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Applying PSO Technique for Optimum Siting and Sizing of DG In Distribution Systems

تطبيق تقنية أمثلة جزنيات الأسراب لتحديد المكان والحجم الأمثل لوحدات التوليد الموزع فى نظم التوزيع

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ملخص البحث:

تعتبرعملية ادماج وحدات التوليد الموزع مع شبكات التوزيع من المهام الصعبة حيث سيؤثر حجم وموقع هذه الوحدات على جهود التشغيل لشبكات التوزيع فى المستقبل، ويمكن تعظيم المزايا الناتجة عن وحدات التوليد الموزع إذا تم ادماج هذه الوحدات بشكل صحيح في النظام. ويقدم هذا البحث منهجية جديدة لتحديد كل من الحجم والموقع الأمثل لوحدات توليد موزع لتحسين استقرار جهود نظام التوزيع باستخدام تقنية أمثلة جزنيات الأسراب. وقد تم التحقق من صحة هذه المنهجية بتطبيقها على موزع معيارى IEEE 13 node distribution feeder، وتم استعراض النتائج التي تم الحصول عليها من تحليل تدفق الطاقة، وتحليل الاستقرار للوصول إلى كل من الحجم الأمثل والموقع الأمثل لوحدات التوليد الموزع.

Abstract

The integration of distributed generation (DG) with the distribution networks is a challenging task. The size and site of the DG will have an effect on the voltages and operations of the distribution networks in the future. The advantages that DG brings to the system can be best utilized if these resources have been properly allocated in the system. This paper presents a new methodology to find the optimal size and location of the DG to improve the voltage stability of the system using Particle Swarm Optimization (PSO) technique. Validation of the methodology is done using the IEEE 13 node distribution feeder. The results obtained from the power flow analysis and the optimization of size and location are presented.

Key words: Distributed generation, Particle Swarm Optimization, distribution networks.

1. Introduction

Alternative energy sources are becoming more cost effective, and many utilities are now providing incentives for alternative power. Placing these alternative energy sources, as well as other smaller traditional energy sources, on the distribution power system, allows the development of a new paradigm related to DG [1].

The installation DG on the distribution system provides numerous benefits. DG can provide peak reduction, improved power quality and reliability, and increased efficiency. DG is usually defined as an electric power source connected

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directly to the distribution network [2]. DGs have different types depending on the source of energy it uses to produce electric power. It could be diesel generation, wind power generation, photovoltaic generation or fuel cell generation [3]. Distributed generations have gained more importance in the recent years and are predicted to inevitably lead to new trends in distribution system operation. The most challenging part for most utilities is to determine siting and sizing of the DG to be installed. Large efforts were done to optimally determine the location and size of the DGs in distribution networks but most of them were based on minimizing the power losses and cost of generation [4-8]. Voltage stability is an important aspect of power system and presence of DG may improve the stability or bring instability in the system depending on the size and location that has been selected.

The collective and individual influence of synchronous and induction embedded generators on stability of a generic distribution network are investigated in [9]. A computer software package is used to determine the characteristics of the system (voltage and angular stability) with a varied mix of embedded generators, system loads and operating conditions.

The models of distribution system components are developed for distribution load flow and voltage stability analysis. In reference [10] the voltage steady-state stability and an initial approach to voltage dynamic stability are studied with several distributed generators under different load characteristics.

A voltage stability analysis was done using an iterative power system simulation package, PowerWorld™ Simulator, to evaluate the impact of strategically placed embedded generators on distribution systems with respect to the critical voltage variations and collapse margins [11].

Analysis of the effect of distributed generation capacity and location on voltage stability enhancement of distribution networks was presented in [12]. The analysis was performed using a steady state voltage stability index which was evaluated at each node of the distribution system.

A methodology for optimal placement of DG units in power networks was presented in [13]. The methodology was used to find the system configuration to meet the desired system reliability requirements and maximize loadability conditions in normal and in contingencies situations taking into account stability limits. In reference [14] the best location and size was computed by choosing limited penetration levels of DG and some possible locations. The best combination was reported by authors, at which the voltage support is maximum or voltage deviation is minimum.

However, most of the mentioned papers apply classical optimization technique to solve the problem. Nowadays, Artificial intelligence (AI) techniques play a prominent role in power system management and control. In [15], a methodology was presented for allocation and sizing of distributed generation in power systems in order to improve network transient stability. The optimization process is conducted by Genetic Algorithm. The paper concluded that both size and location of DG technologies have influenced network stability.

This paper presents a new methodology to find the optimal size and location of the DG to improve the voltage stability of the system using PSO technique. PSO is one from new evolutionary algorithm that may be used to find optimal solutions to numerical problems. PSO has many advantageous over evolutionary and genetic algorithms in many ways. PSO has memory; every particle remembers its best solution (local best) as well as the group best solution (global best) [16]. Another advantage of PSO is that the initial population of the PSO is maintained, and so there is no need for applying operators to the population, a process that is time and memory-storage-consuming. In addition, PSO is based on "constructive cooperation" between particles, in contrast with the genetic algorithms, which are based on "the survival of the fittest" [17].

2. Problem Statement

Traditional distribution systems are designed to operate with the main source and power flowing from the source to the end of the feeder. When DG is connected to the distribution systems the reversal of power flow occurs causing bidirectional power flow. The voltage profile of the system changes with DG size and location. Oversize and improper location of the DG may induce overcurrents in the system resulting in undesired voltage profiles. Undesired voltage profiles due to DG may impact power system in terms of voltage stability, system losses and reliability which have to be taken care before installing DG into the system. So, it is very important to optimize the location of DG and size on a distribution system.

Owing to the importance of the size and location of the DG and the impact of DG on the system stability this chapter aims at finding the optimal size and location of the DG that has to be connected to the grid such that the system is most stable. This work is implemented on IEEE distribution feeders that are unbalanced and aptly suitable for distribution system analysis. As a first step, unbalanced power flow program was used to do the power flow analysis of the test cases without DG and with DG in the system.

Using the voltage profiles obtained, technical analysis can be made to study the impact of DG on the system. A proper stability is selected from the literature using which the stability for distribution systems can be calculated. The test system has to be analyzed for both power flow and stability using the index selected and it was found that as the size of the system increases this analysis will be difficult and time consuming due to enormous amount of the data. This formulation was tested for both the test cases and optimal size and location was obtained without violating the constraints and maintaining the voltage stability of the system. A multi-objective formulation is also developed to address various issues like voltage support, losses and voltage stability.

3. Selection of Voltage Stability Index

Voltage stability is important factor to be considered in power system operation and planning since voltage instability may lead to the system collapse. DG may improve stability or bring instability in the system depending on the size and location that has been selected. In this paper the best size and location of the DG is found with respect to maximizing the system stability, hence a suitable stability index was selected to calculates the stability of the distribution systems. Using this stability index the node that is most vulnerable to voltage collapse can be identified based on the power flow results and appropriate actions can be initiated to prevent the system collapse. The stability index used in this work is selected from [18] and the mathematical formulation for the voltage stability index is derived from power flow equations of two bus network as shown in Figure 1.

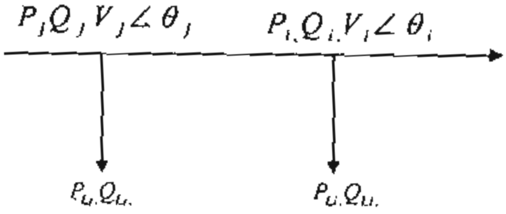

Fig. 1 Two bus network

where,

P_i , Q_i are real and reactive powers injected at bus i.

$V_i\angle\theta_i$ are voltage and voltage angles at bus i

P_{Li} , Q_{Li} are real and reactive power compon-ents of load connected to bus j.

P_j , Q_j are real and reactive powers injected at bus j.

$V_j\angle\theta_j$ are voltage and voltage angles at bus j

P_{Lj} , Q_{Lj} are real and reactive power compon-ents of load connected at bus j.

For this single line network connecting bus *j* and bus *i* the value of stability index *L* at node *i* can be expressed as [18]:

$$L(i) = 4[[V_i V_j \cos(\theta_i - \theta_j) - V_j^2 \cos(\theta_i - \theta_j)^2]/V_j^2] \quad (1)$$

This value will be used to determine the stability of the system:

The system is unstable if L(i) is greater than 1. The system is stable if L(i) is between 0 and 1. In case that L(i) is negative then the absolute value is taken.

The stability index values at all the nodes can be calculated and the node that is more vulnerable to voltage collapse can be identified. Each node has different stability index and the maximum value indicates the voltage stability margin of the system. This concept can be extended to larger systems and stability analysis can be performed using this index.

A voltage support index is the ability of the system to operate normally even when the voltage of distribution system deviates from the rated voltage within limit. Voltage support index is calculated as follows [19]

$$V_{si} = |V - V_n| \quad (2)$$

Where, V is the rated voltage of the particular node and V_n is the expected nodal voltage after contingency. Normalized voltage support index (V_{sin}) is calculated as

$$V_{sin} = \frac{|V - V_n|}{K_{vsi}} \quad (3)$$

K_{vsi} is the constant that represents the percentage of voltage fluctuation allowed in the system, and K_{vsi}= 0.15 for terrestrial distribution power system and is system dependent.

4. Power Flow Analysis

Power flow is used for steady state solution of an electric power network. Power flow analysis gives various information of the system like voltages at all the nodes, line currents and power losses. Using these results different studies related to voltage stability, voltage support, and reconfiguration can be performed. This analysis is done using three phase unbalanced power flow program, which can handle multiple DGs that can be modeled as PQ or PV nodes. There are many techniques used for power flow analysis. In this study the power flow equations were solved using the Gauss Seidel method [20]. A DG modeled as PQ node is placed on the test case considered and by varying the penetration of the DG voltage profiles of the system are obtained by varying the penetration. The data from the power flow can be used to find the stability of the system, power losses and also see the effects of reconfiguration. The results obtained were compared with the base case (case without DG) to see the impact of DG on the voltage profile of the system.

5. Mathematical Model

Optimal allocation and size is the major concern in installing DG units and solution for this can be obtained by complete study of all feasible combinations and location of DG's. The PSO technique is used for finding optimal size and location running power flow for each combination and calculating the stability index values the nodes for each case. The combination that gives the minimum stability index can be considered as optimal size and location. This approach involves handling large amount of data especially for larger systems and it's a time consuming process.

The formulation is based on optimal power flow approach with objective function being maximizing the stability or minimizing the stability index. The power flow equations are embedded in the formulation itself and for each size as well as each location of DG power flow is run.

A multi objective formulation to find the best size and location of the DG such that the voltage stability and voltage support of the system will be maximized is developed. The constraints enforced are *power flow equations (eqs. 5,6), voltage limits (eq. 7), load current limits (eq. 8),* and *DG power limits (eq. 9),*. The mathematical formulation is as shown below

Objective function

$$Min(W_1\, Max(L(i)) + W_2\, Max(V_{sin})) \tag{4}$$

Subject to:

Equality Constraints

$$V_j^p = \left(V_i^p - \sum_{m=a}^{c} Z_{ij}^{mp}\ I_{ij}^p\right) \tag{5}$$

$$\sum_N I_{ij}^p - \sum_O I_{jr}^p - IL_j^p = 0 \tag{6}$$

Inequality Constraints

$$V_i^{min} \le V_i \le V_i^{max} \tag{7}$$

$$P_{DG}^{min} \le P_{DG} \le P_{DG}^{max} \tag{8}$$

$$IL_i^p \le IL_{i.max}^p \tag{9}$$

Where

Z_{ij}^{mp} mutually coupled impedance matrix of the branch between nodes i and j.
IL_i^p load current flowing in node i and phase p.
IL_j^p load current flowing in node j and phase p.
I_{ij}^p load current flowing in node j and phase p.
V_i^p voltage at node *i* for phase p.
V_j^p voltage at node *j* for phase p.
p belongs to set of phases a, b and c.
N the set of branches with currents going into the node *j*.
O the set of branches with currents coming out of the node *j*.
P_{DG}^{min} minimum size of the DG.
P_{DG}^{max} maximum size of the DG.
V_i^{min} minimum voltage limit at node *i*.
V_i^{max} maximum voltage limit at node i.
W_1, W_2 weighting factor for both voltage stability and voltage support indices

6. PSO Technique

Particle Swarm Optimization (PSO) is a relatively recent heuristic search method whose mechanics are inspired by the swarming or collaborative behavior of biological populations. PSO refers to a relatively new family of algorithms that may be used to find optimal (or near optimal) solutions to numerical and qualitative problems. In PSO, a set of randomly generated solutions (initial swarm) propagates in the design space towards the optimal solution over a number of iterations (moves) based on large amount of information about the design space that is assimilated and shared by all members of the swarm. PSO is inspired by the ability of flocks of birds, schools of fish, and herds of animals to adapt to their environment, find rich sources of food, and avoid predators by implementing an "information sharing" approach, hence, developing an evolutionary advantage. References [21] and [22] describe a complete chronicle of the development of the PSO algorithm form merely a motion simulator to a heuristic optimization approach.

The basic PSO algorithm consists of three steps, namely, generating particles' positions and velocities, velocity update, and finally, position update. Here, a particle refers to a point in the design space that changes its position from one move (iteration) to another based on velocity updates. First, the positions, x_k^i, and velocities, v_k^i, of the initial swarm of particles are randomly generated using upper and lower bounds on the design variables values, x_{min} and x_{max}, as expressed in Equations 1 and 2. The positions and velocities are given in a vector format with the superscript and subscript denoting the i^{th} particle at time k. In Equations 10 and 11, *rand* is a uniformly distributed random variable that can take any value between 0 and 1. This initialization process allows the swarm particles to be randomly distributed across the design space.

$$x_o^i = X_{min} + rand(x_{max} - x_{min}) \tag{10}$$

$$v_o^i = \frac{x_{min}+rand(x_{max}-x_{min})}{\Delta t} = \frac{position}{time} \tag{11}$$

The second step is to update the velocities of all particles at time 1 + k using the particles objective or fitness values which are functions of the particles current positions in the design space at time k . The fitness function value of a particle determines which particle has the best global value in the current swarm, p_k^g, and also determines the best position of each particle over time, p^i, i.e. in current and all previous moves. The velocity update formula uses these two pieces of information for each particle in the swarm along with the effect of current motion, v_k^i , to provide a search direction, v_{k+1}^i, for the next iteration. The velocity update formula includes some random parameters, represented by the uniformly distributed variables, *rand*, to ensure good coverage of the design space and avoid entrapment in local optima. The three values that effect the new search direction, namely, current motion, particle own memory, and swarm influence, are incorporated via a summation approach as shown in Equation 12 with three weight factors, namely, inertia factor, w , self confidence factor, c_1, and swarm confidence factor, c_2, respectively.

$$v_{k+1}^i = wv_k^i + c_1\, rand\, \frac{(p^i - x_k^i)}{\Delta t}\; c_2\, rand\, \frac{(p_k^g - x_k^i)}{\Delta t} \tag{12}$$

The three steps of velocity update, position update, and fitness calculations are repeated until a desired convergence criterion is met. In the PSO algorithm implemented in this study, the stopping criteria is that the maximum change in best fitness should be smaller than specified tolerance for a specified number of moves, S, as shown in Equation 13. In this work, S is specified as ten moves and ε is specified as 10-5 for all test problems.

$$\left|f(p_k^g) - f(p_{k-q}^g)\right| \leq \varepsilon \qquad q = 1,2,\ldots S \tag{13}$$

In PSO, the design variables can take any values, even outside their side constraints, based on their current position in the design space and the calculated velocity vector. This means that the design variables can go outside their lower or upper limits, x_{min} or x_{max} which usually happens when the velocity vector grows very rapidly. This phenomenon can lead to divergence. To avoid this problem, in this study,

whenever the design variables violate their upper or lower design bounds, they are artificially brought back to their nearest side constraint. This approach of handling side constraints is recommended by Reference [22] and is believed to avoid velocity "explosion". Functional constraints are handled using a linear exterior penalty function approach as:

$$f(x) = \emptyset(x) + \sum_{i=1}^{N_{con}} r_{i\max[c.g_i(x)]} \qquad (14)$$

In addition to applying penalty functions to handle designs with violated functional constraints, in PSO, it is recommended that the velocity vector of a particle with violated constraints be reset to zero in the velocity update formula as shown in equation 15 [23]. This is because if a particle is infeasible, there is a big chance that the last search direction (velocity) was not feasible.

$$v_{k+1}^{i} - c_1\, rand\, \frac{(p^i - x_k^i)}{\Delta t}\, c_{2\,rand}\, \frac{(p_k^g - x_k^i)}{\Delta t} \qquad (15)$$

In many design applications, especially complex systems, the optimization problem statement usually includes discrete design variables, such as technology choices. Reference [24] suggests a simple but effective way to implement discrete design variables with PSO that is to round particle position coordinates (design variable values) to the nearest integers when the design variables being investigated are discrete. This is the strategy that is implemented in this study.

There has been no recommendation in the literature regarding swarm size in PSO. Most researchers use a swarm size of 10 to 50 but there is no well established guideline [22]. Appropriate value ranges for C_1 and C_2 are 1 to 2, but 2 is the most appropriate in many cases. Appropriate values for ω_{min} and ω_{max} are 0.4 and 0.9 [25] respectively.

7. Architecture of the Proposed Methodology

A Matlab program is developed to represent the previous optimization problem. The program architecture is divided into four main modules:

- *Input module:* In this section each element and all data included in the problem are defined.
- *Power Flow module:* The inputs for the load flow module are the buses data (type, voltage, and load) and lines data (impedance).The result from this module is passed to the optimization phase.
- *PSO module:* This module solves the optimization problem to select optimum size and location of DG for different cases.
- *Output module:* It shows the result clearly, easily and saves the best size and location of DG for different cases.

The previously mentioned modules are explained by Figure 2.

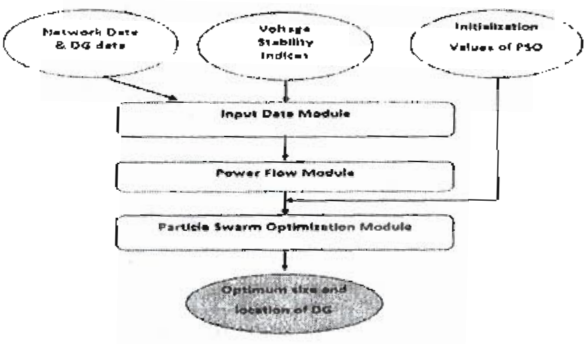

Fig. 2 Flow chart of the proposed methodology

The program is developed and tested for IEEE 13 node feeder to find the optimal size and location such that the constraints on the system are not violated and the voltage stability and voltage support of the system are maximized.

8. Numerical Application

8.1. Description of studied system

IEEE radial distribution feeders are used for this study and the data of these feeders is obtained from the IEEE test case archive for distribution feeders [9]. The feeder is highly unbalanced and closely represent the real time distribution systems. Figure 3 shows the layout of the IEEE 13 node feeder. The details of the test feeder are given in the [26]

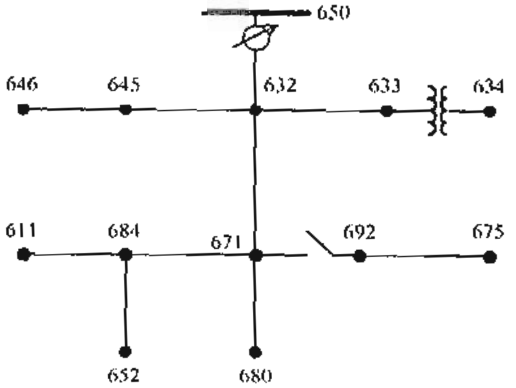

Fig.3 IEEE 13 node feeder

8.2. Voltage stability analysis

IEEE 13 node distribution feeders are modeled in three phase unbalanced power flow software. This test is highly balanced feeder with total load being 3.466 MW. Two DG's modeled as PV nodes are placed at nodes 632 and 671 as shown in Figure 4. The regulator was removed in the original analysis to clearly see the impacts of the DG on voltage profile. Total penetration (Size) of the DG is varied from 10% to 60% of the total load with each DG sharing equally and the voltage profile obtained at each case is compared with that of the base case.

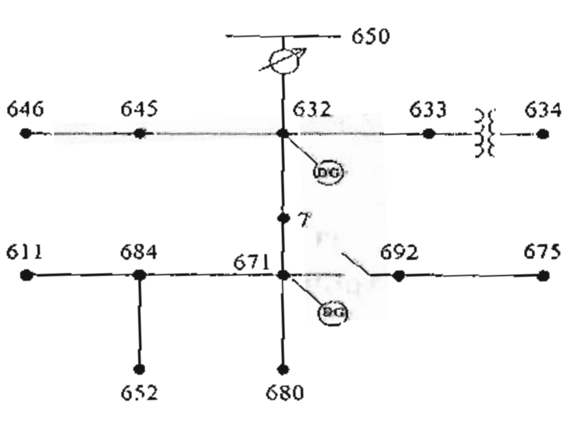

Fig. 4 IEEE 13 node feeder with DG

For the system without the DG, the voltages of the downstream nodes was close to lower tolerance level i.e. 0.95 pu and for stable operation of power system the voltages at all nodes should be 1±0.05pu. In the distribution system the load changes very frequently and if the load on the downstream nodes increases, the voltages at those nodes may further go beyond the lower tolerance level. With the presence of DG at junction nodes 631 and 671 the voltage of the downstream nodes has increased, thus improving the margin of stability for the system during peak load conditions.

Stability index can be used to find the nodes that are close to voltage collapse and brings instability in the system. The stability index selected makes use of voltages and voltage angles at all the nodes obtained from power flow to calculate the stability index values at all the nodes.

8.2.1 Stability of the feeder without DG

Power flow was run on IEEE 13 node feeder with no DG connected and the voltages and voltage angles obtained at the nodes were used to calculate the stability values using Equation 1. Table 1 gives the stability index values for the base case

Table.1 Stability index values without DG

Node no	Phase A	Phase B	Phase C
650	F	F	F
632	0.0571	0.3097	0.1898
633	0.1415	0.2450	0.2870
634	0.6730	0.6730	0.778
645	X	0.4320	0.4194
646	X	0.2911	0.0561
7	0.5506	.2184	0.2366
671	0.6674	0.0457	0.3570
692	0.0113	X	X
675	0.8719	0.2458	0.5027

684	0.7882	X	0.6350
611	X	X	0.6190
652	0.5240	X	X
680	0.6480	X	X

where,

"X" represents that index does not exist at this place as nodes might be single phase or two phase for example node 652 is single phase node and lines does not exist for phase B and phase C

"F" Feeder node

It can be seen from Table 1 that the stability index values of phase A of node 684 and phase A of node 675 are close to 1 (0.7882, 0.8719 respectively), indicating that they are prone to collapse if the load on the system is increased during peak load conditions and necessary preventive actions may need to taken.

8.2.2 Stability of the feeder with DG

Presence of DG at some location on the system may improve the stability of the system hence the same analysis is done with DG at different locations to see the impact of DG on the voltage stability of the system. Two DG's were placed at node 632 and 671 as shown in Figure 4 with the total power supplied by the DG is selected randomly as P_{DG} =2 MW. Applying the developed computer program the stability index values are calculated at all the nodes and the results are shown in Table 2.

Table 2 Stability index values with P_{DG} =2 MW

Node no	Phase A	Phase B	Phase C
650	F	F	F
632	G	G	G
633	0.0216	0.0124	0.0108
634	0.3250	0.4372	0.4540
645	X	0.1770	0.2713
646	X	0.0164	0.0131
7	0.3915	0.0113	0.1825
671	G	G	G
692	0.0003	X	X
675	0.3470	0.1042	0.2735
684	0.3880	X	0.0082
611	X	X	0.0550
652	0.0350	X	X
680	0.0001	X	X

where,

"G" Generator node

The results from this analysis show that with DG in the system the voltage profiles are improved and thus the system is more stable. With DG in the system, the margin of stability limit is improved for the nodes that are close to collapse without DG. The stability index value of node 675 was 0.8719 for the base case and with DG at node 671 the stability index value has moved down to 0.3470 proving that the voltage stability margin of the system has improved. In the similar way stability index values can be calculated for all the possible combinations of DG size and locations and the best combination can be selected based on the minimum stability index values.

8.2.3 Optimizing the size and location of DG for the test system

The aim of the formulations developed in section 5 is to find the optimal size and location of the DG individually. These formulations can be used when the unknown variable is either size of the DG or location of the DG, but there may be situations where size and location of DG has to be found simultaneously. There will be many possible combinations form which the best has to be selected without violating the system constraints. In order to find the optimal size and location the mathematical formulation of the previously mentioned optimization problem was developed in the program and simulated using PSO technique to find the optimum size and location of the DG system. The DG is set at the required location and varying the size, simultaneously power flow is run for each combination and the objective function is minimized without violating the system constraints. The program is applied and tested for IEEE 13 node feeder and the results are discussed in the following sections.

In this case there are 5 possible locations for DG in the test system and the size of the DG is varied from 10% to 70% of the total load in steps of 5%. The optimization problem here is to find the best possible combination of DG size and location at which the system will be more stable and the system constraints are not violated.

The derived multi-objective formulation was implemented using the developed Matlab program then tested for IEEE 13 node. It was found that when DG with 60% penetration was placed at node "671" the multiobjective function has minimized increasing the voltage stability and voltage support of the system. The results are shown in Table 3. The three phase voltage profile of the system with DG integrated at node "671" is shown in Table 4.

It is seen from the Table 3 that the minimized value is "0.3170" at node 675 and phase A. The multi objective values at all the nodes are closer to "0" indicating that the presence of DG has improved the voltage stability margin and voltage stability margin of the system.

Table 3 Results for 60% penetration placed at node "671"

Node no	Phase A	Phase B	Phase C
650	F	F	F
632	0.0249	0.0444	0.0580
633	0.0438	0.1356	0.0737
634	0.1392	0.1447	0.2552
645	X	0.1057	0.1850
646	X	0.0177	0.0843
7	0.1330	0.0545	0.1345
671	G	G	G
692	0.1267	X	X
675	0.3170	0.1364	0.2012
684	0.2880	X	0.1079
611	X	X	0.2150
652	0.2152	X	X
680	0.1834	X	X

Table 4 Voltages profile for the system with DG at node 671

Node ID	V_{an}	$\angle V_{an}$	V_{bn}	$\angle V_{bn}$	V_{cn}	$\angle V_{cn}$
1	1	0	1	-120	1	120
2	0.995	-0.4	0.99	-120.84	0.992	119.61
3	0.981	-0.5	0.989	-120.88	0.991	119.65
4	0.979	-0.5	0.989	-120.90	0.993	119.68
5	-	-	0.982	-120.93	0.994	119.56
6	-	-	0.985	-120.97	0.994	119.54
7	0.984	-0.5	0.991	-120.83	0.989	119.52
8	0.983	-0.9	0.992	-120.77	0.982	119.37
9	0.985	-0.9	0.992	-120.75	0.982	119.35
10	0.982	-0.9	0.992	-120.75	0.982	119.35
11	0.978	-0.9	-	-	0.981	119.37
12	-	-	-	-	0.979	119.34
13	0.960	-0.8	-	-	-	-
14	0.980	-0.9	-	-	-	-

9. Conclusion

Sizing and sitting of DG are important aspects related to distribution network which need to be investigated. The advantages that DG brings to the system can be best utilized if these resources have been properly allocated in the system. DG has significant impacts on the voltage stability of the system as it may improve or reduce it`s margins in the system.

In this paper the PSO technique is applied to provide the best configuration for voltage stability considering both size, location of the integrated DGs. A Matlab program is developed and applied IEEE 13 node feeder to validate the proposed methodology. If the DG size is very large then there are voltages in the system giving undesired voltage profiles, which may bring instability in the system. Using the selected stability index simulation studies shows that the presence of DG has improved the stability margins of the system.

The size of the DG is varied from 10% to 70% of the total load for all the formulations and it is observed from these simulations that IEEE 13 node feeder is more stable with the 60% DG penetration. It can be seen that the presence of DG with optimum size and location has improved the voltage stability margin and voltage stability margin of the system for nearly all nodes of the test system.

The optimal size and location varies for different systems, as it is dependent on the load, distribution of load in the system and distance from the main source. The results from this paper show that this is one possible approach that can be used to find the optimal size and location of DG for any system.

10. References

[1] S. Kotamarty, S. Khushalani, N. Schulz . *"Impact Of Distributed Generation on Distribution Contingency Analysis"* Electric Power Systems Research 78 (2008) 1537–1545

[2] M. M. Elnashar., R. El Shatshat, M. M. Salama, *"Optimum Siting and Sizing Of A Large Distributed Generator In a Mesh Connected System"*, Electric Power Systems Research 80 (2010) 690–697

[3] Pepermans G., Driesen J., Haeseldonckx D., Belmans R., D'Haeseleer W., *"Distributed Generation: Definition, Benefits and Issues"*, Energy Policy, Vol.33, Issue 6, Ref. JEP01382, April, 2005; pp. 787-798.

[4] M.Padma Lalitha,V.C.Veera Reddy, N.Usha, *"Optimal DG placement for maximum loss reduction in radial distribution system"* International journal of emerging technologies and applications in engineering, technology and sciences, July 2009.

[5] M. Ahmadigorji, A. Abbaspour, A Rajabi-Ghahnavieh, M. Fotuhi-Firuzabad, *"Optimal DG Placement in Distribution systems Using Cost/Worth Analysis"*, Proceedings of World Academy of Science, Engineering and Technology Volume 37 January 2009

[6] D. Gautam, N. Mithulananthan, *"Optimal DG Placement in Deregulated Electricity Market"*, Electric Power Systems Research 77 (2007) 1627–1636

[7]P. M. Costa, M. A. Motas, *"A Loss Allocation in Distribution Networks with Embedded Generation"*, IEEE Transactions on Power. Systems, vol. 19, no. 1, Feb.2004

[8]T. Griffin, K. Tomsovic, D. Secrest, A. Law, *"Placement of Dispersed Generations Systems for Reduced Losses"*, Proceedings of the 33rd Hawaii International Conference on System Sciences – 2000

[9] J.V. Milanovic, T.M. David, *"Stability of Distribution Networks with Embedded Generators and Induction Motors"* PES Winter Meeting, IEEE, 2002. Vol. 2, pp.1023 -1028

[10]V.V. Thong, J. Driesen, R. Belmans, *"Improving Voltage Stability with the Connection of DG"*, International conference on power and energy systems (IASTED), Marbella, Spain, September 3-5, 2003; pp. 472-476.

[11] R. K. Jaganathan, T. K. Saha, *"Voltage Stability Analysis of Grid Connected Embedded Generators"*, Australasian Universities Power Engineering Conference (AUPEC 2004), 26-29 September 2004, Brisbane, Australia

[12]N. Hemdan, and M. Kurrat, *"Distributed Generation Location and Capacity Effect on Voltage Stability of Distribution Networks"*, Annual IEEE Student Paper

Conference (AISPC'08), February 15th, 2008 at Aalborg University, Dänemark

[13]M. Alonso, H. Amaris, "*Voltage Stability in Distribution Networks With DG* ", Power Tech Conference IEEE Proceedings, Bucharest, 2009

[14] S. Kotamarty, S. Khushalani, N. Schulz. *"Impact of Distributed Generation on Distribution Contingency Analysis"*, Electric Power Systems Research 78 (2008) 1537–1545

[15] A. Rezazadeh, M. Sedighizadeh, A. Alavian, "*Optimal Sizing and Sitting of Distributed Generation for Power System Transient Stability Enhancement Using Genetic Algorithm"*, IACSIT International Journal of Computer Theory and Engineering, Vol. 1, No. 5, Dec. 2009

[16] M. M. El-Saadawi, A. E. Hassan, R. R. Ebrahim, *"Framework of Particle Swarm Intelligence Optimization for Power System Restoration"*, Al-Azhar Engineering Tenth International Conf., AEIC2008, Cairo 24-26 Dec. 2008

[17] H. Shayeghi, A. Safari, H. A. Shayanfar, "*Multimachine Power System Stabilizers Design Using PSO Algorithm*", International Journal of Electrical Power and Energy Systems Engineering 1;4 © www.waset.org, Fall 2008

[18] T. K Abdul Rahman and G.B Jasmon, "*A New Technique for Voltage Stability Analysis in A Power System and Improves Load Flow Algorithm for Distribution Network*", Inter-national Conference on Energy Management and Power Delivery, 1995, Vol.2, pp. 714-719.

[19] B. Gautham, "*Reconfiguration of Distribution System Using Survivability Index*" Master's thesis, Mississippi state university, 2008.

[20] H. Saadat, *Power System Analysis* Second Edition, Mcgraw-Hill College 2002

[21] J. Kennedy, R. Eberhart, "*Particle Swarm Optimization,*" Proceedings of the IEEE International Conference on Neural Networks, Perth, Australia 1995, pp. 1942-1945.

[22] J. Kennedy, R. Eberhart, "*Swarm Intelligence*, Academic Press, 1st ed., San Diego, CA, 2001.

[23] G. Venter, and J. Sobieski, , "*Particle Swarm Optimization*", AIAA 2002-1235, 43rd AIAA/ASME/ASCE/ AHS/ ASC Structures, Structural Dynamics, and Materials Conference, Denver, CO., April 2002.

[24] M.F. AlHajri; M.R. AlRashidi; M.E. El-Hawary, "*A Novel Discrete Particle Swarm Optimization Algorithm for Optimal Capacitor Placement and Sizing*" Electrical and Computer Engineering, 2007. CCECE 2007. Canadian Conference on Volume , Issue , 22-26 April 2007 Page(s):1286 – 1289

[25] R.C. Eberhart, Y. Shi, "*Comparing Inertial Weights and Constriction Factor In Particle Swarm Optimiza-Tion,*" Proc. of the 2000 International Congress on Evaluationing Computat-ion, San Diego, California, IEEE Service Center, Piscataway, NJ, pp84-88, 2000.

[26]*http://ewh.ieee.org/soc/pes/dsacom/testfeeders/feeder13.zip*