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Dynamic Response of Multi Area Load Frequency Control through Different Computational Techniques

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Abstract

Objective: To employ optimization technique (GA (Genetic Algorithm) Technique) to solve the problem of power generation, by means of mathematical approach to formulate the problem mathematically. **Methods:** Thermal units have been taken as a source of power generation. Transfer function model of thermal generating units has been developed and simulated through MATLAB Simulink software. The main issue of power generation is the continuous mismatching in the generation and consumption of electricity due to which continuous the change in frequency and corresponding power becomes a major issue, which need to be maintained in constancy for regular operation. For this purpose, optimization technique (GA Technique), PI (Proportional Plus Integral), PID (Proportional Plus Integral Plus Derivative) technique have been used to solve the issue of frequency and corresponding power. **Findings:** Solve the issues of change in frequency and corresponding tie line power, a table has been drawn for batter comparison. **Novelty:** The comparative results obtained from all technique have been put in table which shows that the optimization technique (GA Technique) gives very effective, efficient and dynamic results (8 Sec and 11 Sec in Frequency & Power Variation) compared to traditional technique (PI, PID) (28 Sec, 44 Sec & 27 Sec & 43 Sec in Frequency & Power Variation).

Keywords: Traditional Technique; GA (Genetic Algorithm) Technique; Optimization Technique; Power Generation

1 Introduction

A large portion of the conversion of thermal to electrical energy occurs in steam turbines. This has many advantages like, the balanced construction, relatively high efficiency, few moving parts, ease of maintenance, and availability in large sizes.Internally, the steam turbine consists of rows of blades designed to extract the heat and pressure energy of the steam, which is usually superheated, and convert this energy into mechanical energy. To accomplish this goal, high-pressure steam is admitted through a set of control valves and allowed to expand as it passes through the turbine, to be exhausted, usually to a condenser, at relatively low pressure and temperature.

In an interconnected power system, load frequency control (LFC) and automatic voltage regulator (AVR) equipment is installed for each generator. Figure 1 represents the schematic diagram of the load frequency control (LFC) loop and the automatic voltage regulator (AVR) loop. The controllers are set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits. Small changes in real power are mainly dependent on changes in rotor angle δ and, thus, the frequency. The reactive power is mainly dependent on the voltage magnitude (i.e., on the generator excitation). The excitation system time constant is much smaller than the prime mover time constant and its transient decay much faster and does not affect the LFC dynamic. Thus, the cross-coupling between the LFC loop and the AVR loop is negligible, and the load frequency and excitation voltage control are analyzed independently[1–14].

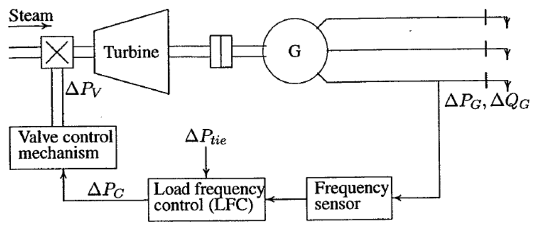

Fig 1. Schematic diagram of LFC of a synchronous generator

Due to complex system structure, Transfer function model of two and three generating unit has been obtained and shown in Figure 2 and Figure 3. These figures represent the governor, turbine and generator transfer function model of two and three generating units.

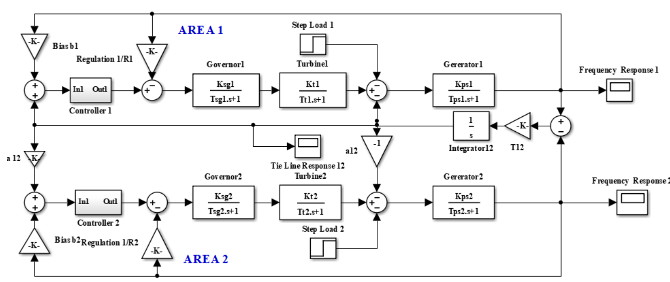

Fig 2. Transfer function model of two generating unit

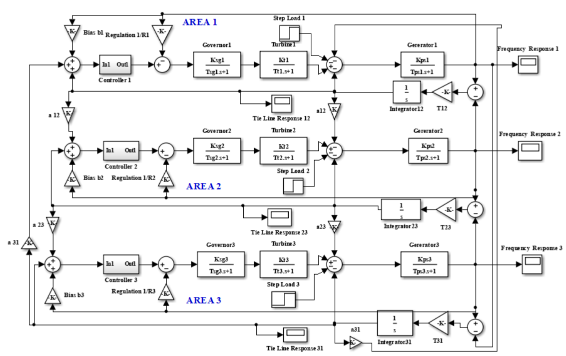

Fig 3. Transfer function model of three generating unit

2 Mathematical Approach

The real power in a power system is being controlled by controlling the position of the control valve to exert the flow of high-pressure steam through the turbine. The mathematical model can be developed which is based on small deviations around a nominal steady state. Let us assume that the steam is operating under steady state and is delivering power P_G from the generator at nominal speed or frequency f. Under this condition, the transfer functions equation of the governor, turbine, generator has been obtained and shown below;

Governor Transfer function = $\frac{Ksg}{Tsg\,s+1}$ (1.1)

Where K_{sg} is the gain of governor and T_{sg} is the time constant of governor, normally range of T_{sg} is $\leq$ 100 ms.

Turbine Transfer function =$\frac{Kt}{Tt\,s+1}$ (1.2)

Where K_t is the gain of turbine and T_t is the time constant of turbine, normally range of T_t is 0.2 to 2 sec.

Generator Transfer Function = $\frac{Kps}{Tps\,s+1}$ (1.3)

Where K_{ps} is the gain of generator and T_{ps} is the time constant of generator, normally range of T_{ps} is 20s. $K_{ps}= \frac{1}{B}$, B is constant parameter in MW/Hz. $T_{ps}= \frac{2H}{Bf_0}$, H be the inertia constant of a generator (MW-s/MVA) and P_r the rating of the turbo-generator (MVA). f_o is frequency [6,8–11,15].

2.1 Mathematical Equation of Frequency

Let us consider a simple case wherein the speed changer has a fixed setting, which means ΔP_C= 0 and the load demand alone changes. Such an operation is known as free governor operation or uncontrolled case since the speed changer is not manipulated (or controlled to achieve better frequency constancy).

For a sudden step change of load demand (ΔP_D),

$\Delta P_G(s) = \frac{\Delta P_D}{s}$ 1.4

For a practical system,

$T_{sg}<T_t<<T_{ps,}$

Typical values are:

T_{sg}= 0.4s

T_t= 0.5s

T_{ps}= 20s

If T_{sg} and T_t are considered negligible compared to $T_{ps,}$ and by adjusting $T_{sg}T_t$= 1, the block diagram of AGC in power system of an single area power system is reduced to a first order system, the change in frequency is given by

$$\Delta F(s)|_{\Delta PC(s)=0} = -\left(\frac{\frac{K_{ps}}{1+sT_{ps}}}{1+\frac{K_{ps}}{1+sT_{ps}}\times\frac{1}{R}}\right] \times \frac{\Delta P_D}{s} \quad (1.5)$$

$$= -\left(\frac{K_{ps}}{(1+sT_{ps})+\frac{K_{ps}}{R}}\right] \times \frac{\Delta P_D}{s}$$

$$= -\left(\frac{K_{ps}}{sT_{ps}+\frac{K_{ps}+R}{R}}\right] \times \frac{\Delta P_D}{s}$$

$$= -\left(\frac{\frac{K_{ps}}{T_{ps}}}{s+\frac{K_{ps}+R}{RT_{ps}}}\right] \times \frac{\Delta P_D}{s}$$

$$= -\frac{K_{ps}\times\Delta P_D}{T_{ps}}\left(\frac{1}{s(s+\frac{K_{ps}+R}{RT_{ps}})}\right]$$

$$\Delta F(s)|_{\Delta PC(s)=0} = -\frac{K_{ps}\times\Delta P_D}{T_{ps}}\times\frac{RT_{ps}}{K_{ps+R}}\left(\frac{1}{s}-\frac{1}{(s+\frac{K_{ps}+R}{RT_{ps}})}\right] \quad (1.6)$$

$$\Delta f(t) = L^{-1}\Delta F(s)$$

$$\Delta f(t) = -\frac{RK_{ps}}{K_{ps+R}}\left(1-e^{\left(-\frac{t}{T_{ps}}\frac{RT_{ps}}{K_{ps+R}}\right]}\right]\Delta P_D \quad (1.7)$$

This is equation for dynamic state, help to determine the dynamic response of the system.

The meaning of dynamic response is how the frequency changes as a function of time immediately after disturbances before it reaches the new steady state condition. The analyzation of dynamic requires the solution of dynamic equation of the system for a given disturbance. The solution involves the solution of different equations representing the dynamic behavior of the system.

The inverse Laplace Transform of $\Delta F(s)$ gives the variations of frequency with respect to time for a given step change in load demand. Comparing the relative values of time constants, we can reduce the third ordered model to a first ordered system [4,7,9–14].

2.2 Mathematical Equation of Power

Corresponding Power must be accounted for the incremental power balance equation of each area, since there is power flow in or out of the area through the tie line.

Power flow out of control area-1 can be expressed as

$P_{TL1} = \frac{|E_1||E_2|}{X_{TL}} \sin(\delta_1 - \delta_2)$ (1.8)

Where $|E_1|$ *and* $|E_2|$ are voltage magnitude of area 1 and area 2, respectively, δ_1 and δ_2 are the power angles of equivalent machines of their respective area, and X_{TL} is the tie line reactance.

If there is change in load demands of two areas, there will be incremental changes in power angles ($\Delta\delta_1$ and $\Delta\delta 2$). Then, the change in the tie line power is

$P_{TL1} + \Delta P_{TL1} = \frac{|E_1||E_2|}{X_{TL}} \sin[(\delta_1 - \delta_2) + \sin(\Delta\delta_1 - \Delta\delta_2)]$ (1.9)

After solving the above equation we get,

$P_{TL1} + \Delta P_{TL1} = \frac{|E_1||E_2|}{X_{TL}} \sin(\delta_1 - \delta_2) + \frac{|E_1||E_2|}{X_{TL}} [\cos(\delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2)]$ (2.0)

Therefore, change in incremental tie-line power can be expressed as

$\Delta P_{TL1} = \frac{|E_1||E_2|}{X_{TL}} [\cos(\delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2)]$ MW (2.1)

$\Delta P_{TL1} = T_{12}(\delta_1 - \delta_2)$ (2.2)

Where $T_{12} = \frac{|E_1||E_2|}{X_{TL}P_1} \cos(\delta_1 - \delta_2)$ MW/rad (2.3)

T_{12} is known as the synchronizing coefficient or the stiffness coefficient of the tie-line. Equation (2.3) can be written as

$T_{12} = \frac{P_{max12}}{P_1} \cos(\delta_1 - \delta_2)$ (2.4)

Where $P_{max12} = \frac{|E_1||E_2|}{X_{TL}P_2}$ = Static transmission capacity of the tie line.

For Control area-1

$\Delta P_{TL1}(s) = 2\pi T_{12} \left(\frac{\Delta F_1(s)}{s} - \frac{\Delta F_2(s)}{s}\right]$ (2.5)

Or this equation can be written as

$\Delta P_{TL1}(s) = \frac{2\pi T_{12}}{s} (\Delta F_1(s) - \Delta F_2(s)]$ (2.6)

For Control area-2

$\Delta P_{TL2}(s) = 2\pi T_{21} \left(\frac{\Delta F_2(s)}{s} - \frac{\Delta F_1(s)}{s}\right]$

$= -2\pi a_{12} T_{12} \left(\frac{\Delta F_1(s)}{s} - \frac{\Delta F_2(s)}{s}\right]$

$\Delta P_{TL2}(s) = \frac{-2\pi a_{12} T_{12}}{s} (\Delta F_1(s) - \Delta F_2(s)]$ (2.7)

Similarly for three generating system the area control error and speed change can be obtained;

$ACE_1(s) = \Delta P_{TL1}(s) + b_1 \Delta F_1(s)$ (2.8)

$ACE_2(s) = \Delta P_{TL2}(s) + b_2 \Delta F_2(s)$ (2.9)

$ACE_3(s) = \Delta P_{TL3}(s) + b_3 \Delta F_3(s)$ (3.0)

Where b_1, b_2, b_3 are constants, and also called area frequency bias of area1, area2 and area3.For applying integral control of ACE_1, ACE_2, ACE_3

$\Delta P_{C1} = -K_{I1} \int(\Delta P_{TL1} + b_1 \Delta f_1)$ (3.1)

$\Delta P_{C2} = -K_{I2} \int(\Delta P_{TL2} + b_2 \Delta f_2)$ (3.2)

$\Delta P_{C3} = -K_{I3} \int(\Delta P_{TL3} + b_3 \Delta f_3)$ (3.3)

3 Control Technique

Two types of techniques (Traditional and Optimization) used to control the limit of frequency and power.

3.1 Traditional Technique

Different types of technique are using from past year for controlling the frequency and power flow in interconnected power system. PI (Proportional Plus Integral) and PID (Proportional Plus Integral Plus Derivative) techniques are the traditional technique.

The transfer function of the PI controller is

$G(s) = Kp + \frac{Ki}{s}$ 3.4

Where K_p is proportional gain and Ki is an integral gain.

The transfer function of the PID controller is

$G(s) = Kp + \frac{ki}{s} + sKd$ 3.5

Where $K_p$is proportional gain, Ki is an integral gain and $K_d$is derivative gain.

3.2 Optimization Technique (GA)

Optimization technique is a decision-making technique which relate to the set of priorities constraints or criteria for maximizing reliability, efficiency, strength and many more.

Genetic Algorithm (GA) is the collective name for a range of problem-solving techniques based on principles of biological evolution, which are being increasingly applied to a variety of problems, ranging from practical applications in industry and commerce to leading-edge scientific research. It uses iterative progress, such as growth or development in a population. This population is then selected in a guided random search using parallel processing to achieve the desired end. Such processes are often inspired by biological mechanisms of evolution.

Genetic algorithms are now used to solve multi-dimensional problems more efficiently with software produced by human designers, by using to optimization to solve highly complex problems. Main parts of GA are chromosomes, selection, recombination (crossover), mutation.

GA apply for optimizing gain coefficients of conventional PID controller. A tuning of PID using Genetic algorithm can be implemented by using the algorithms are discussed bellows;

(i) Start

(ii) Create a population for K_P, K_I, K_D, Initialization of the population of chromosomes for K_P, K_I, K_D(set of randomly generated chromosomes).

(iii) Evaluation of cost function (fitness) for all chromosomes and run the model.

(iv) Selection of parent chromosomes, Crossover and mutation all three-thing done by automatically using cost function.

(v) Find the best value.

(vi) Set iteration and compare the best value to the previous value are equal, optimizations is done then stop.

(vii) It compares the best value to the previous value is not equal. It replaces old population to new population jump to step2, the loop is continuous run until compare the best value to the previous value are equal.

The starting step of GA, opening in the MATLAB toolboxes (gatool) has been given two steps shown with 3 variables and fitness function (@dha_ash) with bounded condition (Upper limit is [0 0 0] and Lower limit [-5 -5 -5]).

The parameter used in GA controller for solving the problem of frequency and power in thermal generating unit is shown in Table 1. All the parameters value has been chosen default.

Table 1. GA Parameters for System

Parameters	Two Generating System	Three Generating System
Fitness Function	@dha_ash	@dha_ash
Variables	6	9
Population Size	25	25
Selection	Stochastic Uniform	Stochastic Uniform
Mutation	Constraint Dependent	Constraint Dependent
Cross Over	Scattered	Scattered
Bound Limit	Upper [0] and Lower [-5]	Upper [0] and Lower [-5]

4 Results

Two and three generating unit model has been obtained and simulated by the MATLAB Simulink software to minimize the problem of frequency and power of thermal generating units arises due to continuous variation of load in generating station. In this simulation different technique (Traditional and Optimization) has been used, comparative response has been obtained and results have been tabulated (Table 2).

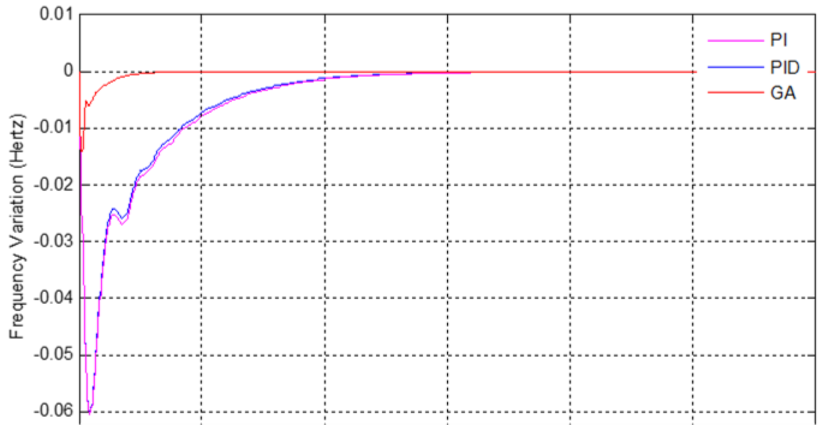

Fig 4. Frequency Variation Response of Two Generating Unit

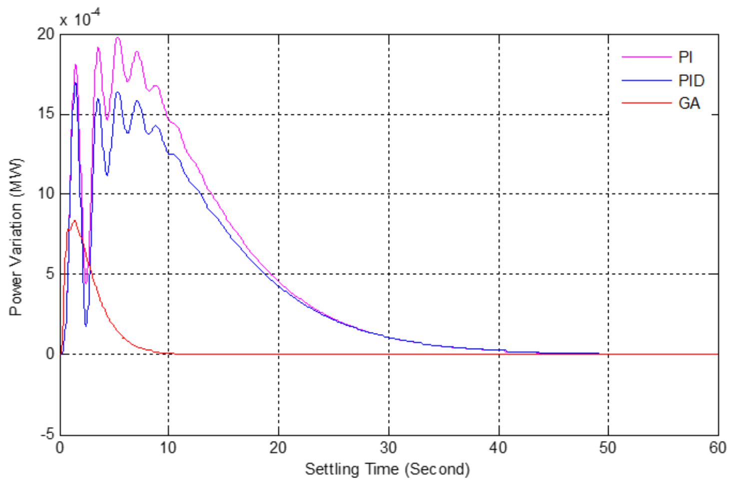

Fig 5. Power Variation Response of Two Generating Unit

Comparative results of all obtained response of two generating units have been tabulated in Table 2.

Table 2. Comparative Result of Two Generating Unit

Techniques	Settling Time (Sec)	
	Frequency Variation (Hertz)	Power Variation (MW)
Traditional (PI)	28	44
Traditional (PID)	27	43
Optimization (GA)	8	11

Table 2 shows that optimization (GA) technique gives improved and efficient result compare to traditional (PI, PID) technique for two thermal generating unit. The settling time is 8 Sec and 11 Sec for frequency and power variation of GA technique.

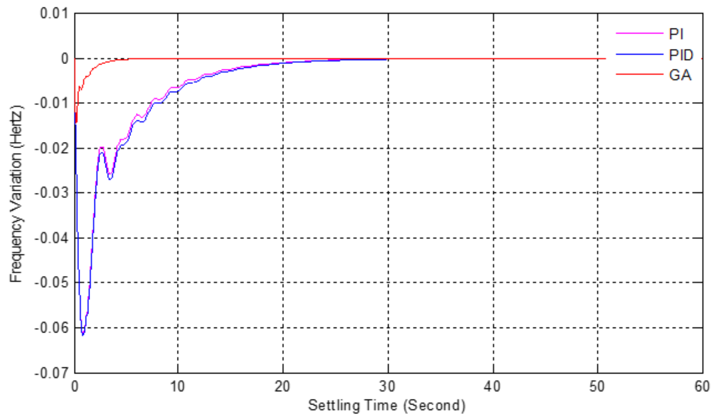

Fig 6. Frequency Variation Response of ThreeGenerating Unit (Area 1)

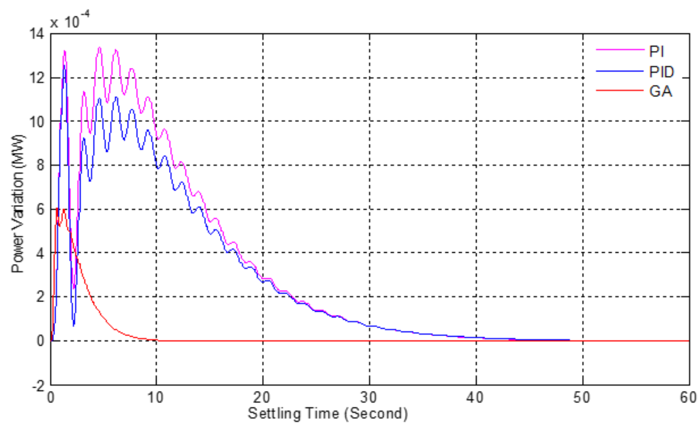

Fig 7. Power Variation Response of Three Generating Unit (Area 1)

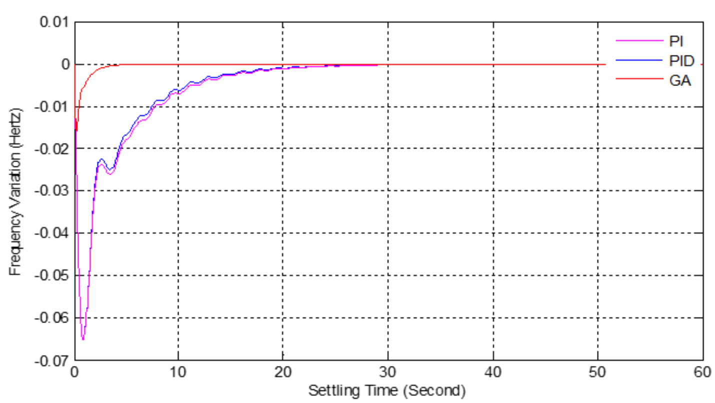

Fig 8. Frequency Variation Response of Three Generating Unit (Area 2)

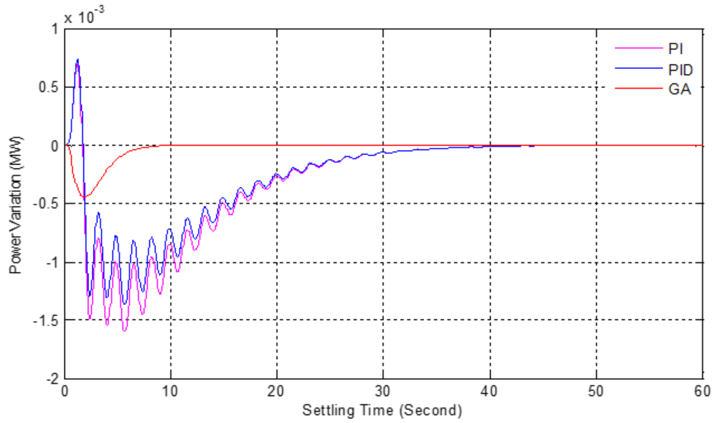

Fig 9. Frequency Variation Response of Three Generating Unit (Area 2)

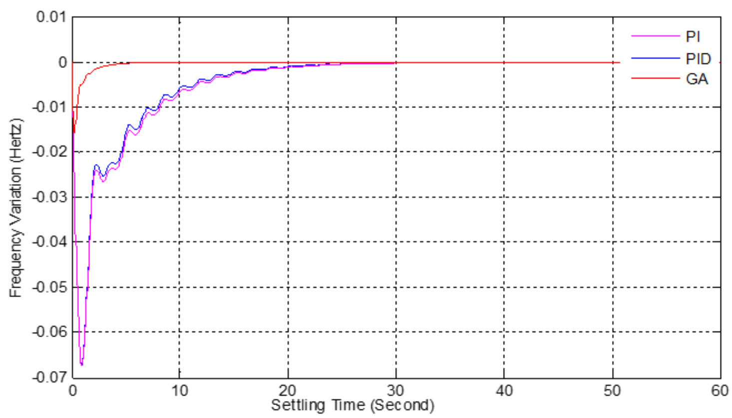

Fig 10. Frequency Variation Response of ThreeGenerating Unit (Area 3)

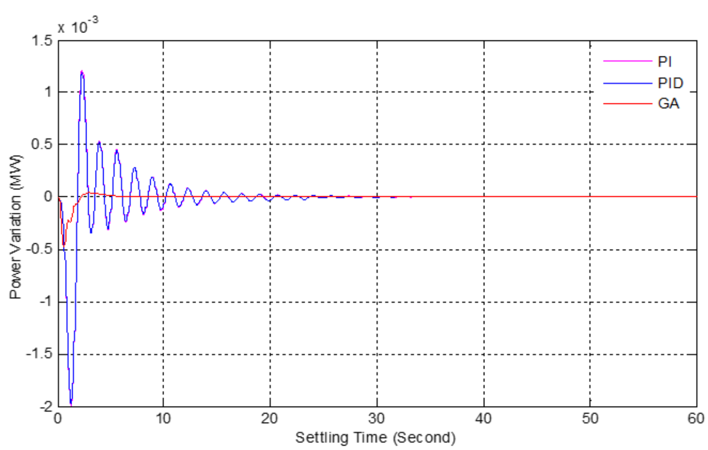

Fig 11. PowerVariation Response of Three Generating Unit (Area 3)

Comparative results of all obtained response of three generating units have been tabulated in Table 3.

Table 3. Comparative Result of Three Generating Unit

Techniques	Settling Time (Sec)					
	Frequency Variation (Hertz)			Power Variation (MW)		
	Area 1	Area 2	Area 3	Area1	Area2	Area3
Traditional (PI)	27	26	26	44	39	26
Traditional (PID)	26	25	25	43	38	25
Optimization (GA)	6	5	6	10	8	6

Table 3 shows that optimization (GA) technique gives improved and efficient resultcompare to traditional (PI, PID) technique for three thermal generating unit. The settling time is 6 Sec, 5 Sec, 6 Sec, 10 Sec, 8 Sec and 6 Sec for frequency and power variation of GA technique.

5 Conclusion

In this study, an optimization technique (GA) and Traditional technique (PI and PID) has been applied to solve frequency and power problem. Mathematical approach is used to formulate the problem mathematically. The optimization technique (GA) gives very efficient, favorable, finest results (optimization technique (GA Technique) gives very effective, efficient and dynamic results (8 Sec and 11 Sec in Frequency & Power Variation) compareto traditional technique (PI, PID) (28 Sec, 44 Sec & 27 Sec & 43 Sec in Frequency & Power Variation)) with respect to the traditional technique. So it can be concluded that optimization technique (GA Technique) performs better when the system is complex with continued increasing load and also this paper satisfying abstract and all the system parameters. The limitation of this technique is to use for small load perturbation but it can be considered for its accuracy and satisfactory results. This technique will also be helpful in restructured power system by giving better response service of frequency due to which regulation of electricity will be better and improve.

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