Optimal Capacitor Placement in Distribution Systems by Using DPSO Algorithm

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Abstract

Usually the parallel capacitor are used in distribution systems with the goal of reducing power losses, improve voltage profile and etc. These goals are depends on how the capacitors are installation and to achieve them, since the capacitor placement is nonlinear problem and has some equally and inequality constraint, so in this paper the dynamic particle swarm algorithm to solve this problem with consider to the changing in load is used. The issue for the 33 bus system sample is implemented and the results are discussed.

Keywords: Capacitor placement, distribution systems, DPSO, power loss

1. Introduction

Studies show that approximately 13% of the power generated in distribution system is spending at the power losses. However, with increasing demand load, voltage profiles during distribution feeders encounter with the decrease and it is less than the extent permitted. Therefore, due to the power losses, reducing voltage and increasing power demands, the necessity of restructuring issue is sense. The parallel capacitor can help to improve the performance the distribution systems. Till now there are many way is used to capacitor placement that in most of them the demand is constant. In [1, 2, and 3] the Genetic
Algorithms is used and the Immune algorithm is used to capacitor placement [4, 5]. In [5-7] the combination of fuzzy logic with optimization is used. In [8, 9] the Particle swarm optimization algorithm is used. Different objectives considered in various papers. For example, in [10] is intended to improve voltage stability, or in reference[8] to reduce losses and costs as a target is selected.

In this paper, adynamical particle swarm optimization algorithmis used. This algorithm isa modified version of the conventional particle swarm optimization algorithms. DPSOis a powerful algorithm for solving the problem of capacitor placement, the algorithm is coded in binary form and by its optimization process can prevent to being in local optimum rather than the global optimum, It also increases the speed is optimized. The objective functions considered is the total cost of power losses, energy and money of capacitance placement and the voltage range is considered as shackles. The method proposed in this paper has been carried out on the bus 33 system.

2. Statement of problem

In capacitors placement problem the location and optimal size of capacitor in the selection of substations are considered, that has some equally and inequality constraint and are discussed as follows:

2-1- The objective functions

The objective function in capacitor placement is contained reduce the cost of system losses, minimizing the cost of capacitor banks and minimizing the voltage deviation by considering the constrained, that defined as follows:
2-1-1- Total active power losses

The first objective function is to minimize the active power losses in the distribution system [8] that in equation (1) is expressed in the following:

\[ f_1 = \sum_{i=1}^{n_b} P_{loss_i} \]  (1)

Where:
- \( n_b \): number of branch network
- \( P_{loss_i} \): the losses in fundamental frequency

2-1-2- Cost of capacitor placement

Another objective is to minimize cost of capacitors placement that is expressed as follows:

\[ f_2 = \sum_{j=1}^{n_c} Q_j \]  (2)

2-1-3- Minimizing voltage deviation

In this function, the goal is reducing the amount of voltage deviation, which is expressed as follows:

\[ f_3 = \sum_{i=1}^{n_b} (V_n - V_{rated})^2 \]  (3)

2-1-4- Cost function

Total objective function or cost function is the total cost of losses and capacitor placement which is expressed as follows:

\[ F = k_p f_1 + k_c f_2 + k_v f_3 \]  (4)
Where:
kc: Annual cost of reactive power injection
kp: Annual Cost per kW power losses
kv: penalty coefficient to minimize the distortion voltage

2-2- Constrained problem

Capacitor placement has equal and unequal problem constraints that are expressed as follows:

2-2-1- Voltage constrain

Effective voltage of each substation consists of the main component and harmonic components that should be placed in the allowed range of \( V_{\text{max}} \), \( V_{\text{min}} \). This range is expressed by the IEEE-519 standard [9]. Where \( V_{\text{max}} = 1.1 \text{pu} \) and \( V_{\text{min}} = 0.9 \text{pu} \).

\[
V_{\text{min}} \leq V_n \leq V_{\text{max}}
\]  

(5)

2-2-2- Constrain of the number and size of capacitors

Parallel capacitors in the industry are available. Parallel capacitors are obtained by integer multiples of the smallest capacitor capacity.

\[
Q_{ci} = L \cdot Q_0
\]  

(6)

\( Q_0 \): The smallest capacity of the capacitor

However, due to economic problems and limited installation space, total capacity available on each substation not exceeds a limit.
$$\sum_{i=1}^{nc} Q_{ei} \leq Q_t \quad (7)$$

$Q_t$: Total reactive power demand
In this paper, the smallest capacitance of the capacitor 1.50 and the number in each substation is 15.

3-2- power flow

Power flow must have high speed and good performance. In this paper, broomsweep method is used to power flow.

2-3-1- process

In this part, brooms sweep power flow in fundamental frequency to determine voltage profile, line flows and losses in the distribution system. The power flow is based on two matrices $[BIBC]$, that is flowing injected transformation matrix into the lines flow and $[BCBV]$ that is branch current transformation matrix into the substation voltage. Substation voltages and line currents are calculated according to the following equation as an iterative process:

$$[V]^k = [V_0] - [BCBV].Z.[BIBC].[I]^k \quad (8)$$

Where:
$V_0$: The substation reference voltage vector
$Z$: The impedance matrix of the network
$[V]$: Vector of substation voltage
$K$: Number of iterations
[I]: is the vector of load current

The following equation is obtained:

\[ I = \left( \frac{P_i+jQ_i}{V_i} \right)^* \] (9)

3. Particle swarm optimization algorithm

The main idea of this algorithm (PSO) by James Kennedy and Russell C. Eberhart was introduced in 1995. In PSO algorithm, there are a number of organisms that is called particle and they are released in a space search of function that we want to minimize that [8, 9].

3-1- Conventional particle swarm optimization algorithm (CPSO)

In PSO algorithm, each particle is composed of three-dimensional vectors that are the space vectors. For \( i \) particle there are three vectors, \( x^i \) current position of the particle, \( v^i \) the particle's speed, and \( p^i \) the best position has ever experienced. \( x^i \) is a set of coordinates that represents the particle's current position at any stage of the algorithm is repeated, \( x^i \) is calculated as a solution to the problem. If the situation is better than previous solutions, it is stored in \( x^{i, \text{best}} \).

3-1-1- Dynamic particle swarm optimization algorithm

The particle in PSO changes the positions in each iteration based on the personal best position, the best position, size, and velocity. The new position of the particle as well as the associated weight depends on these values. These weights can be dynamic or static. A static weight is specified by many iterations of an algorithm, usually set before the program is run.
Dynamic weight is changed for each iteration of PSO. Weight was introduced by Peramand colleagues in [11] and was made to set the coefficient of proportionality. Dynamic weights used in this paper in each iteration, depending on the difference on particle, the best position are changed.

3-2 implements the DPSO algorithm capacitor placement

The implementation of the algorithm is as follows:

1. Read data line and load
2. Set the level of load
3. Perform power flow to obtain the substation voltage and line losses
4. Implementation DPSO algorithm to determine the location and capacity of the capacitor in load.
5. If the algorithm converges, goto the step 6, otherwise go back to step 4.
6. Power flow and determining the substation voltage and system loss after optimal capacitor placement.
7. End

4. Simulation results

To solve the problem of capacitor placement and show the power of DPSO algorithm, it used in two 33 substation IEEE system. The Information of this system is obtained from [12]. Maximum and minimum voltages are 1.1 and 0.9 p.u. The annual cost per kW of power loss and energy in the reference [8] is considered 168$ / kW. Cost of reactive power injection can be seen in the table below:
Table 1: Cost of reactive power injection

<table>
<thead>
<tr>
<th>Qc (kVAR)</th>
<th>150</th>
<th>300</th>
<th>450</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kc($/kVAR)</td>
<td>0.500</td>
<td>0.350</td>
<td>0.253</td>
<td>0.220</td>
</tr>
<tr>
<td>Qc (kVAR)</td>
<td>750</td>
<td>900</td>
<td>1050</td>
<td>1200</td>
</tr>
<tr>
<td>Kc($/kVAR)</td>
<td>0.276</td>
<td>0.183</td>
<td>0.228</td>
<td>0.170</td>
</tr>
<tr>
<td>Qc (kVAR)</td>
<td>1350</td>
<td>1500</td>
<td>1650</td>
<td>1800</td>
</tr>
<tr>
<td>Kc($/kVAR)</td>
<td>0.207</td>
<td>0.201</td>
<td>0.193</td>
<td>0.187</td>
</tr>
<tr>
<td>Qc (kVAR)</td>
<td>1950</td>
<td>2100</td>
<td>2250</td>
<td>2400</td>
</tr>
<tr>
<td>Kc($/kVAR)</td>
<td>0.211</td>
<td>0.176</td>
<td>0.197</td>
<td>0.170</td>
</tr>
</tbody>
</table>

4-1- Specification of networks before capacitor placement

Power flow before capacitor placement is expressed as follows:

Table 2: 33 substation system specifications before capacitor placement

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total power losses</td>
<td>210.98 Kw</td>
</tr>
<tr>
<td>The total annual cost</td>
<td>35445$</td>
</tr>
<tr>
<td>The Lowest Voltage Systems</td>
<td>0.9038 p.u. Related to substation 18</td>
</tr>
</tbody>
</table>

4-2- The results after Capacitor placement by DPSO algorithm

In this part, optimal location and amount of capacitance is performed.
Table 3: System specifications of 33 substations after capacitor placement

<table>
<thead>
<tr>
<th>Substation Number</th>
<th>Amount of capacitor (k var)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>450</td>
</tr>
<tr>
<td>24</td>
<td>450</td>
</tr>
<tr>
<td>30</td>
<td>1050</td>
</tr>
</tbody>
</table>

Table 4: Comparison of power flow results before and after the capacitance placement

<table>
<thead>
<tr>
<th>33 substations system</th>
<th>Before capacitor placement</th>
<th>After capacitor placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest voltage (p.u.)</td>
<td>Substation 18-0.9307</td>
<td>Substation 18-0.9307</td>
</tr>
<tr>
<td>Highest Voltage (p.u.)</td>
<td>Substation 2-0.9970</td>
<td>Substation 2-0.9977</td>
</tr>
<tr>
<td>Power losses (kw)</td>
<td>210.98</td>
<td>138.42</td>
</tr>
<tr>
<td>Annual cost of energy losses</td>
<td>35445</td>
<td>23255</td>
</tr>
<tr>
<td>Capacitors placement cost</td>
<td>0.0</td>
<td>467.1</td>
</tr>
<tr>
<td>Total cost</td>
<td>35445</td>
<td>23722</td>
</tr>
</tbody>
</table>

Figure (1): Diagram of substation voltage profiles before and after the capacitor placement
4-3- Analysis

The standard system is a system of 33 buses. After applying the proposed method on the system and optimal capacitor placement, the voltage profiles are improved and reactive losses are reduced.

Conclusion

Optimal Capacitor placement in distribution networks caused the reduction of losses, improve voltage profiles and release the line capacity. In this paper, the capacitor placement was performed for Standard 33 substation system. According to the results, the optimal capacitor value obtained for this system. The results indicate the high performance of DPSO algorithm in discrete issues such as capacitor placement. High speed, high performance and flexibility of the algorithm show that, we can use this algorithm as software at optimal capacitor placement in real distribution network.

References


