Design of a Controller for Load Frequency Control in a Power System

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Abstract: This paper describes the design of a controller for load frequency control in a power system. This controller is an additional secondary control whose gain parameters are designed to neutralize the steady state frequency error and tie line power error, when the system is subjected to a disturbance. The gains of PI and PID controllers are optimized using Genetic Algorithm. This paper presents the design of a controller for a Hydro-Thermal System.

Introduction

Load frequency control is a very important in Power System Operation and Control for Supplying sufficient and reliable electric power with good quality. One of the main requirements of Load Frequency Control for an Interconnected Power System is to ensure satisfactory area frequencies and inter area tie line transfers. Errors in these quantities arise due to unpredictable load variations, which cause mismatches between generation and load demand. Due to these load variations the operating point of the frequency vs. Power output curve changes, which causes the variations in frequency. Thus a fixed controller may no longer be suitable.

In order to overcome the above mentioned problem, a variable gain secondary controller has to be incorporated in the system which keeps the operating point fixed by changing the frequency vs. power output curve characteristics. Controllers are of many types. This paper presents the design of the gains of INTEGRAL, PROPORTIONAL INTEGRAL, PROPORTIONAL INTEGRAL DERIVATIVE Controllers. Genetic Algorithm is used as the Optimization Technique for the design of controller gains for a Hydro-Thermal system.

1 System Modeling

An interconnected Power system can be considered as being divided into control areas, which are connected by tie lines. In each control area all generators are assumed to form a coherent group. The power system is subjected to local variations of random magnitudes and duration's. Hence it is required to control the deviations of frequency and tie line power of each control area.

1.1 Hydro-Thermal System Modeling

The Block diagram model of a Hydro-Thermal system is shown in the Fig 1.

Where

\[ G_{g1}, G_{t1}, \text{power system}1, \text{are the transfer functions related to thermal system.} \]

\[ G_{g1} = \frac{1}{(1 + STg)} \]

\[ \text{Power system}1 = \frac{K_{pm}}{(1 + STps)} \]

\[ C = \frac{-K_i}{S} \text{(1 controller)}; \]

\[ -\left( K_p + \frac{K_i}{S} \right) \text{(PI controller)}; \]

\[ -\left( K_p + \frac{K_i}{S} + SK_d \right) \text{(PID controller)}; \]

\[ G_{t1} = \frac{1}{(1 + STr)} \text{(for Non Reheat turbine)} \]

\[ G_{t1} = \frac{(1 + S\alpha Trh)}{(1 + STr)(1 + STrh)} \text{(for Reheat turbine)} \]

Where Trh=Reheat time constant; \( \alpha = \text{Per unit megawatt rating} \)

\[ G_{g2}, G_{t2}, \text{power system}2, \text{are the transfer functions related to Hydro system.} \]

\[ \text{Pilot valve} = \frac{1}{T_g(1 + STp)} \; \text{; Power system}2 = \frac{K_{ps}}{(1 + STps)}; \]

\[ \text{Speed droop} = \sigma \; \text{; Dash pot} = \frac{\delta STr}{(1 + STr)}; \]

\[ C = \frac{-K_i}{S} \text{(1 controller)}; \]

\[ -\left( K_p + \frac{K_i}{S} \right) \text{(PI controller)}; \]

\[ -\left( K_p + \frac{K_i}{S} + SK_d \right) \text{(PID controller)}; \]
\[ G_{g2} = \frac{K(1 + TrS)}{(T_1S^3 + T_2S^2 + T_3S + 1)} \]

where \( T_1 = \frac{TpTrTg}{\sigma} \);

\[ T_2 = \frac{(Tp + Tr)}{\sigma}; \quad K = \frac{1}{\sigma}; \]
\[ T_3 = \frac{(Tg + Tr(\sigma + \delta))}{\sigma}; \quad \text{Power System} = \frac{Kps}{(1 + STps)}; \]
\[ G_t = \frac{(1 - STw)}{(1 + 0.5STw)}; \]
\[ G = 2\pi T_{12}/S; \quad G \text{ is the Tie-Line transfer function} \]

Where \( T_{12} = \frac{|V_1|V_2}{P_{12}X_{12}} \cos(\delta_1^0 - \delta_2^0) \) = Synchronizing Coefficient \([1]\)

\( \delta_1^0, \delta_2^0 \) are the power angles of equivalent machines of the two areas.

Typical values of various time constants and gains used for performance computation are:

Area 1 (Thermal system): \( Kps_1 = 100; Tps_1 = 20; Tt_1 = 0.5; \]
\( Tg_1 = 0.4; R_1 = 3; \Delta Pd_1 = 0.01; \)

Area 2 (Hydro System): \( Kps_2 = 2; Tps_2 = 20; Tw = 0.6; \]
\( Tg = 0.2; Tp = 0.04; Tr = 3; \sigma = 0.05; \Delta Pd_2 = 0.0; \delta = 0.2. \]
\( B_1 = B_2 = 0.425; 2\pi T_{12} = 0.05; a_{12} = 1; \)

\[ 2 \text{ Performance Index} \]

The performance index \((J)\) chosen is the INTEGRAL SQUARE ERROR (ISE).

For two Area system Performance Index is chosen as
\[ J = \int_0^t \left( (\Delta f_1 \times \Delta f_1) + (\Delta f_2 \times \Delta f_2) + (\Delta P_{tie} \times \Delta P_{tie}) \right) dt \]

\[ 3 \text{ Response of a Uncontrolled System} \]

The controller \((C)\) is assumed to have a gain value of zero in this particular case, i.e. the feed back loop connected to the controller \((C)\) is neglected in plotting this response.

The state space equations of the above model are formulated in the form \( \dot{X} = AX + BU \) ('A' and 'B' matrices are given in Appendix).

Where 'A' is the System State Matrix, 'X' is the state vector; 'U' is the input vector (in the present case the step disturbance vector).

These simultaneous differential equations are solved using Runga-Kutta (RK) fourth order method and the variations of state variables with respect to time are calculated.
The state variables of frequency and tie line power (for Two-Area case) are plotted with respect to time, which give us the uncontrolled response. (Fig's 2-4)

4 Design of a Controller

The responses of the uncontrolled system have some offset. This offset has to be minimized. For minimization of this offset incorporation of a secondary controller (C) is imperative.

4.1 Types of Controllers

Controllers are of many types. This paper presents the determination of controller gains and the response of a controlled system with three basic types of controller configurations.

1) Integral Controllers, with a transfer function of \( \frac{K_i}{S} \)
2) Proportional Integral Controllers, with a transfer function of \( \frac{K_i}{S} + K_p \).
3) Proportional Integral Derivative Controllers, with a transfer function of \( \frac{K_i}{S} + K_p + SK_d \).

4.2 Optimization

The gains of the various controllers are to be optimized for minimizing the Performance Index. For a pure Integral Controller with only one gain to be optimized no special optimization technique is required. For optimizing the gains of PI and PID controllers where 2 and 3 gains respectively, have to be optimized we have to resort to some optimization technique. After trying out Trial and Error technique, to optimize the gains, which was found to be computationally expensive, the authors adopted Genetic Algorithm approach as the optimization technique for minimizing the Performance Index.

4.3 Genetic Algorithm

This is the robust optimizing technique. A lot of literature is available on this particular topic [3]. The stepwise procedure for the application of the genetic algorithm to the controller design problem is given as follows.

4.4 Genetic Algorithm applied to Controller Design Problem

The following are the steps involved:
1. The values of \( K_i, K_p, K_d \) are chosen randomly. A set of these values determines the population size.
2. Each value of \( K_i, K_p, K_d \) are interpolated within the range specified for \( K_i, K_p, K_d \).
3. Each interpolated value of \( K_i, K_p, K_d \) are passed on to a subprogram which calculates the objective function which is the performance index. The value returned from the subprogram is \( J \).
4. For each set of \( K_i, K_p, K_d \) the values of \( J \) are collected and these values are passed on the fitness function. The
fitness function is calculated using Rowlett wheel method.[3]

5. The minimum value of J is chosen among the fittest individuals (obtained from fitness function). This minimum value, along with their corresponding K_i,K_p,K_d are stored.

6. These fittest values of J are passed on to Crossover and Mutation functions to form a set of new population. These population are the new values of K_i,K_p,K_d obtained after first iteration.(Cross over and Mutation functions[3]).

7. The above steps are repeated till maximum generation. Maximum generation corresponds to the number of loops required to optimize the Performance Index.

8. From the stored minimum values of J the optimum value of J is obtained.

9. The corresponding values of K_i,K_p,K_d gives the optimum values of the controller gains.

5 Response of a Controlled System

The values of controller gains K_i,K_p,K_d are calculated using Genetic Algorithm with the steps outlined above. With these values, the state space equations for the closed loop system for a Hydro-Thermal system in the form of 

\[ \dot{X} = AX + BU \]

('A' and 'B' matrices are given in the Appendix) are formulated. These simultaneous differential equations are solved using Runge-Kutta fourth order method and the responses are plotted. These responses (Fig's 5-10) represent the response of the complete system with controller included.

While computing the responses some simplified assumptions are made.

5.1 Assumptions

1. No Generation rate constraints are considered.
2. Dead band of the Governor is neglected
3. Load-frequency dependency is linear, meaning that the load would increase one percent for once percent frequency increase.[1]

6 Conclusions

The responses of the Hydro-Thermal system with different controllers viz. a) Integral controller b) Proportional Integral controller controller have been evaluated. The application of Genetic Algorithm for the Optimization of gains of the above-mentioned controllers is very efficient and has faster solution finding capability. The different types of controllers mentioned above have neutralized the offset, which appeared in case of an Uncontrolled system.

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References


APPENDIX

Hydro-Thermal System with PI Controller

The state variables chosen are

\[ x_1 = \Delta f_1; x_2 = \Delta P_{t1}; x_3 = \Delta P_{g1}; x_4 = \Delta f_2; x_5 = \Delta P_{t2}; \]
\[ x_6 = \Delta P_{g2}; x_7 = \Delta P_{m0}; x_8 = \Delta P_{c1}; x_9 = \Delta P_{c2}; \]
\[ x_{10} = \dot{x}_6; x_{11} = \dot{x}_{10} \]
The 'A' matrix is
\[
\begin{bmatrix}
-1 & \frac{K_{ps}}{T_{ps}} & 0 & 0 & 0 & 0 & -\frac{K_{ps}}{T_{ps}} & 0 & 0 & 0 & 0 \\
0 & -\frac{1}{T_{tr}} & \frac{1}{T_{tr}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-\frac{1}{T_{g}} & 0 & -\frac{1}{T_{g}} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{T_{ps}} & -\frac{1}{T_{ps}} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{0.5 T_{w}} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{0.5 T_{w}} & 0 & 0 & 0 & 0 \\
2 \pi T_{12} & 0 & 0 & -2 \pi T_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
G_{18} & G_{28} & 0 & G_{48} & 0 & 0 & G_{78} & 0 & 0 & 0 & 0 \\
G_{19} & 0 & 0 & G_{49} & G_{59} & 0 & G_{79} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
G_{1} & 0 & 0 & G_{4} & G_{5} & 0 & G_{7} & 0 & G_{9} & G_{10} & G_{11}
\end{bmatrix}
\]

Where
\[
G_{18} = \frac{K_{p} B_{1}}{T_{ps}} - K_{p} 2 \pi T_{12} - K_{i} B_{1} ; G_{28} = \frac{-K_{p} B_{1} K_{ps}}{T_{ps}} ; G_{48} = \frac{K_{p} 2 \pi T_{12}}{T_{ps}} ;
\]

\[
G_{78} = \frac{K_{p} B_{1} K_{ps}}{T_{ps}} - K_{i} 1
\]

\[
G_{19} = a_{12} K_{p} 2 \pi T_{12} ; G_{49} = \frac{B_{2} K_{p} K_{ps}}{T_{ps}} - B_{2} K_{i} 2 - a_{12} K_{p} 2 \pi T_{12} ; G_{59} = \frac{-B_{2} K_{ps} K_{p}}{T_{ps}} ;
\]

\[
G_{79} = a_{12} K_{i} 2 - \frac{B_{2} K_{p} a_{12} K_{ps}}{T_{ps}}
\]

\[
G_{1} = \frac{K T_{ps} a_{12} K_{ps} 2 \pi T_{12}}{T_{1}} ; G_{4} = \frac{-K T_{ps}}{T_{1}} + \frac{K T_{tr}}{T_{ps} T_{1}} + \frac{K T_{ps} B_{1} K_{ps}}{T_{ps} T_{1}} - \frac{K T_{ps} B_{1} K_{i} 2}{T_{1}} - \frac{K T_{ps} a_{12} K_{ps} 2 \pi T_{12}}{T_{1}} ;
\]

\[
G_{5} = \frac{-K T_{ps} K_{ps} 2}{T_{ps} T_{1}} - \frac{K T_{ps} B_{2} K_{ps} 2 K_{p}}{T_{ps} T_{1}} ;
\]

\[
G_{7} = \frac{-K T_{ps} a_{12} K_{ps} 2}{T_{ps} T_{1}} + \frac{a_{12} K_{i} K_{ps}}{T_{1}} - \frac{K T_{ps} B_{2} K_{ps} 2 a_{12}}{T_{ps} T_{1}} ;
\]

\[
G_{9} = \frac{K}{T_{1}} ; G_{10} = -\frac{1}{T_{1}} ; G_{11} = -\frac{1}{T_{1}} ;
\]

The 'B' matrix is
\[
\begin{bmatrix}
-\frac{K_{ps}}{T_{ps}} & \Delta P_{d} & 0 & 0 & -\frac{K_{ps}}{T_{ps}} & \Delta P_{d} & 0 & 0 & 0 & 0 & T_{8} & T_{9} & 0 & T_{11}
\end{bmatrix}
\]

Where
\[
T_{8} = \frac{K_{p} B_{1} K_{ps} 1}{T_{ps}} \Delta P_{d} 1 ; T_{9} = \frac{B_{2} K_{ps} K_{ps} 2}{T_{ps}} \Delta P_{d} 2 ;
\]

\[
T_{11} = (\frac{K T_{ps} K_{ps}}{T_{ps} T_{1}} + \frac{B_{2} K_{ps} K_{ps} 2 K_{ps} K_{ps}}{T_{ps} T_{1}}) \Delta P_{d} 2
\]
For obtaining the 'A' and 'B' matrices for an Integral controller substitute Kp=0.
For obtaining the 'A' and 'B' matrices for an Uncontrolled system substitute Kp=0;Ki=0.

Fig 5. Frequency (Thermal area) vs. time
Hydro-Thermal system (I controller)

Fig 6. Frequency (Hydro area) vs. time
Hydro-Thermal system (I controller)

Fig 7. Frequency (Thermal area) vs. time
Hydro-Thermal system (PI controller)

Fig 8. Frequency (Hydro area) vs. time
Hydro-Thermal system (PI controller)

Fig 9. Tie line power vs. time
Hydro-Thermal system (I controller)

Fig 10. Tie line power vs. time
Hydro-Thermal system (PI controller)