Analysis and Simulation of Stability Technique of ALFC in Isolated Area of Power System

Sanitha Michail C
CMR Institute of Technology, Bengaluru
E-mail: sanitha.c@cmrit.ac.in

Abstract. Major function of ALFC loop (automatic load frequency control) in a power system is to regulate the megawatt output and frequency of the generator. Variation in the load demand brings variation in the response of the system frequency. State equations of ALFC loop of an isolated power system, with and without integrator, are examined in the paper. This paper deals with the analysis and simulation of pole placement technique for stability of the system. Pole placement method will help the designers to choose the appropriate design parameters to get the desired response from the system.

Keywords: Automatic load frequency loop, power system area, pole placement, frequency deviation, control parameter

1. Introduction
Frequency and voltage are the two important parameters in power system. It has to be continuously monitored and maintained within the limits. The main aim of an interconnected power system is to deliver the load in both active and reactive power by maintaining the voltage and frequency at desired limit. There are two major control loops in generator to achieve this task. (i) Automatic Voltage Regulator (AVR) (ii) Automatic Load Frequency Control (ALFC). Figure 1 shows the schematic diagram of AVR and ALFC loops. Real power changes mainly depend on changes in rotor angle which in turn affects the frequency. Reactive power changes depend on magnitude of voltage which depends on excitation of voltage. Automatic Load Frequency Control loop controls the megawatt output and frequency of the generator while terminal voltage V is controlled by Automatic Voltage Regulator loop. ALFC loop has a fast primary loop which respond to the frequency signal and a slow secondary loop to maintain the fine adjustment of the frequency and maintain megawatt power interchange with other pool members.

2. ALFC of Isolated Area System
Figure 2 shows the schematic diagram of a speed governing system of a generator with a regulation characteristics R. This system can also be called as the primary control loop. Pressurized steam which controls the turbine is in turn controlled by the position of xE. Downward or upward movement of point E decreases or increases the flow of steam to the turbine respectively. It can be measured in megawatt change ΔPv. This flow can be translated into turbine power change ΔPt. Hydraulic amplifiers are used to control the main valve against the high pressure steam.
Position of $x_D$ of the pilot valve is the input to the hydraulic amplifier and position of $x_E$ of the main piston is the output. Position of pilot valve will be changed (i) if there is a change in the power settings $\Delta P_{\text{ref}}$, point A (ii) due to the position changes in main piston, point C (iii) due to the changes of point B due to the variations in speed of the generator.[1]. Figure.3 shows the block diagram of speed governor.

$$\Delta P_g(s) = \Delta P_{\text{ref}}(s) - (1/R)\Delta f(s)$$
Output equation of hydraulic actuator can be written as \( \Delta P_v = k_H \int \Delta x_D \, dt \), \( k_H \) depends on cylinder geometrics and fluid pressure. Change in \( x_D \) can be written as \( \Delta x_D = \Delta P_g - \Delta P_v \)

\[
\Delta P_v(s) = \left( \frac{k_H}{s} \right) \Delta x_D(s)
\]

(1)

\[
\Delta x_D(s) = \Delta P_g(s) - \Delta P_v(s)
\]

(2)

Solving (1) and (2) equations we get,

\[
\Delta P_v(s) = \frac{1}{1+sT_H} \Delta P_g(s), T_H = \frac{1}{k_H}
\]

where \( T_H \) is the hydraulic time constant.

Transfer function of the hydraulic valve actuator can be written as \( G_H(s) = \frac{\Delta P_v(s)}{\Delta P_g(s)} = \frac{1}{1+sT_H} \).

The block diagram of hydraulic actuator is shown in figure 4.

Accelerating power in turbine can be written as \( \Delta P_T(s) - \Delta P_C(s) \).

Transfer function of turbine can be written as \( \Delta P_T(s) = G_T \Delta P_v(s) = \frac{1}{1+sT_T} \Delta P_v(s) \)

Change in generator power \([2]\) depends on the change in load power. \( \Delta P_G(s) = \Delta P_D(s) \)

Linear model of primary ALFC loop is shown in figure 5.
Considering the kinetic energy of the rotor proportional to the square of speed and load as a function of voltage and frequency, \( W_{kin} = W_{kin}^o \left( \frac{f}{f^o} \right)^2 \) MW sec

\[
D = \frac{\partial P_D}{\partial f} \text{ MW / Hz}
\]

Thus \( \Delta P_T - \Delta P_D = \frac{d}{dt} (W_{kin}^o) + D \Delta f \) and \( f = f^o + \Delta f \)

\[
\Delta P_T - \Delta P_D = \frac{2W_{kin}^o}{f^o} \frac{d}{dt}(\Delta f^o) + D \Delta f \text{ MW. Let } H = \frac{W_{kin}^o}{P_r} \text{ MW sec/MW (or sec) then}
\]

\[
\Delta P_T (s) - \Delta P_D (s) = \frac{2H}{f^o} s \Delta f(s) + D \Delta f(s)
\]

\[
\Delta f(s) = G_p(s) [\Delta P_T(s) - \Delta P_D(s)]
\]

\[
G_p(s) = \frac{1}{2Hf^o s + D} = \frac{1}{1 + sT_p} \frac{K_p}{2Hf^o} \text{ where } K_p = \frac{1}{D} \text{ and } T_p = \frac{2H}{f^o D}
\]

Also \( \frac{K_p}{1 + sT_p} \) can be written as \( \frac{1}{2Hs + D} \). Block diagram of primary ALFC loop is shown in figure 6

![Figure 6: Block diagram of primary ALFC Loop](image)

We can make the speed changer be commanded by a signal obtained by amplifying [4] and integrating the frequency error. \( \Delta P_{ref} = -K_i \int \Delta f dt \) where \( K_i \) is the integral control. Figure 7 shows the block diagram of complete ALFC loop

![Figure 7: Block diagram of complete ALFC loop](image)
3. State Space model of single area AGC

From the above equations the state equations can be written as

\[
\begin{bmatrix}
\dot{\Delta f} \\
\dot{\Delta P_T} \\
\dot{\Delta P_V} \\
\dot{\Delta P_{ref}}
\end{bmatrix}
= 
\begin{bmatrix}
-D/2H & 1/2H & 0 & 0 \\
0 & -1/T_R & 1/T_R & 0 \\
-1/RT_H & 0 & -1/T_H & 1/T_H \\
-K & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
\Delta f \\
\Delta P_T \\
\Delta P_V \\
\Delta P_{ref}
\end{bmatrix}
+ 
\begin{bmatrix}
-1/2H \\
0 \\
0 \\
0
\end{bmatrix}
\Delta P_D
\]

Standard form of state space model can be written as

\[
X(t) = AX(t) + Bu(t)
\]

\[
y(t) = CX(t) + Du(t)
\]

where \(y(t)\) is the output, \(u(t)\) is the input vector and \(X(t)\) is the state vector. Here

\[X(t) = \begin{bmatrix} \Delta f & \Delta P_T & \Delta P_V & \Delta P_{ref} \end{bmatrix}^T \]

\[u(t) = \Delta P_D\] and \(y(t) = \Delta f\)

4. Stability technique-Pole Placement Design

The stability of the power system is determined by the matrix A. If the eigen values of matrix A lie on the LHS of s-plane the system will be stable. For an unstable system it is possible to design a controller to locate the poles of the system on LHS. The control signal used is given by \(u(t) = -K X(t)\) where K is the vector of feedback gain as shown in figure.8

![Figure 8 Pole placement design](image)

\[\dot{X}(t) = AX(t) + B(-KX(t))\]

is the modified state vector.

The characteristic equation for the above model is given by \(|sI - A + BK| = |sI - A_p| = 0\)

This equation can be expanded into

\[|sI - A + BK| = s^n + (a_{n-1} + k_n)s^{n-1} + .......(a_1 + k_2)s + (a_0 + k_1) = 0\]

Consider the desired closed loop pole locations are \(-\lambda_1, -\lambda_2, ...., -\lambda_n\), then the desired characteristics equation can be written as

\[d(s) = (s + \lambda_1) + (s + \lambda_1) + ....(s + \lambda_n) = s^n + d_{n-1}s^{n-1} + .... + d_1s + d_0 = 0\]

Equating the two characteristic equations we get
\[ a_{n-1} + k_n = d_{n-1} \Rightarrow k_n = d_{n-1} - a_{n-1} \]
\[ a_0 + k_i = d_0 \Rightarrow k_i = d_0 - a_0 \]
\[ K_i = d_{i-1} - a_{i-1} \]

5. Results & Discussions

Here we have taken an isolated system without AGC, \( T_H = 0.3 \) s, \( T_T = 0.6 \) s, \( H = 5 \) s and \( D = 1 \). For this system \( R > 0.0183 \) for stability. Figure 9 shows the simulink model of a stable primary ALFC loop. Figure 10 shows the frequency deviation of the given system with \( R = 0.05 \) is stable and figure 11 shows that if \( R < 0.0183 \) it is unstable.

![Simulink model of a primary ALFC loop](image1)

![Frequency response of the system for R=0.05](image2)

![Frequency response of the system for R=0.016](image3)

The roots of the characteristics equation of the given system are \(-4.3216 + 0.0000i, -0.3877 + 1.5968i\) and \(-0.3877 - 1.5968i\) if the gain is chosen as 20. Figure 12 shows the frequency deviation of the
complete ALFC system with integral controller $K_I=5$ is stable. The roots of the characteristics equation of the given system with integral controller are $-4.2851 + 0.0000i, -0.2725 + 1.5337i, -0.2725 - 1.5337i$ and $-0.2669 + 0.0000i$.

![Figure 12](image)

Figure 12 Frequency deviation of complete ALDC loop with integral controller, $K_I=5$

If we choose $K_I=16$ system is becoming unstable and roots are $-4.1977 + 0.0000i, 0.0111 + 1.5153i, 0.0111 - 1.5153i$ and $-0.9215 + 0.0000i$. Here the pair of complex conjugate roots lying on RHS clearly explains the instability of the system(Figure 13).

![Figure 13](image)

Figure 13 Frequency deviation of complete ALDC loop with integral controller, $K_I=16$

Pole placement technique will improve the stability of the system. As explained before poles can be placed at the desired location. Consider the conjugate pair of poles to be placed at $-4\pm 6i$. The roots of the characteristics equation of the complete ALFC system with $K_I=16$ are $-4.0000 + 6.0000i, -4.0000 - 6.0000i, -4.3216 + 0.0000i$ and $-0.9215 + 0.0000i$. Figure 14 shows the response of the system after the pole placement where frequency quickly reaches the steady state.

6. Conclusion

Pole placement technique in an isolated area of power system has been explained in the paper to help the designers to choose the design parameters. A detailed discussion of controller poles influence on the closed loop system has been presented in the paper. Once the desired response of the closed loop system is specified, computation of the controller can be calculated automatically. Adequate adaptation of design parameters will help to obtain the desired location of the poles of the system for the realistic problems.
Figure.14 Frequency response after the pole placement

References

[1] Elgerd O L “Electric Energy Systems Theory An Introduction” McGraw Hill Education edition, 1983

[2] G. Shahgholian, P. Shafaghi and H. Mahdavi-Nasab, "A comparative analysis and simulation of ALFC in single area power system for different turbines," 2010 2nd International Conference on Electronic Computer Technology, Kuala Lumpur, Malaysia, 2010, pp. 50-54, doi: 10.1109/ICECTECH.2010.5479992.

[3] Uma Rao.K “Power System: Operation & Control.” Wileyindia, www.wileyindia.com/power-system-operation-control.html/

[4] M S Parvathy Thampi, "Low Voltage High Efficient Synchronous Buck Converter for Mobile Chargers," Journal of Solid State Technology, Volume: 63 Issue: 4 , Publication Year: 2020