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Particle Swarm Optimization based multi objective approach for installation of dispersed generator

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ABSTRACT

This research introduces a Particle Swarm Optimization (PSO) based multi objective approach for installation of dispersed generator (DG). It consists of objectives which are explored by using impedance parameters for evaluating performance parameters of power system required for optimal DG deployment. The performance parameters like capacity, location, operating power factor, percentage penetration etc. are found to be essential while planning a DG installation. This paper presents the methodology explored to find capacity and location through a PSO based multi objective function.

Keywords: Dispersed generator, multi objective approach, Particle Swarm Optimization

INTRODUCTION

Evaluation of optimal injecting point for insertion of dispersed generator (DG) in primary distribution system location is the complicated task of investigation of the most prominent bus at which if DG is installed maximum benefits of its insertion in the system can be availed with satisfied operating constraints.[1-5] It may be voltage profile of the system, overall power generation capacities and radial structure of network.

The selection of capacity, location, operating power factor and penetration level of DG are essential features of DG deployment and inappropriate selection of these parameters may lead to degradation of system performance than without DG.[2,-10] In literature many methods are availble showing the complicacy of the problem. B. Singh et al.[1] has described the challenges and opportunities in this field, E. R. Shafkhatov[2] has presented the novel technique of integration of DGs in power system with various Industrial Enterprises, Researchers have explored various techniques for DG allocation such as Analytical approach,[11] Mixed Integer Non-Linear Programming[7], Ant colony search,[12] BEE Colony Algorithm,[13] Particle Swarm Optimization[10,22] genetic alogorithm[5,10,16] Load Flow Method,[11] chimp optimization,[20] Bilevel approach,[27] artificial hummingbird algorithm[30] etc. This paper introduces a PSO based multi objective approach for successful and adaptive DG deployment found ideal for resilient distribution system planning. To demonstrate the utility of the proposed approach a prototype of the complete power system is designed which constitute generation, system structure and load modeling.

a) Source modeling
b) Distribution system modeling
c) Load modeling

The detailed description of the assumed system formulation is as follows:

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SOURCE MODELING[11]

In this work two streams of power supply are required, one from Substation (S.S.) and another from DG, whose optimal insertion has to be planned. The capacity of S.S. depends on the selected test distribution system whereas the complete DG designing parameters should be chosen so as to attain the maximum possible benefits of its insertion.[9-14] In this work four different types of DGs as mentioned by Satish Kumar Injeti[4] which are given in Table 1 are selected.

Table 1. DG Models[11-13]

DG Type	OPF_{DG}	Power injection capability	Example	Required Site specification
Type I	unity	Active power only	Solar	Abundant radiant light and heat energy from sun
			photovoltaic cells	Abundant radiant light and heat energy from sun
			diesel engine	Far away from the urban areas where transportation is not possible and the climatic conditions doesn't support any specific DG
			fuel cells	Far away from the urban areas where transportation is not possible and the climatic conditions does not support any specific DG
Type II	zero	Reactive Power only	FACTS devices	Installed at intermediate distances throughout transmission lines as per the requirement of reactive power
			Synchronous compensators such as gas turbines	
Type III or combination of Type I and Type III	$0 < OPF_{DG} < 1$, lagging	Active and reactive power both	Synchronous generators Example: combustion turbines etc.	Installed at intermediate distances throughout transmission lines as per the requirement of reactive power
Type IV	$0 < OPF_{DG} < 1$, leading	Active power and consumes reactive power	Wind turbines	Sufficient wind speeds
			Hydro power	Sufficient water head capable of producing sufficient water hear

As per the proposed method, the most suitable DG can be investigated after evaluation of the algorithm. Thus, any of the DGs mentioned in Table 1 which is appropriate with the geographic and climatic situations can be installed.

DISTRIBUTION SYSTEM MODELING

In the available literature various DG deployment methodologies are available.[1-35] Researchers executed their algorithm on practical distribution systems or standard test distribution systems. To execute the utility of the proposed algorithm it is implemented on 38 bus[6] and 69 test distribution systems[7] as mentioned below. The results obtained from the cases considered in this work are compared with the already published methods.

1. 38-bus and 37 branches. It is a radial system with total load for the base configuration is 5.08MW and 2.55 MVAr whose details are given by D. Singh, D. Singh, K.S. Verma[6]
2. 69 bus-68 branches. It is a radial system with the total load demand of 3.80 MW and 2.69 MVAR whose details are given by M. E. Baran and F. F. Wu.[7]

LOAD MODELING[8]

Most of the researchers consider constant load modals for DG planning.[5,9,11, 21] whereas few have implemented studies with respect to load modal varations also.[6, 8] In this paper, impact of load models on size and placement planning of a DG has been examined. A voltage dependent load model represents the power relationship with voltage as an exponential equation, which can be mathematically expressed as equation (1) and equation (2) as given below;

$$P_{loadi} = P_{opi}V_i^{\alpha} \quad \text{---(1)}$$

$$Q_{loadi} = Q_{opi}V_i^{\beta} \quad \text{---(2)}$$

where, P_{loadi} and Q_{loadi} are true power and reactive power respectively of bus i whereas P_{opi} and Q_{opi} are the true power and reactive operating powers respectively of bus i. The Vi is the operating voltage obtained at bus i and α and β are active and reactive power exponents. The Table 1 gives the load models exponent values in order to evaluate the effects of various load models on DG planning. For practical applications, evaluation of coefficients α and β requires field measurement and parameter estimation techniques. Table 2 gives the load types and their exponent values.

Table 2. Load Types and Exponent Values[12-16]

Load type	Season	α	β
Constant	Summer	0	0
Residential	Summer	1.04	4.19
Commercial	Summer	1.50	3.15
Industrial	Summer	0.18	6.00

Thus, the overall system prototype used in this work is shown in Figure 1.

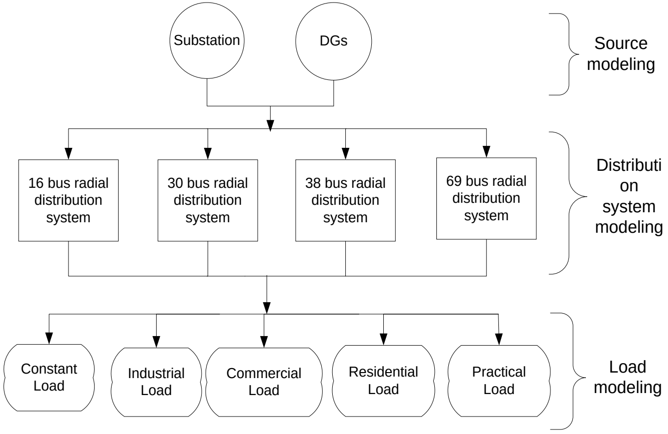

Figure 1: Prototype of system used to implicate the methodology

FORMULATION OF PSO BASED MULTI-OBJECTIVE FUNCTION (MOF)

Significant paybacks of DG[8,9] can be classified in three main categories such as technical, commercial and ecological paybacks. Among all above mentioned benefits, even if few are achieved through successful DG insertion in the system many other interlinked benefits can be ultimately bagged in. Thus, to fulfill this aim the multi-objective function explored in this work constitutes five technical performance indices. These indices and the overall optimization function are used to form a multi-objective optimization problem. The technical indices are developed to depict the impact of DG presence on the voltage profile improvement, real and reactive power losses, loadability enhancement, power flow capacity of conductors and efficiency improvement of the system. The optimization problem is solved by implementing the particle swarm optimization (PSO) optimization, which is capable of finding a global or near-global optimum solution in addition to having a very short simulation time, in the range of a few seconds.[10, 23,27] The characteristics of PSO are as follows;

i. It is based on study on swarms like bird flocking, fish schooling etc.

ii. It works in two steps, which are calculating the particle velocity and updating its position.

In this work, a hybrid analytical and PSO approach is explored to investigate the optimum result. An optimal injection point is evaluated through the PSO technique whereas the evaluations of indices need the set of equations to calculate the DG size, losses, etc. Thus, a blend of analytical as well as PSO technique is developed.

FLOWCHART FOR CALCULATION OF COMPLETE DG DESIGNING PARAMETERS BY PSO BASED MULTI OBJECTIVE APPROACH (PSOMOA)

Figure 2 shows the flow chart for the calculations of the DG designing parameters evaluated by the PSO based multi objective approach explored in this paper.

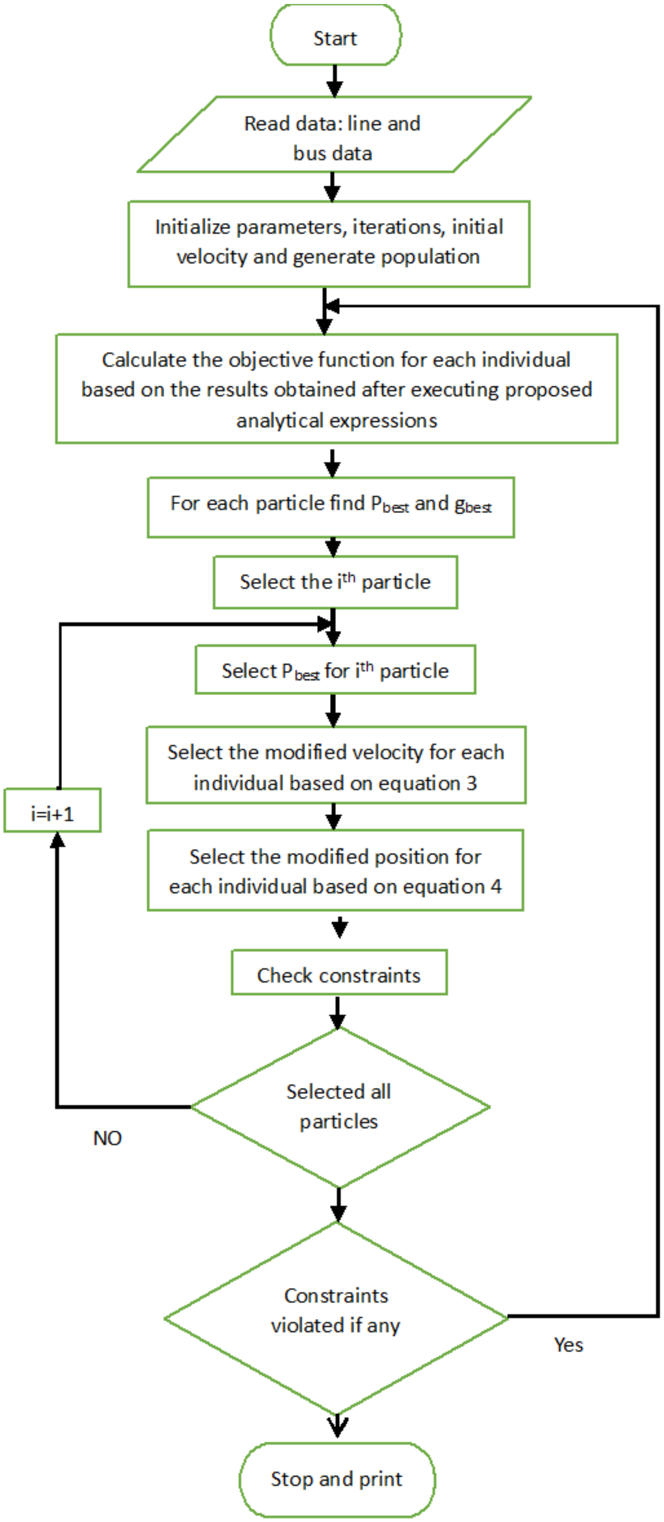

Figure 2: Flowchart for Calculation of Complete DG Designing Parameters by Research Method

PSOMOA APPROACH FOR ITS SUCCESSFUL INCLUSION IN DISTRIBUTION NETWORK

PSO is an evolutionary optimization computation technique is based on research on swarms such as fish schooling and bird flocking.[36,37] The method has been developed through a simulation of simplified social models. It works in two steps, which are calculating the particle velocity and updating its position. Therefore, the computation time is short, and it requires little memory.

In this work PSOMOA function is evaluated for investigation of overall DG parameters suitable for the test distribution systems. The algorithm for evaluating those parameters is given below;

Step 1: IMPLEMENTATION OF PSO

It begins by randomly creating a starting population of all possible results.

Step 2: SIZE LOCATION PAIR INVESTIGATION

i. Each solution requires, investigation of size–location pairs of each single DG installed in the system by satisfying all the considered technical constraints

ii. If any one of these constraints is violated, that solution is discarded

iii. The multi objective function of each individual solution is assessed following the generation of a population of solutions that satisfy the prescribed restrictions

iv. After the population cycle is initialised, each person's position in the solution space is changed using PSO parameters like p_{best}, g_{best}, and agent velocity to produce the most recent population.

v. The DG size and/or position are modified back to fall inside the designated parameters if they exceed the perimeter.

vi. Thereafter the operational constraints are checked

vii. If any of them is broken, the solution is discarded, and the process is repeated until a solution that is within the given parameters is discovered.

viii. The algorithm terminates when the maximum number of generations is reached in item

ix. The PSO algorithm's recommended course of action is the one which is found to be the best in all the generations (g_{best})

The following equation is used to modify the velocity of each agent:

$$v_n^{k+1} = wv_n^k + c_1 rand \times (pbest_n - s_n^k) + c_2 rand \times (gbest - s_n^k) \quad \text{---(3)}$$

Where,

v_n^k is the velocity of agent n at iteration k,

w is the adaptive inertia weight linearly adapted to decrease from $w_{max} = 0.92$ to $w_{min} = 0.04$, such that,

$w = w_{max} - [(w_{max} - w_{min})/\text{number of iterations}] * \text{current iteration number}$,

cm are the accelerating coefficients within the range [0-4], which are conventionally set to a fixed value of 2,

rand is random number between 0 and 1,

S_n^k is the current position of agent n at iteration k,

$pbest_n$ is the pbest of agent n, and

gbest is the group gbest.

Using the above equation, a certain velocity, which progressively gets nearer to pbest and gbest, can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$s_n^{k+1} = s_n^k + v_n^{k+1} \quad \text{---(4)}$$

To validate this algorithm it is applied on all the considered test distribution systems. After executing this algorithm, DG parameters suitable for successful installation in distribution network are evaluated. Table 3 indicates the Location-Size pair identified by this algorithm. To find optimal power factor of the DG, the concept of Maximum Power Transfer (MPT) theorem is used. Maximum Power Transfer theorem states that maximum power transfer can be achieved if load impedance is complex conjugate of source impedance i.e. if load power factor is leading then source power factor should be lagging. In the selected Test distribution systes the overall load is given.[6,7] As per the MPT concept if the load is absorbing the reactive power then DG should supply it and vice a versa. In case of source the leading power factor means, source is absorbing reactive power. On the other hand, the lagging power factor means source is supplying reactive power, which is just differing to load power factor conventions. Therefore, by using equations (3.30) and (3.31) power factor of DG can be written as;

$$OPF_{DG} = \alpha(P_{load}/S_{load}) \quad \text{-----------------------------(4)}$$

Table 4: Summary of evaluated DG parameters

Test Systems	Methods	Optimal Location	DG size (MVA)	OPE_{DG}	Type	P_{Loss}, kW (w/o DG)	P_{Loss}, kW (with DG)	% loss reduction	Critical bus
38 Bus	PSOMOF	30	3.4	0.94	Type 3	501.2	198.2	60.45	34
	ELF	30	3.12	0.94	Type 3	512.1	196.2	61.69	34
	SA	30	3.29	0.95	Type 3	509.4	185.3	63.62	32
69 Bus	PSOMOF	61	2.34	0.81	Type 1	219.28	22.62	89.68	65
	ELF	61	2.11	0.82	Type 1	219.14	23.45	89.31	65
	SA	61	2.243	0.82	Type 1	225.72	24.17	89.29	65

Thereafter as per equation no (4) operating power factor and therafter relavent type of DG, percentage of power loss reduction and critical bus are investigated.

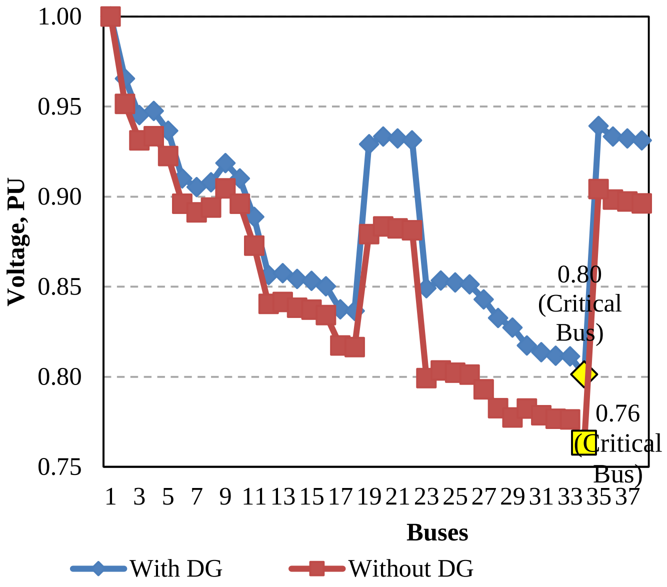

Figure 3: Voltage Profile correction of 38 bus system

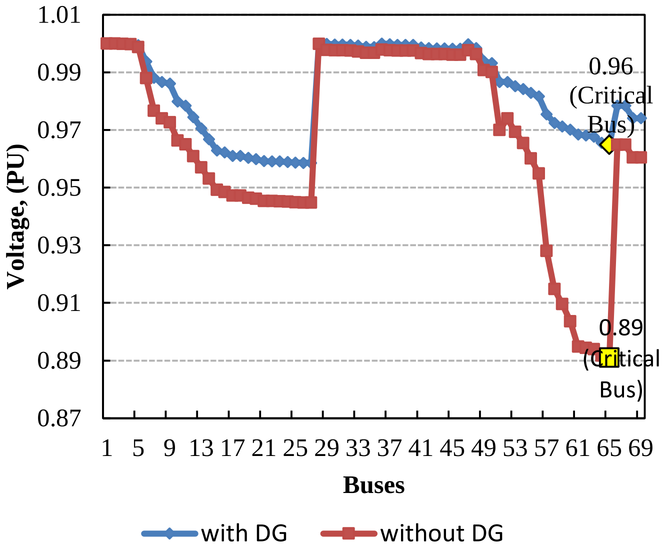

Figure 4: Voltage Profile correction of 69 bus system

Table 4 indicates the summery of all the relative parameters evaluated by research method and presents their comparison with the parameters evaluated by Sensitivity Analysis (SA) and Exact loss formula (ELF) methods. It can be observed that the DG parameters evaluated by research method are approximately same to that as evaluated by SA and ELF.

Table 5. Voltage Profile correction attained in the test distribution systems

System	Voltage @bus before DG		Voltage @bus after DG	
	Min	Max	Min	Max
38 bus	0.78@34	1.00@1	0.82@34	1.00@1
69 bus	0.90@65	1.00@1	0.97@27	1.00@1

After installing the DG with parameters as explained in Table 4, a perceptible improvement in performance of the system such as power loss reduction, voltage profile correction can be observed. In 38 bus system 62% and in 69 bus system 89% power loss reduction is possible. Similarly, an appreciable improvement in voltage profile can be observed in Figures 3 and 4.

Table 5 presents the summarized results of overall voltage profile correction attained after installing the DG with parameters as mentioned in Table 4 in the considered test distribution systems.

Thus, it is verified that the research methodology is found to be suitable for single DG installation planning. Simplicity, ease in computations, computationally less demanding, and requirement of very a smaller number of variables provide higher degree of compatibility to the research method.

Enhanced Load Ability Attained after Installing DG of Optimal Parameters at The Optimal Location Investigated by Applying Research PSOMOA on Chosen Test Distribution Systems

One of the important impacts of DG addition is enhanced ability of the system for load expansion. [29-37] This impact facilitates the deferred requirement of system up gradation. The steps to verify the enhanced loadability attained by the system after DG addition are given as follows;

Step 1. Initial voltage, V1 of the critical bus is recorded

Step 2. The load of the critical bus (bus with minimum voltage) is increased gradually

Table 6. Load expansion attained by the systems after DG addition at optimal location

System	P_{cr1}	P_{cr2}	ΔP	Load Expansion (%)	V_1	V_2	ΔV	Critical Bus Voltage Improvement (%)
38 bus	1.41	1.49	0.08	5.37	0.76	0.8	0.04	5.00
69 bus	2.8	3.5	0.7	20.00	0.84	0.95	0.11	11.58

Step 3. Voltage of critical bus is checked at every increment of load

Step 4. The load is increased until voltage reaches the critical value (V_{cr}). V_{cr} is the voltage at critical bus further addition of load will collapse the system. The load corresponding to V_{cr} is called as critical load, P_{cr}

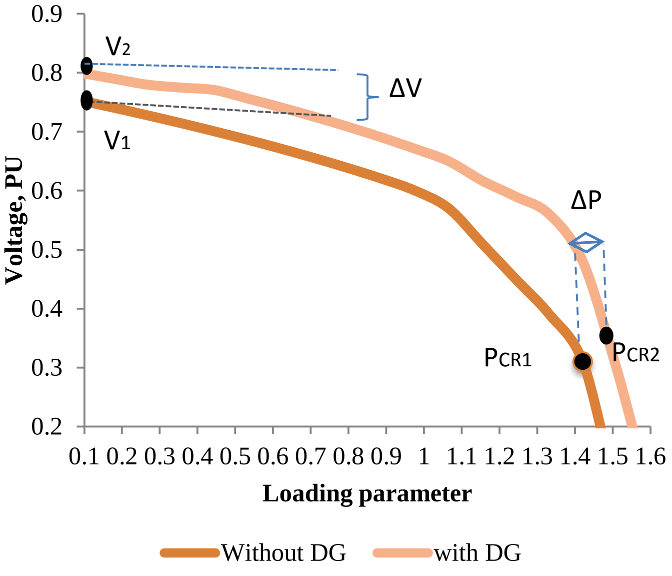

Figure 5: Enhanced Loadability attained after DG addition in 38 bus system

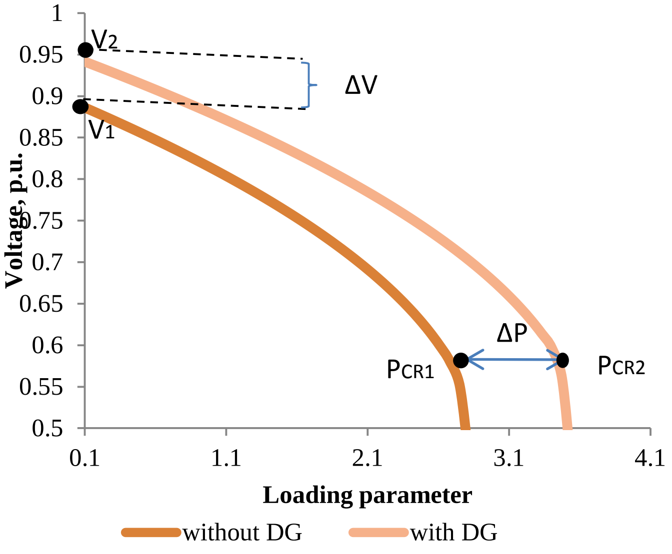

Figure 6: Enhanced Loadability attained after DG addition in 69 bus system

Step 5. Then DG is added at the optimal location investigated by research method.

Step 6. As shown in Figures 5.9 to 5.12 it is observed that in every system the voltage of critical bus is increased which is considered as V_2.

Step 7. The difference between V_2 and V_1 is called as voltage improvement, ΔV attained by the system after DG addition at optimal location

Step 8. Repeat the steps from 2 to 4 and find the value of P_{CR}. (P_{CR1} critical load without DG and P_{CR2} critical load with DG)

Step 9. Difference between P_{CR1} and P_{CR2} is called as load expansion attained after DG addition

Figures 5 to 6 show the enhanced loadability attained after DG addition in 38 bus and 69 bus system.

Table 6 summarizes the parameters indicating the enhanced loadability attained by the test distribution systems. It is observed that 5.37% and 20.00% load expansion is possible with 5.00% and 11.58 % improvement of critical bus voltage in 38 bus and 69 bus respectively.

CONCLUSION

DG installation is the complicated problem which needs the flexible, simple but efficient methodolgy. This paper presents the solutions of the problems with variable intricacy obtained by PSOMOA. The efficacy of proposed methodology is verified by comparing its results with standard methods. Numerous methods available in literature were focused on sitting and sizing of DG to install in distribution system. Most of them assumed the constant load models in which loads remain unaffected by the frequency and the nodal voltage, which contradicts the practical situations. Thus, such methods may appear promising in context with the theoretical discussions but fails to grip the practical state of affairs. The PSOMOA function optimally minimized under different load models in 38 bus and 69 bus test distribution systems. It is found that for this optimization problem the best parameters to be used for PSO in all cases were a population size of 25 and a maximum iteration number of 50. The objective function reached a global minimum and stayed there until the end of iterations. The minimum objective function was attained with a computation time of about 65 seconds. In 38 bus system and the 69 bus system size-loacation pair obtained and the power factor has been obtained. Thereafter proportionally suitable type of DG to be installed has been suggested. It is found that 5.37% and 20.00% load expansion is possible with 5.00% and 11.58 % improvement of critical bus voltage in 38 bus and 69 bus respectively. This method found practically sound and technically fit for DG system planning in any network with variable.

CONFLICT OF INTEREST STATEMENT

Authors declare that there is no conflict of interest for this work.

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