CHAPTER IV

DYNAMIC RESPONSE AND SUBOPTIMAL LOAD FREQUENCY CONTROL OF MULTI AREA SYSTEMS CONSIDERING GENERATION RATE CONSTRAINTS (GRC)

4.1 INTRODUCTION

The dynamic response and suboptimal load frequency control of multi area systems discussed in chapter II and chapter III deal with linear and nonlinear model without considering the generation rate constraints. In practice, there is a maximum limit on the rate of change in generating power of steam power plant. Rate limits are imposed to avoid wide variations of process variables like temperature, pressure, etc. for the safety of the equipment. Thus is restricted by boiler characteristics and is in the range of 0.01 to 0.1 p.u./min. [34,74]. The effect of the limits on the rate of change of power generation in selection of optimum controller gain setting and system dynamic performance are reported in the reference [27,32,49,50,52,55,57,69,74]. Nanda et al. [52] have studied the effect with linear model taking two area
system and have concluded that the system becomes unstable in presence of GRC if the optimum gain setting is taken as found by neglecting GRC. Thus the optimum gain settings achieved by neglecting GRC are unacceptable for actual systems. Further if these limits are not considered in choosing the optimal gain setting of the controller, the system will develop a tendency to chase large momentary disturbance causing undue wear and tear of the controller. In the literature several methods are suggested to include GRC in the model for computation [32,33,34,52]. Some methods are illustrated briefly as below.

One way of considering the generation rate constraints [32,33,34] is dual mode control strategy. In this method the state vector \([x]\) is separated into two groups, one is rate limited as \([x_L]\) and rest by \([x_r]\). The state space representation of system is given by

\[
\begin{bmatrix}
\dot{x}_L \\
\dot{x}_r
\end{bmatrix} = \begin{bmatrix} A_{LL} & A_{Lr} \\ A_{rL} & A_{rr} \end{bmatrix} \begin{bmatrix} x_L \\ x_r \end{bmatrix} + \begin{bmatrix} B_L \\ B_r \end{bmatrix} u \] ...
\] (4.1)

The generation rate constraints are given by

\[
\begin{bmatrix}
\dot{x}_L \\
\dot{x}_L
\end{bmatrix} \leq \begin{bmatrix} x_L \\ x_{L_{\text{max}}} \end{bmatrix} \] ...
\] (4.2)
\[ \begin{bmatrix} A_{LL} X_L + A_{Lr} X_r + B_L u \end{bmatrix} \leq X_{L \text{ max}} \quad \ldots (4.3) \]

The \( u(t) \) is chosen by using

\[ B_L u(t) = K \begin{bmatrix} X_{L \text{ max}} \end{bmatrix} - A_{LL} X_L - A_{Lr} X_r \quad \ldots (4.4) \]

where \( K \) is a \( P \times P \) diagonal matrix with \( \text{sign}(X_j), j = 1,2,\ldots,P \) and \( P \) is the no. of rate limited state variables. So the dual mode control is represented by

\[ \dot{u}(t) = -K X \quad \text{if} \quad X_{L_j} < X_{L_j \text{ max}} \quad j = 1,2,\ldots \]

\[ = -B_L^{-1} \begin{bmatrix} K X_{L \text{ max}} - X \end{bmatrix} \quad \text{if} \quad X_{L_j} > X_{L_j \text{ max}} \quad j = 1,2,\ldots \]

Another simple method is suggested by Nanda et al [52] to include the generation rate constraints during computation. In this method, it is verified at each solution step whether the generation rate constraints are violated or not while solving the state equations. They have applied this method and studied the system dynamic performance for two area system. They have studied the effect of GRC on the choice of optimum gain setting of controller both in continuous and
discrete time dynamic model for two area reheat thermal systems. They have concluded that in continuous mode the optimum integral gain setting in presence of CRC is much lower as compared to unconstrained optimum integral gain setting. Reddoch et al [27] have reported results using LQR approach through tuning of performance index. Such soft constraining does not appear to limit the rate of change of power generation effectively. Venkateswarlu et al [32] have proposed a dual mode control strategy to achieve hard constraint on the rate of change of power generation by limiting the movement of main steam valve position. The control strategy can be implemented for on-line purpose through simple logic circuits. They have simulated two area thermal system considering availability of all state variables.

However in all the above methods the mathematical involvement and computer burden increase as the number of area is increased. The advantages of decomposition technique for studying the dynamic response of multi area systems (developed in chapter II) and suboptimal load frequency control of multi area systems (developed in chapter III) are explained. In this chapter those techniques are tried out to study the effect of
generation rate constraints on dynamic response and optimum value of controller gain setting. The control scheme is proposed with only the tie-line power deviation and frequency deviation as control signal and using a proportional integral control.

4.2 SYSTEM INVESTIGATED

In systems with hydro-thermal combination, the generation rate in hydro area generally remains below the safe permissible limit. As such the possibility of violation of the rate constraints in case of hydro area is remote, therefore the rate constraints for generation of hydro area can be neglected [33,34]. In view of the above facts the effects of the generation rate constraints in the thermal areas are studied. The following systems are studied in this chapter.

SYSTEM I: Two area hydro-thermal system with disturbance in thermal area.

SYSTEM II: Two equal areas of reheat thermal system.

SYSTEM III: Four equal areas of reheat thermal system.

A step load perturbation of 1% of nominal loading has been considered in area 1 in each case and the
limit is taken to be 0.1 p.u./min. for numerical calculations.

4.3 DYNAMIC RESPONSE AND SUBOPTIMAL CONTROL.

The theory of decomposition technique has already been developed in chapter II of this thesis and a detailed study has been made using the same on linear and nonlinear model (considering governor dead band). The same technique is extended to the dynamic response studies of multi area systems considering GRC. At each integration time interval, the generation rate is checked for its magnitude and sign. In case the generation rate exceeds the specified maximum value the change in generation is constrained through the relationship

$$\Delta P_{i+1}^t = \Delta P_i^t + r \Delta t$$

Where $r$ is the maximum limit of generation rate. This is adopted while solving the state equations by trapezoidal integration method. The control scheme is proposed with only the tie-line power deviations and frequency deviations as control signal using proportional integral control. For optimum choice of gain parameter the integral squared error (ISE)
criterion is taken. The performance index to be minimized is expressed as

$$PI = \int_{0}^{T} \left[ \sum_{k=1}^{M-1} \frac{M}{M-1} \Delta f_k^2 + \sum_{k=1}^{T_i} \Delta P_k \right] dt$$

For minimization of $PI$ steepest descent method along with decomposition technique as developed in chapter III of this thesis is followed.

4.4 NUMERICAL EXAMPLES AND RESULTS

The three systems explained in article 4.2 are tried out with the above technique. The nominal system parameters are given in Appendix A. The integration time interval $\Delta t = 0.25$ secs is chosen and the response is studied for 40 secs. The optimum gain setting of the controller of any area is found out considering other areas uncontrolled for both restricted and unrestricted case and the results are given in table 4.1. It is observed that the restrictions on the rate of power generation affect the controller gain setting very much. The optimal gain setting in case of constrained mode of operation is much lower than the optimal gain
Table 4.1

Optimum gain setting

<table>
<thead>
<tr>
<th>System</th>
<th>Mode of operation</th>
<th>$K_{I1}^{initial}$</th>
<th>$K_{I1}^{optimum}$</th>
<th>$P_{I}^{initial}$</th>
<th>$P_{I}^{optimum}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Without GRC</td>
<td>0.0</td>
<td>0.2966$\times 10^{-1}$</td>
<td>0.621</td>
<td>0.4695$\times 10^{-2}$</td>
</tr>
<tr>
<td></td>
<td>With GRC</td>
<td>0.0</td>
<td>0.707$\times 10^{-1}$</td>
<td>0.202</td>
<td>0.5009$\times 10^{-1}$</td>
</tr>
<tr>
<td>2</td>
<td>Without GRC</td>
<td>0.0</td>
<td>0.1575$\times 10^{-1}$</td>
<td>1.18</td>
<td>0.1363$\times 10^{-2}$</td>
</tr>
<tr>
<td></td>
<td>With GRC</td>
<td>0.0</td>
<td>0.2022$\times 10^{-1}$</td>
<td>0.302</td>
<td>0.6285$\times 10^{-2}$</td>
</tr>
<tr>
<td>3</td>
<td>Without GRC</td>
<td>0.0</td>
<td>0.1035$\times 10^{-1}$</td>
<td>0.59</td>
<td>0.1343$\times 10^{-2}$</td>
</tr>
<tr>
<td></td>
<td>With GRC</td>
<td>0.0</td>
<td>0.1333$\times 10^{-1}$</td>
<td>0.07</td>
<td>0.2962$\times 10^{-2}$</td>
</tr>
</tbody>
</table>
setting of unconstrained mode of operation. This result was earlier established by other workers [52]. The dynamic responses of various state variables corresponding to restricted and unrestricted mode of operation are illustrated in Fig.4.1 to Fig.4.15. From the response curves of frequency deviation and tie-line power deviation, it is observed that the settling time is almost same in both mode of operation. But the transient effect is more in constrained mode. From the response curves of generation deviation it is observed that the generation is more sluggish in restricted mode. From the response curves of ACE, it is seen that the generation rate constraints lead to larger deviations in ACE. The deviation in tie line power is more when restrictions are imposed which leads to larger deviation in ACE. Due to the constraints, the generation is not allowed to pick up at a faster rate and hence the disturbed area has to import power from the neighbouring areas via tie-lines during transient state. The above observations have been made by different workers [32,27] by solving the LFC problem in different approach.
FIG 4.1 TEST SYSTEM 1
(FREQUENCY DEVIATION IN AREA 1)
FIG 4.2  TEST SYSTEM 1
(FREQUENCY DEVIATION IN AREA 2)
FIG 4.3 TEST SYSTEM 1
("Tie-Line Power Deviation")
FIG 4.4 TEST SYSTEM 1
(GENERATION DEVIATION IN AREA 1)
FIG 4.5 TEST SYSTEM 1
(AREA CONTROL ERROR IN AREA 1)
FIG 4.6 TEST SYSTEM 2
(FREQUENCY DEVIATION IN AREA 1)
FIG 4-7 TEST SYSTEM 2
(FREQUENCY DEVIATION IN AREA 2)

FREQUENCY DEVIATION IN PU

TIME (SEC)

0 0 2 0
0 0 0 0
-0 0 2 0
-0 0 4 0
-0 0 6 0
-0 0 8 0

WITH GRC

WITHOUT GRC
FIG. 4B TEST SYSTEM 2
(TIE-LINE POWER DEVIATION)
F.G 49 TEST SYSTEM 2
(GENERATION DEVIATION IN AREA 1)
FIG 410 TEST SYSTEM 2
(AREA CONTROL ERROR IN AREA 1)
FIG 4.11 TEST SYSTEM 3
(FREQUENCY DEVIATION IN AREA 1)

FREQUENCY DEVIATION IN PU

TIME (SEC)

WITH GRC
WITHOUT GRC
FIG 412 TEST SYSTEM 3
(FREQUENCY DEVIATION IN AREA 2)
FIG 413 TEST SYSTEM 3
(TIE-LINEPOWER DEVIATION)
FIG 4.14 TEST SYSTEM 3
(GENERATION DEVIATION IN AREA 1)
FIG 4.15 TEST SYSTEM 3
(AREA CONTROL ERROR IN AREA 1)
The technique developed in chapter II and chapter III of this thesis is extended to study the dynamic response and suboptimal load frequency control of multi-area systems considering GRC. The effectiveness of the proposed method has been verified by means of three examples. The suboptimal value of gain parameter has been calculated considering GRC. The system performance curves are found out for restricted and unrestricted mode of operation and compared. The settling time is almost same in both the modes of operations but the transient response is more in case of restricted mode.