

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, the load 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 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 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 $S R Z H U I, Q, R Z$ $ORDG GLVWX$. The following sequence helps for development of block diagram of interconnected power system.

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. [5,7].

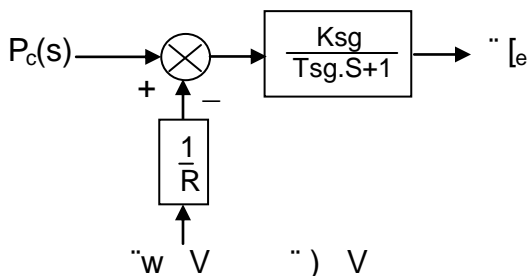


Fig. 1 Speed Governor with drooping characteristics

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. [2,7].

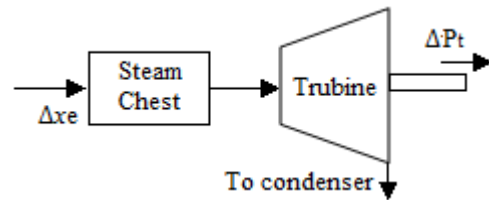


Fig. 2 Non Reheat Steam Turbine

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.

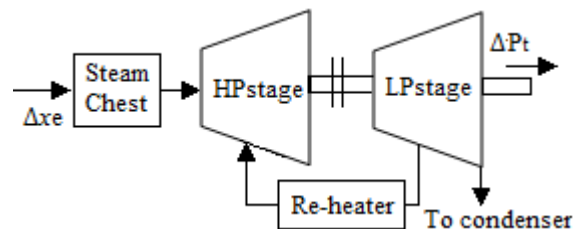


Fig. 3 Reheat Steam Turbine

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 ΔP_{Tij} . The surplus power ΔP_{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.

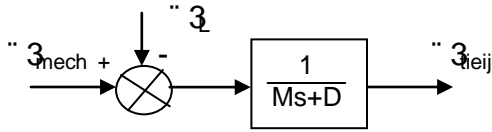


Fig. 4 Generator with load damping

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].

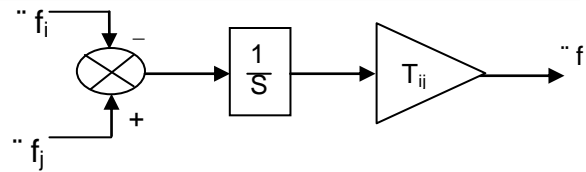


Fig. 5 Tie-line Connections

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 ΔP_{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

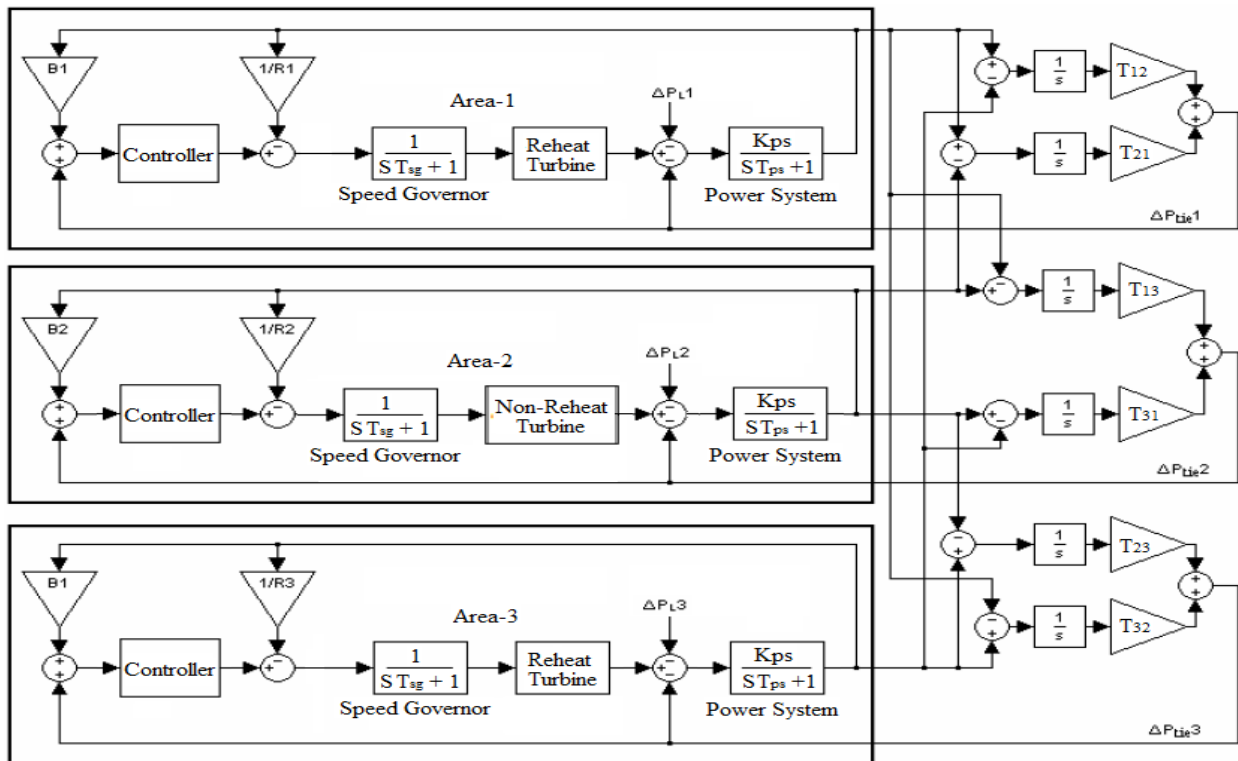


Fig. 6 Three Area Interconnected Electric Power System with Step Load Variations.

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 $L_{H_{tie}} \approx 0$. 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 (IST²E) 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.

Two ants start from their nest (left) and look for the shortest path to a food source (right). Initially, no pheromones are 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.

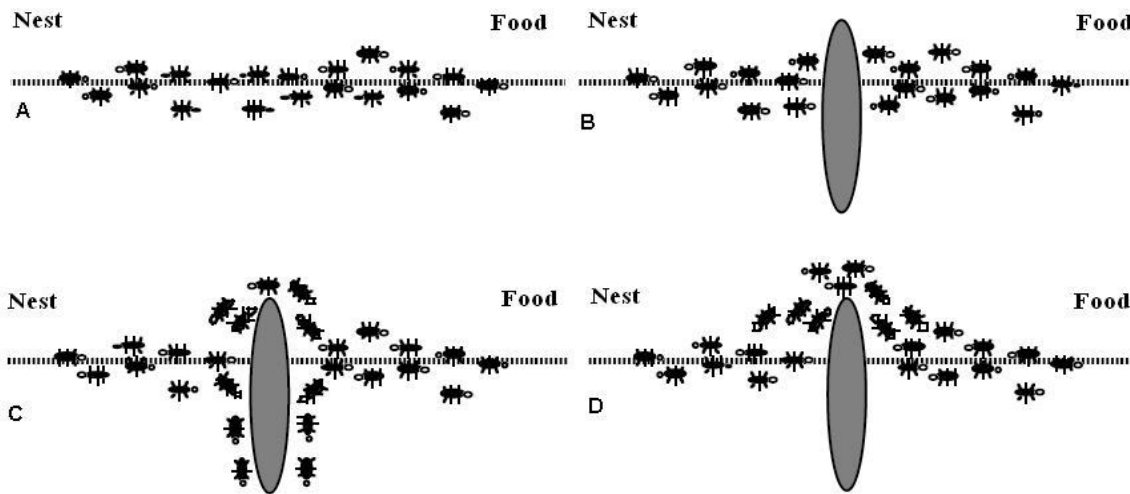


Figure 8(a) Real ants follow a path between nest and food source. (b) An obstacle appears on the path: Ants choose whether to turn left or right with equal probability. (c) Pheromone is deposited more quickly on the shorter path. (d) All ants have chosen the shorter path.

The following algorithmic skeleton shows the pseudocode for Ant Colony Algorithm for optimization problem [1].

```

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 (IR) are 100, Number of SDUDPHWHUV DUH DQG HYDSR. 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.

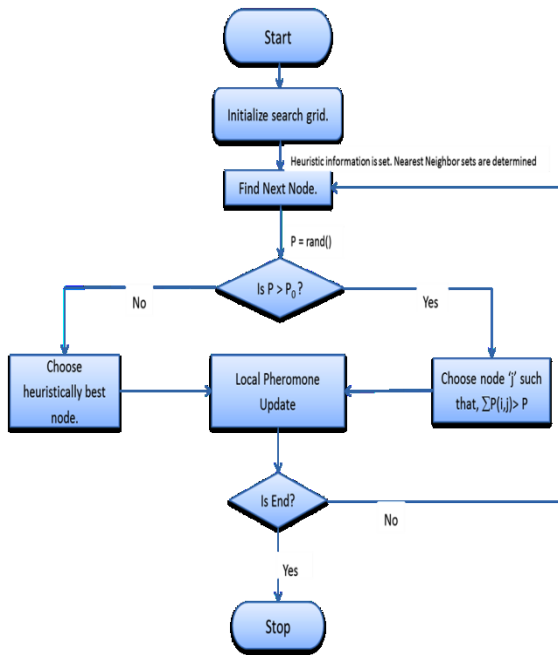


Figure 9(a) Ant Colony Optimization (ACO)

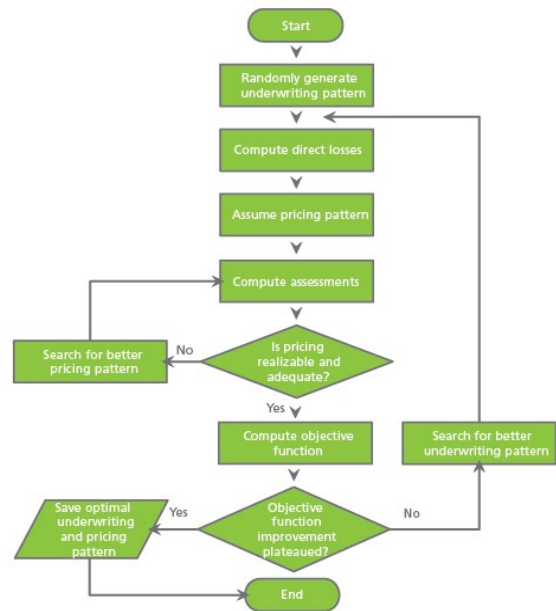


Figure 9(b) Pattern Search Method (PSM)

In the search step(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:

$$M_k = \{ S_k \quad \ddot{k}D_z \quad] \quad \ddot{D} \} \quad (a)$$

parameter, S_k is a mesh local optimizer

Poll set:

$$\{ S_k \quad \ddot{k}d \quad G_k \} \quad (b)$$

Pseudo code of Pattern Search Algorithm

Step- I : Let S_0 be such that $f(S)$ is finite and M_0 is finite. Set $k=0$. Set $i=0$. Set i 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, a feasible iteratex_{k+1} }

$$M_k @ \ddot{Y} \quad I R U \quad Z K L F K S I \quad 6 \quad W K H Q \quad X S G D W$$

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

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

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

$$J = \int_0^{t_s} \sum_{i=1}^n |Wf_i - \sum_{j=1}^n W_{ij}|^2 dt \quad (9)$$

Where t_s is simulation time.

Above objective function is minimized by considering the following constraints:

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

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

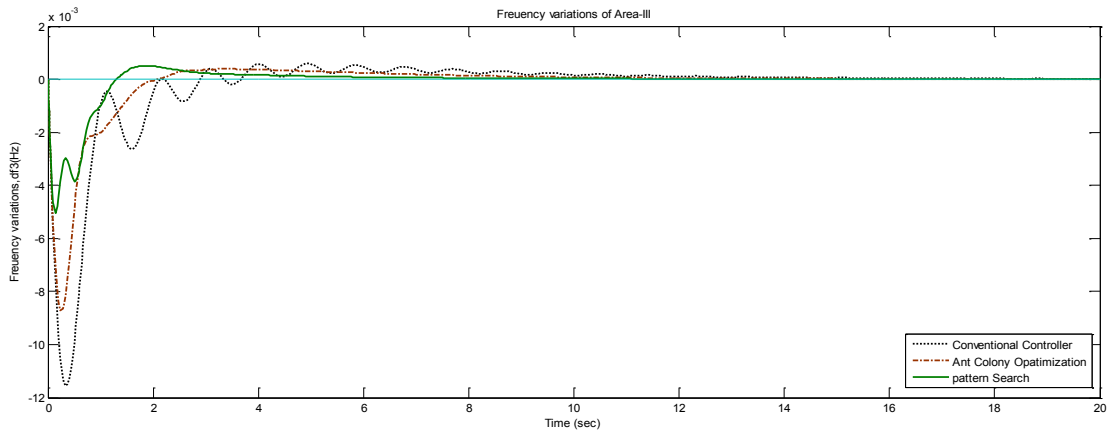
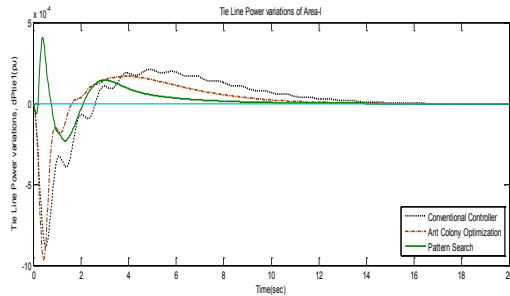
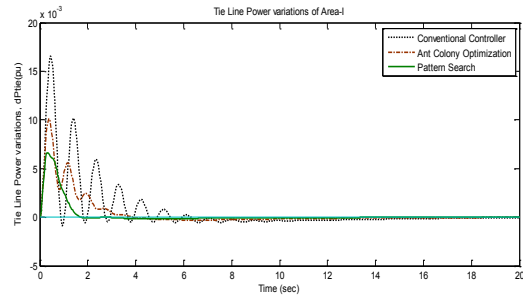


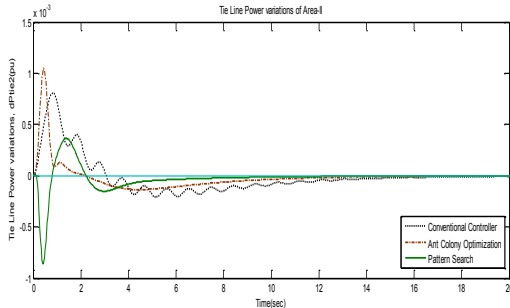
Figure 10(c). Frequency variations in Area-III (Hz)



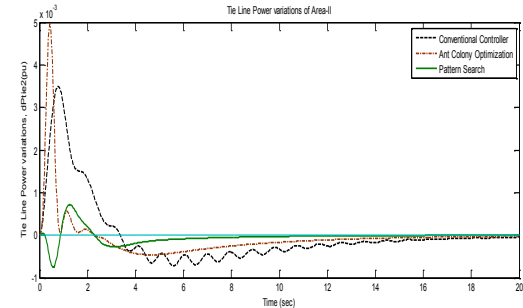
11(a)



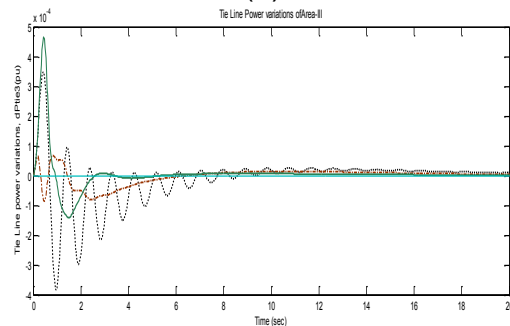
12(a)



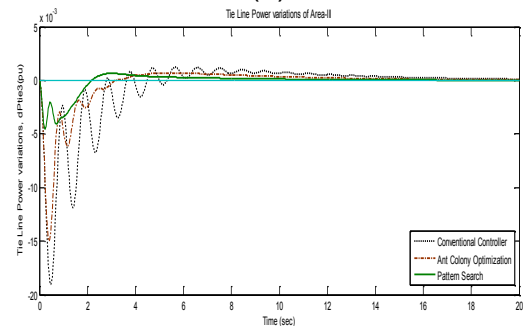
11(b)



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.

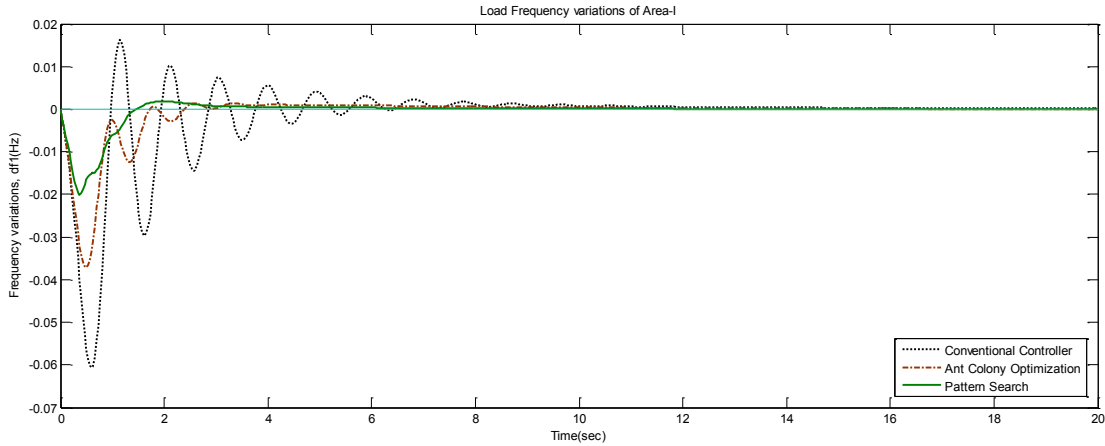


Figure 13(a). Frequency variations in Area-I $df1$ (Hz)

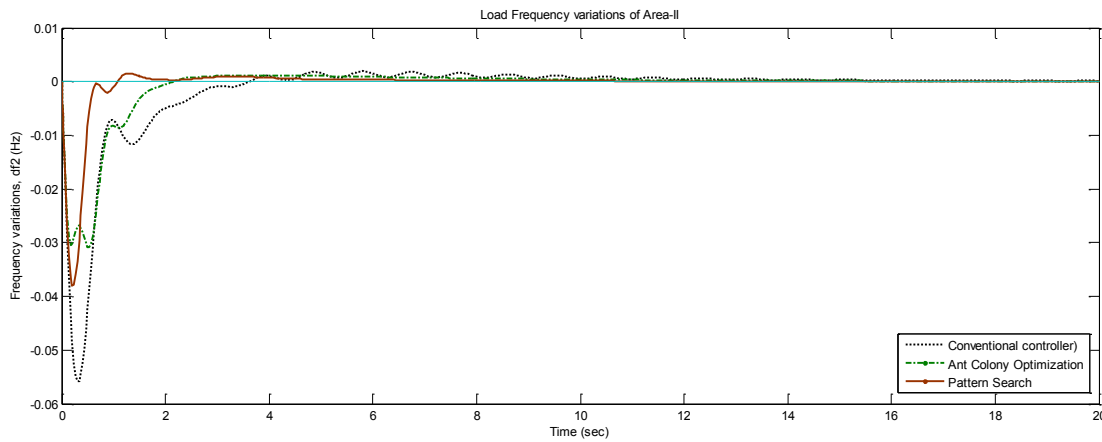


Figure 13(b). Frequency variations in Area-II $df2$ (Hz)

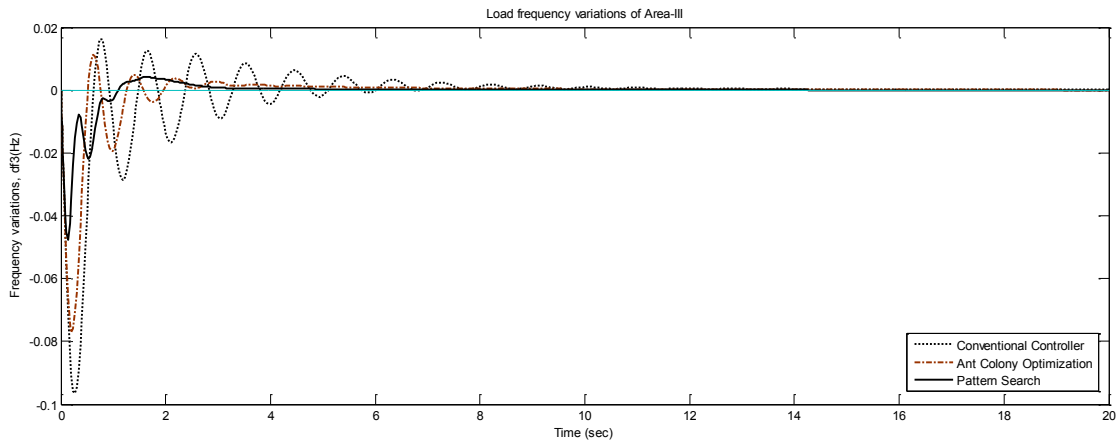


Figure 13(c). Frequency variations in Area-III $df3$ (Hz)

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
- ΔP_L = Change in Load Demand.
- ACE = Area Control Error.
- $B_i = D_i + 1/R_i$

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