PSO Based Voltage Profile Improvement and Line Loss Reduction by Optimizing Size and Location of DGs

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ABSTRACT:
In this paper optimum size and location of distributed generators (DGs) are determined for maximizing voltage profile and minimizing line losses in distribution systems. For this purpose, Particle Swarm Optimization algorithm (PSO) approach is proposed. The significant innovation of this research paper is using new coding in (PSO) which includes both active and reactive powers of DGs to achieve better voltage profile improvement and line loss reduction. Furthermore, four sets of weighting factors are chosen based on the importance and criticality of the different loads. The effectiveness of the proposed method is examined in the 33 bus distribution systems. The results show that determination of optimum size and location of DGs has a considerable effect on voltage profile improvement and line loss reduction.

KEYWORDS: Distributed Generation, Voltage Profile, Line loss reduction, Particle Swarm Optimization, optimal placement, weighting factor.

1. INTRODUCTION

Distributed generation (DG) is small-scale power generation that is usually connected to the distribution system. The Electric Power Research Institute defines DG as generation from 'a few kilowatts up to 50MW' [1]. Recently, the placement of distributed generation systems (DGs) such as photovoltaic cells, fuel cells, battery energy storage systems and cogeneration system on the distribution system can significantly impact power quality and voltage conditions at customers[2]. Meanwhile distributed generators can reduce distribution loss and replace large-scale generators if they are placed appropriately in the distribution systems. DGs are closer to customers so that transmission and distribution cost is avoided or reduced.

Using of DGs has many benefits effects to the customers and the distribution systems, The positive impacts of the performing of DG are as follows [3, 4]: Line loss reduction, Voltage profile improvements, Power quality improvement, Low cost, Reduction of peak power requirements, increased electric system reliability, increased efficiency levels and reduced environmental impacts.

On the other hand, power losses exist in all levels of power systems such as generation, transmission and distribution systems. However, most of them occur in distribution systems because of the low voltage and high current levels and radial configuration of these systems. Distribution systems are organized radially because of better harmony of protective devices, which are used in systems. Using distributed generators with the best placement and sizing will decrease the overall losses of the system. Solving of the problem of finding best placement and sizing of DGs squanders very time requires testing a very large number of network configurations. Hence, the evolutionary algorithms are used to implement it. There are several evolutionary algorithms that can be used to solve distribution problems like Ant Colony Search (ACS) [5], Genetic Algorithm (GA) [6, 7], Particle Swarm Optimization (PSO) [8], and Tabu Search (TS) [9].

In this paper, PSO method based on new coding is proposed for determination of the best location and size of DGs. To evaluate this method, three states viz one DGs, three DGs and five DGs for voltage profile improvement are considered while four weighting factors for various loads are tested. The proposed approach is tested on IEEE 33-bus distribution radial test system, and the program is simulated using MATLAB software.

The rest of the paper is organized as follows: Section II presents problem formulation for maximization voltage profile and minimizing line losses in the distribution system, briefly. In section III, the PSO is described briefly and structure of new coding for sizing determination and DGs placement problems are presented. The results of DGs placement on 33-bus test systems presented and discussed in section IV. Finally, section V summarizes the main points and results of this paper.

2. PROBLEM FORMULATION

Optimal sizing and sitting for DG installations lead to the highest value of overall benefits, one of the explanations for introducing DG is to improve the voltage profile of the system and sustain the voltage at customer terminals within an acceptable range.

There are some voltage profile indices that can be used as problem index of voltage profile. Some of them are: the minimum voltage of network buses, the minimum square error (MSE) amount of voltages of network buses and the mean value of voltages of network buses that formulated below [10]:

$$Maximize \left\{ \frac{\sum_j V_j}{N} \right\} \tag{1}$$

where V_j : voltage magnitude at bus j and N , total buses number.

But the effect of various loads (heavy, light) on the system has not been investigated by the above mentioned voltage profile indices. While , these effects could play great role in voltage profiles.

In this paper determination of size and location of DGs for voltage profile improvement is considered as objective function that expressed bellows:

$$Max\ VPI\% = \frac{VP_{w/DG} - VP_{wo/DG}}{VP_{wo/DG}} \times 100 \tag{2}$$

However, the voltage profile (VP) is given as:

$$VP = \sum_{i=1}^{N} V_i\, L_i \times W_{fi} \tag{3}$$

$$\sum_{i=1}^{N} W_{fi} = 1 \tag{4}$$

where $VPI\%$, percentage improvement of voltage profile; $VP_{w/DG}$,voltage profile index of the system with DG, pu ; $VP_{wo/DG}$, voltage profile index without DG, pu ; V_i ,voltage magnitude at bus i ; W_{fi} ,weighting factor for load bus i ; L_i , load at bus i , pu ; N , total buses number.

As explained, the expression for VP provides an opportunity to quantify and accumulate the importance, amounts, and the voltage levels at which loads are being supplied at the various load busses in the system. This expression should be used only after having confidence that the voltages at all the load busses are within permitted minimum and maximum limits, typically between 0.95 and 1.05 pu . The weighting factors are selected based on the significance and criticality of the different loads. There are no rules for determining the weight coefficients, starting with a set of equal weighting factors, modifications can be made, based on an analysis of the results; the set that will lead to the most acceptable voltage profile on a system-wide basis can be selected. It should be noted that if all the load busses are equally weighted, the value of W_f is given as:

$$W_{f1} = W_{f2} = W_{f3} = \ldots = W_N = \frac{1}{N} \tag{5}$$

And also determination of size and location of DGs for line loss reduction is considered as objective function that expressed bellows:

$$Max\ LLR\% = \frac{LL_{wo/DG} - LL_{w/DG}}{LL_{wo/DG}} * 100 \tag{6}$$

where

$$LL_{w/DG} = \sum_{l=1}^{N} I_{l,w/DG}^2 R_l D_l \tag{7}$$

$$LL_{wo/DG} = \sum_{l=1}^{N} I_{l,wo/DG}^2 R_l D_l \tag{8}$$

And also, LLR% is percentage reduction of line-loss due to DG; $LL_{w/DG}$ is line-loss with the DG , pu ; $LL_{wo/DG}$ is line-loss without considering the DG, pu ; R_l , is line resistance of line l, pu /km; D_l , is line length of line in km; $I_{l,w/DG}$, is current value of line l in pu after DG installation; $I_{l,wo/DG}$, current value of line l in pu before DG installation.

3. CONSTRAINTS

Furthermore, the following constraints are considered in the optimization problem using PSO:

3.1. Traditional generation capacity constraints

For secure and stable operation, the active power at each traditional generator using DG ($P_{gw/DG}$) is restricted by its lower and upper limits.

$$P_g^{\min} \le P_{gw/DG} \le P_g^{\max} \tag{9}$$

3.2. Total number of DG

Number of DG (N_{DG}) must be less than or equal to the maximum number of DG ($N_{DG/MAX}$):

$$N_{DG} \le N_{DG/MAX} \tag{10}$$

3.3. DG generation capacity constraints

The active power at each DG (P_{gd}) is limited by its lower and upper limits:

$$P_{gd}^{\min} \le P_{gd} \le P_{gd}^{\max} \tag{11}$$

3.4. Voltage and current constraints

Voltage magnitude at each bus and Current magnitude of each feeder must satisfy permissible ranges as follows:

$$V_{\min} \le |V_i| \le V_{\max} \tag{12}$$

$$|I_j| \le I_{j,\max} \tag{13}$$

where,

$|V_i|$: The voltage magnitude of nod i,

$V_{\min}, V_{\max}$:the minimum and maximum voltage limits, respectively.

I_j : Current magnitude of each line j,

$I_{j,\max}$: Maximum current limit of line j

4. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization meted first proposed by Dr Kennedy and Dr Eberhart in1995, inspires by social behavior of bird flocking or fish schooling [11]. The PSO as an optimization tool provides a population based search method that individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multi dimensional search space. During the flight, every particle regulates its position considering previous experience (This value is called *Pbest*), and according to the experience of neighboring particles (this value is called *Gbest*), made use of the best position encountered by itself and its neighbor (Figure 1).

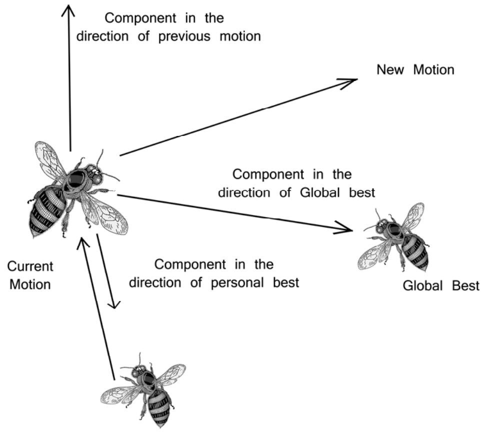

Fig. 1. New motion of particles in PSO that inspired by own motion and global best.

This modification can be represented by the concept of velocity. The particle velocity and new position of the particle are calculated by:

$$\begin{aligned} v_{id}^{k+1} &= w v_{id}^{k} + c_1 rand \times (pbest_{id} - s_{id}^{k}) \\ &\quad + c_2 rand \times (gbest_d - s_{id}^{k}) \end{aligned} \tag{14}$$

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

$$s_{id}^{k+1} = s_{id}^{k} + v_{id}^{k+1} \qquad \begin{aligned} i &= 1,2,\ldots,n, \\ d &= 1,2,\ldots,m, \end{aligned} \tag{15}$$

where s^k is current searching point, s^{k+1} is modified searching point, v^k is current velocity, v^{k+1} is modified Velocity of particle i , v_{Pbest} is velocity based on *Pbest* , v_{Gbest} is velocity based on *Gbest* , n is number of particles in a group, m is number of members in a particle, $Pbest_i$ is *Pbest* of particle i , $Gbest_i$ is *Gbest* of the group, w_i is weight function for velocity of agent i , c_i is weight coefficients for each term.

The following weight function is:

$$w_i = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \bullet iter \tag{16}$$

where, $w_{\min}$ and $w_{\max}$ are the minimum and maximum weights respectively. $iter$ and $iter_{\max}$ are the current and maximum iteration. Appropriate value ranges for C1 and C2 are 1 to 2, but 2 is the most appropriate in many Cases. Appropriate values for $w_{\min}$ and $w_{\max}$ are 0.4 and 0.9 [12] respectively.

4.1. PSO PROCEDURE

The PSO-based approach for solving the Optimal Placement of Distributed Generation (OPDG) problem to maximizing the voltage profile improvement takes the following steps:

Step 1: Input line and bus data, and bus voltage limits.

Step 2: Calculate the voltage profile using distribution load flow based on backward-forward sweep.

Step 3: Randomly generates an initial population (array) of particles with random positions and velocities on dimensions in the solution space. Set the iteration counter $iter = 0$.

Step 4: For each particle if the bus voltage is within the limits, calculate the voltage profile in equation (2).Otherwise, that particle is not practicable.

Step 5: For each particle, compare its objective value with the individual best. If the objective value is lower than *Pbest*t, set this value as the current *Pbest* , and record the corresponding particle position.

Step 6: Choose the particle with the minimum individual best *Pbest* of all particles and set the value of this *Pbest* as the current overall best *Gbest* .

Step 7: Update the velocity and position of particle using (9) and (10) respectively.

Step 8: If the iteration number reaches the maximum limit, go to Step 9. Otherwise, set iteration index $iter = iter + 1$, and go back to Step 4.

Step 9: Print out the optimal solution to the objective problem. The best position includes the optimal locations and size of DGs, and the corresponding fitness value representing the voltage profile improvement.

5. CASE STUDY

In order to indicate and compare the effects of DGs placement in the distribution systems, three cases are considered and the results are compared to the case that there is no DG in the systems. Details of case studies are as follows:

Case ‘I’:One DG installation.

Case ‘II’:Three DGs installation.

Case ‘III’: Five DGs installation.

In this paper four set of weighting factors are considered to investigate the importance of various loads in voltage profile of the system. This sets expressed below:

Set1: the same weighting factor for all loads like equation (5), W_{f1} .

Set2: importance (higher weighting factor) given to heavy load buses, W_{f2} .

Set3: importance (higher weighting factor) given to light load buses, W_{f3} .

Set 4: this set is average between set 2 & set 3 , W_{f4} .

The results are briefly summarized in the following sections.

33-Bus Test system.

The single line diagram of the 12.66 kV, 33-bus, 4-lateral radial distribution system is shown in Fig. 2.

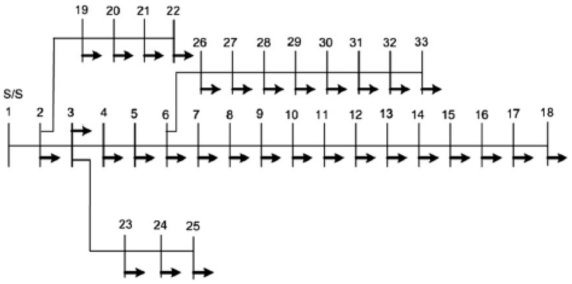

Fig. 2. Single line diagram of 33 bus distribution test system.

The data of the system are obtained from [13]. The total load of the system is considered as (3715+ j 2300) kVA and total active and reactive power losses in the system before DG installation are 202.64 kW and 134.37 kW, respectively.

The Fig 3 shows the voltage profile improvement regarding case II. As it is clear, heavy loads are causing higher voltage drop, so when we assume higher weighting factors concerning heavy loads, we could get better voltage profile. Conversely, allocating higher weighting factors to light loads leads to worst results.

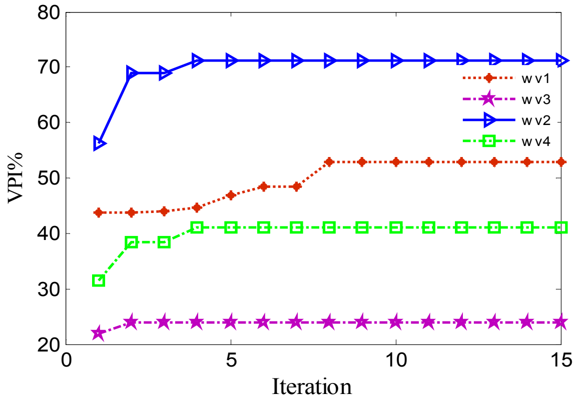

Fig. 3. VPI with case II and weighting factor impacts

The procedure presented in case study section is applied to 33-Bus Test system and the numerical results are shown in Table 1.

The same results are obtainable for Fig4. Voltage of buses is compared in different weighting factors using case III. in Fig 5 and 6 and Fig 7 shows the effectiveness of different cases in voltage profile improvement.

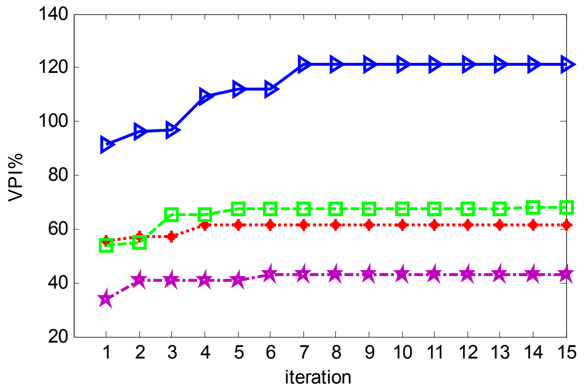

Fig. 4. VPI with case III and weighting factor impacts

Table 1. Weighting factors related to various loads

Bus Number	W_{v1}	W_{v2}	W_{v3}	W_{v4}	Bus Loads
1	0	0	0	0	0
2	0.03125	0.03279	0.0309	0.031845	0.0117
3	0.03125	0.0246	0.0335	0.029	0.0098
4	0.03125	0.03279	0.0309	0.031845	0.0144
5	0.03125	0.0164	0.03608	0.02624	0.0067
6	0.03125	0.0164	0.03608	0.02624	0.0063
7	0.03125	0.0164	0.03608	0.02624	0.0088
8	0.03125	0.0491	0.0258	0.03745	0.0224
9	0.03125	0.0164	0.03608	0.02624	0.0063
10	0.03125	0.0409	0.0284	0.03465	0.0193
11	0.03125	0.0164	0.03608	0.02624	0.0054
12	0.03125	0.0164	0.0309	0.031845	0.0069
13	0.03125	0.0164	0.03608	0.02624	0.0069
14	0.03125	0.03279	0.0309	0.031845	0.0144
15	0.03125	0.0164	0.03608	0.02624	0.0061
16	0.03125	0.0164	0.03608	0.02624	0.0063
17	0.03125	0.0164	0.03608	0.02624	0.0063
18	0.03125	0.0246	0.0335	0.029	0.0098
19	0.03125	0.0246	0.0335	0.029	0.0098
20	0.03125	0.0246	0.0335	0.029	0.0098
21	0.03125	0.0246	0.0335	0.029	0.0098
22	0.03125	0.0246	0.0335	0.029	0.0098
23	0.03125	0.0246	0.0335	0.029	0.0103
24	0.03125	0.0819	0.0154	0.04865	0.0465
25	0.03125	0.0819	0.0154	0.04865	0.0465
26	0.03125	0.03279	0.0309	0.031845	0.0119
27	0.03125	0.0168	0.03608	0.02624	0.0065
28	0.03125	0.0164	0.03608	0.02624	0.0063
29	0.03125	0.03279	0.0309	0.031845	0.0139
30	0.03125	0.1147	0.00515	0.051904	0.0632
31	0.03125	0.03279	0.0309	0.031845	0.0166
32	0.03125	0.0491	0.0258	0.03746	0.0233
33	0.03125	0.017	0.036037	0.02669	0.0072

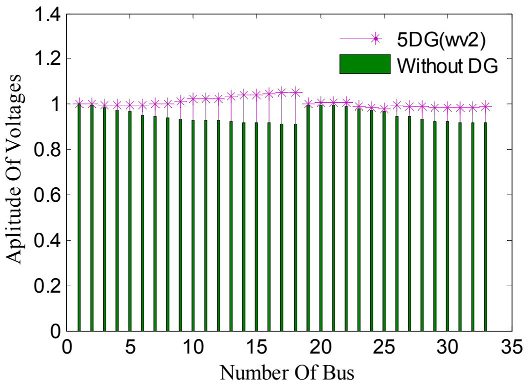

Fig. 5. Comparing voltage of buses case III using W_{f2}

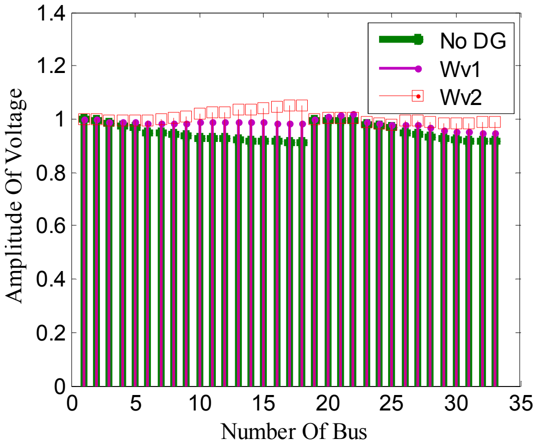

Fig. 6. Comparing voltage of buses case III using W_{f1} and W_{f2}

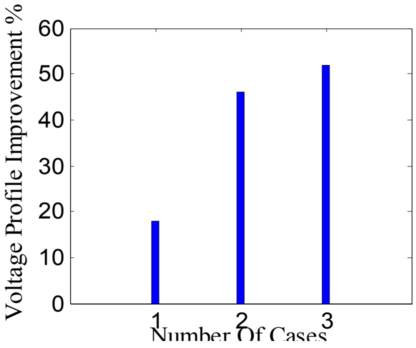

Fig. 7. The effectiveness of different cases in voltage profile improvement

Optimum size and locations of DGs for voltage profile improvement (VPI) using PSO in the different cases are determined and are shown in Table II. It can be seen from this table that determination of optimum size and location of DGs has a considerable effects on voltage profile VPI in the test system. From Table II, it is observed that 17.77% VPI in the case I, 45.92% VPI case II and 51.85% VPI in the case III are achieved rather than to the base case.

Table 3 shows the considerable effects of optimum size and location of distributed generation to reduction of line losses of distributed systems.

From Table 3, it is observed that 16.09% LLR in the case I, 37.53% LLR case II and 58.78% LLR in the case III are achieved rather than to the base case.

6. CONCLUSION

In this paper optimum size and location of distributed generators for improvement of voltage profile and line loss reduction in distribution systems are proposed. For this purpose, a new coding is employed in PSO which considers state, size and location of DGs. Furthermore, four set of weighting factors are chosen based on the importance and criticality of the different loads. The effectiveness of the proposed method is examined in the 33 bus distribution systems. The results show that determination of optimum size and location of DGs has a considerable effect on line loss reduction and voltage profile improvement when using weighting factor set 2 and case III.

Table 2. The result of DGs installation in the 33bus test system using wv1

Method		Bus. No	DG size (KW)	DG size (KVar)	$VP_{w/DG}$	VPI%
PSO	Case I	9	80	520	0.0159	17.77
	Case II	11	400	320	0.0197	45.92
		14	108	280		
		25	480	500		
	Case III	3	360	0	0.0205	51.85
		8	40	440		
		11	520	360		
		26	440	280		
		28	520	600		

Table 3. The result of DGs installation in the 33bus test system for line loss reduction

Method		Bus. No	DG size (KW)	DG size (KVar)	$LL_{w/DG}$ active %	$LL_{w/D}$ reactive %
PSO	Case I	17	12	112	16.09	16.34
	Case II	10	125	0	37.53	38.55
		13	0	12.5		
		31	113	37.5		
	Case III	6	175	100	58.78	59.92
		11	12	25		
		14	113	87.5		
		27	75	187.5		
		31	188	100		

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