Decentralized $H_\infty$ Load Frequency Controller (LFC) for Power Systems

P. Amani, B. Labibi
K. N. Toosi University of Technology Dep. Control Engineering

Abstract: A decentralized robust $H_\infty$ control strategy for load frequency control of interconnected power systems will be presented. For simplicity and without loss of generality, the performance of this controller for a two area interconnected power system will be studied. Results are compared with the robust $H_\infty$ controller designed in [1]. This shows that the frequency

Keywords: Decentralized Controller, $H_\infty$ Controller, LFC, Power System.

1- Introduction
For large-scale power systems which usually consist of interconnected control areas, it is of great importance to keep the system frequency and inter-area tie power as close as possible to some desired values. This is done by load frequency control (LFC). By designing a decentralized robust $H_\infty$ controller, robust stability and nominal performance for a typical two area power-system will be guaranteed. In the Dynamical operation of a power plant usually decentralization of the control action into some individual areas is of great importance due to cost savings provided in data communication and in reducing scope of the monitoring network. The concept of variable structure systems is used to design an LFC [2-5]. Various adaptive control schemes have been presented to deal with parameter variations [6-8]. A Riccati Equation based approach is used to solve the problem of stabilization of linear uncertain systems [6-9]. It is shown in [10] that the problem of designing a decentralized controller for a large scale power system can be changed into designing a decentralized controller for a multi input-multi output MIMO equivalent power-system. Robust control strategies are applied to this equivalent plant.

2- Model of a typical power - system
Figure1 shows a typical two area power-system. Due to small changes in the load, during operation of the power system, a linear model can be used for LFC control. A state-space model of the power-system of Figure1 can be considered as follows:
\[ \dot{x} = Ax + Bu \]
\[ y = Cx \]

Where:
\[ u = [u_1 \quad u_2]^T, y = [y_1 \quad y_2]^T, \Delta f_1 \Delta f_2]^T \]

\[ x = \begin{bmatrix} -1 & \frac{k_1}{T_{p1}} & 0 & 0 & \frac{k_1}{T_{p1}} \frac{k_1}{T_{p1}} & 0 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \eta_1 & 0 & 0 & 0 & 0 & -\eta_1 & 0 & 0 & 0 \\ \eta_2 & 0 & 0 & 0 & 0 & -\eta_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & k_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \end{bmatrix} \]

\[ A = \begin{bmatrix} \frac{k_1}{T_{p1}} & \frac{k_1}{T_{p1}} & 0 & 0 & \frac{k_1}{T_{p1}} \frac{k_1}{T_{p1}} & 0 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \eta_1 & 0 & 0 & 0 & 0 & -\eta_1 & 0 & 0 & 0 \\ \eta_2 & 0 & 0 & 0 & 0 & -\eta_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & k_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \end{bmatrix} \]

\[ B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ \end{bmatrix} \]
The system is stable and the control task is to minimize the system frequency deviation $f_1$ in area 1, $f_2$ in area 2 and the deviation in the tie-line power flow $\Delta P_{tie}$ between the two areas under the load disturbances $\Delta P_{D1}$ and $\Delta P_{D2}$. The whole system is observable and controllable.

3- Decentralized $H_\infty$ controller design

We consider the power system as a two input two output system as shown in equation 2.

$$\begin{bmatrix} \Delta f_1 \\ \Delta f_2 \\ \Delta P_{D1} \\ \Delta P_{D2} \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} & G_{13} & G_{14} \\ G_{21} & G_{22} & G_{23} & G_{24} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ \Delta P_{D1} \\ \Delta P_{D2} \end{bmatrix}$$

Block diagram of controlled system showing design topology is shown in figure 2. By considering the 5th state as uncertainty, the system can be divided into two identical subsystems. This results to:

$$G_{11} = G_{22}, G_{21} = G_{12}, G_{13} = G_{24}, G_{14} = G_{23}$$

So two identical controllers can be designed for this system.

The transfer function from the first output $\Delta f_1$ to $u_1$ would be:

$$\Delta f_1 = \frac{G_{11}(1+k_1 G_{12})G_{13} G_{14}}{1+k_1 G_{11}+k_1 G_{22}+k_1 G_{23} G_{24}}$$

Considering 3:

$$\Delta f_1 = \frac{G_{11}(1+k_1 G_{12})-G_{13} G_{14}}{(1+k_1 G_{11})^2-(k_1 G_{12})^2}$$

That is:

$$\Delta f_1 = \frac{G_{11}(1+k_1 G_{12})-G_{13} G_{14}}{(1+k_1 (G_{11} - G_{12}))(1+k_1 (G_{11} + G_{12}))}$$

As the system is divided into two identical systems the transfer function from second output $\Delta f_2$ to the inputs and disturbances will be the same as for $\Delta f_1$.

We are to make the closed loop system internally stable. As the system is stable and minimum phase, for internal stability it would be enough that the polynomial 10 has no zeros in RHP.

$$(1+k_1 (G_{11} - G_{12}))(1+k_1 (G_{11} + G_{12}))$$
the condition above is true if both 
\((1+k_1(G_{11}+G_{12}))\) and 
\((1+k_1(G_{11}-G_{12}))\) have 
no unstable zeros. Considering 
\(\frac{G_{12}}{G_{11}}\) as a 
multiplicative uncertainty for 
\(G_{11}\), the above 
polynomials can be written as follows in a 
more general way as 
\((1+k_1(G_{11}(1+\Delta G_{12}/G_{11}))\) 
and \(|\Delta|<1\). By using the LMI approach, all 
the zeros of 
\((1+k_1G_{11}(1+\Delta G_{12}/G_{11}))\) will be 
placed in the LHP for all \(|\Delta|<1\). Now it can 
be concluded that using this approach, in 
limits, polynomial 10 has been stabilized. 
The other objective of this \(H_\infty\) robust 
controller is to make the infinity norm of 
\(G_{13}\) and \(G_{14}\) as small as possible to vanish 
the effect of disturbances in the outputs of 
the system as fast as possible.

Figure 3 Multiplicative uncertainty

The weighting functions \(W_T\) and \(W_S\) in 
design of a \(H_\infty\) robust controller that 
guarantees both robust stability and nominal 
performance with LMI approach are chosen 
as follows:

\[ W_T = \frac{G_{12}}{G_{11}} \quad W_S = \begin{bmatrix} G_{13} \\ G_{14} \end{bmatrix} \quad (11) \]

The resulted \(\gamma_{opt}\) is equal to 0.8046, so 
robust stability is guaranteed. 
The designed controller is of order 13. Bode 
diagram of the designed controller is shown 
in Figure 4.

Figure 4 Bode Diagrams of Designed Controller

Figure 5 shows the close loop singular values 
of the system. It can be concluded that, the 
system has robust stability and nominal 
performance.

Figure 6 Singular values of closed loop system

4- Simulation results

In this section the responses of the system to 
unit step disturbances will be shown. The 
results will be compared with the results 
shown in [1]. Nominal values from [1] have 
been used for these simulations. In all steps 
the control signal was acceptable. 
Figure 9 shows response of the first output 
of the controlled system \(y_1\) to the unit step 
disturbance, \(\Delta P_{D2}\). With the designed 
controller the frequency deviation in area 1 
due to the unit step disturbance \(\Delta P_{D2}\) has 
been regulated to zero in about 7 seconds 
but the controller shown in [1] could not 
make that zero. Our response is faster and
results in less frequency deviations than the controller in [1].

Figure 8 Response $\Delta f_1$ to unit step disturbance $\Delta P_{D2}$.

Figure 9 shows that our controller results in less frequency deviations.

Figure 9 Response of $\Delta f_1$ to the unit step disturbance $\Delta P_{D1}$.

Figure 10 shows the deviation in the tie-line power flow $\Delta P_{tie}$ between the two areas under the load disturbance $\Delta P_{D1}$. It shows that the designed controller results in regulation of the tie-line power deviation to zero and less average tie-line power deviation than the controller in [1]. Our response is also faster.

Figure 10 Response of $\Delta P_{tie}$ to unit step disturbance $\Delta P_{D2}$.

Figure 11 shows that the designed controller regulates the tie-line power deviation into zero in an acceptable time.

Figure 11 Response of $\Delta P_{tie}$ to unit step disturbance $\Delta P_{D1}$.

5-Conclusion
A decentralized $H_{\infty}$ controller for the sample two area power system is developed and the results are compared with the results shown in [1]. The design methodology is somehow conservative, by choosing proper $W_T$ and $W_S$ this can be compensated. As shown this controller makes the two areas uncoupled.

6- References:
[2] A.Y. Sivaramakrishnan, M.V. Hariharan and M.C. Srisailam, "Design of variable structure load-