CHAPTER 7

GENCO AND TRANSCO RESERVE BASED CONTROL STRATEGY FOR TWO AREA DEREGULATED POWER SYSTEM

7.1 INTRODUCTION

The widely used tie line bias control strategy, allows only GENCOs in same area of violation to participate in LFC during contract violation. However, there can be GENCOs that generate power more economically than the same area GENCOs. The existing tie line bias strategy fails to make use of the reserve of these GENCOs in neighbouring areas. Thus, a new control strategy named ‘GENCO reserve based control strategy’ has been proposed to achieve this requirement. With this strategy, the neighbouring area GENCOs participate for the un-contracted power. This results in variation of TRANSCO power from the scheduled value. There can be increase or decrease in TRANSCO power. Increase in TRANSCO power indicates the use of TRANSCO reserve. The power through the TRANSCO now depends on the participation of GENCOs, represented by \( epf \), in neighbouring areas. Larger is the contract violation, more is the variation in TRANSCO power. However, it is inevitable to allow any contract violations in the system. Large disturbances can cause the TRANSCO power to exceed its maximum limit. This results in TRANSCO line congestion. The proposed GENCO reserve based control strategy does not take care of TRANSCO line congestion, while, it allows any amount of power to flow through the TRANSCO if GENCOs in neighbouring areas have enough reserves. Hence, this control strategy is further modified to consider transmission line reserve in addition to GENCO reserves. This chapter develops a new control strategy that allows TRANSCO to use its reserve up to the maximum limit during compensation made by the neighbouring area GENCOs to meet the violated demand.

This chapter explains in detail the operation of proposed GENCO and TRANSCO reserve based control strategy in two area deregulated power system. For each mathematical model developed under single buyer, bilateral and poolco market, in chapter 3, the proposed strategy is then incorporated. These models are then analysed under contract violation to prove for its effective and efficient performance. A better comparison is made with tie line bias control, GENCO reserve based strategy and GENCO and TRANSCO reserve based control strategy.
using bar charts for contract violations in area 1 and area 2 under different market models. Based on the comparisons made, conclusions are finally derived.

7.2 PROPOSED GENCO AND TRANSCO RESERVE BASED CONTROL STRATEGY

As explained in Chapter 6, the operation of control strategy is purely based on the input to the secondary controller. Under tie line bias control strategy, the input to the secondary controller is made as $\beta \Delta f$ and $\Delta P_{\text{TRANSCO12}}$. The secondary controller of LFC makes these inputs to zero. This strategy allows only same area GENCOs to compensate for the violated demand. However, there can be GENCOs in neighbouring areas that compensate more economically compared to same are GENCOs. Thus, tie line bias control strategy has been replaced by GENCO reserve based control strategy by giving only $\beta \Delta f$ as input to the secondary controller of LFC. This strategy, tries to make the system frequency variations within limit by letting all willing GENCOs to compensate for the violated demand. However, this strategy gives no consideration to the TRANSCO reserve. The strategy allows all neighbouring area GENCOs to compensate for any contract violations. Compensation of these GENCOs for larger contract violations may cause power flow through TRANSCO beyond the maximum limit. This control strategy fails to limit the TRANSCO power to the maximum limit if the exceeds the maximum level.

Thus, GENCO reserve based control strategy is again modified to manage the TRANSCO reserve in addition to GENCO reserves. The new proposed strategy replacing GENCO reserve based control strategy, use TRANSCO corridor, and at the same time, limits its power within maximum during violation. The block diagram representation showing $ACE$ input selection in proposed strategy is furnished in Figure 7.1.

![Figure 7.1: ACE input selection strategy](image)

During compensation of violated power by the neighbouring area GENCOs, resulting in TRANSCO power within limit, the strategy operates like GENCO reserve based control
strategy. This makes the governor to operate based on $\Delta f$, that is given as the input to the secondary controller of LFC. This means that the frequency change alone is made to settle at zero but not TRANSCO power variation. Thus, $ACE$ of compensating GENCOs is $\beta \Delta f$. This is represented in Figure 7.1 with switch open. The compensation made by participating GENCOs is based on $epf$ value as per equation (6.2). The power generation of willing GENCOs becomes as given in equation (7.1).

For any GENCO ‘k’ in any area, $\Delta P_{gk} = P_{gk,\text{contract}} + (epf_k \times \Delta P_D)$ \hspace{1cm} (7.1)

However, participation of GENCOs in neighbouring area results in increase or decrease in TRANSCO power. Increase in TRANSCO power implies that system uses available TRANSCO reserve.

Nevertheless, if the TRANSCO power exceeds maximum capacity, governor should act so as prevent the power from exceeding the limit. This means that in addition to bring frequency variation to zero, TRANSCO power must be set to maximum limit. This is possible when $ACE$ becomes $\beta \Delta f + \Delta P_{\text{TRANSCO1toler}}$. This is achieved from Figure 7.1 with switch closed. This allows use of TRANSCO corridor only up to its maximum limits, while bringing frequency change to zero. The changes in GENCO power is as per equation (7.2).

$$
\Delta P_{gk} = \left\{ \begin{array}{ll}
epf_k \times \frac{1}{\Sigma epf_i} \times (\Delta P_D - \Delta P_{\text{TRANSCO1toler}}) & \text{For GENCO ‘k’ in violated area -- i} \\
epf_k \times \frac{1}{\Sigma epf_j} \times \Delta P_{\text{TRANSCO1toler}} & \text{For GENCO ‘k’ in area -- j outside violated area}
\end{array} \right.
$$

Thus, when TRANSCO limit is reached, the switch is closed, allowing LFC to operate under tie line bias strategy, making GENCOs in same area of contract violation to act immediately so as to meet remaining unscheduled power.

The proposed strategy hence makes use of reserve of both neighbouring area willing GENCOs and TRANSCO, thus the name ‘GENCO and TRANSCO reserve based control strategy’.

The proposed GENCO and TRANSCO reserve based control strategy is required to be analysed for its performance. The complete mathematical model under each market model, developed in Chapter 3, is incorporated with this proposed strategy. The proposed strategy is analysed for its performance with contract violation that creates TRANSCO power above the limit. The following sections analyse the performance of proposed GENCO and TRANSCO
reserve based control strategy under single buyer, bilateral and poolco model with TRANSCO line limit as 0.5 p.u..

7.3 ANALYSIS OF GENCO AND TRANSCO RESERVE BASED CONTROL STRATEGY UNDER SINGLE BUYER MODEL

This section deals with the analysis of the proposed GENCO and TRANSCO reserve based control strategy under single buyer model for its performance. The complete mathematical model of single buyer market, developed in Chapter 3, is incorporated with the proposed GENCO and TRANSCO reserve based control strategy. The effective performance of proposed GENCO and TRANSCO reserve based control strategy is tested for contract violation in area 1 and area 2. Finally, performance comparison of proposed strategy is done with tie line bias control and GENCO reserve based strategy under single buyer model during contract violation in the form of bar chart.

7.3.1 GENCO power incorporating GENCO and TRANSCO reserve based control strategy under single buyer model

The proposed GENCO and TRANSCO reserve based control strategy is incorporated in the mathematical model of single buyer market developed in Chapter 3. From Appendix IV it is clear that the willing GENCOs ready to participate during contract violation are GENCO 1 (G_{11}), GENCO 2, (G_{21}) and GENCO (G_{22}). These GENCOs have offer price of Rs.1750/MW, Rs.1500/MW and Rs.1800/MW respectively. epf values are computed using equation (6.2) with values given in Appendix IV. However, under single buyer model, each pool is considered as separate maintaining TRANSCO power always zero. In case of any violations, GENCOs in same area of contract violation take care of meeting the unscheduled power. Thus, for a contract violation in area 1, only GENCO 1 (G_{11}) and GENCO 2 (G_{21}) participate in meeting the violated power.

Hence, during contract violation in area 1, G_{11} and G_{21} meet the un-contracted demand by the epf ratio of 0.462:0.538 as per equation (6.2), with the sum unity. Similarly, during contract violation in area 2, G_{22} alone contribute to meet the unscheduled demand. Thus, epf of G_{22} is unity.

The GENCOs and TRANSCO powers under single buyer model incorporating GENCO and TRANSCO reserve based control strategy using these epf for violation in area 1 and area 2 is tabulated in Table 7.1.
Table 7.1: GENCOs and TRANSCO powers during violation incorporating GENCO and TRANSCO reserve based strategy under single buyer model

<table>
<thead>
<tr>
<th>Contracted power</th>
<th>Violation of 0.01 p.u. in area 1</th>
<th>Violation of 0.01 p.u. in area 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG(_{11})</td>
<td>0.375</td>
<td>0.376</td>
</tr>
<tr>
<td>PG(_{21})</td>
<td>0.625</td>
<td>0.630</td>
</tr>
<tr>
<td>PG(_{12})</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>PG(_{22})</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>P(_{\text{TRANSCO12}})</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

It is clear from Table 7.1 that during contract violation in area 1, output power of GENCO 1 (G\(_{11}\)) and GENCO 2 (G\(_{21}\)) is increased from 0.375 p.u. to 0.3796 (i.e., 0.375+0.462×0.01) p.u. and from 0.625 p.u. to 0.6304 (i.e., 0.625+0.538×0.01) p.u..

Similarly, for a violation in area 2, power output of GENCO 4 (G\(_{22}\)) is increased from 0.5 p.u. to 0.51 (i.e., 0.5+1×0.01) p.u.

As only same area GENCOs compensate for the un-contracted power, the TRANSCO power remains at zero. The performance of the proposed strategy is same as that with tie line bias control strategy and matches with Table 4.2 and Table 6.1.

It is now required to simulate the mathematical model of single buyer model with the proposed GENCO and TRANSCO reserve based control strategy under contract violation.

7.3.2 Simulation result incorporating GENCO and TRANSCO reserve based control strategy under single buyer model

The mathematical model of two area LFC system under single buyer model is developed in MATLAB/Simulink. A contract violation of 0.01 p.u. is created at 350s in area 1 and the GENCOs and TRANSCO power responses are obtained as in Figure 7.2.

From Figure 7.2, it is clear that the power of GENCO 1 (G\(_{11}\)) and GENCO 2 (G\(_{21}\)) is increased from 0.375 p.u. to 0.3796 p.u. and 0.625 p.u. to 0.6304 p.u. respectively. Since the violated power is met by same area GENCOs, TRANSCO power remains same. The obtained values match with the tabulated values shown in Table 7.1.

Later, a contract violation of 0.01 p.u. is created in area 2 at 350s and corresponding power responses of GENCOs and TRANSCO is shown in Figure 7.3.
Figure 7.2: GENCOs and TRANSCO power responses during violation of 0.01 p.u. at 350s in area 1 incorporating GENCO and TRANSCO reserve based strategy under single buyer model.

Figure 7.3: GENCOs and TRANSCO power responses during violation of 0.01 p.u. at 350s in area 2 incorporating GENCO and TRANSCO reserve based strategy under single buyer model.

Figure 7.3 clearly shows that GENCO 4 (G22) power is increased from 0.5 p.u. to 0.51 p.u., while the power output of remaining GENCOs remain same. The violation in area 2 is met by same area GENCO and hence TRANSCO power remains unchanged. The obtained values match with the tabulated values shown in Table 7.1.
A comparison between the performance of tie line bias, GENCO reserve and GENCO and TRANSCO reserve based control strategies under single buyer model can be made with the help of bar chart.

### 7.3.3 Performance comparison of GENCO and TRANSCO reserve based strategy with tie line bias control and GENCO reserve based strategy for a violation of 0.01 p.u. in area 1 under single buyer model

This section presents the performance comparison between tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategy for a violation in area 1 under single buyer model with the help of bar chart. The values for GENCOs and TRANSCO powers under single buyer model for violation of 0.01 p.u. in area 1 obtained from Table 4.2, Table 6.1 and Table 7.1 incorporating tie line bias control, GENCO reserve based strategy and GENCO and TRANSCO reserve based strategy, is consolidated and summarized in the form of bar chart as shown in Figure 7.4.

Figure 7.4: Performance comparison of tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for violation of 0.01 p.u. in area 1 under single buyer model

Figure 7.4 gives the GENCOs and TRANSCO power changes during violation in area 1 under single buyer model incorporating tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies respectively. In single buyer model, the demand in each area is met by the same area GENCOs; hence, contracted TRANSCO power is zero. This is clear from Figure 7.4.
With tie line bias control strategy, same area willing GENCOs, GENCO 1 (G1) and GENCO 2 (G2), meets the un-contracted power. Thus power output of these GENCOs (G1(1) and G2(1)) increase as given in Figure 7.4. Since, GENCO 1 (G1) and GENCO 2 (G2) belong to same area of violation, TRANSCO (T(1)) power deviation is zero as shown in Figure 7.4.

The GENCO reserve based control strategy put together with the system model, allows all economic GENCOs to take part in meeting unscheduled demand. GENCO 1 (G1), GENCO 2 (G2) and GENCO 4 (G4) are found to be the willing GENCOs that participate for unscheduled demand. However, in single buyer model, each pool is considered separately and thus, for any violation, GENCOs in same area contribute to meet the unscheduled demand. Thus, even with GENCO reserve based strategy, during contract violation in area 1, only GENCO 1 (G1) and GENCO 2 (G2) compensate for the unscheduled power. Thus power output of these GENCOs (G1(2) and G2(2)) increase. This is clear from Figure 7.4.

The rescheduling of GENCOs is same while incorporating GENCO and TRANSCO reserve based control strategy. This is clear from the increase in power output of GENCO 1 (G1(3)) and GENCO 2 (G3(3)) shown in Figure 7.4.

Figure 7.4 shows that under a single buyer model, only same area GENCOs can contribute to meet the unscheduled power so as to maintain the two pools individually. The GENCOs and TRANSCO power for a violation of 0.01 p.u. is same irrespective of the adopted control strategy.

Again, the performance of GENCO and TRANSCO reserve based control strategy is compared with tie line bias and GENCO reserve based control strategies for a contract violation of 0.01 p.u. in area 2.

7.3.4 Performance comparison of GENCO and TRANSCO reserve based strategy with tie line bias control and GENCO reserve based strategy for a violation of 0.01 p.u. in area 2 under single buyer model

In this section, the performance comparison between tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for a violation in area 2 under single buyer model is presented. The values for GENCOs and TRANSCO powers under single buyer model for violation of 0.01 p.u. in area 2 incorporating tie line bias, GENCO reserve and GENCO and TRANSCO reserve based control strategy, obtained from Table 4.2,
Table 6.1 and Table 7.1. These values are consolidated and summarized in the form of bar chart as shown in Figure 7.5.

Figure 7.5: Performance comparison of tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for violation of 0.01 p.u. in area 2 under single buyer model

Figure 7.5 shows the power increase in GENCOs and TRANSCO using tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies. Since, the two areas are considered separate pool, the contracted TRANSCO power is zero. This is clear from Figure 7.5. Thus for a contract violation in area 2, only same area willing GENCOs are allowed to compensate for the unscheduled power. Thus, there is an increase in power generation of GENCO 4 (G4) as seen from Figure 7.5.

It can be concluded that under single buyer model, tie line, GENCO reserve based and GENCO and TRANSCO reserve based control strategies perform in similar manner for any contract violation in any area.

7.4 ANALYSIS OF GENCO AND TRANSCO RESERVE BASED CONTROL STRATEGY UNDER BILATERAL MODEL

In this section, the analysis of the proposed GENCO and TRANSCO reserve based control strategy under bilateral model. The complete mathematical model under bilateral market, developed in Chapter 3, is incorporated with the proposed GENCO and TRANSCO reserve based control strategy. The proposed strategy is tested with two different contract violations for its performance. One of the violation that result in TRANSCO power flow within
maximum limit, while the other with power flow above the limit. Finally, performance of proposed strategy is compared with tie line bias control and GENCO reserve based strategy under bilateral model for these violations in the form of bar chart.

7.4.1 GENCO power incorporating GENCO and TRANSCO reserve based control strategy under bilateral model

The mathematical model of single buyer market developed in Chapter 3 is incorporated with the proposed GENCO and TRANSCO reserve based control. Under contracted condition, the TRANSCO power is 0.46 p.u. flowing from area 1 to area 2. With the limit as 0.5 p.u., the TRANSCO can let 0.04 p.u. of extra power to flow through the TRANSCO. When a contract violation occurs such that TRANSCO power is within limit, the proposed GENCO and TRANSCO reserve based control strategy allows all GENCOs to participate for LFC based on the $epf$ value. Thus, under this situation, the proposed strategy works similar to GENCO reserve based control strategy. If the violation results in TRANSCO power beyond the limit, the control strategy operate in such a way that it let 0.04 p.u. of power though the TRANSCO and the remaining power is generated from the GENCOs in the same area of violation. Hence, to test and compare the proposed GENCO and TRANSCO reserve based control strategy with tie line bias and GENCO reserve based control strategy, the model with $epf$ values is subjected to violations in area 1 and area 2 respectively.

The willing GENCOs that participate in LFC during contract violation under bilateral model are GENCO 1 ($G_{11}$), GENCO 2 ($G_{21}$), GENCO 3 ($G_{12}$) and GENCO 4 ($G_{22}$). These GENCOs participate with $epf$ of 0.3, 0.2, 0.1 and 0.4 respectively.

For any contract violation in area 1, the tie line bias control strategy allows only GENCO 1 ($G_{11}$) and GENCO 2 ($G_{21}$) to participate during the violation in the ratio 0.6:0.4. This is clear from Table 4.4. As explained in Chapter 6 using Table 6.2, the GENCO reserve based control strategy allows all GENCOs to participate based on the ratio 0.3:0.2:0.1:0.4. The participation of GENCO 3 ($G_{12}$) and GENCO 4 ($G_{22}$) results in power flow from area 2 to area 1 in addition to 0.46 p.u. of power from area 1 to area 2. Hence, TRANSCO power gets decreased. Since, the TRANSCO power is within the limit of TRANSCO, the proposed GENCO and TRANSCO reserve based control strategy operates similar to GENCO reserve based strategy. The GENCOs and TRANSCO powers under bilateral model incorporating GENCO and TRANSCO reserve based control strategy using the $epf$ for violation of 0.01 p.u. in area 1 is shown in Table 7.2.
Table 7.2: GENCOs and TRANSCO powers during violation of 0.01 p.u. in area 1 incorporating GENCO and TRANSCO reserve based strategy under bilateral model

<table>
<thead>
<tr>
<th>GENCO</th>
<th>Contracted power</th>
<th>Violation in area 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG11</td>
<td>0.42</td>
<td>0.423</td>
</tr>
<tr>
<td>PG21</td>
<td>0.34</td>
<td>0.342</td>
</tr>
<tr>
<td>PG12</td>
<td>0.26</td>
<td>0.261</td>
</tr>
<tr>
<td>PG22</td>
<td>0.18</td>
<td>0.184</td>
</tr>
<tr>
<td>PTRANSCO12</td>
<td>0.46</td>
<td>0.455</td>
</tr>
</tbody>
</table>

Table 7.2 shows that for a contract violation in area 1, the proposed strategy rescheduled all GENCOs. Thus, the power output of all GENCOs are increased from 0.42 p.u., 0.34 p.u., 0.26 p.u. and 0.18 p.u. to 0.423 (i.e., 0.42+0.3×0.01) p.u., 0.342 (i.e., 0.34+0.2×0.01) p.u., 0.261 (i.e., 0.26+0.1×0.01) p.u. and 0.184 (i.e., 0.18+0.4×0.01) p.u. respectively. The participation of GENCO 3 (G12) and GENCO 4 (G22) results in TRANSCO power to decrease from 0.46 p.u. to 0.455 (i.e., 0.46 – 0.5×0.01) p.u.. The performance of the proposed GENCO and TRANSCO reserve based control strategy is similar to that incorporating GENCO reserve based control strategy. This is evident by comparing Table 7.2 with Table 6.2.

Meanwhile, a contract violation in area 2 increases the TRANSCO power from the scheduled value. To test the performance of LFC with the newly proposed GENCO and TRANSCO reserve based strategy, the mathematical model is subjected to a contract violation that results in TRANSCO power above the limit.

For the mathematical model of power system under bilateral market, a contract violation of 0.09 p.u. created in area 2. If the model is incorporated with the tie line bias control strategy, only GENCO 3 (G12) and GENCO 4 (G22) meet the unscheduled power. The compensation is done based on the *epf* ratio of 0.2:0.8. With GENCO reserve based control strategy, all GENCOs in both areas area made to do compensation in the ratio 0.3:0.2:0.1:0.4. This makes TRANSCO power to increase from the scheduled value, but not beyond the limit. However, the proposed strategy allows only 0.04 (i.e., 0.5 – 0.46) p.u. of extra power to flow through the TRANSCO from area 1. This power is met by GENCO 1 (G11) and GENCO 2 (G21) in the ratio 0.6:0.4. While the remaining violated demand is met by the same area GENCOs in the ratio 0.2:0.8. The GENCOs and TRANSCO powers under bilateral model incorporating tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based
control strategy using the \textit{epf} for violation in area 2 is tabulated as per equation (3.27) and is shown in Table 7.3.

Table 7.3: GENCOs and TRANSCO powers during violation of 0.09 p.u. in area 2 under bilateral model

<table>
<thead>
<tr>
<th></th>
<th>Contracted power</th>
<th>Tie line bias control strategy</th>
<th>GENCO reserve based control strategy</th>
<th>GENCO and TRANSCO reserve based control strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG_{11}</td>
<td>0.42</td>
<td>0.42</td>
<td>0.447</td>
<td>0.444</td>
</tr>
<tr>
<td>PG_{21}</td>
<td>0.34</td>
<td>0.34</td>
<td>0.358</td>
<td>0.356</td>
</tr>
<tr>
<td>PG_{12}</td>
<td>0.26</td>
<td>0.278</td>
<td>0.269</td>
<td>0.27</td>
</tr>
<tr>
<td>PG_{22}</td>
<td>0.18</td>
<td>0.252</td>
<td>0.216</td>
<td>0.22</td>
</tr>
<tr>
<td>P_{TRANSCO12}</td>
<td>0.46</td>
<td>0.46</td>
<td>0.505</td>
<td>0.5</td>
</tr>
</tbody>
</table>

From Table 7.3, it is clear that the tie line bias control strategy allows only GENCO 3 (G_{12}) and GENCO 4 (G_{22}) to meet the violated demand and hence the TRANSCO power is same. This is clear from Column 3. Column 4 shows that the GENCO reserve based control strategy allows all GENCO to meet the unscheduled power and hence, the power of GENCO 1 (G_{11}), GENCO 2 (G_{21}), GENCO 3 (G_{12}) and GENCO 4 (G_{22}) is increased from 0.42 p.u., 0.34 p.u., 0.26 p.u. and 0.18 p.u. to $0.447$ (i.e., $0.42 + 0.3 \times 0.09$) p.u., $0.358$ (i.e., $0.34 + 0.2 \times 0.09$) p.u., $0.269$ (i.e., $0.26 + 0.1 \times 0.09$) p.u. and $0.216$ (i.e., $0.18 + 0.4 \times 0.09$) p.u. respectively. The participation of neighbouring area GENCOs results in TRANSCO power increase from 0.46 p.u. to $0.505$ (i.e., $0.46 + 0.5 \times 0.09$) p.u. which is beyond the TRANSCO limit. Thus, the GENCO and TRANSCO reserve based control strategy allows GENCO 1 (G_{11}) and GENCO 2 (G_{21}) to generate such that only the available TRANSCO corridor of 0.04 p.u. is made use of. This means that GENCO 1 and GENCO 2 increases its power output so as to meet the demand of 0.04 p.u. Thus the power output of GENCO 1 and GENCO 2 is increased from 0.42 p.u. and 0.34 p.u. to $0.444$ (i.e., $0.42 + 0.6 \times 0.04$) p.u. and $0.356$ (i.e., $0.34 + 0.4 \times 0.04$) p.u. The remaining power of 0.05 (i.e., $0.09 - 0.04$) p.u. is met by GENCO 3 (G_{12}) and GENCO 4 (G_{22}) in the ratio 0.2:0.8. The power output of GENCO 3 and GENCO 4 increases from 0.26 p.u. and 0.18 p.u. to $0.27$ (i.e., $0.26 + 0.2 \times 0.05$) p.u. and $0.22$ (i.e., $0.18 + 0.8 \times 0.05$) p.u. respectively.

Now the above cases of contract violation in area 1 and area 2 is to be created in the mathematical model of the system shown in Figure 3.6 under bilateral model so as to analyse the performance of the proposed strategy.
7.4.2 Simulation result incorporating GENCO and TRANSCO reserve based control strategy under bilateral model

The mathematical model of two area LFC system under bilateral model explained in Chapter 3 is developed in MATLAB/Simulink. The model is subjected to contract violations as explained in Section 7.4.1 incorporating the GENCO and TRANSCO reserve based control strategy. Later the performance of proposed is compared with that obtained with tie line bias and GENCO reserve based control strategy.

7.4.2.1 Contract violation of 0.01 p.u. in area 1 incorporating GENCO and TRANSCO reserve based control strategy under bilateral model

The mathematical model of two area LFC system under bilateral model explained in Chapter 3 is submitted to a contract violation of 0.01 p.u. at 350s in area 1, as explained in Section 7.4.1. Incorporating GENCO and TRANSCO reserve based control strategy, the GENCOs and TRANSCO power responses for this condition are obtained and are shown in Figure 7.6.

Figure 7.6 clearly shows that the GENCO and TRANSCO reserve based strategy increases the power generation of willing GENCOs (GENCO 1, GENCO 2, GENCO 3 and GENCO 4 from 0.42 p.u., 0.34 p.u., 0.26 p.u. and 0.18 p.u. to 0.423 p.u., 0.342 p.u., 0.261 p.u. and 0.184 p.u. respectively. Meanwhile, TRANSCO power is decreased from 0.46 p.u. to 0.455 p.u.. These values match with the expected values given in Table 7.2.
To analyse the performance of the proposed GENCO and TRANSCO reserve control strategy under TRANSCO line congestion, the system shown in Figure 3.6 under bilateral model is subjected to contract violation of 0.09 p.u. The performance is then compared with that incorporating tie line bias and GENCO reserve based control strategies. This is explained in the following three sections.

7.4.2.2 Contract violation of 0.09 p.u. in area 2 incorporating tie line bias control strategy under bilateral model

The two area system shown in Figure 3.6, operating under bilateral model is incorporated with tie line bias control strategy and is subjected to a contract violation of 0.09 p.u. at 350s in area 2. The GENCOs and TRANSCO power responses are generated and are shown in Figure 7.7.

![GENCOs and TRANSCO power responses during violation of 0.09 p.u. at 350s in area 2 incorporating tie line bias control strategy under bilateral model](image)

Figure 7.7: GENCOs and TRANSCO power responses during violation of 0.09 p.u. at 350s in area 2 incorporating tie line bias control strategy under bilateral model

From Figure 7.7, it is evident that power output of GENCOs in the area of violation, GENCO 3 and GENCO 4 increases from 0.26 p.u. and 0.18 p.u. to 0.278 p.u. and 0.252 p.u. respectively as per the explanation given using Table 7.3. The TRANSCO power remains unvaried in this case.

7.4.2.3 Contract violation of 0.09 p.u. in area 2 incorporating GENCO reserve based control strategy under bilateral model

GENCO reserve based control strategy, explained in chapter 6 is now incorporated in the mathematical model of two area system shown in Figure 3.7. With the system operating at
bilateral model as explained in Chapter 3, the GENCOs and TRANSCO power responses are simulated for a contract violation of 0.09 p.u. at 350s in area 2 and are shown in Figure 7.8.

![Figure 7.8: GENCOs and TRANSCO power responses during violation of 0.09 p.u. at 350s in area 2 incorporating GENCO reserve based control strategy under bilateral model](image)

It is seen from Figure 7.8, that the power generation of GENCO 1, GENCO 2, GENCO 3 and GENCO 4 increases from 0.42 p.u., 0.34 p.u., 0.26 p.u. and 0.18 p.u. to 0.447 p.u., 0.358 p.u., 0.269 p.u. and 0.216 p.u. respectively. The TRANSCO power in this condition is also increased from 0.46 p.u. to 0.505 p.u.. The simulated values match with the expected values tabulated in Table 7.3.

### 7.4.2.4 Contract violation of 0.09 p.u. in area 2 incorporating GENCO and TRANSCO reserve based control strategy under bilateral model

Now, the same system is incorporated with the proposed GENCO and TRANSCO reserve based control strategy. The model is subjected to a contract violation of 0.09 p.u. at 350s in area 2 and the GENCOs and TRANSCO power responses are obtained and are shown in Figure 7.9.

![Figure 7.9: GENCOs and TRANSCO power responses during violation of 0.09 p.u. at 350s in area 2 incorporating GENCO and TRANSCO reserve based control strategy under bilateral model](image)

Figure 7.9 clearly shows that the proposed GENCO and TRANSCO reserve based control strategy limits the TRANSCO power to the maximum limit of 0.5 p.u.. Hence, the proposed strategy imposes limit to increase of power generation of GENCO 1 and GENCO 2 such that only 0.5 p.u. power flows through TRANSCO.
Thus, GENCO 1 and GENCO 2 power generation is less than that with GENCO reserve based control strategy. These GENCOs increases its power generation from 0.42 p.u. to 0.444 p.u. and 0.34 p.u. to 0.356 p.u. respectively. The remaining power is met by GENCO 3 and GENCO 4. Hence, its power generation is increased from 0.26 p.u. and 0.18 p.u. to 0.27 p.u. and 0.22 p.u. respectively, which is greater than that incorporating GENCO reserve based control strategy. These values are as per the expected values given in Table 7.3.

### 7.4.3 Performance comparison of GENCO and TRANSCO reserve based strategy with tie line bias control and GENCO reserve based strategy for a violation of 0.01 p.u. in area 1 under bilateral model

This section presents the performance comparison between tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for a violation in area 1 under bilateral model. The values for GENCOs and TRANSCO powers under bilateral model for violation of 0.01 p.u. in area 1 incorporating tie line bias, GENCO reserve and GENCO and TRANSCO reserve based control strategies are obtained from Table 4.4, Table 6.2 and Table 7.2. The obtained values are presented in the form of bar chart and are shown in Figure 7.10.
Figure 7.10: Performance comparison of tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for violation of 0.01 p.u. in area 1 under bilateral model

The GENCOs and TRANSCO contracted power and deviations with tie line bias, GENCO reserve and GENCO and TRANSCO reserve based control strategies are shown in Figure 7.10. For a contract violation in area 1, tie line bias control strategy allows only same area GENCOs to meet the unscheduled power demand. This causes GENCO 1 (G1(1)) and GENCO 2 (G2(1)) power to increase as shown in Figure 7.10. Since, same area GENCOs to contribute for the un-contracted power, TRANSCO power (T(1)) remains same.

The GENCO reserve based control strategy not only allows same area GENCOs to participate in LFC during contract violation, but also let willing GENCOs in the neighbouring area to contribute to meet the violated demand. From Chapter 6 it is found that GENCO 1 (G1), GENCO 2 (G2), GENCO 3 (G3) and GENCO 4 (G4) meet the unscheduled power in area 1. Thus there is an increase in GENCOs power (G1(2), G2(2), G3(2) and G4(2)) from the scheduled value. Contribution of GENCOs in area 2 to meet the un-contracted power demand of DISCO in area 1, results in decrease of TRANSCO power (T(2)) from the scheduled value as shown in Figure 7.10.

GENCO and TRANSCO reserve based control strategy allows all willing GENCOs to meet for the unscheduled power demand till the TRANSCO limit. The contribution of willing GENCO 3 (G3) and GENCO 4 (G4) to meet the violated demand of DISCO in area 1 decrease TRANSCO power and hence, this strategy does not impose any limit to the power
generation of GENCO. This strategy behaves similar to GENCO reserve based strategy. This is seen in Figure 7.10.

From Figure 7.10, it can be concluded that for a violation in area 1 DISCO, unlike tie line bias control, GENCO reserve based and GENCO and TRANSCO reserve based control strategy allows all willing GENCOs to compensate for the violated demand of DISCO in area 1. Since, the TRANSCO power is within maximum limit, the performance of GENCO and TRANSCO reserve based control strategy is similar to that of GENCO reserve based control strategy.

### 7.4.4 Performance comparison of GENCO and TRANSCO reserve based strategy with tie line bias control and GENCO reserve based strategy for a violation of 0.09 p.u. in area 2 under bilateral model

This section provides the performance comparison between tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategy for a violation of 0.09 p.u. in area 2 under bilateral model. Using the values from Table 7.3, the bar chart is plotted and is shown in Figure 7.11.

![Figure 7.11: Performance comparison of tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for violation of 0.09 p.u. in area 2 under bilateral model](attachment:image.png)

Figure 7.11 shows contracted power and deviation in GENCOs and TRANSCO with tie line bias control, GENCO reserve based and GENCO and TRANSCO reserve based strategy. Incorporating tie line bias control strategy enable same area GENCOs to meet the unscheduled power demand so that TRANSCO power (T(1)) is maintained unchanged as
given in Figure 7.11. Thus power generation of GENCO 3 (G3(1)) and GENCO 4 (G4(1)) is increased from scheduled value. This is clear from Figure 7.11.

However, GENCO reserve based control strategy allows all willing GENCOs to meet the unscheduled demand in area 2. The contribution of GENCO 1 (G1(2)) and GENCO 2 (G2(2)) to meet the violated demand in DISCO in area 2, results in increase in TRANSCO power (T(2)) from scheduled value. This is evident from Figure 7.11. However, contract violation of 0.09 p.u. in area 2 results in TRANSCO power above 0.5 p.u., the limit of TRANSCO. Figure 7.11 shows that the GENCO reserve based control strategy fails to limit the TRANSCO power to the maximum value.

Meanwhile, GENCO and TRANSCO based control strategy provide limit on the TRANSCO power (T(3)) to its maximum value as depicted in Figure 7.11. This is achieved by letting the other area willing GENCOs to meet the violated demand equal to the available transfer capability, while, empowers the same area willing GENCOs to meet for the remaining violated power.

Hence, from Figure 7.11 it is evident that increase in power generation of GENCO 1 (G1(3)) and GENCO 2 (G2(3)) incorporating the proposed GENCO and TRANSCO reserve based control strategy is less than with GENCO reserve based control strategy(G1(2) and G2(2)). Meanwhile, the increase in power output of GENCO 3 (G3(3)) and GENCO 4 (G4(3)) incorporating GENCO and TRANSCO reserve based strategy is more compared to that with GENCO reserve based control strategy (G3(2) and G4(2)).

7.5 ANALYSIS OF GENCO AND TRANSCO RESERVE BASED CONTROL STRATEGY UNDER POOLCO MODEL

In this section, the analysis of the proposed GENCO and TRANSCO reserve based control strategy under bilateral model. The complete mathematical model of bilateral market, developed in Chapter 3, is incorporated with the proposed GENCO and TRANSCO reserve based control strategy. The proposed strategy is tested with two different contract violations for its performance. One of the violation that result in TRANSCO power flow within maximum limit, while the other with power flow above the limit. Finally, performance of proposed strategy is compared with tie line bias control and GENCO reserve based strategy under bilateral model for these violations in the form of bar chart.
7.5.1 GENCO power incorporating GENCO and TRANSCO reserve based control strategy under poolco model

The mathematical model of two area LFC system under poolco model explained in Chapter 3 is developed in MATLAB/Simulink. The model is incorporated with GENCO and TRANSCO reserve based control strategy. During any contract violation, the proposed control strategy allows all GENCOs to participate for LFC based on the \( epf \) value till maximum limit of TRANSCO. From Appendix IV, it is seen that willing GENCOs in area 1 and area 2 are \( G_{11} \), \( G_{21} \) and \( G_{22} \). These GENCOs offer price of Rs. 1750/MW, Rs. 1500/MW and Rs. 1800/MW respectively. The \( epf \) values for these GENCOs are calculated using these offer prices from equation (6.2) and is obtained as 0.329, 0.37 and 0.31 respectively. From Table 4.5, it is seen that under poolco model (with market equilibrium in both areas) 0.367 p.u. of scheduled power flows from area 1 to area 2 through TRANSCO. Assuming TRANSCO line limit of 0.5 p.u., the TRANSCO can let an extra power of 0.133 p.u.. Thus, if any contract violation results in TRANSCO power to beyond its limit, this strategy lets the willing, more economic neighbouring area GENCOs to meet 0.133 p.u. of power. This makes TRANSCO power to reach its limit of 0.5 (i.e., 0.367 + 0.133) p.u.. At the same, the strategy makes all willing same area GENCOs to meet for the remaining unscheduled power.

To analyse and compare the performance of the proposed GENCO and TRANSCO reserve based control strategy with tie line bias and GENCO reserve based control strategy, the mathematical model of two area system shown in Figure 3.6 with \( apf \) values computed from Chapter 4 and \( epf \) values computed above, is subjected to violations in area 1 and area 2 respectively.

Initially, a contract violation of 0.01 p.u. at 350s at area 1 in two area system under poolco model. As per the discussion made in Chapter 4, the tie line bias control strategy during this situation allows only GENCO 1 (\( G_{11} \)) and GENCO 2 (\( G_{21} \)) to participate during the violation in the ratio 0.462:0.538. This is shown in Table 4.6. The GENCO reserve based control strategy, as explained in Chapter 6, allows all GENCOs to participate based on the ratio 0.329:0.37:0.31. This is presented in Table 6.3. The contribution of GENCOs in area 2 to meet the violated demand in area results in power flow from area 2 to area 1 through TRANSCO, in addition to the scheduled TRANSCO power of 0.367 p.u. from area 1 to area 2. This makes the net TRANSCO power to reduce and hence, the TRANSCO power flow is less than maximum limit. Hence, as per the performance of the proposed GENCO and
TRANSCO reserve based control strategy, all GENCOs contribute for the unscheduled demand without forbidding the generation of any GENCOs as per the computed \( epf \) values.

The GENCOs and TRANSCO powers under poolco model incorporating GENCO and TRANSCO reserve based control strategy using the computed \( epf \) values are presented in Table 7.4.

Table 7.4: GENCOs and TRANSCO powers during violation of 0.01 p.u. in area 1 incorporating GENCO and TRANSCO reserve based strategy under poolco model

<table>
<thead>
<tr>
<th>GENCOs</th>
<th>Contracted power</th>
<th>Violation in area 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG11</td>
<td>0.3003</td>
<td>0.303</td>
</tr>
<tr>
<td>PG21</td>
<td>0.4998</td>
<td>0.503</td>
</tr>
<tr>
<td>PG12</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>PG22</td>
<td>0.333</td>
<td>0.3361</td>
</tr>
<tr>
<td>( P_{TRANSCO12} )</td>
<td>0.367</td>
<td>0.3639</td>
</tr>
</tbody>
</table>

Table 7.4 shows that for a contract violation in area 1, the proposed strategy reschedules willing GENCOs. Thus, the power output of all GENCO 1 (\( G_{11} \)), GENCO 2 (\( G_{21} \)) and GENCO 4 (\( G_{22} \)) are increased from 0.3003 p.u., 0.4998 p.u. and 0.333 p.u. to 0.3035 (i.e., 0.3003+0.32×0.01) p.u., 0.5035 (i.e., 0.4998+0.37×0.01) p.u. and 0.3361 (i.e., 0.333+0.31×0.01) p.u. respectively. The participation of GENCO 4 (\( G_{22} \)) results in TRANSCO power to decrease from 0.367 p.u. to 0.3639 (i.e., 0.367 – 0.31×0.01) p.u.. Comparing GENCOs and TRANSCO powers in Table 7.4 with Table 6.3, it is seen that the proposed GENCO and TRANSCO reserve based control strategy performs similar to GENCO reserve based control strategy.

Conversely, a contract violation in area 2 results TRANSCO power to increase from the scheduled value. Hence, to analyse the performance of proposed strategy, the mathematical model is subjected to contract violation that results in TRANSCO power to exceed the maximum limit. The power system under poolco model is subjected to a contract violation of 0.2 p.u. in area 2. As explained in Chapter 4, the tie line bias control allows only same area willing GENCOs to meet the unscheduled demand. Whereas, GENCO reserve based control strategy allows all more economic willing GENCOs to meet the violated demand. The participation of GENCOs in area 1 to meet the un-contracted demand in area 2 increases TRANSCO power beyond maximum limit. The GENCO reserve based control strategy allows this power even though it exceeds the limit and fails to limit the TRANSCO power thereby. However, the proposed GENCO and TRANSCO reserve based control strategy
limits the TRANSCO power by allowing the neighbouring area willing GENCOs to compensate for the violated demand equal to the available transfer capability of TRANSCO. The remaining unscheduled power is compensated by the willing GENCOs in area 2.

Incorporating the three control strategies, the GENCOs and TRANSCO powers are computed for two area system under poolco model and is given in Table 7.5.

Table 7.5: GENCOs and TRANSCO power during violation of 0.2 p.u. in area 2 under poolco model

<table>
<thead>
<tr>
<th></th>
<th>Contracted power</th>
<th>Tie line bias control strategy</th>
<th>GENCO reserve based control strategy</th>
<th>GENCO and TRANSCO reserve based control strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG11</td>
<td>0.3003</td>
<td>0.3003</td>
<td>0.3643</td>
<td>0.3617</td>
</tr>
<tr>
<td>PG21</td>
<td>0.4998</td>
<td>0.4998</td>
<td>0.5738</td>
<td>0.5714</td>
</tr>
<tr>
<td>PG12</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>PG22</td>
<td>0.333</td>
<td>0.533</td>
<td>0.395</td>
<td>0.4</td>
</tr>
<tr>
<td>PTRANSCO12</td>
<td>0.367</td>
<td>0.367</td>
<td>0.505</td>
<td>0.5</td>
</tr>
</tbody>
</table>

During violation, the tie line bias control strategy allows only same area willing GENCOs to participate in LFC. Thus GENCO 4 (G22) increases it power output from 0.333 p.u. to 0.533 p.u. (i.e., 0.333+1×0.2) p.u. The TRANSCO power is maintained same by this control strategy. Thus, Column 3 of Table 7.5 is as per the objectives of LFC explained in Chapter 4.

For the same violation, GENCO reserve based control strategy allows more economic willing GENCOs in neighbouring area to meet the violated demand. Thus, the power output of GENCO 1 (G11), GENCO 2 (G21) and GENCO 4 (G22) increases from 0.3003 p.u., 0.4998 p.u. and 0.333 p.u. to 0.3643 p.u., 0.5738 p.u. and 0.395 p.u. (i.e., 0.3003+0.32×0.2) p.u., 0.4998+0.37×0.2) p.u. and 0.333+0.31×0.2) p.u. respectively.

The contribution of GENCO 1 (G11), GENCO 2 (G21) to meet violated demand in area 2 increases TRANSCO power from 0.367 p.u. to 0.505 p.u. (i.e., 0.367+(0.32+0.37)×0.2) p.u. which exceeds the TRANSCO limit. GENCO reserve based control strategy allows this power through TRANSCO.

However, the proposed GENCO and TRANSCO reserve based control strategy restricts the TRANSCO power from 0.505 p.u. to 0.5 p.u., by allowing GENCO 1 (G11), GENCO 2 (G21) to contribute only 0.133 (i.e.,0.5 – 0.367) p.u. of power in the ratio 0.462:0.538.
Thus, the power output of GENCO 1 ($G_{11}$), GENCO 2 ($G_{21}$) is increased from 0.3003 p.u. and 0.4998 p.u. to **0.3617** (i.e., 0.3003+0.462×0.133) p.u. and **0.5714** (i.e., 0.4998+0.538×0.133) p.u. respectively. The remaining power of 0.067 (i.e., 0.2 – 0.133) p.u. is met by GENCO 4. Thus the power output increases from 0.333 p.u. to **0.4** (i.e., 0.333+1×0.067) p.u..

The above cases of contract violation in area 1 and area 2 are now created in the mathematical model of the system shown in Figure 3.7 under poolco model so as to analyse the performance of LFC incorporating the new proposed strategy.

**7.5.2 Simulation result incorporating GENCO and TRANSCO reserve based control strategy under poolco model**

The mathematical model of two area power system shown in Figure 3.6 under poolco model explained in Chapter 3 is developed in MATLAB/Simulink. Incorporating each control strategy, the model is subjected to contract violations as explained in Section 7.5.1. The performance of the proposed GENCO and TRANSCO reserve based control strategy is compared with tie line bias and GENCO reserve based control strategy.

**7.5.2.1 Contract violation of 0.01 p.u. in area 1 incorporating GENCO and TRANSCO reserve based control strategy under poolco model**

The mathematical model of two area LFC system under poolco model explained in Chapter 3 is subjected to a contract violation of 0.01 p.u. at 350s in area 1, as explained in Section 7.4.1. Incorporating GENCO and TRANSCO reserve based control strategy; the GENCOs and TRANSCO power responses for this condition are obtained and are shown in Figure 7.12.

Figure 7.12 shows that power generation of economic and willing GENCOs (GENCO 1 ($G_{11}$), GENCO 2 ($G_{21}$) and GENCO 4 ($G_{22}$)) are increased from 0.3003 p.u., 0.4998 p.u., 0.333 p.u. to **0.3035 p.u.**, **0.5035 p.u.** and **0.3361 p.u.** respectively. Participation of GENCOs in area 2 to meet the un-contracted demand in area 2, causes power flow from area 2 to area 1, in addition to the contracted power from area 1 to area 2. This results in decrease of TRANSCO power from **0.367 p.u.** to **0.3639 p.u.**. These values match with the expected values given in Table 7.4.
Now, a contract violation is created in area 2 that results an increase in TRANSCO power. To analyse and compare the operation of the newly proposed strategy with tie line bias and GENCO reserve based control strategy, the mathematical model of the system under poolco model is subjected to violations of 0.2 p.u. (causes TRANSCO power within limit) that causes TRANSCO line congestion. The GENCOs and TRANSCO power responses are then obtained incorporating different strategies as explained in the following three sections.

7.5.2.2 Contract violation of 0.2 p.u. in area 2 incorporating tie line bias control strategy under poolco model

The two area system shown in Figure 3.6, operating under poolco model is incorporated with tie line bias control strategy and is subjected to a contract violation of 0.2 p.u. at 350s in area 2. The GENCOs and TRANSCO power responses are generated and are shown in Figure 7.13.

The tie line bias control strategy increases the power generation of GENCO 4 (G_{22}) shown in Figure 7.13 from 0.333 p.u. to 0.533 p.u.. GENCO 4 (G_{22}) is not willing to meet the uncontracted power. Hence, the power remains same as contracted. Whereas, the neighbouring area GENCOs (GENCO 1 (G_{11}) and GENCO 2 (G_{21})) do not contribute to meet the violated demand. At the same time, TRANSCO power is kept un-changed.
Figure 7.13: GENCOs and TRANSCO power responses during violation of 0.2 p.u. at 350s in area 2 incorporating tie line bias control strategy under poolco model

The observed power values match with the values given in Table 7.5.

7.5.2.3 Contract violation of 0.2 p.u. in area 2 incorporating GENCO reserve based control strategy under poolco model

GENCO reserve based control strategy, explained in chapter 6 is now incorporated in the mathematical model of two area system shown in Figure 3.7. With the system operating at poolco model as explained in Chapter 3, the GENCOs and TRANSCO power responses are simulated for a contract violation of 0.2 p.u. at 350s in area 2 and are shown in Figure 7.14.

Figure 7.14: GENCOs and TRANSCO power responses during violation of 0.2 p.u. at 350s in area 2 incorporating GENCO reserve based control strategy under poolco model
The LFC models are tested for a unit step load disturbance of 0.01 p.u. (1%). However, to load the TRANSCO above its rated value, the system is subjected to a load disturbance of 0.2 p.u. (20%). Due to this large magnitude of disturbance, more oscillations are seen in Figure 7.14.

Figure 7.14 shows that the power generation of GENCO 1 (G11), GENCO 2(G21) and GENCO 4 (G22) is increased from 0.3003 p.u., 0.4998 p.u. and 0.333 p.u. to 0.3643 p.u., 0.5738 p.u. and 0.395 p.u. respectively. Meanwhile, TRANSCO power is increased from 0.367 p.u. to 0.505 p.u.. The values match with those presented in Table 7.5.

7.5.2.4 Contract violation of 0.2 p.u. in area 2 incorporating GENCO and TRANSCO reserve based control strategy under poolco model

Now, the same system is incorporated with the proposed GENCO and TRANSCO reserve based control strategy. The model is subjected to a contract violation of 0.2 p.u.at 350s in area 2 and the GENCOs and TRANSCO power responses are obtained and are shown in Figure 7.15.

For a violation of 0.2 p.u. in area 2, the GENCO reserve based control strategy cause TRANSCO power to exceed the maximum limit. However, this power is limited to 0.5 p.u., when the system is incorporated with GENCO and TRANSCO reserve based control strategy, as shown in Figure 7.15. So as to maintain TRANSCO power at 0.5 p.u., the
The proposed strategy imposes limit on the power generation of GENCO 1 (G\textsubscript{11}) and GENCO 2 (G\textsubscript{21}). Hence, the output of GENCO 1 (G\textsubscript{11}) and GENCO 2 (G\textsubscript{21}) is from \textbf{0.3003 p.u.} and \textbf{0.4998 p.u.} to only \textbf{0.3617 p.u.} and \textbf{0.5714 p.u.} respectively. The remaining violated power is met by GENCO 4 (G\textsubscript{22}) and thus the power generation of GENCO 4 (G\textsubscript{22}) is increased from \textbf{0.333 p.u.} to \textbf{0.4 p.u.}. The results match with the values given in Table 7.5.

\textbf{7.5.3 Performance comparison of GENCO and TRANSCO reserve based strategy with tie line bias control and GENCO reserve based strategy for a violation of 0.01 p.u. in area 1 under poolco model}

The comparison between the performance of tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for a violation of 0.01 p.u. in area 1 under poolco model is made using the values obtained from Table 4.6, Table 6.3 and Table 7.4 respectively. The comparison is done with the help of bar chart as shown in Figure 7.16.

![Figure 7.16: Performance comparison of tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for violation of 0.01 p.u. in area 1 under poolco model](image)

Figure 7.16 presents the increase in GENCOs and TRANSCO powers from the contracted value, deploying tie line, GENCO reserve and GENCO and TRANSCO reserve based control strategy respectively. During any contract violation, TRANSCO power is maintained at scheduled by tie line bias control strategy as seen from \text{T(1)} in Figure 7.16. This enables same area willing GENCOs to meet the un-contracted power. Thus, GENCO 1 (G\textsubscript{1}(1)) and GENCO 2 (G\textsubscript{2}(1)) power is increased from contracted value as seen in Figure 7.16.
Incorporating GENCO reserve based control strategy allows more economic willing neighbouring GENCOs to meet the violated demand. From Chapter 4, it is seen that these GENCOs that participate for LFC during contract violation are GENCO 1 (G1), GENCO 2 (G2) and GENCO 4 (G4). Thus there is an increase in power output of these GENCOs as observed in G1(2), G2(2) and G4(2) in Figure 7.16. The participation of GENCO 4 (G4) to meet violated power in area 1 results TRANSCO power T(2) to decrease from scheduled value. At this instance, the TRANSCO power is within the limit.

As the TRANSCO power during contract violation in area 1 is within the maximum limit, GENCO and TRANSCO reserve based control strategy operates as per the strategy of GENCO reserve based control. Thus, G1(2), G2(2) and G4(2) are similar to G1(3), G2(3) and G4(3) respectively.

It can be concluded that GENCO reserve and GENCO and TRANSCO reserve based control strategy operate in similar manner for contract violation resulting in TRANSCO power within maximum limit.

7.5.4 Performance comparison of GENCO and TRANSCO reserve based strategy with tie line bias control and GENCO reserve based strategy for a violation of 0.2 p.u. in area 2 under poolco model

The performance of LFC incorporating tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategy for a violation of 0.2 p.u. in area 2 under poolco model is compared with the help of bar chart. Using the values of GENCOs and TRANSCO obtained from Table 7.5, the bar chart is sketched and is shown in Figure 7.17.

The increase in power output of GENCOs and TRANSCO from scheduled value is depicted in Figure 7.17. For a contract violation in area 2, tie line bias control preserve power flow through TRANSCO at scheduled value as shown in T(1) of Figure 7.17. This is achieved by allowing same area willing GENCOs to meet the un-contracted demand. The willing is GENCO 4 (G4). Thus, the power output of GENCO 4 (G4(1)) increases as shown. However, the strategy does not make use of reserve of willing GENCOs in the neighbouring area.
Figure 7.17: Performance comparison of tie line bias, GENCO reserve based and GENCO and TRANSCO reserve based control strategies for violation of 0.2 p.u. in area 2 under poolco model

GENCO reserve based control strategy allows willing GENCOs in the neighbouring area to take part in LFC during contract violation. From Chapter 4 it is clear that the willing GENCOs are GENCO 1 (G1), GENCO 2 (G2) and GENCO 4 (G4). Thus, the power output of these GENCOs (G1(2), G2(2) and G4(2)) increases as seen in Figure 7.17. The participation of neighbouring economic GENCOs results in increase in power flow through TRANSCO. It is evident from Figure 7.17 that contract violation of 0.2 p.u. creates TRANSCO power flow T(2) above 0.5 p.u., the maximum limit of TRANSCO. The GENCO reserve based control strategy allows this power through TRANSCO without limiting it to maximum value.

However, the proposed GENCO and TRANSCO reserve based control strategy limit this power flow through TRANSCO at its maximum limit T(3) of 0.5 p.u.. This is clearly shown in Figure 7.17. While doing so, the proposed strategy lets economic GENCOs in neighbouring area to meet part of the violated demand equal to the available transfer capability of TRANSCO and the remaining violated power is made to meet from the same area willing GENCOs. Thus, increase in power output of willing GENCOs in neighbouring area, incorporating the proposed control strategy is less than with GENCO reserve based control strategy. While, the increase in power generation of same area GENCOs is greater using the proposed strategy than with GENCO reserve based control strategy.
From Figure 7.17, it can be concluded that the proposed GENCO and TRANSCO reserve based control strategy is efficient and effective in allowing willing GENCOs in neighbouring area and at the same time effective in limiting the TRANSCO power to the maximum limit.

Appendix IV shows that GENCO 1, GENCO 2 and GENCO 4 participate for the second round auction. With tie line bias control strategy, during violation in area 2, GENCO 4 participate to meet the violated demand. The price offered by GENCO 4 is Rs. 1800/MW. However, it is seen from Appendix IV, that there are more economic GENCOs (GENCO 1 and GENCO 2) in area 1 willing to contribute for the violated power with a price of Rs. 1750/MW and Rs. 1500/MW respectively. Hence, it is expected to have lesser cost incurred in meeting violated power, incorporating GENCO reserve, GENCO and TRANSCO reserve based strategy than that with tie line bias control. The cost incurred in meeting unscheduled power demand of 0.2 p.u., incorporating different control strategies, is tabulated in Table 7.6.

Table 7.6: GENCOs costs and TRANSCO power during violation of 0.2 p.u. in area 2 under poolco model

<table>
<thead>
<tr>
<th></th>
<th>Tie line bias control</th>
<th>GENCO reserve based strategy</th>
<th>GENCO and TRANSCO reserve based strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENCO 1 cost (Rs)</td>
<td>0</td>
<td>112</td>
<td>107.53</td>
</tr>
<tr>
<td>GENCO 2 cost (Rs)</td>
<td>0</td>
<td>111</td>
<td>107.33</td>
</tr>
<tr>
<td>GENCO 3 cost (Rs)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GENCO 4 cost (Rs)</td>
<td>360</td>
<td>111.6</td>
<td>120.6</td>
</tr>
<tr>
<td>Total cost (Rs)</td>
<td><strong>360</strong></td>
<td><strong>334.6</strong></td>
<td><strong>335.46</strong></td>
</tr>
<tr>
<td>TRANSCO power (p.u.)</td>
<td>0.367</td>
<td>0.505</td>
<td><strong>0.5</strong></td>
</tr>
<tr>
<td>Change in TRANSCO power (p.u.)</td>
<td>0</td>
<td>0.138</td>
<td>0.133</td>
</tr>
</tbody>
</table>

From Table 7.6 it is clear that the cost incurred to meet the violated demand of 0.2 p.u., incorporating tie line bias control is the highest. The cost to meet this unscheduled power incorporating GENCO reserve based strategy is less than that with tie line bias control. However, this method causes TRANSCO line congestion. Incorporating GENCO and TRANSCO reserve based control strategy, the cost of meeting 0.2 p.u. of un-contracted power is slightly greater than that with GENCO reserve based strategy, while, less than with tie line bias control. The strategy also maintains TRANSCO line power at maximum limit of 0.5 p.u.. From Figure 7.17 and Table 7.6, it can be concluded that an effective, efficient and economical operation of LFC is guaranteed by incorporating GENCO and TRANSCO reserve based control strategy.
7.6 CONCLUSIONS

The GENCO reserve based strategy proposed in chapter 6, allows more economic willing GENCOs in neighbouring area to meet for the un-contracted power. This makes use of TRANSCO reserve. However, in case of large violations, GENCO reserve based strategy fails to limit the TRANSCO power at maximum. This problem is overcome by modifying GENCO reserve based strategy considering TRANSCO limit. This modified control strategy based on GENCO and TRANSCO reserve allows all willing and economic GENCOs to meet the unscheduled power and at the same time, limits the TRANSCO power to maximum value. The performance of the proposed GENCO and TRANSCO reserve based control strategy is explained in detail with the help of schematic representation of ACE input selection. The \textit{epf} values are calculated from the offer price of all willing GENCOs in all the areas. The power generation of GENCOs are then calculated using \textit{epf} values. The proposed strategy is incorporated in the mathematical model of two area hydro thermal system under different market models. The system is analysed under contract violation that cause TRANSCO power to exceed the limit. The observed GENCOs and TRANSCO power are then compared with the calculated values. The effective performance of the proposed GENCO and TRANSCO reserve is compared with GENCO reserve based strategy and tie line bias control and is presented in the form of bar chart. Finally, the cost incurred in meeting the violated power demand, under different control strategies are computed. On comparing the cost, it is proved that the GENCO and TRANSCO reserve based control strategy provides economic operation and effective control in limiting the TRANSCO power over tie line bias and GENCO reserve based control strategies.