# Optimal Placement & Sizing Of Distributed Generation (DG) To Minimize Active Power Loss Using Particle Swarm Optimization (PSO)

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**Abstract:** Growing concerns over environmental impacts, conditions for improvement of the whole distribution network, and rebate programs offered by governments have contributed to an increment in the number of DG units in commercial and domestic electrical power output. It is known that the non optimal size and non optimal placement of DG units may lead to high power losses, bad voltage profiles. Therefore, this paper introduces a sensitivity analysis to determine the optimal sitting and sizing of DG units. A new methodology PSO for the placement of DG in the radial distribution systems to reduce the active power losses and to improve the voltage profile. A two-stage methodology is practiced for the optimal DG placement. In the first stage Power System Analysis Toolbox (PSAT), an open source MATLAB software package for analysis and design of small to medium size electric power systems for power flow and in the second stage, PSO is used to find the optimal size and site of DG in distribution systems. The effectiveness of the proposed method is demonstrated through IEEE 16 bus standard test systems.

**Keywords**: DG, PSAT, PSO, Loss minimization, Radial distribution system.

## 1. INTRODUCTION

The increasing demand on the power system has posed a challenging task to power system engineers in maintaining a reliable system economically. In the heavily loaded network, the load current drawn from the source would increase. This may lead to an increase in voltage drop and system losses[13-14][17-18]. The performance of distribution system becomes inefficient due to the reduction in voltage magnitude and increase in distribution losses. With this regard, changing environment of power systems design and operation has necessitated the need to consider active distribution network by incorporating DG unit [1]. DG is grid-connected or stand-alone electric generation units located within the electric distribution system at or near the end user. The integration of DG in distribution system would lead to improving the voltage profile and reduce active power loss in Power supply[3-6]. Optimization is a mathematical tool which can be used to locate and size the DG units in the system, so as to utilize these units optimally within certain limits and constraints. The optimal power flow problem has been introduced by Carpentier in 1962 [1]. It has taken over decades to develop efficient algorithms for its solution because it is a very large, non-linear mathematical programming problem. Many different mathematical approaches have been applied for seeking its solution [8-10]. The methods discussed in the literature use one of the following five methods [2][11][12]. They are (i) Lambda iteration method as found in economic dispatch problem solving, (ii) Gradient method, (iii) Newton-Raphson Method, (iv) Linear programming and (v) Interior point method. Apart from analytical approaches, there also exist heuristic search methods. Newly developed heuristic approaches called PSO has been introduced [7]. This method combines social psychology principles and evolutionary computation to motivate the behavior of organisms such as fish schooling, bird flocking, etc. A novel PSO algorithm for distribution system for minimization of active power loss, voltage drop with respect to their loading capabilities. This method thoroughly avoids premature convergence as well as convergence towards global optima. J.Z. Zhu [1], has proposed an improved method to study distribution network reconfiguration (DNRC) based on a refined genetic algorithm (GA). The DNRC model, in which the objective is to minimize the system power loss, is set up. In order to get the precise branch current and system power loss, a 16 bus radial distribution network load flow (RDNLF) method is presented in the study. The refined genetic algorithm is also set up, in which some improvements are made on chromosome coding, fitness function and mutation pattern. Altaf Q.H. Badar, B.S. Umre, A.S. Junghare,[2] has presented Particle Swarm Optimization Algorithm, with dynamic weights, applied to reduce the real power loss in a system. Particle Swarm Optimization with detailed study on weights of particle movements is used. Particle Swarm Optimization has been applied to IEEE 6 bus system to present the case. P. Ravibabu, K. Venkatesh, and C. Sudheer Kumar[3], has presented Network reconfiguration of an electrical distribution system is an operation to alter the topological structure of the distribution system by changing the status (open/closed) of sectionalizing and tie switches. This presents a new approach for optimal network reconfiguration of a Distribution system using genetic algorithm to determine the optimal network reconfiguration. The switches are taken into consideration for crossover process. After obtaining a number of solutions from the combinational analysis, the optimal solution is selected based on the fitness function, i.e., the solution is having the minimum index value. The proposed approach is tested on an IEEE 16 bus system. Duong Quoc Hung et[5]. all investigated the problem of multiple distributed generator (DG units) placement to achieve a high loss reduction in large-scale primary distribution networks. An improved analytical (IA) method is proposed in this paper. This method is based on IA expressions to calculate the optimal size of four different DG types and a methodology to identify the best location for DG allocation. For Graphical environment (Simulink) Matlab-based commercial, research and educational power system tools have been introduced. In This paper PSAT tool is used for evaluating the voltage profile and total $I^2R$ loss of the system. The PSAT toolbox, an open source Matlab software package for power flow, continuation power flow, optimal power flow, small-signal stability analysis, and time-domain simulation[16]. The toolbox is also provided with a complete graphical interface and a Simulink-based one-line network editor[19][21]. The proposed improved based method has been tested on a 16-bus test system and compared with the genetic algorithm (GA) based method.

## 2. BASIC PARTICLE SWARM OPTIMIZATION ALGORITHM

Particle swarm optimization is a heuristic global optimization method put forward originally by Doctor Kennedy and E berhart in 1995(Kennedy J, Eberhart, R, 1995; Eberhart, R, Kennedy J, 1995) It is developed from swarm intelligence and is based on the research of bird and fish flock movement behavior[15][7]. In the basic particle swarm optimization algorithm, particle swarm consists of "i" particles, and the position of each particle stands for the potential solution in D-dimensional space. The particles change its condition, according to the following three principles:

(1) To keep its inertia
(2) To change the condition according to its most optimist position
(3) To change the condition according to the swarm's most optimist position.

The position of each particle in the swarm is affected both by the most optimist position during its movement (individual experience) and the position of the most optimist particle in its surroundings (near experience). When the whole particle swarm is surrounding the particle, the most optimist position of the surrounding is equal to the one of the whole most optimist particle; this algorithm is called the whole PSO[15][20]. Each particle moves to the new position using velocity according to its own experience as called $P_{best}$. $G_{best}$ is the overall best value obtained so far by any particle in the population. By time to time, the PSO consists of velocity changes of each particle towards its $P_{best}$ and $G_{best}$. Each particle tries to modify its current position and velocity according to the distance between its current position and $P_{best}$, and the current position and $G_{best}$[15]. After finding the best values the particle updates its velocity and position. The velocity of each particle can be modified by equation.

$$V_i^{K+1} = wV_i^K + c_1r_1(P_{best\,i}^K - X_i^K) + c_2r_2(G_{best\,i}^K - X_i^K) \quad (1)$$

$V_i^{k+1}$ =velocity of particle at iterations

W=weight function

C1 & C2 =-weight coefficient both equal to 2

r1 & r2=random number between 0 and 1

$X_i^k$ =current position of particle at iteration

$P_{best}$ = best position of particle $i^{th}$ up to the current iteration

$G_{best}$= best overall position found by the particle up to the current iteration.

Weight function is given by

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} * iter$$

Where

$W_{max}$=initial weight equal to 0.9

$W_{min}$=initial weight equal to 0.4

$iter_{max}$=maximum iteration number

iter=current iteration number

The new position can be modified by

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (2)$$

The unique process for establishing PSO is as follows:

1. Initialize population of particle with random position and velocities and D dimensions in the random search space.
2. Identify the particle in the swarm through the best achievement so far, and assign its index to the changeable.
3. For every particle, assess the desired optimization fitness function in ith variables. Evaluate particle's robustness evaluation with its. If present value is better than, then set equal to the current value, and equals to the current location in D-dimensional space.
4. Update the velocity and position of particles according to equations.
5. If reached to termination criteria such as minimum fitness or maximum iteration, then STOP process and return to the best solution otherwise repeat steps from 3 to5.

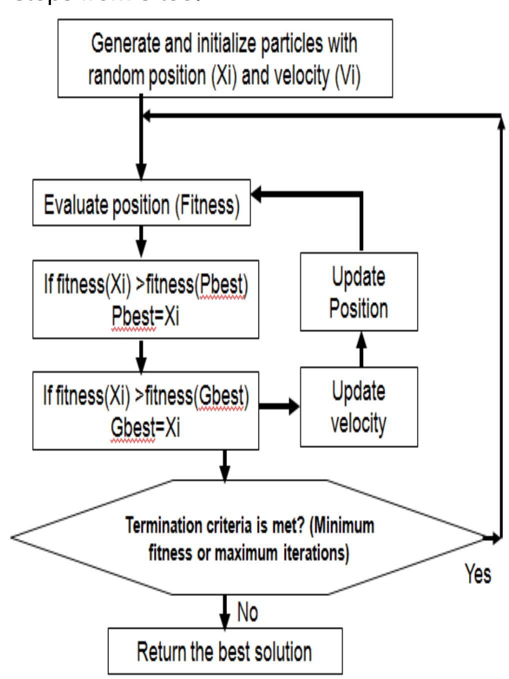


**Fig. 1:** Basic PSO flow chart

The flow chart for the implementation of sizing and siting of DG using PSO for 16-bus system with PSAT is given below.

## 3. OBJECTIVE FUNCTION

As the main objective of this work is to determine the optimal location and sizing of the distributed generation in the distribution network to minimize the losses (active power loss), the following objective function is selected as:

$$F_l = min\ P_{loss} = \sum_{k=1}^{ntl} |I_k|^2 . R_k \quad (3)$$

Where
$F_l$ is the objective function to minimize power losses.
$P_{loss}$ is the active power loss.
*ntl* is the number of lines in the distribution system.

Subjected to constraints:

$$V_i^{min} \le V_i \le V_i^{max} \quad (4)$$
$$I_i \le I_i^{max} \quad (5)$$
$$V_{DG}^{min} \le V_{DG} \le V_{DG}^{max} \quad (6)$$
$$P_{DG}^{min} \le P_{DG} \le P_{DG}^{max} \quad (7)$$

Where,
$P_{DG}$ : real power generations of DG.
$V_i$ : voltage magnitudes at bus *i.*
$V_{DG}$ : voltage magnitudes at bus *i.*
$I_i$: *i*th feeder current loading.

## 4. PROBLEM FORMULATION

The problem formulation for the optimal location and sizing of the distributed generation in the distribution network to minimize the active power loss includes the power flow with and with-out distributed generation in the distribution system. The distributed generation is considered as active power sources at a particular voltage, which is at unity power factor. The well known basic load flow equations are[20][6]:

$$S_i = P_i + jQ_i = V_i . I_i^* \quad (8)$$

$$= V_i \sum_{k=1}^{n} Y_{ik}^* V_k^* = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \angle(\delta_i - \delta_k + \theta_{ik}) \quad (9)$$

Resolving into the real and imaginary parts, then the power flow equations with-out DG are given as:

$$P_i = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \cos(\delta_i - \delta_k + \theta_{ik}) = P_{Gi} - P_{Di} \quad (10)$$

$$Q_i = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\delta_i - \delta_k + \theta_{ik}) = Q_{Gi} - Q_{Di} \quad (11)$$

The basic power balance equations:

$$P_{Gi} = P_{Di} + P_L \quad (12)$$

$$Q_{Gi} = Q_{Di} + Q_L \quad (13)$$

The power flow equations considering losses with DG for the practical distribution system and the DG is an active power source at unity power factor (PV generator) then flow are given as:

$$P_i + P_{DGi} = P_{Di} + P_L \quad (14)$$

$$Q_i + Q_{DGi} = Q_{Di} + Q_L \quad (15)$$

The DG is active power source only at unity power factor, so $Q_{DGi}$=0.

$$P_i + P_{DGi} = P_{Di} + P_L \quad (16)$$

$$Q_i = Q_{Di} + Q_L \quad (17)$$

The final power flow equations for distribution system are:

$$\sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \cos(\delta_i - \delta_k + \theta_{ik}) + P_{DGi} = P_{Di} + P_L \quad (18)$$

$$\sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\delta_i - \delta_k + \theta_{ik}) = Q_{Di} + Q_L \quad (19)$$

$$\sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \cos(\delta_i - \delta_k + \theta_{ik}) + P_{DGi} - P_{Di} - P_L = 0 \quad (20)$$

$$\sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\delta_i - \delta_k + \theta_{ik}) - Q_{Di} - Q_L = 0 \quad (21)$$

$$P_i^{min} \le P_i \le P_i^{max} \quad (22)$$

$$Q_i^{min} \le Q_i \le P_i^{max} \quad (23)$$

$$V_i^{min} \le V_i \le V_i^{max}$$

$$P_{DG}^{min} \le P_{DG} \le P_{DG}^{max} \quad (25)$$

Where,
$P_i$, $Q_i$ : real and reactive power flow at bus *i.*
$P_{Di}$, $Q_{Di}$ : real and reactive loads at bus *i.*
$V_i$ , $V_k$ : voltage magnitudes at bus *i* and *k.*
$P_{DGi}$ : real power of DG at bus *i.*
N: total number of buses.
$\delta_i, \delta_k$ : voltage angles of bus *i* and k.
$Y_{ik}$ : magnitude of the *ik*th element in bus admittance matrix.
$\theta_{ik}$ : angle of the *ik*th element in bus admittance matrix.

## 4. PSAT IMPLEMENTATION OF TEST SYSTEM

In this work, we have presented the load flow simulation results of the 16-bus distribution System using PSAT, an advanced open source Power System Analysis Toolbox[16].

### 4.1 Introduction of PSAT (Power System Analysis Toolbox)

This paper describes the Power System Analysis Toolbox (PSAT), an open source MATLAB and GNU/Octave-based software package for analysis and design of small to medium size electric power systems. PSAT includes power flow, continuation power flow, optimal power flow, small-signal stability analysis, and time-domain simulation, as well as several static and dynamic models, including nonconventional loads, synchronous and asynchronous machines, regulators, and FACTS. PSAT is also provided with a complete set of user-friendly graphical interfaces and a Simulink-based editor of one-line network diagrams. Basic features, algorithms, and a variety of case studies are presented in this paper to illustrate the capabilities of the presented tool and its suitability for educational and research purposes[19]. Power System Analysis Toolbox (PSAT) is a Matlab toolbox for electric power system analysis and control. Besides basic power flow analysis, PSAT offers several other static/dynamic analyses like CPF (Continuation Power Flow), OPF (Optimal Power Flow), Small-signal stability analysis, Time-domain simulations etc. Only the power flow feature is explored for the simulation purpose of this work[16][19][21]. Newton-Raphson (NR) method, Fast decoupled methods (both BX and XB), Runge-Kutta method, Simple robust method are the available algorithmic options provided by PSAT to conduct power flow analysis. Both theoretically and practically NR algorithm converges faster to the solutions than the others, which is why we applied it to our system.

### 4.2 IEEE-16 Bus Radial Distribution System Modelling

This section illustrates the modeling and implementation of the 16-bus test system, which is given below. The single line diagram if IEEE 16-bus test system given in fig 5. Fig. 6 depicts the model of the IEEE 16-bus network built using the PSAT Simulink library (see Fig. 4). Once defined in the Simulink model, one can load the network in PSAT and solve the power flow. Power flow results can be displayed in a GUI and exported to a file in several formats including, notepad, Excel and LaTeX[19]. PSAT also allows displaying bus voltages and power flows within the Simulink model of the currently loaded system.

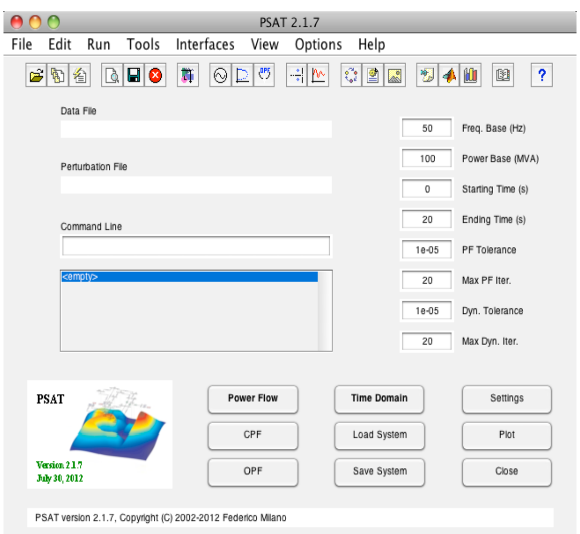


**Fig. 3:** Executing the PSAT in GUI Mode

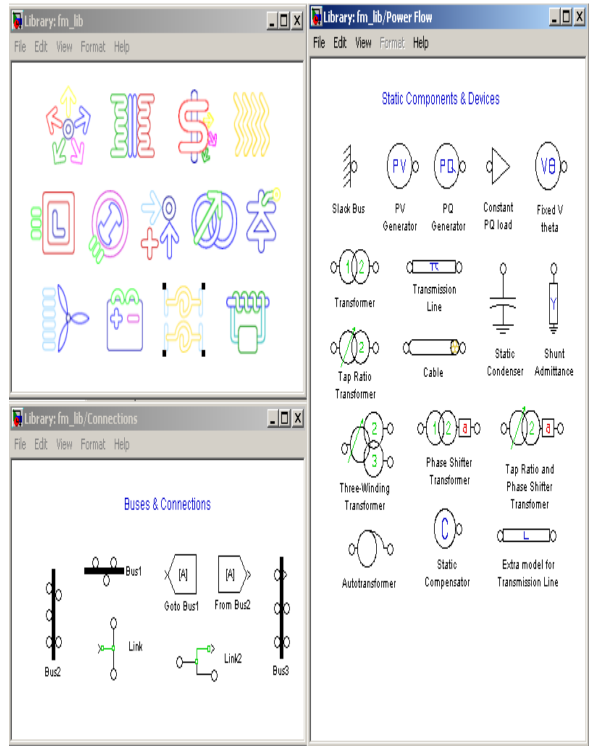


**Fig. 4:** The PSAT Simulink model library

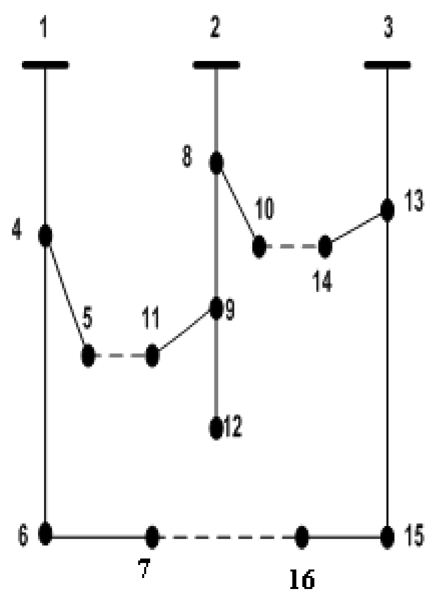


**Fig. 5:** IEEE 16-bus distribution test system

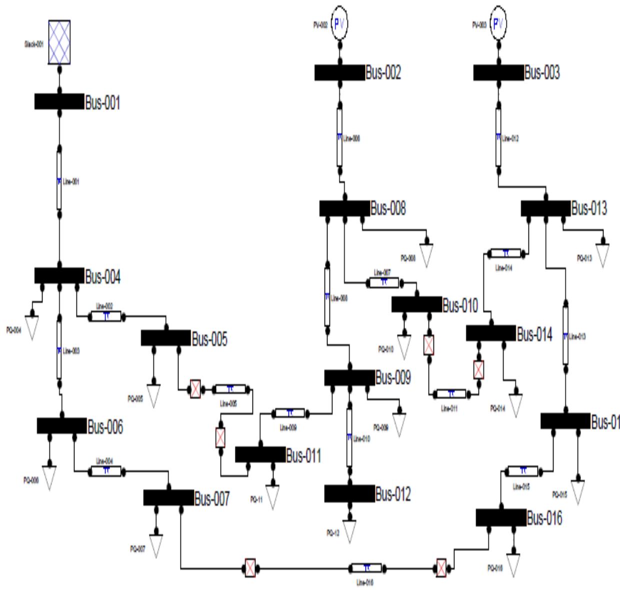


**Fig. 6:** The PSAT Simulink model of IEEE 16-Bus distribution system

## 5. Results Analysis

The proposed algorithm is tested using both a 16-bus radial test system. The base values used are 100 MVA and 23 kV. A DG size is considered in a range of 1 kW to–30 kW. In this study, it is considered that the DG is operated at unity power factor. The first bus is considered as the feeder of electric power from the generation/transmission network. The remaining buses of the distribution system except the reference buses are considered for the placement of a DG of given size from the range considered.

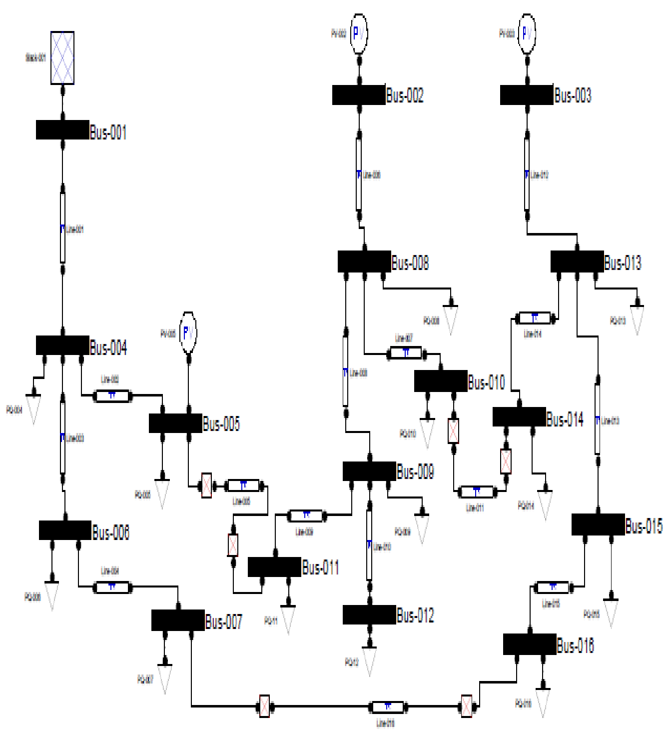


**Fig. 7:** The PSAT Simulink model of IEEE 16-Bus distribution system after installing DG

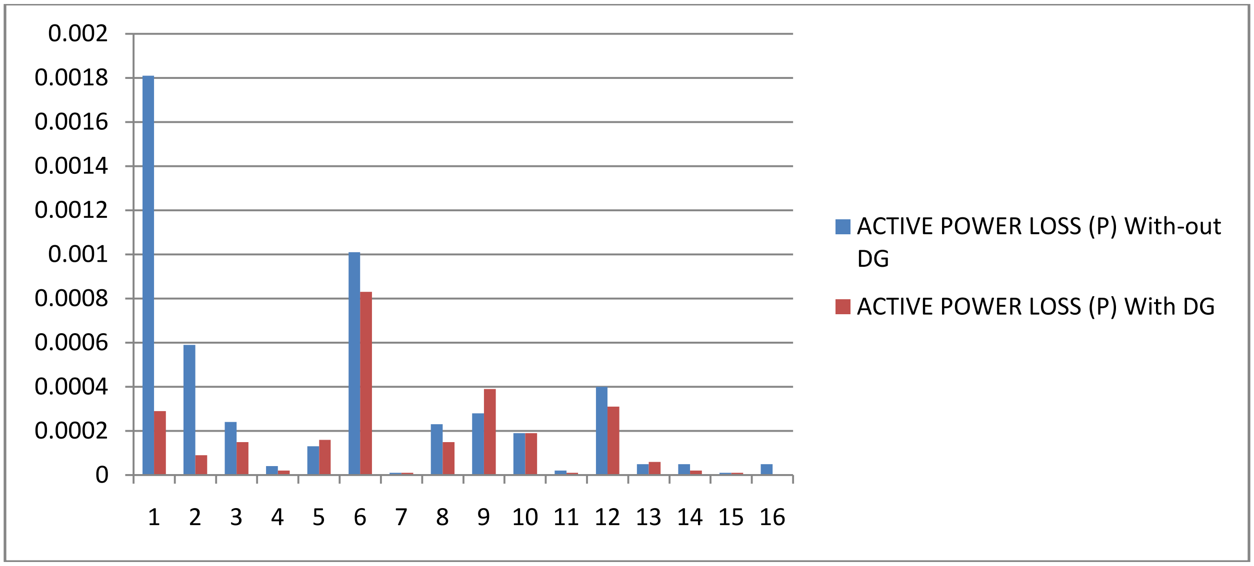


**Fig. 7:** The active power loss at buses with and with-out DG

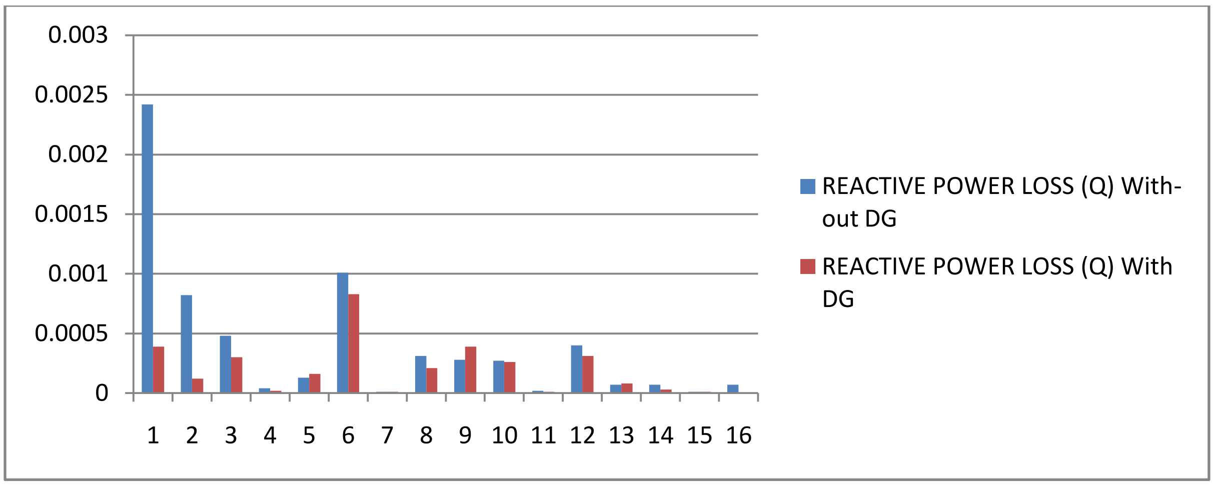


**Fig. 8:** The reactive power loss at buses with and with-out DG

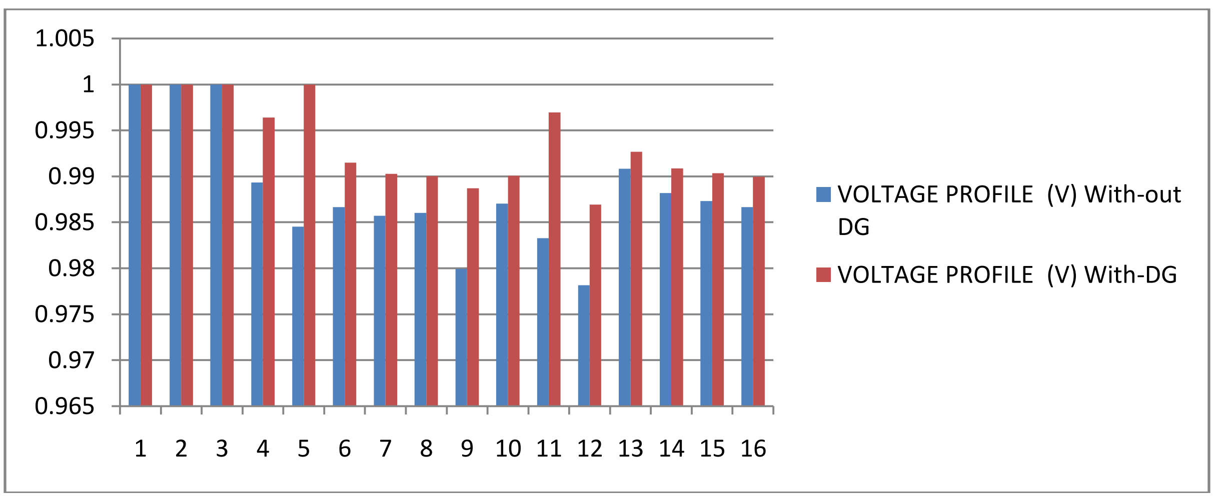


**Fig. 9:** The Voltage profile at buses with and with-out DG

**Table-1:** Active, Reactive power loss and Voltage of 16-bus system with-out and with DG

| | With-out DG | | | With DG | | |
|---|---|---|---|---|---|---|
| **Bus No.** | **Active Power Loss** | **Reactive Power Loss** | **VOLTAGE PROFILE (V)** | **Active Power Loss** | **Reactive Power Loss** | **VOLTAGE PROFILE (V)** |
| 1. | 0.00181 | 0.00242 | 1 | 0.00029 | 0.00039 | 1 |
| 2. | 0.00059 | 0.00082 | 1 | 9.00E-05 | 0.00012 | 1 |
| 3. | 0.00024 | 0.00048 | 1 | 0.00015 | 0.0003 | 1 |
| 4. | 4.00E-05 | 4.00E-05 | 0.98934 | 2.00E-05 | 2.00E-05 | 0.9964 |
| 5. | 0.00013 | 0.00013 | 0.98453 | 0.00016 | 0.00016 | 1 |
| 6. | 0.00101 | 0.00101 | 0.98666 | 0.00083 | 0.00083 | 0.9915 |
| 7. | 1.00E-05 | 1.00E-05 | 0.98572 | 1.00E-05 | 1.00E-05 | 0.99026 |
| 8. | 0.00023 | 0.00031 | 0.98601 | 0.00015 | 0.00021 | 0.99003 |
| 9. | 0.00028 | 0.00028 | 0.97995 | 0.00039 | 0.00039 | 0.98871 |
| 10. | 0.00019 | 0.00027 | 0.98705 | 0.00019 | 0.00026 | 0.99008 |
| 11. | 2.00E-05 | 2.00E-05 | 0.98327 | 1.00E-05 | 1.00E-05 | 0.99696 |
| 12. | 0.0004 | 0.0004 | 0.97816 | 0.00031 | 0.00031 | 0.98694 |
| 13. | 5.00E-05 | 7.00E-05 | 0.99083 | 6.00E-05 | 8.00E-05 | 0.99269 |
| 14. | 5.00E-05 | 7.00E-05 | 0.9882 | 2.00E-05 | 3.00E-05 | 0.99086 |
| 15. | 1.00E-05 | 1.00E-05 | 0.98732 | 1.00E-05 | 1.00E-05 | 0.99033 |
| 16. | 5.00E-05 | 7.00E-05 | 0.98664 | 0 | 0 | 0.98996 |

**Table-2: Total Real and Reactive power loss of the 16 bus radial system**

| PARAMETER | WITH-OUT DG | WITH DG |
|---|---|---|
| REAL POWER [P.U.] | 0.00511 | 0.00267 |
| REACTIVE POWER [P.U.] | 0.00639 | 0.0031 |

**Table-3: Size and location of DG in the 16 bus radial system**

| Work | Method | Optimum location | Optimum DG size (pu) | Power loss (pu) | | % Of Loss Reduction |
|---|---|---|---|---|---|---|
| | | | | Without DG | With DG | |
| Proposed | PSO | Bus 5 | 0.091243 | 0.00511 | 0.00269 | 47.35% |
| Existing | GA | | | 0.00511 | 0.00466 | 8.8% |

The results show the overall losses of the system are reduced by optimal placement of the DG, which is shown in fig. 7, fig 8 and table 1, table 2, table3. The voltage profiles of the overall system are also improved as shown in fig. and 9, and tables 1.

## 6. CONCLUSIONS

The results clarified the efficiency of this algorithm for the improvement of the voltage profile, reduction of power losses of the grid, and also for increasing the voltage stability margin and maximum loading. This work presents an efficient method for choosing the suitable placement and size of Distributed Generation (DG) to achieve the third objective which is the minimization of an objective function hence the lowest real power loss. PSO is used to determine the best location and size of DG to achieve these objectives. From the results obtained show that the proper size and site of DG can improve system performance by reducing the loss, and additionally the improve the voltage profile of the system. The conclusions for the objectives are given as:

- Voltage profile is significantly improved by placing DG in Distribution system.
- Particle Swarm Optimization is proposed for finding the optimal size of DG and the location is found where loss is minimized.
- Size and location of DG Estimated for loss minimization.
- Active Power losses have been reduced by **47.35%**

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