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Performance Evaluation of Controller for Load Frequency Control in Power System

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ABSTRACT

Load frequency control(LFC) play a vital role in order to maintain the frequency regulation in power system. This study shows a comparative analysis of PID controller tuning methods for load frequency control in power system. Five tuning methods namely Honeywell, Lee, Skogested, Inter Model Control (IMC) based PID controller and IMC based PID controller with first order filter is adapted to evaluate their performance and used to solve the problem of load frequency control. In this paper higher order single input and single output (SISO) system is carried out with the help of Routh approximation and Skogestad methods to reduce second order model and first order plus dead time (FOPDT) model. The performance analysis is compared to time response specification such as maximum peak overshoot, settling time, rise time and peak time and it is observed that Inter Model Control based PID Controller with first order filter exhibit better performance comparatively.

Keywords: PID Controller; Tuning method; IMC based PID Contrpller; First order filter

I.INTRODUCTION

Load frequency control (LFC) is the main part of the power system to control its mechanism. The prime intention of Load frequency control is keeping a uniform frequency with changing the load. When system frequency will be changed, the crucial complication is that the generating units of the power system may not be controlled with specified units is called load frequency control (LFC) [1]. Due to increased power, complexity increased of modern power system, advanced control institution are used in load frequency control; e.g. variable structure control [2]; conventional control [3]-[4]; intelligent control [5]; optimal control [6]-[7]; adaptive and self-tuning control [8]; robust control [9]-[10]; and advanced fuzzy and ANN controller [11-14] etc. The Advance controlled technique is required to get the knowledge of the system and improved performance is identified through online recognizer parameters. Due to advanced control technique, unknown parameters are increased and it is not used for the practical purpose for load frequency controller study due to their simplicity.PID controller employed to their simplicity. The Power system has multiple conventional, mercantile and industrial loads and rotating parts of the machine due to the turbine, Governors, and Generators with help of loads giving to satisfy performance at a uniform and immovable frequency. So frequency control is an extremely significant and specific crux in power system operation, process, influence, and control with good quality, to provide sufficient, easy, a dependable and accuracy electric power. When power demand is high due to commercial and industrial load, electric power will be complex and loaded. As the load fluctuates at single, double and multiple areas of the power system, frequency affected multi-area power system through transmission lines and frequency fluctuate again. A measured frequency consist transients and load performance equipments damage, equipments and apparatus of the machine. When tie line overload, networks fully interfered to protect the equipments, so that tuning controllers are manufactured to protect the system's equipments. Tuning controllers are designed to control the transient parts, unstable condition and maintain the frequency. The main point is that, when the load frequency controller removed transient and unstable condition of the system, system stable. All condition and equipment (loads, governor and turbine) of the power system is assimilated [15]. Controlled are used to control active and reactive power, equipment of the system safe. Because active power is directly proportional to the system frequency of the power system for e.g. if the system's frequency is 50 hertz, and the network frequency falls below due to many disturbance is 48.5 hertz, and goes to high 51.5 hertz, blades of the turbine are damaged and all equipments of the system will be damaged. It is very difficult to control the whole part of the machine and system. The Power system's equipments may be harmful [16]. So load frequency control is an important role to provide power quality [17-18] and robustness and controller are designed to maintain disturbance rejection capability [19] and uncertainty of the system and maintain zero steady-state error due to frequency. There are many controllers designed to control the different parameters of the load and frequency in the Power system by researchers over the past decades. When frequency is transient and fluctuated, so the main aim of the load frequency control is to adjust the output power of the power system like generator turbine, and load at prescribing level. There are many tuning methods are used in the power system to control the system via PID tuning using Honeywell [20], Lee [21], Skogestad [22], Internal Model Control based PID controller [23] and Inter model control (IMC) based PID controller with first order filter [24-27]. The flow of active and passive power in the transmission and distribution lines are independent to each other and this paper follow to control design for load frequency control and the controller can be improved the transient part of the power system [28] and system's stability improved. In this paper transfer function of load frequency control is third order system, the main drawback of higher order system is that system is complex and higher order controller is designed to control the system. Model order reduction technique used to reduce higher order system to second order system, second order plus dead time (SOPDT) and first order plus dead time (FOPDT) using Routh approximation [29]-[30] and Skogestad method [31]. All parameters of time response specification (percentage overshoot, settling time, rise time and steady-state error) are equal to model approximation (MOR) technique and higher- order system. In this paper Internal Model control based PID control using First order filter is required. It is the best technique than other four (PID tuning using Honeywell, Lee, Skogestad and IMC based PID controller) and generally IMC based PID controller using first order filter is a advanced technique to reduce higher order system to lower order system and system is less complex and all parameters (percentage overshoot, settling time, rise time, peak time and steady state error) of the system is less than PID tuning using Honeywell, Lee, Skogestad and IMC based PID controller without changing parameters of FOPDT, SOPDT, Second order system and higher order system.

Much advanced control, strategies improve and implement in load frequency control and automation generation control of single area power system, double area and multi-area power system [32-35] e.g. Robust PID controller design method based on the maximum peak response specification may be given in [36-37].

The rest of the paper is organized as follows: The transfer function model of Non-Reheated Turbine Power system with no Droop characteristic was presented in section 2, A PID controllers has being designed for a first, second and third order system with transfer function in section 3, Different types of technology use to design a PID controller in section 4. Simulation Results and discussions are given in section 5 and finally, the paper is concluded in section 6.

II.LFC PID DESIGN

1 . LFC Design Non-Reheated Turbine with no Droop Characteristics

A proportional-integral-derivative controller (PID controller) is derived to closed loop control system which is used in industrial, manufacturing and commercial control system. A PID controller can be used to minimize the steady state error, rise time, peak time and maximum overshoot. The controller attempted to lowest possible value of the error to adjust the process through use of a manipulated variable. A PID controller design to reduce higher order system into FOPDT and Second order using PID tuning techniques and its performance has been noticed. In this paper five techniques (PID tuning using Honeywell, Lee, Skogestad, IMC based PID controller and IMC based PID controller using first order filter) is employed to find controller parameters to receive satisfactory closed loop performances, and this performance of being compared between PID tuning using Honeywell, Lee, Skogestad, IMC based PID controller and IMC based PID controller using first order filter is presented. In this study we have compared the performance of these tuning methods. The plant for a power system with a non-reheated turbine (LFC design without droop characteristics) consists of three parts as shown in fig.1:

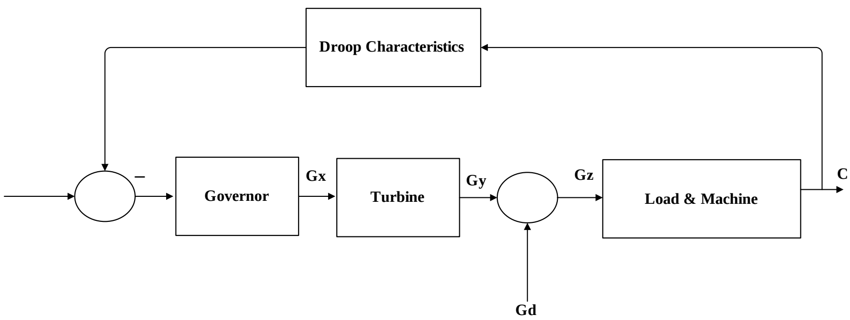

Fig 1: Block diagram of a single area power system with droop characteristics

1) Governor with dynamics:

$$G_x(s) = \frac{1}{1+T_x s} \qquad (1)$$

2) Turbine with dynamics:

$$G_y(s) = \frac{1}{1+T_y s} \quad (2)$$

3) Load and Machine with dynamics:

$$G_z(s) = \frac{K_z}{1+T_z s} \quad (3)$$

The open loop transfer function of load frequency control (LFC) is:

$$C(s) = G_x(s)G_y(s)G_z(s) \quad (4)$$

$$C(s) = \frac{K_z}{(1+T_x s)(1+T_y s)(1+T_z s)} \quad (5)$$

2 . Generalised Model of PID Controller

PID controller employed in the process control industry. The main reason is that by the control system engineers due to their flexibility and reliability and robust of the system PID controller is widely used. Fig 2 shows block diagram of PID controller with load frequency control with single area power system with droop characteristics. Where G_x, G_y and G_z show governor, turbine and load and machine transfer function. A PID controller represented in transfer function form as:

$$K(s) = K_p + \frac{K_i}{s} + K_d s \quad (6)$$

Where

K_p = Proportional gain

K_i = Integral gain

K_d = Derivative gain

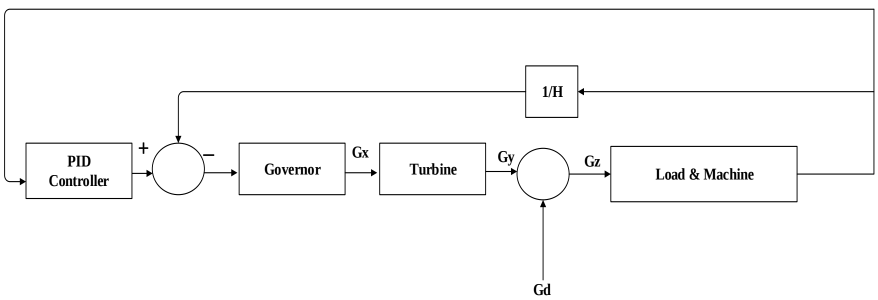

Fig 2: Block diagram of PID Controller with LFC

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III.DESIGN CONSIDERATION

PID controller is designed for a first, second and third order system with transfer function. Third order transfer function is Non-Reheated Turbine without droop characteristics. Third order model is approximated into second order model by Routh approximation. Higher order model is converted into FOPDT model through Skogestad method (Model order reduction).Fig 3 show a step response of third order, second order and FOPDT model without changing parameters means all time specification response parameters are equal plant as well as model.

1) Higher order (Third order) model.

$$G(s)=\frac{120}{(0.08s+1)(0.3s+1)(20s+1)} \qquad (7)$$

$$G(s)=\frac{120}{0.48s^3+7.624s^2+20.38s+1} \qquad (8)$$

2) Second order model {Routh approximation ($\alpha-\beta$ expansion)}.

$$\overline{G}(s)=\frac{15.7666}{s^2+2.6814s+0.1313} \qquad (9)$$

3) First order plus dead time model (FOPDT)

$$\overline{G_M}(s)=\frac{120.08e^{-0.19s}}{20.23s+1} \qquad (10)$$

Where Time delay -0.19

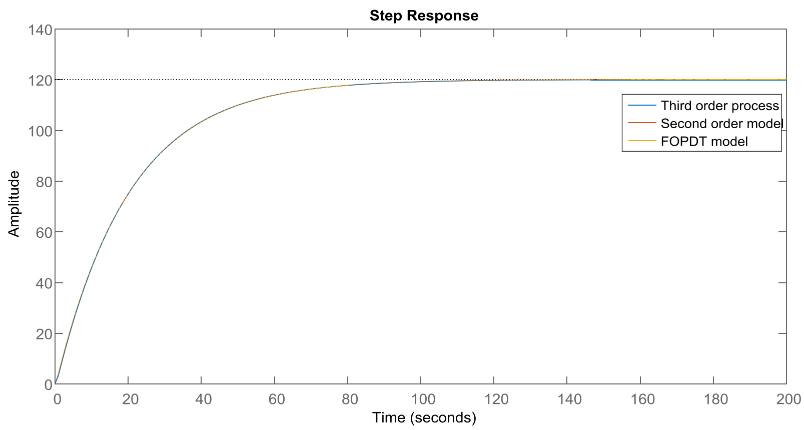

Fig 3: Step response of Third, Second and FOPDT model

IV.DESIGN OF PID CONTROLLER FOR DIFFERENT TUNING METHOD

1 . PID Tuning using Honeywell

PID tuning using Honeywell is a modified tuning method of PID Controller structure. In this method the basic structure of PID is written as in the form as-:

$$R(s) = K_p\left(1+\frac{1}{T_I s}\right)\left(\frac{T_D s+1}{\beta T_D s+1}\right) \qquad (11)$$

Tuning parameters depend on this formula-:

$$K_P = \frac{3}{K}, T_I = \tau_a + \tau_b, T_D = \frac{\tau_a \tau_b}{\tau_a + \tau_b}, \beta = 0.1 \qquad (12)$$

Where K= system gain, τ_a, τ_b = Time constant of the system and β = Tuning parameter

1.1 Numerical Studies

Equ.8 reduced in second order system in the form of equ.9 and second order equation is written as-:

$$\bar{G}(s) = \frac{K}{(\tau_a s+1)(\tau_b s+1)}, \tau_a \text{ ? } \tau_b \qquad (13)$$

$$\bar{G}(s) = \frac{120.08}{(20.04s+1)(0.38s+1)} \qquad (14)$$

2 . PID Tuning using Lee

In this design method, to obtain PID controller parameters through this formula-:

$$\bar{G}(s) = \frac{K}{\tau^2 s^2 + 2\xi\tau s + 1} \qquad (15)$$

To obtain the PID controller parameters substitute the values in this formulas-:

$$K_P = \frac{\tau}{2K\lambda}; T_I = 2\xi\tau - \frac{\lambda}{2}; T_D = T_I - 2\xi\tau + \frac{\tau^2}{\lambda T_I} \qquad (16)$$

Where λ = tuning parameter, ξ = Damping ratio of the system

2.1 Numerical Studies

Equ.8 reduced in second order system in the form of equ.9 and equ.9 written as-:

$$\bar{G}(s) = \frac{15.7666}{s^2 + 2.6814s + 0.1313} \qquad (17)$$

$$\overline{G}(s)=\frac{120.08}{7.6161s^2+20.35s+1} \qquad (18)$$

Where τ **= 2.7597,** ξ **= 3.7**

3 . PID Tuning using Skogestad

In this method first equ.8 converted into equ.9 and equ.9 is modified in the form of equ.13. And next equ.13 approximate into first order time delayed system and it is written as-:

$$\overline{G_M}(s)=\frac{Ke^{-\alpha s}}{\tau s+1} \qquad (19)$$

Where α = time delay of the system

$$\alpha=\frac{\tau_b}{2};\tau=\tau_a+\frac{\tau_b}{2} \qquad (20)$$

Now PI setting written as-:

$$K_P=\frac{\tau}{K(\lambda+\alpha)};T_I=\min\{\tau_1,4(\lambda+\alpha)\} \qquad (21)$$

3.1 Numerical Studies-:

Equ.8 reduced in second order system in the form of equ.9 and equ.9 written as-:

$$\overline{G}(s)=\frac{15.7666}{s^2+2.6814s+0.1313} \qquad (22)$$

$$\overline{G}(s)=\frac{K}{(\tau_a s+1)(\tau_b s+1)},\tau_a\ ?\ \ \tau_b \qquad (23)$$

$$\overline{G}(s)=\frac{120.08}{(20.04s+1)(0.38s+1)} \qquad (24)$$

$$\overline{G_M}(s)=\frac{120.08e^{-0.19s}}{20.23s+1} \qquad (25)$$

4 . Internal Model Control based PID Controller

In single area power system IMC based PID controller design for load frequency control. There are many control strategies to design a robustness of load frequency control but Internal model control is easy task than other technique because IMC has only one tuning parameter and easy to understand. Basically IMC is used to disturbance rejection and tracking. So IMC play important role to reduce a order and complexity of the power system and size of the system and cost will be reduced. Fig 4 shows internal model control setting, where $C_a(s)$ show transfer function of the system this giving system controlled by the controller, $C_m(s)$ is reduced model and it is controlled, Q(s) is IMC control parameter and it is design to tuning parameter and $C_d(s)$ show some type of disturbances occur. In this paper internal model control based PID controller without first order filter and with filter is compared each other. So show that filter is required to modify the system and model and all parameters reduce than other technique

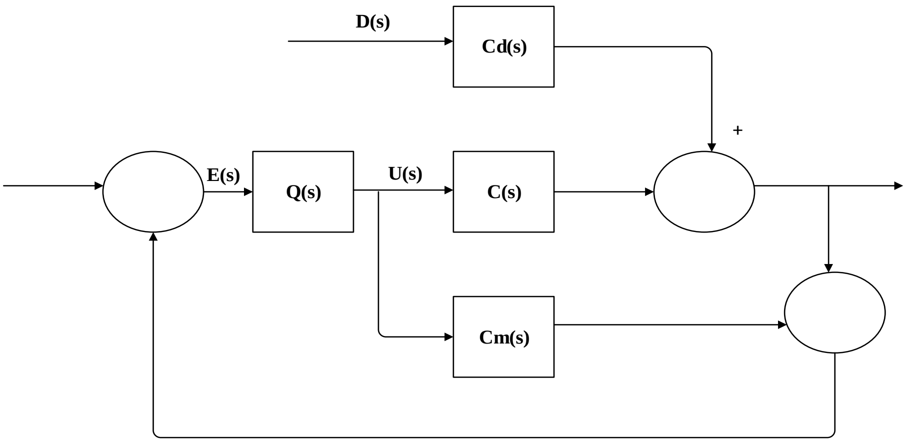

Fig 4: Basic structure of Internal Model Control

4.1 IMC based PID controller

$$K_P = \frac{\tau_t + \frac{\alpha}{2}}{K_g\left(\tau_c + \frac{\alpha}{2}\right)} \qquad (26)$$

$$\tau_I = \tau_t + \frac{\alpha}{2} \qquad (27)$$

$$\tau_d = \frac{\tau_t \alpha}{2\tau_t + \alpha} \qquad (28)$$

4.2 Numerical Study

The third order transfer function of single area LFC is reduced into FOPDT model.

$$G(s) = \frac{120}{(0.08s+1)(0.3s+1)(20s+1)} \qquad (29)$$

$$\overline{G_M}(s) = \frac{Ke^{-\alpha s}}{\tau s + 1} \tag{30}$$

$$\overline{G_M}(s) = \frac{120.08e^{-0.19s}}{20.23s + 1} \tag{31}$$

5 . Internal Model Control based PID Controller with first order filter

In the Internal model control based PID controller design, the filter selection is most important role. So IMC suggest n^{th} order filter but n^{th} order filter is a higher order filter and system is heavy complex, cost and size of the controller increased so n^{th} order filter reduce into second and first order filter but first order filter easy to formulation of the IMC based PID controller structure. The most important advantage of first order filter is that to predict sharp reference tracking, good disturbance rejection and minimum integral error performance. In this technique three parameters is obtained of PID Controller with the help of single parameter is called internal model control filter time constant. Various higher order filter is designed but the controller is designed generally a low pass filter (first order filter). System is easy to manage different tasks. It is written as-

$$F(s) = (1 + \lambda s)^{-n} \tag{32}$$

Where F(s) =low pass filter, n =number of order of filter

IMC controller Q(s) design the selecting process of filter. Q(s) represent into controller C(s) of conventional unity feedback control system.

$$C(s) = \frac{Q(s)}{1 - \overline{G_M}(s)Q(s)} = \frac{F(s)\overline{G_M}^{-1}(s)}{1 - F(s)} \tag{33}$$

$$Q(s) = \overline{G_M}^{-1}(s)F(s) = \frac{F(s)}{\overline{G_M}(s)} \tag{34}$$

Where $\overline{G_M}$ show model structure and It is modified in the form of FOPDT/SOPDT system. For FOPDT system n(no of filter) is 1 and for SOPDT n is 2 and main drawback of second order filter is that to generate extra leg term including PID controller.So first order filter is proposed and no need of higher order filter for higher order plant and first order filter with PID structure obtained free from extra additional leg term. The basic procedure for designing IMC controller filter

1) IMC based PID controller with First order filter

$$\overline{G_M} = \frac{K}{as^2 + bs + c}; K, a, b, c\ ?\ \ 0 \tag{35}$$

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$$F(s)=\frac{1}{(1+\lambda s)^{n}};n=1 \tag{36}$$

$$Q(s)=\frac{F(s)}{\overline{G_M}(s)}=\frac{as^2+bs+c}{K(1+\lambda s)} \tag{37}$$

$$C(s)=\frac{Q(s)}{1-\overline{G_M}(s)Q(s)}=\frac{as^2+bs+c}{K\lambda s} \tag{38}$$

Where $\overline{G_M}(s)$ represent model of th system (second order process) and K, a, b, c is dependant variable and it is greater than always zero. C(s) is a controlled process and equ.38 and equ 39 compare it and determine the value of PID control parameters.

$$C(s)=K_P+\frac{K_I}{s}+K_D s \tag{39}$$

$$K_P=\frac{b}{K\lambda};K_I=\frac{c}{K\lambda};K_D=\frac{a}{K\lambda} \tag{40}$$

V.RESULT AND CONCLUSION

A Proportional-Integral-Derivative tuning method of Power system load frequency control suggest on a PID tuning using Honeywell, PID tuning using Lee, PID tuning using Skogestad, IMC based PID controller and last one IMC based PID controller with first order filter. This paper covered an overview and this is summary of PID controller, design a PID controller using PID tuning using Honeywell, PID tuning using Lee, PID tuning using Skogestad, IMC based PID controller and IMC based PID controller with first order filter for first, second and third order process. Fig 5 shows simulation result for given process with PID Tuning technique, PID tuning using Honeywell, PID tuning using Lee, PID tuning using Skogestad, IMC based PID controller and IMC based PID controller with first order filter and IMC based PID controller with first order filter provide better performance than other four technique PID tuning using Honeywell, PID tuning using Lee, PID tuning using Skogestad, IMC based PID controller.

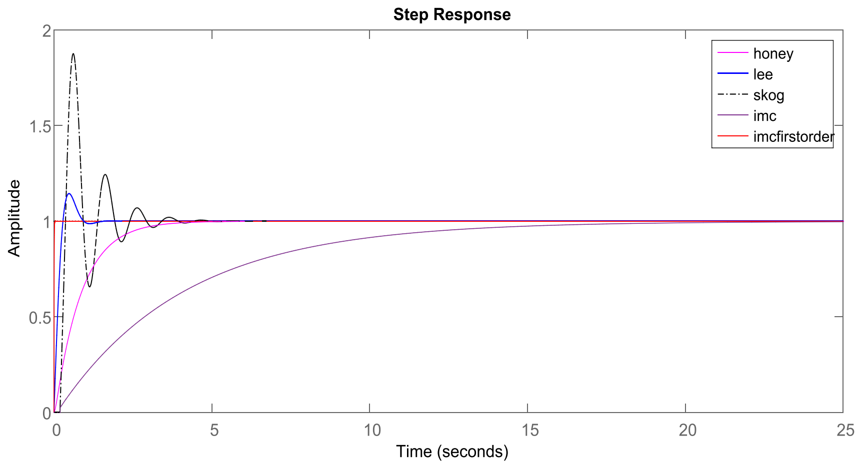

Fig 5: Simulation plot for given process with PID Tuning techniques

Simulation results using MATLAB Simulink and programing discuss for PID tuning using Honeywell, PID tuning using Lee, PID tuning using Skogestad, IMC based PID controller and IMC based PID controller with first order filter. PID tuning using Lee and Skogestad suggest high overshoot. It is a main drawback for this tuning method and Internal model control based PID controller and PID tuning using Honeywell gives zero steady state error and no overshoot and rise time, peak time and settling time will be increased so this technique can not be suggested for this process and Internal model control based PID control with first order filter is a best technique than other four technique, all parameters (steady state error, maximum overshoot, rise time, peak time and setting time controlled it than obtain using PID tuning using Lee, PID tuning using Skogestad, IMC based PID controller. The simulation result shown in Table 1.

Table 1: Comparison of PID tuning techniques with time specification parameters

Method	**M_p(%)**	**T_s(sec)**	**T_r(sec)**	**T_p(sec)**
Honeywell	**0**	**3.3216**	**1.8399**	**6.0372**
Lee	**14.3880**	**0.8499**	**0.2154**	**0.4832**
Skogestad	**87.7049**	**3.6518**	**0.1406**	**0.6169**
IMC	**0**	**16.1537**	**8.8670**	**36.6380**
IMC with filter	**0**	**0.0196**	**0.0110**	**0.0527**

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