Research Article

PERFORMANCE EVALUATION OF LOAD FREQUENCY CONTROL WITH DIFFERENT TECHNIQUES WITH PID CONTROLLER

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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. Six tuning methods namely Ziegler-Nichols Method (Z-N), Tyreus-Luyben Method, Internal Model Control (IMC), Direct Synthesis Method (DS), Robust PID Controller and Optimum PID tuning for set point changes and Disturbance Rejection 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 Method (- expansion) and Pade Approximation Method to reduce second order model 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.

INTRODUCTION

The Power system has a long history of the trouble with the Automatic Generation Control (AGC) or Load Frequency Control (LFC) and is one of the sincerely fundamental two of researches with methodical exploration and perusal of objects and sources in order to install facts and approach new inferences of interconnected power systems. As an auxiliary service in a power system, load frequency control plays an important and fundamental role in maintaining the reliability of the power system at a reasonable level. It has been gained importance with the change in the structured of the electrical power system and growth of size and complexity of interconnected systems [1-5]. For comprehensively electrical power system, the unified and interrelated control areas are composed to load frequency. It is crucial to hold the frequency and distinction surface tie power with calculated significance power. Input mechanical power has been employed to control the frequency of the generator, variation and transformation in frequency and tie-line power, which is a measure to shift and variation in the rotor angle. A well-prepared power system should be able to provide an acceptable level of power to maintain the magnitude of the frequency and voltage within satisfactory boundaries. Some changes in the electrical power system, load especially affected the system frequency, while

the reactive power is shorted susceptive to change in the frequency and is mainly subordinate on the motility of the voltage magnitude. Therefore, the control of active and reactive power in the electrical power system is trade separately. So weight frequency control is mainly related to system frequency and actual power control, while the automatic voltage regulator loop controls is used to change in the reactive power and voltage appearance and magnitude. Load Frequency control is an elevated level of many promotions and advanced concepts, which governs the dimensions of the electrical power system. Load Frequency Control (LFC) has a basic control structure or arrangement, of parts of the machine and similar devices in term of power system operation and control. Load Frequency Control use to keep the uniform frequency during changing load. When system frequency is changed, the main problem is that the system output of generating units cannot be controlled with in specified limit is called load frequency control (LFC) [6-8]. The speed depends on the frequency of the alternative current power supply. These are the main situation when speed permanence is required to be higher order. Electrical chronometers are operated by synchronous motors. The precision of the chronometer do not depend only on the frequency but the integral part of the frequency error. If the normal frequency of any network is 50 hertz, and the network frequency falls below 48.5 hertz, and goes to high level 51.5

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hertz so in this condition the blades of the turbine are damaged and all equipments of the power system like generators, governors will be damaged. When there are different loads are connected to the system in the power system then the frequency and speed will be changed due to changing the loads. If there is no need to sustain the constant frequency in a system then the manipulator does not need to change the setting of the generator. But if constant and continuous frequency expected then the manipulator can coordinate the governor characteristics and manipulated the speed of the turbine and when necessary. If variation in the load carried out, it is very difficult to run by two generating station at parallel and system is complicated and complexity becomes increases. It is very difficult to control the whole part of the power system and active power can be reflected, so the power system's equipments may be harmful [9]. The first step to the giving gadget is that it analyzed the mathematical modeling of the system's variety of factors and make use of the control system technology. There are different modes of electrical drives loaded on the electricity system. The instruments used for irradiation purposes are basically resistive in nature and rotating devices are basically combinatorial with resistive and inductive components. The electrical power is greater from mechanical power input, the electric load increased. As a result, the power shortage in the load side is derived from the rotating energy of the turbine. This is a suitable motive for the kinetic power of the turbine i.e. the stored energy is decreased in the machine and the governor dispatch a signal to supply the excess quantity of water or vapor or gas to speed up the prime mover to restitute for the shortage of speed. Visioli in this paper, suggested that even after so much advancements in control theory there is a lot of scope for research in PID controllers, since it is renowned that generally controllers are not tuned properly in industrial applications, and the performance that is recognized can be enhanced several times by using a more accomplished construction prescript for the PID-based control system. In this paper we described many important results achieved recently in the field of PID controllers, and reviews in particular those related to tuning and designing PID-based control fabrication [10]. The control system performs poor and even it will be unstable, if the values of PID parameters adjust improper. So it is necessary to tune the parameter of PID controller in the appropriate option by which good control performance may be obtained. There are many tuning methods which are used to tune a PID controller.

LFC Design without Droop Characteristics

There are three different types of turbines consisted in without droop characteristics.

Governor with Dynamics

$$G_a(s) = \frac{1}{1 + \tau_a s} \qquad\qquad 1$$

Turbine with Dynamics

$$G_c(s) = \frac{1}{1 + \tau_c s} \qquad\qquad 2$$

Load and Machine with dynamics:

$$G_l(s) = \frac{K_l}{1 + \tau_l s} \qquad\qquad 3$$

4) 1/R is the droop characteristics a kind of feedback gain to improve the damping properties of the power system

Non-Reheated Turbine [11]

The open loop transfer function without droop characteristic of load frequency control (LFC) is:

$$P(s) = G_a(s)G_c(s)G_l(s) \qquad\qquad 4$$

$$P(s) = \frac{K_l}{(1 + \tau_a s)(1 + \tau_c s)(1 + \tau_l s)} \qquad\qquad 5$$

The open loop transfer function of load frequency control (LFC) is [12]

$$P(s) = G_a(s)G_c(s)G_l(s) \qquad\qquad 6$$

$$P(s) = \frac{K_l}{(1 + \tau_a s)(1 + \tau_c s)(1 + \tau_l s)} \qquad\qquad 7$$

$K_l = 120, \quad \tau_c = 20, \quad \tau_b = 0.3, \quad \tau_a = 0.08, R = 2.4$

$$P(s) = \frac{120}{(1 + 0.08s)(1 + 0.3s)(1 + 20s)} \qquad\qquad 8$$

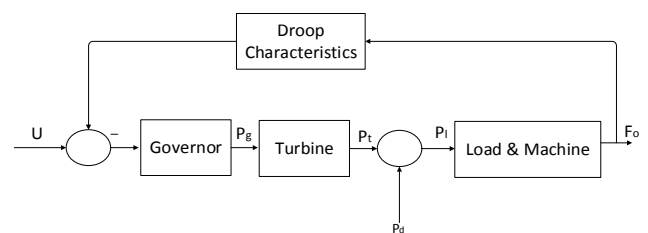$$P(s) = \frac{120}{0.48s^3 + 7.624s^2 + 20.38s + 1} \qquad\qquad 9$$

Fig 1 A single area Power system with droop characteristics

The feedback gain is used in power system is known as droop characteristics and it is used to improve the damping properties of power system and it is generally represented as 1/R and connected before load frequency control design. So there are two ways for LFC design.

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

$$P(s) = \frac{G_g G_t G_p}{1 + G_g G_t G_p / R} \qquad\qquad 10$$

$$P(s) = \frac{K_p}{T_p T_t T_g s^3 + (T_p T_t + T_t T_g + T_p T_g)s^2 + (T_p + T_t + T_g)s + (1 + K_p / R)} \quad\quad 11$$

$$P(s) = \frac{120}{0.48s^3 + 7.624s^2 + 20.38s + 51} \quad\quad 12$$

MOR Techniques- [12-15]

The nth higher order model for the continuous system which is not feasible because of its unsatisfactory performance. Now we are trying to find a rth reduce order system or process for the original model having desired performance, where r is a random number and r<n. Also the reduced model should be fairly accurate to the original process so the results starting the state space of reduce model and the original model should also be approximate. The main motive of this process is to find a simplified model with reduced complexity and cost with the desired performance. In this section, the higher order transfer function of the LFC system has been Figure 2 it can seen the PID controller with component transfer function of LFC system. With these components transfer function calculation of the closed loop response of LFC system has been done. The reduced order model for the LFC system with applied six different techniques can be listed below:-
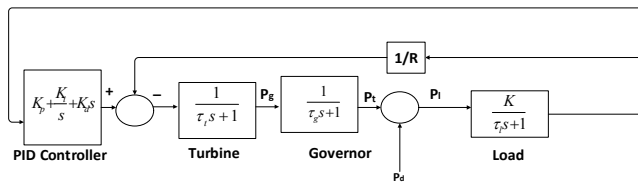
Figure 2 A practical high-order LFC system controlled by a PID controller

$$G_{MR}^{Routh}(s) = \frac{18.68}{s^2 + 3.173s + 7.94}$$
$$13$$

$$G_{MR}^{Pade}(s) = \frac{-1.91s + 18.92}{s^2 + 2.708s + 8.043} \quad\quad 14$$

It has been observed that the parameters of controllers vary for different tuning method. Futher in next chapter we concluded the result analysis and conclusion. The results show all the details about design analysis for different six tuning method with and without controller.

Generalised Model of PID Controller

PID controllers are the majorly used controllers in industries because of their robustness and the overall performance of super management. Apart from this, PID controllers are trouble-free and easy to execute. The PID controller contains the three basic components; namely Proportional control, Integral control and Derivative control. All these components of PID controller have certain specific effects on the process. The tuning parameters which are determined to tune the PID controller are the respective gain values of PID such as: Proportional gain (K_P), Integral term (K_i) and Derivative gain (K_D). These benefits affect the procedure in a sure way. It means that these parameters have the tendency to change the characteristics of the process. Since the LFC system to maintain the fluctuating frequency to a constant value, it is required to understand the reason of variability in the frequency of the alternator at its terminus. The main reason of the variation in the frequency is the load variations which are acting upon the supply system. These variations in the load and hence in the voltage, may lead to functioning of the power system, due to damage of various equipments of power system. Hence, it is highly required to control the voltage and loads of a turbine and governor. This work describes the various methodologies and technique to control the terminal voltage of the system through LFC system. The terminal voltage and frequency can be controlled through various control techniques. However, PID control technique is the most commonly utilized controllers in industries. The next section discusses a basic and concise principle about the PID controller. The figure 3 demonstrated a basic structure of the PID controller.
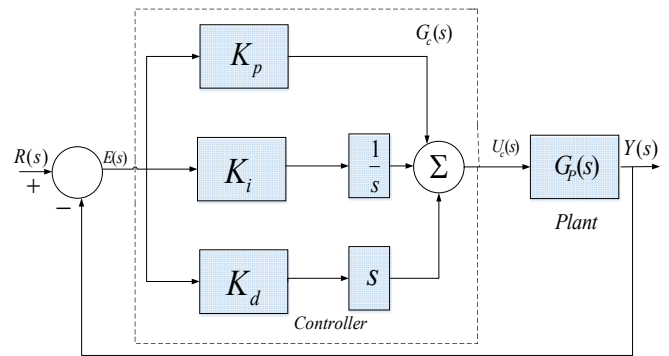
Fig 3 Structure of PID controller

For the desired response from the given plant, the PID controllers need to be tuned effectively. The behavior of the plants depend the tuning parameters of the PID controller. The PID controller shall be tuned in such a way that it can withstand the various disturbances and keep the response of the plant with in desirable limits. Tuning of the controller simply means the selection of three gains viz: Proportional gain (K_p), Integral gain (K_i) and derivative gain (K_d). These gains can be obtained through various tuning techniques developed for PID controller. The output of the PID controller actually depends upon these three types of gains and is depicted in equation 19. In spite of, the Integral and Derivative gains rely upon the Integral time constant (T_i) and Derivative time constant (T_d) respectively. $G_p(s)$ represents the LFC system transfer function and $T_f(s)$ indicates the sensor transfer system and $G_c(s)$ is the controller transfer function. Hence, the controller's output in term of the time constant is given in equation 115. The PID controller may be written in the following manner. [16-20].

$$G_c(s) = \frac{U_c(s)}{E(s)} = K_p(1 + \frac{1}{T_i s} + T_d(s)) \quad\quad 15$$

$$G_c(S) = K_p + \frac{K_p}{T_i s} + K_p T_d s \quad\quad 16$$

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s \quad\quad 17$$

PID controller can be systematized in the form of close-loop system as feed-forward or feedback control, Cascade control etc. and PID controller may be obtained single-loop controller

in the form of parallel and series form. The PID controller has many types of different structure-

Idealstructure

$$G_{c1}(s) = K_c\left(1 + \frac{1}{\tau_i s} + \tau_d s\right) \qquad 18$$

SeriesStructure

$$G_{c2}(s) = K_c\left(1 + \frac{1}{\tau_i s}\right)\left(\frac{\tau_d s + 1}{\alpha\tau_d s + 1}\right) \qquad 19$$

ParallelStructure

$$G_{c3}(s) = K_c\left(1 + \frac{1}{\tau_i s} + \frac{\tau_d s}{\alpha\tau_d s + 1}\right) \qquad 20$$

Seriesfilter

$$G_{c4}(s) = K_c\left(1 + \frac{1}{\tau_i s} + \tau_d s\right)\left(\frac{1}{\tau_f s + 1}\right) \qquad 21$$

Where,

$U_c(s)$ - Control signal,
$E(s)$ - Error signal,
$R(s)$ – Reference signal, and
$Y(s)$ – Output of LFC

In PID designing, the parameters of controller must be tuned in this way that the closed loop system meets for Robustness in stability, it often precise in domain of frequency, Transitory response includes rise time, settling time and overshoot and Accuracy in immovable situation distinction.
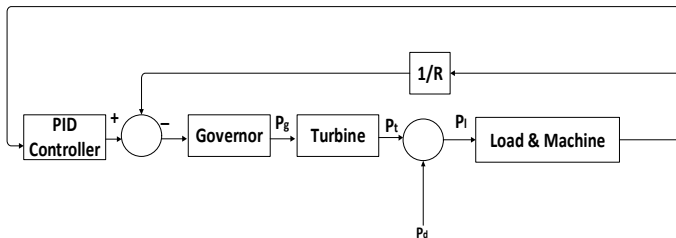

Fig 4 Block diagram of PID controller with LFC

Design PID Controller Techniques

Ziegler-Nichols Method (Z-N)

(Ziegler, and Nichols 1942) [21] is a vastly utilitarian tuning technology to design PID controller. ZN method is of two types- one is based on reaction curve of the system and other one depends upon ultimate gain K_u and ultimate period T_u when step response of the plant exhibits s-shape curve with zero overshoot than reaction curve method is applied. The traction curve is described through two consecutive parameters, which delay time L and time constant T. Second method considers trial and error tuning which based on proportional gain K_p by increasing the value of K_p output exhibit sustains oscillations. This rule works well only when delay time is less than half the length of time constant. The disadvantage of this technique is that it is time consuming and this is not applicable for first and second without time delay process because some process does not have ultimate gain. The method performs well in disturbance rejection but poor in tracking reference change.

Table 1 Controller Settings for ZN

Type of Controller	Parameter of Controller		
	K_P	T_I	T_D
P	$0.5K_U$	-	-
PI	$0.45K_U$	$0.84T_U$	-
PID	$0.6K_U$	$0.5T_U$	$0.125T_U$

Tyreus-Luyben Method

The Tyreus-Luyben Method [22] is a same process to the Ziegler-Nichols method but the final value of controller setting is different than Ziegler-Nichols technique. This method use only PI and PID conytrollers. It depends upon ultimate gain K_u and ultimate period T_u when step response of the plant exhibits s-shape curve with zero overshoot than reaction curve method is applied.

Table 2 Controller Settings for TL

Type of Controller	Parameter of Controller		
	K_P	T_I	T_D
PI	$0.45K_U$	$2.2T_U$	
PID	$0.45K_U$	$2.2T_U$	$\dfrac{T_U}{6.3}$

Internal Model Control (IMC)

There are many method of tuning IMC-PID based controller [23-24] but first method was developed by Morari et. al. (1986) for tuning parameter which is called Internal Model Control. This method is based on model based control technique. Internal Model Control (IMC) based PID controller [25] is encompassed in manufacturing, technical and insdustrial control structure. The design gives a superior concession along with set point tracking, disturbance rejection and robustness. In fact, in the Internal Model Control, the original model of the system agglutinated in parallel form with the help of model of the plant and fed back to the controller is shown as the distinction between the process and the process model. The advantage of this approach is good set point tracking, but sluggish trouble response, especially when there is a continuous ratio of time / time in the process. This process is not desirable for the industry because the application point for many control procedures is more important than troubleshooting rejection sets point tracking Li et al. (2000). The general block diagram IMC based approach shown in figure 5. This diagram is used to control the process in $A_c(s)$, $A_p(s)$ process, model $A_m(s)$ and D (s) is unknown turbulence. Now, instead of taking model precisely same as plant, we consider the reduce order model of the original system, i.e., $P(s) = P_{MOR}$ to acquire controller. To demonstrate this process, let the original system be

$$P(s) = \frac{a_m s^m + a_{m-1}s^{m-1} + a_{m-2}s^{m-2} + \dots + a_0}{b_n s^n + b_{n-1}s^{n-1} + b_{n-2}s^{n-2} + \dots + b_0}, m \le n \qquad 22$$
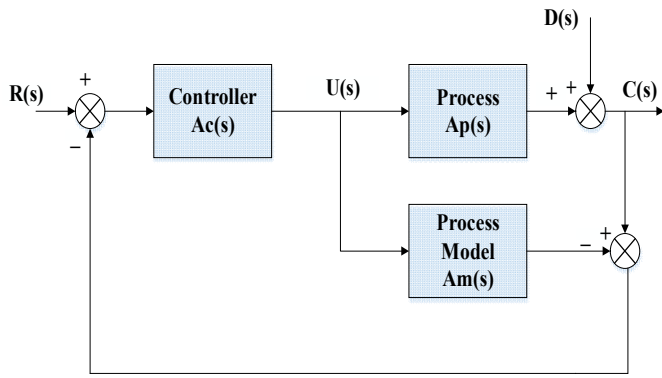
Fig 5 Basic Block diagram of Internal Model Control.

Using MOR, the reduced model can be written as

$$P_{MOR}(s) = K(\tau s + 1)^{-1} \qquad 23$$

Where K and τ are constants. The above $P_{MOR}(s)$ can be determined by various MOR techniques as reported in control literature. The next step is to include this model for IMC-PID design. In case, if the plant is of first order type then PI is requisite for IMC technique. For second order type system it is found that IMC-PID is required in consideration of IMC procedure. Furthermore, the most interesting feature is that all the parameters of controller (K_p, K_i, K_d) depend on a value of single user-defined parameter λ in case of IMC based PID control. The generalized form of controller is given by as follow:-

$$C(s) = K_p + K_i s^{-1} + K_d s \qquad 24$$

We adopt a two degree of freedom IMC-PID tuning method for load frequency controller. The method for SOPDT model goes as follows.

Design an IMC controller

$$Q(s) = \frac{s^2 + 2\xi\omega_n s + \omega_n^2}{k\omega_n^2(\lambda s + 1)^2} \qquad 25$$

Here λ is a tuning parameter such that the desired setpoint response is $\dfrac{1}{(\lambda s + 1)^2}$.

(2) Design a controller of the form

$$Q_d(s) = \frac{\alpha s^2 + \beta s + 1}{(\lambda_d s + 1)^2} \qquad 26$$

Where λ_d is another tuning parameter for disturbance rejection.

$$\alpha = \frac{p_1 e^{-\theta p_2}(p_2\lambda_f - 1)^4 - p_2 e^{-\theta p_1}(p_1\lambda_f - 1)^4 - p_1 + p_2}{p_1 p_2 (p_2 - p_1)} \qquad 27$$

$$\beta = \frac{p_1^2 e^{-\theta p_2}(p_2\lambda - 1)^4 - p_2^2 e^{-\theta p_1}(p_1\lambda - 1)^4 - p_1^2 + p_2^2}{p_1 p_2 (p_2 - p_1)} \qquad 28$$

Transform it to a Conventional Unity Feedback Controller

$$K(s) = \frac{Q(s)Q_d(s)}{1 - P(s)Q(s)Q_d(s)}$$

29

Direct Synthesis Method (DS)

Direct Synthesis approach [26-27] has consisted on the way of PID controller and the desired closed loop transfer function is introduced for the describing and identifying of system's disturbances. Analytical expression process model for PID controllers is taken for many common types, along with first order, including dead time, second order along with dead time model. The Direct Synthesis method is similar to internal model control technique. Fig 6 show basic closed loop system structure of the process. Where G_p is the process, it is controlled by the controller (G_c) and G_v is the actuator and G_c is the Direct Synthesis (DS) controller to design.
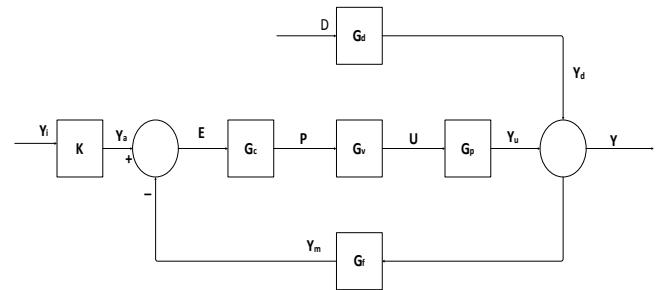

Fig 6 Basic Block diagram of Direct Synthesis (DS).

Design an DS Controller

For easy implementation of PID controller, G_c is considered in the following form.

$$G_c = K_c\left(1 + \frac{1}{T_i s} + \frac{T_d s}{\varepsilon T_d s + 1}\right) \qquad 30$$

Where the derivative filter constant is typically fixed by the manufacturer and $\varepsilon = 0.1$. The nominal complementary sensitivity for load disturbances rejection can be obtained as

$$T = \frac{GG_c}{1 + GG_c} \qquad 31$$

In order to reject a step change in load of power system, the asymptotic constraint should be satisfied so that the close loop internal stability can be achieved. The desired closed loop complementary sensitivity function is as-

$$T = \frac{(\alpha_2 s^2 + \alpha_1 s + 1)}{(\lambda s + 1)^4} e^{-\theta_m s} \qquad 32$$

Where λ is a tuning parameter for obtaining the desirable performance of the power system and α_2 and α_1 are an additional parameter used to determine desired closed loop system.

$$\alpha_2 = \frac{p_1 e^{-\theta p_2}(p_2\lambda-1)^4 - p_2 e^{-\theta p_1}(p_1\lambda-1)^4 - p_1 + p_2}{p_1 p_2(p_2-p_1)}$$

33

$$\alpha_1 = \frac{p_1^2 e^{-\theta p_2}(p_2\lambda-1)^4 - p_2^2 e^{-\theta p_1}(p_1\lambda-1)^4 - p_1^2 + p_2^2}{p_1 p_2(p_2-p_1)}$$ 34

Where p_1 and p_2 are the two poles of the reduced model
Where P_1 and P_2 are the two poles of the process. When $\xi = 1$

, there exists $P_1 = P_2 = \omega_n$.

Robust PID Controller

Robust controller [28] deal with plant uncertainty. If there is slight change in gain K, time constant T and delay time L Robust controller will provide uncertainty and achieves robustness and stability here we are calculating PID parameter for FOPDT system which based on $H\infty$ control theory. The performance of PID is determined by value of λ. Here we choose value of tunable parameter λ is 0.1 respectively and 0.3 respectively.

$$G_c(s) = K_p\left[1 + \frac{1}{T_i s} + \frac{T_d s}{T_f s + 1}\right]$$ 35

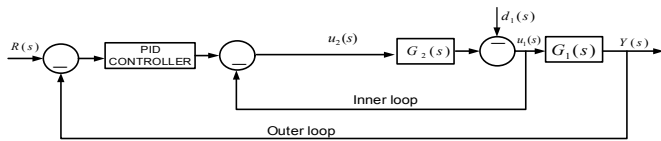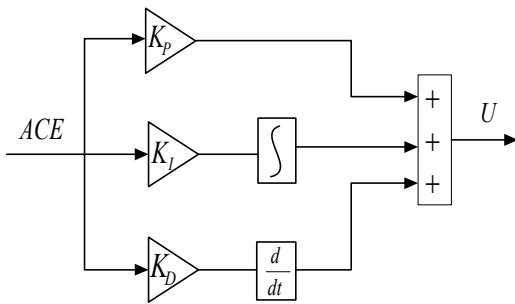**Fig 7** Robust PID controller structure.

Fig 8 PID controller structure.

$$T_f(s) = \frac{\lambda^2}{2\lambda + \dfrac{L}{2}}$$ 36

$$K_p(s) = \frac{T_i}{k\left(2\lambda + \dfrac{L}{2}\right)}$$ 37

$$T_i(s) = T + \frac{L}{2} - T_f$$ 38

$$T_d = \frac{TL}{2T_i} - T_f$$ 39

Optimum PID Tuning for set Point Changes and Disturbance Rejection [29-30]

The shape of close loop response of the system from initial state t=0 to final state could be used to find exact controller setting. To reduce the use of these rules, the PID controller is used to get the optimum tuning value of the parameter Integral Square Error (ISE), Integral Absolute Error (IAE), Integral time Absolute Error (ITAE), Integral Square Time Error (ISTE), Integral Square Time Square Error (IST²E) performance criteria. These tuning formulas were found by (zhuang and Atherton 1993), IAE is good to eliminate small error but it produces slower response and it does not add weight for any error in response. To use this harmful ITAE and ITE performance criteria, ISE will bear short errors, short dimensions, small errors for the charge for long periods, which settles faster than other two because it integrates the absolute value of error multiplied by time (Rahimi & Famouri 2014).

$$IAE = \int_0^t |e(t)| \, dt$$ 40

$$ISE = \int_0^t e^2(t)dt$$ 41

$$IAE = \int_0^t t|e(t)| \, dt$$ 42

$$ISTE = \int_0^t t^2 e(t)dt$$ 43

$$IST^2 E = \int_0^t t^2 e^2(t)dt$$ 44

Model Order Reduction Techniques

Model order reduction is an influential tool that permits the logical creation of cost-efficient representations for huge scale processes. The various MOR techniques available and have been used in the current are discussed below:

Routh Approximation Method (α - β expansion)

This is the simplest method based on the expansion of Routh array [31]; both the coefficient of the numerator and denominator are expanded by Routh array expansion. To reduce the higher order model, the Routh stability array can be achieved by estimating the coefficients of the Routh table for the high order system of the polynomial of the numerator and the denominator.

$$G_{MOR}^{Routh}(s) = \frac{P(s)}{Q(s)} = \frac{\overline{P}(s)}{\overline{\overline{Q}}(s)}$$ 45

Where $G_{MOR}^{Routh}(s)$ is called second order reduced model and P(s) describe numerator and Q(s) describe denominator

respectively. We first interchange $G_{MOR}^{Routh}(s)$ using rapport $L(s) = \left(\frac{1}{s}\right)L\left(\frac{1}{s}\right)$. Thus the reciprocated model of G(s) occurs-

$$\overline{G}(s) = \frac{Ks^2}{Ds^3 + Cs^2 + Bs + A} \qquad 46$$

And then, enhance $\overline{G}(s)$, namely

$$\overline{G}(s) = \frac{\overline{P_i}(s)}{\overline{Q_i}(s)} = \sum_{t=1}^{n} \beta_t \prod_{j=1}^{t} F_j(s) \qquad 47$$

Where $\beta_i (i=1,2)$ are constant and $F_i(s)$ (i=1,2) contains α_i terms. Next, we need to compute α and β tables corresponding to, which is shown in table 1.7.are reported in [26]. These α and β terms gives reciprocated reduce-order numerator P(s) and denominator Q(s) for second order reduced model as-

$$\overline{P}(s) = \beta_b + \alpha_b \beta_a s \qquad 48$$

$$\overline{Q}(s) = 1 + \alpha_b s + \alpha_a \alpha_b s^2 \qquad 49$$

On substituting values of α and β in (1.38) and (1.39), we get

$$\overline{P}(s) = \frac{CKs}{(BC - AD)} \qquad 50$$

$$\overline{Q}(s) = \frac{1 + C^2 s}{(BC - AD) + \frac{CDs^2}{(BC - AD)}} \qquad 51$$

$$G_{MOR}^{Routh}(s) = \frac{CK}{\left((BC - AD)s^2 + C^2 s + CD\right)} \qquad 52$$

Table 3 α - β table for Routh approximation

α **Table**	β **Table**
$\alpha_a = \dfrac{D}{C}$	$\beta_a = \dfrac{K}{C}$
$\alpha_b = \dfrac{C^2}{BC - AD}$	$\beta_b = 0$

Pade Approximation Method

The coefficient of the original model is reduced by using reduction method [32] with the help of coefficient of Taylor series expansion about s=0. In order to convert higher order system G(s) into second order reduced model $G_{MOR}^{Pade}(s)$, we define as-

$$G_{MOR}^{Pade}(s) = \frac{(a_i s + a_j)}{s^2 + b_i s + b_j} \qquad 53$$

Let suppose system is given as;

$$G(s) = \frac{K}{As^3 + Bs^2 + Cs + D} \qquad 54$$

$$G(s) = \frac{\dfrac{K}{A}}{s^3 + \left(\dfrac{B}{A}\right)s^2 + \left(\dfrac{C}{A}\right)s + \left(\dfrac{D}{A}\right)} \qquad 55$$

Power series expansion can be articulated like the colligation of G(S).

$$G(s) = C_0 + C_1 s + C_2 s^2 + C_3 s^3 + \ldots \ldots \qquad 56$$

Where,

$$C_0 = \frac{K}{D}, \qquad C_1 = \frac{-CK}{D^2}, \qquad C_2 = \frac{(C^2 - BD)K}{D^3},$$

$$C_3 = \frac{(2BCD - AD^2 - C^3)K}{D^4} \qquad 57$$

Now, second order reduced order model $G_{MOR}^{Pade}(s)$ can be obtained from mentioned in this equation, the parameter a_i and b_i (i=0,1) can be estimated by illuminate -

$$\begin{pmatrix} c_2 & c_1 \\ c_3 & c_2 \end{pmatrix} \begin{pmatrix} b_0 \\ b_1 \end{pmatrix} = \begin{pmatrix} -c_0 \\ -c_1 \end{pmatrix}, \begin{pmatrix} a_0 \\ a_1 \end{pmatrix} = \begin{pmatrix} c_0 & 0 \\ c_1 & c_0 \end{pmatrix} \begin{pmatrix} b_0 \\ b_1 \end{pmatrix} \qquad 58$$

Comparative Analysis

In this section, a comparative view of all the algorithms used to design PID controller for LFC system has been presented.
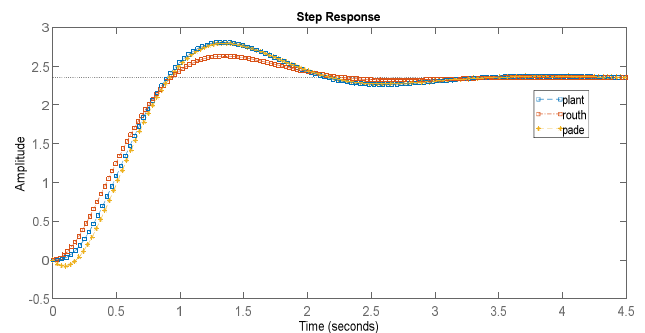
Fig 9 Step response with reduced model with droop characteristics

Table 4 Reduced Model with Non-Reheated Turbine

Sys	M_p(%)	T_r(sec)	T_s(sec)	T_p(sec)	ITAE	IAE	ISE
Plant	19.2496	0.5712	3.0161	1.3497	-	-	-
Routh	11.7532	0.6278	2.0808	1.3353	1.38	0.4336	0.05125
Pade	18.7510	0.5392	2.9924	1.3605	2.96	0.6985	0.08481
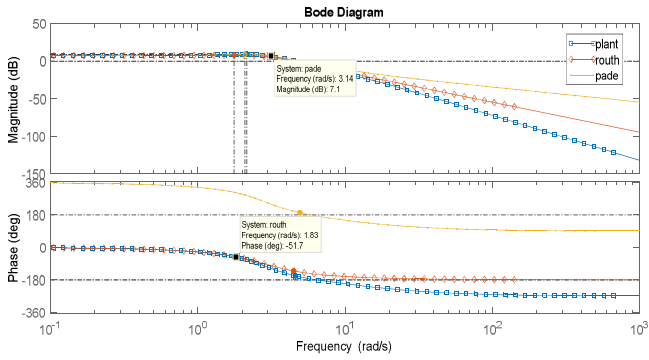
Fig 10 Frequency response with reduced model with droop characteristics

Fig 11 Nyquist plot with reduced model with droop characteristics

Fig 12 Pole-Zero plot with reduced model with droop characteristics

Responses of Systems with Controller

In this section the results presented for each system (original and reduced); when the designed controllers have been applied to each system. Figure 13

Figure 13 Step response for given process with PID tuning techniques

Figure 14 Bode plot for given process with PID tuning techniques

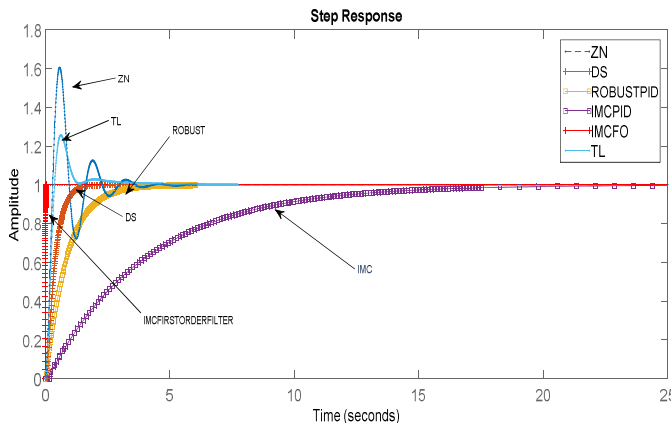**Figure 15** Nyquist plot for given process with PID tuning techniques

Table 5 Comparative Analysis of PID Tuning Techniques

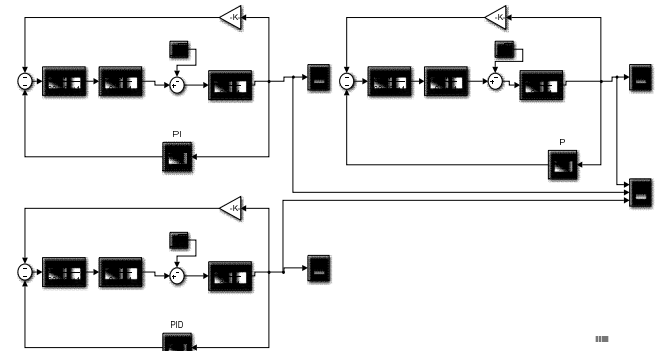| Process	M_p(%)	T_r(sec)	T_s(sec)	T_p(sec)
Plant	0	43.9456	78.6278	146.4444
ZN	60.4726	0.2013	3.3803	0.5807
TL	25.6365	0.2554	2.4737	0.6251
IMC	0	8.3368	15.3738	26.7997
DS	0	0.7014	1.3325	3.2254
IMCfirstorderfilter	0	0.0110	0.0196	0.0527
Robust PID Controller	0	1.839	3.3216	6.0372

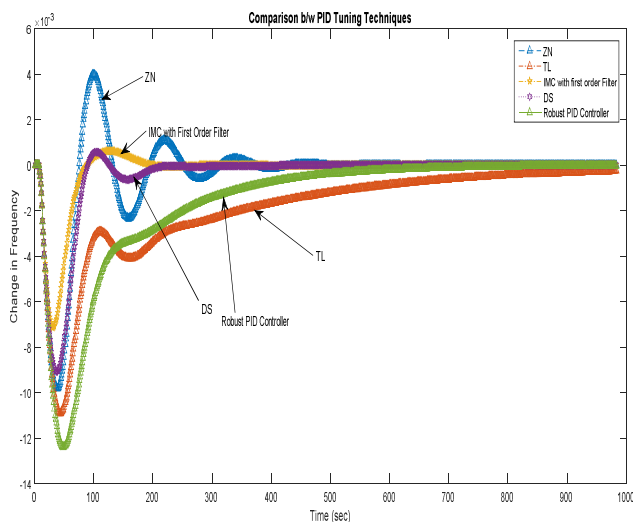

Figure 16 Simulink Model of LFC

Figure 17 Comparison between reduced order LFC with Controller

Figure 4.23 show the compare between five techniques [ZN, TL, DS, Robust PID Controller and IMC based first order filter]. IMC based first order filter give a best response than ZN, TL, DS and Robust PID controller about frequency deviation and set point.

CONCLUSION AND RESULT

The work described in this report has been carried out to test the performance of LFC system. Since the frequency is the crucial parameter and needs to be controlled precisely. For this purpose and Load Frequency Control is used in power system. The performance of LFC has been tested with the PID controller. For this work, the original LFC model has been reduced to lower order using different MOR techniques. Then the PID controller is designed for each reduced system. The PID controller has been tuned using five different techniques viz; Z-N, T-L, IMC, DS and Robust PID controller tuning methods. The performance of each reduced system has been tested for for tuning techniques. Then the performance of original system has been tested for the same PID controllers. For the analysis it has been observed that Robust PID controller with first order plus dead time (FOPDT) reduced order process and Internal Model control with filter give the better performance among all other methods. In the present work, the LFC system has been studied on reduced order by applying various model order reduction techniques and finding the reduced order transfer function of LFC. To identify the LFC and develop its Mathematical model and to develop and design PID tuning techniques for LFC and reduced order modeling of the third order transfer function of the LFC of the research have been briefly discussed. In the next Chapter, the problem formulation discussed and the the main focus will be on to design the desired optimal controller. So, to accomplish the stated problem and desired performance of the Load Frequency Control for the current work, some objectives have been identified which are listed below- To identify the LFC and develop its Mathematical model and To develop and design PID tuning techniques for LFC.

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