Load Frequency Control Of Multi Area Power System Using Fuzzy And Optimal Control Techniques

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Abstract—This paper deals with Load Frequency Control of two area thermal-thermal system with conventional LQR Controller and Fuzzy Logic Controller. The simulation is realized by using Matlab/Simulink software. The investigation revealed that the LQR Controller performs better than the fuzzy logic Controller.

Keywords—Area Control Error(ACE), Linear Quadratic Regulator (LQR), Fuzzy Logic Controller(FLC), State Feed Back control(SFC),Optimal Feedback.

I. INTRODUCTION

This chapter deals with the control mechanism needed to maintain the system frequency. The topic of maintaining the system frequency constant is commonly known as AUTOMATIC LOAD FREQUENCY CONTROL (ALFC). It has got other nomenclatures such as Load Frequency Control, Power Frequency Control, Real Power Frequency Control and Automatic Generation Control.

The basic role of ALFC is:

1. To maintain the desired megawatt output power of a generator matching with the changing load.
2. To assist in controlling the frequency of larger interconnection.
3. To keep the net interchange power between pool members, at the predetermined values.

The ALFC loop will maintain control only during small and slow changes in load and frequency. It will not provide adequate control during emergency situation when large megawatt imbalances occur.

II. SYSTEM MODELLING

Modeling of physical system is an important task of the power system design procedure. The first step in the analysis of a dynamic system is to derive its mathematical model. Mathematical model may assume different forms. Once a mathematical model of a system is obtained various analytical and computer tools can be used for analysis and synthesis purposes[1].

2.1 Speed Governing System Model.

If a generating unit is operated with fixed mechanical power output from the turbine, the result of any load change would be a speed change sufficient to cause the frequency sensitive load to exactly compensate for the load change[2]. This condition would allow system frequency to drift for outside acceptable limits. This is overcome by adding a governing mechanism that senses the machine speed and adjusts the input valve to change the mechanical power output to compensate for load changes and to restore frequency to nominal value.

Equation of the speed governor model,
2.2 Turbine Model.
Prime-movers are devices which convert any form of energy into a mechanical energy. There is incremental increase in turbine power, due to the change in valve position that will result in an increased generator power.

\[ \Delta X(s) = \left[ \Delta P_C(s) - \frac{1}{R} \Delta F(s) \right] \cdot \frac{K_g}{1 + sT_g} \]

2.3 Generator Load Model
The synchronous machine as an ac generator driven by a turbine is the device, which converts mechanical energy into electrical energy. An isolated generator is only supplying local load and is not supplying power to another area via tie line. Suppose there is a real load change \( \Delta P_D \), due to the action of turbine controllers, the generator increases its output by the amount \( \Delta P_G \).
Prime-movers are devices which convert any form of energy into a mechanical energy. There is incremental increase in turbine power, due to the change in valve position that will result in an increased generator power.

\[ \Delta F(s) = \left[ \Delta P_g(s) - \Delta P_D(s) \right] \cdot \frac{K_p}{1 + sT_p} \]

III. LINEAR QUADRATIC REGULATOR
The theory of optimal control is concerned with operating a dynamic system at minimum cost. The case where the system dynamics are described by a set of linear differential equations and the cost is described by a quadratic function is called the LQ problem. One of the main results in the theory is that the solution is provided by the linear-quadratic regulator (LQR), a feedback controller whose equations are given below. The LQR is an important part of the solution to the LQG (Linear-Quadratic-Gaussian) problem. Like the LQR problem itself, the LQG problem is one of the most fundamental problems in control theory [3]. In order to study understand LQR we must know about state space equations of two area system. The state space dynamic equations of the system is given below
\[ \dot{x} = Ax + Bu + \tau d \]
\[ y = cx \]

*Figure 2. Block diagram for two area thermal-thermal power system*

The states of automatic load frequency control system are as below:

\[ x_1 = \Delta f_1 \quad x_2 = \Delta pg_1 \quad x_3 = \Delta pt_1 \quad x_4 = \Delta f_2 \quad x_5 = \Delta pg_2 \quad x_6 = \Delta pt_2 \quad x_7 = \Delta p_{zle} \]
\[ x_8 = ACE1 \quad x_9 = ACE1 \]

The matrices \( A, B \) and \( \Gamma \) are:

\[
A = \begin{bmatrix}
\frac{1}{T_{p_1}} & 0 & 0 & 0 & 0 & \frac{1}{T_{p_1}} & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
-\frac{1}{R_{e}T_{g_1}} & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

\[
\Gamma = \begin{bmatrix}
-\frac{1}{T_{g_1}} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

The control inputs are linear combinations of system states given by \( u = -Kx \) where \( K \) (2×9) is the feedback gain matrix where, \( K \) (2×9) is the feedback gain matrix.
3.1 Determination of the Feedback Gain Matrix (K):

The design of an optimal controller is to determine the feedback matrix ‘K’ in such a way that a certain Performance Index (PI) is minimized.

\[ PI = \frac{1}{2} \int_0^{\infty} (x^T Q x + u^T R u) dt \]

The matrices Q and R are determined on the basis of following system requirements.

1) The excursions (deviations) of ACEs about steady values are minimized.

\[ \Delta CE_1 = \Delta f_1 + \Delta p_{vis} \]
\[ \Delta CE_2 = \Delta f_2 + \Delta p_{vis} \]

2) The excursions of control inputs \( u_1 \) and \( u_2 \) about steady values are minimized.

Under these considerations, the PI takes a form and the optimal control is given by

\[ u = -Kx \]

‘K’ is the feedback gain matrix given by

\[ K = R^{-1}B^T S \]

where, ‘S’ is a real, symmetric and positive definite matrix which is the unique solution of matrix Riccati Equation [10]

\[ A^T S + SA - SBR^{-1}B^T S + Q = 0 \]

The closed loop system equation is

\[ x = Ax + B(-Kx) \]

The matrix \( A_c = A - BK \) is the closed loop system matrix. The stability of closed loop system can be tested by finding eigenvalues of \( A_c \).

In solution of the above equation, Riccati equation solution is used. From Riccati equation matrix optimal feed-back gaining and state response of the system at the beginning are solved. For the solution of Riccati equation, \([k, p] = lqr (A, B, Q, R)\) function in Mat lab Control Toolbox is used. In the modeling of electric power system on the state space and controlling of optimal LQR load frequency, journal of electrical and electronics engineering 2009, volume 9, number 2 preferred Q and R parameters to design the optimal LQR. [9] Using the Riccati equations, K feed-back gaining matrix is selected. If the system response is not stable, the new Q and R weight matrices are determined.

IV. FUZZY LOGIC CONTROLLERS

Fuzzy logic is a novel approach that incorporates an alternate way of thinking which allows one to model complex systems using a higher level of abstraction. It is a very powerful method of reasoning when mathematical models are not available and input data are imprecise. It also finds extreme application wherever a logic in the spirit of human thinking can be introduced. In fuzzy logic, a particular object has a degree of membership in a given set which is in the range of 0 to 1. A Fuzzy
Logic Controller (FLC) uses fuzzy logic as a design methodology which can be applied in developing linear and non-linear systems. FLC techniques have been found to be a good replacement for conventional control techniques, which require highly complicated mathematical models. The FLC comprises of four principal components[6].

1) A fuzzification interface
2) A knowledge base
3) A decision making logic and
4) A defuzzification interface

4.1 Fuzzification and Membership Functions
Fuzzification implies the process of transforming the crisp control values of the inputs to a controller, to fuzzy domain. Selection of the control variables relies on the nature of the system and its desired output. Seven linguistic variables for each input variables were used to get the desired performance. The linguistic variables are specified by Gaussian membership function. Membership function forms a crucial part in a fuzzy rule base model because they only actually define the fuzziness a control variable or a process variable. A set of membership defined for seven linguistic variables are NB, NM, NS, ZE, PS, PM, PB respectively is shown in fig.3 and fig.4.

4.2 Rules Creation and Inference
In general fuzzy systems map input fuzzy sets to output fuzzy sets. Fuzzy control rules provide a convenient way for expressing control policy and domain knowledge. The proper choice of process state variables and control variables are essential to the characterization of the operation of a fuzzy system. The modes of deriving fuzzy rules are based on trial and error method. Since each of the input variables contain seven linguistic variables, as a result of 49 rules are devised.
Table 1. Fuzzy inference rules

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<thead>
<tr>
<th>$\Delta F$</th>
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<th>NS</th>
<th>ZE</th>
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V. SIMULATION AND RESULTS

In this work two area thermal-thermal power system is simulated, the simulation circuit for two area system with fuzzy logic control is shown in figure 5 and simulation circuit for LQR control circuit is shown in figure 6.

*Figure5. simulation circuit for LQR controller.*
The results obtained are as shown below for a 0.1 step load change in area1 the change in frequency in area 1 and area 2 are shown in figure 7 and figure 8.

![Simulation Circuit for Fuzzy Logic Controller](image)

*Figure 6. Simulation circuit for fuzzy logic controller.*

*Figure 7. Frequency change in area 1 and area 2 for step load change in area 1.*
The result obtained for simulation circuit in figure 5 are shown in figure 8 and figure 9; it is control with lqr and the results obtained are better than fuzzy logic control shown in figure 10 and figure 11.

**Figure 8** frequency change in area 1 for step load change in area 1 with lqr control

**Figure 9** frequency change in area 2 for step load change in area 1 with lqr control
VI. CONCLUSION

Model of a two area interconnected power system has been developed with different area characteristics for optimal and conventional control strategies. The control equations and the state equations have successfully been derived in continuous time for a two area power system. The model developed here has also been examined for the stability before and after the application of state feedback control. Optimal control technique has a huge application over control engineering. An optimal regulator called Linear Quadratic Regulator (LQR) has been applied for Load Frequency Control (LFC) of a two area power system. A control law is generated on the basis of measured output and present states for infinite period of time. A State space model was developed by the help
of state equations for the application of LQR. So by the application of state feedback controller the stability of area frequency and tie line power was obtained which is been proved as one of the effective controller in this proposed work.

REFERENCES