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# Proportional Integral Observer Based Load Frequency Control for Stable Operation of Power System

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***Abstract*: Real and reactive power both change in every moment and random in nature. Change in real power causes change in system frequency and this change should not cross the threshold and preset value. To control the real power, prime mover input is regulated and hence require a continuous control mechanism for load frequency control (LFC). In this research paper proportional integral observer (PIO) method for LFC is investigated and used for controlling frequency deviation due to change in real power. To validate the proposed method, several computer simulations were performed in MATLAB/Simulink environment. The performance of the controller depict that the frequency deviation is perfectly controlled to make the system for steady state operation.**

***Keywords*: Automatic gain control, frequency deviation, load frequency control, proportional integral observer.**

## 1. Introduction

The geographical distributions and interconnection make the modern power system very complicated. In this complicated system the generated and demand power of each area should be matched in terms of different power system parameters. The demand of real and reactive power are not steady and change in every moment and random in nature. Real power is controlled by manipulating the prime mover input, and controlled excitation of generator is used to regulate reactive power. So, as the both power demand change every time, continuous controlling mechanism is necessary to avoid frequency deviation. The exchange of power of interconnected power system and corresponding system frequency must be align to their preset nominal values for the steady state operation and continuity of power flow. This can be achieved by applying the suitable method of controlling the system frequency. Various methods of frequency control are investigated so far, for example, Droop control, isochronous control, and load frequency control [1]. In case of Droop method, all connected generators are bound to response the change of frequency, whereas Droop control assign a large capacity of generator to maintain the frequency letting rest of the generator operated in constant power. On the contrary, Load Frequency control (LFC) uses a directorial control to gain superior performance maintaining zero tolerance of steady state change in frequency to track the demand of load. Different control methods have been suggested for this controller design. The most broadly proposed methods are traditional PI and PID controller due to their simple implementation procedure and the design of these controller depends on the targeted system model [2, 3]. If, the parameters vary somehow, then the performance of these controller decrease. To cope with this constraint, researchers offers two degree of PID, linear quadratic regulator (LQR), genetic algorithm, particle swarm optimization [4, 5] etc. methods to compensate for the effect of change in frequency. But, due to system complexity, the direct analysis of the above methods are not straightforward. Moreover, LQR methods assume all state information of the model is accessible [6] to use as feedback to the input and for real life problem that is impractical. To overcome this limitation, in this PIO method is proposed that uses the partial state information of the system.

## 2. System model

Basic schematic diagram of LFC method is shown in Fig. 1. The frequency sensor sense the change in frequency and processed with tie line power to generate the input command signal for prime mover to change the torque.

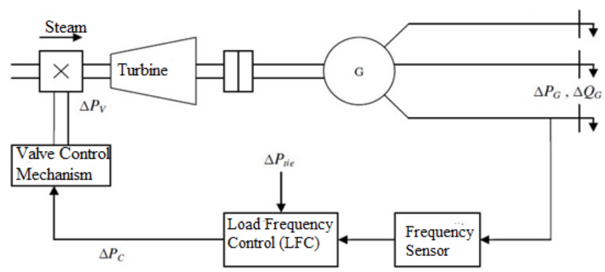


Fig. 1. Load frequency control schematic diagram

*Generator model:*

The swing equation of a synchronous generator including small disturbances is given by [6]

$$\frac{2H}{\omega_s}\frac{d\Delta\Omega}{dt} = \Delta P_m - \Delta P_e \quad (1)$$

Where, $\Delta P_m$ is change in mechanical power, $\Delta P$ is that of electrical power, and $\Delta\Omega$ is change in angular speed of the generator. Applying Laplace transform on the above equation results

$$\Delta\Omega(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s)] \quad (2)$$

The equation (2) can be represented in the form of block diagram as

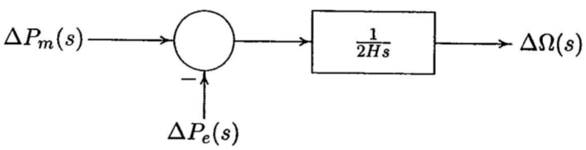


Fig. 2. Generator block diagram

The speed-load characteristics of composite load is approximated as, $\Delta P_e = \Delta P_L + D\Delta\omega$, where, $D$ is expressed in percent change in load to percent change in frequency.

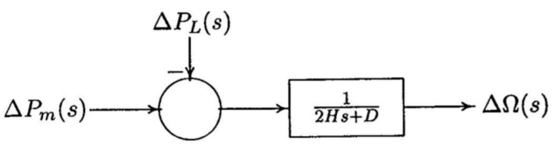


Fig. 3. Generator and load block diagram

*Prime mover:*

Mechanical power output of a prime mover $\Delta P_m$ depends on the steam valve setting, for steam turbine and can be modeled by using the following transfer function.

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T s} \tag{3}$$

The function of the governor in power generation system is to sense the change in speed of the turbine and to adjust the valve position for steady-state operation. The speed governing system for steam turbine is presented in the following Figure 4. Assuming a linear relationship with simple time constant $\tau_g$, input-output relation of governor can be obtained as follows,

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s) \tag{4}$$

Considering governor, turbine, and generator the LFC block diagram is drawn as shown in Fig. 5.

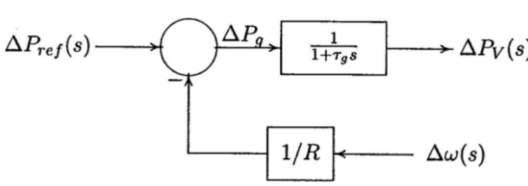


Fig. 4. Speed governing system for steam turbine

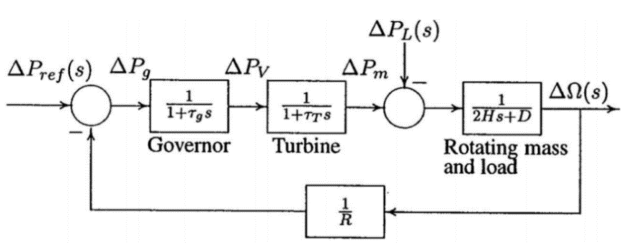


Fig. 5. Load frequency block diagram for an isolated power system

The outputs of governor, turbine, and generator can be written in s-domain as follows,

$$\begin{aligned}
(1+\tau_g)\Delta P_V(s) &= \Delta P_{ref}(s) - -\frac{1}{R}\Delta\Omega(s) \\
(1+\tau_T s)\Delta P_m(s) &= \Delta P_V \\
(2H_s + D)\Delta\Omega(s) &= \Delta P_m - \Delta P_L
\end{aligned} \tag{6}$$

Solving for first derivative term of above equations results

$$\begin{aligned}
s\Delta P_V(s) &= -\frac{1}{\tau_g}\Delta P_V - \frac{1}{\tau_g}\Delta\Omega(s) + \frac{1}{R\tau_g}\Delta P_{ref}(s) \\
s\Delta P_m(s) &= \frac{1}{\tau_T}\Delta P_V - \frac{1}{\tau_T}\Delta P_m \\
s\Delta\Omega(s) &= \frac{1}{2H}\Delta P_m - \frac{D}{2H}\Delta\Omega(s) - \frac{1}{2H}\Delta P_L
\end{aligned} \tag{7}$$

In matrix form,

$$\begin{bmatrix} \Delta\dot{P}_V \\ \Delta\dot{P}_m \\ \Delta\dot{\omega} \end{bmatrix} = \begin{bmatrix} -\frac{1}{\tau_g} & 0 & -\frac{1}{R\tau_g} \\ \frac{1}{\tau_T} & -\frac{1}{\tau_T} & 0 \\ 0 & \frac{1}{2H} & -\frac{D}{2H} \end{bmatrix} \begin{bmatrix} \Delta P_V \\ \Delta P_m \\ \Delta\omega \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ -\frac{1}{2H} \end{bmatrix} \Delta P_L + \begin{bmatrix} \frac{1}{\tau_g} \\ 0 \\ 0 \end{bmatrix} \Delta P_{ref} \tag{8}$$

### 3. Proposed PIO controller

The PI as well as Luenberger observer are same in terms of structure as an extended state observer for disturbance estimations, but, PI-observer consists of an extra integral feedback loop to estimate the error and offers two degrees of freedom for the estimation task. Firstly, enhance the robustness of estimations and secondly step disturbance estimation. The state space model shown in equation (8) can be expressed as follows where, $x$ is that state, $u$ is input, and $d$ is disturbance [7].

$$\begin{aligned}
\dot{x} &= Ax + Bu + Ed \\
\dot{d} &= 0 \\
y &= Cx
\end{aligned} \tag{9}$$

The state space model of the proportional observer is given bellow, where $\hat{x}$ is the estimated state variables.

$$\dot{\hat{x}} = A\hat{x} + Bu + L(y - C\hat{x}) \tag{10}$$

The error between actual and estimated values,

$$\begin{aligned}
\dot{e} &= \dot{x} - \dot{\hat{x}} = Ax + Ed + (A - LC)\hat{x} - Ly \\
&= (A - LC)e + Ed
\end{aligned} \tag{11}$$

From equation (11), it is seen that if disturbance, $d = 0$, the PO can estimate the state variables if $(A - LC)$ is stable. But, if $d \neq 0$, a constant steady state error occurs. To resolve this problem for estimation, a disturbance observer (DO) is used as follows,

$$\dot{\hat{x}} = A\hat{x} + Bu + L_P(y - C\hat{x}) + E\hat{d}$$
$$\dot{\hat{d}} = L_I(y - C\hat{x}) \tag{12}$$

As shown in [5], the state space model of PIO is given by,

$$\dot{\hat{x}} = A\hat{x} + Bu + Ev + G(y - C\hat{x})$$
$$\dot{v} = F(y - C\hat{x}) \tag{13}$$

From above equations (12), (13), it is obvious that the DO can be regarded as PIO in a special case. The block diagram of PIO is shown below:

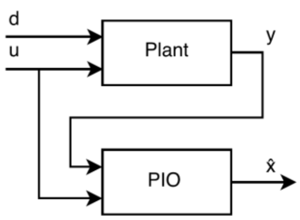


Fig. 6. Block diagram of PIO

First two equations in (9) can be combined together by defining, $z = \begin{bmatrix} x \\ d \end{bmatrix}$, so that

$$\dot{\hat{z}} = \begin{bmatrix} A & E \\ 0 & 0 \end{bmatrix}\begin{bmatrix} x \\ d \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix}u = A_z z + B_z z \tag{14}$$

The output of the plant in the same manner is given by

$$y = Cx = \begin{bmatrix} C & 0 \end{bmatrix}\begin{bmatrix} x \\ d \end{bmatrix} = C_z z \tag{15}$$

Similarly, the state space model of DO can be rewritten as follows

$$\dot{\hat{z}} = \begin{bmatrix} A - L_P C & E \\ -L_I C & 0 \end{bmatrix}\hat{z} + \begin{bmatrix} L_P \\ L_I \end{bmatrix}y + \begin{bmatrix} B \\ 0 \end{bmatrix}u \tag{16}$$

Adding feedback to the system shown in Figure 6, PIO based regulator is formed as shown in Fig. 7.

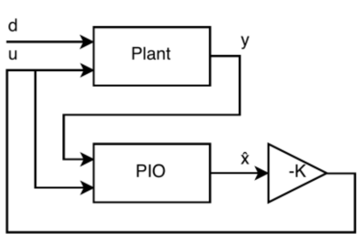


Fig. 7. PIO based regulator

The state space equation of PIO can be written as combining equations (9) and (12),

$$\begin{bmatrix} \dot{x} \\ \dot{\hat{x}} \\ \dot{\hat{d}} \end{bmatrix} = \begin{bmatrix} A & -BK & 0 \\ L_P C & A - BK - L_P C & E \\ L_I & -L_I C & 0 \end{bmatrix}\begin{bmatrix} x \\ \hat{x} \\ \hat{d} \end{bmatrix} + \begin{bmatrix} E \\ 0 \\ 0 \end{bmatrix}d \tag{17}$$

To make the algorithm robust, perturbation is added to the system shown in Figure 7 and the state equations will be as follows:

$$\dot{x} = Ax + B(w - K\hat{x})u + Ed = Ax - BK\hat{x} + Bw + Ed$$
$$\dot{\hat{x}} = A\hat{x} - BK\hat{x} + L_p(y - C\hat{x}) + E\hat{d}$$
$$= L_p Cx + (A - BK - L_p C)\hat{x} + E\hat{d}$$
$$\dot{\hat{d}} = L_I Cx - L_I C\hat{x} \tag{18}$$

To calculate the robustness, the disturbance is set to zero that results,

$$\begin{bmatrix} \dot{x} \\ \dot{\hat{x}} \\ \dot{\hat{d}} \end{bmatrix} = \begin{bmatrix} A & -BK & 0 \\ L_p C & A - BK - L_p C & E \\ L_I & -L_I C & 0 \end{bmatrix}\begin{bmatrix} x \\ \hat{x} \\ \hat{d} \end{bmatrix} + \begin{bmatrix} E \\ 0 \\ 0 \end{bmatrix}d$$
$$v = \begin{bmatrix} 0 & -K & 0 \end{bmatrix}\begin{bmatrix} x \\ \hat{x} \\ \hat{d} \end{bmatrix} \tag{19}$$

By forming

$A_{z(n+l\times n+l)} = \begin{bmatrix} A & E \\ 0 & 0 \end{bmatrix}$, $B_{z(n+l\times p)} = \begin{bmatrix} B \\ 0 \end{bmatrix}$, $C_{z(q\times n+l)} = \begin{bmatrix} C & 0 \end{bmatrix}$ $K_{z(p\times n+l)} = \begin{bmatrix} K & 0 \end{bmatrix}$, $L_{z(n+l\times q)} = \begin{bmatrix} L_p \\ L_I \end{bmatrix}$, the equation (19) can be rewritten as

$$\begin{bmatrix} \dot{x} \\ \dot{\hat{z}} \end{bmatrix} = \begin{bmatrix} A & BK_z \\ L_z C & A_z - B_z K_z - L_z C_z \end{bmatrix}\begin{bmatrix} x \\ \hat{z} \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix}w \tag{20}$$
$$v = \begin{bmatrix} 0 & -K_z \end{bmatrix}\begin{bmatrix} x \\ \hat{z} \end{bmatrix}$$

## 4. Simulation and results

To demonstrate the performance of the proposed controller the model was simulated in MATLAB/Simulink environment using model shown in Figure 8. The parameters for the simulations are as follows. Turbine time constant, $\tau_T = 0.5$ sec, generator time constant $\tau_g = 0.2$ sec, generator inertia constant, $H = 5$ sec, change in load, $D = 0.8$, governor speed regulation, $R = 0.05$ per unit. The turbine rated output is 250 MW at nominal frequency of 60 Hz sudden load change of 50 MW (0.2 per unit) occurs. Considering the system parameter and according to equation (8), the value of state space matrices will be as follows:

$$A = \begin{bmatrix} -5 & 0 & -100 \\ 2 & -2 & 0 \\ 0 & 0.1 & -0.08 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ -0.1 \end{bmatrix}, C = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$$

The feedback gain, K is obtained by the command, >>K=place(A, B, poles), where poles equals to $s^4/T_s$, where $s^4$ is the Bessel poles, and $T_s$ is the settling time of the regulator.

From Fig. 9 it is clear that the three states of state space model are perfectly estimated and reaches to steady state within very short time. The output of frequency deviation with time is shown in Figure 10 that indicates that change in frequency gets stable and PIO perfectly estimates the output. Fig. 11 and 12 show the actual and estimated state variables, respectively.

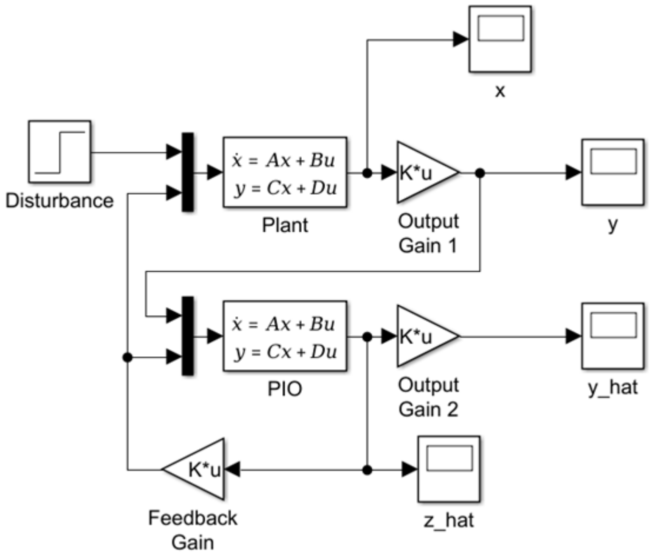


Fig. 8. PIO based regulator

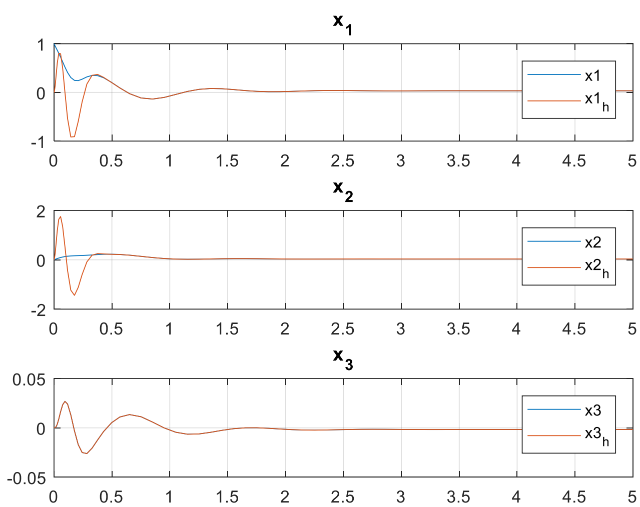


Fig. 9. State variable estimation

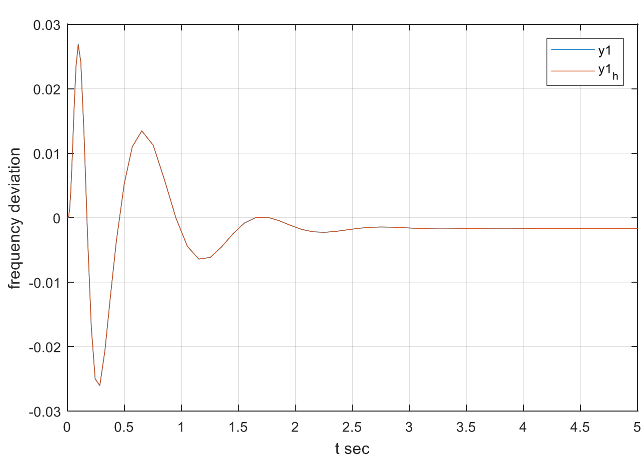


Fig. 10. Output estimation

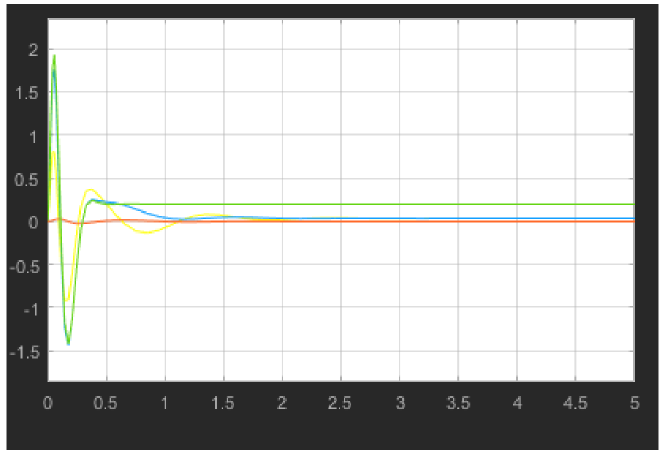

Fig. 11. State variables

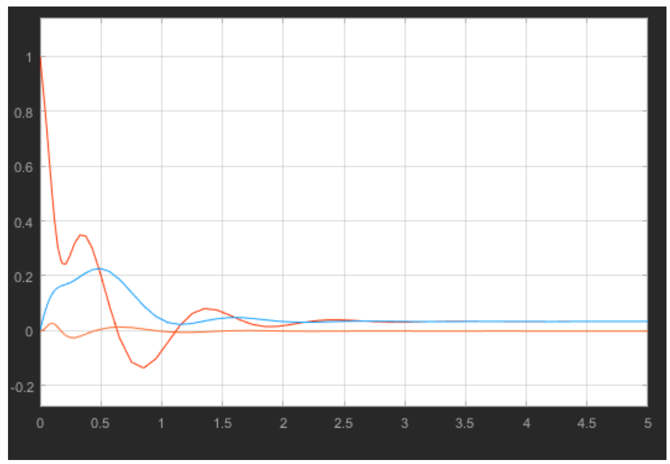

Fig. 12. Estimated state variables

## 5. Conclusion

In this paper a PIO based load frequency algorithm is investigated and applied to the control system for LFC. The performance shows that the proposed method can perfectly estimate all the state variables and using the variables, the controller makes the system stable by optimizing the frequency deviation caused by random change in real power.

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