Vector Swarm Optimization algorithm for Distributed Generator Allocation

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Abstract- In recent years Evolutionary Algorithms (EAs) have been used in solving many numerical optimization problems and their strengths and weaknesses are identified and new strategies for improving them are provided. This paper presents the Vectors Swarm Optimization (VSO) Algorithm for the placement of Distributed Generators (DGs) in the radial distribution systems to reduce the real power losses and to improve the voltage profile. A tow-step procedure is used for the optimal DG placement method. In the first step, single DG placement method is used to fine the optimal DG locations and in the second step, VSO algorithm is used to find the size of the DGs corresponding to maximum loss reduction. The proposed method is tested on standard IEEE 33-bus test system and the results are presented. The proposed method has overcome the other methods in terms of the quality of solution and computational efficiency.

Keywords- Vector Swarm Optimization (VSO), Distributed Generator (DG), Loss reduction, radial distribution system, capital and operational costs.

1. Introduction

Distributed generation (DG) is related with the use of small generating units installed in strategic points of the electric power system and, mainly, close to load centres. The technologies applied in DG comprise small gas turbines, micro-turbines, fuel cells, wind and solar energy, etc. DG can be used in an isolated way, supplying the consumer's local demand, or in an integrated way, supplying energy to the remaining of the electric system. In distribution systems, DG can provide profits for the consumers as well as for the utilities, especially in sites where the central generation is impracticable or where there are deficiencies in the transmission system [1].

The benefits of DG are numerous and the reasons for implementing DGs are energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, ease of finding sites for smaller generators, shorter construction times and lower capital cost of smaller plants and proximity of the generation plant to heavy loads, which reduces transmission costs. Also it is accepted by many countries that the reduction in gaseous emission (mainly CO2) offered by DGs is major legal driver for DG implementation [2], [3]. Another benefit of using DG is to reduce the transmitted power through lines. This increases the free capacity of lines, substation and etc.

Different method and algorithms have been developed to evaluate the avail from DGs to a network in the form of short circuit capacity (SCC) augmentation [4], loss reduction, loading level reduction, voltage deviation reduction [1]-[28].

The main different is in the optimization method and fitness function. In some papers the optimization problem has been solved by methods based on sensitivity parameter [5], [6]. Because of high accuracy and finding global optimal point, intelligent algorithms are frequently implemented in DG allocation. Some investigation have been done DG planning with the stability, reliability and optimal line loading goals [8]-[10] and others as an instrument to improve power quality and voltage profile [24],[25]. [11]- [16] have used DG to minimize the cost of expansion in generation and transmission networks and some different cases have implemented DGs to reach the least active and reactive power losses[1],[15]-[17].

According to network topology, placement of DGs could have some beneficial and detrimental effects on the distribution network. The amount of these effects depends on DG contribution in network loads covering. In the state of using DGs with optimal planning, some advantages and positive effects are appeared in the network regarding to the distribution company's view:

- Lower level of transmission congestion and network losses.
- Power quality improvement.
- Reliability enhancement.
- Decreasing amount of energy purchased from other countries.
- To defer or cancel the creation of new and large power plants.

On the other hand compared with conventional plants, DG units would experience more working states. One difference between DG and conventional stations is that the main conventional stations usually have 2-state model. DG operates in several working states. Another difference is the behavior of resources used in DG converting to electric energy. Renewable energies like wind and solar and their output power depends on the amount of available resource at the moment.

Considering this fact, the power produced by renewable energy may experience more variations. Since it does not usually happen in the conventional plants and hence, this issue affects the distribution system reliability.

From the technology point of view and the power generation, different kind of DGs is discussed below:

- Plants with only active power output, like photovoltaic systems.
- Resources with active and reactive power output, like synchronous generators.
- Generators with active power output as the base and reactive power consuming like induction generator in wind turbines.

In this paper DGs with active power generation are used and reactive power generation is ignored. From references [28] capital and operational costs are used, 200000$/MW and 27$/MWh respectively.

This paper investigates the application of VSO in placing DGs in a power system considering minimizing active power losses, minimizing voltage deviation, and minimizing active and reactive power pricing.

2. Vector Swarm Optimization Algorithm

VSO same as most of the evolutionary techniques is started with an initial population randomly and the steps of algorithm are iteratively repeated until a termination criterion is met such as a maximum number of generations or when there has been no change in the solution found of the problem for a given number of generations. VSO method is completely studied in [29].

VSO algorithm can be simplified as below:

1) Initialize population of random vectors(the parents population of the first iteration)

$$V_{i,j}[0] = V_j^{low} + rand.(V_j^{up} - V_j^{low}) \quad (1)$$

Where Npop is number of population, D is dimension, i ∈[1, Npop] and represents the i–th population vector, j∈[1, D] and represents j–th dimension of Vi vector, Vi,j [0] represents the value of j–th dimension of i–th vector of initial populations.

2) Calculate the fitness of each vector

3) Generate a new population of vectors based on fitness children of population is obtained by changing in the value of each dimension of each parental population based on four operators: Participation, Mutation, Conformation and Selection.

4) Repeat steps 2 and 3 until a termination criterion is met.

2.1.1. *Participation (A Cooperative Effect Of Cooperation)*

This operator is introduced by suitable combines of multiple vectors for problem search space, which is consist of two sections: a) Vector Direct cooperation, b) Vector Difference Cooperation.

2.1.2. *Vector Direct Cooperation*

Direct cooperative vector ($V_{Direct-\ cooperation}$) can be built from a appropriate combination of cooperative vectors, $V_{current}$, V_{ave} , V_{best} , $V_{local-\ best}$ and V_{rand} , where $V_{current}$ is current response vector, V_{ave} is average of response vectors, V_{best} is the fittest response vector until now, $V_{local-\ best}$ is fittest vectors in the neighborhood of i–th vector and V_{rand} is a random vector in every generation that their value is stored. Purpose of direct cooperation is that each of these five vectors can be involved in determining the direct cooperative vector. Formulated as direct cooperation, we can show the following:

$$V_{Direct\_cooperation}[k] = w_1.V_{current}[k] + w_2.V_{ave}[k] + w_3.V_{best}[k] + w_4.V_{local\_best}[k] + w_5.V_{rand}[k] \quad (2)$$

Where w_1, w_2, w_3, w_4 and w_5 are cooperative weighting coefficients and cannot be zero simultaneously and are in the interval [0,1] and should be selected so that $V_{Direct\text{-}cooperation}$ is in the allowable $V_{i,j} \in [V_j^{low}, V_j^{up}]$.

2.1.3. *Vector Difference Cooperation*

Difference cooperative vector can be built from cooperation of an appropriate percentage of differential of vectors, $V_{current}$ and V_{ave} ($V_{current}$ -V_{ave}) , $V_{current}$ and V_{best} ($V_{current}$ -V_{best}), $V_{current}$ and $V_{local\text{-}best}$ ($V_{local\text{-}best}$-$V_{current}$), and $V_{current}$ and V_{rand} ($V_{local\text{-}best}$-$V_{current}$). Effect of Difference cooperative vector is in small-scale search and orients the current response vector $V_{current}$ to other cooperative vectors.

$$V_{Difference\_cooperation}[k] = w_6.(V_{ave}[k] - V_{current}[k]) + w_7.(V_{best}[k] - V_{current}[k]) + w_8.(V_{local\_best}[k] - V_{current}[k]) + w_9.(V_{rand}[k] - V_{current}[k]) \quad (3)$$

where w_6 ,w_7 ,w_8 and w_9 are the cooperative weighting coefficients and are in the range (0,1) and contrary to the direct cooperation, all of them can be zero simultaneously.

In other words, direct and differential cooperative cooperation complete each other and by transferring the differential cooperative vector to location of the direct cooperative vector, can have:

$$V_{cooperation}[k] = V_{Direct\_cooperation}[k] + V_{Difference\_cooperation}[k] \quad (4)$$

Where $V_{Cooperation}$ [k] is cooperative vector in k–th iteration.

2.2. Mutation

In VSO algorithm is proposed that with a specific probability mp, mutation operation is done as transfer origin point to the point where a good distance from the origin has. Suitable distance depends on the, such as can be definite 0.01 scale dimensions of the problem, and dynamically, decreasing until reduced to zero. The idea of using mutations is creating diversity and prevent of pin in a local optimum. According to the above description, for Mutation vector can be written:

$$V_{mutation\ i,j}[k] = \frac{d}{100}.rand.[V_j^{up} - V_j^{low}] \quad (5)$$

Where d is the number that starts from 1 and dynamically with algorithm's repetition decreases until get to zero level. Finally, the final vector we can write as the following:

$$V[k] = V_{cooperation}[k] + V_{mutation}[k] \quad (6)$$

In above relation, the V[k] is new solution vector or offspring vector.

2.3. Conformation(Boundary Check)

After each stage of new vectors production, new vectors should be checked for prevent them to leave out problem space. This practice is called conformity. In VSO algorithm has been suggested that if $V_{i,\,j}$ isn't in the allowable interval then it is equal to Vbest of previous level.

2.4. Selection

Two selection methods is proposed in VSO algorithm:

1) Children of New generation (current population) is used as the parents of next generation.

2) N_{pop} population are selected between all of parents and offspring based on their fitness to generate next population.

In this investigation we considered the first method.

3. Recognition of Optimal DG Locations by Single DG Placement Algorithm

This algorithm define the optimal size and location of DG units that should be placed in the system to minimize loss. DG units for all nodes are determined for essential case and best one is chosen based on the maximum loss saving. This process is repeated if multiple DG locations are required by modifying the base system by inserting a DG unit into the system one-by-one [3].

3.1. Active Power Losses

The total I^2R loss PL in a distribution system having n number of branches is given by:

$$P_{Lt} = \sum_{i=1}^{n} I_i^2 R_i \quad (7)$$

Here I_i is the magnitude of the branch current and R_i is the resistance of the i_{th} branch respectively. The branch current can be obtained from the load flow solution. The branch current has two components, active component I_a and reactive component I_r. The loss associated with active and reactive components of branch currents can be written as:

$$P_{La} = \sum_{i=1}^{n} I_{ai}^2 R_i \quad (8)$$

$$P_{Lr} = \sum_{i=1}^{n} I_{ri}^2 R_i \quad (9)$$

Note that for a given configuration of a single source radial network, the loss P_{La} associated with the active component of branch current cannot be minimized because all active power must be supplied by the source at the root bus. But by placing DGs, the active component of branch current is reduced.

3.2. Methodology

Assume that a single-source radial distribution system with n branches and a DG is to be placed at bus m and α be a set of branches connected between the source and bus m. The DG produces active current I_{DG}, and for a radial network it changes only the active component of current of branch set α. The currents of other branches are unaffected. Thus the new active current I_{ai}^{new} of the i_{th} branch is given by:

$$I_{ai}^{new} = I_{ai} + D_i\, I_{DG} \quad (10)$$

where Dm = 1; if branch i∈α

= 0; otherwise

The loss P_{La}^{com} associated with the active component of branch currents in the compensated currents in the compensated system (when the DG is connected) can be written as

$$P_{La}^{com} = \sum_{i=1}^{n} (I_{ai} + D\, I_{DG})^2\, R_i \tag{11}$$

The loss saving PS is the difference between equation (9) and (11) and is given by

$$P_S = P_{La} - P_{La}^{com} = -\sum_{i=1}^{n} (2 D_i\, I_{ai}\, I_{DG} + D_i\, I_{DG}^2)\, R_i \tag{12}$$

The DG current I_{DG} that provides the maximum loss saving can be obtained from

$$\frac{\partial P_S}{\partial I_{DG}} = -2 \sum_{i=1}^{n} (D_i\, I_{ai} + D_i\, I_{DG}) R_i = 0 \tag{13}$$

Thus the DG current for the maximum loss saving is

$$I_{DG} = -\frac{\sum_{i=1}^{n} D_i\, I_{ai}\, R_i}{\sum_{i=1}^{n} D_i\, R_i} = -\frac{\sum_{i\in\alpha} I_{ai}\, R_i}{\sum_{i\in\alpha} R_i} \tag{14}$$

The corresponding DG size is

$$P_{DG} = V_m\, I_{DG} \tag{15}$$

V_m is the voltage magnitude of the bus m. The optimum size of DG for each bus is determined using equation (15). Then possible loss saving for each DG is determined by using equation (12).The DG with highest loss saving is identified as candidate location for single DG placement. When the candidate bus is identified and DG is placed, the above technique can also be used to identify the next and subsequent bus to be compensated for loss reduction [3].

4. Problem Formulation

The goal is finding the location of DGs and its parameter in order to minimize the real power losses, the voltage deviation, and the real and reactive power pricing. So the fitness function is a combination of three objectives. The objective functions can be defined as follow:

4.1. Active Power Losses

The active power losses that defined in section 3.1.

4.2. Voltage Deviation

To have a good voltage performance, the voltage deviation at each load bus must be made as small as possible. The voltage deviation to be minimized is as follows:

$$V_d = \sum_{k\in\Omega} (v_k - v_{refk})^2 \tag{16}$$

Where Ω is the set of all load buses, V_k is the voltage magnitude at load buses k, and V_{refk} is the nominal or reference voltage at bus k.

4.3. Real and Reactive Power Pricing

Because of the balance created between generation units and congestion management in the lines after the installation of DG devices, significant reduction is achieved in the price of the real and reactive powers. For this purpose, the objective function can be defined as:

$$C = \sum (C_P + C_Q) + \sum C_I \tag{17}$$

Where; C is total cost, C_p, C_Q are P and Q generation costs respectively and C_I is the installation cost of DG [10], [11].

5. Results and Discussion

First load flow is conducted for IEEE 33-bus test system. The power loss due to active component of current is 136.9836 kW and power loss due to reactive component of the current is 66.9252 kW. A program is written in “MATLAB” to implement single DG placement algorithm . For the first iteration the maximum saving is occurring at bus 6. The candidate location for DG is bus 6 with a loss saving of 92.1751 kW. The optimum size of DG at bus 6 is 2.4886 MW. By assuming 2.4886 MW DG is connected at bus 6 of base system and is considered as base case. Now the candidate location is bus 15with 0.4406 MW size and the loss saving is 11.4385 KW. This process is repeated till the loss saving is insignificant. The results are shown in Table 1.

Table 1. Single DG placement results

Iteraton No.	Bus No.	DG Size (MW)	Saving
1	6	2.4886	92.1751
2	15	0.4406	11.4385
3	25	0.6473	7.6936
4	32	0.4345	8.1415

The candidate locations for DG placement are taken from single DG placement algorithm are 6,15,25,32.With these locations, sizes of DGs corresponding to global solution are determined by using VSO Algorithm described in section 2. The sizes of DGs are dependent on the number of DG locations. Generally it is not possible to install many DGs in a given radial system. Here 4 number of DGs is considered. DG sizes in the optimal locations, saving in KW and the saving in KW for 1 MW DG installation are given in Table 2.

Total real power losses before and after DG installation, the percentage of voltage improvement, and price before and after DG installation are given in Table 3.

Table 2. Result of IEEE-33 bus system

Bus locations	DG size(MW)	Total size(MW)	Saving (KW)	Saving/ DG Size
6	1.0767	3.09055	137.3201	44.43
15	0.5769			
25	0.7831			
32	0.6538			

Table 3. comparison between loss, minimum voltage and price before and after DG installation

Loss before DG istallation	Loss after DG installation	% Voltage improvement	Price after DG installation ($/MWh)		Price before DG installation ($/MWh)	
			Min	Max	Min	Max
203.9088	66.5892	6.56	37.59	42.029	37.72	42.188

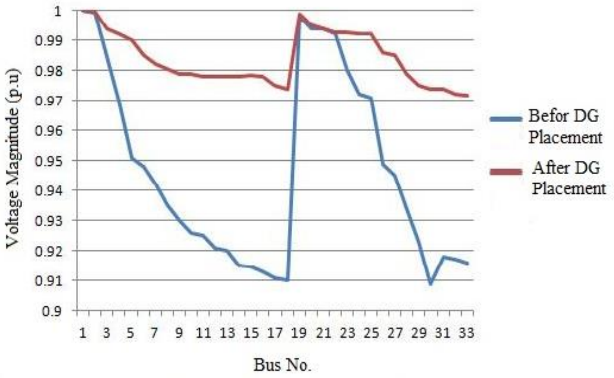

Fig. 1. Voltage profile with and without DG placement

Minimum voltage after DG placement occurred in bus 30 with the amount of 0.9714 and % improvement in minimum voltage compared to base case is 6.54% so voltage profile is significantly improved.

In Table 4, %improvement in power loss due to active and reactive component of branch current and total active power loss of the system is considered. Although the aim is reducing the PLa losses, the PLr losses is also reduced due to improvement in voltage profile.Voltage profile is shown in figure 1.

A comparision of result by proposed method with an existing analytical method [30] is shown inTtable 5. Saving by PSO algorithm is a little bit higher than the PSO method.

Table 4. Loss reduction by DG placement

	P_{La}	% improve P_{La}	P_{Lr}	%improve P_{Lr}	P_{Lt}	%improve P_{Lt}
Before DGs Placement	136.98	-------	66.92	-------	203.909	-------
After DGs Placement	5.5672	95.94	61.0199	8.82	66.5887	67.34

Table 5. Compration of Swarm sizes, iterations and average times of two algorithms

	Swarm size	Avg. No. of iteration	Avg. Time (sec)
VSO	40	200	12.25
PSO	50	200	14.17

Both method dive same size for DGs though the number of iterations are the same for both algorithms. VSO takes less computation time because of its ease when compared to PSO method.

6. Conclusion

In this paper, a new intelligent methodology for finding the optimal locations and sizes of DGs corresponding to maximum loss reduction and reduce capital and operational DG costs and to improve the voltage profile is presented. Single DG placement method is used to find the optimal DG locations and a VSO algorithm is proposed to find the optimal DG sizes. Voltage and line loading constraints are included in the algorithm.

This methodology is tested on IEEE 33-bus test system. By installing DGs at all the potential locations, the total power loss of the system and the total generation costs have been reduced effectively and the voltage profile of the system is also improved.

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