

# An Optimal Load Shedding Approach for Distribution Networks with DGs considering Capacity Deficiency Modelling of Bulked Power Supply

A. R. Malekpour, A.R. Seifi

**Abstract**—This paper discusses a genetic algorithm (GA) based optimal load shedding that can apply for electrical distribution networks with and without dispersed generators (DG). Also, the proposed method has the ability for considering constant and variable capacity deficiency caused by unscheduled outages in the bulked generation and transmission system of bulked power supply. The genetic algorithm (GA) is employed to search for the optimal load shedding strategy in distribution networks considering DGs in two cases of constant and variable modelling of bulked power supply of distribution networks. Electrical power distribution systems have a radial network and unidirectional power flows. With the advent of dispersed generations, the electrical distribution system has a locally looped network and bidirectional power flows. Therefore, installed DG in the electrical distribution systems can cause operational problems and impact on existing operational schemes. Introduction of DGs in electrical distribution systems has introduced many new issues in operational and planning level. Load shedding as one of operational issue has no exempt. The objective is to minimize the sum of curtailed load and also system losses within the frame-work of system operational and security constraints. The proposed method is tested on a radial distribution system with 33 load points for more practical applications.

**Keywords**—DG, Load shedding, Optimization, Capacity Deficiency Modelling.

## I. INTRODUCTION

THE phenomenal growth in load demand both in developing and developed countries has emerged as a potential challenge to the power system planners and operators. Projections show that the growth in load demand is always going to be ahead of the growth in generation. Electric supply failures can have serious monetary impacts on the system customers. During an emergency situation, system operators are required to make load shedding decisions based on system security concerns, such as voltage, current, power

and frequency constraints, to alleviate constraints and maintain system stability.

The distribution systems are the final link of the interconnection between power systems and the consumers. If there is the necessity to alleviate the load in order to guarantee the safety restrictions, usually the curtailment occurs in the distribution system. An important aspect in the operation of these systems is that the load curtailment originates from failures in the generation and transmission system. Distributed generation (DG) is normally defined as small generation units (<10 MW) installed in distribution systems [2]. Distributed generation is expected to play an increasing role in emerging electric power systems. Studies have predicted that DG will be a significant percentage of all new generation going on line. It is predicted that they would have about 20% of new generations being installed [3]. They use different types of resources and technologies to serve energy to power systems. DG applications result in positive and negative side effects for both utility and customers [4], [5]. Different techniques have been proposed to solve the load shedding problem in distribution network. Aoki et al [6] describes a load curtailment procedure as part of a service restoration algorithm considering a violation vector with current capacity and voltage drop violations as components. A quantity called effective length of remaining violations is defined in [6]. Loads in the end sections of the violating feeders that have the smallest value of this quantity are curtailed. Sarma et al [7] consider load shedding in system with switch able capacitors and on-load tap changers. For voltage drop violations, if the load point with violation does not have a switch able capacitor, it will be shed. For current capacity violation at a component, a low priority load at a point beyond that component is shed. However, the steps to be taken when several current capacity and voltage drop violations are simultaneously present are not specified in this paper. Wang et al [8] investigates the effect of load-shedding procedures on distribution system reliability cost indices. Customer concerns regarding interruption costs are incorporated in the load-shedding decision process when a bulk system deficiency occurs. Cost weight factors for different feeder types, based on capacity and cost match, are used to determine the load-

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shedding priority among feeders. In [9], an optimal load shedding strategy for power system with multiple DGs is presented and in this paper discretization and mathematical programming has been introduced. In [10], a genetic algorithm is employed to search for supply restoration and optimal load shedding in distribution networks. In [11] line ampacity violations and voltage drop violations at the load points are considering for load shedding in radial distribution systems. But, to our knowledge, hardly anything has been reported in the literature on the problem of online load shedding with the objective of minimizing system loss during generation deficiency conditions caused by unscheduled outages in generation and transmission system for maneuver applications in case of emergency for distribution system. In [12] authors applied a GA optimization method for load shedding in distribution networks considering DG units.

This paper presents a new approach for solving the steady state load-shedding problem in distribution network during generation deficiency conditions with DGs. The problem is formulated to minimize the sum of curtailed load and also system losses. The problem is subjected to equality and inequality constraints. The formulated optimization problem is solved using GAs technique [1]. The method is tested on a radial distribution network with 33 load points. The effects of GAs parameters and operators are studied. Results are reported and discussed.

## II. MATHEMATICAL MODEL OF THE PROBLEM

Load shedding problem can be formulated as an optimization problem with the following objective function and constraints:

$$\text{Min} \left( \sum_{k=1}^{N_b} R_k \times I_k^2 \right) + W_L P_L \quad (1)$$

Such that:

$$P_{gi} - P_{di} - V_i \sum_{j=1}^N V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (2)$$

$$Q_{gi} - Q_{di} - V_i \sum_{j=1}^N V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (3)$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad i=1 \dots N_b \quad (4)$$

$$P_{ij}^{\min} \leq P_{ij} \leq P_{ij}^{\max} \quad i=1 \dots N_l \quad (5)$$

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \quad i=1 \dots N_{DG} \quad (6)$$

$$Q_{gi} = Q_g \quad \text{if} \quad Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max}$$

$$Q_{gi} = Q_{gi}^{\min} \quad \text{if} \quad Q_{gi} \leq Q_{gi}^{\min}$$

$$Q_{gi} = Q_{gi}^{\max} \quad \text{if} \quad Q_{gi}^{\max} \leq Q_{gi} \quad i=1 \dots N_{DG} \quad (7)$$

Where:

$N_b$ : Total number of branches

$R_k$ : Resistance of  $k^{\text{th}}$  branch

$I_k$ : Absolute value of current of the  $k^{\text{th}}$  branch

$W_L$ : Importance degree of customer L

$P_L$ : Demand active power of customer L

$P_{gi}$  : Generating active power at bus i

$P_{gi}^{\min}$  : Minimum limit for generating active power at bus i

$P_{gi}^{\max}$  : Maximum limit for generating active power at bus i

$P_{di}$  : Demand active power at bus i

$V_i$  : Magnitude of voltage at bus i

$Y_{ij}$  : Magnitude of (i, j) element of  $Y_{\text{Bus}}$  admittance matrix

$\theta_{ij}$  : Angle of (i, j) element of  $Y_{\text{Bus}}$  admittance matrix

$\delta_i$  : Angle of voltage at bus i

$Q_{gi}$  : Generating reactive power at bus i

$Q_{di}$  : Demand reactive power at bus i

$V_i^{\min}$  : Minimum limit for magnitude of voltage at bus i

$V_i^{\max}$  : Maximum limit for magnitude of voltage at bus i

$P_{ij}^{\min}$  : Minimum limit for active power of branch between buses i and j

$P_{ij}^{\max}$  : Maximum limit for active power of branch between buses i and j

In the set of equations (1) through (7),  $R_k \times I_k^2$  is the Ohmic loss of the  $k^{\text{th}}$  branch while  $k$  refers to  $k^{\text{th}}$  branch of the network. Equations (2) and (3) are well-known load flow equations. Security and operational constraints have been formulated as (4) and (5). Where, (4) refers to voltage limits and (5) point at thermal limit of distribution lines of the network. Equation set (7) refers to reactive limits of dispersed generators.

The steady state model of DG is used in this paper. This model is suitable for some kind of DGs such as gas turbine, combustion engines and hydro generation. DGs are modelled as constant power factor units. Considering this point, the bus connected to the DG can be modeled as PQ bus [13]. The output and the ramp rate are two constraints for this kind of DG. It must be pointed out that minimum output of some generation is an important constraint because of the cogeneration. They must generate certain power to ensure the heat supply [9]. These constraints can be written as set of equations 7 with  $N_{dg}$  as the number of installed DG in the system. Now the problem can be stated as minimization of the objective function (OBF) satisfying all system constraints stated above. A GA software package was written for simulation of load shedding in electrical distribution networks with and without DGs. This program initializes a random sample of individuals with different parameters to be optimized using the genetic algorithm approach. The population size of 100 is found to be appropriate for our problem. By tuning the GA parameters, the optimal performance was reached with one child per pair of parents. Chromosome length is of length number of buses plus one fitness bit.

III. CASE STUDY

A radial distribution network with 33 load points is used to simulate the load shedding problem with dispersed generation. The data of this test system is taken from [14].

The system is a hypothetical 12.66 kV system. When there is a disturbance in the network, the system operator may request the distribution utility or industrial customer to shed

load to maintain the system integrity. Two cases are studied. Case 1 occurred when DGs can not compensate decrease in power flows to the network. (Decrease in power is more than total installed DGs). Case 2 occurred when DGs can compensate decrease in power flows to the network. (Decrease in power is not more than total installed DGs).

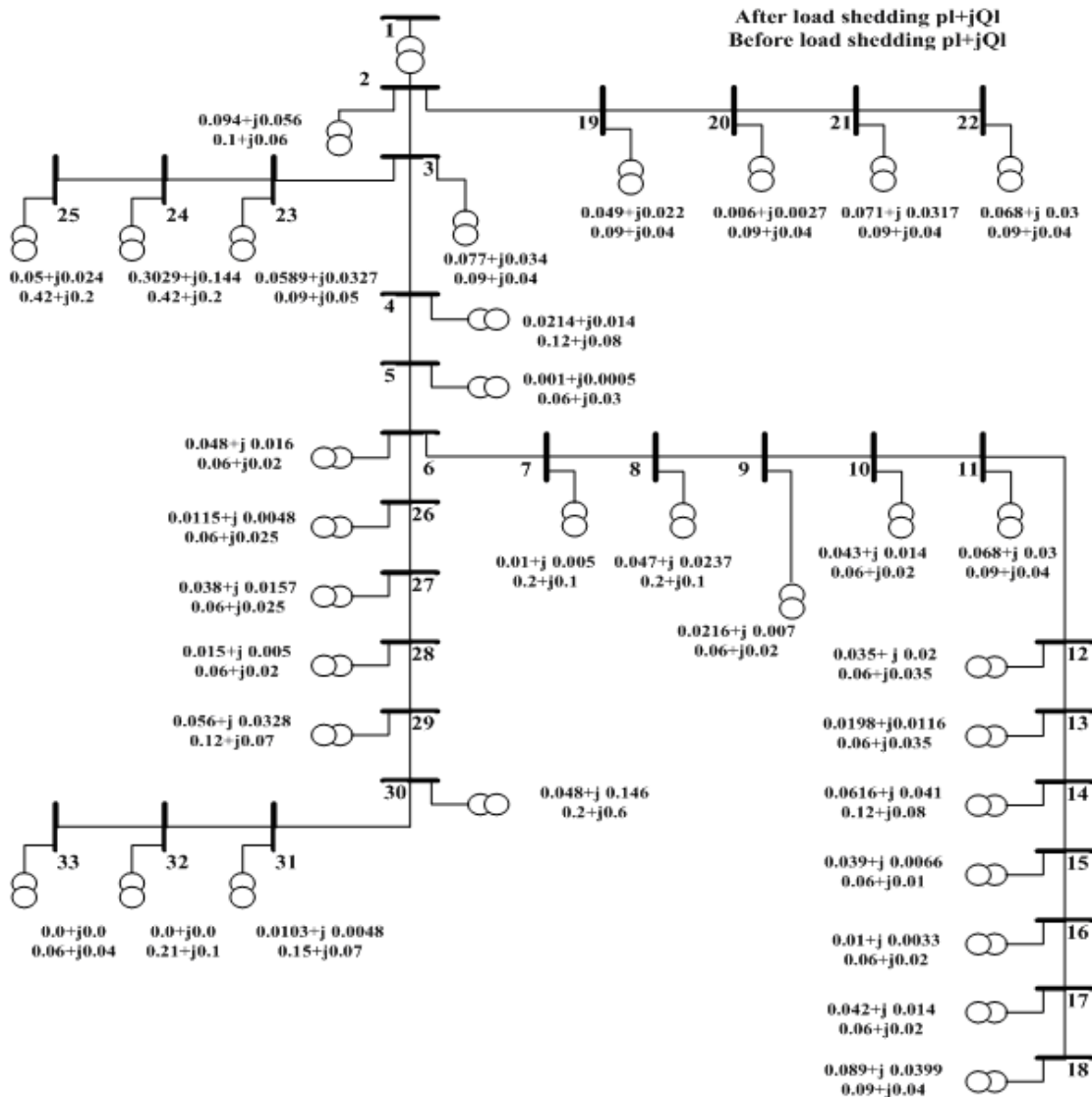


Fig. 1 Optimal load shedding considering constant capacity deficiency modelling of bulked power supply with out installed dispersed generators

Case 2 occurred when DGs can compensate decrease in power flows to the network. (Decrease in power is not more than total installed DGs).

A. Optimal load shedding considering constant capacity deficiency modelling of bulked power supply

Suppose now that the power flows to the network decreases to 1.5 per unit (the power flows to the network without DG in normal case is 3.9128 per unit) and caused emergency case for loads.

Using the proposed algorithm the resulting network topology is shown in Fig 1. The active and reactive load powers before and after load shedding can be compared in the network.

Table I shows the installation node and old and new operational power of DG's for the test system. DGs are installed in heavy loaded node. Suppose now that the power flows to the network decreases to 1.5 pu. Using the proposed algorithm in case 1 the resulting network topology is shown in

Fig 2.

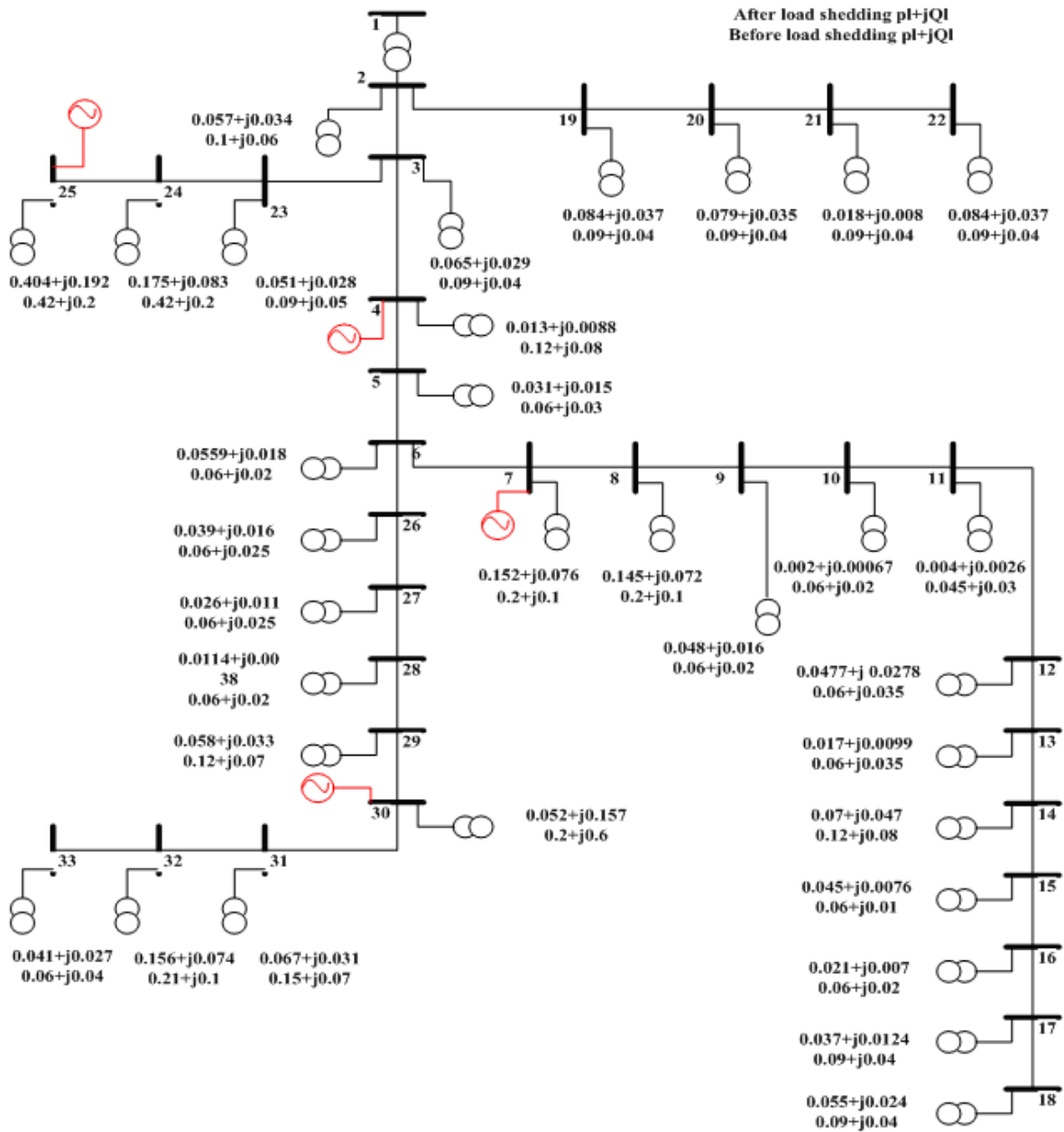


Fig. 2 Optimal load shedding considering constant capacity deficiency modelling of bulked power supply with installed dispersed generators

TABLE I  
INSTALLED NODE WITH OPERATING POINT OF DISPERSED GENERATORS

Node #	Operating point of DG before load shedding (kW/power factor)	Operating point of DG after load shedding (kW/power factor)	Max active power (kW/power factor)
4	50/0.8	83.3/0.8	193/0.8
7	100/0.9	161.23/0.9	175/0.9
25	200/0.9	284.63/0.9	300/0.9
30	100/1	163.04/1	175/1

Table II shows objective function, summation of loads, loss and profile index (PI)<sup>1</sup> of case study with/without DG.

TABLE II  
OBJECTIVE FUNCTION, TOTAL LOAD, LOSS, PI

Index	Load Shedding without DG	Load Shedding with DG
OBF	6.189	4.12
$\sum P_{load}$	1.464	2.211
$\sum Q_{load}$	0.8162	1.1806
Loss	0.023	0.0225
PI	0.019435	0.017425

*B. Optimal load shedding considering variable capacity deficiency modeling of bulked power supply*

For the proposed system, using the proposed formulation, the total supplied load decreases to 3.045 per unit by 0.02 per unit

unit decreasing step in case two.

For each case the result has been saved in a table and when the supplied power to the distribution system decreases in case of an emergency state, the optimum load shedding can be loaded from the table and applied to the system by system operator.

1) *Load shedding is not necessary (case1)*

Because the total maximum installed DGs is 0.793 per unit by decreasing the total supplied to 3.045 per unit by 0.02 per unit decreasing step load shedding is not needed and DGs can compensate the decreased power. Figure 3 shows the remained active load with and without DG in case one. Figure 4 and 5 shows the profile index (PI) and Percentage loss (the ratio of total loss to total generated power) of the system with and without DG in case one.

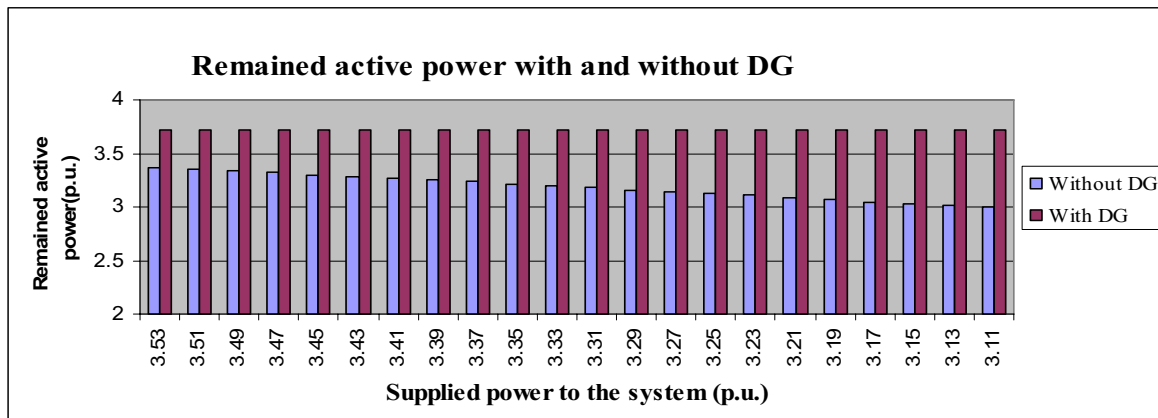


Fig .3 Remained active load of distribution network considering variable capacity deficiency modelling of bulked power supply with and without installed dispersed generators (case 1)

decreasing step in case one and 2.985 to 1.505 per unit by 0.02 per

$$^1 PI = \sum_{i=1}^N (V_i - 1)^2 \text{ (Voltages are in per unit)}$$

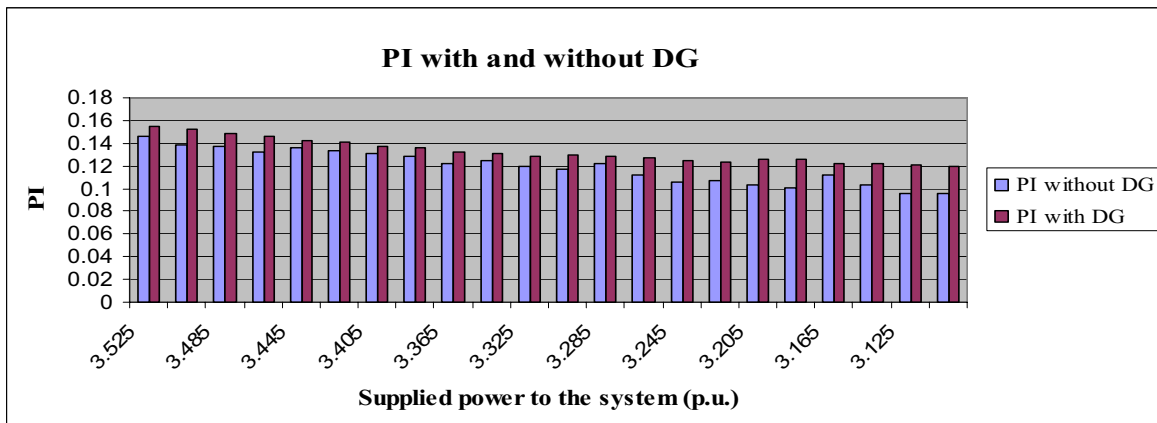


Fig. 4 Profile index (PI) of distribution network considering variable capacity deficiency modeling of bulked power supply with and without installed dispersed generators (case 1)

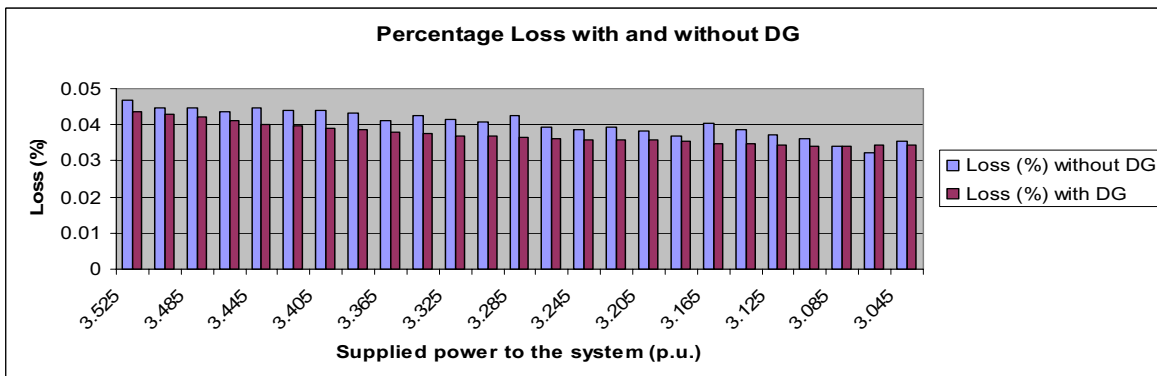


Fig. 5 Percentage loss of distribution network considering variable capacity deficiency modeling of bulked power supply with and without installed dispersed generators (case 1)

## 2) Load shedding is necessary (case2)

In this case because DGs are at maximum injection power by decreasing the total supplied load from 2.985 to 1.505 per unit by 0.02 per unit decreasing step load shedding is necessary and total decreased power can not be compensated by DGs. Figure 6, 7, and 8 shows the remained active load, profile index (PI) and Percentage loss of the system with and without DG considering variable capacity deficiency modeling of bulked power supply in case2.

considering constant and variable capacity deficiency modeling of bulked power supply. When deficiency occurred the main objective would be maintaining much more load of the system. In case1 this objective is satisfied by DGs. Also the proposed algorithm can improve the percentage loss in comparison the cases without DG according to figures 3, 4, 5. But in contrast the voltage profile was worse than cases without DG. These results were also shown in case2 and figures 6, 7, and 8.

## IV. ANALYSIS OF THE RESULTS

The proposed algorithm was successful in solving the optimization problem of optimal load shedding in distribution networks with and without installed DGs

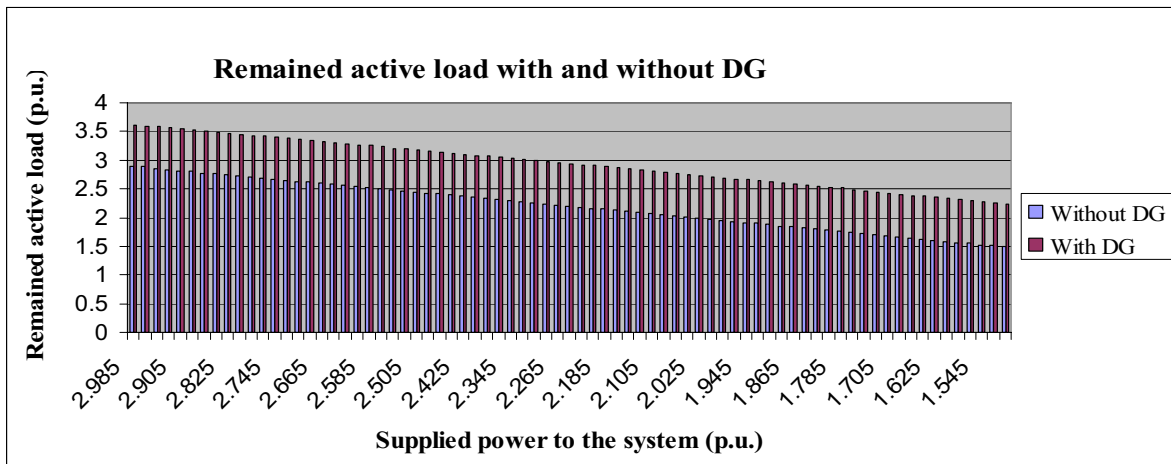


Fig. 6 Remained active load of distribution network considering variable capacity deficiency modeling of bulked power supply with and without installed dispersed generators (case 2)

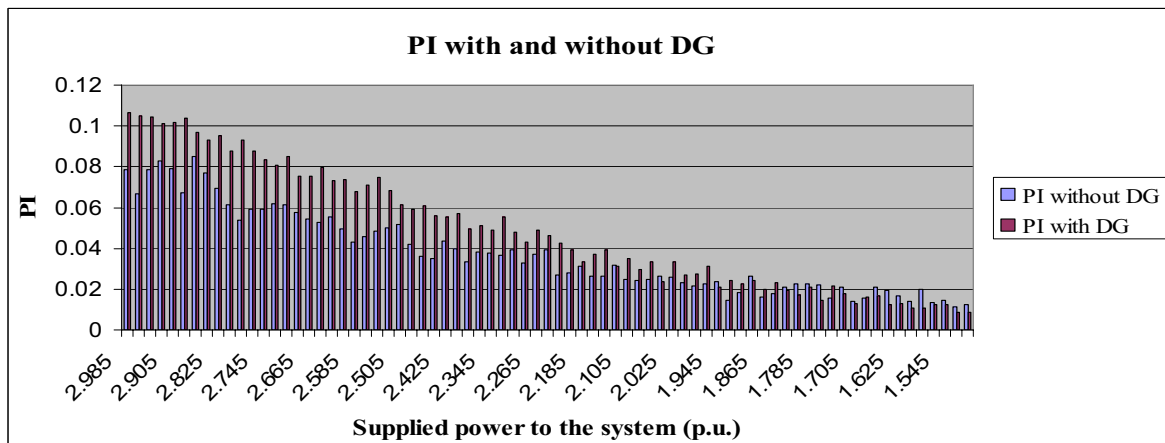


Fig. 7 Profile index (PI) of distribution network considering variable capacity deficiency modeling of bulked power supply with and without installed dispersed generators (case 2)

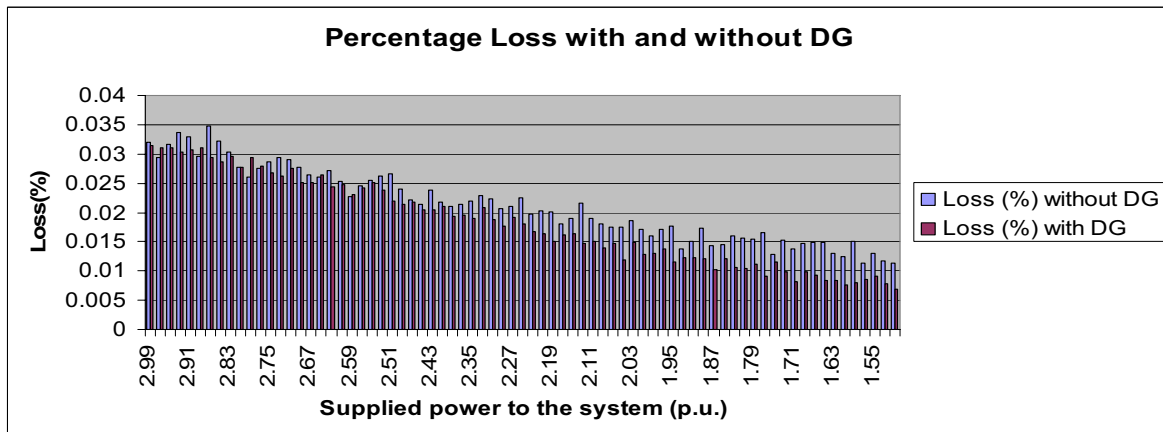


Fig. 8 Percentage loss of distribution network considering variable capacity deficiency modeling of bulked power supply with and without installed dispersed generators (case 2)

## V. CONCLUSION

The energy deficit originated from failures in the generation and transmission systems promotes load curtailments in the distribution system. There are many policies or strategies that can be adopted to perform these load curtailments. This paper proposed a GA-based methodology for finding optimum load shedding strategy for distribution networks with and without installed DGs considering constant and variable capacity deficiency modeling of Bulk Power Supply points of distribution networks. The model is based on minimization of total curtailed load based on their assigned importance degree and system losses within the frame work of load shedding equality and inequality constraints. A test system was used in order to apply the methodology and the results were presented for the various load shedding alternatives.

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