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Optimal Distributed Generator Sizing and Placement by Analytical Method and PSO Algorithm Considering Optimal Reactive Power Dispatch

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Abstract**—**In this paper, an approach combining analytical method for the distributed generator (DG) sizing and meta-heuristic search for the optimal location of DG has been presented. The optimal size of DG on each bus is estimated by the loss sensitivity factor method while the optimal sites are determined by Particle Swarm Optimization (PSO) based optimal reactive power dispatch for minimizing active power loss. To confirm the proposed approach, it has been tested on IEEE-30 bus test system. The adjustments of operating constraints and voltage profile improvements have also been observed. The obtained results show that the allocation of DGs results in a significant loss reduction with good voltage profiles and the combined approach is competent in keeping the system voltages within the acceptable limits.

Keywords**—**Analytical approach, distributed generations, optimal size, optimal location, optimal reactive power dispatch, particle swarm optimization algorithm.

I. Introduction

DURING recent years, the electric power systems are facing many different problems concerning technical, economic and environmental issues. To get rid of these issues, the conventional configuration of power system networks has been changed with the integration of distributed generation (DG) units [1]. If the DGs are properly allocated to the network, they can improve system reliability and power quality.

Renewable and non-renewable energy resources are adopted for DG plants: mostly applied technologies are micro-turbines, fuel-cells, wind, solar, hydro and biomass units [2]. Considering the size of DGs, the DGs with ratings between 1 and 5 kW are called micro DGs; between 5 kW and 5 MW are called small DGs; between 5-50 MW are called medium DGs; and the DGs ratings in 50-300 MW are large DGs [2].

Different types of DG's can be classified as [3];

- Type I: DG capable of injecting real power only, e.g., PVDG, fuel cell DG.
- Type II: DG capable of injecting reactive power only, like capacitors, synchronous condensers, etc.
- Type III: DG capable of injecting both real and reactive power, e.g., synchronous machines like diesel generator DGs, gas turbine DGs.
- Type IV: DG which injects real power but consumes reactive power, e.g., induction generator-based wind turbines.

Two important aspects in this area of DG optimizations are sizing and sitting which are required attentions to ensure reliable supply of electricity at minimum real power loss [4]. The size of DG is determined by the load. Location of DGs should be optimally decided as influences the distribution losses. Thus, the issues of DG placement and sizing are very important. Present investigation has considered these two aspects for analysis.

The DG planning means the proper location of and size as well as properly coordinated control of multiple DGs in the power system network. Most of the approaches presented so far to evaluate the optimal placement problem of DG are only considering type-I DGs [2]. Various methods have been proposed [2] to find out the optimum size and location of DGs in the distribution network. Many different algorithms [5] have been developed and implemented to solve the optimal DG problems in different systems. Genetic Algorithm (GA), PSO, Fuzzy Logic, Tabu Search algorithm are some of the popular computational tools used in such optimization problems [5].

In this paper, the optimal sizing of DG is evaluated by taking into account the system power loss and voltage deviation at each bus while the optimal placement of DG by applying optimal reactive power dispatch (ORPD) with objective function of total real power loss minimization. Therefore, type-III DGs are considered for optimal placement considering reactive power control capability.

The contribution of this paper is to find the optimal allocation of single or multiple DGs to reduce the active power losses considering ORPD of the power system network.

The rest of the paper is organized as follows: The analytical technique for DG sizing and PSO based ORPD for DG sitting are presented in 'Proposed Approach for DG Allocation'; step-by-step procedures for combination of analytical method and meta-heuristic search for DG allocation are described in 'Computational Procedure for DG Allocation'; the test system of IEEE 30 bus for DG placement in MV distribution network is presented in 'Configuration of Investigated Network'. Analytical results for DG sizing and numerical simulation results for DG sitting are discussed in 'Results and Discussion.' Finally, conclusion is drawn based on the results

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in the section of 'Conclusion.'

II. Proposed Approach for DG Allocation

The problem of allocation of DG is to determine the optimal size and DG location with minimizing the desired objective function. In this paper, the analytical approach based on the exact loss formula [6] is utilized for optimal sizing of DG on each candidate bus in the investing test system (case study network). The optimal location is set up using PSO algorithm based ORPD [7] with the objective function of minimizing the total active power losses.

A. Analytical Approach for DG Sizing

For DG sizing at allied bus, the real power loss and voltage deviation are considered as the decision parameters based on the power loss in the system as given by "Exact Loss" formula:

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(P_iP_j - Q_iQ_j\right)\right] \quad (1)$$

where, $\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$, $B_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$ and $Z_{ij} = r_{ij} + jx_{ij}$ are the ijth element of [Zbus] with $[Zbus] = [Ybus]^{-1}$. The total power losses of the system is minimum if the partial derivative of (1) with respect to the injected power turns into zero, i.e., the rate of change of losses with respect to the injected power is zero. Therefore, the injection of real power at bus i can be represented as

$$P_i = -\frac{1}{\alpha_{ii}}\left[\sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right] \quad (2)$$

And also, the injected power, P_i can be represented as the difference between real power generation and the real power demand:

$$P_i = P_{DGi} - P_{Di} \quad (3)$$

where, P_{DGi} is the real power injection from DG at bus i, and P_{Di} is the load demand at node i, respectively. By substituting (2) into (3), the optimum size of DG for each bus i, for the loss to be minimum, can be expressed as

$$P_{DGi} = P_{Di} - \frac{1}{\alpha_{ii}}\left[\sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right] \quad (4)$$

Similarly, for the reactive power, differentiating P_L with respect to Q_i, and equating the rate of change to zero follows that the reactive power injection at bus i as

$$Q_i = -\frac{1}{\alpha_{ii}}\left[\sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}Q_j + \beta_{ij}P_j\right)\right] \quad (5)$$

where,

$$Q_i = Q_{DGi} - Q_{Di} \quad (6)$$

Therefore, the optimal size in terms of reactive power injection at bus i can be given as

$$Q_{DGi} = Q_{Di} - \frac{1}{\alpha_{ii}}\left[\sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}Q_j + \beta_{ij}P_j\right)\right] \quad (7)$$

In fact, the four types of DG are considered based on their terminal characteristics [3]. In this research work, only type-III DG capable of injecting both real and reactive power is considered because of gas-turbine DG integration in practical network. In case of the optimal location for the placement of type-III DG, (4) and (7) can be combined to determine the size and power factor of DG to be placed at bus i. Therefore, the size of DG unit capable of delivering both real and reactive power can be expressed as

$$S_{DG} = \sqrt{P_{DGi}^2 + Q_{DGi}^2} \quad (8)$$

And also, the optimal power factor of the type-III DG can be evaluated as

$$OPF = \frac{P_{DGi}}{\sqrt{P_{DGi}^2 + Q_{DGi}^2}} \quad (9)$$

In case of leading power factor of load, the DG with reactive power absorption capability will be required. The bus having least power loss may be considered as the candidate location for the placement of DG subject to the satisfaction of the system constraints.

B. Problem Formulation for DG Sitting

The mathematical models for considering optimal sitting of DG from the point of view of ORPD will be discussed in this section.

1) Objective Function

The objective function of ORPD study is minimizing the active power loss of the system by controlling the reactive power control devices' capacity and the DG's reactive power. The objective function, f can be expressed [8] as:

$$f = \sum_{k\in NL} P_{kloss} = \sum_{k\in NL} G_k(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}) \quad (10)$$

where, NL is the number of branches (lines) in network, G_k is the conductance of the kth line, V_i and V_j are the voltage magnitudes at the end buses i and j of the kth line and θ_{ij} is the voltage angle difference between buses i and j.

2) System Constraints

The ORPD problem consists of two major constraints; inequality and equality constraints.

Equality Constraints: Minimization of objective function is subjected to follow equality constraints representing power balance equations.

$$P_{Gi} - P_{Di} - V_i \sum_{j \in NB} V_j [G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)] = 0 \quad (11)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j \in NB} V_j [G_{ij} \sin(\delta_i - \delta_j) + B_{ij} \cos(\delta_i - \delta_j)] = 0 \quad (12)$$

where, P_G is the active power generated, Q_G is the reactive power generated, P_D is the active power demand, Q_D is the reactive power demand, NB is total number of buses, G_{ij} and B_{ij} are the transfer conductance and susceptance between bus i and j.

Inequality Constraints: The inequality constraints are typically technical limitations of the power system devices in the network. The inequality constraints represent the system operating limits [9] as:

a) *Generator Constraints*: The terminal voltage of generator and reactive power output generated are constrained as:

$$V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max} \quad (13)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad (14)$$

where, i=1, 2, 3,….,Ng. Ng is no. of generator buses.

b) *Transformer Constraints*: The tap setting of power transformers are limited to constraints as:

$$T_i^{\min} \le T_i \le T_i^{\max} \quad (15)$$

where, i=1, 2, 3,….,Nt. Nt is no. of tap setting transformers.

c) *Shunt VAR Compensator Constraints*: In this study, the shunt capacitors' limits are considered as:

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max} \quad (16)$$

where, i=1, 2, 3, …, Nc. Nc is no. of shunt capacitor installed buses.

The variables to be controlled are self-constrained variables. In this ORPD problem, the inequality constraints are integrated as penalty provisions into the objective function in (10). The fitness function for this problem can be expressed as:

$$F = f + \sum_{i \in Npq} \lambda_{Vi}(V_i - V_i^{\lim})^2 + \sum_{i \in Nt} \lambda_{Ti}(T_i - T_i^{\lim})^2 + \sum_{i \in Ng} \lambda_{Gi}(Q_{Gi} - Q_{Gi}^{\lim})^2 \quad (17)$$

where, λ_{Vi} is the penalty multiplier for voltage limit, λ_{Ti} is the penalty multiplier for transformer tap setting limit and λ_{Gi} is the penalty multiplier for generated reactive power limit, respectively. Penalty multipliers are large positive constants for minimum deviation in these inequality constraints. The minimum and maximum limitations of V_i, T_i and Q_i are defined as:

$$V_i^{\lim} = \begin{cases} V_i^{\max}; V_i > V_i^{\max} \\ V_i^{\min}; V_i < V_i^{\min} \end{cases} \quad (18)$$

$$T_i^{\lim} = \begin{cases} T_i^{\max}; T_i > T_i^{\max} \\ T_i^{\min}; T_i < T_i^{\min} \end{cases} \quad (19)$$

$$Q_{Gi}^{\lim} = \begin{cases} Q_{Gi}^{\max}; Q_{Gi} > Q_{Gi}^{\max} \\ Q_{Gi}^{\min}; Q_{Gi} < Q_{Gi}^{\min} \end{cases} \quad (20)$$

C. PSO Algorithm Combined with MATPOWER for ORPD

In this study, all the controlled variables such as the generator bus voltages, the transformer tap setting and the generated reactive power are the elements of the solution of ORPD problem. The heuristic algorithm optimization is required in finding these optimal settings of control variables. In this paper, the technique of PSO algorithm inspired with MATPOWER [10] is contributed to solve ORPD problem integrating a type-III DG. The PSO, firstly introduced by Kennedy and Eberhart, is a population-based evolutionary heuristic technique [11]. It takes account of two terms p_{best} and g_{best}. The velocity of each particle is updated over the course of iteration from these mathematical equations:

$$v_{id}^{k+1} = w^k . v_{id}^k + c_1 . rand_1 . (pbest_{id} - x_{id}^k) + c_2 . rand_2 . (gbest_d - x_{id}^k) \quad (21)$$

where, c_1, c_2 are acceleration constants, k is the current iteration number. In (21), the first part is concerned with momentum to the particles. It provides diversification to the particles in investigate process. The inertia weight constant of the particles, w^k which reins the exploration of the seek space, is set by:

$$w^k = w^{\max} - \frac{w^{\max} - w^{\min}}{iter^{\max}} * iter \quad (22)$$

The second and third parts of (21) are known as cognitive component and social component, respectively. These components offer attraction towards best ever position and attraction towards best previous performance of neighborhood, respectively. The 'iter' is the number of iterations to be carried out. Each particle's position can be updated using (23):

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \quad (23)$$

These particles are representing continuous variables in the PSO population.

III. Computational Procedure for DG Allocation

The combination of two-step approach for determining the optimal size and the location of DG are given step-by-step in the following. First step is to find the optimal DG size of each candidate bus using the analytical approach and the second one is PSO based ORPD technique for determining optimal location which has been applied from the sizes of DG at each candidate bus for minimum real power loss. The fitness function (F) represented in this study is to reduce the lowest point of the active power loss combining the sum of product of penalty multipliers and square of controlled variables in terms of respective limits. In MATPOWER, the power balance equations given in (11) and (12) are easily fulfilled Therefore, PSO algorithm for DG location is scripted merging with MATPOWER Toolbox.

A. Procedure for DG Sizing

MATLAB based computer program has been scripted to calculate the optimum sizes of DG at various buses. Well-known Newton-Raphson algorithm based load flow solver [12] is used to solve the base case solution and the base case exact loss is calculated using (1). The optimum sizes of DG for each candidate bus except the reference bus and generator buses are calculated using (4), (7) and (8). And then, the optimal power factor is calculated using (9) in case of type-III DG.

B. Step-by-step Procedure for DG Sitting

In this paper, the two-step combination for the optimal location of DG into distribution network is presented. Therefore, after finding the individual optimal sizes of DG, the respective cases including the system data and optimal DG size at the respective buses are saved in MATPOWER 'case' files.

The computation procedure to find the optimal location DG through optimal size to minimize the real power loss considering ORPD technique is described below.

Step1. Initialize PSO parameters.

Step2. Load randomly MATPOWER case file including with respective system data and DG size

Step3. Initialize various particles' (control variables) values randomly.

Step4. Find fitness value of fitness function and save p_{best} and g_{best} values.

Step5. Update the velocity and position of each particle using (21) and (23).

Step6. Call MATPOWER function 'runpf' to run power flow updated particles' position and velocities.

Step7. Display simulation results and loss of each particle after power flow calculation using MATPOWER routine.

Step8. Check whether the inequality constraints violate the limits or not at the end of power flow calculation. If the solution exceeds the limits, penalize the violations.

Step9. Find the new fitness value of fitness function using updated particle position and velocity.

Step10. Measure up to new fitness value with previous one. If the new fitness value obtained is better than the preceding one, keep posted new p_{best} and g_{best}.

Step11. If the iteration number reaches the maximum limit, go to step 12. Otherwise, set iteration index k=k+1, and go back to step 6.

Step12. Print out the optimal solution to the target problem.

These steps are repeated again for another test case files. The optimal solution results are compared according to ranking of how much losses are minimized. The best position includes the optimal size and site of DGs and the corresponding fitness value represents the minimum total real power loss.

IV. Configuration of Investigated Network

The proposed methodology is tested on IEEE-30 bus system which represents a portion of the American Electric Power System shown in Fig. 1. Parameters of test system are given in [12]. The system has 30 buses, mainly 132 kV and 33 kV buses, and 41 branches. Total active and reactive powers of the system loads are 283 MW and 126.2 MVAr, respectively.

The system under study already consists of six generating stations which are located at the buses 1, 2, 5, 8, 11 and 13, which of four are used as synchronous condensers for reactive power compensation as shown in Fig. 1. The minimum and maximum constraints for control variables of test system are summarized in Table I.

In the base case power flow study, bus number 1 is considered as the slack bus based on 100 MVA base. Since the investigated network is composed of 132 kV transmission network and 33 kV distribution network, the DG allocation is only considered on the distribution area only because a DG source may not be connected directly to 132 kV bus.

TABLE I
Limits of Control Variables

Control Variables	V_{min} (pu)	V_{max} (pu)	T_{Kmin} (pu)	T_{Kmax} (pu)	Q_{Cmin} (MVAr)	Q_{Cmax} (MVAr)
Limit	0.90	1.10	0.90	1.10	0.00	20.0

V. Results and Discussions

The proposed procedure is coded in MATLAB environment. It is applied to the network shown in Fig. 1 in order to test the effectiveness of the proposed two-step combined technique.

A. Analytical Results for Optimal DG Size

As explained in Section III, firstly the optimal size for each candidate bus has been evaluated using the analytical approach. The results of optimal size in MVA and respective optimal power factors are depicted in Figs. 2 and 3, respectively.

Since the integration of DG is evaluated on 33 kV network areas, only 18 candidate buses are considered to calculate optimal sizing. The optimal sizes for various locations on each

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33 kV distribution area are ranging from 4.188 MVA to 35.143 MVA with respective to the optimal power factor rating of 0.549 pu (leading) to 0.995 pu (leading). According to descending order in sizing, the biggest size is the DG to be installed at bus 10 while the smallest one is at bus 26. The second largest one is at bus 12.

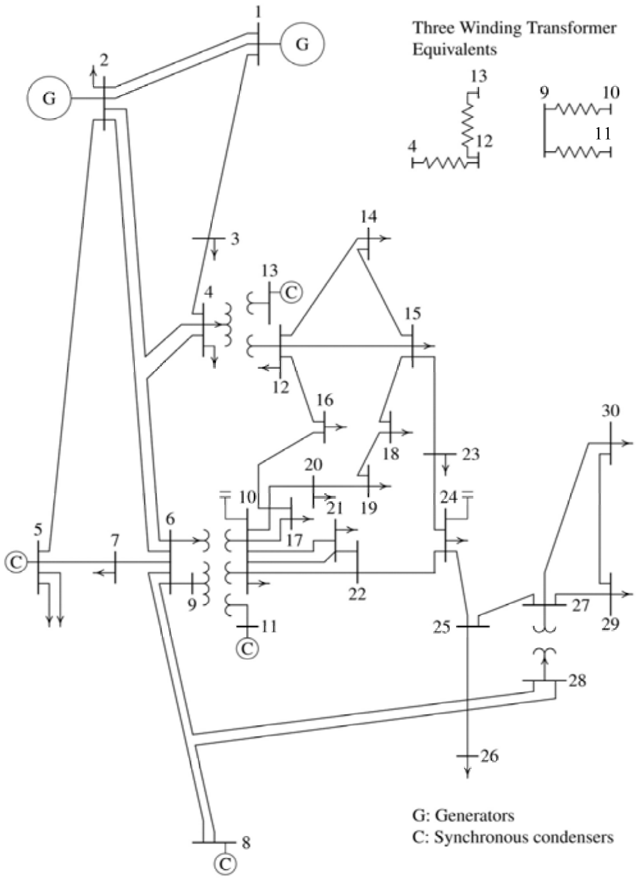

Fig. 1 IEEE 30 Bus Test System

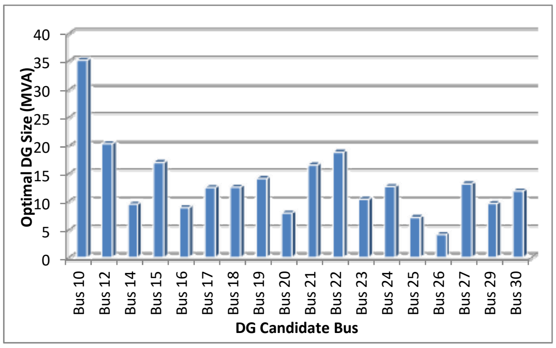

Fig. 2 Optimal DG Size at Allied Candidate Bus

The respective DG candidate bus data are implemented in 18 different MATPOWER case files for determining the optimal DG site in distribution area. These case files are used as input data files to find the optimal location of DG through PSO based ORPD.

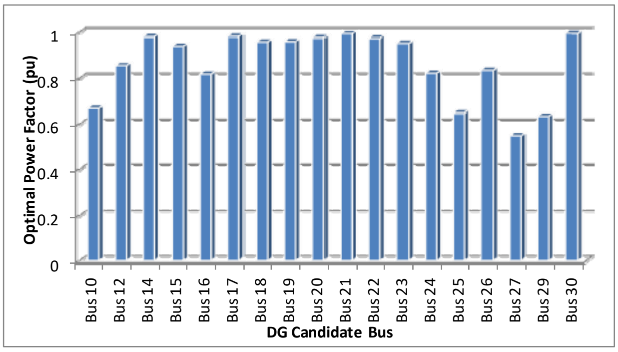

Fig. 3 Optimal Power Factor for DG at Allied Bus

B. Numerical Results for DG Optimal Location

Optimal site selection of DG for its optimal placement in distribution network is very essential for better system planning. Installation of DG at improper location causes higher system losses. Since, in this study, the optimal DG site is decided based on PSP algorithm, the basic parameters that need to be tuned in algorithm are required and these parameters are expressed in Table II.

The estimated optimal sizes of DG on each candidate bus are implemented on the different MATPOWER script files and the proposed PSO algorithm has been applied for solving different cases and the respective numerical records of each case are stored and compared for real power loss minimization. Fig. 4 depicts the results in terms of optimal placement of DG unit. The real total power losses of system without DG, considering only ORPD solution without DG and ORPD with DG on each candidate bus are illustrated with bar chart in Fig. 4.

TABLE II
BASIC PARAMETERS OF PSO

Sr.No.	Parameters	Value
1	Population Size	40
2	Maximum Inertia Weight	0.9
3	Minimum Inertia Weight	0.4
4	Acceleration Constants [c1, c2]	[2.05, 2.05]
5	Maximum Number of Iterations	100
6	Random Number	[0, 1]

It can be clearly seen that the best (optimal) location of DG injection is bus 21, followed by bus 10 and bus 30. The optimization process integrating the optimal size of DG at bus 21 is shown in Fig. 5, in terms of convergence characteristics of fitness function.

At the beginning of the optimization process, the positions of particles are randomly selected. The global optimal active power loss is initially about 16.13 MW through PSO based ORPD. Since the respective particles modernize their positions continually towards the best position, maintaining the function of minimizing in real power loss, processing till up to final iteration, as shown in Fig. 5. After iterations, the active power loss converges to 14.0144 MW as compared to base case power loss of 17.5941 MW and ORPD without DG of 17.3885 MW. The total CPU time is 1197.67 seconds.

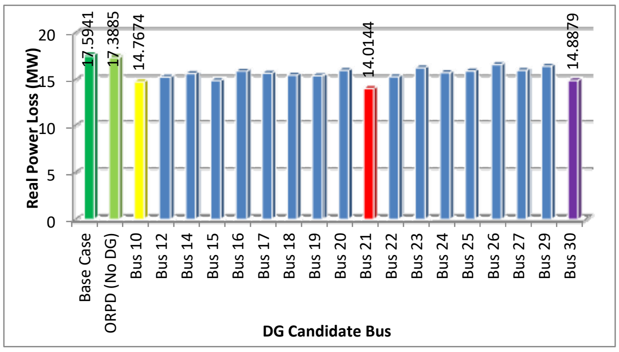

Fig. 4 Total Power Loss of Test System with and without DG Integrated at Allied Bus

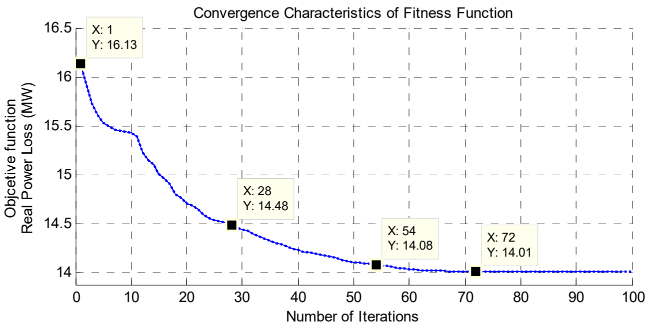

Fig. 5 Convergence Characteristics of PSO Algorithm for Optimal DG Placement @ Bus 21

The first three optimal DG sites are summarized in Table III with respective to optimal size and respective percent reduction in active power loss after optimization process.

TABLE III
OPTIMAL RANKING IN SIZES AND LOCATIONS

Optimal Location	Optimal Size (MVA, pf)	Active Power Loss (MW)		% Reduction in Power Loss
		ORPD Without DG	ORPD With DG	
Bus 21	16.5, 0.9 (lead)	17.5941	14.0144	20.3460
Bus 10	35.14, 0.768(lead)	17.5941	14.7674	16.0662
Bus 30	11.97, 0.91(lead)	17.5941	14.8879	15.3813

It can be easily observed that the type-III DG injected at bus 21 gives the most reduction in power loss of about 20.35% by comparing ORPD without DG solution. Therefore, it can be decided that installing DG at bus 21 is the optimal location among other different candidate buses, with the optimal size of 16.5 MVA rating.

C. Performance Analysis of DG Allocation

As discussed in above, bus 21 is the best (optimal) candidate bus for DG allocation with total power loss of test system of 14.0144 MW. According to the loss comparison results, the optimal location of newly DG at bus 21 is determined to optimally dispatch reactive power in the investigated system. Table IV gives the data related to the voltage profiles (showing minimum and maximum values with respective to bus number) for without and with DG installed at bus 21.

TABLE IV
VOLTAGE PROFILE BEFORE AND AFTER DG

Voltage @ Bus Before DG			Voltage @ Bus After DG		
Min	Max	Max @ 33 kV	Min	Max	Max @ 33 kV
0.960 @33	1.069 @1	1.018 @12	0.965 @33	1.087 @1	1.054 @12

To compare and evaluate the performance of multiple DG allocations with the single DG placement, the two DGs placement and the three DGs placement are considered with PSO based ORPD. As described in Table III, DGs installed at bus 10 and at bus 30 are second and third optimal positions ranked on minimum active power losses. Therefore, firstly, the two DGs are installed at bus 21 (first optimal allocation) and bus 10 (second position). After that, the three DGs are implemented at bus 21, 10 and 30, respectively, with respective to their optimal sizing. After the optimization process, the optimal values obtained are recorded and compared for before and after DG placement.

Table V highlights the maximum and minimum voltage profiles of before and after the two DGs placement while Table VI presents voltage profile comparisons for before and after the three DGs allocation.

TABLE V
VOLTAGE PROFILE BEFORE AND AFTER 2 DGS

Voltage @ Bus Before DG			Voltage @ Bus After DG		
Min	Max	Max @ 33 kV	Min	Max	Max @ 33 kV
0.960 @33	1.069 @1	1.018 @12	0.970 @33	1.090 @1	1.006 @10

TABLE VI
VOLTAGE PROFILE BEFORE AND AFTER 3 DGS

Voltage @ Bus Before DG			Voltage @ Bus After DG		
Min	Max	Max @ 33 kV	Min	Max	Max @ 33 kV
0.960 @33	1.069 @1	1.018 @12	0.989 @26	1.094 @1	1.022 @10

In this study, the system voltage profile is improved through ORPD in terms of loss reduction. The allowable voltage regulation of system is ± 10 %, i.e., the voltage maintains 0.9 pu and 1.1 pu, respectively. The improvement in voltage profiles based on system average load condition is analyzed and the system voltage profiles of test system (before and after single DG and multiple DGs installation) are demonstrated in Fig. 6.

Observing Tables IV-VI, the results in terms of optimal placement of DG units are identical. To discuss more emphasis, the content of loss reduction in single DG should be compared with that of multiple DGs placement. In Table VII, the corresponding results for optimal control parameters like: the generator voltage (pu), the transformer tap setting (pu) and the shunt capacitor (MVAr) are summarized for before and after DG installations. Consequently, the percentage of result accuracy (RA) for loss reduction of the combined technique is evaluated to test the effectiveness on system during optimization process, identifying the high RA value. Based on the numerical results, RA of the proposed strategy is determined by:

$$RA = \frac{NP - BP}{NP} \times 100\% \qquad (24)$$

where, NP is the normal (ORPD without DG) power loss and BP is the best minimum power losses (ORPD with DG/DGs).

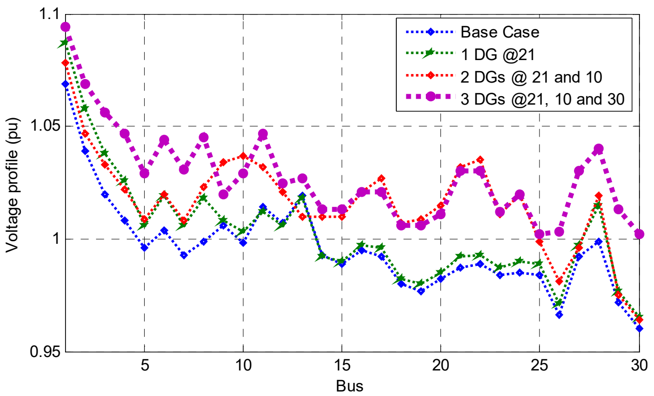

Fig. 6 System Voltages of Test System: Before and After DG

The corresponding results of total power losses and percentage RA are also tabulated in Table VII. Though the total power losses and RA for two DGs placement and three DGs placement are much more effective (less than in power loss and higher than in RA) than that of single DG placement at the best (optimal) location at bus 2, they are not cost effective. For the investigated network, just only one DG allocation with optimal size and optimal site is adequate to minimize the active power loss through reactive power control.

VI. Conclusion

In this work, the approach combining analytical method for optimal sizing and the PSO based ORPD technique for optimal sitting has been applied for the type-III DG allocation problem in power distribution network. The proposed strategy has been tested on IEEE 30 Bus test system and the DG allocation is considered on 33 kV distribution areas. Estimating DG sizing based on the loss sensitivity analysis is performed and the optimal DG sitting problem is formulated as PSO based ORPD which aims to minimize the active power loss. According to the results, the DG unit with appropriate size at optimal location can reduce the system losses to a considerable amount. The technique of combining analytical method and PSO algorithm considering reactive power dispatch for DG placement not only reduces the total line losses but also improves the voltage profiles of system within the constraints. The optimal installed DG at bus 21 with optimal size of 16.5 MVA, 0.9 pf (leading) reduced the system loss from 17.3885 MW to 14.0144 MW with the reduction percentage of about 20.35%. In conclusion, the optimal allocation of DG gives direction for the economic planning and operation of power system in the age of integrated grid.

TABLE VII
Optimal Values Obtained and Result Accuracy before and after DGs

Sr. No.	Control Parameters		ORPD without DG	One DG placement	Two DGs placement	Three DGs placement
1	Generator voltages (pu)	V_{G1}	1.081978958	1.08768188	1.09013168	1.09417024
		V_{G2}	1.064523787	1.06780298	1.05300618	1.04850195
		V_{G5}	1.009441307	1.02574705	1.01011897	1.0069929
		V_{G8}	1.012752912	1.03340118	1.0163771	1.01272387
		V_{G11}	1.04662861	0.99476985	1.03924589	1.00804286
		V_{G13}	0.994746136	1.01110062	1.02427497	1.01776815
		$V_{G21(DG)}$	-	1.0131435	1.0276477	1.02151713
		$V_{G10(DG)}$	-	-	1.02682851	1.02262569
		$V_{G30(DG)}$	-	-	-	1.02087831
2	Transformer tap setting (pu)	$T_{K(6\text{-}9)}$	1.01962682	0.99894247	1.01212705	1.00420364
		$T_{K(6\text{-}10)}$	1.025615518	1.01176953	1.01604575	0.98630468
		$T_{K(4\text{-}12)}$	1.004376168	1.03067642	0.98433394	0.98205301
		$T_{K(28\text{-}27)}$	0.970634258	0.98487706	0.96738955	0.98544523
3	Shunt compensators (MVAr)	Q_{C10}	9.48012332	9.21430138	4.94266194	7.54930165
		Q_{C24}	11.9150158	12.1970918	9.87430506	11.2297449
4	Total power losses(MW)	P_{loss}	17.3885	14.0144	12.6974	11.4380
5	Result Accuracy (%)	RA	-	20.3460	27.8315	34.9896

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