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Firefly Based Multi-Area Multi-Source Automatic Generation Control

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***Abstract*—** Automatic Generation Control is one of the issues in electric power system design / operation and is becoming much more significant recently with increasing size, changing structure and complexity in interconnected multi area Multi-source system. Each control area is provided with three generation systems with thermal, hydro and gas turbines. It is proposed to apply a Proportional derivative–Proportional integral derivative (PD–PID) cascade controller in AGC. Controller gains are optimized simultaneously using more recent and powerful evolutionary Fire Fly algorithm (FFA). Performance of classical controllers such as Proportional Integral (PI) and Proportional Integral Derivative (PID) controller are investigated and compared with PD–PID cascade controller. The system dynamic performances are studied with 1% step load and 2% Step load perturbation in Area.

***Keywords*—** Automatic Generation Control(AGC), PD –PID Controller, Firefly Algorithm (FA).

I. INTRODUCTION

A. Overview

Power system operation has to ensure adequate power is being delivered to the consumers reliably and economically. In ensuring satisfactory operation, challenges persist in Modeling, Prediction, Comprehensive analysis of the problem, Simulation methodologies with efficient optimization techniques, cause and effect relationships, analysis, optimization and control of large-scale interconnected power networks, their interconnections and their interactive nature require quality control in power system.Large scale power systems are normally managed by viewing them as being made up of control areas with interconnections between them. Each control area must meet its own demand and its scheduled interchange power. Any mismatch between the generation and load can be observed by means of a deviation in frequency. This balance between load and generation can be by using Automatic Generation Control (AGC).

1) Reasons for the Limits on Frequency

Following are the reasons for keeping a strict limit on the system frequency variation:

1. The speed of the alternating current motors depends on the frequency of the power supply. There are situations where speed consistency is expected to be of high order.
2. The electric clocks are driven by the synchronous motors. The accuracy of the clocks is not only dependent on the frequency but also is an integral of this frequency error.
3. If the normal frequency 50 Hertz and the system frequency falls below 47.5 Hertz or goes up above 52.5 Hertz then the blades of the turbine are likely to get damaged so as to prevent the stalling of the generator.
4. The under frequency operation of the power transformer is not desirable. For constant system voltage if the frequency is below the desired level then the normal flux in the core increases. This sustained under frequency operation of the power transformer results in low efficiency and over-heating of the transformer windings.

2) Significance of Automatic generation Control

- To achieve zero static frequency
- To distribute generation among areas so that interconnected tie- line flows match a prescribed schedule;and
- To balance the total generation against the total load and tie-line power exchanges.

B. Objectives Of Work

- The optimization of controller gains of several controllers such as PD and PID controllers, when these controllers are considered separately in a three area thermal system using firefly.
- Comparison of dynamic responses for evaluation of dynamic performances for PD-PID cascade controller, PI and PID cascade controller, PI and PID controllers to find the best.
- Sensitive analysis of the optimum parameters of the best controllers obtained at nominal conditions.
- The Simulation results show that the proposed design method is simple to follow, can achieve good performance, and results in implementable PI-PID controllers.

The paper is organized as follows: Section 2 deals with the mathematical model of AGC. Section 3 describes detail of firefly algorithm. Section 4 describes the details of simulation diagram and results. Lastly, conclusion is given in Section 5.

II. MATHEMATICAL MODELS OF AGC

A. Various Components Of mathematical Modelling In Agc

If the system is connected to a number of different loads in a power system then the system frequency and speed change with the governor characteristics as the load changes. If it is not required to keep the frequency constant in a system then

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the operator is not required to change the setting of the generator. But if constant frequency is required the operator can adjust the speed of the turbine by changing the governor characteristic as and when required. If a change in load is taken care by two generating stations running at parallel then the complexity of the system increases.

B. Mathematical Modelling Of Generator

Applying the swing equation of a synchronous machine to small perturbation, we have:

$$\frac{2H}{\omega}\frac{d^2\Delta\delta}{dt^2} = \Delta Pm - \Delta Pe$$

Or

In terms of small deviation in speed,

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta Pm - \Delta Pe)$$

Taking Laplace Transform, we

$$\Delta\Omega(s) = \frac{1}{2Hs}[\Delta Pm(s) - \Delta Pe(s)]$$

obtain

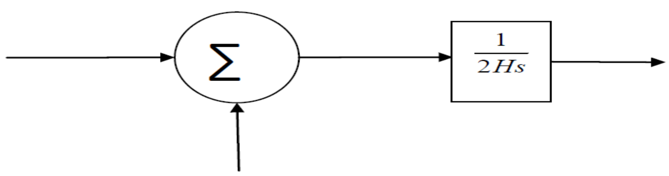

Fig 2.1 Mathematical Modeling of Generator

C. Mathematical Modelling Of Load

The load on the power system consists of a variety of electrical drives. The equipments 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:

$\Delta P_e = \Delta P_L + D\Delta\omega$

Where,

ΔPL is the non-frequency- sensitive load change,

DΔis the frequency sensitive load change,

D is expressed as percent change in load by percent change in frequency.

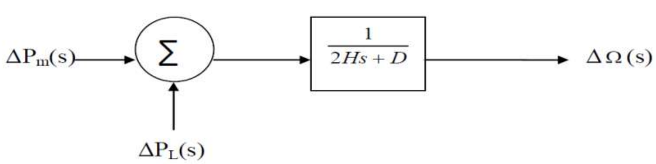

Fig 2.2. Modeling for load

D. Mathematical Modelling For Prime Mover

The source of power generation is commonly known as the prime mover. It may be hydraulic turbines at waterfalls, steam turbines whose energy comesfromSburning of the coal, gas and other fuels. The model for the turbine relates the changes in mechanical power output ΔPm to the changes in the steam valve position ΔPv.

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

Where,

$\tau_T$the turbine constant is, in the range of 0.2 to 2.0 seconds

E. Mathematical Modelling For Governor

When the electrical load is suddenly increased then the electrical power exceeds the mechanical power input. As a result of this the deficiency of power in the load side is extracted from the rotating energy of the turbine. Due to this reason the kinetic energy of the turbine i.e. the energy stored in the machine is reduced and the governor sends a signal to supply more volumes of water or steam or gas to increase the speed.

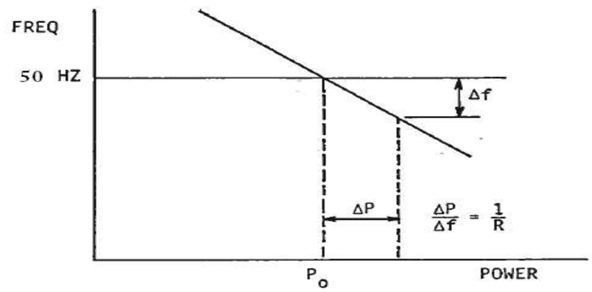

Fig 2.3 Graphical Representation of speed regulation by governor

The slope of the curve represents speed regulation R. Governors typically has a speed regulation of 5-6 % from no load to full load.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f$$

In s- domain

$$\Delta P_g(s) = \Delta P_{ref} - \frac{1}{R}\Delta\Omega(s)$$

The command ΔPg is transformed through hydraulic amplifier to the steam valve position command ΔPV. We assume a linear relationship and consider simple time constant we have the following s-domain relation:

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

Combining all the block diagrams from earlier block diagrams for a single are system we get the following:

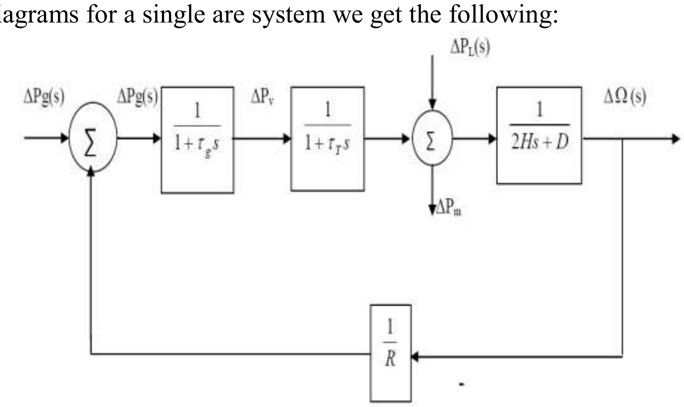

Fig2.4. Mathematical Modeling of Block Diagram of single area system consisting of Generator, Load, Prime Mover and Governor.

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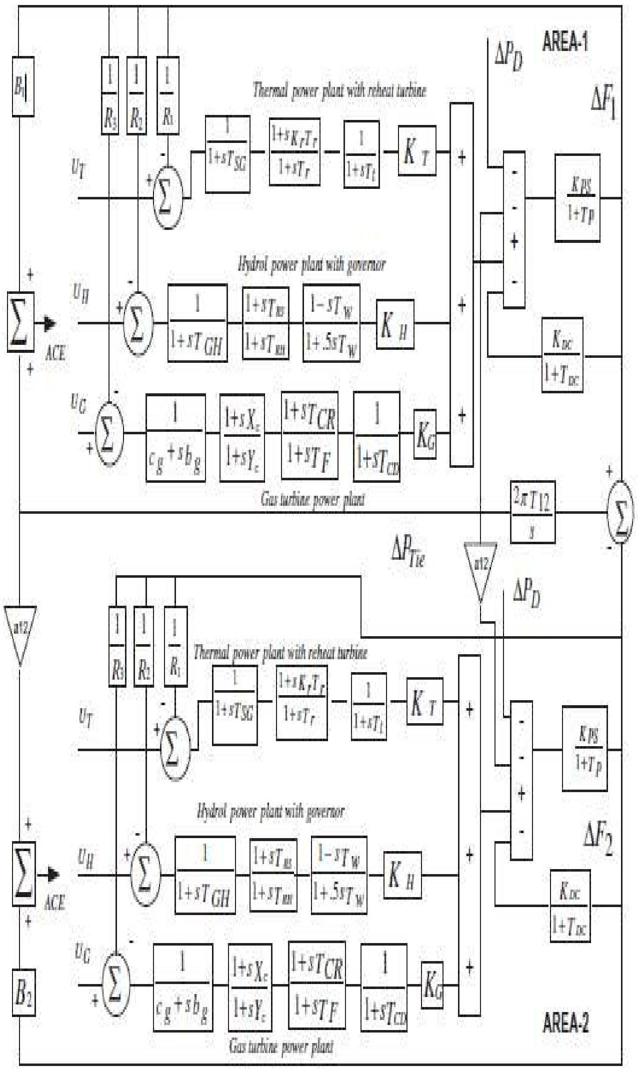

2.5 Transfer function model of multiple sources of multiple area system

III. FIREFLY ALGORITHM

A. Introduction

In this Project, two Scenarios are taken to analyze the dynamic characteristics behaviour of the three area system by optimally tuning the PD-PID,PI and PID controller using Firefly Algorithm

1. 1% Step load perturbation in Area1.
2. 2% Step load perturbation in Area1

The Control Performance Measure of ISE is used to validate the dynamic characteristics

B. Meta-heuristic Firefly Algorithm for Tuning the Controller

The movement of a firefly i is attracted to another more attractive(brighter) firefly j is determined by

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_i - x_j) + \alpha_t \epsilon^t_i$$

Where,

The second term is due to the attraction.The distance between any two fireflies i and j at and can be the Cartesian distance Third term is randomization with being the randomization parameter, and is a vector of random numbers drawn from a Gaussian distribution or uniform distribution at time t.If β0 = 0, it becomes a simple random walk. and otherwiseγ = 0, it reduces to a variant of particle swarm optimisation. Artificial diversification is also applied in the Firefly population to avoid premature convergence, which corresponds to a local optimum. In this work, random movement of firefly is used by simple mutation method like that of used in Genetic Algorithm.In this work, it is assumed that for a given firefly *x*, if the dimension O_k is selected, then the resulting dimension will be selected using the equation.

Where, $$O_k = a_k + (b_k - a_k) \times rand$$

a_k and b_k are lower and upper bands of O_k and *r*andis a uniform random number chosen in the range of (0, 1).

The Firefly algorithm was developed by Xin-She Yang and it is based on idealized behaviour of the flashing characteristics of fireflies. Nature based algorithms are highly effective and efficient to solve difficult optimization problems.

FFA is nature inspired algorithm and gaining popularity recently for solving nonlinear optimization problems technique. For simplicity,we can summarize the flashing characteristics of the FFA as the following three rules:

1. All fireflies are unisex, so that one firefly is attracted to other fireflies regardless of their sex
2. Attractiveness is proportional to their brightness, thus for any two flashing fireflies, the less bright one will move towards the brighter one.
3. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If no one is brighter than a particular firefly, it will move randomly. The brightness of a firefly is affected or determined by the landscape of the objective function to be optimized

Step1: Initialize the objective function as given in Performance Index Slide.

Step2: Initialize a population of fireflies X with the population size ofNF x N.

Where,NF is the Number of fireflies as 30 and N is the Dimension size dependson the number of Gain Values of the Controller available in the test systems

Step3: The light absorption coefficient is defined as random search between 0 to 10.

Step4:

While (t<=Max Generation(100))

For i=1:n (all n fireflies)

For j=1:i

Light Intensity of each firefly is determined by the objective function

If

Move firefly i towards j in all the dimensions as per the equation Else

Move firefly i randomly by creating a new dimension as per the equation

End if

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Evaluate newly created firefly Light Intensity and update the Light Intensity solution

End for j

End for i

Rank the fireflies based on its Light Intensity

Extract the Local best firefly(Best Controller Gain value in a iteration)

IV. Simulation And Results

A. Simulation Diagram

- To illustrate the effectiveness of the modeling strategy and three area power system is considered as a test system

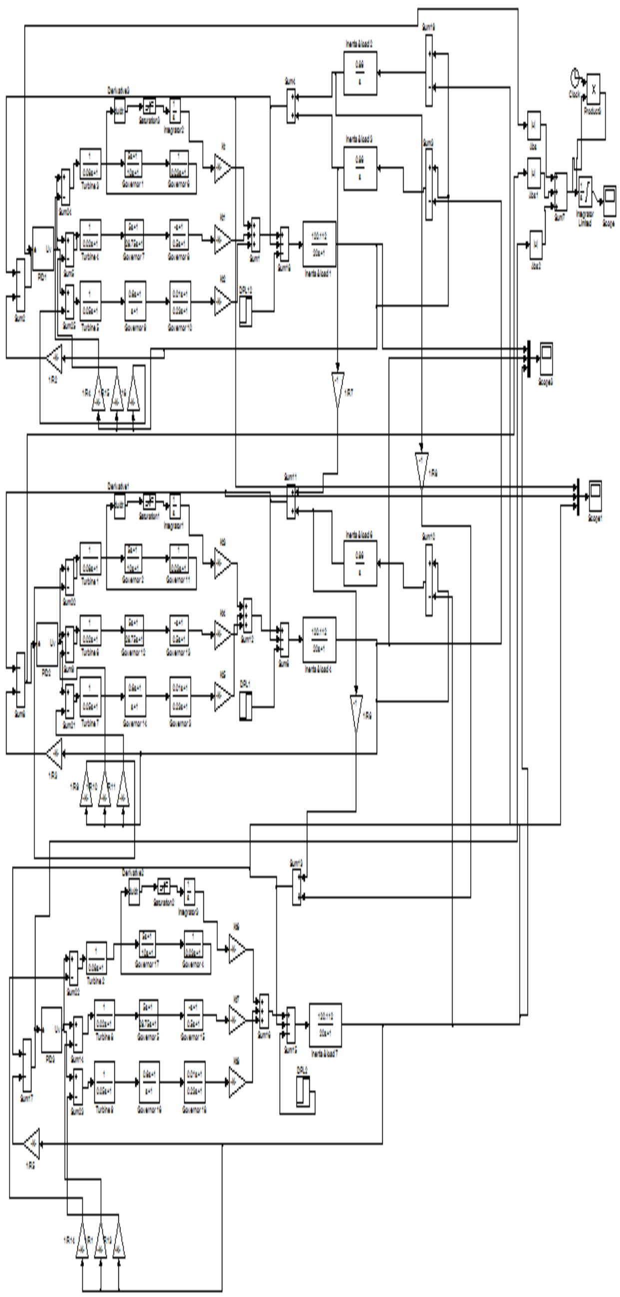

Fig4.1 simulation diagram

B. Simulation Results

Objective Results scenario 1 (step load perturbation=1%)

Table4 .1 Data for controller value 1

Controller	*ITAE*
Without Controller	13045.1
FFA PI Controller	446.1741
FFA PID Controller	166.6041
FFA PD-PID Controller	145.6509

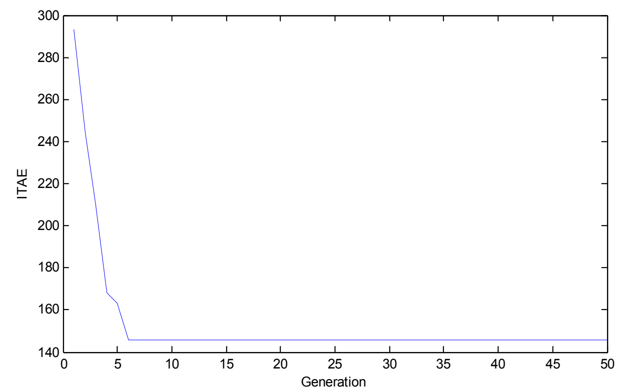

Fig 4.2 Graph for PD-PID controller 1

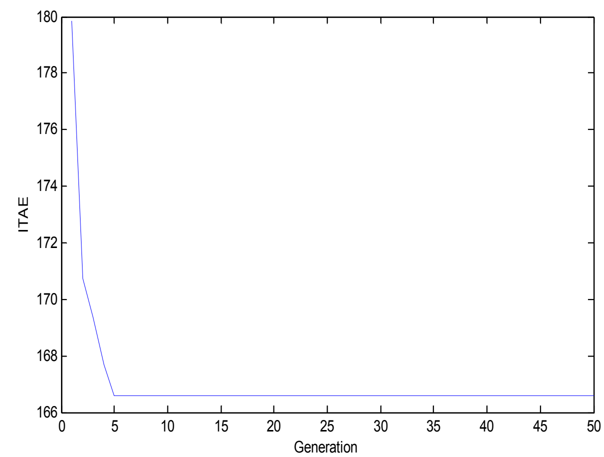

Fig 4.3 Graph for PID controller 1

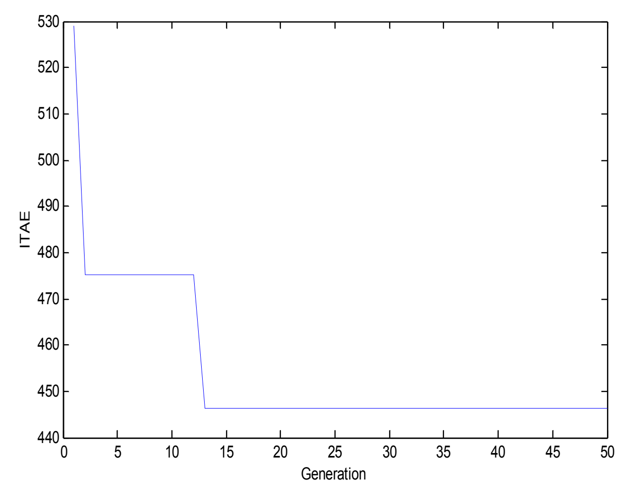

Fig 4.4 Graph for PI controller 1

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Dynamic Performance of the Scenario-1 (step load perturbation=1%)

Table 4.2 Dynamic performance value 1

Parameter	Controller	Settling Time	Peak overshoot	Peak overshoot (- Ve)
Del F1	FFA PI Controller	30	0.0019	0.013
	FFA PID Controller	20.5	0.0006	0.007
	FFA PD-PID Controller	14.8	0.0005	0.0042
Del F2	FFA PI Controller	27	0.00156	0.0116
	FFA PID Controller	21	0.0007164	0.00724
	FFA PD-PID Controller	20	0.0005133	0.003145
Del F3	FFA PI Controller	28	0.000671	0.01076
	FFA PID Controller	22	0.000927	0.007585
	FFA PD-PID Controller	19.8	0.0005453	0.002456

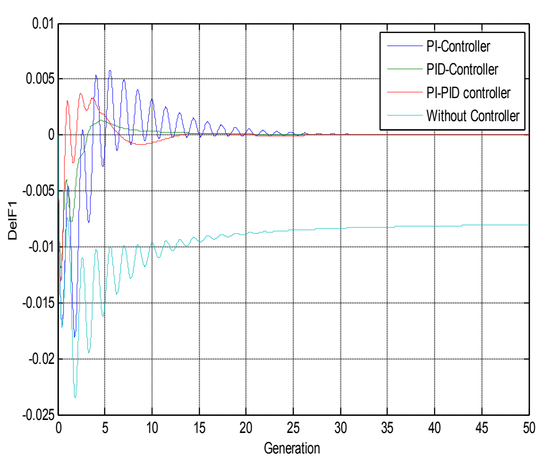


Fig 4.5 Del ptie-1

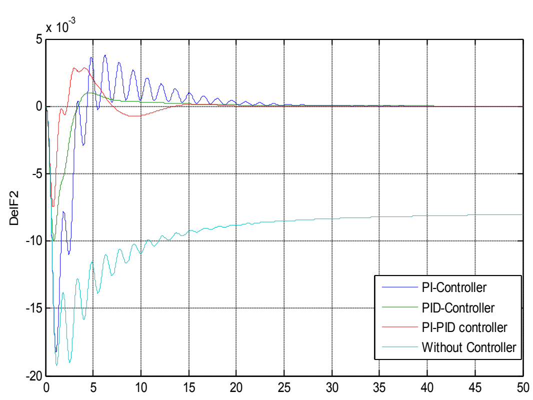


Fig 4.6 Del ptie-2

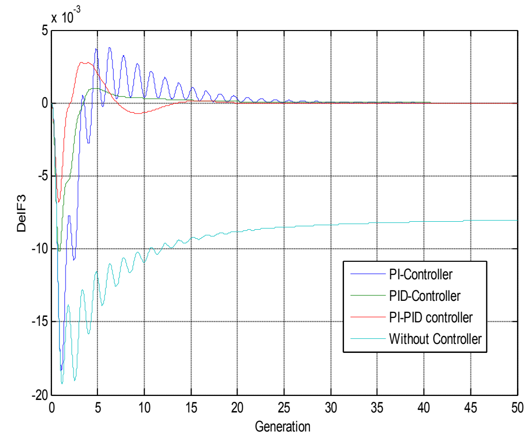


Fig 4.7 Del ptie-3

Objective Results Scenario 2 (step load perturbation=2%)

Table 4.3 Data for controller value2

Controller	ITAE
Without Controller	27191
FFA PI Controller	895.5022
FFA PID Controller	355.6448
FFA PD-PID Controller	217.0069839

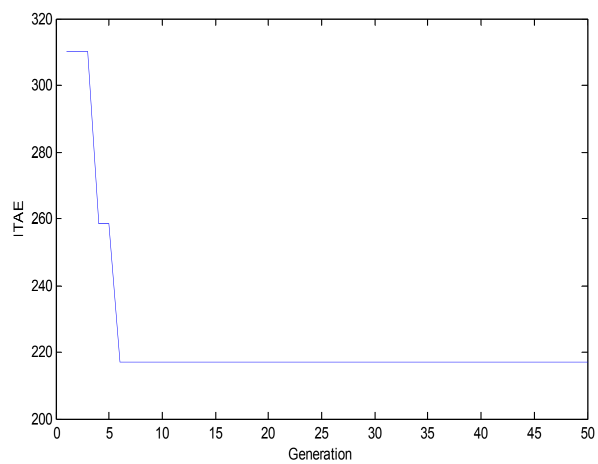


Fig 4.8 Graph for PD-PID controller value 2

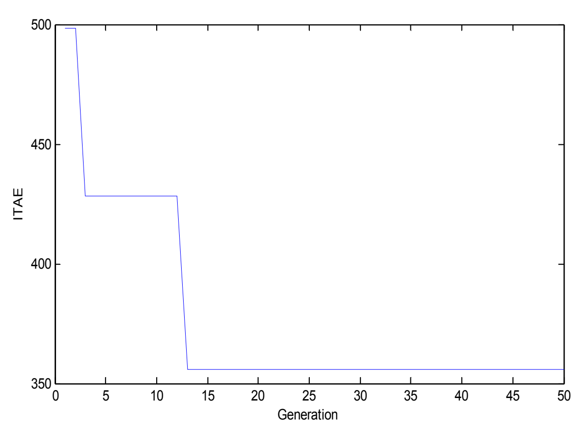


Fig 4.9 Graph for PID controller 2

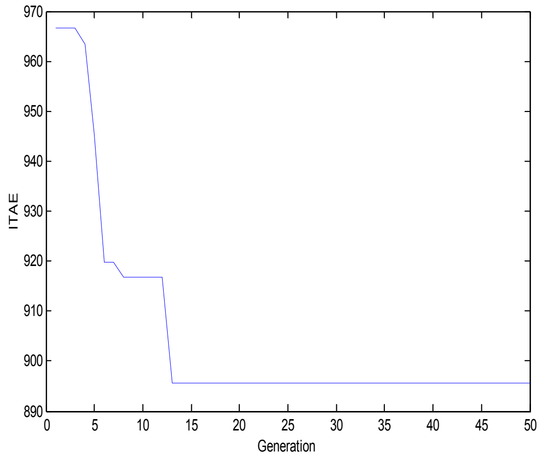


Fig 4.10 Graph for PI controller 2

Dynamic Performance of the Scenario-2 (step load perturbation=2%)

Table 4.4 Dynamic performance value 2

Parameter	Controller	Settling Time	Peak overshoot	Peak overshoot (- Ve)
Del F1	FFA PI Controller	22.5	0.00289	0.0251
	FFA PID Controller	18	0.000964	0.0075
	FFA PD-PID Controller	16	0.002108	0.0055
Del F2	FFA PI Controller	22.5	0.00163	0.000316
	FFA PID Controller	15	0.003653	0.00724
	FFA PD-PID Controller	15	0.002737	0.00114
Del F3	FFA PI Controller	22.5	0.00299	0.0217
	FFA PID Controller	18	0.00399	0.000285
	FFA PD-PID Controller	16	0.003921	0.00072
PTie1	FFA PI Controller	24.35	0.00086	0.01531
	FFA PID Controller	22.3	0.001355	0.01481
	FFA PD-PID Controller	3.68	0.00206	0.006199
Ptie2	FFA PI Controller	22.25	0.00812	0.0003681
	FFA PID Controller	21.87	0.003142	0.01547
	FFA PD-PID Controller	3.93	0.00247	0.0009057
Ptie3	FFA PI Controller	19.99	0.0067922	0.00142
	FFA PID Controller	21.87	0	0.01566
	FFA PD-PID Controller	3.53	0.003422	0.0009131

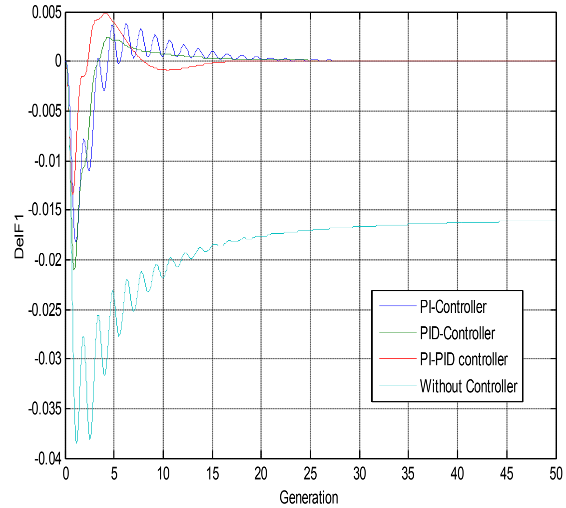
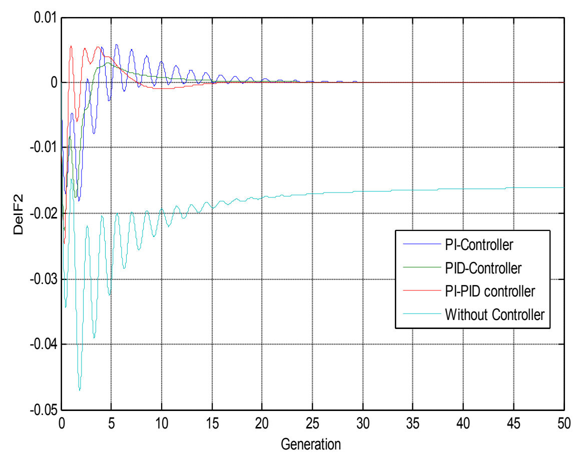


Fig
4.12 Graph for Del ptie 1



Fi
g 4.13 Graph for Del ptie2

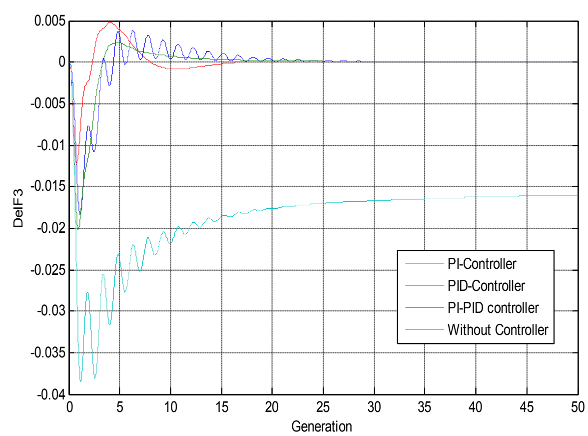


Fig 4.14 Graph for Del ptie3

V. CONCLUSION

The Automatic Generation Control system was modeled with three areas and three sources were interconnected. The system was controlled with PD-PID controller. The development of control strategy combines the advantages of the firefly algorithm based PD-PID controllers for achieving the desired level of robust performance, such as precise

reference frequency tracking and disturbance attenuation under a wide range of area load changes and disturbances. Moreover, it has a simple structure and is easy to implement, which makes it ideally useful for the real world power system. The system parameters were optimized by implementing the firefly algorithm. From the results it is concluded that the system is optimized i.e. the steady state time is reduced and the peak overshoot is reasonably reduced. The system performance may be improved by implementing a new optimization technique or by incorporating new control technique.

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