Optimal Allocation of Distributed Generator to Ameliorate the Voltage Stability Employing Circular Optimization Algorithm

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Abstract - This paper proposes a new estimated power collapse index (EPCI) to identify sensitive nodes for optimal placement of DGs. The proposed index is used to rank the buses according to their voltage sensitivity. Circular optimization algorithm is used to perceive optimal size of DG to ameliorate voltage stability and voltage profile of the system and also reduces line congestion. The proposed methodology has been tested on IEEE 30-bus test system to substantiate its applicability. The results are deliberated and key conclusion drawn.

Index Terms – voltage stability; distributed generation; line congestion; optimization.

I. INTRODUCTION

The aggregate size of power system along with Technical, Economical and Environmental (TEE) constraints, the plausible threat of voltage instability is a noticeable in the power system [1]. Numerous incidents associated to voltage instability have been reported globally [2]-[4]. The problems connected to voltage collapse are insufficient flow of reactive power, heavy loading on transmission lines, power shipping across long distances. To avoid voltage collapse either load is to be curtailed or distribution generators (DG) are placed at optimum locations. Introducing DGs at suitable locations are the most practical way to ameliorate voltage profile, which in turn enhances stability margin [5]. In literature lot of researchers have reported different methods or techniques to identify weak nodes. Traditionally PV and QV curves were castoff to identify critical nodes. These curves produced through large data of repetitive power-flow solutions which entail large time and also computationally inefficient. Various other methods are also reported in literatures i.e. L-index [6], modal analysis [7], etc. to identify weak buses or lines. This paper presents a new voltage stability index for recognizing the most sensitive node to the voltage collapse in power transmission network. The developed index identifies the voltage sensitive nodes of power system. Higher value of proposed index for a bus indicates higher voltage-sensitivity of the bus. Then the distributed generators are placed on the most critical bus.

The remaining paper is organized as follows: Section II present methods for identifying critical lines/buses. Section III presents distributed generation. In Section IV, presents optimization technique In Section V, proposed index is formulated. Simulation results and discussions on IEEE 30-bus test system are presented to authenticate the feasibility in Section VI. Conclusion is presented in Section VII.

II. METHODS FOR IDENTIFYING CRITICAL BUS/LINES

The voltage stability index plays a crucial role in identifying critical lines/buses of the system. The most established methods for determining stability are discussed below.

A. L-index

The utmost weakest bus of the system is determined through L-index [6] for a particular loading condition. should be centered above. The value of L-index varies between zero to one from no load to a maximum loading point. If the assessed value tending towards 1.0, it shows that the bus or node is critically stressed and voltage collapse may occur.

$$L = \max (L_i) \cdot L_j \quad 1, 2, \ldots, n_i$$

where, \(n\), indicates the number of a load bus.

B. Modal Analysis

In this investigation, smallest eigen value and its connected eigenvectors are evaluated. Eigen number close to zero stipulates that the system is on the edge of collapse and system has limited voltage stability margin [7]. This proximity of collapse can be estimate through the valuation of positive eigen value. Weak bus of the system can be resolve by calculating eigen vector for different buses in the system.

III. DISTRIBUTED GENERATION

Distribution Generation (DG) uses generation from few kW to MW at different locations close to load centers. The DGs are used against captive power plants. DGs are available
in several forms such as micro-turbine, diesel engine, reciprocating engines, gas turbines, fuel cells, wind, photovoltaic etc. Owing to the unlike climate circumstances, such as wind speediness and its direction, sun energy, emission penalty, fuel cost and so on, companies may have different choices concerning the types of DG units. Infact, planners contemplate these factors in DG selection and the situation of installing them. In this paper, dispatchable DGs are considered for planning purpose [8].

The subsequent assumptions are engaged in the problem formulation:

- Candidate buses are determined through proposed voltage stability index.
- DG connection is modeled as a negative PQ load.
- Power factor of non-dispatchable units are fixed.

The problem is formulated for an objective of active power loss and L-index minimization so that voltage stability of the system can be enhanced as deficit power is supplied through DG. This investigation measures total power losses minimised after installation of dispatchable DGs on vulnerable buses.

\[
\min (P_t) = \sum_{k=1}^{N_p} G_k (V_i^2 + V_j^2 - 2V_iV_j \cos \theta_{ij})
\] (2)

The multi-objective function of minimum power loss and L-index is minimized by using circular optimization algorithm subject to following conditions.

A. Active Power Limits

Algebraic sum of sending and receiving powers including line losses and power generated from DG must be equal to zero.

\[
P^{\text{act}} = P_t + P_l - P^{\text{DG}}
\] (3)

Where, \(P_t\) = real power demand of system; \(P_l\) = represent real power loss of the system; \(P^{\text{DG}}\) = real power produced by DG.

B. DG real power generation limits

Real power produced by each DG \(P^{\text{DG}}\) is limited by its lower and upper limits as,

\[
P^{\text{DG}}_{\text{min}} \leq P^{\text{DG}} \leq P^{\text{DG}}_{\text{max}}
\] (4)

C. Voltage profile limits

Voltage magnitude of each bus in the system is defined as:

\[
V^{\text{DG}}_{\text{min}} \leq V^{\text{DG}} \leq V^{\text{DG}}_{\text{max}}
\] (5)

Voltage at each bus must be retained within limits.

D. Line limits

The power in distribution system is fed through the feeder in the system, and the feeder must not exceed line limits

\[
S_{o,j} \leq S^{\text{line}}_{i,j}
\] (6)

IV. OPTIMIZATION TECHNIQUE

In this paper, a new optimization technique i.e. circular optimization technique (COT) is used. The technique is classified as constraint optimization method. Depending upon the number of variables of the objective function, they are implemented. This method deals with optimization problems for two variables. The circumference points are obtain in each iteration using the following equations

\[
X = X_0 + a \cos \theta
\] (7)

\[
Y = Y_0 + a \sin \theta
\] (8)

Where \(X, Y\) are the circumference coordinates \(X_0, Y_0\) are the centre coordinates \(a\) is the radius of the circle, \(\theta\) is angle taken anticlockwise with respect to x axis.

These circumference points or coordinates are then implemented in the objective function and a turning point is obtained. A turning point is a point at which a local minima or a local maximum is obtained [9]. This turning point along with the optimized value of the objective function is stored at some location for future use.

Now next iteration gives another saddle point and a corresponding objective function value, which is stored in next location corresponding to the previous turning point. Finally, after obtaining all the turning points and the corresponding objective function values, the global minima amongst them can be obtained. The flowchart of the circular optimization algorithm is shown in Fig 1.

V. PROPOSED INDEX

The condition of voltage stability in a power system can be known by using static voltage stability indices. A new voltage stability index called Estimated Power Collapse Index (EPCI) is introduced in the paper, which is based on the deviation of average voltage from base case to the measured and then their average voltages at different loading conditions. Buses with higher deviations are highly sensitive buses.

Mathematically, the proposed Estimated Power Collapse Index (EPCI) is signified by

\[
\Delta V_i = V^{\text{base}}_i - \frac{1}{N} \sum_{k=1}^{k} V_i \quad \forall k=1,2,...,N^d
\] (9)

where \(k\) represents number of buses in the system, \(i\) represents loading state and \(N^d\) represents total number of buses. The estimated index for each node in the system is near to 0, which reveals that the system is under stable condition. However, if the sensitivity of any bus is higher, shows that flow of active power flow has larger impact on the voltage profile of the system. Correspondingly, all buses are organized in descending order of EPCI.
IV. PROBLEM FORMULATION

Optimal placement of dispatchable DGs are the most prominent solution on voltage sensitive buses which are designated on the basis of proposed index. Optimal sizing of DGs are selected on the basis of circular optimization algorithm [7]. The problem formulation for identification of weak buses and computing the size of DG includes the following steps:

Step 1: For the base case system (considering without DG), the voltage profile and L-index is evaluated for each bus and is referred as voltage profile and L-index at base case.

Step 2: From calculations, proposed EPCI index is estimated for each bus.

Step 3: Rank the crucial buses in descending order based on EPCI.

Step 4: Finally using circular optimization algorithm optimal size of DG is identified. The mathematical formulation is represented below.

The multi objective problem can be converted into single objective problem by combining Eq1 and Eq 2 in following way:

$$\text{Min } (F) = \lambda_1 \times \text{min } (L) + \lambda_2 \times \text{min } (P_L)$$

(11)

where, \(\lambda_1\) and \(\lambda_2\) are weighing factors. The objective function is minimized using circular optimization algorithm subject to the aforementioned constraints.

VI. CASE STUDY AND DISCUSSIONS

The proposed index is investigated on IEEE 30- bus test system as shown in Fig.2. Initially, weak buses are acknowledged through proposed index and categorized on the basis of severity. The position is confirmed through L-index. Three most critical buses are chosen for placement of DG and their sizing is computed using circular optimization algorithm so as to enhance VSM and reduce line congestion. The simulation results with dispatchable DGs are also compared with without DGs in the following section.

A. L-index

Primarily, the L-index for each load bus is plotted at base loading. The information is depicted in Fig. 4. The Fig. 4 shows that the L-index of bus 30 is observed to be higher than other load buses. As loading of the system is increasing, bus 30 is increasing sharply towards point of collapse. Hence, from voltage stability stand point, bus 30 is the most critical for the system. Other critical buses are also identified on the basis of Fig. 3.
B. EPCI Index

Secondly, proposed EPCI is evaluated for each bus and results are shown in Table I. The maximum value of EPCI is reported for bus 30. The information from the table shows that the bus 30 is the most vulnerable among other load buses. Moreover, other critical buses are classified on the basis of proposed index which is shown in Table 2. The similar pattern of vulnerable buses was observed through L-index as shown in Fig 3. Thus, the results authenticate the efficacy of the proposed EPCI index.

Table 1: PROPOSED INDEX FOR MOST CRUCIAL BUSES IN DESCENDING ORDER

<table>
<thead>
<tr>
<th>Rank</th>
<th>Bus</th>
<th>Proposed Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>0.123865</td>
</tr>
<tr>
<td>2</td>
<td>29</td>
<td>0.118042</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>0.120642</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>0.092078</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>0.07806</td>
</tr>
</tbody>
</table>

C. Optimal Allocation of DG

The sensitivity in terms of voltage for each bus is resolved on the basis of proposed EPCI index. Buses are categorized according to EPCI index. Bus number 30, 29 and 26 are the most sensitive buses as perceived from Table II. According to the literatures [10], selection of three DGs is the optimal choice for minimum active power loss. The DG units at these locations have dispatchable units. Based on the literature, the locations for DG placement on crucial buses are 30, 29 and 26. Now, circular optimization algorithm is implemented to determine the optimal sizing of dispatchable DGs such that power loss and L-index should be minimum.

Table 2: PROPOSED INDEX FOR ALL BUSES FOR IEEE 30 BUS SYSTEM

<table>
<thead>
<tr>
<th>Bus Number</th>
<th>Proposed Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0000</td>
</tr>
<tr>
<td>2</td>
<td>0.0000</td>
</tr>
<tr>
<td>3</td>
<td>0.0225</td>
</tr>
<tr>
<td>4</td>
<td>0.0267</td>
</tr>
<tr>
<td>5</td>
<td>0.0506</td>
</tr>
<tr>
<td>6</td>
<td>0.0276</td>
</tr>
<tr>
<td>7</td>
<td>0.0226</td>
</tr>
<tr>
<td>8</td>
<td>0.0270</td>
</tr>
<tr>
<td>9</td>
<td>0.0299</td>
</tr>
<tr>
<td>10</td>
<td>0.0457</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bus Number</th>
<th>Proposed Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>0.0000</td>
</tr>
<tr>
<td>12</td>
<td>0.0358</td>
</tr>
<tr>
<td>13</td>
<td>0.0160</td>
</tr>
<tr>
<td>14</td>
<td>0.0470</td>
</tr>
<tr>
<td>15</td>
<td>0.0506</td>
</tr>
<tr>
<td>16</td>
<td>0.0495</td>
</tr>
<tr>
<td>17</td>
<td>0.0578</td>
</tr>
<tr>
<td>18</td>
<td>0.0598</td>
</tr>
<tr>
<td>19</td>
<td>0.0598</td>
</tr>
<tr>
<td>20</td>
<td>0.0569</td>
</tr>
</tbody>
</table>

Table 3: OPTIMAL RESULTS AFTER DG PLACEMENT AT BASE CASE

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Optimal Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG30</td>
<td>14.77 MW</td>
</tr>
<tr>
<td>DG29</td>
<td>14.84 MW</td>
</tr>
<tr>
<td>DG26</td>
<td>14.58 MW</td>
</tr>
<tr>
<td>Ploss (Without DG)</td>
<td>17.599 MW</td>
</tr>
<tr>
<td>Ploss (With DG)</td>
<td>13.580 MW</td>
</tr>
<tr>
<td>L-index (Without DG)</td>
<td>0.1366</td>
</tr>
<tr>
<td>L-index (With DG)</td>
<td>0.072</td>
</tr>
</tbody>
</table>

Application results of optimal allocation of DG are shown in Table 3. It is observed from Table 3, that the performance of the system enhanced remarkably with optimal allocation of DG. The active power loss decreased from 17.599 MW to 13.580 MW and voltage stability margin improved as L-index decreased from 0.1366 to 0.072.

Effect of allocation of DGs on L-index before and after DG placement is shown in Fig. 4. It is observed from Fig. 4 that the allocation of DG at weak buses comprehensively reduces the L-index. The reduction in index implies enhanced voltage stability margin. The results are supported on the basis of L-index as shown in Fig 4. The voltage profile comparison before and after DG placement is also observed for all buses as shown in Fig 5. From Fig 5, it is observed that the voltage profile of the system is increased substantially after optimal allocation of DG. Thus, the use of DG quite helpful in improving the voltage profile of most of the buses in the system.
The consequence of allocation of DGs on EPCI before and after DG placement is shown in Fig. 6. It is clearly visible from Fig. 6, that the allocation of DG at weak buses reduces the value of index. The reduction in value of index implies the improved voltage stability margin.

At particular loading it is also perceived that power flow in several lines are above the permissible line limits. Allocation of DG supports in alleviating the congestion of lines. Fig. 7 shows that after allocation of DG, power flow in all the branches are under their MVA limits and system is distant from congestion.

VII. CONCLUSION

In this paper, a new estimated power collapse index (EPCI) is proposed to recognize vulnerable nodes for optimal placement of DGs. Allocation of DGs with appropriate sizing ensued in enhanced voltage stability margin, improved voltage profile, and reduced overloading of lines. Effect of DGs on other performance parameters of power systems can also be investigated.

REFERENCES


