

Optimal Sizing of Distributed Generation using Particle Swarm Optimization

R V S Lakshmi Kumari, Dr G V Nagesh Kumar, Dr S Siva Nagaraju and M. Babita Jain, *Member, IEEE*

Abstract—Owing to the ever increasing demand in power sector and increased benefits of Deregulated system, a number of problems related to transmission line management effectively in the big electric network are quite frequent. The placement of Distributed Generation (DG) has been growing rapidly in power systems since it is a reliable solution to many of the distribution system issues such as voltage regulation, power loss reduction etc. The optimal placement of generating sources into the distribution system can significantly impact the operating state and dynamics of both the transmission and distribution system. Depending of the operating status, the effects of placing DG will be either positive or negative. Non suitable location of DG may results in negative impact in the efficiency of the system. An optimal location and sizing plays a very effective and important role in the improvement of system efficiency by reducing the active power loss and by improving the voltage profile at each and every bus in the system. This paper proposes a novel methodology using the population based heuristic approach namely Particle Swarm Optimization (PSO) and New Particle Swarm Optimization (NPSO) for determining the optimal sizing of Distributed Generator (DG) in the distribution systems. The work also focuses and investigates on the technical aspects of the distribution system such as active power losses and improvement in voltage profile. This proposed approach is implemented for IEEE 15 Bus and IEEE 33 Bus radial distribution systems. The results obtained show the effectiveness in performance of the NPSO optimized system over the PSO optimized and the non-optimized system for system loss reduction and voltage profile improvement.

Index Terms— Particle Swarm Optimization (PSO), New Particle Swarm Optimization (NPSO), Distributed Generation Placement, Meta-heuristic, Voltage Profile

I. INTRODUCTION

he ever growing demand for electrical power generation due to rapid industrialization growth, population growth and the limited economical constraints over the installation of new transmission lines for long distance for reliable power transfer over the transmission line from long distances have created interest towards power generation using distributed Generators (DG). Distributed Generation (DG) system is related with the use of small-scale generators installed at optimal points of electric power system or customer side of the meter. Distributed Generation (DG) units can be used in power systems for grid integration, supplying the customer's power demand and on-peak operating costs, voltage profile improvement, deferring or eliminating for system upgrades and improving system efficiency. In some markets, the quite costly grid electricity is being replaced by DG. DG can provide for the complete or part of a customer's power needs.

When DGs are connected to a distribution or transmission system, power can also be sold to the utility or a third party.

Some of the reasons to interconnect the DG units with existing utilities can be summed up as follows [1]:

- Installation of DG is more economic than the construction of new power lines for supplying the power need to the remote locations.
- It supplies primary power, with the utility providing backup and supplementary power
- It also provides better power quality for electronic equipment
- It supplies backup power for facilities requiring uninterrupted service and also during utility system outages
- It improves overall energy efficiency
- It provides network stability for the usage of immediate response from the equipment even in emergency situations
- It helps to restore some portion of the utility system without outside support after a system collapse

Implementing of DG in the electric system involves in several factors, such as: the optimal location, the best technology to adopt, the number of the units to be placed, the type of the network connection, the type of DG etc. For planning electric power systems for the installation of DG units in the network, also requires indicators such as size of generative resources, etc. The effects of installing DG on the system losses, Profile voltage, network stability and certainty, and also the security for critical operating conditions must be separately examined. Non optimal placement of DG in a system will results in increased system losses and increased cost of operation.

Many interesting algorithms and solutions have been developed and implemented by the researchers. Some of the methods are mentioned in as analytical approaches, numerical programming and heuristic. All methods have their own benefits and limitations which rely on the system data under consideration. The differences are in the problem associated and considered, formulation of the problem, method to proceed, assumptions and constraints being made. Usually, in all the literature survey the objective function is to minimize the real power losses and improve voltage or both, while considering to all the physical constraints equations in terms of voltage and power. The allocation of DG in the system is formulated is generally non linear, stochastic or even a fuzzy function as either an objective function or constraint. The variable limits in the optimization technique must also be satisfied.

Optimal DG location and sizing constitutes of two sub problems, where in the first one, the best location is to be determined for achieving effectiveness of the system performance and the second one is the optimal sizing of DG satisfying the minimum and maximum limits of DG size. Keane and Malley [2] solved for the optimal sizing of DG in the Irish system by implementing a constrained Linear Programming technique (LP) and this was aimed towards the maximization of DG generation in the system. The nonlinear constraints were liberalized with the goal of utilizing them in the LP method. A DG unit was installed at all the system buses and the best location for placing the DG, were ranked according to their optimal objective function values. A. Kumar [3] used mixed integer non-linear programming (MINLP) technique for obtaining the optimal location and number of units in hybrid electricity sector. The most appropriate zone for placement of DG was identified based on real power nodal price and real power loss sensitivity index as an economic and operational criterion. In [4] the real power loss for the system was reduced by the proper DG allocation with application of an analytical method. In [5] a multi-objective index was used to reduce voltage drop and power loss. Kashem [6] developed an analytical approach to determine the optimal DG sizing based on power loss sensitivity analysis. The proposed method was based on minimizing the distribution system power losses. In [7] a multi-objective GA was performed for optimizing corrective actions, planning and operation of distribution network. to minimize the total system real power loss Abu-Mouti, F.S. et al. [8] presented a new optimization approach that employs an artificial bee colony (ABC) algorithm to determine the optimal DG-unit's size, power factor, and location. The paper aimed at reduction of line losses and improvement in voltage profile in the radial distribution network. It is found that the losses are reduced and the bus voltage is improved if the distributed generation is placed in the system.

In this paper optimal placement of DG is obtained by considering the voltage profile. Once the load flow is carried out for the base case and all the buses are arranged in the descending order with respect to the voltage magnitudes at all the buses, the highest priority is given to the first bus in the order with low voltage comparatively. Here Particle Swarm Optimization (PSO) and New Particle Swarm Optimization (NPSO) are employed to obtain the optimal sizing of DG. This methodology needs the load flow to be carried out only twice, once for the base case and once at the end, with DG included, to obtain the best solution.

II. PROBLEM FORMULATION

The main objective of this paper is to study the reliable performance of the system after placing the DG optimally at a suitable location. Since the purpose of DG is to minimize the total active power loss and improving the voltage profile, the installation of DG units at non-optimal places may not give good results which will be beneficial for improving the system

performance. However the losses cannot be completely removed, but they can be brought down to an acceptable value. Since the impact of distributed generation on system performance depends on system operating conditions and the type of the distributed generation, it is necessary to use some solutions in planning and operation to attain the best performance. The first objective is to minimize the total real power loss in the power system accounting DG which expressed as follows:

$$f = \sum_{i=1}^N P_{Loss_i} \quad \text{with DG} \quad (1)$$

Minimization of
Subject to real power constraints given by:

$$\sum_{i=1}^N P_{DG_i} = \sum_{i=1}^N P_{D_i} + P_L \quad (2)$$

The inequality constraints on P_{DG_i} of DG given by:

$$P_{DG_i}^{\min} \leq P_{DG_i} \leq P_{DG_i}^{\max} \quad (3)$$

where f is the total loss of the system, P_{Loss_i} is the real power loss at bus i , P_{G_i} is the active power generation at bus i , P_L is the total active system loss, P_{D_i} is the total power demand, P_{DG_i} is the real power generation for distributed generators, $P_{DG_{i\min}}$ and $P_{DG_{i\max}}$ are the minimum and maximum generation limits at bus i for DG values and N is the total number of buses in the system.

The second objective is directed towards the improvement in voltage profile represented by the objective function (OF) governed by the relation (4):

$$OF = 1 - \sum_{i=1}^n v(i) \quad (4)$$

Here OF = Objective Function in terms of voltages of all the buses and $v(i)$ is the voltage at bus i in the system.

The algorithm of this approach is presented in the flowchart as given in figure 1. The PSO and NPSO algorithms are used for the optimal sizing of the DG's taking the minimum system losses as the constraint. The optimization algorithm runs until there is no more reduction in system losses taking in to account that the constraints are obeyed.

III. OPTIMAL LOCATION OF DG

In this paper, the optimal location of DG is identified by the base case load flow. This can be obtained by running the load flow for the base case and the buses are arranged in the descending order with respect to their voltage profile. The highest priority for placing the DG has been given to the bus having comparatively less voltage profile. The next step in the proposed technique determines the optimal size of DGs at the feasible location by applying the meta-heuristic optimization algorithm, PSO and NPSO.

IV. PSO & NPSO

Artificial Intelligence has grown leaps and bounds in the past two decades. The advent of various artificial intelligence techniques such as Fuzzy Logic, Neural Networks, Genetic Algorithms, Neuro-Fuzzy Systems, Support Vector Machines, Swarm Intelligence and so many others has aided to research in various different fields take new dimensions and deal with various constraints. The work presented in this paper uses Particle swarm optimization (PSO). The PSO is a simple population dependent optimization technique inspired by the natural behavior of the birds and it was proposed by Dr. Eberhart and Dr. Kennedy in 1995 [9-11]. The PSO draws its motivation from nature. It basically tries to mimic the natural behavior of the birds flying together in search of food. Off late the applications of swarm intelligence to the optimization requirements in the research domain has increased drastically [12].

The particle swarm optimization has many things in common to the widely used evolutionary technique of genetic algorithms. Basic schema of the particle swarm optimizations is to have a population of a number of particles with prior initializations capable of generating random solutions to the problem at hand. The population is continuously updated to search or obtain the optimum or the best solution for the problem domain. The PSO does not have any crossover or mutation operators as in the case of the genetic algorithms. In comparison to the other artificial techniques the particle swarm optimization is very simple and easy to implement. It has very few system parameters to deal with. It is free from the curse of dimensionality and can be easily implemented for the multi-objective constraints based problem domains. The very basic concept of the PSO is that its particles move in the problem space by following the latest optimum particles. Every particle, in every upcoming iteration, updates its current position with the offsets of the previous iteration's best particles as given in the next section.

There are two basic criteria used for the updation of any particle. The two criteria are the particle best value and the global best value. The particle best value is that value of the particle for which the best result was obtained by that particular particle in hand. It is updated after every iteration and the particle best value is always stored. The second parameter is that value of any particle for which the best solution has been obtained till that instant. This is called the global best and the value of the global best is also updated after every iteration. The best value of the solution obtained in both the particle best and global best instances values are also stored. These two parameters i.e. pbest and gbest form the basis for the updation of the current particles velocity vector. Thus obtained velocity vector is used for the updation of the position of the current particle.

Given below is the pseudo code for the methodology followed in implementing the particle swarm optimization algorithm:

```

For each particle
  Initialize particle
END
Do
  For each particle
    Calculate fitness value
    If the fitness value is better than the best fitness value
    (pBest) in history set current value as the new pBest
  End
  Choose the particle with the best fitness value of all the
  particles as the gBest
  For each particle
    Calculate particle velocity according equation (5)
    Update particle position according equation (6)
  End
While maximum iterations or minimum error criteria is not
attained.

```

After finding the two best values, the particle updates its velocity and positions with equations (5) and (6).

$$v[i] = v[i] + c1 * rand() * (pbest[i] - present[i]) + c2 * rand() * (gbest[i] - present[i]) \quad (5)$$

$$present[i] = present[i] + v[i] \quad (6)$$

$v[i]$ is the velocity of the particle, $present[i]$ is the current solution of the particle. $pbest[i]$ and $gbest[i]$ are as per the criteria given earlier. $rand()$ is a random number generator and it generates a number between (0,1). $c1, c2$ are constants known as the learning factors and their value is generally taken as $c1 = c2 = 2$.

The flow chart of the PSO implementation procedure is as follows:

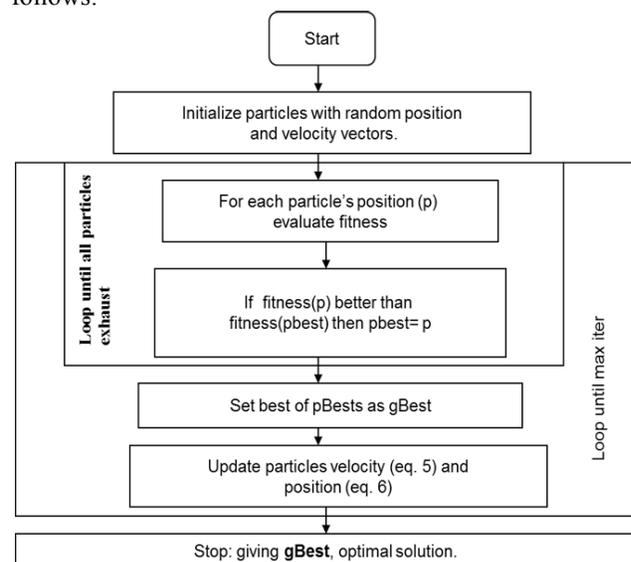


Figure 1 Flow Chart

The velocity of the particle in each dimension is restricted or limited to a maximum value specified by the maximum velocity V_{max} . In any case if the velocity of a particular dimension exceeds the maximum velocity V_{max} , then the velocity of that dimension for the particle is clamped to the value of the maximum velocity.

One of the variations of the particle swarm optimization is the New Particle Swarm Optimization (NPSO). The background for the NPSO is primarily on the intuition that even in our personal life scenarios the experiences prove that we tend learn more from our mistakes than our success stories. This very concept is the variation used in the implementation of the new particle swarm optimization algorithm [13, 14] which is based on this social behavior. Each particle tries to move away from its previous worst position as well as the group's previous worst position [14]. The NPSO algorithm also does not rely on the mutation or crossover operators similar to the PSO algorithm. It stores the particle worst and the global worst position and values and updates its current position as per the equations 7 and equation 8. The velocity term and the equations clearly indicate the particle's attempt to move away from the worst position.

In comparison to the other artificial techniques the particle swarm optimization is very simple and easy to implement. It has very few system parameters to deal with. It is free from the curse of dimensionality and can be easily implemented for the multi-objective constraints based problem domains. Every particle, in every upcoming iteration, updates its current position with the offsets of the previous iteration's worst particles as given in the next section.

The individual particle's worst value till the current instant is stored as p_{worst} and the group's worst value till the current instant is stored as g_{worst} . The new velocity and position of each particle are then recalculated as given below.

$$v[i] = v[i] - c1 * rand() * (p_{worst}[i] - present[i]) - c2 * rand() * (g_{worst}[i] - present[i]) \quad (7)$$

$$present[i] = present[i] + v[i] \quad (8)$$

The velocity of the particle in each dimension is restricted or limited to a maximum value specified by the maximum velocity V_{max} . In any case if the velocity of a particular dimension exceeds the maximum velocity V_{max} , then the velocity of that dimension for the particle is clamped to the value of the maximum velocity.

The pseudo code for the implementation of the NPSO algorithm is similar to that of the PSO algorithm with the only change that the equations used are 7&8 instead of 5&6. The PSO works on the concept of the new particle going closer to the best or good particle and the NPSO believes in the concept of going away from the worst or bad particle.

V. RESULTS AND DISCUSSIONS

The proposed method has been simulated in MATLAB environment and tested for distribution systems. To verify the effectiveness and efficiency of the PSO and NPSO methods, they have been applied to IEEE-15 bus, IEEE-33 bus systems. In this paper, reduction in the active power loss and improvement in voltage profile are considered as objective functions. The parameters of PSO and NPSO methods used for solving the problems presented in this paper are furnished in Table I.

TABLE I
Configuration parameters of PSO & NPSO

| Parameters | PSO | NPSO |
|----------------------|-----|------|
| Population Size | 49 | 49 |
| Number of Iterations | 10 | 3 |
| C1/wi0* (initial) | 2.0 | 2.0 |
| C2/wi1* (initial) | 2.0 | 2.0 |
| V(0)/wi2* (initial) | 1.0 | 1.0 |

Case I: IEEE-15 bus system

The proposed method was applied to a IEEE 15-bus system with the total active load of 1654 KW and reactive load of 1654 KVAR. The real power losses are 59.3146 KW and reactive power losses are 55.2795 KW when calculated by using load flow for the base case. The voltage values of all the buses are obtained and arranged in the ascending order, so that the first bus will be considered as the best location for placing the DG optimally. From the load flow analysis, the optimal location for placing the DG is identified as bus 13. Figure 2 represents the comparison of voltage profile at each bus for IEEE 15 bus system without and with DG using PSO algorithm. Figure 3 represents the comparison of voltage profile at each bus for 15 bus system without and with DG using NPSO algorithm. Figure 4 depicts the comparison of voltage profile without and with DG using PSO and NPSO. Table II represents the real and reactive power loss reduction after placing DG using PSO and NPSO.

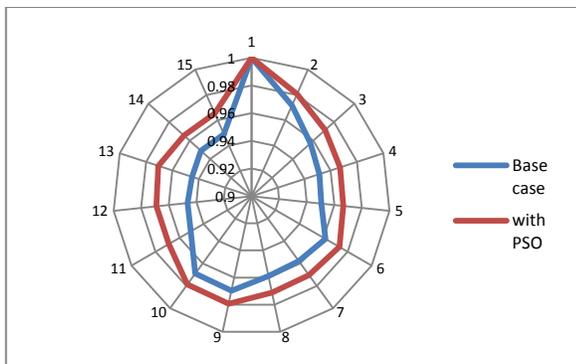


Figure 2 Voltage Profile Comparison for IEEE 15 bus system DG without PSO and DG using PSO

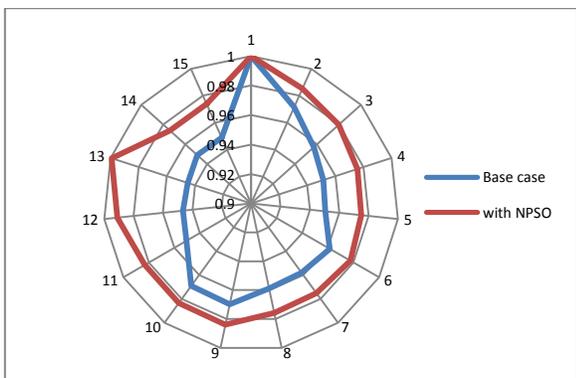


Figure 3 Voltage Profile Comparison for IEEE 15 bus system DG without PSO and DG using NPSO

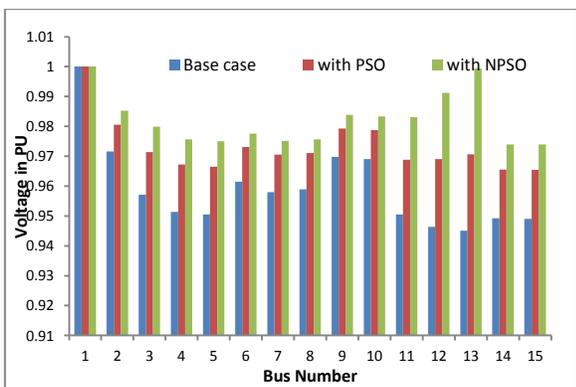


Figure 4 Voltage Profile Comparison for IEEE 15 bus system between base case (without DG), PSO and NPSO (with DG)

Table II
Power Loss Reduction for IEEE 15 bus system

| | Base Case | PSO | NPSO |
|-------------------------|-----------|----------|----------|
| DG Location | NO DG | 13 | 13 |
| DG Size (KW) | -- | 197.5509 | 490.8025 |
| Real Power Loss(KW) | 59.3146 | 36.8995 | 35.0493 |
| Reactive Power Loss(KW) | 55.2795 | 36.7552 | 30.9674. |

Case II: IEEE-33 bus system

The proposed method was also applied to a IEEE 33-bus system with the total active load of 3715 KW and reactive load of 2400 KVAR. The real power losses are 201.8925 KW and reactive power losses are 134.6413 KW when calculated by using load flow for the base case. The voltage values of all the buses are obtained and arranged in the ascending order, so that the first bus will be considered as the best location for placing the DG optimally. From the load flow analysis, the optimal location for placing the DG is identified as bus 18. Figure 5 represents the comparison of voltage profile at each bus for IEEE 33 bus system without and with DG using PSO algorithm. Figure 6 represents the comparison of voltage profile at each bus for 33 bus system without and with DG using NPSO algorithm. Figure 7 depicts the comparison of voltage profile without and with DG using PSO and NPSO. Table III represents the real and reactive power loss reduction after placing DG using PSO and NPSO. Figure 8 represents the comparison of percentage of real power loss reduction between PSO and NPSO.

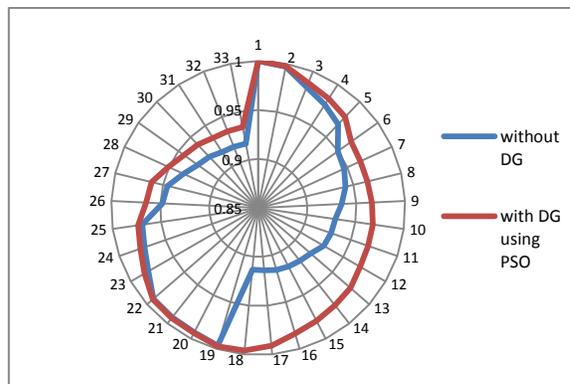


Figure 5 Voltage Profile Comparison for IEEE 33 bus system for DG with and without using PSO

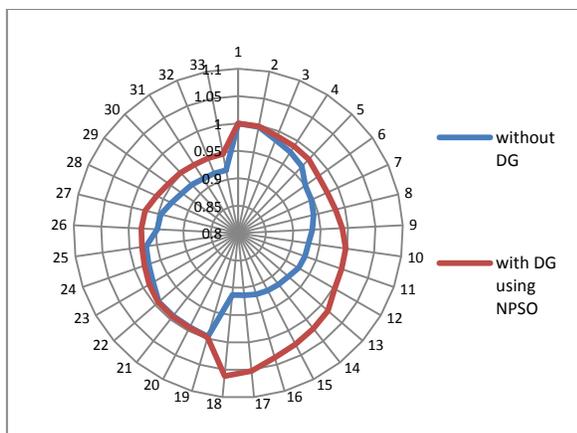


Figure 6 Voltage Profile Comparison for IEEE 33 bus system for DG with and without using NPSO

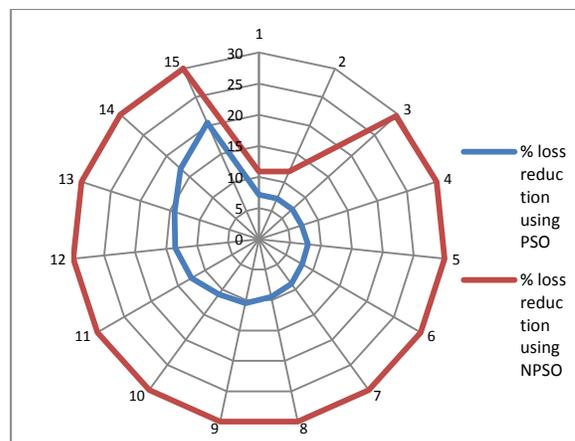


Figure 8 % real power loss reduction comparison for IEEE 33 bus system using PSO and NPSO

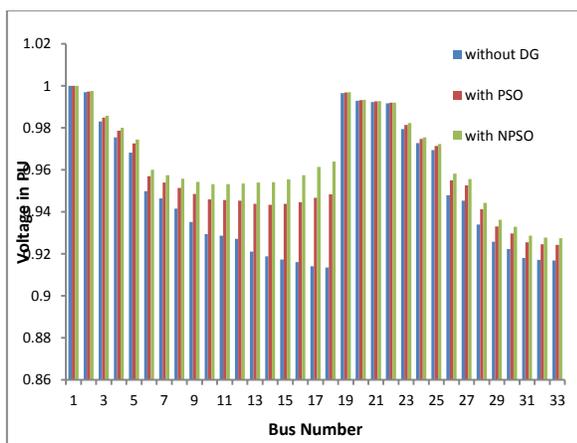


Figure 7 Voltage Profile Comparison for IEEE 33 bus system with and without DG using PSO and NPSO

Table III
Power Loss Reduction for IEEE 33 Bus System

| | Base Case | PSO | NPSO |
|-------------------------|-----------|----------|----------|
| DG Location | -- | 18 | 18 |
| DG Size (KW) | -- | 525.2843 | 656.9124 |
| Real Power Loss(KW) | 201.8925 | 150.7899 | 145.0304 |
| Reactive Power Loss(KW) | 134.6413 | 100.5244 | 97.6974 |

VI. CONCLUSION

In view of ever increasing load demand in the power sector, DG is playing a very vital role to improve the system performance by reducing the real power losses and improving the voltage profile. Optimal capacity and location of DG are very significant in the application of DG for loss minimization and voltage profile improvement in electric power system. Improper placement of DG in the system operation will lead to the negative effect on system operation. This paper presents new population based heuristic methods i.e. PSO and NPSO algorithms are used to place the optimal sizing of DG at suitable location. The optimal location for placing the DG is identified with comparatively less voltage profile. To validate the proposed method, IEEE-15 bus and IEEE-33 bus systems are examined and the results obtained are compared. The results are tabulated and the voltage profile improvement is shown graphically. Reduction in active power losses and improvement in voltage profile can be observed. The results shown that the integration of DG in NPSO is highly effective in reducing total real power losses and voltage profile improvement compared to PSO.

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