW
			51.36 kVar

Table 3. Active and reactive power loss reduction by DG placement for different cases in 33-bus test system

Different Cases	$P_{T,Loss}$ (kW)	%improvement	$Q_{T,Loss}$ (kVar)	%improvement
Base Case	76.34	-	50.73	-
Case 1	15.96	79.09	13.08	74.21
Case 2	16	79.04	12.91	74.55
Case 3	15.07	80.26	10.61	79.08
Case 4	12.57	83.53	9.31	81.64

As it is illustrated in Table 3, optimal placement of DGs in all cases result in considerable loss reduction in the test system. In addition, it is observed from Table 3 that installation of DGs decreases active power losses from 76.34 kW to 15.96, 16, 15.07 and 122.57 kW in four cases, respectively; and also decreases reactive power losses from 50.73 kVar to 13.08, 12.91, 10.61 and 9.31 kVar, respectively. Moreover, it is observed from this table that DG installation in fourth case causes more loss reduction compared to other cases. In addition to minimize the power losses in distribution networks, proper DG planning can improve the overall network voltage magnitude profiles. Figures 7, 8, 9 and 10 show the voltage profile improvement before and after DG installation in different cases for summer day, summer night, winter night and winter day load levels in the 33-bus system.

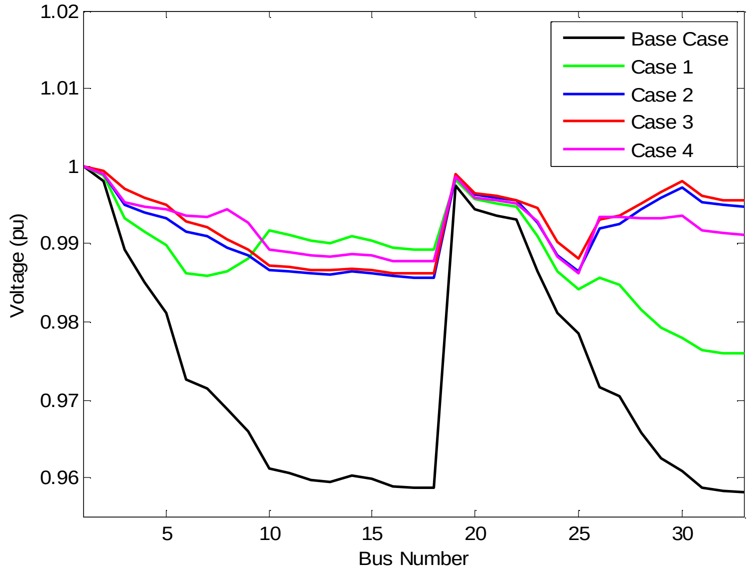

Figure 7. Voltage profile for four DG installation cases and the base case for Summer-Day load level in 33-bus system

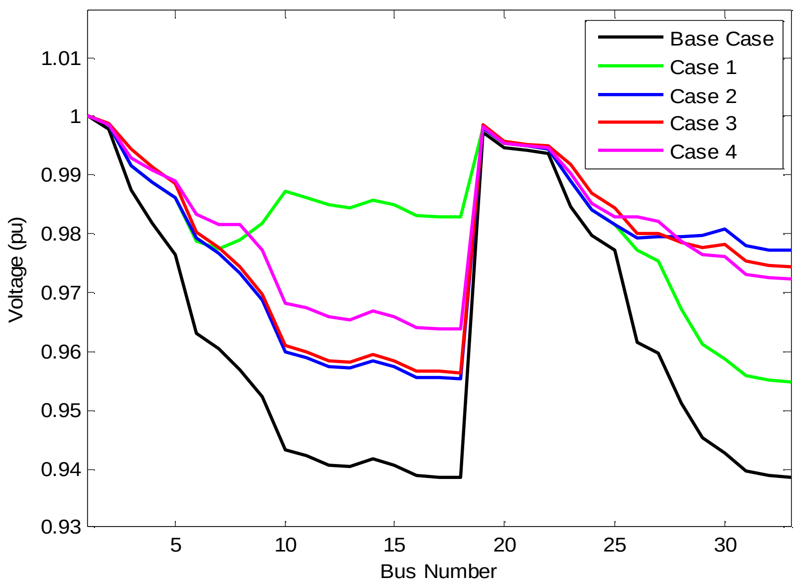

Figure 8. Voltage profile for four DG installation cases and the base case for Summer- Night load level in 33-bus system

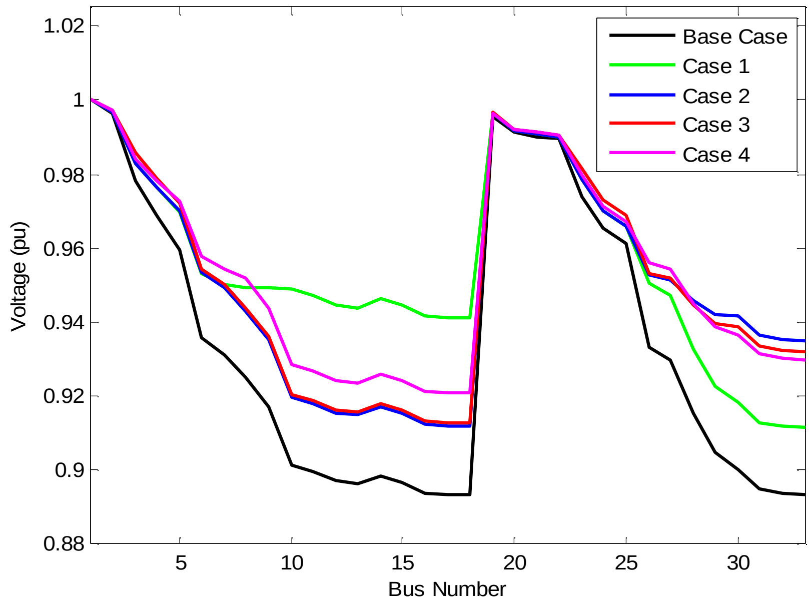

Figure 9. Voltage profile for four DG installation cases and the base case for Winter-Day load level in 33-bus system

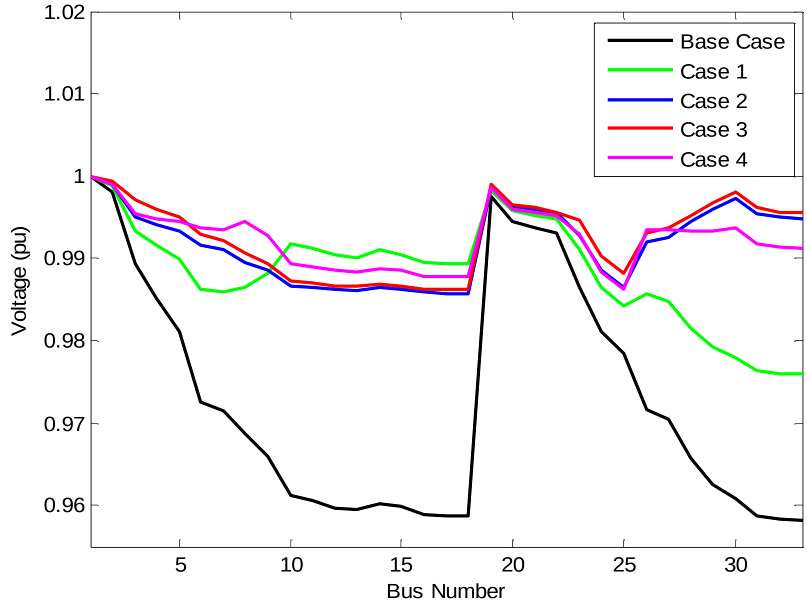

Figure 10. Voltage profile for four DG installation cases and the base case for Winter-Night load level in 33-bus system

5.2 69 Bus radial distribution system

69-bus radial distribution system with total load of 3.80 MW and 2.69 MVar in the base case is considered as another test system. This system has seven laterals, 69 buses and 68 branches, and data of the test system was extracted from [14].

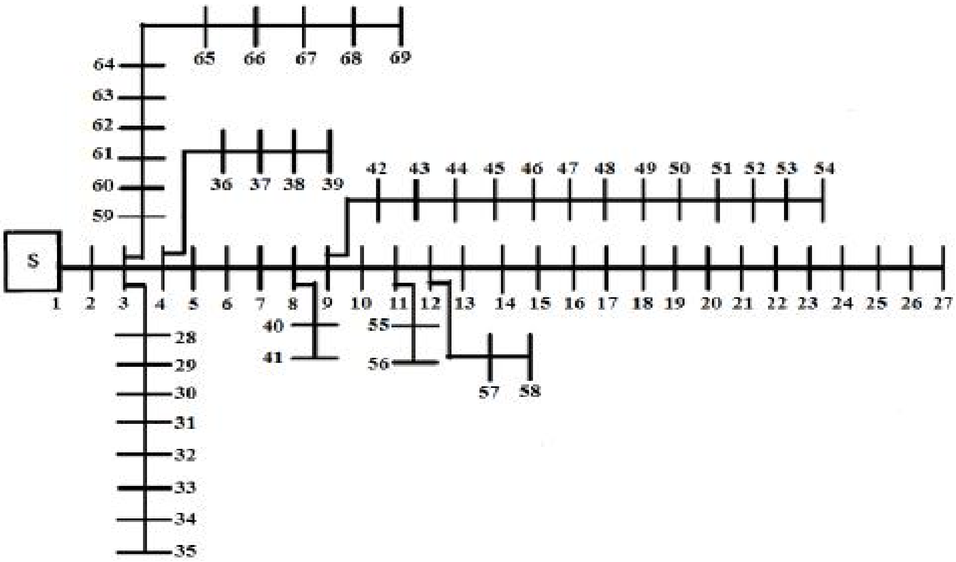

Figure 11. Single line diagram of a 69-bus radial distribution system

The best place and size for installation of DGs for each of the four cases are demonstrated in Table 4. Similarly to 33-bus test system, in all four cases, active and reactive power losses are reduced by optimal DG placements (Table 5).

Table 4. Optimum size and location of DGs in 69-bus test system for different cases

Different Cases		Location	Size
Case 1	DG in Type-I	Bus 44	1311.5 kW
Case 2	DG in Type-II	Bus 51	957 kW
			278.36 kVar
Case 3	DG in Type-I	Bus 11	759.23 kW
	DG in Type-I	Bus 49	567.8 kW
Case 4	DG in Type-II	Bus 51	932.32 kW
			490.64 kVar
	DG in Type-II	Bus 12	586.6 kW
			472.7 kVar

Table 5. Active and reactive power loss reduction by DG placement for different cases in 69-bus test system

Different Cases	$P_{T,Loss}$ (kW)	%improvement	$Q_{T,Loss}$ (kVar)	%improvement
Base Case	103.42	-	50.07	-
Case 1	7.14	79.09	5.63	74.21
Case 2	6.54	79.04	5.18	74.55
Case 3	5.2	80.26	4.62	79.08
Case 4	4.32	83.53	4.28	81.64

Results of table 5 show that installation of DGs with optimum size at optimum location, decreases active power losses from 103.42 kW to 7.14, 6.54, 5.2 and 4.32 kW for cases 1-4, respectively. On the other hand, as another result of this installation, reactive power losses is decreased from 50.07 kVar to 5.63, 5.18, 4.62 and 4.28 kVar in cases 1-4, respectively. It can be observed from the table that, DG installation in fourth case causes more active and reactive power loss reduction in comparison with the other cases. Moreover, Figs.12, 13, 14 and 15 show the voltage profile improvement before and after DG installation in different cases for summer day, summer night, winter day and winter night load levels in the 69-bus test system.

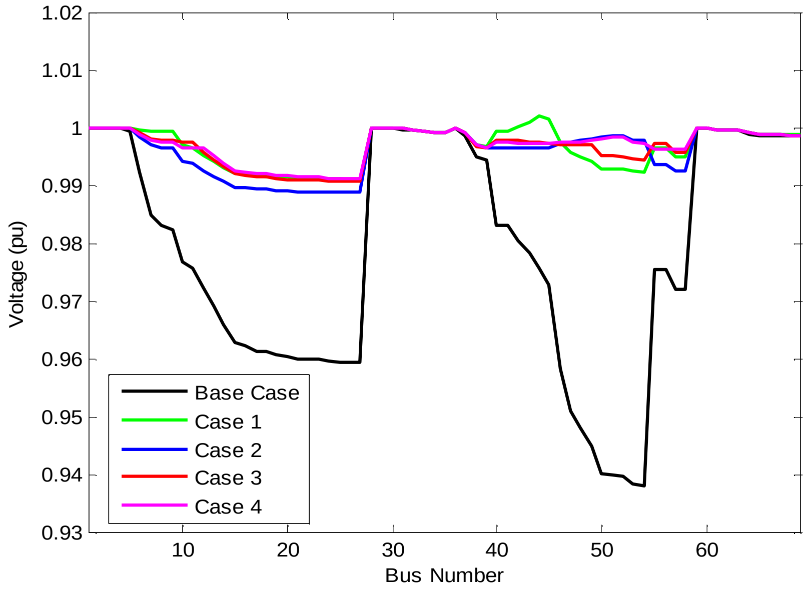

Figure 12. Voltage profile for four DG installation cases and the base case for Summer-Day load level in 69-bus system

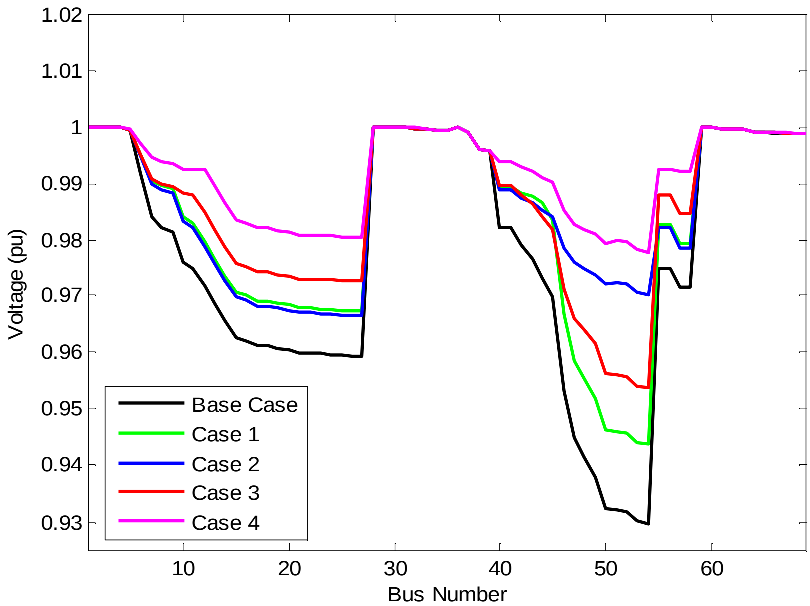

Figure 13. Voltage profile for four DG installation cases and the base case for Summer- Night load level in 69-bus system

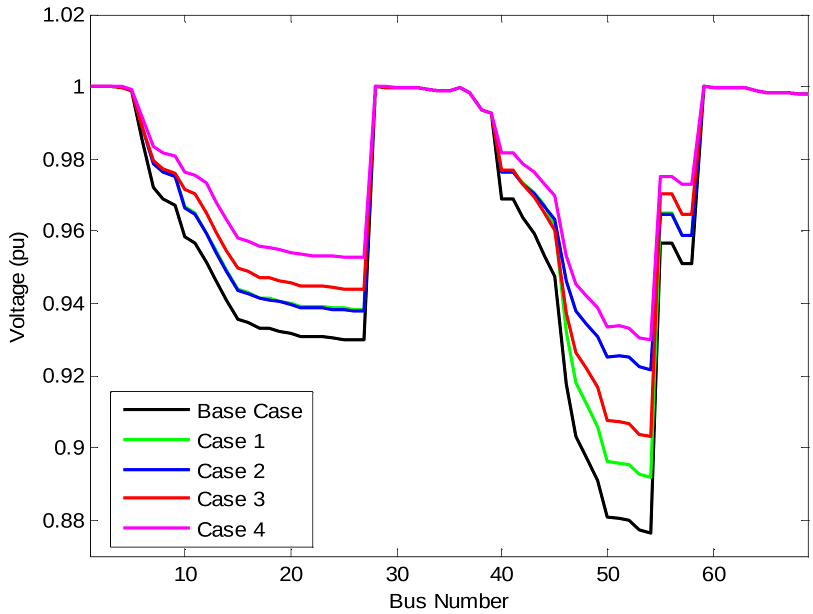

Figure 14. Voltage profile for four DG installation cases and the base case for Winter-Day load level in 69-bus system

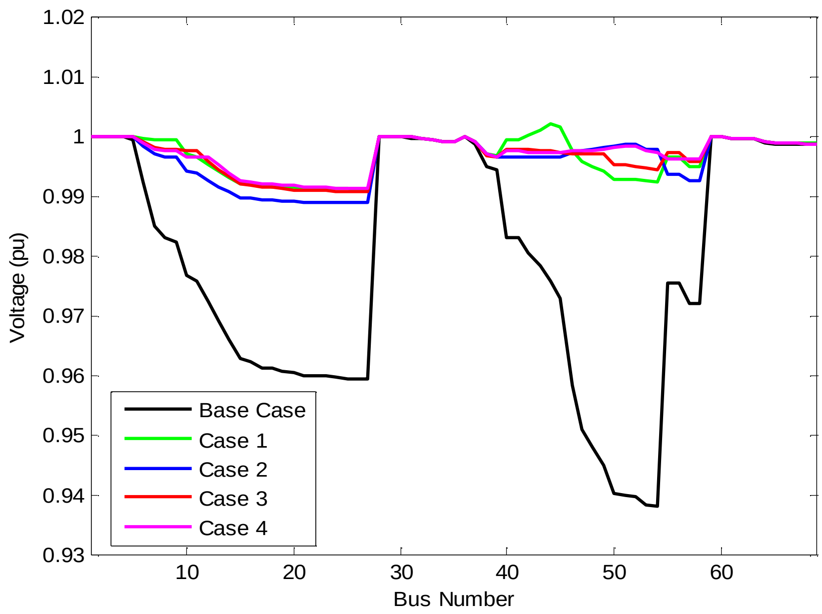

Figure 15. Voltage profile for four DG installation cases and the base case for Winter-Night load level in 69-bus system

Totally, in comparing the effect of DG installation in the two test systems, it is concluded that placement of optimal DG(s) on optimal bus(es) in the systems have similar effects on loss reduction and voltage improvement.

6. Conclusions

In this paper optimum size and location of DG(s) for loss reduction in distribution systems considering load models using genetic algorithm are determined. For this purpose, the impacts of various DG models in power loss reduction are evaluated with various voltage dependent load models. Also, different cases consisting of one DG and two DG installation with various type of output power generation including active and reactive power output are considered. The proposed optimization algorithm is applied to two test system. The results obtained show that the optimal placement of DG in the distribution systems causes to significant power losses reduction and also voltage profile improvement in two test systems.

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