A FREQUENCY - RELATED MARKET STRUCTURE
FOR AN INDIAN REGIONAL GRID UNDER
DEREGULATED CONDITION

6.1 INTRODUCTION

Power generation in India has been largely state owned. There are total five regional grids in India namely Northern grid, Southern grid, Western grid, Eastern grid and North-Eastern grid. All the states are connected to these grids as per their geographical locations. The existing systems in INDIA do not have automatic load frequency control. There was no grid discipline and hence frequency fluctuated widely. Availability Based Tariff (ABT) was introduced to maintain grid frequency, which has brought in grid discipline in the various states. Even though the introduction of ABT has brought the frequency only close to the nominal value, still the control is manual and cannot satisfy the requirement in deregulated environment. Hence a market structure with a suitable control frame work for frequency related ancillary services is proposed for a typical Indian Regional Grid under the deregulated environment.

6.2 INDIAN POWER GRID: CURRENT SITUATION

India plans to have an integrated National Grid. This will assist in meeting demand with the least cost supply. The five Regional grids work at vastly varying operational parameters today. Frequency level is one such
operational parameter. The target frequency prescribed by the Indian Electricity Rules is 50 Hz. Integrated grid operations require the normalisation of frequency across all five Regions. The alternative is to insulate each Regional Grid by Back-to-Back HVDC links. This is an expensive option. Normalisation of frequency requires proactive load management by beneficiaries and despatch discipline by generators. There is currently no formal system of financial incentives to promote grid discipline. Hence ABT based controller for maintaining the frequency is introduced to maintain the grid discipline. This section briefly explains the ABT based controller with UI pricing scheme.

### 6.2.1 Availability Based Tariff (ABT)

Availability Based Tariff (ABT) is a very special Tariff system in INDIA alone (Pachiappan and Narayanan 2003). It is a performance-based tariff for the supply of electricity by generators owned and controlled by the central government. It is also a new system of scheduling and despatch, which requires both generators and beneficiaries to commit to day-ahead schedules. It is a system of rewards and penalties seeking to enforce day ahead pre-committed schedules, though variations are permitted if notified one and one half hours in advance (Kalki Communication Technologies Private Limited 2008).

The main objectives of the ABT based Tariff are:

1. The unacceptably rapid and high frequency deviations (from 50 Hz) causing damage and disruption to large-scale industrial consumers

2. Frequent grid disturbances resulting in generators tripping, power outages and power grid disintegration.
The most significant aspect of ABT is the splitting of the existing monolithic energy charge structure into three components viz. capacity charges (fixed), energy charges (variable) and UI (unscheduled interchange) charges. It is the last component that is expected to bring about the desired grid discipline (Agalgaonkar et al 2005).

6.2.2 UI Pricing Logic

Unscheduled interchange (UI) is defined as the difference between the schedule interchange (I_{sch}) and the actual interchange (I_{act}). This is given by the following equation:

\[ UI = I_{sch} - I_{act} \]  \hspace{1cm} (6.1)

The ABT regime stipulates that UI (Unscheduled Interchange) charges are payable under the following conditions.

a) A generator generates more/less than the schedule causing grid frequency to deviate upwards/downwards from the nominal value (50 Hz).

b) A beneficiary draws more/less than the schedule causing grid frequency to deviate downwards/upwards from the nominal value (50 Hz).

The incentive/discentive imposed varies with the grid condition at the time of the indiscipline and the magnitude increases with the severity of the frequency deviation caused. The current UI price curve is shown in Figure 6.1.
If frequency (f) is 49.02 Hz or below, UI price is maximum (7.45 Rs/KWhr), and this price is minimum (zero Rs), when frequency is 50.05 Hz or above

If \( f > 50.5 \text{ Hz} \), then
\[
\text{UI rate} = 0.0 \text{ Rs/KWh} \quad (6.2)
\]

If \( f < 49.02 \text{ Hz} \), then
\[
\text{UI rate} = 7.45 \text{ Rs/KWh} \quad (6.3)
\]

If frequency is between 49.02 Hz and 49.5 Hz, the UI price varies linearly as given in the following equation
\[
\text{UI rate} = (415.95-8.33*f) \text{ Rs/KWh} \quad (6.4)
\]

If frequency is in between 49.5 Hz and 50.5 Hz, the UI price varies linearly, given by the following equation
\[
\text{UI rate} = (174.225-3.45*f) \text{ Rs/KWh} \quad (6.5)
\]
6.2.3 Working of ABT Mechanism

In the Availability based Tariff (ABT) controller scheme the primary regulation control loop is the same as in the conventional frequency control, but the secondary loop is changed to incorporate the unscheduled interchange (UI) price signal as shown in Figure 6.1.

The block diagram of ABT based frequency control scheme of an area under disturbance is shown in Figure 6.2 (Tyagi and Srivastava 2004).

Figure 6.2 Block diagram of ABT based controller

In Figure 6.2 tie line deviation ($\Delta P_{\text{tie}}$) is defined as the difference between the scheduled tie line flow ($P_{\text{tie-sch}}$) and the actual tie line flow ($P_{\text{tie-act}}$). This is given by the following equation:

$$\Delta P_{\text{tie}} = P_{\text{tie-act}} - P_{\text{tie-sch}}$$
When a disturbance occurs in an area and if tie-line deviation for that area is negative, that is unscheduled interchange (UI) is positive then only the penalty or UI pricing is applicable to that area as per the UI price curve. On the other hand, if the tie-line deviation signal is positive and the unscheduled interchange (UI) is negative then UI price is taken as zero and no control action is taken in that area. To include this concept a signal from the tieline deviation is included in the work reported in the reference (Tyagi and Srivastava 2004).

It is assumed that the generating plant of an area is generating at its scheduled output and the frequency of the grid is at the nominal value (50 Hz), when a load change of $\Delta P_d$ occurs in the system. This results in deviation in the supply frequency.

In Figure 6.3, S1 to S5 are defined as follows:

S1 = Actual frequency of the system
S2 = UI price signal
S3 = Actual generation
S4 = Incremental cost
S5 = Actuating signal for the speed changer

Actual frequency of the system (S1) is given by,

$$S1 = \text{Nominal Frequency} (f_0) + \text{change in frequency} (\Delta f) \quad (6.7)$$

At this frequency S1, the UI price signal S2 is calculated using equations (6.1) to (6.4), which is derived from Figure 6.2. This UI price signal S2 is compared with the incremental cost signal S4 to generate the signal S5. Signal S4 can be calculated as,
\[ S4 = a \cdot S3 + b \] (6.8)

where, \( a \) and \( b \) are incremental cost coefficients and depend on the type of the plant.

\[ S3 = \text{Scheduled generation} + \Delta P_g \] (6.9)

where, \( \Delta P_g \) is the change in turbine power

\[ S5 = S2 - S4 \]

\[ S5 = \text{UI price} - \text{Incremental cost of generation} \] (6.10)

This signal \( S5 \) can be used to change the input power to the governor \( \Delta P_c \).

\[ \Delta P_c = k_i \cdot S5 \] (6.11)

where \( k_i \) is the proportionality constant.

In the next section, this ABT based controller is implemented for the Indian regional grid under deregulated power system.

### 6.3 DESIGN OF MARKET STRUCTURE FOR THE INDIAN REGIONAL GRID UNDER Deregulated Power System

Indian Power system is currently in the process of restructuring. As a first step the charged-cum-bilateral market structure is proposed for a typical Indian regional grid. The diagrammatic representation of the inter area links of the typical Indian regional grid shown in Figure 6.3 is used to design the market structure in the deregulated power system.
6.3.1 Sample System for Simulation

The Indian regional grid consisting of four areas and they are interconnected with links as shown in Figure 6.3 is taken for simulation. It is assumed that there are two Gencos and two Discos in each area participating in the contract. Figure 6.4 shows the four area system model for the Indian regional grid under deregulated environment. Details of the load following and the regulation service providers for the four area system are shown in Table 6.1. Generating units and turbine shown in Figure 3.7 is used in the four area deregulated system model. The data of this structure are given in Appendix 2.
Figure 6.4 Four-area deregulated system for the Indian regional grid

Table 6.1 Details of four area system for the Indian regional grid

<table>
<thead>
<tr>
<th>Area</th>
<th>Charged Structure (ISO)</th>
<th>Bilateral Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Genco</td>
<td>Disco</td>
</tr>
<tr>
<td>1</td>
<td>Regulation</td>
<td>Load Following</td>
</tr>
<tr>
<td></td>
<td>Load Following</td>
<td>G_{11} G_{12}</td>
</tr>
<tr>
<td>2</td>
<td>Regulation</td>
<td>Load Following</td>
</tr>
<tr>
<td></td>
<td>Load Following</td>
<td>G_{21} G_{22}</td>
</tr>
<tr>
<td>3</td>
<td>Regulation</td>
<td>Load Following</td>
</tr>
<tr>
<td></td>
<td>Load Following</td>
<td>G_{31} G_{32}</td>
</tr>
<tr>
<td>4</td>
<td>Regulation</td>
<td>Load Following</td>
</tr>
<tr>
<td></td>
<td>Load Following</td>
<td>G_{41} G_{42}</td>
</tr>
</tbody>
</table>
6.4 PERFORMANCE OF VARIOUS CONTROL SCHEMES FOR AN INDIAN REGIONAL GRID UNDER DEREGULATED POWER SYSTEM: SIMULATION RESULTS

The following controllers are implemented separately as a controller for the four area charged-cum-bilateral structure of an Indian regional grid.

Controller 1: ABT based controller
Controller 2: Conventional integral controller
Controller 3: NERC standards-based fuzzy tuned controller

Simulations were carried out in the four area charged-cum-bilateral structure with ramp load disturbance of 0.5 puMW/hr and random load disturbance of maximum +0.05 and minimum -0.05 puMW with time interval of two seconds. This is shown in Figure 6.5. The simulation responses of the above three controllers are obtained and the performance indices are also compared in the next sections.

Figure 6.5 Load variation in area 1
6.4.1 Simulation Responses with ABT Based Controller

Frequency deviation response, speed changer response and UI price curve of the four area charged-cum-bilateral structure with ABT based controller are obtained as shown in Figures 6.6, 6.7 and 6.8.

**Figure 6.6** Frequency deviation in area 1 - ABT based controller

**Figure 6.7** Speed changer response in area 1 - ABT based controller
6.4.2 Simulation Responses with Integral Controller

Frequency deviation response and speed changer response of the charged cum bilateral structure with integral controller are obtained as shown in Figures 6.9 and 6.10.
6.4.3 Simulation Responses with NERC Standards-based Fuzzy Tuned Controller

In this section, NERC standards-based fuzzy tuned controller discussed in chapter 5 is used for simulation. Frequency deviation response and speed changer response of the charged cum bilateral structure with NERC standards-based fuzzy tuned controller are obtained as shown in Figures 6.11 and 6.12.
6.4.4 Comparison of the Performance of Different Control Schemes

The Performance index CPS1 for the ABT based controller, Integral controller and NERC Standards-based Fuzzy Tuned Controller are calculated for one hour and plotted as shown in Figure 6.13. Table 6.2 shows the percentage of the Performance Index CPS2 in % of the different controllers.
Table 6.2 \hspace{1em} Comparison of the performance index CPS2 of the ABT based controller with the other controllers

<table>
<thead>
<tr>
<th>Controller</th>
<th>ABT based</th>
<th>Integral controller</th>
<th>NERC standards-based fuzzy tuned controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPS2 in %</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

To prove the reduction in wear and tear of the equipment by NERC standards-based fuzzy tuned controller, change in speed changer responses of area 1 are obtained as shown in Figures 6.10 and 6.12. Excess raise/lower signals of integral controller over the NERC standards-based fuzzy tuned controller of area 1 are shown in Figure 6.14.

![Figure 6.14](image)

**Figure 6.14** Excess raise/lower signals of integral controller over NERC standards based fuzzy tuned controller in area 1

6.4.5 Discussion

To comply with NERC standards the value of CPS1 should not be less than 100% and compliance factor CF_{ac} should be less than one. From
Figure 6.6, it is observed that the frequency deviation is very high for the ABT based controller compared to the other two controllers. Also the value of the compliance factor $C_{ac}$ is greater than one and the minimum and maximum percentage of CPS1 is -350 and -355. It is also observed from Figure 6.13, integral controller is highly compliant with CPS1 with minimum and maximum values of 160 and 171 % and NERC standards-based fuzzy tuned controller is compliant with CPS1 with minimum and maximum values of 105 and 110 %.

According to NERC control performance standard CPS2, the ten minute averages of ACE divided by the constant $L_{10}$ must be less than one at least 90% of the time to comply with CPS2. From the results, it is observed that all ten minute averages of ACE divided by the constant $L_{10}$ values are less than one for the integral controller and NERC standards- based fuzzy tuned controller and greater than one for the ABT based controller. This indicates that the integral and NERC standards-based fuzzy tuned controller are highly compliant with CPS2 (100%) and the ABT based controller is not compliant with CPS2, which is shown in Table 6.2. Hence it is suggested that ABT based controller is not feasible for the Indian regional grid under deregulated environment.

From Figure 6.7 it is also observed that, the speed changer operations of ABT based controller is not comparable with the other two controllers due to its high frequency error. The excess maneuvering of the integral controller is better seen in Figure 6.14, where the difference between both signals are plotted to show the superior performance of the NERC standards-based fuzzy tuned controller. The results show that the NERC based fuzzy tuned controller is better in reducing the unnecessary wear and tear of the equipment compared to the other two controllers.
6.5 CONCLUSION

This chapter discussed the current situation of an Indian regional grid with Availability based tariff and UI pricing logic. Subsequently charged-cum-bilateral structure is designed for a four-area Indian regional grid under deregulated condition. Three controllers such as ABT based controller, Integral controller and NERC standards-based fuzzy tuned controller are implemented in the four-area system of the Indian regional grid for providing regulation and load following ancillary services. The performances of the three controllers are simulated and the performance indices are compared. The results show that ABT based controller is not feasible and charged-cum-bilateral structure with NERC standards-based fuzzy tuned controller is proposed for frequency related ancillary services for an Indian regional grid under deregulated environment.