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# Optimal Allocation And Sizing Of Distributed Generation Using Linear Programming

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***Abstract:*** Distributed generation (DG) is becoming more important due to the increase in the demands for electrical energy. Distribution system loss reduction is one of the prime objectives for planning of distributed generation. To minimize the losses, optimal sizing and location of distributed generation (DG) is critically important. In this thesis, the optimal DG placement and sizing problem is investigated using single-objective optimization problem, where the system's power losses are considered as the objective to be minimized. These problems are formulated as constrained linear optimization problems using the Linear Programming method (LP).

The proposed method is demonstrated on IEEE-15 bus and IEEE-33 bus radial distribution systems extensively used as examples in solving the optimal location and sizing problem of distributed generators. Simulation results with the DG shows improvement in terms of voltage profile enhancement and power losses reduction are obtained satisfactorily.

***Index Terms*** **- Optimal Location, Distributed Generation (DG), Linear Programming Method (LP), Voltage profile enhancement.**

## I. Introduction

The electric power systems at present are mostly based on central generation. In these system, large generators feed power through transformers to high voltage transmission network to transport it over considerable distances. This power is then extracted through distribution transformers for delivery to the end users. However, around the world, the shortage of transmission system capacities along with the need for reliable power supply is causing an increased interest in Distributed Generation; DG can be defined as the integrated use of small generation units directly connected to a distribution system or inside the facilities of a customer. The potential development of DG is sustained in the following areas increasing power quality requirements, avoiding or shifting investment in transmission lines and/or transformers, ohmic losses minimization, environmental protection, and existence of high energy prices at retail level traditionally, a distribution company purchases energy from wholesale market, at a high voltage level, and then transfers this energy to final customers. Nevertheless, the restructuring process of the energy sector has stimulated the introduction of new agents and products, and the unbundling of traditional distribution company to technical and commercial tasks, including ancillary services. These units are of limited size and can be connected directly to the distribution network or on the customer site. Generally, the term Dispersed or Distributed Generation refers to any electric power production technology that is integrated within distribution systems, close to the point of use.

Distribution systems must deliver electricity to each customer's service entrance at an appropriate voltage rating. The X/R ratio for distribution levels is low compared to transmission levels, causing high power losses and a drop-in voltage magnitude along radial distribution lines. Studies [1] have indicated that approximately 13% of the total power generated is consumed as real power losses at the distribution level. Such non-negligible losses have a direct impact on the financial issues and overall efficiency of distribution utilities. Traditionally, distribution power losses are minimized through proper dispatch of reactive power control devices, which can be done by deploying automatic voltage regulators (tap changing transformers) and shunt capacitors installed at low voltage buses [2]. In recent years the integration of DG units in power distribution network has increased. To optimize electrical distribution network operation, it is necessary to provide the best location and size of DG. Installation of multiple DGs, objective is to minimize the total power, design variable are location and size are some of the common characters tics of optimal distributed generation plant [3]. Distributed power unit can be directly connected to consumer. It responds very quickly to system problem that can help in reduction in investment and can become more reliable. It can also reduce transmission losses, power wheeling cost and certain environmental emission costs. Economic efficiency is one of the major concerns of distributed generation customers. With many techno-economic restrictions and scenarios we could employ a flexible and reliable planning for renewable and distributed generations [4]. It is important to select the capacity of different type of DG to ensure reliability of micro- grid system. Grid connected system are constructed and output model of various DG are built. Power of wind turbine is predicted by linear interpolation and the output is calculated using reindl-hay model [5].

To solve the linear programming various methods are developed. Initially LP problem solved by graphical analysis but this method is not suitable for large decision variables. To solve the large decision variables simplex algorithm is used. Depend on objective function and constraints different cases of simplex algorithm are developed. Big m, two phase methods are the part of simplex algorithm [6]. Linear programming where all coefficients are fuzzy can be solved by resolution method. In this method rank is assigned to fuzzy objective and depends on feasibility degree objective value is decided. Higher the feasibility degree worst will be the objective value. To give rank to the fuzzy objective value, fuzzy raking method is used [7]. There are many techniques to distributed generation and each one has their own merit and demerit. Different techniques have different modular size and efficiency and based on different factor there generation cost are different from each other. Some have very low operation and maintenance cost and some have high. The penetration of DGs is very economical if their size and site are selected optimally by single or multiple objective functions under certain operating constraints. Its objective can be minimize cost or minimize power loss under different load condition. Constraints can be on no. of unit used or capacity of DGs [8]. Micro-grid has been integrated with the distributed renewable energy. It is environment friendly and provides higher reliability, reduces transmission loss and reduced greenhouse gas emission. Optimal power operation is determined to minimize the cost function. An optimization model has been presented and three cases are considered. Result is shown with no battery and 10 KW batteries [9]. A linear model is developed whose objective is to maximize the DG energy. Load factor is also included in the objective function. Constraints are putted on capacity allocation, location and plant size. The result is tested on 38 kV distribution network. Loss adjustment factor, effective load factor are also calculated [10].

## II. Optimal Allocation of DG using Linear Programming

George B. Dantzig in 1947 introduced linear programming. It is a method of optimizing an objective function by solving a system of linear equations where the solution is depending on constraints. The first polynomial-time algorithm for systems of linear equations was given by Khachiyan in 1979. LP problem consists of an objective function and a set of constraints. Feasible solution is the solution which satisfies all the constraints [8]. Most solution algorithms start by finding a feasible solution and then move from one feasible solution to another until the objective function has been optimized i.e. maximized or minimized. LP models can be considered as a special kind of decision model in which constraints is used to define the decision space, the objective function is used to define the aim (utility) and the type of decision is assumed under certainty. LP refers to the problem in which both the objective function to be optimized and all the constraints should be linear in terms of the decision variables i.e. there should be no square root, second degree polynomials. Simple models of linear programming can easily be solved graphically and this is particularly helpful, as it makes the intuition behind the process very clear but if numbers of variables are more than graphical method will become complex hence simplex method is used to solve the linear programming [11].

### 2.1. Standard form of a linear programming problem

The general linear programming problem can be stated in the following standard forms: [32]

Scalar Form

Minimize $f(x_1, x_2, \dots, x_n) = c_1x_1 + c_2x_2 + \cdots + c_nx_n$

Subject to the constraints

$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = b_1$ $a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = b_2$

$$a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n = b_m$$

$$x_1 \geq 0, x_2 \dots\dots n \geq 0$$

where $c_j$, $b_j$, and $a_{ij}$ $(i = 1, 2, \dots, m;\ j = 1, 2, \dots, n)$ are known constants and xj are the decision variables.

Matrix form:

The characteristics of a linear programming problem, stated in standard form, are

1. The objective function is of the minimization type.
2. All the constraints are of the equality type.
3. All the decision variables are nonnegative.

### 2.2. Solution of linear programming by simplex algorithm

There are many methods to solve linear programming but the most efficient method is simplex algorithm. It is simple and computationally efficient method. Other method is graphical method. Graphical method is preferable where numbers of variable are two, when number of variables increases graphical method become complex as it is difficult to locate point in three dimensional spaces, whereas simplex algorithm can take N number of decision variables to solve Linear Programming. Hence simplex algorithm is the most efficient method to solve the linear programming. Flow chart of simplex algorithm is shown below:

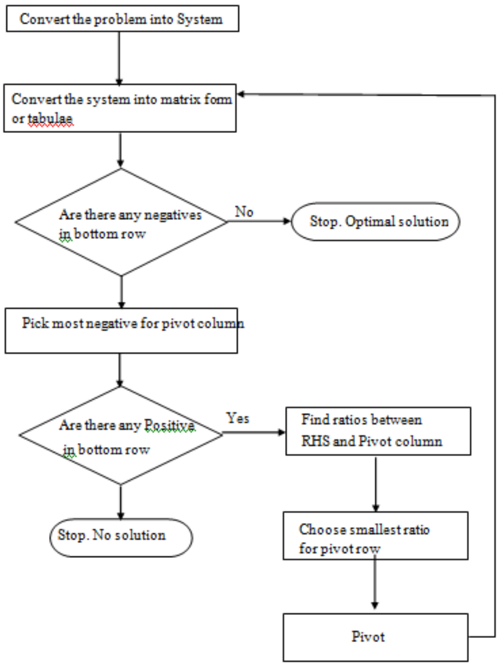


Figure .1: Flow chart for Simplex Algorithm

Simplex algorithm helps to move from one vertex to another adjacent vertex which is closest to the optimal solution among all other adjacent vertices. Thus, it follows the shortest route to reach the optimal solution from the starting point. Figure 1 shows the steps to solve the linear programming problem by simplex method. At initial stage problem is converted into a system and represent it into tabular form. After representing into tabular form we checked if there is any negative in bottom row if no then iteration will be over and we will get optimal solution and if we found negative element from bottom row then pick the most negative from the bottom row to find pivot column and find whether any positive in pivot column, if there is no positive in pivot column then there will be no solution and if we got positive then we need to find the ratio between RHS and pivot column. Smallest ratio will be pivot row. Intersection between pivot row and pivot column will be pivot element [11]. Again, the complete process will be repeated until the optimal solution is obtained.

**2.3. Determination of optimal capacity of DG using linear programming**

**2.3.1 Optimal allocation methodology**

An optimization problem can be mathematically defined as the minimization or maximization of a function (called the objective function) while satisfying a number of equality and/or inequality constraints on its variables.

**2.3.2. Mathematical formulation**

Based on the given condition objective function and subject to constraints are developed and formulated in mathematical form. Assumption taken in formulation of linear mathematical model.

The following Pre-assumptions are made:

a. It is considered that system is balanced test radial distribution network.
b. The voltage at all the buses is close to 1 PU.
c. All loads are constant power load.
d. Maximum DG capacity for present test system is not exceeds from system connected load.
e. Numbers of unit of DGs plant are single.

Power flow equations:

Distribution system power flow is calculated by the following set of recursive equations derived from the single line diagram shown in Fig. 14. From Fig. 14, the equivalent current injected at node k is calculated as

$$I_k = \left( \frac{P_{LK} + jQ_{LK}}{V_K} \right)^* \quad \text{…..(1)}$$

Branch current in the line section connecting buses k and k + 1 is calculated by using Kirchhoff's Current law as

$$I_K = I_{K+1} + I_{K+2} \quad \text{…..(2)}$$

The above equation is generalized in matrix form by using Bus current Injection to Branch Current matrix (BIBC) [13]. Now the branch current at each line can be calculated in a matrix form as follows:

$$[J] = [BIBC] \times [I] \quad \text{…..(3)}$$

By Kirchhoff's voltage law, the voltage at the bus k + 1 can be calculated as

$$V_{K+1} = V_K - I_K \times (R_K + jX_K) \quad \text{…..(4)}$$

The power loss in the line section connecting buses k and k + 1 is computed as

$$P_{LOSS}(K,K+1) = I^2 \times R_K = R_K \times \left( \frac{P_K^2 + Q_K^2}{|V_K^2|} \right) \quad .....(5)$$

The total power loss of the system is determined by the summation of losses in all the line sections, which is given as Eq (6)

$$P_{T,LOSS} = \sum_{K=1}^{n_b} P_{LOSS}(K,K+1) \quad .....(6)$$

*Voltage deviation index*

One of the main advantages of the optimal network reconfiguration and DG installation is the fall in voltage deviation. This index rebukes the configuration and size of DGs which gives the higher voltage deviation. The voltage deviation index (ΔVD) can be defined as Eq (7)

$$\Delta V_D = \left( \frac{V_1 - V_K}{V_K} \right) \qquad \forall K = 1,2.........N \quad .....(7)$$

During network reconfiguration and DG installation, if the state of the system has voltage limit violations, the proposed technique will try to minimize ΔVD closer to zero and thereby improves voltage stability and network performance.

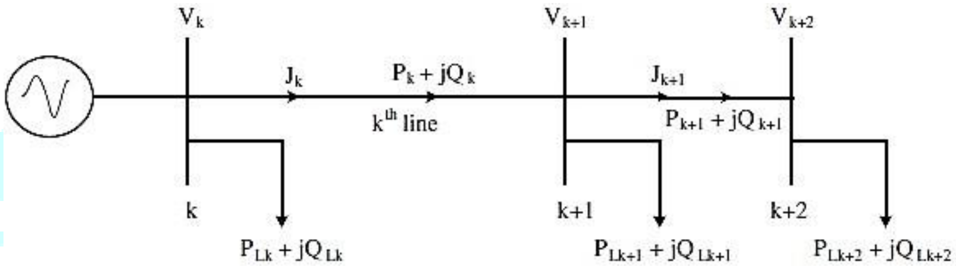


Figure.2.Single line diagram of radial Distribution system

**Objective function of the problem**

The proposed objective function (I) of the problem is formulated to minimize the total power loss subjected to following constraints which is given by Eq (8)

$$Minimize\ I = \min \sum_{K=1}^{n_b} P_{T,LOSS} \quad .....(8)$$

Subjected to

Voltage limit constraints Eq(9)

$$|V_K^{\min}| \le |V_K| \le |V_K^{\max}| \quad .....(9)$$

Distributed generation real and reactive power capacity constraints are given in Eq(10)

$$P_K^{\min} \le P_{DG} \le P_{DG}^{\max} \quad .....(10)$$
$$Q_K^{\min} \le Q_{DG} \le Q_{DG}^{\max}$$

Furthermore, the radial nature of distribution network must be maintained, and all loads must be served. If any one of the above constraints is violated, the resultant solution will be rejected.

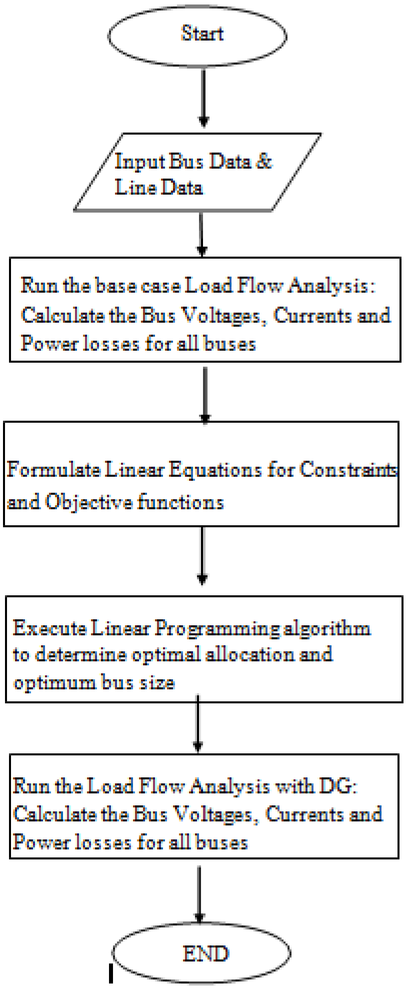


Figure 3: Flow chart for optimal allocation methodology

*Mathematical Model of Dg:*

A DG unit can be modelled as either a PV or PQ bus in the distribution system. If DGs have control over the voltage by regulating the excitation voltage (synchronous generator DGs) or if the control circuit of the converter is used to control P and V independently, then the DG unit may be modelled as a PV type. Other DGs, like induction generator-based units or converters used to control P and Q independently, are modelled as PQ types [13]. The DG reactive power can be calculated by the following equation:

$$Q_{DGi} = P_{DGi} \times \tan\left(\cos^{-1}\left(PF_{DGi}\right)\right) \quad .....(11)$$

## III. Voltage profile behaviour with DG installations

From the expression for complex power, note that S is specified at the load bus

$$S_L = P_L + jQ_L = V_L I_L^* \quad .....(12)$$

$$I_L = \frac{P_L - jQ_L}{V_L} \quad .....(13)$$

Voltage at the DG is

$$V_{DG} = V_L + I_L\left(R + jX\right) \quad .....(14)$$

$$V_{DG} = V_L + \left(\frac{P_L - jQ_L}{V_L}\right)\left(R + jX\right) \quad .....(15)$$

$$V_{DG} = V_L + \frac{RP_L + XQ_L}{V_L} + j\frac{XP_L - RQ_L}{V_L} \quad .....(16)$$

Where PDG and QDG are the active and reactive power of the generator, respectively, Z = R + jX$_L$ is the impedance of the line, PL and QL are active and reactive power at the bus, and VDG and VL are the voltages at the generator and bus, respectively. Thus, it can be seen that the generator voltage will be the load bus voltage plus some value related to the impedance of the line and the power flows along that line. It is evident that the larger the impedance and power flow, the larger the voltage rise. The increased active power flows on the distribution network have a large impact on the voltage level because the resistive element of the lines on distribution networks are higher than other lines. The voltage must be kept within standard limits at each bus

$$V_{\min,i} \le V \le V_{\max,i,} \quad i \ \forall \ N \quad .....(17)$$

Where $V_{min}$, i and $V_{max}$, i refer to the minimum and maximum voltage limits at the ith bus. The relationship between voltage and power injections at each bus is determined. As MWs are added at each individual bus, the voltage rises. Increasing levels of generation are added incrementally at each bus in turn, and load flow analysis is carried out to determine a voltage versus active power characteristic (slope of Voltages/Active powers) for each bus. The interdependence of the bus voltage levels is examined. Once again, increasing levels of generation are added incrementally at each bus, but now the voltage level at every other bus is examined. Thus, characteristics are determined for voltage levels at each bus due to generation at all other buses. By combination of these characteristics, the voltage constraint may be formalized into algebraic equations for each bus, as shown in the following:

$$\mu_i P_{DGi} + \beta_i + \sum_{j=1}^{n} \mu_{ji} P_{DGi} \le V_{\max,i} \quad i \forall N,\ i \ne j \quad .....(18)$$

where μi is the dependency of the voltage level at bus i on power injections at bus i, i.e., the slope of the voltage versus power injection characteristic of the ith bus *i* refers to the initial voltage level at the ith bus with no generation, and μi refers to the dependency of the voltage level at bus *i* on power injections at bus j.

## IV. Simulation Results of IEEE 15 and IEEE 33 Bus Radial distribution systems:

The proposed optimal DG size and placement in the distribution systems is implemented on IEEE 15 and IEEE 33 Bus Radial distribution systems and is coded in MATLAB® Version 8.5.0.197613 (R2015a). The following analysis is performed with the test systems and presented accordingly:

i. Determining the optimal size and placing of DG.
ii. The effect of DG allocation on a voltage profile.
iii. The effect of DG allocation on a power loss.

A voltage deviation index was calculated in all tests and cases to show improvements in the voltage profiles as shown in tables.

### 4.1. Radial Distribution System (IEEE-15 BUS)

The first test was applied on an existing rural distribution feeder. This system consists of 15 buses and 14 branches at 12.66 KV voltage level. The capacity of the system is 3802 kW real power and 2694 KVAR reactive power. Figure 4 shows the single line diagram of the IEEE 15 bus radial distribution system under study, with its lateral branches. The optimization problem is investigated for single DG installation and two DGs installation as follows.

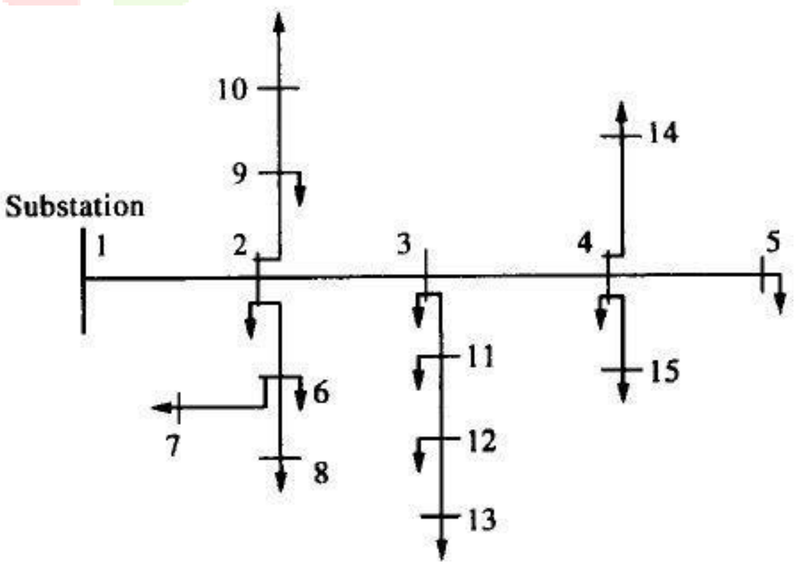


Figure 4: A single-line diagram of a 15-bus radial distribution system.

**4.2. Installing single DG**

The proposed method was applied to a 15-bus radial distribution system by installing one DG. Table 1 shows the DG optimal size and corresponding real power losses and voltage deviation at all of the system buses. The optimal location of DG is determined by LP is at bus numbers 12. Installing the DG at bus 12 with a size of 467 KVA caused a reduction in apparent power losses from 512.7 KVA to 358.8 KVA, which is about a 30.16% reduction. Table 2 shows the improvement in the voltage profile after installing the DG unit at bus 12. Here it can be observed that voltage deviation is improved to 1.2%. The obtained results are verified with [14].

Table 1: Real and Reactive power loss comparison with single DG

| BUS No. | P Loss w/oDG (KW) | P Loss with DG(KW) | Q Loss w/o DG(KVAR) | Q Loss with DG(KVAR) |
|---|---|---|---|---|
| 2 | 235.0531 | 168.7537 | 229.9111 | 165.0620 |
| 3 | 70.1895 | 38.7811 | 68.6540 | 37.9328 |
| 4 | 15.1891 | 15.0112 | 14.8568 | 14.6829 |
| 5 | 0.3443 | 0.3403 | 0.2322 | 0.2295 |
| 6 | 0.8677 | 0.8623 | 0.5853 | 0.5817 |
| 7 | 0.2048 | 0.2035 | 0.1381 | 0.1372 |
| 8 | 22.3133 | 22.1723 | 15.0505 | 14.9554 |
| 9 | 5.9023 | 5.8649 | 3.9812 | 3.9559 |
| 10 | 2.9459 | 2.9273 | 1.9871 | 1.9745 |
| 11 | 13.5184 | 1.4078 | 9.1182 | 0.9496 |
| 12 | 3.7304 | 1.7664 | 2.5162 | 1.1915 |
| 13 | 0.4587 | 0.4458 | 0.3094 | 0.3007 |
| 14 | 1.2726 | 1.2576 | 0.8584 | 0.8483 |
| 15 | 2.7320 | 2.7000 | 1.8428 | 1.8212 |
| TOTAL | 374.722 KW | 262.4943 KW | 350.0413 KVAR | 244.623 KVAR |

Table 2: Voltages (P.U) before and after placement of DG

| BUS No. | Voltages (P.U) w/o DG | Voltages (P.U) with DG | %Voltage Improvement |
|---|---|---|---|
| 1 | 1 | 1 | 0 |
| 2 | 0.9815 | 0.9846 | 0.195 |
| 3 | 0.9721 | 0.9778 | 0.353 |
| 4 | 0.9685 | 0.9742 | 0.366 |
| 5 | 0.9678 | 0.9735 | 0.366 |
| 6 | 0.9745 | 0.9776 | 0.196 |
| 7 | 0.9721 | 0.9752 | 0.197 |
| 8 | 0.9727 | 0.9758 | 0.218 |
| 9 | 0.9803 | 0.9834 | 0.195 |
| 10 | 0.9797 | 0.9829 | 0.185 |
| 11 | 0.9675 | 0.9767 | 0.575 |
| 12 | 0.9647 | 0.9785 | 0.861 |
| 13 | 0.9638 | 0.9778 | 1.105 |
| 14 | 0.9669 | 0.9726 | 0.366 |
| 15 | 0.9667 | 0.9725 | 0.367 |

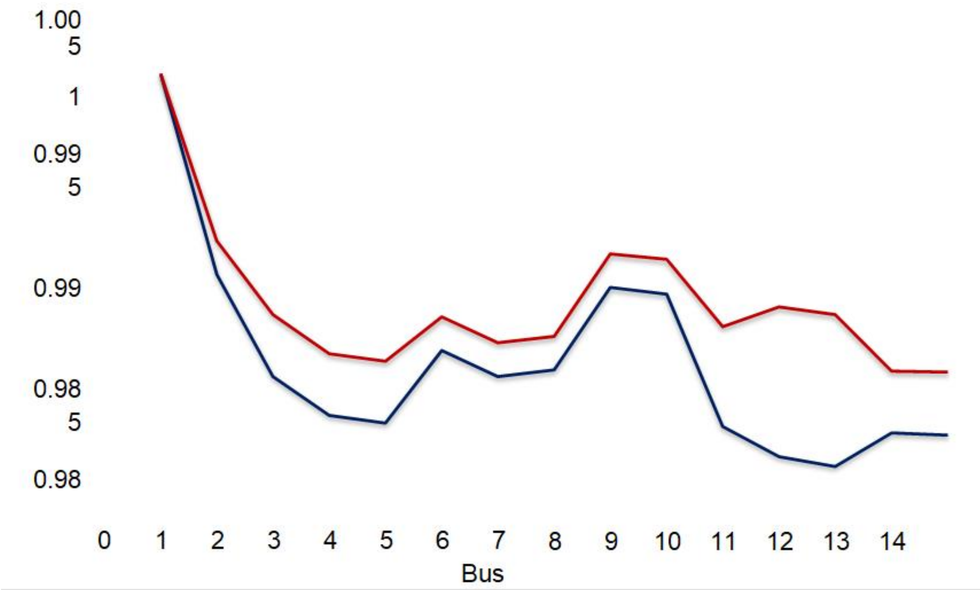


Figure .5: Voltage profiles of 15-bus radial distribution system with installing single DG

### 4.3 Installing two DGs

The proposed method was applied by installing two DGs. Table 3 shows the DG optimal size and corresponding real power losses and voltage deviation at all of the system buses. The optimal location of DG is determined by LP is at bus numbers 4 and 11. Installing the DG at these buses with a size of 261 KVA and 337 KVA caused a reduction in apparent power losses from 512.7 KVA to 163.26 KVA, which is about 68.16% reduction. Table 4 shows the improvement in the voltage profile after installing the DG units at bus numbers 4 and 11. Voltage profiles are also improved to 1.76 % and 1.78 % at buses 4 and 11 respectively, the obtained results are verified with [14].

Table 3: Real and Reactive power loss comparison table with installing two DGs

| BUS No. | P Loss w/o DG(KW) | P Loss with DG(KW) | Q Loss w/o DG(KVAR) | Q Loss with DG(KVAR) |
|---|---|---|---|---|
| 2 | 235.0531 | 75.1135 | 229.9111 | 73.4703 |
| 3 | 70.1895 | 5.5793 | 68.6540 | 5.4573 |
| 4 | 15.1891 | 1.7452 | 14.8568 | 1.7070 |
| 5 | 0.3443 | 0.3315 | 0.2322 | 0.2236 |
| 6 | 0.8677 | 0.8527 | 0.5853 | 0.5752 |
| 7 | 0.2048 | 0.2012 | 0.1381 | 0.1357 |
| 8 | 22.3133 | 21.9235 | 15.0505 | 14.7876 |
| 9 | 5.9023 | 5.7989 | 3.9812 | 3.9114 |
| 10 | 2.9459 | 2.8944 | 1.9871 | 1.9523 |
| 11 | 13.5184 | 0.3383 | 9.1182 | 0.2281 |
| 12 | 3.7304 | 3.5743 | 2.5162 | 2.4108 |
| 13 | 0.4587 | 0.4395 | 0.3094 | 0.2964 |
| 14 | 1.2726 | 1.2252 | 0.8584 | 0.8264 |
| 15 | 2.7320 | 2.6303 | 1.8428 | 1.7741 |
| TOTAL | 374.722 KW | 122.6484 KW | 350.0413 KVAR | 107.7569 KVAR |

Table 4: Voltages (P.U) before and after placement of DG

| BUS No. | Voltages (P.U) w/o DG | Voltages (P.U) with DG | %Voltage Improvement |
|---|---|---|---|
| 1 | 1 | 1 | 0 |
| 2 | 0.9815 | 0.9884 | 0.703 |
| 3 | 0.9721 | 0.9883 | 1.666 |
| 4 | 0.9685 | 0.9855 | 1.755 |
| 5 | 0.9678 | 0.9847 | 1.746 |
| 6 | 0.9745 | 0.9854 | 1.118 |
| 7 | 0.9721 | 0.9853 | 1.357 |
| 8 | 0.9727 | 0.9883 | 1.603 |
| 9 | 0.9803 | 0.9883 | 0.816 |
| 10 | 0.9797 | 0.9856 | 0.602 |
| 11 | 0.9675 | 0.9847 | 1.777 |
| 12 | 0.9647 | 0.9855 | 2.156 |
| 13 | 0.9638 | 0.9853 | 2.230 |
| 14 | 0.9669 | 0.9884 | 2.223 |
| 15 | 0.9667 | 0.9883 | 2.234 |

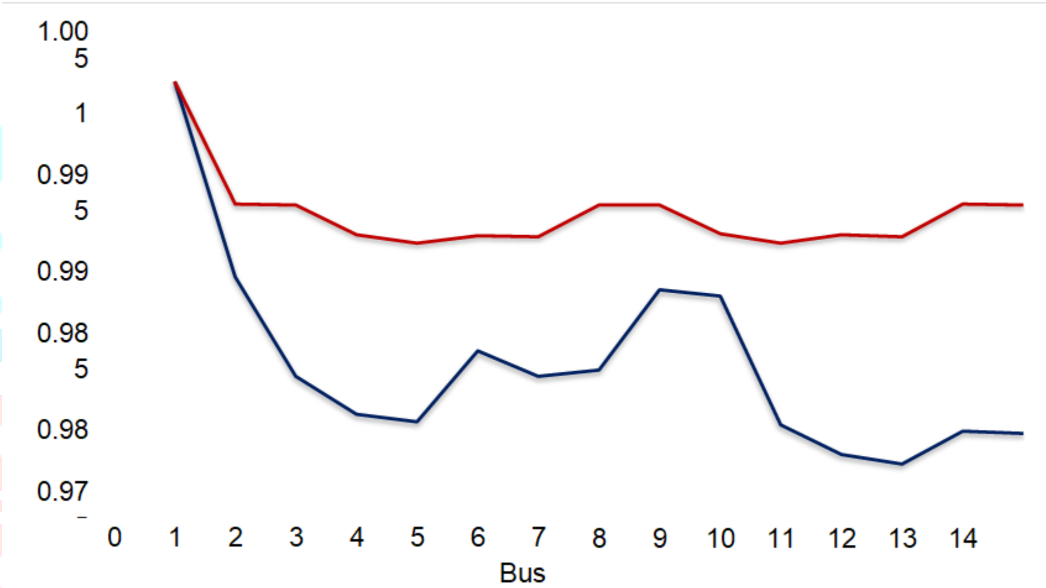


Figure. 6: Voltage profiles of 15-bus radial distribution system with installing two DGs

### 4.4. IEEE-33 Bus Meshed Distribution System

In the second test, a meshed distribution system was used to investigate the proposed optimization problem in finding the optimal DG size and place. The 33-bus meshed distribution system is a 12.66 kV voltage level and has 33 bus and 37 branches. The total active and reactive loads are 3715 kW and 2300 KVAR, respectively. The corresponding single line of the IEEE 33 bus radial distribution system is shown in Figure 7.The optimization problem is solved for single DG installation and two DGs installation as follows.

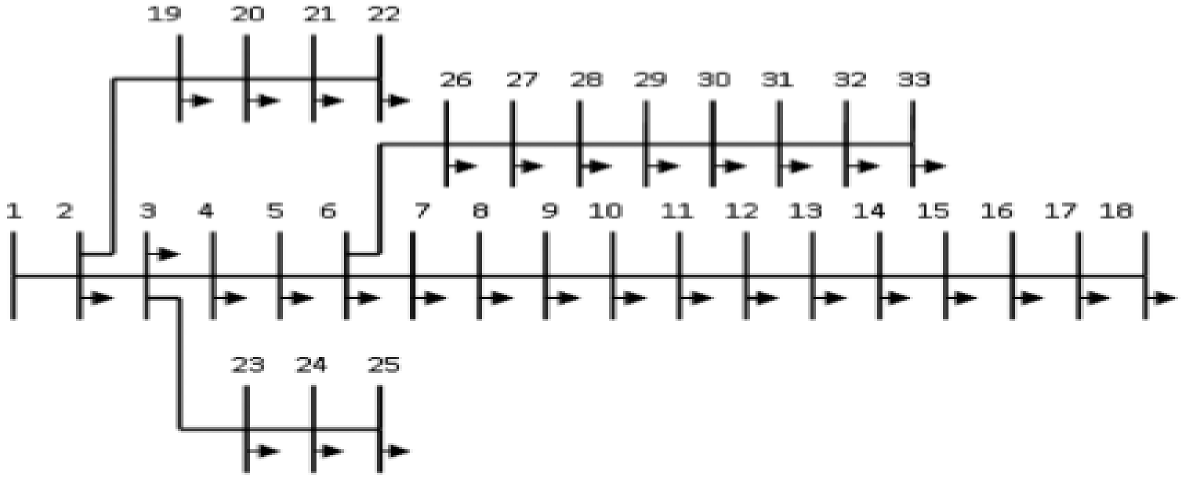


Figure 7: A single-line diagram of a 33-bus meshed distribution system

### 4.5. Installing single DG

At all of the 33 buses, the optimal DG sizing problem was solved for installing a single DG. The results are listed in Table 5 shows the corresponding total real and reactive power losses for installing an optimal DG size at each bus of the system. The optimal location of DG is determined by LP is at bus number 26. By locating the single DG at bus 26 with power output of 2646 KVA, the total real power loss is reduced from 2436 KVA at no DG installed to 805.5 KVA, which is an approximate reduction of 66.96% in losses. As shown in Table 6, voltage profiles are also improved to 5.19%.

Table 5. Real and Reactive power loss comparison with installation of single DG

| BUS No. | P Loss w/o DG(KW) | P Loss with DG (KW) | Q Loss w/o DG(KVAR) | Q Loss with DG(KVAR) |
|---|---|---|---|---|
| 2 | 122.4042 | 19.2584 | 62.3970 | 9.8172 |
| 3 | 517.9123 | 53.7658 | 263.7886 | 27.3846 |
| 4 | 199.0048 | 1.4810 | 101.3511 | 0.7543 |
| 5 | 186.9894 | 0.7789 | 95.2365 | 0.3967 |
| 6 | 382.4862 | 1.7982 | 330.1804 | 1.5523 |
| 7 | 19.1452 | 17.4107 | 63.2854 | 57.5520 |
| 8 | 48.3797 | 43.9640 | 15.9883 | 14.5290 |
| 9 | 41.8054 | 37.9552 | 30.0349 | 27.2688 |
| 10 | 35.6091 | 32.3212 | 25.2402 | 22.9096 |
| 11 | 5.5370 | 5.0248 | 1.8307 | 1.6613 |
| 12 | 8.8113 | 7.9947 | 2.9136 | 2.6436 |
| 13 | 26.6624 | 24.1854 | 20.9775 | 19.0287 |
| 14 | 7.2916 | 6.6134 | 9.5978 | 8.7051 |
| 15 | 3.5697 | 3.2369 | 3.1771 | 2.8809 |
| 16 | 2.8147 | 2.5519 | 2.0555 | 1.8636 |
| 17 | 2.5163 | 2.2811 | 3.3597 | 3.0456 |
| 18 | 0.5314 | 0.4817 | 0.4167 | 0.3777 |
| 19 | 1.6095 | 1.6037 | 1.5359 | 1.5304 |
| 20 | 8.3218 | 8.2917 | 7.4986 | 7.4714 |
| 21 | 1.0076 | 1.0039 | 1.1771 | 1.1728 |
| 22 | 0.4363 | 0.4348 | 0.5769 | 0.5748 |
| 23 | 31.8163 | 31.0771 | 21.7397 | 21.2346 |
| 24 | 51.4368 | 50.2397 | 40.6167 | 39.6715 |
| 25 | 12.8745 | 12.5739 | 10.0740 | 9.8388 |
| 26 | 26.0090 | 23.6226 | 13.2479 | 12.0324 |
| 27 | 33.2899 | 30.2292 | 16.9495 | 15.3912 |
| 28 | 113.0086 | 102.5974 | 99.6375 | 90.4582 |
| 29 | 78.3335 | 71.1093 | 68.2423 | 61.9488 |
| 30 | 38.9567 | 35.3598 | 19.8430 | 18.0109 |
| 31 | 15.9364 | 14.4578 | 15.7499 | 14.2886 |
| 32 | 2.1320 | 1.9340 | 2.4849 | 2.2542 |

| | | | | |
|---|---|---|---|---|
| 33 | 0.1317 | 0.1195 | 0.2048 | 0.1857 |
| TOTAL | 2026.8 KW | 637 KW | 1351.4 KVAR | 493.4 KVAR |

Table 6: Voltages (P.U) before and after placement of DG

| BUS No. | Voltages (P.U)w/o DG | Voltages(P.U)with DG | % Voltage Improvement |
|---|---|---|---|
| 1 | 1 | 1 | 0 |
| 2 | 0.9970 | 0.9988 | 0.180542 |
| 3 | 0.9829 | 0.9945 | 1.180181 |
| 4 | 0.9755 | 0.9943 | 1.927217 |
| 5 | 0.9681 | 0.9945 | 2.726991 |
| 6 | 0.9496 | 0.9949 | 4.77043 |
| 7 | 0.9462 | 0.9916 | 4.79814 |
| 8 | 0.9413 | 0.9870 | 4.854988 |
| 9 | 0.9351 | 0.9811 | 4.91926 |
| 10 | 0.9292 | 0.9755 | 4.982781 |
| 11 | 0.9284 | 0.9747 | 4.987075 |
| 12 | 0.9269 | 0.9733 | 5.005934 |
| 13 | 0.9207 | 0.9675 | 5.083089 |
| 14 | 0.9185 | 0.9653 | 5.095264 |
| 15 | 0.9171 | 0.9639 | 5.103042 |
| 16 | 0.9157 | 0.9626 | 5.121765 |
| 17 | 0.9137 | 0.960 | 5.067309 |
| 18 | 0.9131 | 0.9602 | 5.158252 |
| 19 | 0.9965 | 0.9983 | 0.180632 |
| 20 | 0.9930 | 0.9947 | 0.171198 |
| 21 | 0.9922 | 0.9941 | 0.191494 |
| 22 | 0.9916 | 0.9934 | 0.181525 |
| 23 | 0.9794 | 0.9910 | 1.184399 |
| 24 | 0.9727 | 0.9844 | 1.202837 |
| 25 | 0.9694 | 0.9812 | 1.217248 |
| 26 | 0.9477 | 0.9969 | 5.191516 |
| 27 | 0.9452 | 0.9945 | 5.215827 |
| 28 | 0.9338 | 0.9837 | 5.343757 |
| 29 | 0.9255 | 0.9759 | 5.445705 |
| 30 | 0.9219 | 0.9725 | 5.488665 |
| 31 | 0.9178 | 0.9685 | 5.524079 |
| 32 | 0.9168 | 0.9677 | 5.55192 |
| 33 | 0.9165 | 0.9674 | 5.553737 |

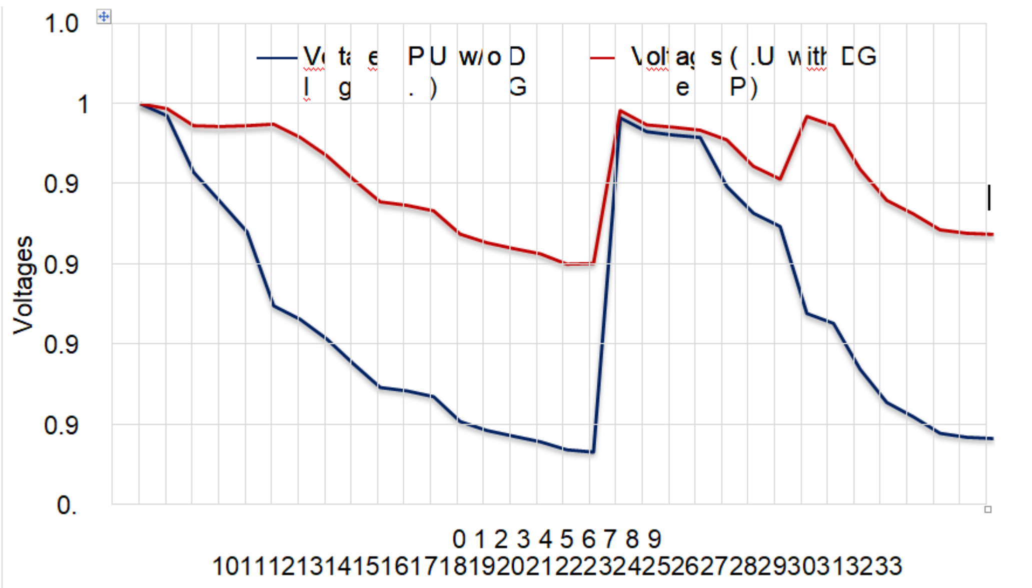


Figure 8: Voltage profiles of IEEE-33 bus system with installing single DG

**4.5. Installing two DGs:**

The optimal DG location and sizing problem was solved for installing a two DGs. The results are listed in Table 7 which shows the corresponding total real and reactive power losses for installing an optimal DG size at each bus of the system. The optimal location of DG determined by LP is at bus numbers 12 and 30. By locating the two DGs at buses 12 and 30 with power output of 892 KVA and 1249 KVA, the total real power loss is reduced from 2436 KVA at no DG installed to 383.5 KVA, which is an approximate reduction of 84.2% in losses. As shown in Table 8, voltage profiles are also improved to 7.91% and 8.45% at buses 12 and 30 respectively.

Table 7: Real and Reactive power loss comparison table after installing two DGs

| BUS No. | P Loss w/o DG(KW) | P Loss with DG (KW) | Q Loss w/o DG(KVAR) | Q Loss with DG(KVAR) |
|---|---|---|---|---|
| 2 | 122.4042 | 20.6149 | 62.3970 | 10.4579 |
| 3 | 517.9123 | 59.0134 | 263.7886 | 29.8596 |
| 4 | 199.0048 | 2.0342 | 101.3511 | 1.0111 |
| 5 | 186.9894 | 0.9212 | 95.2365 | 0.4592 |
| 6 | 382.4862 | 1.6678 | 330.1804 | 1.4307 |
| 7 | 19.1452 | 0.3397 | 63.2854 | 1.4575 |
| 8 | 48.3797 | 1.1724 | 15.9883 | 0.2852 |
| 9 | 41.8054 | 8.0424 | 30.0349 | 4.7363 |
| 10 | 35.6091 | 10.989 | 25.2402 | 6.5499 |
| 11 | 5.5370 | 2.7005 | 1.8307 | 0.7667 |
| 12 | 8.8113 | 6.3910 | 2.9136 | 1.8444 |
| 13 | 26.6624 | 22.7818 | 20.9775 | 17.9562 |
| 14 | 7.2916 | 6.2290 | 9.5978 | 8.2138 |
| 15 | 3.5697 | 3.0484 | 3.1771 | 2.7179 |
| 16 | 2.8147 | 2.4030 | 2.0555 | 1.7580 |
| 17 | 2.5163 | 2.1479 | 3.3597 | 2.8729 |
| 18 | 0.5314 | 0.4535 | 0.4167 | 0.3562 |
| 19 | 1.6095 | 1.6038 | 1.5359 | 1.5305 |
| 20 | 8.3218 | 8.2923 | 7.4986 | 7.4720 |
| 21 | 1.0076 | 1.0040 | 1.1771 | 1.1729 |
| 22 | 0.4363 | 0.4348 | 0.5769 | 0.5748 |
| 23 | 31.8163 | 31.0937 | 21.7397 | 21.2451 |
| 24 | 51.4368 | 50.2667 | 40.6167 | 39.6912 |
| 25 | 12.8745 | 12.5806 | 10.0740 | 9.8437 |
| 26 | 26.0090 | 1.6000 | 13.2479 | 0.8969 |
| 27 | 33.2899 | 2.7609 | 16.9495 | 1.5663 |
| 28 | 113.0086 | 12.7951 | 99.6375 | 12.6134 |
| 29 | 78.3335 | 12.1165 | 68.2423 | 11.7666 |
| 30 | 38.9567 | 11.2993 | 19.8430 | 6.3771 |
| 31 | 15.9364 | 13.5511 | 15.7499 | 13.3670 |
| 32 | 2.1320 | 1.81264 | 2.4849 | 2.1086 |
| 33 | 0.1317 | 0.1119 | 0.2048 | 0.1737 |
| TOTAL | 2026.8 KW | 312.27 KW | 1351.4 KVAR | 223.13 KVAR |

Table 8: Voltages (P.U) before and after placement of two DGs

| BUS No. | Voltages (P.U)w/o DG | Voltages (P.U)with DG | %Voltage Improvement |
|---|---|---|---|
| 1 | 1 | 1 | 0 |
| 2 | 0.9970 | 0.9982 | 0.1757 |
| 3 | 0.9829 | 0.9940 | 1.1312 |
| 4 | 0.9755 | 0.9934 | 1.8492 |
| 5 | 0.9681 | 0.9932 | 2.6069 |
| 6 | 0.9496 | 0.9929 | 4.5581 |
| 7 | 0.9462 | 0.9928 | 4.9355 |
| 8 | 0.9413 | 0.9931 | 5.5024 |
| 9 | 0.9351 | 0.9955 | 6.4744 |
| 10 | 0.9292 | 0.9985 | 7.4613 |
| 11 | 0.9284 | 0.9990 | 7.6170 |
| 12 | 0.9269 | 1.000 | 7.9122 |
| 13 | 0.9207 | 0.9945 | 8.0150 |
| 14 | 0.9185 | 0.9924 | 8.0538 |
| 15 | 0.9171 | 0.9911 | 8.0780 |
| 16 | 0.9157 | 0.9898 | 8.1015 |
| 17 | 0.9137 | 0.9880 | 8.1368 |
| 18 | 0.9131 | 0.9874 | 8.1473 |
| 19 | 0.9965 | 0.9982 | 0.1759 |
| 20 | 0.9930 | 0.9946 | 0.1772 |
| 21 | 0.9922 | 0.9939 | 0.1774 |
| 22 | 0.9916 | 0.9933 | 0.1777 |
| 23 | 0.9794 | 0.9905 | 1.1395 |
| 24 | 0.9727 | 0.9839 | 1.1550 |
| 25 | 0.9694 | 0.9806 | 1.1628 |
| 26 | 0.9477 | 0.9932 | 4.8022 |
| 27 | 0.9452 | 0.9937 | 5.1440 |
| 28 | 0.9338 | 0.9959 | 6.6655 |
| 29 | 0.9255 | 0.9979 | 7.8345 |
| 30 | 0.9219 | 0.9998 | 8.4597 |
| 31 | 0.9178 | 0.9960 | 8.5340 |
| 32 | 0.9168 | 0.9952 | 8.5505 |
| 33 | 0.9165 | 0.9949 | 8.5556 |

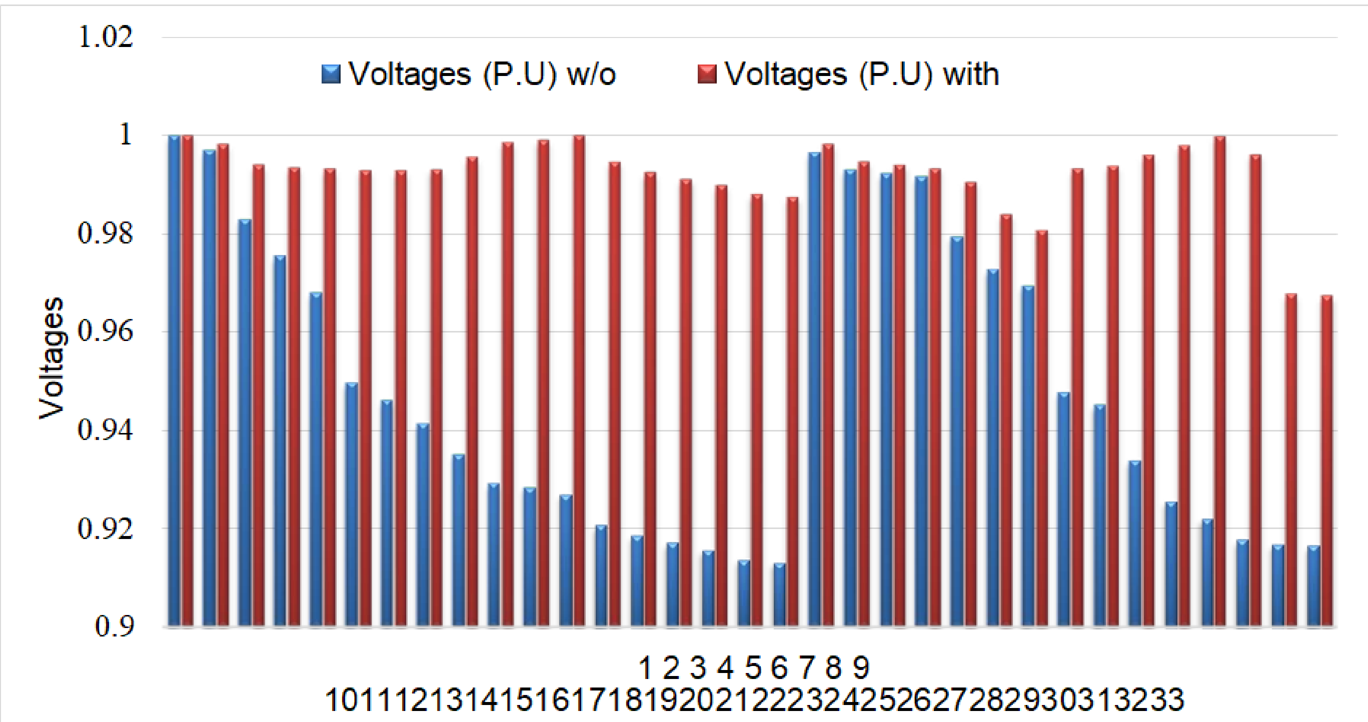


Figure 9: Comparison chart of Voltage profile for IEEE-33 Bus system with installing two DGs

## CONCLUSIONS

DGs are perfect solution of today's and future's power generation and distribution system which could meet the demanding needs of the consumers economically and environmentally by minimizing the cost, reducing power losses, improving voltage profiles, complexity, interdependencies and inefficiencies associated with onsite power generation, transmission and distribution network.In this paper, the optimal placement and sizing of DGs within distribution networks was investigated. The single-objective optimization problem is attempted to determine DG's optimal location and size by using total real power losses as an objective to be minimized by using Linear Programming. Single DG installation cases were studied using two different topology distribution systems, a 15-bus radial distribution system and a 33-bus meshed distribution system. The results were compared to a case without DG. It was shown that choosing proper DG size and place has a significant impact on minimizing power losses and improving voltage profiles. The following points are the major contributions of this paper: (i) Including additional advantages in reducing power losses and improving voltage profile and (ii) The optimal DG size and placement problem could be investigated using DG with different practical values of power factor, such as 0.9, 0.95 and unity, or using DG with unspecified power factors.

## FUTURE SCOPE

In this thesis work we dealt with single objective function with minimization of real power losses and constraints were voltage and size of DG. It can be multiple objective functions and different constraints with uncertainty included in objective function as well as in constraints. Multiple objective functions may include minimization of cost as well as maximization of profit. Multiple objective functions with constraints in optimal distributed generation plant may include.

Objective function : (i) Minimization of total cost of the system, (ii) Minimization of the energy losses, (iii) Minimization of the voltage deviation, (iv) Maximization of DG capacity and (v) Maximization of voltage limit liability

Constraints: (i) Power flow equality constraints, (ii) Bus voltage or voltage drop limit, (iii) Short circuit level limit, (iv)Power generation limit, (v) Discrete size of DG units and (vi) Limited buses for DG installation.

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