CHAPTER 4

FORMULATION OF OVERLOAD VALUE INDEX

4.1 INTRODUCTION

Power system planners are designing the network to deliver power reliably. Expansion of the system is planned considering the contingences of the transmission lines and the other elements of the system, apart from the maintenance outage planning needs. However, the system outages due to the unexpected power system scenario will lead to congestion. Managing congestion is a challenging task for the system operator. The system operator manages the load-generation balance by load shedding, generation rescheduling or mechanical switching of different devices such as shunt capacitors and reactors under contingency conditions. The system congestion during contingencies could be managed efficiently, if additional network infrastructure is available. These factors motivate the planners to explore the possibilities of utilizing infrastructure facilities to the optimal capacity by installing FACTS controllers.

FACTS controllers are enabling the system to improve its utilization upto the thermal limit by modifying the line reactance and to improve the voltage profile by providing or absorbing the reactive power. Still, increasing the line capacity to the thermal limit and improvisation of the voltage profile depends on the location of FACTS controllers in the network and their optimum settings. CSI based ranking has been adopted by Sutha
and Kamaraj (2008), Slochanal et al (2005) for placement of FACTS controllers to minimize the SOL under contingencies. The drawbacks of using the ranking method suggested by the researchers are discussed and a method to overcome this drawback is presented in this chapter.

### 4.2 Problem Formulation

The objective of the present research is to optimally locate the FACTS controllers to minimize the SOL of the system as well as to control the voltage under contingencies. To achieve this, an index called Overload Value Index (OVI) is formulated and utilized along with the CSI used by the prior researches.

### 4.3 Contingency Severity Index

The CSI of a branch “j” is defined as the sum of the sensitivities of branch “j” to all the considered contingencies and is expressed by Sutha and Kamaraj (2008), Slochanal et al (2005) as,

$$\text{CSI}_j = \sum_{i=1}^{n} \left( p_i u_{ij} w_{ij} \right)$$  \hspace{1cm} (4.1)

- $p_i$ Probability of occurrence for contingency $i$

- **U matrix**, a (m x n) binary matrix consists of 1 or 0 based on the overloading of the branches. “n” is the total number of branches of interest and m is the total number of contingencies.

- **W matrix**, is an (m x n) matrix based on over loaded value with respect to base case power flow, through branch “j” during contingency “i” and is given by,
\[ w_{ij} = \frac{P_{ij, \text{contingency}}}{P_{ij, \text{base case}}} - 1 \]  

\( P_{ij, \text{contingency}} \) Power flow through branch \( j \) during contingency \( i \)  
\( P_{ij, \text{base case}} \) Power flow through branch \( j \) in base case  

The CSI values of all the branches are calculated by using the Equation (4.1). A branch which has the highest CSI value will be more sensitive for security margin.

### 4.4 OVERLOAD VALUE INDEX (OVI)

#### 4.4.1 Drawbacks of using CSI to Assess the Security Margin

The CSI is calculated using power flow during contingency cases with respect to the base case. However, in many practical situations, during contingencies, the transmission facilities will be loaded closer to the thermal limit. Since the CSI is based on the base case flow, it may not reflect the actual overloading and SOL of the system.

Consider a sample system consisting of lines \( x, y \) and \( z \) with the probability of occurrence for contingency of line \( z \) is 0.02, assuming there is no overload during other contingencies. The power flow during the base case and contingency condition with the thermal limit of the lines are given in Table 4.1.
Table 4.1 Sample system power flow

<table>
<thead>
<tr>
<th>Line</th>
<th>Power flow in MW</th>
<th>Base case</th>
<th>During contingency of line-z</th>
<th>Thermal limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line-x</td>
<td>10</td>
<td>110</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Line-y</td>
<td>50</td>
<td>150</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

For the above system, compute CSI using the formula given in the Equation (4.1). For line-x, $u_{ij}$ is 1 since line-x getting overloaded for contingency of line-z.

Compute $W_{ij}$.

$$w_{ij} = \frac{110}{10} - 1 = 10$$

$CSI = 0.02 \times 1 \times 10$

$CSI = 0.2$

Similarly for the line-y, $u_{ij}$ is 1 since line-y getting overloaded for contingency of line-z.

Compute $W_{ij}$

$$w_{ij} = \frac{150}{50} - 1 = 2$$

$CSI = 0.02 \times 1 \times 2$

$CSI = 0.04$
The CSI of line x and y are given in Table 4.2.

**Table 4.2 CSI values for the sample system**

<table>
<thead>
<tr>
<th>Line</th>
<th>CSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line-x</td>
<td>0.20</td>
</tr>
<tr>
<td>Line-y</td>
<td>0.04</td>
</tr>
</tbody>
</table>

In this case, the line –x gets loaded to 110% with reference to the thermal limit. However, line-y is loaded to 150 % with reference to the thermal limit. If arranged as per CSI ranking, line-x gets higher priority for placement of the FACTS controllers than line-y. However, the line-x is only marginally overloaded under contingency. Since, due to low base case power flow and marginal overloading under contingency, a high CSI value is found for line –x.

Whenever there is marginal overloading of lines under contingency condition with low power flow during base case, it will lead to high CSI value. Under this situation, if the lines are ranked based on CSI alone, it will lead to incorrect results. Hence, it is essential to make improvements in the ranking of lines so as to place FACTS controllers optimally in the system.

Further, the objective of the present research is to optimally locate the FACTS controllers to minimize the SOL of the system under contingencies. Therefore, the index needs to be formulated to correlate the SOL of the system.
4.4.2 OVI

To overcome the drawback in CSI, an index called OVI is proposed using power flow during contingencies with respect to the thermal limit of the branch.

In case of contingencies, some of the branches may be overloaded. The OVI for a specific branch “j” for different contingencies is defined as,

\[
OVI_j = \sum_{i=1}^{m} \left( \frac{P_{ji,contingency}}{P_{j,limit}} \right)^k u_{ij}
\]  

\[ P_{j,limit} \quad \text{Thermal Limit for Power flow through branch j} \]

\[ P_{ji,contingency} \quad \text{Power flow through branch j during contingency i} \]

\[ U_{ij} \quad \text{Same as used in CSI} \]

The expression for OVI depicts the summation of over load values of a particular line for contingencies of all other lines considered. If the exponent \( k \) is considered less than or equal to one, it may then not identify the actual severity of over loading since, the system with a huge violation is much more severe than one with many small violations. To avoid this masking effect, higher order expression for OVI is preferred and hence, \( k > 1 \).

Since OVI is to be correlated with SOL of the system, contingency power flow is considered with respect to the thermal limit of the branch

4.4.3 Significance of OVI in the Selection of Branches for Placing the FACTS controllers

As the CSI is calculated using power flow during contingency cases with respect to the base case, if FACTS controllers are placed based on CSI
only, it will lead to under utilization of the network facilities. As the power system planners are always looking for optimum utilization of the existing infrastructure, it would be appropriate to consider OVI along with CSI for deciding the optimal location of FACTS controllers. Thus, high value CSI arises under the situation of the marginal overloading of lines under contingency condition with low power flow during the base case, CSI only based ranking cannot be relied upon.

Instead OVI is to be used along with the CSI to rank the lines for the optimal placement of FACTS controllers in the system thereby avoiding the incorrect ranking of the lines of high CSI which are marginally overloaded with low power flow during the base case. Further, to improve optimum utilization of infrastructure more importance is given for OVI in the ranking of lines.

4.5 CONCLUSION

The drawback in using the CSI to rank the branches for the placement of FACTS controllers to minimize the SOL of the system has been identified. An index OVI to overcome the drawback in CSI has been formulated. The significance of OVI in the selection of branches for placing the FACTS controllers is also discussed.