CHAPTER 4

CONGESTION MANAGEMENT USING FUZZY EP TECHNIQUE

Congestion in the transmission lines is one of the technical problems that appear quite often in the deregulated environment because of unexpected contingencies such as generator outage, line outage and/or sudden increase in load demand. Solving a congestion management problem with more than one objective is a very challenging task. Usually multi-objective optimization problem is converted into single-objective optimization with suitable weighting/penalty factors. Tuning the weighting factors is a difficult task in a multi-objective optimization problem.

To overcome the above difficulties, in this chapter suitable fuzzy models are developed and incorporated in EP algorithm to solve multi-objective power system congestion management problem. Total congestion cost, transmission line overloads and bus voltage deviations are minimized simultaneously by rescheduling the active powers of the participating generators.

4.1 PROBLEM FORMULATION

The objective of the proposed method is to find the optimum values of shift in active power generations which minimize simultaneously the total congestion cost, transmission congestion and bus voltage violations subjected to network constraints. Transmission congestion and bus voltage violation are measured by the transmission congestion index and voltage deviation index respectively. This problem may be stated as follows:
1. Minimize total congestion cost

\[ CC = \sum_{j=1}^{N_g} C_{Gj}^u \Delta P_{Gj}^u + C_{Gj}^d \Delta P_{Gj}^d \]  \hspace{1cm} (4.1)

2. Minimize the transmission congestion index

\[ TC = \sum_{L=1}^{N_L} \begin{cases} 0 & \text{if } P_{L \text{ max}} \leq P_{L}^\text{max} \\ (P_L - P_{L \text{ max}})^2 & \text{if } P_L > P_{L \text{ max}} \end{cases} \]  \hspace{1cm} (4.2)

3. Minimize the voltage deviation index

\[ VD = \sum_{n=1}^{N_d} \begin{cases} 0 & \text{if } \left| V_n^\text{min} \right| \leq \left| V_n \right| \leq \left| V_n^\text{max} \right| \\ \left( \left| \left| V_n \right| - \left| V_n^\text{max} \right| \right| \right)^2 & \text{if } \left| V_n \right| < \left| V_n^\text{min} \right| \\ \left( \left| V_n^\text{min} \right| - \left| V_n \right| \right)^2 & \text{if } \left| V_n \right| > \left| V_n^\text{max} \right| \end{cases} \]  \hspace{1cm} (4.3)

Subjected to various constraints

\[ P_{Gi} - P_{m} = \sum_{j=1}^{N_B} |V_i||V_j|Y_{ij} \cos (\delta_i - \delta_j - \theta_{ij}) \quad i = 1, 2, \ldots, NB \]  \hspace{1cm} (4.4)

\[ Q_{Gi} - Q_{m} = \sum_{j=1}^{N_B} |V_i||V_j|Y_{ij} \sin (\delta_i - \delta_j - \theta_{ij}) \quad i = 1, 2, \ldots, NB \]  \hspace{1cm} (4.5)

where

\[ P_{Gj} = P_{Gj}^c + \Delta P_{Gj}^u + \Delta P_{Gj}^d \quad j = 1, \ldots, N_g \]  \hspace{1cm} (4.6)

\[ P_{Di} = P_{Di}^c + \Delta P_{Di}^d \quad i = 1, 2, \ldots, N_d \]  \hspace{1cm} (4.7)

\[ Q_{Di} = P_{Di} \tan (\Phi_{Di}) \quad i = 1, 2, \ldots, N_d \]  \hspace{1cm} (4.8)

\[ P_{Gj}^\text{min} \leq P_{Gj} \leq P_{Gj}^\text{max} \quad j = 1, 2, \ldots, N_g \]  \hspace{1cm} (4.9)

\[ Q_{Gj}^\text{min} \leq Q_{Gj} \leq Q_{Gj}^\text{max} \quad j = 1, 2, \ldots, N_g \]  \hspace{1cm} (4.10)

\[ \Delta P_{Gj}^u \geq 0 \quad j = 1, 2, \ldots, N_g \]  \hspace{1cm} (4.11)
\[ \Delta P_{Gj}^d \geq 0 ; ~ j= 1, 2, \ldots, N_g \]  \hspace{1cm} (4.12)

\[ \Delta P_{Dj}^d \geq 0 ; ~ j= 1, 2, \ldots, N_d \]  \hspace{1cm} (4.13)

Constraints (4.4) and (4.5) correspond to active and reactive power balance at all buses. Final powers are expressed in terms of market clearing values and are given in (4.6) and (4.7). Active and reactive power demands are related through (4.8) taking constant load power factor. Constraints (4.9) and (4.10) are the upper and lower bounds for real and reactive power of generators. Finally constraints (4.11-4.13) ensure that the increment and decrement in powers are positive.

In this chapter a cost effective congestion management method in a pool based electricity market using multi-objective fuzzy EP technique is presented. The objective functions considered are simultaneously minimizing the congestion cost, transmission congestion alleviation and bus voltage violations. Using fuzzy operator a unique objective function combining the different fuzzy models of the objective functions is developed. These models are incorporated into the EP technique and overall Fuzzy EP algorithm for transmission congestion alleviation in deregulated electricity market is obtained. The developed technique is tested to prove its validity.

### 4.2 FUZZY EP ALGORITHM

In this section, the fuzzy EP algorithm is developed for the problem formulated in the previous section. It includes the development of fuzzy models for the objective functions (4.1-4.3). These fuzzy models are incorporated into the EP algorithm forming the fuzzy EP algorithm. Let \( X= [X_1 \ X_2 \ \ldots \ X_{NG}] \) be the vector comprising of the combination of the shift in real power generations. The control variables are the randomly generated increment or decrement of the generation dispatch satisfying their practical constraints

\[ (P_{Gj}^* - P_{Gj}^{min}) = \Delta P_{Gj}^{min} \leq \Delta P_{Gj} \leq \Delta P_{Gj}^{max} = (P_{Gj}^{max} - P_{Gj}) ; ~ j= 1, 2, \ldots, N_g \]  \hspace{1cm} (4.14)
4.2.1 Fuzzy Model for Total Congestion Cost

Let the congestion cost be \( CC^i = f_{CC}(X^i) \). The function \( f_{CC}(X^i) \) is defined in Equation 4.1. A fuzzy satisfaction parameter \( \mu_{CC}^i \) is then defined associating the satisfaction level with the solution vector \( X^i \) as below

\[
\mu_{CC}^i = \frac{CC^\text{max} - CC^i}{CC^\text{max} - CC^\text{min}} = \frac{CC^\text{max} - f_{CC}(X^i)}{CC^\text{max} - CC^\text{min}} \quad (4.15)
\]

In the above equation, \( CC^\text{max} \) and \( CC^\text{min} \) refer to the maximum and minimum congestion cost that would occur when the solutions \( X_1 \) to \( X_{NC} \) are considered for implementation. The diagram for the satisfaction of parameter is shown in Figure 4.1.

![Figure 4.1 Fuzzy model of Congestion Cost](image)

4.2.2 Fuzzy Model for Transmission Congestion Index

Let the transmission congestion index be \( TC^i = f_{TC}(X^i) \). The function \( f_{TC}(X^i) \) is defined in Equation (4.2). The \( f_{TC}(X^i) \) is the transmission congestion index calculated for \( X^i \) real power re dispatch by running NR power flow. A fuzzy parameter \( \mu_{TC}^i \) is the defined considering the satisfaction level with the solution \( X^i \) as below
Here $TC_{max}$ and $TC_{min}$ refer to the maximum and minimum transmission overload that would occur when the solutions $X_1$ to $X_{NC}$ are considered for implementation. The diagram for the satisfaction of parameter is shown in Figure 4.2.

![Diagram](image)

**Figure 4. 2 Fuzzy model of Transmission Congestion index**

### 4.2.3 Fuzzy Model for Voltage Deviation Index

Let $VD_i = f_{VD}(X^i)$, be the the voltage deviation index for $X^i$ real power generation re dispatch considered. The function $f_{VD}(X^i)$ is defined in Equation 4.3. The $f_{VD}(X^i)$ is evaluated after running NR power flow for the solution vector $X^i$ considered. A fuzzy parameter $\mu_{VD}^i$ is defined, considering the satisfaction level with the solution $X^i$ as below

$$\mu_{VD}^i = \frac{VD_{max} - VD^i}{VD_{max} - VD_{min}} = \frac{VD_{max} - f_{VD}(X^i)}{VD_{max} - VD_{min}}$$

(4.17)

In Equation (4.17), $VD_{max}$ and $VD_{min}$ refer to the maximum and minimum transmission voltage deviation index that would occur when the solutions...
$X_1$ to $X_{NC}$ are considered for implementation. The diagram for the satisfaction of parameter is shown in Figure 4.3.

**Figure 4.3 Fuzzy model of Voltage Deviation index**

### 4.2.4 Development of Fuzzy Evaluation Method

With these three fuzzy models for congestion cost, transmission congestion index and voltage deviation index defined in the previous sub-sections, the overall evaluation of a solution vector $X^i$ is done by selecting the fuzzy intersection operators, since the fuzzy intersection operator has been proved to be better than the other operators. Thus the resultant satisfaction parameter associated with a solution $X^i$ is determined as

$$
\mu^i_X = \mu^i_{CC} \ast \mu^i_{TC} \ast \mu^i_{VD}
$$

(4.18)

In order to determine the best solution vector amongst the NC solution vectors $X_1$ to $X_{NC}$, the associated satisfaction parameter values $\mu^1_X$ to $\mu^{NC}_X$ have to be evaluated. Then the solution vector $X^*$ having the highest satisfaction parameter value is chosen as the best solution vector.
4.3 FEP ALGORITHM FOR CONGESTION ALLEVIATION

The steps involved in the fuzzy EP technique for transmission congestion alleviation are given below:

1. Randomly generate NC combination of solution vectors $X_1, X_2, X_3, \ldots, X_{NC}$ (changes in generation for all buses except slack bus)

2. Set iteration count $k=1$

3. Evaluate fuzzy objective function $\mu_{X_i}$ using Equation (4.18) for each of $X_i, \quad i = 1, 2, \ldots, NC$

4. Generate NC more solution vectors $X_{NC+1}, X_{NC+2}, \ldots, X_{2NC}$ through Gaussian mutation

$$X_{NC+i} = \beta \cdot \frac{2(r)-r_m}{r_m}(X_{\text{max}} - X_{\text{min}}) \frac{\mu_{X_{\text{max}}}}{\mu'_{X_{\text{max}}}} + X^i$$

(4.19)

where $r$ is a random number between 0 to $r_m$; $r_m = 2$ to 3; $\beta$ is the adaptive scaling factor; $X_{\text{max}}$ and $X_{\text{min}}$ are the maximum and minimum values of $X$

5. Evaluate the newly generated solution vectors $X_{NC+1}, X_{NC+2}, \ldots, X_{2NC}$.

Choose the best NC solution vectors having the higher satisfaction value of $\mu_{X_i}$ among 2NC solution vectors $X_1, X_2, X_3, \ldots, X_{2NC}$ and designate the chosen set as $X_1, X_2, X_3, \ldots, X_{NC}$

6. Increment iteration count $k=k+1$

7. Check the iteration count ($k$) $< \text{maximum iteration} (k_{\text{max}})$: If yes go to step 4. Else go to next step.

8. Among the NC available solutions ($X_1, X_2, X_3, \ldots, X_{NC}$), choose the best having the highest value of $\mu_{X_i}$. 
4.4 RESULTS AND DISCUSSION

The proposed technique is tested on modified IEEE 14 bus and IEEE 30 bus systems for various cases of congestion. All system data are extracted from [86]. The parameters adopted for fuzzy EP are as follows:

Gaussian distribution function is used for mutation operation and adaptive scaling factor $\beta$ is used. The number of generation is chosen as 100. The particle size is taken as 50. The proposed problem is implemented using MATLAB 7.0.

The congestion management study is conducted for the six different cases considered in previous chapters based on the procedure given in Section 4.3 and the results are presented in the following sections.

Table 4.1 shows the new incremented or decremented power of each generator (MW) and total cost ($/hr) for different cases of IEEE 14 bus system.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Changes in generation (MW)</th>
<th>Congestion Cost($/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta P_{G1}$</td>
<td>$\Delta P_{G2}$</td>
</tr>
<tr>
<td>Case 1A</td>
<td>-71.34</td>
<td>11.913</td>
</tr>
<tr>
<td>Case 1B</td>
<td>-73.18</td>
<td>72.843</td>
</tr>
<tr>
<td>Case 1C</td>
<td>-47.06</td>
<td>18.372</td>
</tr>
</tbody>
</table>

Figure 4.4 shows the values of fitness function for different iterations corresponding to case 1A. It shows that after some iteration the fitness function value becomes almost constant from which it is evident that solution is attained. Similarly, for cases 1B and 1C also the fitness function value becomes constant after some iteration. Results obtained for case 2A are shown in Figure 4.5.
Table 4.2 shows the new incremented or decremented power of each generator (MW) and total cost ($/hr) for different cases of IEEE 30 bus system.
Table 4.2 Generation rescheduled powers and congestion cost for IEEE 30 bus system

<table>
<thead>
<tr>
<th>Cases</th>
<th>∆P_{G1}</th>
<th>∆P_{G2}</th>
<th>∆P_{G5}</th>
<th>∆P_{G8}</th>
<th>∆P_{G11}</th>
<th>∆P_{G13}</th>
<th>Congestion Cost($/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 2A</td>
<td>-19.46</td>
<td>82.44</td>
<td>2.163</td>
<td>9.677</td>
<td>20.92</td>
<td>17.62</td>
<td>4210</td>
</tr>
<tr>
<td>Case 2B</td>
<td>-8.11</td>
<td>0</td>
<td>14.38</td>
<td>2.431</td>
<td>28.26</td>
<td>20.60</td>
<td>2914</td>
</tr>
<tr>
<td>Case 2C</td>
<td>-15.38</td>
<td>77.05</td>
<td>0.152</td>
<td>45.7</td>
<td>31.25</td>
<td>2.93</td>
<td>5330</td>
</tr>
</tbody>
</table>

4.5 CONCLUSION

In this chapter an efficient method is proposed for solving the multi-objective congestion management problem in pool based electricity market using Fuzzy EP Technique. The challenging task of tuning the weighting factors of a multi-objective optimization is eliminated by developing fuzzy EP model. The proposed FEP approach has strong ability in searching global optimal solutions when compared to other multi-objective evolutionary algorithms. The feasibility and robustness of the proposed method is demonstrated on IEEE 14 bus and IEEE 30 bus systems for severe line outages. The proposed approach simultaneously minimizes the congestion cost, transmission congestion and bus voltages violation by means of generation rescheduling alone without any load shedding for all the simulation cases considered in this study. The transmission congestion index and voltage deviation index are zero for all the cases considered meaning that the transmission overload is completely alleviated and all the load bus voltages are within the limits.

The method proposed in this chapter gives one compromised solution satisfying all the objectives considered. This does not provide any other choice to the operator. To overcome this drawback, in the next chapter a multi-objective congestion management method which can yield a set of pareto-optimal solutions are discussed.