

# 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 inter connected 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 and Q. 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 increase 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 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.





## 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,  $P_{tie} = 0$ . In this case the local feedback control will be  $u_i = -K_i(s)B_i^{-1} |$ . 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  $\hat{\omega}_i$ , the deviation in the tie line S R Z H U I, Q, R Z O R D G G L V W, X T H E F O L L O W I N G sequence helps for development of block diagram of interconnected power system [7].

### 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].

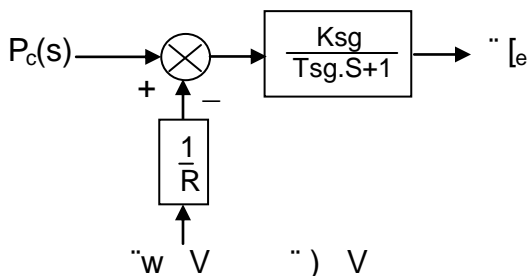


Fig. 1 Speed Governor with drooping characteristics

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

$$G_{sg}(s) = \frac{1}{(1 + sT_{sg})} = \frac{NUM_{sg}(s)}{DEN_{sg}(s)} \quad (1)$$

### 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].

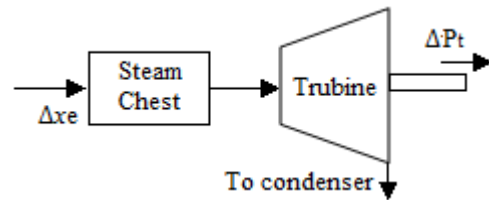


Fig. 2 Non Reheat Steam Turbine

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

$$G_{nr}(s) = \frac{1}{(1 + sT_t)} = \frac{NUM_t(s)}{DEN_t(s)} \quad (2)$$

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

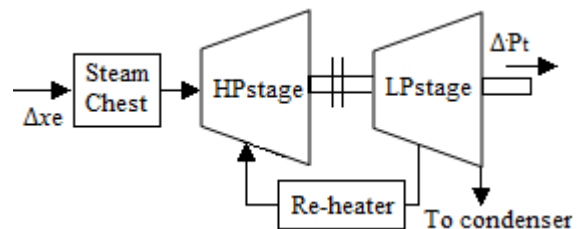


Fig. 3 Reheat Steam Turbine

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

$$G_r(s) = \frac{1 + sCT_{rt}}{(1 + sCT_{rt})(1 + sT_{lp})} = \frac{NUM_t(s)}{DEN_t(s)} \quad (3)$$

### 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

3. Due to the action of the turbine controllers, the generator increases its output by  $\Delta P_{Tij}$ . The surplus power  $\Delta P_{Tij}$  will be absorbed by the system of generator with load damping (D) effect. Fig. 4 shows the block diagram of generator with load damping.

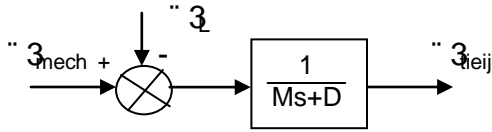


Fig. 4 Generator with load damping

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

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

#### D. Tie-Line Modeling

Practically, all power systems now a days are interconnected by number of ties with the neighboring areas. When the frequency variations in two areas are different, a power exchange occurs through the tie between the connected two areas. The block diagram of tie-line is as shown in Fig5 [7-8].

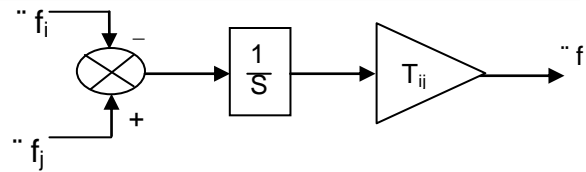


Fig. 5 Tie-line Connections

The Laplace transform of tie line is given as

$$\Delta P_{Tij}(s) = \frac{T_{ij}(\Delta F_i(s) - \Delta F_j(s))}{s} \quad (5)$$

Where  $\Delta P_{Tij}$  is tie line power exchange between areas i and j, and  $T_{ij}$  is the tieline 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

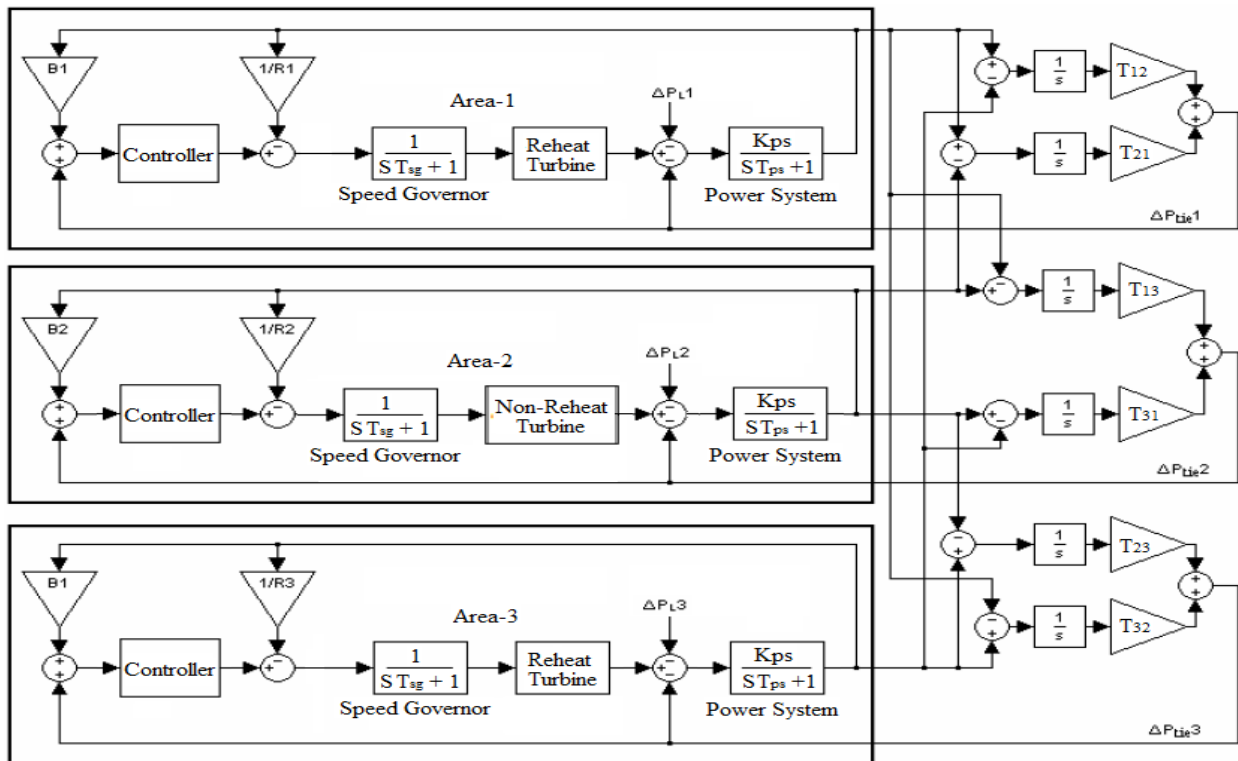


Fig. 6 Three Area Interconnected Electric Power System with Step Load Variations.

The transfer functions of all three areas of interconnected power system are as follows (see Appendix A for Turbine, Speed Governor and Power system parameters):

$$\text{For } i^{\text{th}} \text{ Area, } G_i(s) = \frac{\text{NUMsg}(s)\text{NUMt}(s)\text{NUMps}(s)}{\text{DENsg}(s)\text{DENT}(s)\text{DENps}(s) + \text{NUMsg}(s)\text{NUMt}(s)\text{NUMps}(s)/R} \quad (6)$$

$$\text{For Area1, the transfer function is } G_1(s) = \frac{48.75s + 16.25}{s^4 + 16s^3 + 44.312s^2 + 55s + 16.25} \quad (7)$$

$$\text{For Area2, the transfer function is } G_2(s) = \frac{10625}{s^3 + 15.88s^2 + 42.46s + 106.25} \quad (8)$$

$$\text{For Area3, the transfer function is } G_3(s) = \frac{53.125s + 10.625}{s^4 + 15.98s^3 + 44.05s^2 + 58.41s + 10.625} \quad (9)$$

### 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 [10]:

$$G_c(s) = K_p + \frac{K_i}{s} + sK_d = K_p \left( 1 + \frac{1}{sT_i} + sT_d \right)$$

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-line power should return to the scheduled values. So the combination of both, called Area Control Error (ACE), is used as feedback variable. For  $i$  area, the ACE is defined as  $ACE = \sum_{i=1}^n \Delta f_i + B_i \Delta P_i$  and Feedback control signal is  $u_i = -K_i(s) AEC$ . A PID load frequency controller can be tuned assuming that there is no tie line power exchange  $L_{H_{tie}} \cong 0$ . Now the feedback control signal  $u_i = -K_i(s) B_i \Delta P_i$ . 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

$$J_n(\theta) = \int_0^{\infty} t^n [e(\theta, t)]^2 dt \quad (10)$$

: KHUH § LV WKH 3, ' FRQWUROO DQG H § W LV WKH HUURU ZK 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 Squared Error (IST<sup>2</sup>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









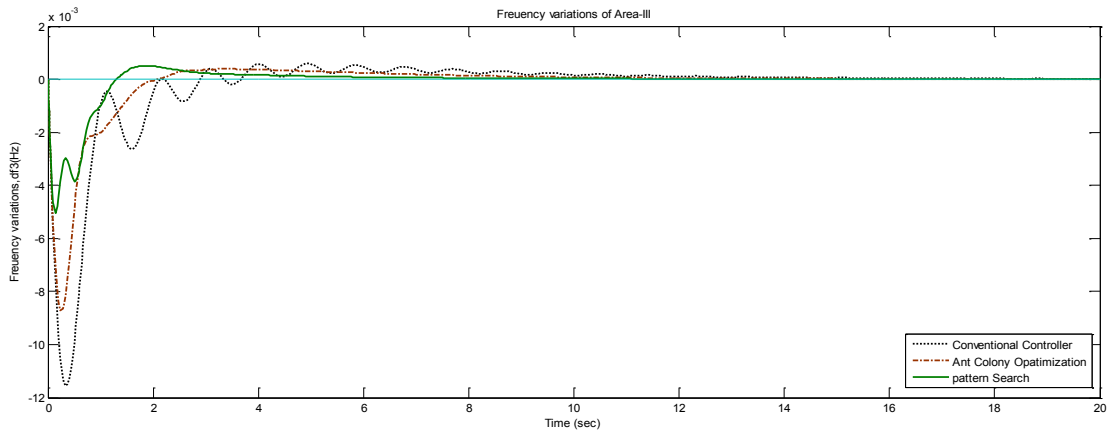
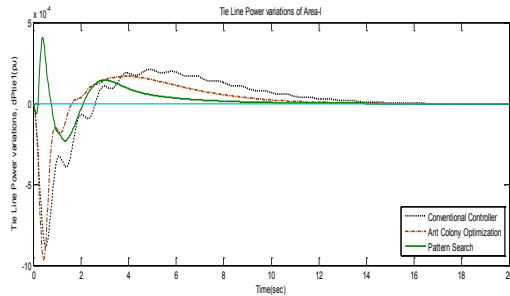
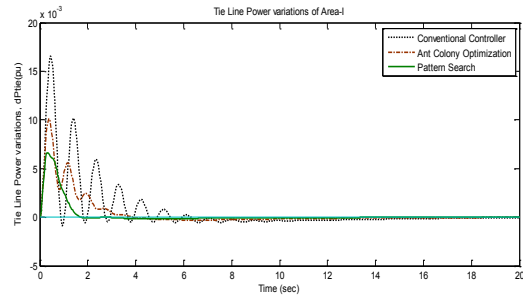


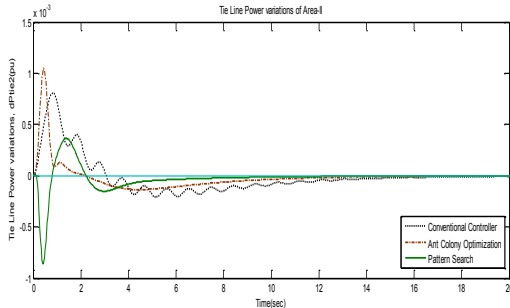
Figure 10(c). Frequency variations in Area-III (Hz)



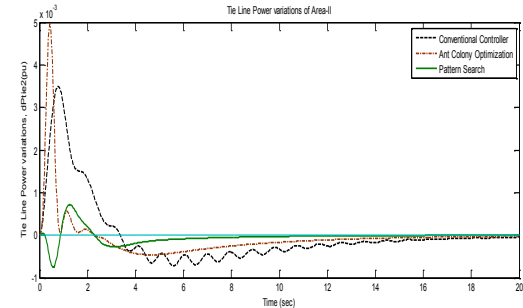
11(a)



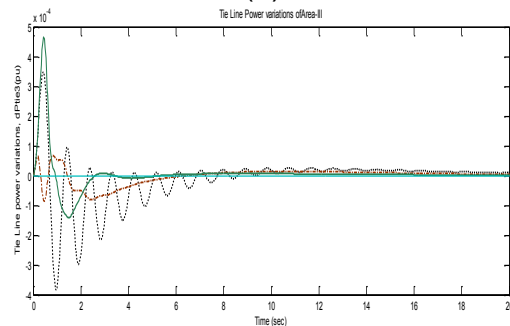
12(a)



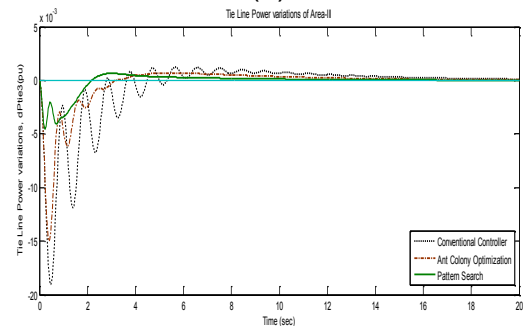
11(b)



12(b)



11(c)



12(c)

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

**B. Illustration-II**

Now let the step load perturbations  $\Delta P_{L1} = 0.01pu$ ,  $\Delta P_{L2} = 0.05pu$  and  $\Delta P_{L3} = 0.1pu$  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.

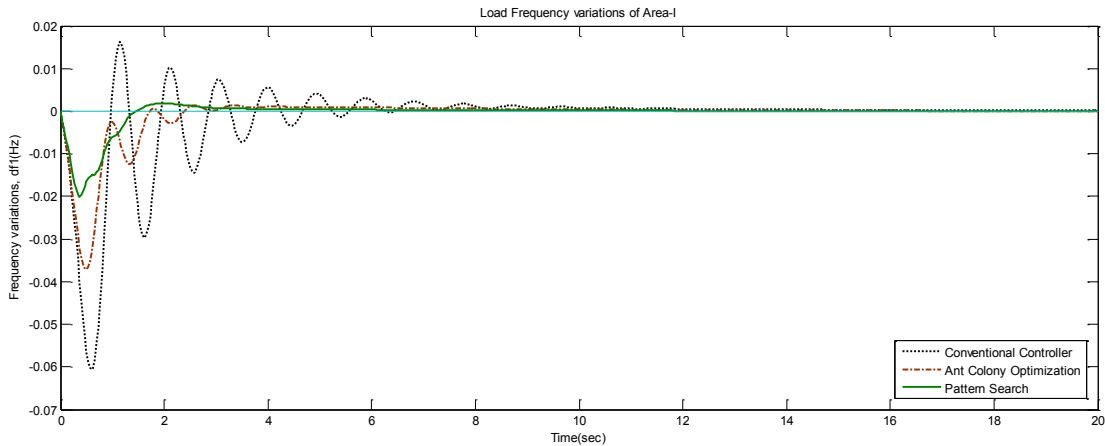


Figure 13(a). Frequency variations in Area-I (Hz)

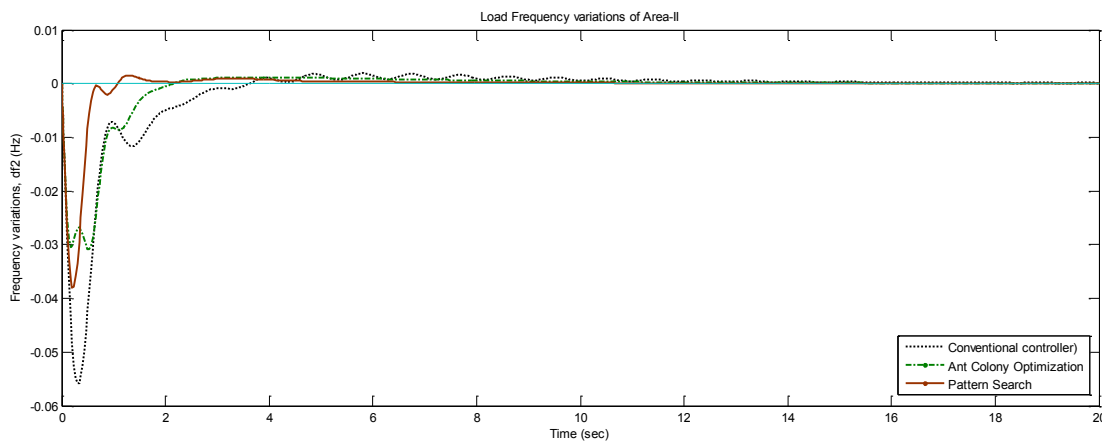


Figure 13(b). Frequency variations in Area-II (Hz)

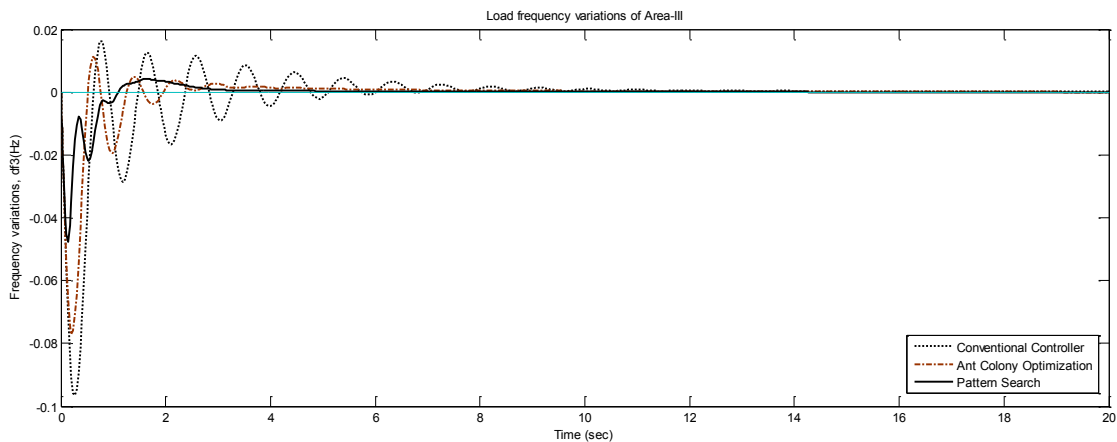


Figure 13(c). Frequency variations in Area-III (Hz)

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 below from Table 2 to Table 4.

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

Area-i	Conventional Controller		Ant Colony Optimization (ACO)			Pattern Search Algorithm (PSA)		
	1 <sup>st</sup> peak over shoot	Settle Time	1 <sup>st</sup> peak over shoot	Settle Time	Improvement in performance	1 <sup>st</sup> 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)		
	1 <sup>st</sup> peak overshoot	Settle Time	1 <sup>st</sup> peak over shoot	Settle Time	Improvement in performance	1 <sup>st</sup> 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  $dP_{L1} = dP_{L2} = dP_{L3} = 0.095pu$

Area-i	Conventional Controller		Ant Colony Optimization (ACO)			Pattern Search Algorithm (PSA)		
	1 <sup>st</sup> peak over shoot	Settle Time	1 <sup>st</sup> peak over shoot	Settle Time	Improvement in performance	1 <sup>st</sup> 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. Nominal 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 reheat steam turbine (HP)	0.3	-	0.53
Reheat Time Constant (LP)	10	-	10

Rated capacity,  $P_r = 2000\text{MW}$ ;  $P_{r\text{max}} = 200\text{MW}$ ;  
 $(1 - 1/2) = 30^\circ$ ; Rated frequency  $f_r = 60\text{Hz}$   
 $D_i = 8.33 \times 10^3$ ; Syn. Coefficient  $T_{ij} = 0.545$ .

Nomenclature

- ALFC = Automatic Load Frequency Control.
- $P_D$  = Active Power Demand.
- $Q_D$  = Reactive Power Demand.
- $T_{sg}$  = Speed Governor Time Constant.
- $T_{rt}$  = Reheat Turbine Time Constant.
- $T_{nrt}$  = Non-Reheat Turbine Time Constant.
- $K_{sg}$  = Speed Governor Gain.
- $K_{ps}$  = Power System Gain.
- $T_{ps}$  = Power System Speed Governor
- $\Delta P_L$  = Change in Load Demand.
- ACE = Area Control Error.
- $B_i = D_i + 1/R_i$

REFERENCES

[1] Pasala Gopi, Potla Linga Reddy, 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 Mi, 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, Critical review on AGC strategies in interconnected power system Proceedings of IET Int. Conf. on Sustainable Energy and Intelligent, pp 299305, 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 15, 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 4<sup>th</sup> 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 1 L F K R O V 7 X Q L IJETE, pp 14, 2008.

[10] Xue Dingyü, Chen Yang, and Atherton. 'H U H 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] 3 D V D O D \* R S L 3 R W D S D R / b f Q J D Robust Load Frequency Controller for Multi-Area Interconnected Power System using 6'2 6 R I W, Z D D u r n a l of Electrical Engineering Vol.15, Issue.4 Sep Dec. 2015.