

Teaching-Learning-Based Optimization based Load Frequency Controller

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Abstract

The goals of the LFC are to maintain zero steady state errors in a multi area interconnected power system. With computer based control systems and multiple inputs, an automatic generation control system can take into account such matters as the most economical units to adjust, the coordination of thermal, hydroelectric, and other generation types, and even constraints related to the stability of the system and capacity of interconnections to other power grids. A proportional integral derivative controller (PID controller) is a generic loop feedback (controller) widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then instigating a corrective action that can adjust the process accordingly and rapidly, to keep the error minimal. The PID controller calculation involves three separate parameters; the proportional, the integral and derivative values. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element.

Keywords: Load frequency control, Constant frequency, PID controller, Jaya technique.

Introduction

Today in electric power system Load–frequency control (LFC) is important field for design and operation. In an interconnected power system, the generation of power within each area has to be controlled so as to maintain the scheduled power interchange. The modern power systems with industrial and commercial

loads need to operate at constant frequency with reliable power. Owing to the continuous growth of electrical power system in size and complexity with increasing interconnections, the problem of power and frequency oscillations due to unpredictable load changes, has become increasingly serious.

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In the large scale electric power systems with interconnected areas, Load Frequency Control (LFC) plays an important role. The objective of the LFC in an interconnected power system is to maintain the frequency of each area within limits and to keep tie-line power flows within some pre-specified tolerances by adjusting the MW outputs of the generators so as to accommodate fluctuating load demands. The load frequency control of an interconnected power system is being improved over the last few years.

This article work uses a new Artificial Intelligence (AI) technique (ACO) for optimal tuning of PID controllers. The motivation behind this research is to prove and demonstrate the robustness of ACO based PID, and to improve the transient response of frequency deviation under various loading conditions in presence of system nonlinearities.

System Model

In an interconnected power system there is number of generators supplying the power system load, so there must be some methods, by which change in load could be allocated to each generator. This mechanism by which load is allocated to a generator can be controlled by system consisting of number of units which are being modelled here:

Mathematical Modelling of Load

The load on the power system consists of a variety of electrical drives. The equipment's used for lighting purposes are basically resistive in nature and the rotating devices are basically a composite of the resistive and inductive components. The speed-load characteristic of the composite load is given by:

$$\Delta P_{ee} = \Delta P_L + D\Delta\omega \tag{1}$$

Where, ΔP_L is the non-frequency- sensitive load change, $D\Delta\omega$ is the frequency sensitive load change. D is expressed as percent change in load by percent change in frequency.

Mathematical Modelling of Generator

A generator converts the mechanical energy into electrical energy. During steady state mechanical power input is such that it supplies the generator losses and electrical output power means mechanical torque is equal to electrical torque so the generator speed and fundamental output frequency remains constant. Let steady state operating generators parameters are:

$$\omega_o = \text{steady state speed}$$

$$\delta_o = \text{steady state rotor angle}$$

Under any mechanical or electrical perturbation will lead to deviation from steady state speed and frequency due to acceleration or retardation created due to imbalance in electrical and mechanical torque. Let α be acceleration which results in $\Delta\omega$ deviation in steady state speed and $\Delta\delta$ deviation in steady state rotor angle.

Now, $\Delta\delta$ will be related to $\Delta\omega$ as:

$$\Delta\delta = \omega_o t + \frac{1}{2}\alpha t^2 - \omega_o t \tag{2}$$

$$\text{or } \Delta\delta = \frac{1}{2}\alpha t^2 \tag{3}$$

So we can express the deviation in rated speed $\Delta\omega$ of generator as:

$$\Delta\omega = \alpha t = \frac{d}{dt}(\Delta\delta) \tag{4}$$

Now the net accelerating torque can be expressed in terms of speed deviation and phase angle deviation, as

$$T_{net} = I \frac{d^2}{dt^2}(\delta) \tag{5}$$

Now, the difference of electrical output power and input mechanical power is related to net accelerating torque as

$$\Delta P_m - \Delta P_e = \omega_o (\Delta T_m - \Delta T_e) = \omega_o \Delta T_{net} \tag{6}$$

or we can have

$$\Delta P_m - \Delta P_e = \omega_o I \frac{d}{dt}(\delta) = M \frac{d}{dt}(\delta) \tag{7}$$

Taking Laplace transform of the eq. 3.6 we will have

$$\Delta P_m - \Delta P_e = Ms \Delta \omega \tag{8}$$

For the equation 8 obtained, the block diagram is shown in Fig. 1.

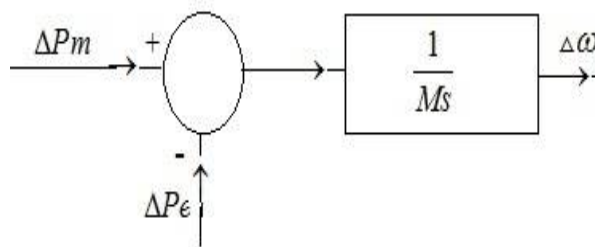


Figure 1. Relationship between Mechanical and Electrical Power and Speed Change

The units for M are watts per radian per second per second. We will always use per unit power over per unit speed per second where the per unit refers to the machine rating as the

base. So, combined block diagram of generator and load as appeared at prime mover can be drawn as:

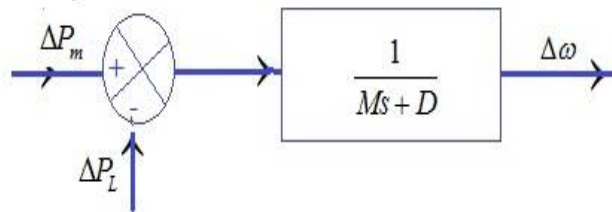


Figure 2. Combined Block Diagram of Generator-Load

Mathematical Modelling of Prime Mover

According to availability of natural source of energy there are various types of prime movers to convert into mechanical power (ΔP_m) also called turbine are used in power system which runs the generator. For example steam turbine of non-reheat, reheat type or hydro turbine etc. The main function of prime mover is to

drive a generator unit and thus extract the mechanical power from source. For this dissertation work the simplest type of turbine that is no reheat turbine has been used. There is a time delay occurs between the opening/closing of steam valve and production of torque to run prime mover. The transfer function for a non-reheat type is of first order shown below as by block diagram:

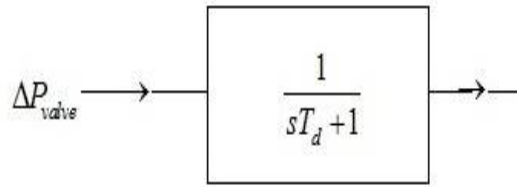


Figure 3. Block Diagram of Non-Reheat Prime Mover

The prime mover transfer function can be represented as:

$$G_{NR}(s) = \frac{1}{sT_d + 1} \tag{9}$$

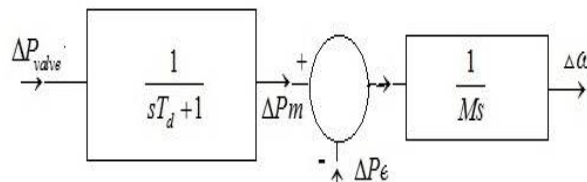


Figure 4. Combined Turbine and Generator Model

Mathematical Modelling of Governor

We will illustrate such a speed-governing mechanism with the diagram shown in Figure 5. The speed-measurement device's output, ω , is compared with a reference, ω_{ref} to produce an error signal, $\Delta\omega$. The error, $\Delta\omega$, is negated and then amplified by a gain K_G , and integrated to produce a control signal, ΔP_v , which causes the main steam supply valve to open (ΔP_{valv}

position) when $\Delta\omega$ is negative. If, for example, the machine is running at reference speed and the electrical load increases, m will fall below ω_{ref} and $\Delta\omega$ will be negative. The action of the gain and integrator will be to open the steam valve, causing the turbine to increase its mechanical output, thereby increasing the electrical output of the generator and increasing the speed.

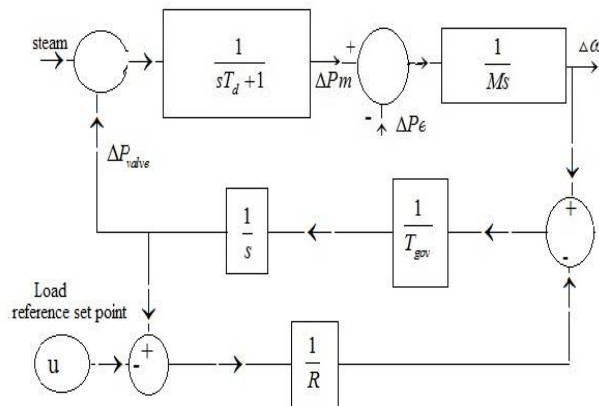


Figure 5. Governor with Speed-droop Feedback Loop

When ω exactly equals ω_{ref} the steam valve stays at the new position (further opened) to allow the turbine generator to meet the increased electrical load.

The result of adding the feedback loop with gain R is a governor characteristic as shown in Fig. 6.

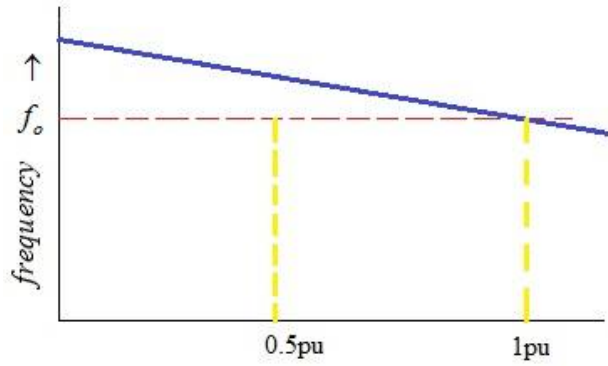


Figure 6.Speed-droop Characteristic

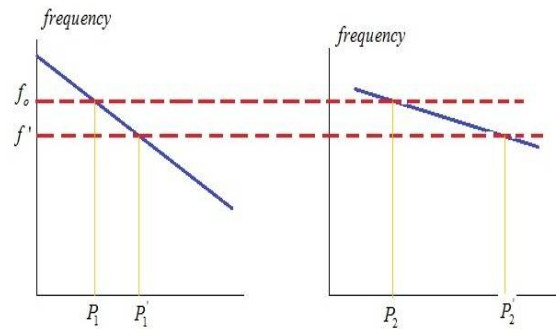


Figure 7.Allocation of Unit Outputs with Governor Droop

The value of R determines the slope of the characteristic. That is, R determines the change on the unit’s output for a given change in frequency. Common practice is to set R on each generating unit so that a change from 0 to 100% (i.e., rated) output will result in the same frequency change for each unit. As a result, a change in electrical load on a system will be

compensated by generator unit output changes proportional to each unit’s rated output.

$$R = \frac{\Delta\omega}{\Delta P} pu \dots (10)$$

At this point, we can construct a block diagram of a governor-prime-mover, rotating mass/load model as shown in Fig. 8.

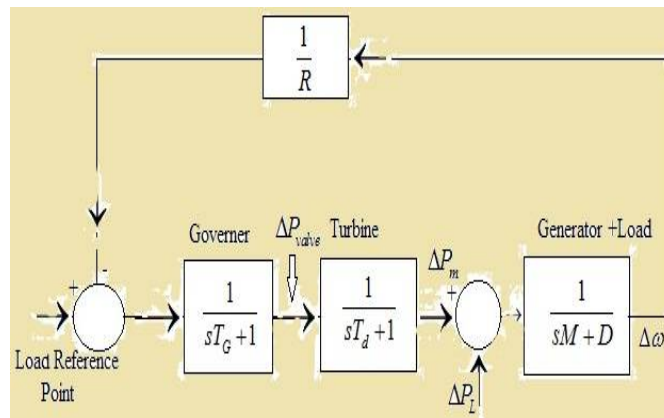


Figure 8.Schematic Diagram of a Speed Governing Unit Redrawn and Modified Form

Suppose that this generator experiences a step increase in load,

$$\Delta P_L(s) = \frac{\Delta P_L}{s} \tag{11}$$

The transfer function relating the load change, ΔP to the frequency change, $\Delta\omega$ is

$$\Delta\omega(s) = \Delta P_L(s) \left[\frac{\frac{-1}{Ms + D}}{1 + \frac{1}{R} \left(\frac{1}{sT_G + 1} \right) \left(\frac{1}{sT_d + 1} \right) \left(\frac{-1}{Ms + D} \right)} \right] \quad (12)$$

Applying the final value theorem to equation 13, the steady state value of generators angular velocity can be obtained as:

$$\Delta\omega_o = \lim_{s \rightarrow \infty} [s\Delta\omega_o(s)] = \frac{\Delta P_L}{\frac{1}{R} + D} \quad (13)$$

AGC in a Single-Area System

In a single area system Fig. 9, there is no tie-line schedule to be maintained. Thus the

function of the AGC is only to bring the frequency to the nominal value, which will be achieved during the supplementary loop which uses the integral controller to change the reference power setting so as to change the speed set point. The integral controller gain K_i needs to be adjusted for satisfactory response (in terms of overshoot, settling time) of the system.

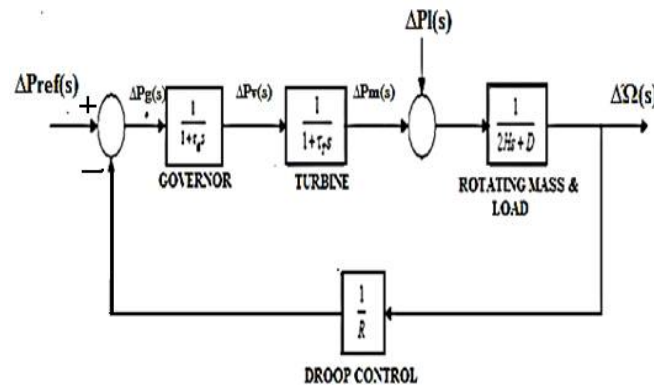


Figure 9. The Block Diagram Representation of Single Area Power System

Although each generator will be having a separate speed governor, all the generators in the control area are replaced by a single equivalent generator, and the ALFC for the area corresponds to this equivalent generator. With the primary LFC loop, a change in the system load will result in a steady-state frequency deviation, depending on the governor speed regulation. In order to reduce the frequency deviation to zero, there should

be a reset action. The reset action can be achieved by introducing an integral controller to act on the load reference setting to change the speed set point. The integral controller increases the system type by 1 which forces the final frequency deviation to zero. The integral controller gain K_1 must be adjusted for a satisfactory transient response. The close loop transfer function of the control system with only ΔP_L as input becomes.

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{s(1 + \tau_g s)(1 + \tau_r s)}{s(2Hs + D)(1 + \tau_g s)(1 + \tau_r s) + K_i + s/R} \quad (14)$$

PID-controller and its Tuning Techniques

Proportional Integral and Derivative (PID) Controller is a feedback based controller which gets the error output based on the characteristics of the error and gives good result. PID is used in a closed loop .it has three elements P, I, D. The PID controller is by far the most commonly used Controller Strategies in the process control industry.

PID controller is widely used in industrial control systems which are composed of proportional, integral and derivative control action. There are many forms of PID controller implementations such as a Distributed Control System (DCS) or stand-alone controller. It is widely used due to its simple structure and robust performance. PID controller is

implemented as either stand-alone controller. Every parameter has gain by which we control the contribution, or control systems. PID controller is used as pneumatic, hydraulic or mechanical controller or had a simple interface for manual tuning of the controller. PID is simply an equation that the controller uses to evaluate the controlled variables. The controller then compares the feedback to the set point and generates to the controller. The value is examined with one or more of the three proportional, integral and derivative control mode. The controller issues the necessary commands or process inputs to correct the error.

PID controller can be used in closed loop with plant as given Fig. 10:

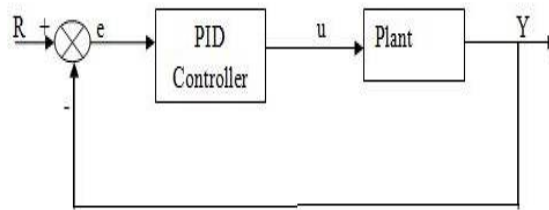


Figure 10.PID Control with Plant in Closed Loop System

Soft-computing Techniques PID Controller Tuning

For all these methods it is very urgent to know precise transfer function of the system than only soft computing methods can be applied for tuning the PID controller. But in practical applications, to a different extent, most of the industrial process exists to be nonlinear, the variability of parameters and there is high uncertainty in model of system, thus it is very typical and complex job to obtain precise control of the process using conventional tuning methods of PID controller. For tuning by common methods it is required that the process model should have system mathematical model of a certain type, as we

have 'First order plus dead time' model as an example. This problem of precise tuning can be overcome by the applying soft-computing methods PID controller parameters tuning. Soft-computing methods are especially useful for solving problems which involve very large amount of complicated and lengthy calculation and also mathematically in traceable. This is due to the convenience of combining natural systems with intelligent machines effectively with the help of soft-computing methods. Among these entire soft-computing methods available neural network, fuzzy logic, genetic algorithm and Particle Swarm Optimization, Teacher learning based optimization techniques and Jaya optimization techniques are the most important.

System Simulation and Result Analysis

In this dissertation work I have examined the effectiveness of Jaya optimization technique by applying the same in load frequency control

problem in power system. For this the proposed method has been applied to determine the controller parameters for load frequency control of single area system.

Table 1. Power System Parameters

S. No.	Description	Symbol	Value
1	Inertia constant	H	10
2	Load constant	D	0.8
3	Governor time constant	τ_g	0.2
4	Turbine time constant	τ_t	0.5
5	Drop coefficient	R	0.01

Response of Isolated Power System without Controller

With Matlab Simulink software model of isolated load frequency control has been developed which is shown below in Fig. 11.

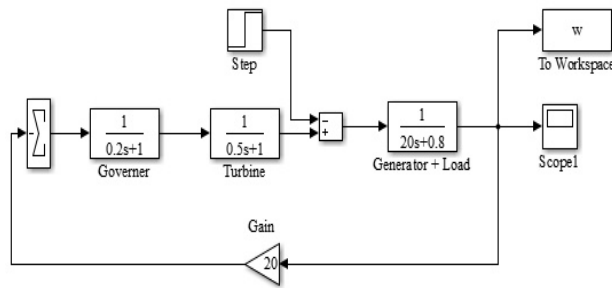


Figure 11. Simulink Model of Isolated Non-reheat Type Power System

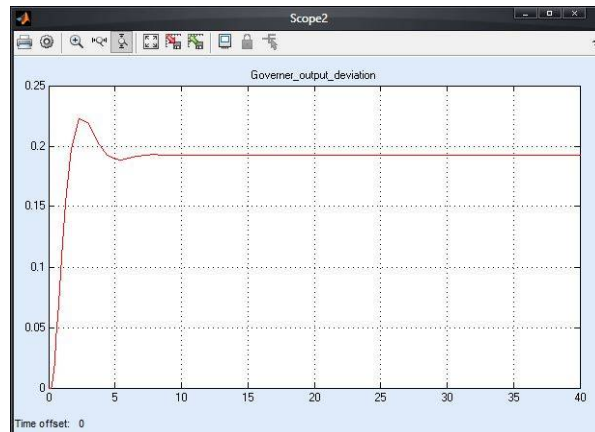


Figure 12 (a). Step Response of Governor Output Deviation without Secondary Control Loop

For a large variation in system load steady state error is also large and does not depends on turbine or governor action. Their faster and

improved performance can only reduce the deviation of system frequency during transient at the beginning of the perturbation.

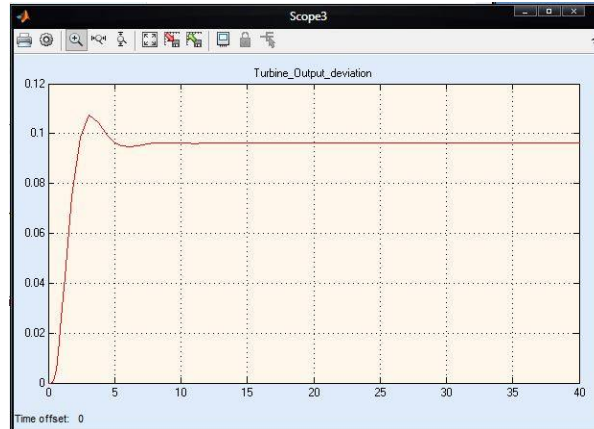


Figure 12 (b).Step Response of Turbine Output Deviation without Secondary Control Loop

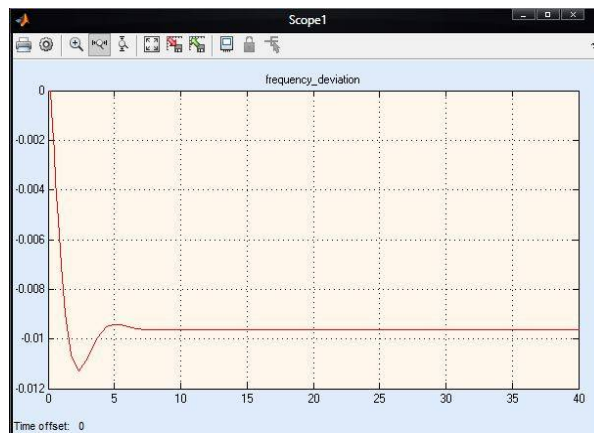


Figure 12 (c).Step Response of Generator-load Frequency without Secondary Control Loop

From the above step response graphical representation of the system frequency and governor and turbine power it is clear that there is inherent steady state error in load frequency response of system for a step input. So there is urgent need of stable feedback control which could reduce the frequency error to zero after a load change. During transient time which should be tried to keep as small as possible, and control loop should be designed such way the deviation of system frequency could be minimized further integral frequency is to be kept within certain limit.

Response of Isolated Power System with Jaya Optimization Based PI Controller

As the load on system changes depending on governor dynamics there occur a deviation in

system frequency from its steady state value. So there is a further requirement of system frequency regulation by some reset action which can be obtained by introducing an integral control term. The integral control term will act to change the speed set point by acting on load reference point. By introduction of integral term system type increases by 1 which results in opposition to frequency deviation to zero.

Figure 13 shows the load frequency control block diagram with additional integral control term. Now, value of gain of integral control term should be such that system dynamics get improved. In Fig. 14 both the parallel controller terms have been combined in one.

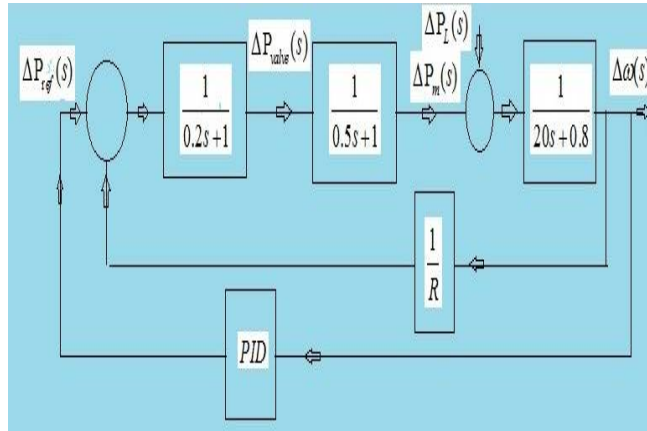


Figure 13. Experimental System Block Diagram with Secondary Loop

Using the block diagram shown in Fig. 14, the system transfer function can be expressed as:

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{\left(\frac{1}{1+0.2s}\right)\left(\frac{1}{1+0.5s}\right)}{\left(\frac{1}{1+0.2s}\right)\left(\frac{1}{1+0.5s}\right)\left(\frac{1}{0.8+20s}\right) + \frac{1}{R} + \frac{K_i}{s} + K_p + sK_d} \quad (15)$$

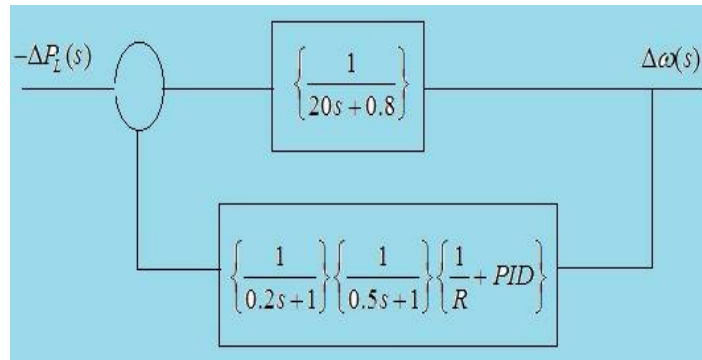


Figure 14. Reduced Experimental System Block Diagram without Secondary Loop

Applying Jaya optimization technique the value obtained so overall transfer is: of $K_i = 278$ and $K_p = 130$ and $K_d = 381$ are

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{\left(\frac{1}{1+0.2s}\right)\left(\frac{1}{1+0.5s}\right)}{\left(\frac{1}{1+0.2s}\right)\left(\frac{1}{1+0.5s}\right)\left(\frac{1}{0.8+20s}\right) + \frac{1}{0.01} + \frac{278}{s} + 130 + 381s} \quad (16)$$

Above shown single area system has been provided with a PID controller for purpose of controlling the deviation of system frequency. The frequency, turbine and governor deviation

response of system for a 20% load change controlled with Teaching learner based optimization technique based PID controller has been shown in Fig. 16 (a) - (d).

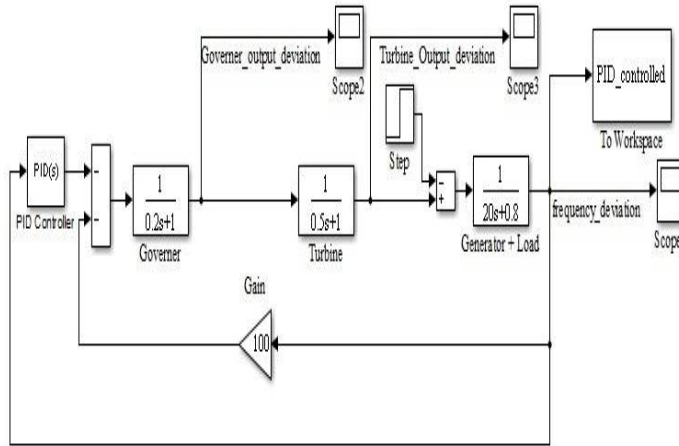


Figure 15. Simulink Model of Isolated Non-reheat Type Power System with Secondary PID Controller

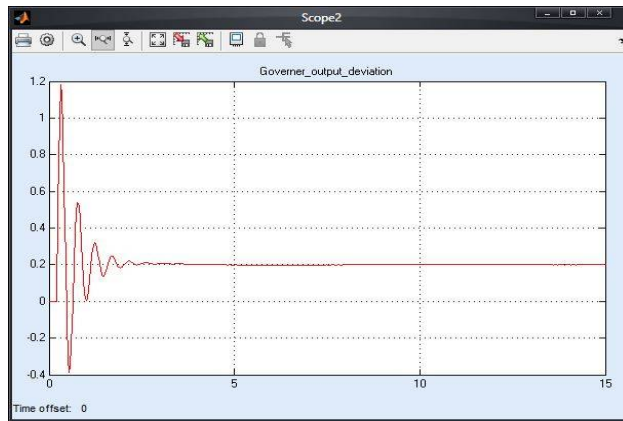


Figure 16 (a). Step response of Governor Output deviation with Jaya based PID Secondary Control Loop

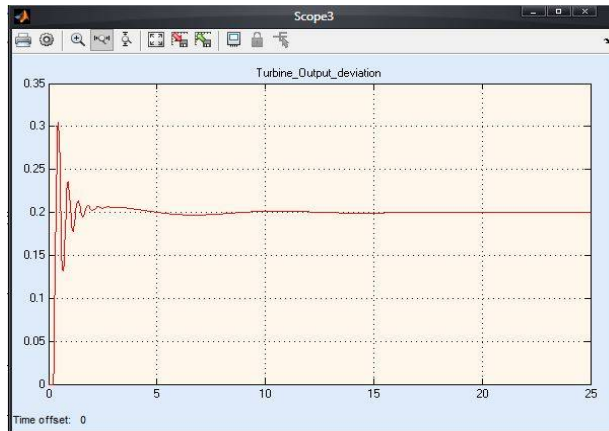


Figure 16 (b). Step Response of Turbine with Jaya based PID Secondary Control Loop

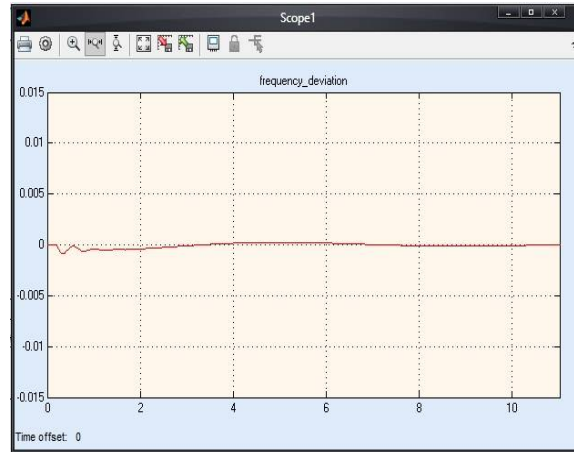


Figure 16 (c).Step Response of Generator-load Frequency Deviation with TLBO based PID Secondary Control Loop



Figure 16 (d).Zoom View of Step Response of Generator-load Frequency Deviation with TLBO based PID Secondary Control Loop

Table 2.Comparison of Dynamic Response of Single Area Power System

	Power System without Controller	Power System with PID Controller
Steady state error	0.012pu	0
% reduction in Steady state error		100 %
Peak overshoot	-0.0048	-0.0009
% reduction in peak overshoot		81.25 %
Settling time	6	3
% reduction in settling time		50 %

Conclusion

The graphical representation of step response for system controlled with TLBO based PID controller, the steady state frequency returns to its rated value and deviation reduces to zero

about in 3 seconds. The value of peak deviation in system frequency also has reduced to very low value, resulted in 82% low overshoot. Maximum value of magnitude of transient oscillation has also reduced many folds so the system has become more stable. Thus

proposed TLBO based PID controller has results in true optimal gains, reduced oscillation leading to quicker stability and peak overshoot also minimum settling time during transient period shown in Fig. 16 (a) - (d).

The frequency response for the PID controller is better than compared to the response of I and PI controllers. It is seen that the settling and rise time in case of PID controller has been smaller as compared to the others and also the oscillations are relatively less for the system than that for I and PI controllers. It is also seen at higher step load change (i.e. ± 0.01); the responses become more oscillated with higher settling time. By comparison of deviation response with and without controller it is clear that Jaya technique based PID load frequency controller can regulate the deviation of frequency, turbine and governor response to converge to the required acceptable value in acceptable time, even when system parameters are not at their nominal value. This shows the robustness of Jaya technique based PID load frequency controller of the system.

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