COMPUTATION OF STABILIZING PI/PID CONTROLLER FOR LOAD FREQUENCY CONTROL

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Abstract—As power system is highly non-linear in nature, its operating point changes continuously. So, the system performance is very poor, which affect the real and reactive power. Changes in real power mainly affect the system frequency and changes in reactive power mainly depend on changes in voltage magnitude. Thus, real and reactive powers can be controlled separately. The Load Frequency Control (LFC) controls the real power and the Automatic Voltage Regulator (AVR) regulates the voltage magnitude and hence the reactive power. Load Frequency Control (LFC) of interconnected system is defined as the regulation of power output of generators. In general the Fixed gain controllers are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions. So, to keep system performance near its optimum, it is desirable to track the operating conditions and use updated parameters to compute the control. In this paper a new method of finding stabilizing PI, PID controllers has been proposed for LFC control system loop that is determined using "Boundary Locus Method".

Index Terms - Boundary locus method, Load frequency control, PID controller, Relative stabilization.

I. INTRODUCTION

Load fluctuations and abnormal conditions such as the generation outages, cause the system frequency to decay from the desired value. To ensure the quality of the power supply, it is necessary to regulate the generator loads depending on the optimal frequency value with a proper LFC design. In order to take the parametric uncertainty and the nonlinear constraints into account, and to keep the system performance near its optimal operating condition, different approaches have been applied in the past [1].

A controller is one which compares controlled values with the desired values and has a function to correct the deviation produced. The main objective of any controller is to attain the stability of a system.

- Controllers improve steady state accuracy by decreasing the steady state errors.
- As the steady state accuracy improves, the stability also improves.
- They also help in reducing the offsets produced in the system.
- Maximum overshoot of the system can be controlled using these controllers.
- They also help in reducing the noise signals produced in the system.
- Slow response of the over damped system can be made faster with the help of these controllers.

In this paper, a new method for the computation of all stabilizing PI controllers [2] and [3] is given. The proposed method is based on plotting the stability boundary locus in the (k_p; k_i) plane and then computing the stabilizing values of the parameters of a PI controller. The technique presented does not need to use Padé approximation and does not require sweeping over the parameters and also does not use linear programming to solve a set of inequalities. Thus it offers several important advantages over existing results obtained in this direction. Beyond stabilization, this method is used to compute stabilizing PI controllers which achieve specified gain and phase margins. The proposed method is also used to design PID controllers for control systems with and without time delay. The limiting values of a PID controller which stabilize a given system with time delay are obtained in the (k_p; k_i) plane, (k_p; k_d) plane, and (k_i; k_d) plane.

II. BOUNDARY LOCUS METHOD

Consider the single input, single output (SISO) control system of Fig.1 where

\[ G(s) = \frac{N(s)}{D(s)} \]  \hspace{1cm} (1)

is the plant to be controlled and C(s) is a PI controller of the form

\[ C(s) = k_p + \frac{k_i}{s} \]  \hspace{1cm} (2)

The problem is to compute the parameters of the PI controller of Eq.(2) that stabilize the system of Fig.1.

Fig. 1. SISO control system

Decomposing the numerator and the denominator polynomials of Eq.(1) into their even and odd parts and substituting \( s = j\omega \), gives
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\[ G(j\omega) = \frac{N_c(-\omega^2) + j\omega N_d(-\omega^2)}{D_c(-\omega^2) + j\omega D_d(-\omega^2)} \]

The closed loop characteristic polynomial of the system can be written as

\[ \Delta(s) = (k_p N_c(-\omega^2) - k_p w^2 N_d(-\omega^2) - w^2 D_c(-\omega^2)) + j(w k_p N_c(-\omega^2) + w k_i N_d(-\omega^2) + w D_d(-\omega^2)) \]  

(3)

Equating real and imaginary part to zero,

\[ k_p(-\omega^2 N_c(-\omega^2)) + k_i(N_d(-\omega^2)) = w^2(D_c(-\omega^2)) \]  

(4)

\[ k_p w N_c(-\omega^2) + k_i w N_d(-\omega^2) = -w^2(D_d(-\omega^2)) \]  

(5)

\[ \Rightarrow k_p Q(w) + k_i R(w) = X(w) \]

\[ \Rightarrow k_p S(w) + k_i U(w) = Y(w) \]

By substitution

\[ k_p = \frac{X(w) U(w) - Y(w) R(w)}{Q(w) U(w) - R(w) S(w)} \]  

(6)

\[ k_i = \frac{Y(w) Q(w) - X(w) S(w)}{Q(w) U(w) - R(w) S(w)} \]  

(7)

Where,

\[ Q(w) = -w^2 N_c(-\omega^2), R(w) = N_d(-\omega^2) \]

\[ S(w) = w N_c(-\omega^2), U(w) = w N_d(-\omega^2) \]

\[ X(w) = w^2 D_c(-\omega^2), Y(w) = -w^2 D_d(-\omega^2) \]  

(8)

Solving \( k_p \) and \( k_i \) equations simultaneously, the stability boundary locus, \( l(k_p; k_i) \), in the \((k_p; k_i)\) plane can be obtained. Choosing a test point within each stable region that contains the values of stabilizing \( k_p \) and \( k_i \) parameters can be determined. Assume Eq.(2) in the PID controller form then

\[ C(s) = k_p + \frac{k_i}{s} + s k_d \]

Using the above procedure, the stability boundary locus in the \((k_p; k_i)\) plane can be obtained for a fixed value of \( k_d \) or in the \((k_p; k_d)\) plane for a fixed value of \( k_i \). However, it is not possible to obtain the stability boundary locus in the \((k_i; k_d)\) plane for a fixed value of \( k_p \) since \( Q(\omega)U(\omega) - R(\omega)S(\omega) \) will be equal to zero for this case. Although the stability region in the \((k_i; k_d)\) plane for a fixed value of \( k_p \) is a convex polygon, the stability region in the \((k_p; k_d)\) plane for a fixed value of \( k_i \) or in the \((k_p; k_d)\) plane for a fixed value of \( k_d \) is not a convex polygon.

The respective \( k_p \), \( k_i \) and \( k_d \) equations are given as,

\[ k_p = \frac{w^3 N_c D_c + w N_c D_d}{-w^2 N_c^2 - N_c^2} \]

\[ k_i = \frac{(w^2 N_c D_c - w^2 N_c D_d)}{-w^2 N_c^2 - N_c^2} \]

Substituting \( k_i \) in terms of \( k_d \)

\[ k_i = \frac{(w^2 N_c D_c - w^2 N_c D_d) + k_d w^2(-w^2 N_c^2 - N_c^2)}{-w^2 N_c^2 - N_c^2} \]

(9)

\[ k_i = -\frac{(w^2 N_c D_c - w^2 N_c D_d) + k_i(-w^2 N_c^2 - N_c^2)}{w^2(-w^2 N_c^2 - N_c^2)} \]

Thus, using these equations the stability regions in the \((k_i; k_d)\) plane and \((k_p; k_d)\) plane can be obtained.

III. BASIC GENERATION CONTROL LOOPS

In an interconnected power system, LFC and AVR control loops are designed for each generator. The schematic diagram of the voltage and frequency control loop is represented in Fig. 2. The controllers are set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits. Small changes in real power are mainly dependent on changes in rotor angle \( \delta \) and, thus, the frequency \( f \). The reactive power is mainly dependent on the voltage magnitude (i.e. on the generator excitation) \[4\]. Change in angle \( \delta \) is caused by momentary change in generator speed. Therefore, load frequency and excitation voltage controls are non-interactive for small changes and can be modelled and analyzed independently. Furthermore, excitation control is fast acting while the power frequency control is slow acting since, the major time constant contributed by the turbine and generator moment of inertia-time constant is much larger than that of the generator field. Thus, the cross coupling between the LFC loop and the AVR is negligible, and the load frequency and excitation voltage control are analyzed independently. In power system, both active and reactive power demands are never steady they continuously change with the rising or falling trend. The changes in real power affect the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on Changes in voltage magnitude. The main purpose of system generation control is to balance the system generation against the load and losses so that the desired frequency and power interchanges between neighbouring systems are maintained. The two main control loops of a generation are Load Frequency Controller (LFC) and Automatic Voltage Regulator (AVR).

Fig. 2. Schematic diagram of LFC and AVR of a synchronous generator

\[ \text{Excitation System} \]

\[ \text{Automatic Voltage Regulator (AVR)} \]

\[ \text{Generator} \]

\[ \text{Valve Control mechanism} \]

\[ \text{Load Frequency Control (LFC)} \]

\[ \text{Frequency Sensor} \]

\[ \text{Voltage Sensor} \]
IV. LOAD FREQUENCY CONTROL (LFC)

Load frequency control is important in electrical power system design and operation. Moreover, to ensure the quality of the power supply, it is necessary to design an LFC system, which deals with the control of loading of generator depending on the frequency. Conventional controllers are quite often impractical for the implementation due to following reasons.

The optimal control is a function of all the states of the system. In practice all the states may not be available. The inaccessible states or missing states are required to be estimated. It may not be economical to transfer all the information over long distances. The control, which is a function of the states in turn, is dependent on the load demand. Accurate prediction of load demand may be essential for realizing optimal controller.

The aim of LFC is to maintain real power balance in the system through control of system frequency. Whenever the real power demand changes, a frequency change occurs. This frequency error is amplified, mixed and changed to a command signal which is sent to turbine governor. The governor operates to restore the balance between the input and output by changing the turbine out-put. This method is also referred as Megawatt frequency or Power-frequency (P-f) control.

### TABLE I

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Block</th>
<th>Gain</th>
<th>Time constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Governor</td>
<td>$k_g = 1$</td>
<td>$T_g = 0.2$</td>
</tr>
<tr>
<td>2</td>
<td>Turbine</td>
<td>$k_t = 1$</td>
<td>$T_t = 0.5$</td>
</tr>
<tr>
<td>3</td>
<td>Inertia</td>
<td>H=5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Regulator</td>
<td>R=0.05</td>
<td></td>
</tr>
</tbody>
</table>

A. Design of PID controller

From the Fig.(3) the transfer function between $\Delta(\omega)$ and $\Delta(P)$ is

$$\Delta(\omega)/\Delta(P) = \frac{1}{1 + \frac{2H + D}{(2Hs + D)(1 + T_g s)(1 + T_t s)}}$$

(Substituting the parameter values listed in Table-1)

$$\Delta(\omega)/\Delta(P) = G(s) = \frac{1}{(1 + 0.2s)(1 + 0.5s) + \frac{0.05}{s^2 + 0.7s + 1}}$$

$$\Rightarrow G(s) = \frac{0.1s^2 + 0.7s + 1}{s^3 + 7.08s^2 + 10.56s + 20.8}$$

(10)

Substituting $s = js$;

$$\Rightarrow G(jw) = \frac{(-0.1w^3 + 1) + jw(0.7)}{(-7.08w^2 + 20.8) + jw(-w^2 + 10.56)}$$

(11)

From Eq.(8), we have

$$\Rightarrow R(w) = -0.1w^2 + 1, U(w) = 0.7w$$

$$Q(w) = -0.7w^2, S(w) = -0.1w^3 + w$$

$$Y(w) = 7.08w^3 - 20.8w, X(w) = -w^4 + 10.56w^2$$

$$\Rightarrow k_p = \frac{0.008w^5 - 7.76w^3 + 20.8w}{-0.01w^5 - 0.29w^3 - w}$$

(12)

$$\Rightarrow k_i = \frac{-0.1w^3 - 2.0w^3 + 4w^3}{-0.01w^3 - 0.29w^3 - w}$$

(13)

In the analysis and design of control systems, it is important to shift all poles of the characteristic equation of a control system to a desired region in the complex plane, for example, to a shifted half plane that guarantees a specified settling time of the response. The aim of this section is to find all values of $k_p$ and $k_i$ that put all the closed loop poles to the left of $s = \rho$, where ($\rho = constant$). Using $s + \rho$ instead of $s$ in Eqs (1 and 2).

Now calculate the relative stabilization of $k_p$, $k_i$ plane and $\rho = 0.5$. Repeating the above procedure, we calculate $k_p$, $k_i$.

$$\Rightarrow k_p = \frac{0.058w^5 + 0.117w^3 + 38.46w}{-0.01w^5 - 0.36w^3 - 1.8906w}$$

(14)

$$\Rightarrow k_i = \frac{-0.1w^3 - 3.65w^3 + 2.9w^3}{-0.01w^3 - 0.36w^3 - 1.8906w}$$

(15)

And also the stability boundary line for $\omega = 0$ is given as

$$k_i = \frac{k_p\rho N_c (-w^2) - \rho D_c (-w^2)}{N_c (-w^2)}$$

(16)

From the Eqs (12,13,14,15 and 16), the stability region is shown in Fig.4.
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Now consider \( k_d \).

Step 1: Let’s consider \( k_i \) from Eq.(13)

\[
\Rightarrow k_i = \frac{a_1 w^5 + a_2 w^3 + a_3 w^3}{-0.01 w^5 - 0.29 w^3 - w}
\]

where \( a_1 = -0.1 - 0.01 k_d, \ a_2 = -2.9 - 0.29 k_d, \ a_3 = 4 - k_d \)

Stability regions for \( k_d = 0 \)

\[
k_i = \frac{-0.1 w^5 - 2.9 w^3 + 4 w^3}{-0.01 w^5 - 0.29 w^3 - w}
\]

(17)

Stability regions for \( k_d = 1 \)

\[
k_i = \frac{-0.11 w^5 - 3.19 w^3 + 3 w^3}{-0.01 w^5 - 0.29 w^3 - w}
\]

(18)

Now the plots are obtained for \( k_p \) and \( k_i \).

From the above 2 graphs we obtain 8 points for \( k_p = (6.568; 0); (9.257; 1); (0; 0); (0; 1); (0; 2.419); (1; 2.028); (0; 0); (1; 0) \).

From these we obtain 4 straight lines.

\[
k_d = 0.37188(k_i - 6.568), \ k_i = 0,
\]

\[
k_d = 0.391 k_i - 2.419, \ k_i = 0
\]

Now draw the patch form for these lines.

Now the plots are obtained for \( k_p \) and \( k_i \) and \( k_d \). These colour regions represent gain stability regions at different readings of \( k_p \) at 1.5, 0.6, -1.

Similarly we can draw patches for different values of \( k_p \).

For example let \( k_p = 0.8 \).

Now we obtain 4 straight lines

\[
k_d = 0.3333(k_i - 8), \ k_i = 0, \ k_d = \frac{k_i}{0.3} - 2.6, \ k_d = 0
\]

V. SIMULATION RESULTS

The constructed simulink block is shown in Fig.8.

![Simulink LFC block](Fig. 8. Simulink LFC block)

From the above 2 graphs we obtain 8 points for \( k_p = (6.568; 0); (9.257; 1); (0; 0); (0; 1); (0; 2.419); (1; 2.028); (0; 0); (1; 0) \).

![Plot for change in frequency for a step load change of 0.1 p.u.](Fig. 9. Plot for change in frequency for a step load change of 0.1 p.u.)
Suppose the gains of conventional PID controller be $k_p = 1$, $k_i = 0.25$ and $k_d = 0.8$ in Fig. 8.

From the above section we evaluate the optimal $k_p$, $k_i$ and $k_d$ stabilizing regions.

Fig. 10. Plot for change in frequency for a step load change of 0.1 p.u.

CONCLUSION

The quality of the power supply is determined by the constancy of frequency and voltage. The stabilizing PID control parameters of LFC control system for controlling the real power and frequency are obtained using "Stability boundary locus method". The simulation results revealed that the proposed PID Controller using "Boundary Locus Methods" can obtain the optimal parameters of LFC quickly and efficiently. It can be concluded that, the PID controllers provide a satisfactory stability between frequency overshoot and transient oscillations with zero steady state error. The simulation results demonstrate the effectiveness response.

REFERENCES


