Optimal Sizing and Placement of a SVC and DG in Power Systems using PSO Algorithm

Alireza Basiri¹, S.M. Mousavi G²*

Department of Electrical Engineering, University College of Science and Research, Damavand².School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran.

Corresponding Author email: ariana.enginer@gmail.com

ABSTRACT: Recent advancements in the field of renewable resources technology, accompanied by an increase in load demand and clean and inexpensive energy requirement, have increased tendency towards the use of Distributed Generation (DG). Today, DG is mainly used in low-voltage and household networks. In case of correct placement, this equipment can increase reliability, reduce losses, improve voltage profile, and delay line development investments. One of the weaknesses of low-voltage networks is their voltage domain which can be improved by distributed generators through injecting reactive power. Therefore it seems like that active and reactive power compensation of the network must be done separately. In addition, Static Var compensator (SVC) causes the reactive power to be compensated, with the purpose of improving Voltage domain of the system. Meanwhile, in this paper the placement of DG and SVC leads to the release of generator's capacity to generate active power and to reduce losses remarkably in the upstream network. Moreover, the SVC which is added to the network makes improvement in voltage and supports network reactive power. Particle Swarm Optimization (PSO) Algorithm is used for Optimal Placement and Sizing of DG and SVC.

Keywords: Static Var Compensator, Distributed Generators, Distribution System Particle, Swarm Optimization Algorithm

INTRODUCTION

Generally, any type of power generations in relatively small capacities carried out in consumption place or near it (mainly in power network distribution section) is referred to as DG, regardless of the technology used in its generation process. These resources often take advantage of new energies. Generation capacity of these resources is much smaller (often 50 kW to 5 MW) than the other conventional resources of electrical power generation and the technologies used in the power generation are very diverse and different. Although DG plays a role in voltage domain improvement and reactive power supply, the main purpose of installing these generators is to locally supply the active and reactive powers. In other words, these generators are not able to obviate the problems related to reactive power of power systems. As a result, in addition to supplying local load and releasing the network, simultaneous installation of DG and SVC increase transmission capacity of the network, and delay the need for building new transmission lines. In addition, the SVC system controls the voltage as well as the power coefficient of transmission lines by adjusting the reactive power injected into the network. Usually, the changes range of the system voltage is specified by the SVC system to be ±5%. The issue of the placement of DG is a non-linear problem, mainly solved by smart algorithms. The main reasons to use PSO algorithm in this paper is;

- the simplicity of performance & application
- High calculation speed
- Low needed internal memory low capacity

Above mentioned specifications’ should be considered so advantages comparing other algorithms.

Has studied the issue of locating distributed generations based on Frog Leaping Algorithm, and discussed the issue of locating distributed generations in order to improve reliability indexes[1]. Nowadays, the penetration of DG (distributed generation) units into distribution networks has been increasing rapidly, because of the liberalization of transmission lines capacity, constraints on building new transmission and distribution lines, environmental impacts, technological advances in power electronics and energy storage devices. Exploiting local RES (renewable energy sources) on-site and exporting surplus energy from on-site generation to utility grids is part of the strategy to increase the share of renewable energy within the grids, thereby reducing resource consumption and associated carbon emissions [2]. By providing a multi-objective method to
locate and determine the optimal capacity of distributed generation in distribution systems, taking into account the environmental considerations and aiming at reducing losses, improving the voltage profile, improving the reliability and reducing initial investment, maintenance using Sorting Algorithms have been studied [3]. Power industry deregulation, fossil fuel resource depletion and environmental concerns have encouraged the integration of renewable DG units (e.g., biomass, wind and solar) in distribution systems. These units have offered several potential benefits such as loss reduction, voltage stability and voltage profile enhancement, reliability improvement, network reinforcement deferral, and greenhouse gas emission reduction [4]. Various techniques of optimal placement of DG units have been nicely reviewed [5-8]. Studding the plan and operational aspects is one of the important issues in DG Trade. Reduce losses and increase reliability correct placement and optimum capacity of DGS networks distributions has been studied to improve the voltage profile. In other hand, installation and commissioning of DG is the most important problem in distributed generation units [9] Many studies have used smart algorithms in order to solve the issue of locating SVC. For this purpose, the smart methods Genetic Algorithm and Particle Swarm Algorithm have been mainly used [10]. In locating wind turbine and SVC have been discussed to be used for increasing reliability and active power using genetic algorithm [11]. With the purpose of reducing losses and costs, discusses SVC-locating process using genetic algorithm [12]. Has investigated economic location and assessment using PSO algorithm [13]. This reference has considered the required elements at first, which is a weakness for this method. In this method, all three too ling has been placement on the line at first and indexes calculated then, additional elements have been eliminated using genetic algorithm [14].

What can be determined from these references as a new research problem is simultaneous optimal placement and sizing of DG and SVC.

**Statement of the Problem and Mathematical Model**
The mathematical model used in the present paper includes three parts.

**Load flow calculations in distribution networks**
To solve the question under study, load flow tool has been used. For load flow calculations in distribution networks, as we know, the popular methods Gauss–Seidel and Newton-Raphson do not work out due which is due to the high resistance to reactance in distribution networks. So far, several methods have been proposed by various authors to perform load distribution calculations in radial distribution networks, the most well-known of which is Load Factor Design [LFD] load-flow method [15-18].

Load flow calculation of distribution network is important and strong tools for analyzing distribution networks. Distribution automation and distribution networks management systems such as grid optimization, reactive power planning, etc. require a rapid and precise load flow plan.

It should be emphasized that despite remarkable advancements due to high R/X ratio in distribution networks, load-distribution calculation methods in transmission networks are not suitable for such networks. The mentioned reason as well as well some of inherent properties of distribution networks as radial characteristic of the network, unbalanced and unbalanced operation, tremendous number of feeders and bus bars and relatively broad range of resistance and reactance values of lines have made researchers try to find new load flow calculation methods for distribution networks. Lots of studies have been carried out in this field, each proposing specific methods. The method used in this papers is based on two matrices; the first one is

$$\sum_{i=1}^{n} S_i = (P_i + jQ_i)$$

Where:

- **S**: apparent power
- **P**: real power
- **Q**: reactive power
- **i**: bus number
- **n**: total number of buses

The second one is

$$I = \left( \frac{P + jQ}{V} \right)$$

Where:

- **V**: voltage
- **P**: real power
- **Q**: reactive power
- **I**: current

Calculation of distribution network losses, which is a weakness for this method. In this method, all three too ling has been placement on the line at first and indexes calculated then, additional elements have been eliminated using genetic algorithm [14].

What can be determined from these references as a new research problem is simultaneous optimal placement and sizing of DG and SVC.

**How to build the used matrices**
1) Feeders' current matrix in terms of bus-bars' injecting current:
For a bus-bar number 1, the apparent power \(S_i\) is calculated as follows [17-18]:

$$S_i = (P_i + jQ_i) = 1, 2, ..., n \quad (1)$$

- **N**: number of bus-bars
- **V**: voltage

So, relevant bus-bars' injecting currents are calculated using the following formula [15-18]:

$$I = \left( \frac{P + jQ}{V} \right) *$$

Voltage of the i bus-bar in the k iteration: \(V_{ik}\)
equivalent injected current in the I bus-bar in the k iteration: $I_i^k$

Fig. 3 shows simple radial system used to form matrix Bus Injection Branch Current (BIBC). Bus-bars’ injecting currents are calculated according to Equation 16. A series of current Equations are also written for the grid using Kirchhoff’s current laws. Therefore, branches’ currents can be rewritten in terms of bus-bars’ injecting current.

$$\begin{bmatrix} I_{s1} \\ I_{s2} \\ I_{s3} \\ I_{s4} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix}$$

(3)

In the above Equation

Load current in the I the bus-bar: $I_i$

I the section current: $I_{si}$

$$I_{s1} = I_1 + I_2 + I_3 + I_4$$
$$I_{s2} = I_2$$
$$I_{s3} = I_3 + I_4$$
$$I_{s4} = I_4$$

The Equation can be rewritten in the following general form:

$$[B] = [BIBC] [I]$$

2) Bus-bars' voltage matrix in terms of branches' current:

The relationship between branches' current and bus-bars' voltage for the shown example is rewritten using Kirchhoff's current laws as follows:

$$V_1 = V_0 - Z_1 I_{s1}$$
$$V_2 = V_0 - Z_1 I_{s1} - Z_2 I_{s2}$$
$$V_3 = V_0 - Z_1 I_{s1} - Z_3 I_{s3}$$
$$V_4 = V_0 - Z_1 I_{s1} - Z_3 I_{s3} - Z_4 I_{s4}$$

(4)

The above Equation can be rewritten in the following general form:

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} V_0 \\ V_0 - Z_1 I_{s1} \\ V_0 - Z_1 I_{s1} - Z_2 I_{s2} \\ V_0 - Z_1 I_{s1} - Z_3 I_{s3} \end{bmatrix} - Z_1 \begin{bmatrix} 0 & 0 & 0 & I_{s1} \\ 0 & 0 & 0 & I_{s2} \\ 0 & 0 & 0 & I_{s3} \\ 0 & 0 & 0 & I_{s4} \end{bmatrix}$$

(5)

The above Equation can be rewritten in the following general form:

$$[V] = [V_0] - [BCBV] [B]$$

$$[\Delta V] = [BCBV] [B]$$

BCBV: Branch Current to Bus Voltage

**Losses Calculation**

Although, losses of the whole system are equal to the sum of losses for all the individual parts of the system as Equ. 8, it is possible to use the sum of active powers in load points and active powers injected into the system by the bulk power substation, instead of calculating losses for all the individual parts, as stated in the following:

$$P_{loss} = \text{real}(\sum_{i=1}^{m} Z_i I_i I_i^*)$$

(7)

m: Number of branches
\[ P_{loss} = real(S_{substation} - \sum_{i=1}^{n} S_i) \]  

(8)

\( n \): Number of bus-bars

It is worth noting that in radial structure, there is one feeder for one bus-bar, except for the case of bulk power substation bus-bar. Thus, in the above Equations: \( m=n \). Due to load uncertainty, fuzzy load flow will be used in this paper. For this purpose, we have considered a triangular membership function for each bus-bar load. In the first assumption, voltages are considered as the first and the last values of the triangle 1pu. Then, fuzzy algebraic rules will be applied [18].

**Optimization Algorithm**

In Flock algorithm optimization, each bird will be as a possible solution for an optimization problem. In solution space, birds move towards the optimum point through accidental paths, while they are guided by velocity vectors which will be explained later in this paper [18].

The aforementioned velocity vectors are in fact factors affecting the birds' movement. These are as follows:

1- Bird's previous velocity
2- Bird's memory of its prior best position.
3- Bird's memory of the flock's best recorded position

In this way, birds will move towards the absolute optimum point, while considering local optimum ones.

---

**Objective Function**

Presence of DG in distribution network will have two effects on the grid; the first one is improvement of voltage profile, and the second one is change in losses. Moreover, SVC will lead to improvement in voltage profile. Therefore, it would be possible to define the objective function of the problem as a function maximizing voltage profile improvement and minimizing the losses.

In the present paper, profile voltage improvement has been defined as the sum of two terms; the first one is the absolute difference between the voltage domain from the desired value (for instance, 1 Pu), and the other one is the difference between bus-bars' voltage domain and their value before installation of DG and SVC. Therefore, the objective function of the problem is stated as follows:

\[ OF = min \left[ \left( W_L * Risk_{voltage} \right) + \left( W_{v1} * Risk_{voltage} \right) \right] \]  

(9)

\( W_L \) is weight coefficient of losses, \( W_{v1} \) is eight coefficient of the first term relevant to voltage profile, \( W_{v2} \) weight coefficient of the second terms relevant to voltage profile. Each of the three components of the target function is presented in detail:

**Constraints of the Problem**

Operation constraints include bus-bars voltage (10) limitation whose target function has been calculated, power balance constraints, lines' current constraints, the equations governing each one each one
will be presented later in this paper. The first Equ. (11) indicates bus-bars' voltage limitation, the second
Equ. (12) indicates power balance, and the lines' flow restriction.
\[
V_{\min} \leq V_i \leq V_{\max}
\]  
(10)
\[
V_{\min} \text{ and } V_{\max} \text{ represent minimum and maximum bus-bars' allowable voltage domain, respectively. These}
\]
values are usually ranged from -5\% to +5\% in terms of per unit. Also, generator's capacity limitation is
introduced by the third Equ. (13).
\[
\sum_{i=1}^{N_{DG}} P_{dg} = P_d + P_L.
\]  
(11)
\[
P_t^2 + Q_t^2 \leq S_t^{\max}
\]  
(12)
\[
P_{dg}^{\min} < P_{dg} < P_{dg}^{\max}, \; Q_{dg}^{\min} < Q_{dg} < Q_{dg}^{\max}
\]  
(13)

Limitations discussed so far are those relevant to load-flow. Here, rewriting load-flow equations has
been avoided.

In this paper, three types of distributed generation generators and three types of SVCs have been
used. It is also assumed that, at most, one distributed generation generator and one SVC will be located. It is
worth noting that the different types discussed are different from each other only in terms of capacity. \(U_{ij}\)
Variables, in which includes generator or SVC and \(j\) include the numbers from 3 to 1, are binary variables and
limitations are defined among them. The following limitation requires only one type of generator as well as only
one type of SVC to be added to the grid

**System Information**

System information includes technical and topological information of the system as well as information
on generators' price and capacity. Table 1 shows the information about topology and system load. The load
given is system bus-bars' peak load which has been considered as similar to most of the studies on locating
distributed generations for the time period under study.

Table 1. Information system [18]

<table>
<thead>
<tr>
<th>Line no</th>
<th>From bus</th>
<th>To bus</th>
<th>Resistance(Ω)</th>
<th>Reactance(Ω)</th>
<th>Real power load(kw)</th>
<th>Reactive power load (kvar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0.3664</td>
<td>0.1807</td>
<td>16.78</td>
<td>20.91</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0.0547</td>
<td>0.0282</td>
<td>16.78</td>
<td>20.91</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>4</td>
<td>0.5416</td>
<td>0.2789</td>
<td>33.80</td>
<td>37.32</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>5</td>
<td>0.193</td>
<td>0.099</td>
<td>14.56</td>
<td>12.52</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>9</td>
<td>0.7431</td>
<td>0.3827</td>
<td>19.31</td>
<td>25.87</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>6</td>
<td>1.3110</td>
<td>0.6752</td>
<td>10.49</td>
<td>14.21</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>7</td>
<td>0.0598</td>
<td>0.0308</td>
<td>8.821</td>
<td>11.66</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>8</td>
<td>0.2905</td>
<td>0.1496</td>
<td>14.35</td>
<td>18.59</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>10</td>
<td>0.0547</td>
<td>0.0282</td>
<td>14.35</td>
<td>18.59</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>11</td>
<td>0.675</td>
<td>0.3481</td>
<td>16.27</td>
<td>19.48</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>12</td>
<td>0.0547</td>
<td>0.0282</td>
<td>16.27</td>
<td>19.48</td>
</tr>
<tr>
<td>12</td>
<td>11</td>
<td>13</td>
<td>0.3942</td>
<td>0.203</td>
<td>82.13</td>
<td>71.65</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>14</td>
<td>1.0460</td>
<td>0.5388</td>
<td>34.71</td>
<td>30.12</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>15</td>
<td>0.022</td>
<td>0.0116</td>
<td>34.71</td>
<td>30.12</td>
</tr>
<tr>
<td>15</td>
<td>14</td>
<td>16</td>
<td>0.0547</td>
<td>0.0282</td>
<td>80.31</td>
<td>70.12</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>17</td>
<td>0.03212</td>
<td>0.1654</td>
<td>49.62</td>
<td>47.82</td>
</tr>
<tr>
<td>17</td>
<td>17</td>
<td>18</td>
<td>0.0949</td>
<td>0.0488</td>
<td>49.62</td>
<td>47.82</td>
</tr>
<tr>
<td>18</td>
<td>17</td>
<td>19</td>
<td>0.574</td>
<td>0.2959</td>
<td>43.77</td>
<td>38.93</td>
</tr>
<tr>
<td>19</td>
<td>19</td>
<td>20</td>
<td>0.1292</td>
<td>0.066</td>
<td>37.32</td>
<td>35.96</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>21</td>
<td>0.0871</td>
<td>0.045</td>
<td>37.32</td>
<td>35.96</td>
</tr>
<tr>
<td>21</td>
<td>20</td>
<td>22</td>
<td>0.5329</td>
<td>0.2744</td>
<td>31.02</td>
<td>29.36</td>
</tr>
</tbody>
</table>

It should be noted that three load levels with the coefficients equal to 0.6, 1, 1.6 times as much as
the load have been considered in table 1 have been considered the system. Occurrence times for these three
load levels are 2000, 5260, and 1500 hours a year, respectively.

Tables 2 and 3 show the information related to type of generators and SVCs' capacity, respectively.

Table 2. Market data generators to be installed in the system

<table>
<thead>
<tr>
<th>Type of generator</th>
<th>Initial investment cost ($ / kW)</th>
<th>Efficiency %</th>
<th>Availability %</th>
<th>Useful life</th>
<th>The cost of energy produced at the interface ($ / kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocating engine</td>
<td>433</td>
<td>40</td>
<td>97</td>
<td>20</td>
<td>110</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>420</td>
<td>29</td>
<td>97</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>750</td>
<td>42</td>
<td>97</td>
<td>10</td>
<td>131</td>
</tr>
</tbody>
</table>
Table 3. SVC data available for installation in the system

<table>
<thead>
<tr>
<th>Type SVC</th>
<th>The initial investment cost ($ / kVAR)</th>
<th>Capacity (kVAR ±)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>450</td>
</tr>
</tbody>
</table>

**Numerical results**

In this part of the paper, we are about to study the results of applying the proposed optimization method to solve the problem brought up in the system.

Table 4. shows the voltage profiles of three times for 21 buses used in network optimization

<table>
<thead>
<tr>
<th>Voltage Profile (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99.90</td>
</tr>
<tr>
<td>99.90</td>
</tr>
<tr>
<td>99.90</td>
</tr>
<tr>
<td>99.80</td>
</tr>
<tr>
<td>99.80</td>
</tr>
<tr>
<td>99.80</td>
</tr>
<tr>
<td>99.76</td>
</tr>
<tr>
<td>99.75</td>
</tr>
<tr>
<td>99.73</td>
</tr>
<tr>
<td>99.73</td>
</tr>
<tr>
<td>99.50</td>
</tr>
<tr>
<td>99.50</td>
</tr>
<tr>
<td>99.36</td>
</tr>
<tr>
<td>99.36</td>
</tr>
<tr>
<td>99.28</td>
</tr>
<tr>
<td>99.01</td>
</tr>
<tr>
<td>99.01</td>
</tr>
<tr>
<td>99.01</td>
</tr>
<tr>
<td>98.97</td>
</tr>
<tr>
<td>98.97</td>
</tr>
<tr>
<td>98.94</td>
</tr>
<tr>
<td>98.93</td>
</tr>
<tr>
<td>98.93</td>
</tr>
</tbody>
</table>

Rate of improvement in losses and voltage profile have been used as indices for determining the coefficients. Rate of losses in the first mode has been calculated to be averagely 23.1463 kilowatt, and in the second mode 15.4029 KW, representing a 7.7433 kilowatt difference. On the other hand, the mean difference between voltage profile in the first and second modes is 0.4021%. Therefore, improvement in losses seems to be around 10 kilowatt and improvement in voltage profile around 0.5%. In addition, the target voltage value that is 1 per unit is different from the calculated voltages in the range of 0.1511 and 4.4514 per unit, which average is 1.7783 per unit. Given that the first coefficient in the target function is multiplied by a number between 0 and 10, the second one by a number between 0.0 and 2, and the third one by a number between 0.0 and 0.5, the following Equations, therefore, exist among these coefficients.

![Figure 3. The network losses after simultaneous placement of DG and SVC](image-url)

The mortality in (Kwh)
Table 5. Placement & optimized for DG & SVC installation

<table>
<thead>
<tr>
<th>Resources</th>
<th>Number of housing bass</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVC</td>
<td>13</td>
<td>300</td>
</tr>
<tr>
<td>DG</td>
<td>16</td>
<td>433</td>
</tr>
</tbody>
</table>

CONCLUSION

In this paper, introducing the problems existing in distribution systems, the simultaneous placement of distributed generations and SVC in distribution networks, the necessity of installing active and reactive power resources and the reduction of losses in the grid were addressed. The main problems are reducing energy cost including active and reactive power reducing the initial investment cost and decreasing losses costs. The entire mentioned problems were done with installing one distributed generation generator with the capacity of 433 MW and one SVC with a capacity of 300 MW in places located in an optimized manner. A 22-busbar network was considered for the problem and particle swarm algorithm was used as an optimization tool. The current study indicates that simultaneous placement of distributed generation generator and SVC leads to the release of generator's capacity to generate active power and remarkably reduce losses in the upstream network. By the way, the SVC added to the grid leads to voltage profile improvement and supplies the part of reactive power needed by the grid.

REFERENCES


Hasan Doagou-Mojarrad a, G.B. Gharehpstin b, H. Rastegar a, Javad Olamaei b, Optimal placement and sizing of DG (distributed generation) units in distribution networks by novel hybrid evolutionary algorithm, energy conversion and management Volume 54, 1 June 2013, Pages 129–138

Hortensia Amaris, Monica Alonso, Coordinated reactive power management in power networks with windturbines and FACTS devices, Elsiver, Energy Conversion and Management Volume 52,(2011) Pages 2575–2586


Seyed Salman Dorkosh, Haidar Samet Restricting minimum size of DGs to confirm correct operation of fast directional protection switches in their simultaneous allocation with DGs, Elsiver Energy Conversion and Management Volume 94 (2015), Pages 482–492
