Tuning of Load Frequency PID Controller of Electric Power System using Metaheuristic Algorithms

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Abstract: *This paper investigates Load Frequency Control of multi area inter connected power system having different turbines with PID controller. The gain values of controller are optimized using different Metaheuristic Algorithms. The performance and validity of designed controllers were checked on multi area interconnected power system with various Step Load Perturbations. Finally, the performance of proposed controllers was compared with conventional controller and from the result it was proved that the proposed controller exhibits superior performance than conventional controller for various Step Load Perturbations.*

***Index Terms*—PID Tuning, Metaheuristic Algorithms, Multi-area Power System, Load Frequency Control, Step Load Perturbations.**

I. INTRODUCTION

As the demand changes the system voltage and frequency deviate from the initial values causing an unpredictable small amount of change in the state of the system. An automatic control system is assigned to detect the change and it initiates a set of counter control actions in order to nullify effectively and at the earliest any deviation in the state of the system. In any interconnected system deviation of the state of the system may well disturb the state of economic operation and may even cause overloads on the interconnecting ties with the risk of having lost the continuity of operation. The obvious way to maintain a perfect power balance at each bus could be to continuously keep the generated powers in balance with the changing load power P_D and Q_D. The real power is controlled through the turbine torque while the reactive power is controlled via exciter[3].

Automatic control of generators involves two major control loops in power system equipped with large generators. These two major loops are *Automatic Voltage Regulator* (AVR) and *Automatic Load Frequency Control* (ALFC) loops. This paper mainly concentrated on Load Frequency Control (LFC). The ALFC loop regulates the real power output & corresponding frequency of the generator power output. The primary ALFC loop senses the turbine speed and controls the operation of the control valves of turbine power input via the speed governor. When the power system is subjected to sudden load increments (ΔP_D), the turbine output ΔP_T is increased to a new value as rapidly as the primary ALFC loop permits. However, this load increase causes negative frequency error. It causes a slow growing positive integrator output and a corresponding increase in power reference setting. The signal (Δf) fed to the integrator is known as *Area Control Error* (ACE). *Integral* control will give rise to *zero* static frequency error following a step load change i.e the secondary ALFC loop eliminates the frequency error. In order to keep values of system frequency and tie-line power within the limit during the sudden and normal load conditions, there is several control techniques have been proposed for the LFC of power system. The same authors have explained a critical literature survey on different control strategies of power system LFC.

In this paper, Ant Colony Optimization (ACO) and Pattern Search (PS) PID tuning methods were used for Load Frequency Control (LFC) in three area interconnected power system. The performance of ACO-PID and PS-PID were compared with conventional PID controller.

Pattern Search Optimization (PS) is a new optimization method and is used for solving the different optimization issues[2]. In this paper Ant Colony Optimization, Pattern Search technique was implemented for tuning of PID controller of three area power system.

Comparative study:

Sl. No.	Name of the Authers	Title of the paper	Synopsis
1	Naimul Hasan	An Overview of AGC Strategies in Power System.	This paper presents a comprehensive literature review of the Philosophies of automatic generation control (AGC) of power systems. This article is aimed to highlight the various control and structural aspects of AGC used in the power systems. The AGC schemes based on power system models and control strategies are reviewed.
2	Wen Tan	Unified Tuning of PID Load Frequency Controller for Power Systems via IMC	A unified PID tuning method for load frequency control of power systems is discussed in this paper. The tuning method is based on the two-degree-of-freedom (TDF) internal model control (IMC) design method and a PID approximation procedure. The time-domain performance and robustness of the resulting PID controller is related to two tuning parameters, and robust tuning of the two parameters is discussed. The method is applicable to power systems with non-reheated, reheated, and hydro turbines.
3	Ibraheem, Prabhat Kumar, D. P. Kothari	Recent Philosophies of Automatic Generation Control Strategies in P S	This paper presents a critical review of the recent philosophies in the area of AGC. Due attention has also been paid to recent developments, such as AGC schemes based on the concepts of neural networks and fuzzy logic and the incorporation of parallel AC/HVDC links in the designs of AGC regulators. Emphasis has been given to categorizing various AGC strategies reported in the literature that highlights their salient features.
4	K. Wadhwa, SouravChoubey, Pardeep Nain	Study of Automatic Generation Control Of two area thermal-thermal system with GRC and without GRC	In this paper presenting the critical literature review and an up-to-date bibliography on the AGC of power system. Various control aspects concerning the AGC problem have been highlighted. Simulation of AGC schemes based on an interconnected two area thermal-thermal system with generation rate constraints (GRC) and without GRC are studied using MATLAB. Here they shown only simulation results for the case of with-out GRC, no simulation results for with GRC.
5	Eisa Bashier M. Tayeb	Automation of Interconnected Power System using Fuzzy Controller	In this paper, a fuzzy logic controller is proposed for load frequency control problem of interconnected power system. The study has been designed for a two area interconnected power system. Here there is not proper comparison between the controllers.

6	M .Ismail, M. A. Mustafa Hassan	Load Frequency Control Adaptation Using Artificial Intelligent Techniques for One and Two Different Areas Power System	In this proposed study, a new GA, PSO and fuzzy Algorithm based PID has been introduced for automatic load frequency control of a single & multi area power system and shown that the proposed control algorithms are effective and provides significant improvement in system performance.
7	SuryaPrakash S. K. Sinha	Application of artificial intelligence in load frequency control of Inter- connected P S.	This paper presents the use of artificial intelligence to study the load frequency control of interconnected power system. Here the control methodology is developed using Artificial Neural Network (ANN) and Fuzzy Logic controller (FLC) for interconnected hydro-thermal power system. A comparison of Fuzzy controller and ANN controller were made, from the comparison they shows that of proposed ANN based approach is superior to Fuzzy one for different loading conditions.
8	R. N. Patel, S. K. Sinha, R. Prasad	Design of a Robust Controller for AGC with Combined Intelligence Techniques	In this work Artificial Intelligence (AI) techniques like Fuzzy logic, GA and PSO have been used to improve the performance of the Automatic Generation Control system. Instead of applying GA and PSO independently for optimizing the parameters of the conventional AGC with PI controller, an intelligent tuned Fuzzy logic controller (acting as the secondary controller in the AGC system) has been designed. The controller gives an improved dynamic performance for both hydro-thermal and thermal-thermal power systems under a variety of operating conditions.
9	P.V.R.Prasad, Dr. M. Sai Veeraju	Fuzzy Logic Controller Based Analysis of Load Frequency Control of Two Area Inter-connected Power System	In this paper, they compared the results of PI and PID controller with fuzzy PI controller for two area power system in the presence of parameters variation and non-linearity.
10	G. Panda, Sidhartha. P and C. Ardil	Automatic Generation Control of Multi-Area Electric Energy Systems Using Modified GA	Here they present their pioneering work on AGC regulator design using Modified GA. A four area intercon-nected power system consisting of four identical power plants of reheat thermal turbines was considered for investigations.
11	K. P. Singh Parmar S. Majhi, D. P. Kothari	Optimal Load Frequency Control of an Interconnected Power System	Here an attempt has been made to design the optimal output feedback controller for a two area interconnected Thermal-Thermal Power system incor-porating reheat type turbine in one of the areas. In this paper the proposed controllers are tested and their dynamic responses are compared with conventional controllers and observed that optimal state feedback controllers give good dynamic responses that satisfy the requirements of LFC.

ABOVE TABLE SHOWS THE COMPARATIVE STUDY OF VARIOUS CONTROLLERS PROPOSED BY DIFFERENT AUTHORS

II. MODELING OF ELECTRIC POWER SYSTEM

The main difference between Load Frequency Control of multi-area system and that of single area system is, the frequency of each area of multi-area system should return to its nominal value and also the net interchange through the tie-line should return to the scheduled values. So a composite measure, called area control error (ACE), is used as the feedback variable. A decentralized controller can be tuned assuming that there is no tie-line exchange power, $P_{tiei} = 0$. In this case the local feedback control will be $u_i = -K_i(s)B_i \Delta f_i$. Thus load frequency controller for each area can be tuned independently. To illustrate the decentralized PID tuning method, consider a Three-Area power system with load perturbations. The system frequency deviation Δf_i, the deviation in the tie-line power flow ΔP_{tiei}, load disturbance ΔP_{Li}. The following sequence helps for development of block diagram of interconnected power system[1].

A. Governor Equations and its Modeling

If the load increases, the speed of the alternator reduces slightly. The governor of any thermal unit reacts to this speed variation and permits the entry of some more steam from the boiler to turbine which increases the speed. Many forms of the governor system have been devised all of which includes, the variation of the turbine-alternator shaft speed as the basis on which the change of position of the turbine. Typical speed droop characteristics for most governor range between 5 to 10%. The block diagram of speed governor system is shown in Fig. 1[5,7].
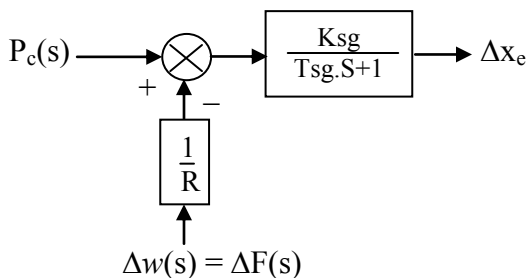

Fig. 1 Speed Governor with drooping characteristics

The transfer function of speed governor with drooping characteristics can be represented as

$$Gsg(s) = \frac{1}{(1 + sTsg)} = \frac{NUMsg(s)}{DENsg(s)} \quad (1)$$

B. Turbine Equations and its Modeling

Turbine dynamics are very important because they also affect the overall response of the generating plant to load changes. *Non-reheat turbines* are first-order units and its block diagram is shown in Fig. 2 [5,7].
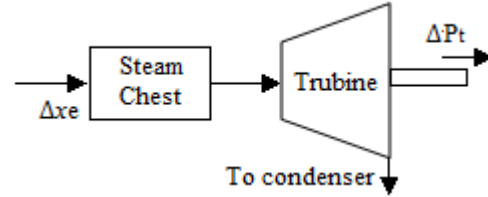

Fig. 2 Non-Reheat Steam Turbine

The transfer function of the non-reheat turbine is represented as

$$Gnr(s) = \frac{1}{(1 + sTt)} = \frac{NUMt(s)}{DENt(s)} \quad (2)$$

After passing the control valve the high pressure steam enters the turbine via the steam-chest that introduces time delay T_{nrt} usually in order of 0.2 to 0.5s. The above model is modified to get Reheat Steam turbine as shown in Fig. 3.
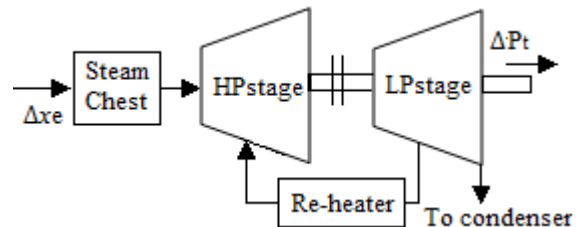

Fig. 3 Reheat Steam Turbine

The *Reheat turbines* are modeled as second-order units because of presence of high and low steam pressure. It is more efficient and is used for modern-day large sets. The overall transfer function of Reheat turbine is

$$Gr(s) = \frac{1 + sCTrt}{(1 + sCTrt)(1 + sTlpr)} = \frac{NUMt(s)}{DENt(s)} \quad (3)$$

C. Generator-Load Modeling

The Generator which is supplying local load and is not supplying power to another area via a tie-line. Suppose there is a real load change of

ΔP_D. Due to the action of the turbine controllers, the generator increases its output by the amount ΔP_G. The net surplus power ΔP_G - ΔP_D will be absorbed by the system of generator with load damping (D) effect. The Fig. 4 shows the block diagram of generator with load damping.
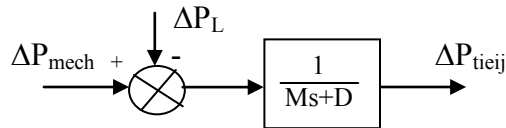

Fig. 4 Generator with load damping

The transfer function of generator with load damping or power system is

$$Gps(s) = \frac{1}{(D + Ms)} = \frac{Kps}{(1 + sTps)} = \frac{NUMsg(s)}{DENsg(s)} \quad (4)$$

D. Tie-Line Modeling

Practically, all power systems now a days are interconnected by number of tie-lines with the neighboring areas. When the frequency variations in two areas are different, a power exchange occurs through the tie-line between the connected two areas. The block diagram of tie-line is as shown in Fig. 5 [7-8].
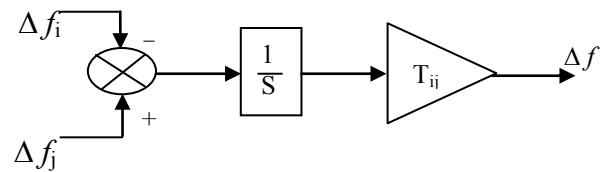

Fig. 5 Tie-line Connections

The Laplace transform of tie line is given as

$$\Delta Ptieij(s) = \frac{Tij(\Delta Fi(s) - \Delta Fj(s))}{s} \quad (5)$$

Where ΔP_{tieij} is tie line power exchange between areas i and j, and T_{ij} is the tie-line synchronizing coefficient between area i and j.

By connecting all above blocks, we can get the overall block diagram of an interconnected electric power system. The Fig. 6 shows the block diagram representation of three area interconnected electric power system with step load variations. Let area 1, 2, 3 are non identical systems with Reheat, Non-reheat and Reheat turbines in all three areas respectively. The transfer function of each area with generator drooping characteristics can be defined as
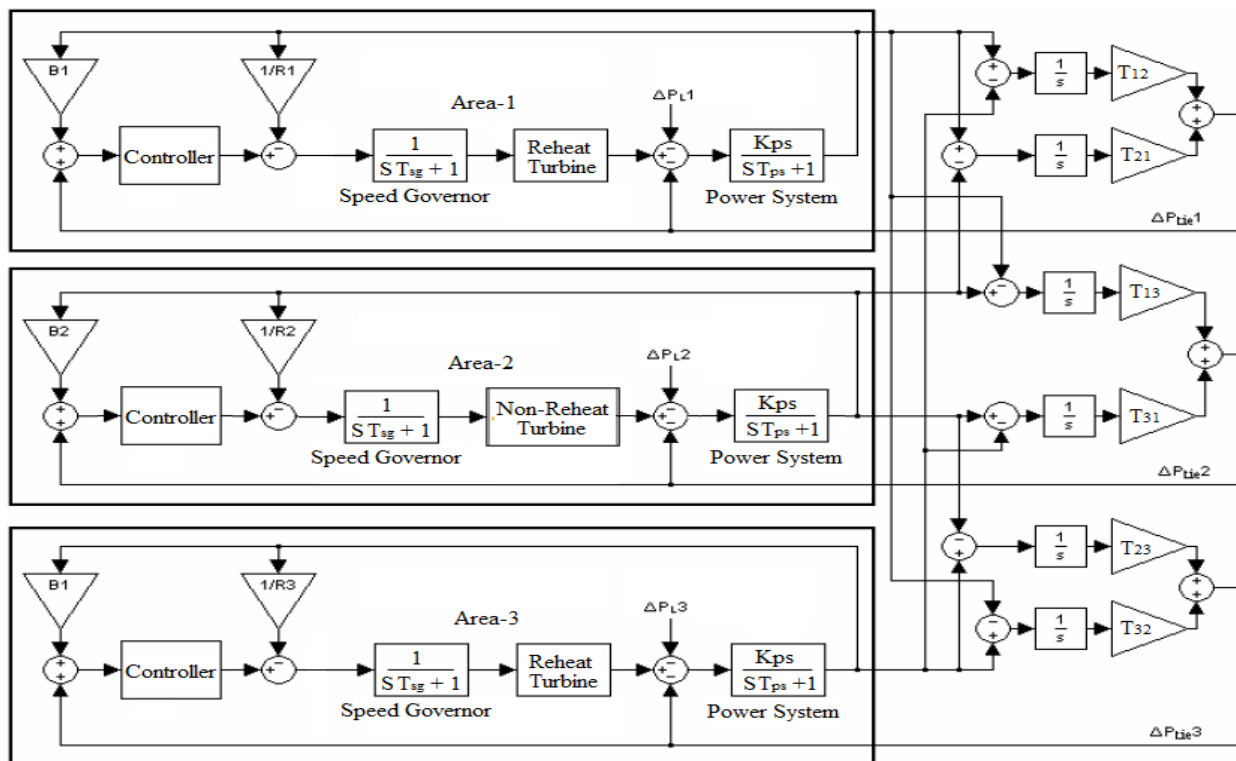

Fig. 6 Three Area Interconnected Electric Power System with Step Load Variations.

The transfer functions of all three areas of interconnected power system are as follows (see appendix-I for Turbine, Speed Governor and Power system parameters) [4,12]:

$$\text{For } i^{th} \text{ Area, } G_i(s) = \frac{NUMsg(s)NUMt(s)NUMps(s)}{DENsg(s)DENt(s)DENps(s) + NUMsg(s)NUMt(s)NUMps(s)/R_i} B_i \qquad (6)$$

$$\text{For Area-1, the transfer function is } G_1(s) = \frac{48.75s + 16.25}{s^4 + 16s^3 + 44.312s^2 + 55s + 16.25} \qquad (7)$$

$$\text{For Area-2, the transfer function is } G_2(s) = \frac{106.25}{s^3 + 15.88s^2 + 42.46s + 106.25} \qquad (8)$$

$$\text{For Area-3, the transfer function is } G_3(s) = \frac{53.125s + 10.625}{s^4 + 15.98s^3 + 44.05s^2 + 58.41s + 10.625} \qquad (9)$$

III. TUNING OF PID CONTROLLER

For industrial plant process, the conventional PID controllers are most commonly used. There are several prescriptive rules used for tuning of PID controller. The parallel form of a PID controller has transfer function [9]:

$$Gc(s) = Kp + \frac{Ki}{s} + sKd = Kp(1 + \frac{1}{sTi} + sTd)$$

Where K_p = Proportional Gain constant; K_i = Integral Gain constant; T_i = Reset Time constant $=K_p/K_i$, K_d = Derivative gain constant; T_d = Derivative time constant. The tuning of PID load frequency controller of multi-area power system that it has to bring frequency of each area to its nominal value and also the change in tie-line power should return to the scheduled values. So the combination of both, called Area Control Error (ACE), is used as feedback variable. For i^{th} area, the ACE is defined as $ACE_i = \Delta P_{tiei} + B_i \Delta f_i$ and Feedback control signal is $u_i = - K_i(s) AEC_i$. A PID load frequency controller can be tuned assuming that there is no tie line power exchange i.e $\Delta P_{tiei} = 0$. Now the feedback control signal $u_i = - K_i(s) B_i \Delta f_i$. In this paper three different types PID controllers were designed i.e Conventional controller, Metaheuristic (*Ant Colony* and *Pattern Search* based) Controller.

A. Conventional Controller
Zhuang and Atherton were proposed optimum setting algorithms for a PID controller.

The general form of the optimum criterion is

$$J_n(\Theta) = \int_0^\infty t^n [e(\Theta, t)]^2 dt \qquad (10)$$

Where Θ is the PID controller parameter vector and $e(\Theta,t)$ is the error which passes through controller. There are three different optimum criteria for tuning of PID controller, those are Integral Squared Error (ISE) criterion, Integral Squared Time weighted Error (ISTE) criterion and Integral Squared and Time Squired Error (IST^{2}E) criterion. The optimal parameters are obtained by minimizing the above equation [10].

B. Metaheuristic Methods
Recently, most of the researchers focused on new algorithms called Metaheuristic. A Metaheuristic is a set of algorithm concepts that can be used to define heuristic methods applicable to wide set of different applications. The use of Metaheuristic has significantly increased the ability of finding very high quality solutions to hard and practically relevant combinatorial optimization problems in a reasonable time [11].

1) Ant Colony Optimization:
A particularly successful Metaheuristic inspired by the behavior of real Ants. Starting Ant system, a number of algorithmic approaches based on the very same ideas were developed and applied with considerable success to a variety of combinatorial optimization problems from academic as well as from real world applications. The ACO Metaheuristic has been

proposed as a common framework for the existing applications and algorithmic variants of a variety of Ant algorithms. Ants are able to find the shortest path between a food source and the nest without the aid of visual information, and also to adapt to a changing environment. It was found that the way ants communicate with each other is based on pheromone trails. While ants move, they drop a certain amount of pheromone on the floor, leaving behind a trail of this substance that can be followed by other ants. The more ants follow a pheromone trail, the more attractive the trail becomes to be followed in the near future. The basic idea is illustrated in Fig.8.

Two ants start from their nest (left) and look for the shortest path to a food source (right). Initially, no pheromone is present on either trails, so there is the same chance of choosing either of the two possible paths. Suppose one ant chooses the upper trail, and the other one the lower trail. The ant that has chosen the upper (shorter) trail will have returned faster to the nest. As a result, there is a greater amount of pheromone on the upper trail as on the lower one. The probability that the next ant will choose the upper (shorter) trail will be higher. More ants will choose this trail, until all (majority) ants will follow the shorter path.
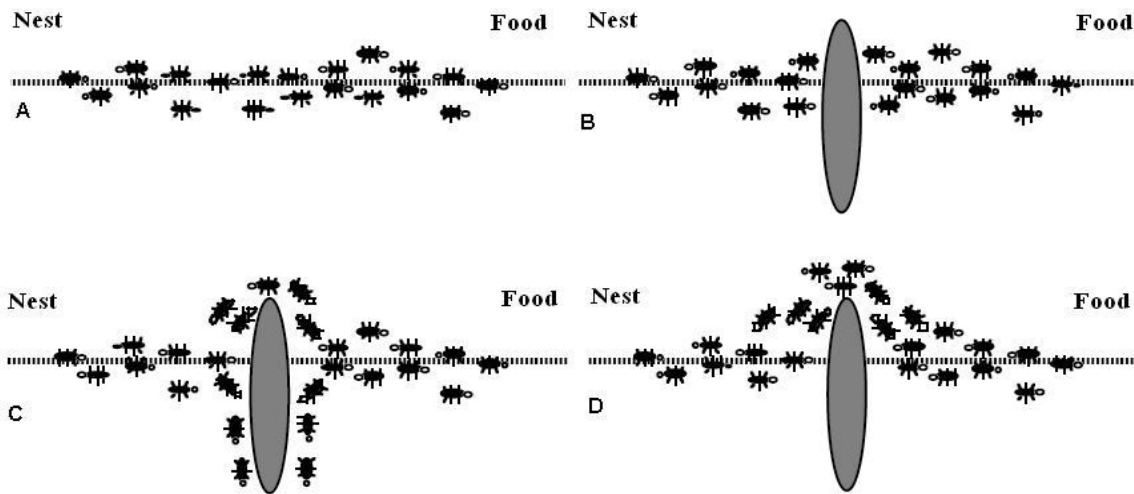

Figure 8 (a) Real ants follow a path between nest and food source. (b) An obstacle appears on the path: Ants choose whether to turn left or right with equal probability. (c) Pheromone is deposited more quickly on the shorter path. (d) All ants have chosen the shorter path.

The following algorithmic skeleton shows the *pseudo-code* for Ant Colony Algorithm for optimization problems [11].

Procedure ACO Metaheuristic
      Set parameters, initialize pheromone trails
      while (termination condition not met) **do**
      Construct Ants Solutions
      Apply Local Search   *% optional*
      Update Pheromones
      end
  end

In this paper, Number of Ants (NA) is 100, Number of Iterations (ITR) are 100, Number of parameters are 3 and evaporation rate (ρ) is 0.95. The simple flowcharts of Ant Colony and Pattern Search Optimization are shown in Figures 9(a) and 9(b) respectively.

2) Pattern Search:
The Pattern Search (PS) Algorithm generates a sequence of iterates with non-increasing objective function values. Iteration is divided into two phases: an optional search and a local poll.
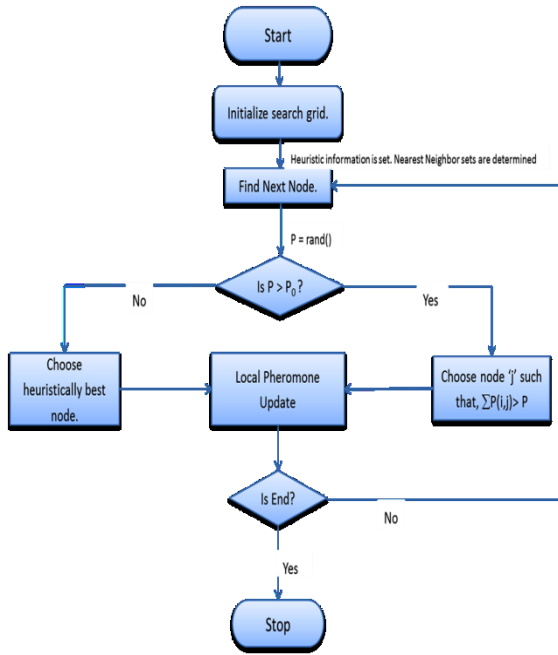
Figure 9(a) Ant Colony Optimization (ACO)

Figure 9(b) Pattern Search Method (PSM)

In the search step f(s) is evaluated at a finite number of points on a mesh to one that yields a lower f(s) value than the incumbent. Mesh is a discrete subset of bounded search space with lower and upper boundaries.

Mesh:

$$M_k = \{ S_k + \Delta_k D_z : z \in Z_+^D \} ; \quad (a)$$

Where D is a +ve spanning set, Δ_k is mesh size parameter, S_k is a mesh local optimizer.

Poll set:

$$\{ S_k + \Delta_k d : d \in D_k \} \quad (b)$$

Pseudo code of Pattern Search Algorithm

Step - I : Let S_0 be such that $f(S_0)$ is finite and M_0 be the initial mesh defined by $\Delta_0 > 0$, & D_0. Set the iteration counter k to 0.

Step - II : Perform the search and possibly the poll steps until an improved mesh point S_{k+1} with the lowest so far f(s) values is found on the mesh M_k defined by Eq.(a). Evaluate f(s) on the poll set defined in Eq.(b).

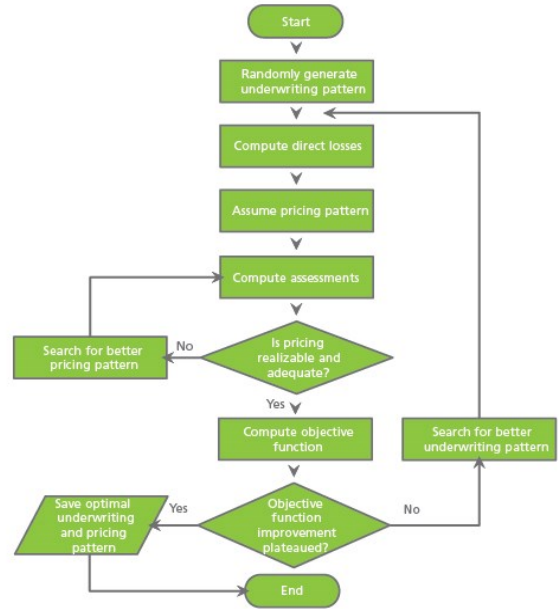*Step-III*: If the search or the pole produced an improved mesh point, i.e a feasible iterate $x_{k+1} \in$

$M_k \cap \Omega$ for which $f(S_{k+1}) < f(S_k)$, then update $\Delta_{k+1} \geq \Delta_k$ by $\Delta_{k+1} \geq T^{wk}\Delta_k$.

For $0 < T^{wk} < 1$ where $T > 1$ is a rational number that remains constant over all iterations, and $w_k \geq 0$ is an integer. If, $f(S_k) < f(S_k + \Delta_k d)$ for all $d \in D_k$, set $S_{k+1} = S_k$, update $\Delta_{k+1 < } \Delta_k$ by $w_k \leq -1$.

Increase k by k+1 and go back to **Step-I**.

In order find the Performance Index of all above controllers, Integral of Time multiply Absolute Error (ITAE) of deviations of frequency and tie-line power of all area were considered as objective function. Accordingly, the objective function is defined as

$$J = \int_0^{t_s} t(\Delta f_i + \Delta P_{tieij})^2 \, dt \quad (9)$$

Where t_s is simulation time.

Above objective function is minimized by considering the following constraints:

$$K_P^{min} < K_P < K_P^{max} \qquad K_I^{min} < K_I < K_I^{max}$$

$$K_D^{min} < K_D < K_D^{max}$$

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The optimized values of PID controller using above algorithms are listed in Table 1.

TABLE I Optimized values of various PID Controller

Area-i	Conventional Controller			Ant Colony Optimization			Pattern Search Algorithm		
	K_P	K_I	K_D	K_P	K_I	K_D	K_P	K_I	K_D
Area-I	6.0241	3.6946	0.9717	7.5762	6.9697	1.705	14.1607	17.9244	6.2195
Area-II	2.7969	3.7178	0.4173	4.1053	5.8268	1.705	2.766	8.8002	1.0729
Area-III	5.7858	3.7821	0.9095	7.833	6.9697	1.5986	12.4074	16.877	4.6455

IV. Results and Analysis

The performance and validity of the designed controllers are explained by the following illustrations by considering various step load variations in three area interconnected electric power system having different turbines in respective areas. The parameters of all three areas are collected from various steam power stations in India and are shown in appendix-I.

A. Illustration -I

Let the step load perturbations as dP_{L1} = 0.01pu, dP_{L2} = 0.01pu and dP_{L3} = 0.01pu are applied to Area-I, Area-II and Area-III respectively at t = 0sec. The figures from 10(a) to 10(c) shows the variations in frequency for applied load power disturbances in three areas respectively. Similarly, the figures from 11(a) to 11(c) shows the variations in Tie Line Power variations for applied load power disturbances in three areas respectively.
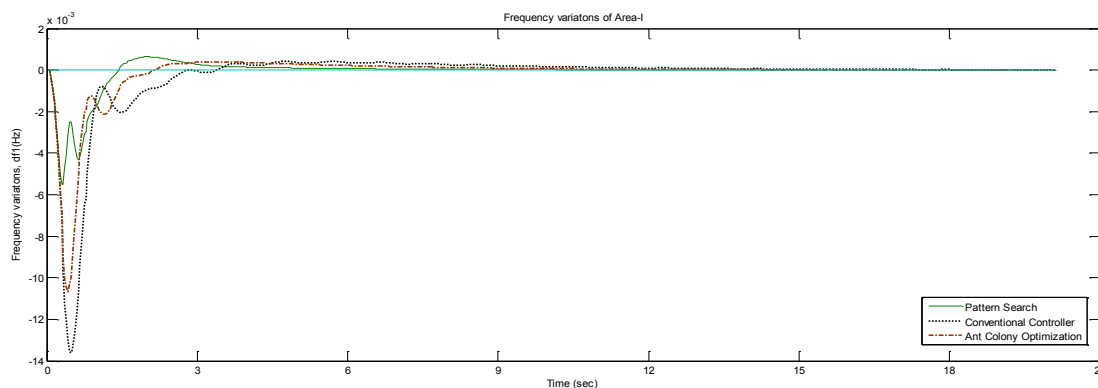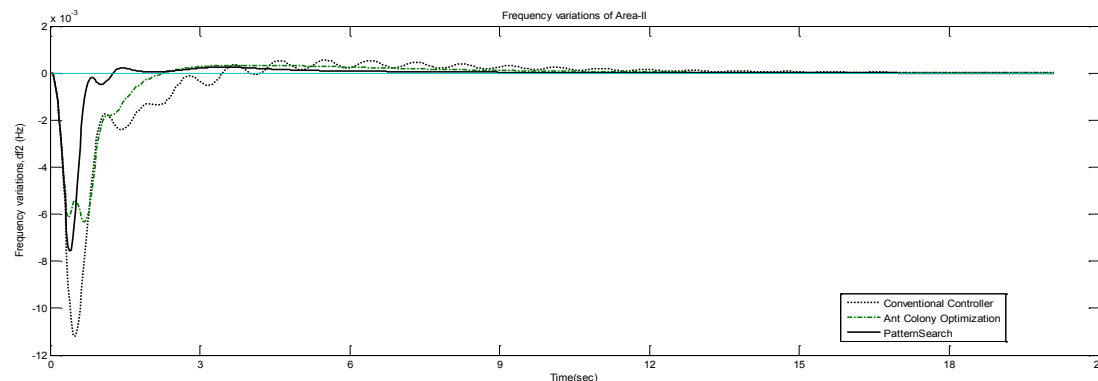

Figure 10(a). Frequency variations in Area-I, df1 (Hz)
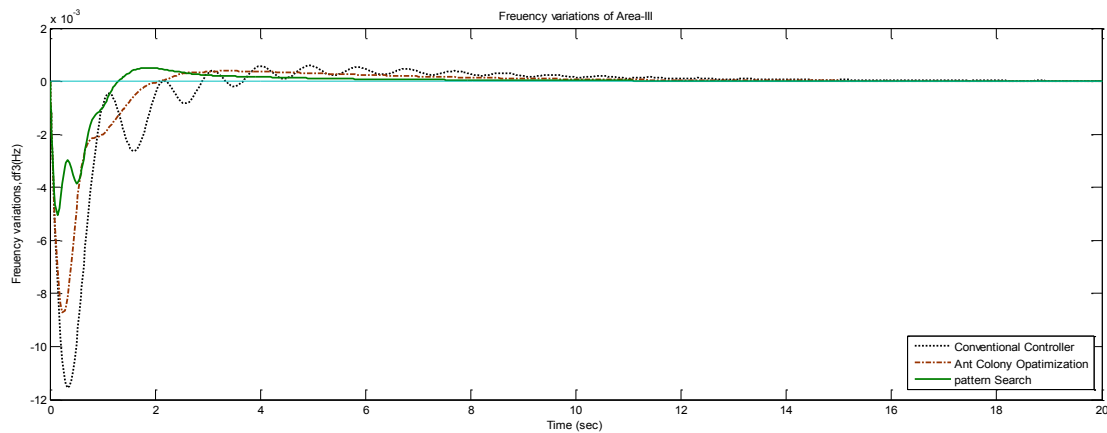

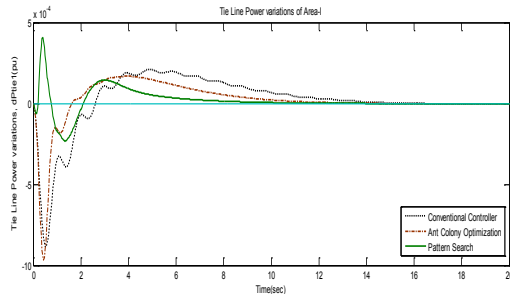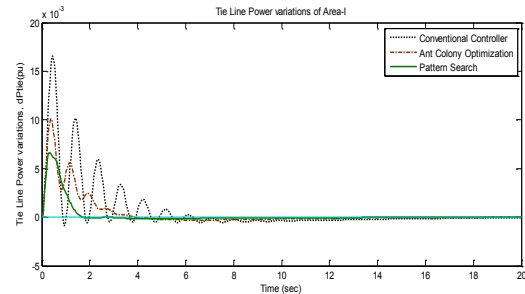Figure 10(b). Frequency variations in Area-II, df2 (Hz)
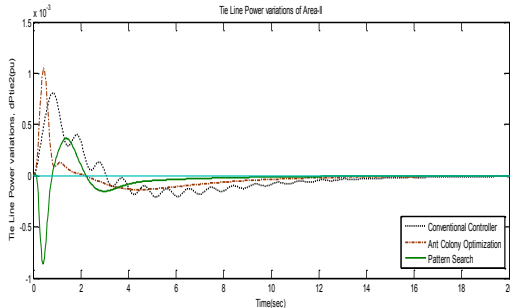
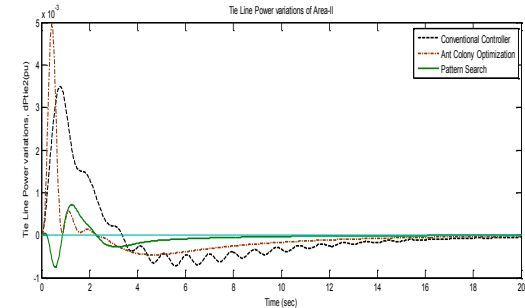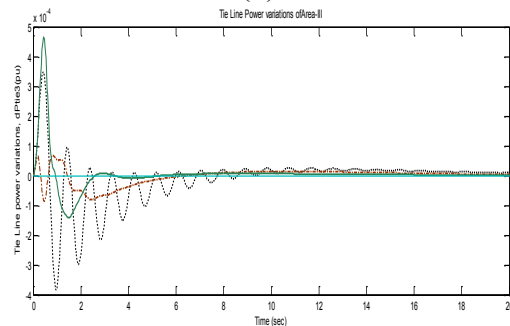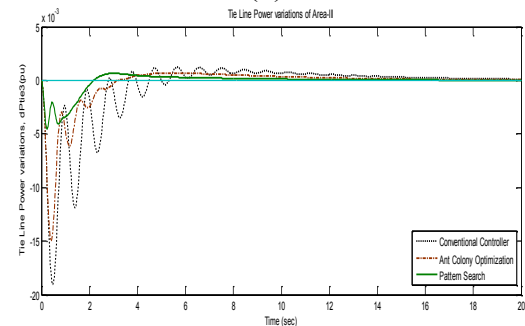Figure 10(c). Frequency variations in Area-III, df3 (Hz)

11(a)

12(a)

11(b)

12(b)

11(c)

12(c)

Figure11 (a) -11(c) shows Tie-Line Power variations in three areas for $dP_{L1} = dP_{L2} = dP_{L3}$ =0.01
Figure12 (a) -12(c) shows Tie-Line Power variations in three areas for $dP_{L1} = 0.01$, $dP_{L2} =$ 0.1pu and $dP_{L3} = 0.15$pu

B. Illustration -II
Now let the step load perturbations as $dP_{L1} = 0.01pu$, $dP_{L2} = 0.05pu$ and $dP_{L3} = 0.1pu$ are applied to Area-I, Area-II and Area-III respectively at $t = 0sec$. The figures from 13(a) to 13(c) shows the variations in frequency for applied load power disturbances in all three areas respectively. Similarly, the figures from 12(a) to 12(c) shows the variations in Tie Line Power variations for applied load power disturbances in all three areas respectively.
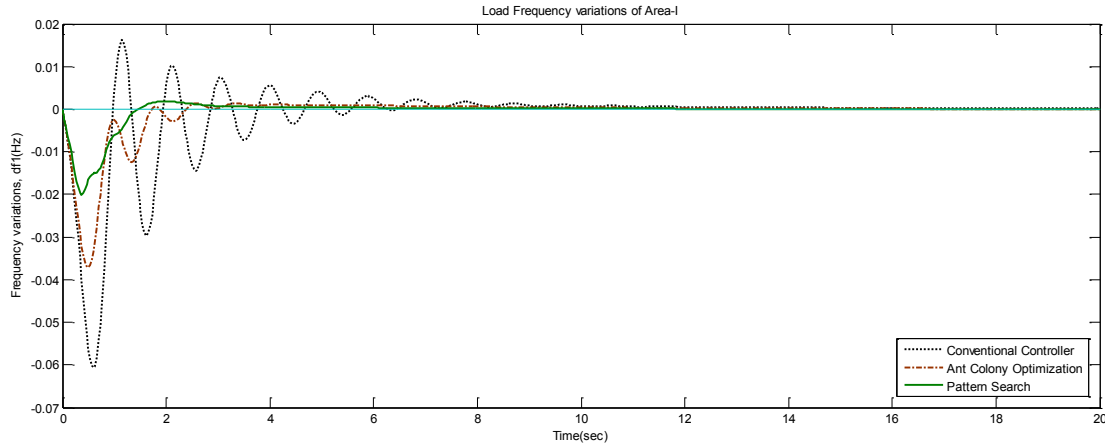

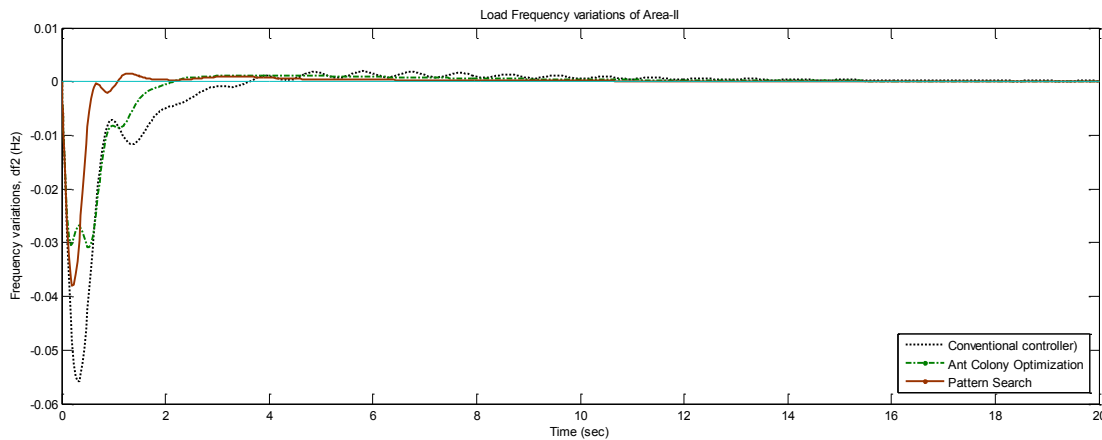Figure 13(a). Frequency variations in Area-I, df1 (Hz)

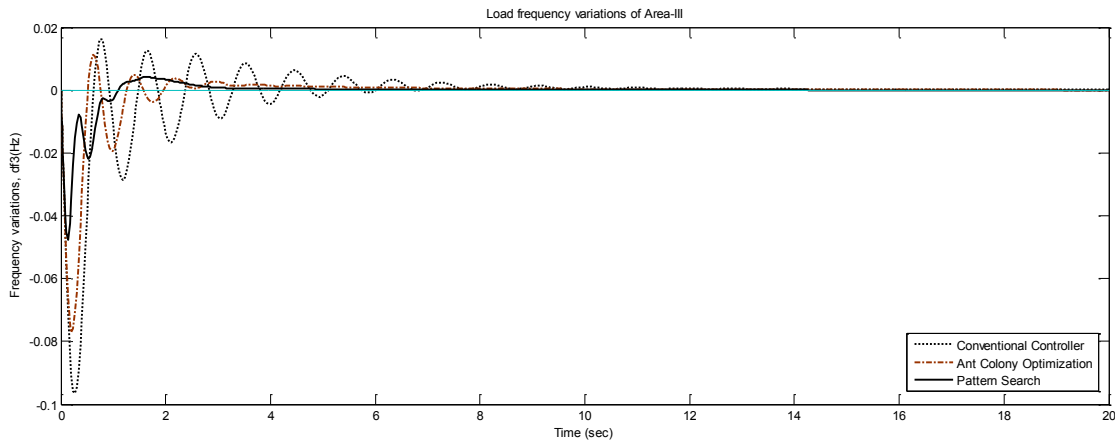Figure 13(b). Frequency variations in Area-II, df2 (Hz)

Figure 13(c). Frequency variations in Area-III, df3 (Hz)

Including above simulation results, to check the performance and validity of the designed controller, additional simulation also done for various step loads and its performance is listed in below from Table 2 to Table 4.

TABLE II PERFORMANCE OF THREE AREA ELECTRIC POWER SYSTEM WITH $dP_{L1} = dP_{L2} = dP_{L3} = 0.02$pu

Area-i	Conventional Controller		Ant Colony Optimization (ACO)			Pattern Search Algorithm (PSA)		
	1st peak over shoot	Settle Time	1st peak over shoot	Settle Time	Improvement in performance	1st peak over shoot	Settle Time	Improvement in performance
Area-I	-0.0136	17.80	-0.0107	12.80	39.06	-0.0055	5.80	190.70
Area-II	-0.0112	17.20	-0.0063	14.10	22.00	-0.0076	9.00	91.10
Area-III	-0.0128	17.52	-0.0105	12.25	33.16	-0.0053	5.65	187.15

TABLE III PERFORMANCE OF THREE AREA ELECTRIC POWER SYSTEM WITH $dP_{L1} = 0.01$, $dP_{L2} = 0.05$ $dP_{L3} = 0.1$

Area-i	Conventional Controller		Ant Colony Optimization (ACO)			Pattern Search Algorithm (PSA)		
	1st peak over shoot	Settle Time	1st peak over shoot	Settle Time	Improvement in performance	1st peak over shoot	Settle Time	Improvement in performance
Area-I	-0.0607	23.21	-0.0372	22.15	4.80	-0.0201	13.25	75.17
Area-II	-0.0558	22.00	-0.0308	18.12	21.40	-0.038	10.45	110.5
Area-III	-0.0964	22.10	-0.0771	20.80	6.25	-0.0475	15.75	40.31

TABLE IV PERFORMANCE OF THREE AREA ELECTRIC POWER SYSTEM WITH $dP_{L1} = dP_{L2} = dP_{L3} = 0.095$pu

Area-i	Conventional Controller		Ant Colony Optimization (ACO)			Pattern Search Algorithm (PSA)		
	1st peak over shoot	Settle Time	1st peak over shoot	Settle Time	Improvement in performance	1st peak over shoot	Settle Time	Improvement in performance
Area-I	-0.1360	16.30	-0.0106	12.00	35.83	-0.0550	11.20	42.85
Area-II	-0.1118	18.60	-0.0758	10.45	78.00	-0.0630	13.45	38.30
Area-III	-0.1156	18.80	-0.0872	13.33	41.05	0.0506	10.08	86.50

(% age) Improvement in performance in terms of *settle time*

V. CONCLUSION

In this paper tuning PID controller using metaheuristic algorithms has been proposed for load frequency control of interconnected electric power systems. From the simulation result, it can be concluded that the metaheuristic controllers gives superior and better results than conventional controller. The Metaheuristic controller exhibits good performance and have more validity than that of conventional controller for various load variations. In Metaheuristic controllers, Pattern Search algorithm gives better performance of three area interconnected power system with various step load variations than Ant Colony Optimization and Conventional controller

Appendix - I

The nominal parameters of Reheat and Non-Reheat Turbines are collected from various Thermal power plants in India and are as shown below Table 5. Area-I data is collected from Sothern Grid and Neively Lignite Corporation, Tamil Nadu, India. Area-II data is from RTPP, A.P. India.

Table 5. Nominar parameters of turbine in all three areas.

Parameters	Area-I	Area-II	Area-III
Speed Governor Time constant	0.08	0.08	0.08
Speed Governor Regulation	2.4	2	2.4
Power System Gain Constant	20	15	20
Turbine Time Constant	0.3	0.3	0.3
Coefficient of re-heat steam turbine (HP)	0.3	-	0.53
Reheat Time Constant (LP)	10	-	10

Rated capacity P_r = 2000MW; P_{tiemax}=200 MW; $(\delta_1 - \delta_2)$ = 30^0 ; Rated frequency f^0 = 60Hz D_i = 8.33×10^{-3}; Syn. Co-efficient T_{ij} = 0.545.

Nomenclature:

ALFC = Automatic Load Frequency Control.
P_D = Active Power Demand.
Q_D = Reactive Power Demand.
Δf = Change in frequency.
Tsg = Speed Governor Time Constant.
Trt = Reheat Turbine Time Constant.
Tnrt = Non-Reheat Turbine Time Constant.
Ksg = Speed Governor Gain.
Kps = Power System Gain.
Tps = Power System Speed Governor.
ΔP_L = Change in Load Demand.
ACE = Area Control Error.
$B_i = D_i + 1/R_i$

REFERENCES

[1] Pasala Gopi, Potla Linga Reddy, "A Robust Decentralized Controller Design for Inter-connected Power System with Random Load Perturbations using SDO Software" *Proceedia Technology*, vol. 21, no. 2, pp 406 - 414, 2015.

[2] Zhang Xin, Dang Jianwu, Liu Min., "Parameter Optimization of PID Controller Based on PSO for Multi-leaf Collimator" *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 11, no. 10, pp 6127- 6134, 2013.

[3] Pasala Gopi and Dr. Polta Linga Reddy, "A Critical review on AGC strategies in interconnected power system", *Proceedings of IET Int. Conf. on Sustainable Energy and Intelligent*, pp 299-305, 2013.

[4] Wen Tan, "Unified Tuning of PID Load Frequency Controller for Power Systems via IMC", *IEEE Tran. on Power Systems*, vol. 25 no. 1, pp 341-350, 2010.

[5] K. P. Singh Parmar S. Majhi, D. P. Kothari, "Optimal Load Frequency Control of an Interconnected Power System", *MIT Int. Journal of Electrical & Inst. Engineering*, vol.1, no. 1, pp 1-5, 2011.

[6] S.Ohba, H.Ohnishi & S.Iwamoto "An Advanced LFC Design Considering Parameter Uncertainties in Power Systems" , *Proceedings of IEEE conf. on Power Symposium*, pp 630– 635, 2007.

[7] Abhitit Chakrabarti, Sunita H "Power System Analysis Operation & Control", 4th ed. 2008.

[8] P. Kundur "Power System Stability and Control", *New York, McGraw-Hill*, 2003.

[9] Brian R Copeland, "The Design of PID Controllers using Ziegler Nichols Tuning", *IJETE*, pp 1-4, 2008.

[10] Xue Dingyü, Chen Yang Quan, and Atherton. Derek "Linear Feedback Control: Analysis and Design with MATLAB", *Printed by United States of America*, chapter 6, pp 187-232, 2007.

[11] Marco Dorigo, Thomas Stutzle (2004) "Ant Colony Optimization- A Bradford book". London, *The MIT Press Publisher*, 2004.

[12] Pasala Gopi, Potla Linga Reddy, "Design of Robust Load Frequency Controller for Multi-Area Interconnected Power System using SDO Software", *Journal of Electrical Engineering*, Vol.15, Issue.4, Sep-Dec. 2015.