Salp Swarm Optimizer based NCTF controller for AGC of multi-area multi source non-linear power system

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Abstract
The proposed work aims to develop Automatic generation control (AGC) of a two area six unit based inter connected power network by implementing a robust Nominal Characteristic Trajectory Following (NCTF) controller. The AGC focuses on stability of a system in order to keep both frequency and inter line power flow within their predetermined values. The deviation of both frequency and interline power occurs when there is a sudden change of load or due to certain disturbances. The proposed controller diminishes the Area Control Error (ACE) which includes both local control signals (Δf and ΔP_{tie}) and tries to maintain both deviated values to zero. This article proposed a novel Salp swarm Optimizer (SSO) algorithm for tuning the gain parameters of above proposed controller. To develop least overshoot and minimal settling time oriented responses Integral of Time Multiplied Absolute Error (ITAE) have been utilized as objective function in proposed optimization scenario. To justify superiority of proposed NCTF controller it's performances are compared with additional PID and PI controller through different responses. For technique comparison and to impose supremacy of proposed SSO algorithm it is examined along with PSO and GA optimization technique which results supremacy of proposed SSO technique. Robust performance of proposed controller is checked with the variation of turbine time constant and variation applied load.

Keywords: Automatic generation control (AGC), Salp Swarm Optimizer (SSO), Integral of Time Multiplied Absolute Error (ITAE). Generation Rate Constraint (GRC), GDB (Governor Dead Band), NCTF

1. Introduction

The electrical system is broadly classified in two different categories in regards their external connection. These are interconnected system and isolated system. In modern electrical system all power grids are in interconnected type which facilitates most reliable and avoids complete beak down of system. In reliable concern the system should provide ancillary services like voltage control and active power control. Due to instant load condition and different disturbances the system voltage and frequency oscillates from their nominal values. So the system goes for unstable and if such behavior continues the system may be permanent black out. In order to keep system stable certain controlled mechanism have been applied which enable to maintain system stable. In this regard Automatic Generation Control (AGC)[1] is required which makes smooth coordination between power generation and net electrical demand. Due to this the Area Control Error (ACE) deviates towards zero and both frequency and tie line powers are forced to move respective nominal values. Another huge issue for power engineers is integration of renewable energy source based energy sources. Due to large dynamic nature and uncertainty nature of different renewable sources advanced skill and control mechanism is required for making support of their different electrical signals with grid parameters. It has been studied from different research articles that in today's research scenario centrally and digitally controlled systems are implemented to control and coordination of different operations in a précised manner. SCADA (Supervisory Control and Data Acquisition) system operates in such a manner to make coordination among all functions with the implementation of a centralized system in response to proper information which enables to control different signals of interconnected system. The SCADA systems have been installed in power sectors for controlling both active and reactive powers in response to control voltage and frequency in different unstable conditions. Articles reported through different journals suggest that AGC analysis has been developed both in single and multi areas along with both interconnected and isolated systems. Kundur [2] has developed AGC analysis in inter connected system and also given idea of both primary and secondary control loops. In this regard the in build primary control loop of AGC is developed due to both governor and turbine closed loop system. The primary control loop in efficient to produce close optimum results in regards system frequency and tie line power. According to Elgerd et. al[3] the secondary control loop is very much efficient to maintain stable operation of system for AGC of interconnected system. Hossain et. al [4]proposed a single area system model for AGC analysis in electrical system by implanting secondary control loop. To move few steps in forward Rakhshani et.al [5] proposed two area system in the research area of AGC with the introduction of tie line system of proposed model. From the literature study of above AGC analysis many researchers have been proposed three are[6] and four area systems along with realization of system non linearity both inter connected and isolated systems. In view of this saikia et. al proposed three area systems along with effective non linearity constraints for AGC analysis in electrical system more over Hou et.al [8]proposed four area systems for AGC study in interconnected electrical system. However to perform AGC in an interconnected system the secondary control loop requires different controllers for its operation. In regard to this many conventional controllers like I, PI, PID[8] have been proposed both for single and multi area systems. Apart from this by eliminating slower and large parameter limitations of above proposed conventional controllers sahu et. al [9] proposed degree of freedom based 2 degree of freedom (2DOF) controllers and Debabarma et.al [10]proposed Fractional

order based PID controllers in the area of AGC of interconnected power network. Recently some robust controllers like multi-stage controller[11], fuzzy controllers[12], fuzzy type-2 controller have been proposed in AGC analysis of interconnected network. This paper proposed a robust NCTF controller for making secondary control loop of AGC analysis.The problem to produce very accurate and closed value of gain parameters create challenges for different researchers. Initially trial and error method helps to update gain values of different proposed controllers. With the development of different updating based algorithm researchers have been proposed novel optimized techniques while tuning gain parameters of different proposed controllers. In view of this different conventional techniques like GA[134], PSO[14] and some meta heuristic algorithm like CSA[15], DE[16], ALO etc have been implemented for tuning gain values of different controllers. This research article proposed a population based Salp Swarm Optimizer(SSO)[17] technique for tuning above proposed controllers.
The proposed work focuses on

1. To keep both frequency and inter line power exchange within their predetermined values.
2. To propose different source oriented system model for AGC analysis.
3. Proposes a robust NCTF feedback type controller for creating secondary control loop.
4. Apply a population based SSO technique to tune gain values of proposed controllers.
5. Sensitive analysis to justify robust nature of proposed controller.

System Investigated

The system model considered for this research study is a two area six unit based interconnected power network. Each area is allocated with three different units i.e Thermal, Hydro, and Gas with a rating of 2000MW. Different participation factors are allocated for smooth distribution of total applied load among different units without over loaded. For realization of non linearity different physical constraints like GDB and GRC are introduced in the proposed network model. In present work GDB is due to back lash non linearity and estimated as 0.05% for thermal system and 0.02% for hydro system. Like this GRC with estimated 3% per minute is chosen for thermal plant and estimated GRC of 270% and 360% per minute is chosen increasing and decreasing generation respectively of hydro system. The transfer function model of proposed two area system is depicted in fig.1 .Different equations given below depicts individual transfer function model. Equation1 gives idea about the power balance equation i.e.

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

Equation (2) depicts Hydraulic actuator (Governor) Transfer function.

$$G_H(s) = \frac{\Delta P_V(s)}{\Delta P_g(s)} = \frac{1}{1+T_H s} \quad (2)$$

Equation (3) depicts Turbine dynamics Transfer function .That is

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1+T_T(s)} \cdot \frac{1+sT_r K_r}{1+sT_R} \quad (3)$$

The dynamic nature based power system has been energised through generating system is expressed by equation (4)

$$G_P(s) = \frac{K_P}{1+sT_P} \quad (4)$$

$$R = \frac{\Delta f}{\Delta P} \quad K_P = \frac{1}{D}, \ D = \frac{dP_D}{df}, \ T_P = \left(\frac{2H}{FD}\right)$$

Finally, $\Delta f(s) = G_P(s)(\Delta P_T(s) - \Delta P_D(s) - \Delta P_{tie})$.

Tie-line power between ar1 and ar2 for this proposed model is depicted in equation (5)

$$\Delta P_{12}(s) = \frac{2\pi T}{s}(\Delta f_1(s) - \Delta f_2(s)) \quad (5)$$

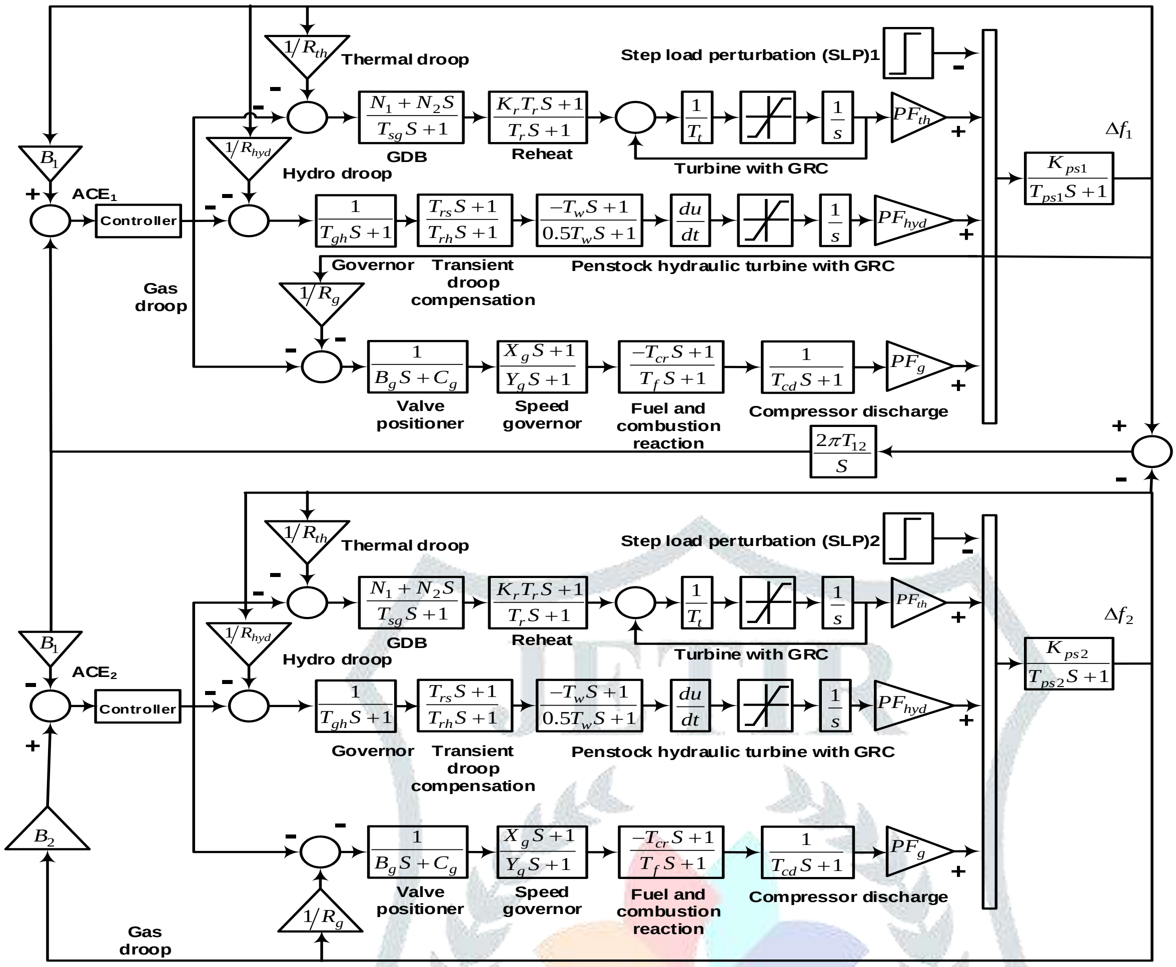


Fig.1 (a) Two area multi source power system

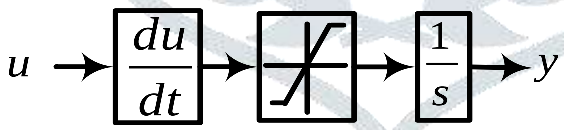


Fig.1 (b) Generation Rate Constraint (GRC)

II. Proposed NCTF controller

The block diagram of proposed NCTF controller is depicted in fig.2 which suggests the controller comprises by taking two important blocks i.e NCT block and compensated PI block. The operation of NCTF controller based on the principle of object response in open space in which the function of PI controller controls the response of object in response to NCT and at last it converged to origin. It is also popularly favoured as Continuous motion type controller.(CM-NCTF)

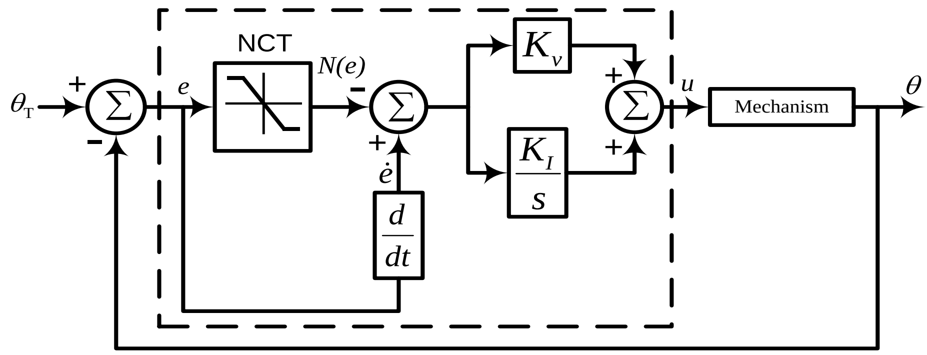


Fig2. Proposed NCTF controller

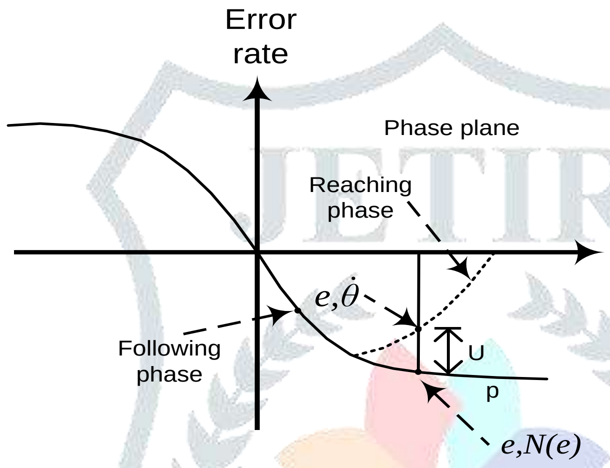


Fig. 3 Nominal characteristic Trajectory (NCT)

From the phase plane analysis it has been suggested that the proposed controller is positioned in two phases i.e Reaching phase and Following Phase. In reaching phase the object motion is guided by PI controller and in following phase PI controller helps to control motion to converge at origin.

Here θ = Output signal; θ_r= Reference signal; U_P= NCT output signal; U = Controlled signal

III. Fitness function

The fitness function is the main tool of different proposed algorithms of optimized research scenario. After testing different bench mark functions the proposed approach should be implemented with suitable fitness functions in order to produce suitable responses. The fitness function takes different error signals as input response and processed output is realized through connected workspace. Due to least settling time and overshoot based response producing ability many researchers select Integral of Time Multiplied Absolute Error (ITAE) as fitness function on their respective research works. This proposed work also taken ITAE as fitness function.

$$J = \int_0^{tsim} \left(|\Delta f_1|\right)+\left(|\Delta f_2|\right)+\left(|\Delta f_3|\right)+\left(|\Delta P_{tie}|\right)t.dt \quad (6)$$

Where Δf_1 = Area1 frequency oscillation
Δf_2 = = Area2 frequency oscillation
Δf_3 = = Area3 frequency oscillation
ΔP_{tie} = Tie line power oscillation
tsim = time range of simulation.

IV. Salp Swarm Optimizer (SSO) Technique

The population of salp is splitted in two categories i.e leader and follower. In salp chain the leader remains at front of the chain to which other salps follow(follower). Similar to other type of swarm based optimization technique[15], the salp occupies a place and is derived in n-dimensional search space and n stands for number of variables. There is a matrix 'X' which stores all the position of salps. In search space the main target of salps is of food location and is noted by 'F'. The below equation helps to update the position of leader

$$X_j^1 = \{F_j + C_1((ub_j - lb_j)C_2 + lb_j) when C_3 \geq 0$$

And

$$X_j^1 = \{F_j - C_1((ub_j - lb_j)C_2 + lb_j) when C_3 < 0 \quad (7)$$

Where X_j^1= position of leader in *jth* dimension. F_j = position of food source in jth dimension, *ub* & *lb* = upper and lower bounds.; C_1, C_2 & C_3 are the random numbers. .

The random number c1 helps to balance the exploration and exploitation and is equated as

$$C_1 = 2e^{-(\frac{4l}{L})^2} \quad (8)$$

Where *l*= current iteration ; *L*=max number of iteration

Below equation helps to revise the position of followers and is formed according to Newton's Law's of motion.

$$X_j^i = \frac{1}{2}at^2 + V_0 t \quad (9)$$

Where $i \geq 2$; X_j^i = Position of i^{th} follower salp in j^{th} dimension at time t sec; V_0 = initial speed

$$a = \frac{V_{finitial}}{V_0}; v = \frac{x - x_0}{t}; \quad (10)$$

Considering V_0 and discrepancy between iteration the modification of above equation will be

$$X_j^i = \frac{1}{2}(X_j^i + X_j^i - 1), i \geq 2 \quad (11)$$

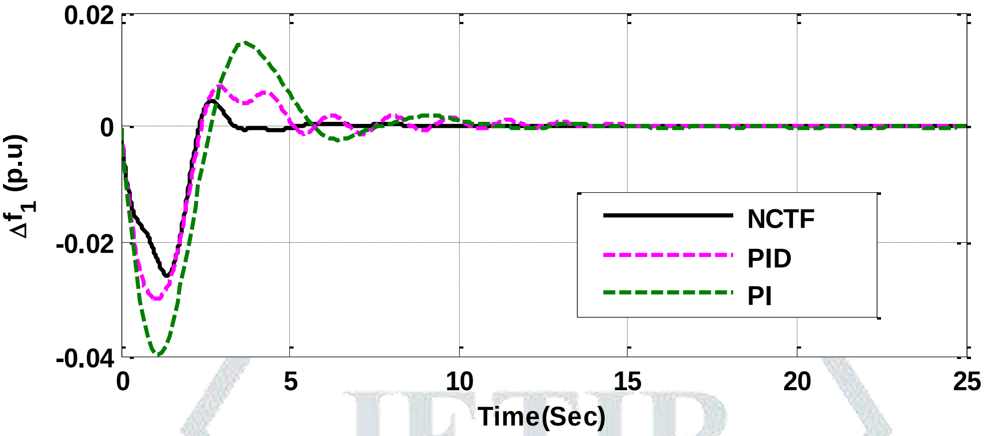
Finally simulation of salp chain is occurred with the above equation.

Pseudo code of SSO Algorithm

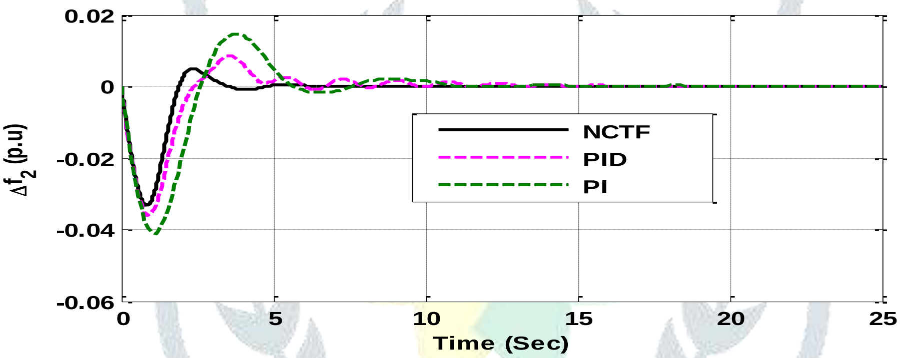
```
Initialization of salp population    Xi (I = 1,2,3……….n), ub & lb
    While  (condition not satisfied)
              Fitness of each salp is calculated
               F = Best salp
                              Update equation (5)
        for  each salp (Xi)
                  if   (i  = = 1
                  update leading salp  by eq(4)
                  else
                 update follower  by eq(8)
                  end
            end
  Amend salps according to upper bound and lower bound
            end
        return  F
```

V. Result & Analysis

Frequency variation of area-1, area-2 along with tie-line power variation (ΔP_{12}) are plotted with different intelligence technique and with different controllers which shows the superiority of SSO optimized proposed NCTF controller over optimized PID nad PI controller and is depicted through dynamic responses shown in fig.4



4 (a)



4 (b)

Fig.4 Frequency deviation of (a) area-1 and (b)area-2 with different controllers having 2% step load perturbation in area-1

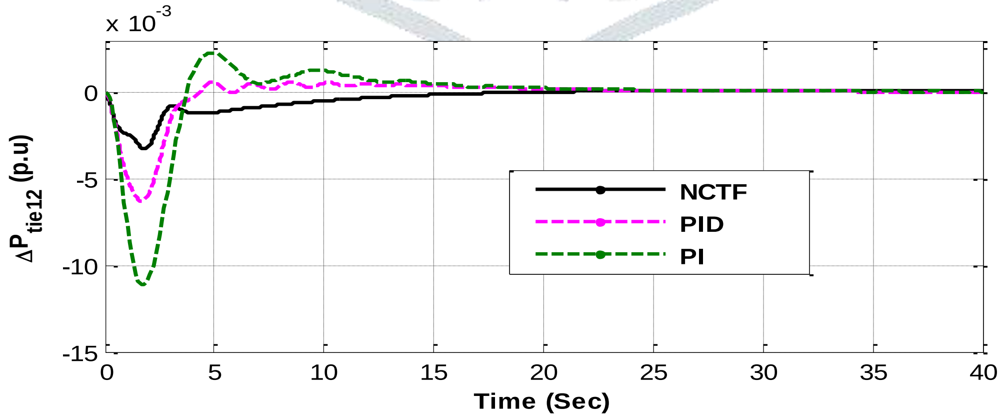


Fig.5(a) Deviation of tie-line power between area-1 and area-2 with different controllers having 2% SLP at ar-1

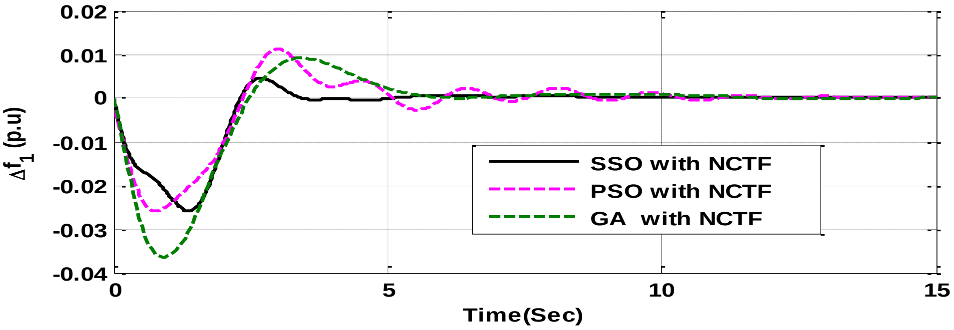


Fig.5(b) Change in frequency of area1 due to different techniques

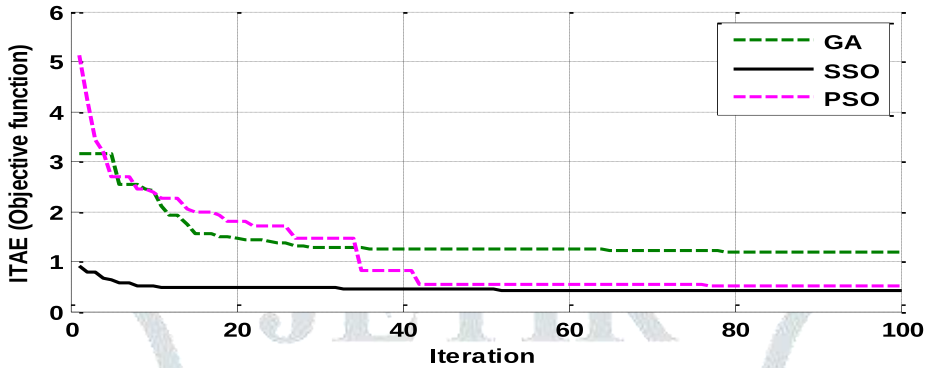


Fig.6 Convergence curve

Fig.5 reveals that the proposed approach SSO algorithm gives better dynamic responses in view of over shoot and settling time. It has been more observed through convergence curve shown in fig.6 that realization of proposed SSO technique is superior

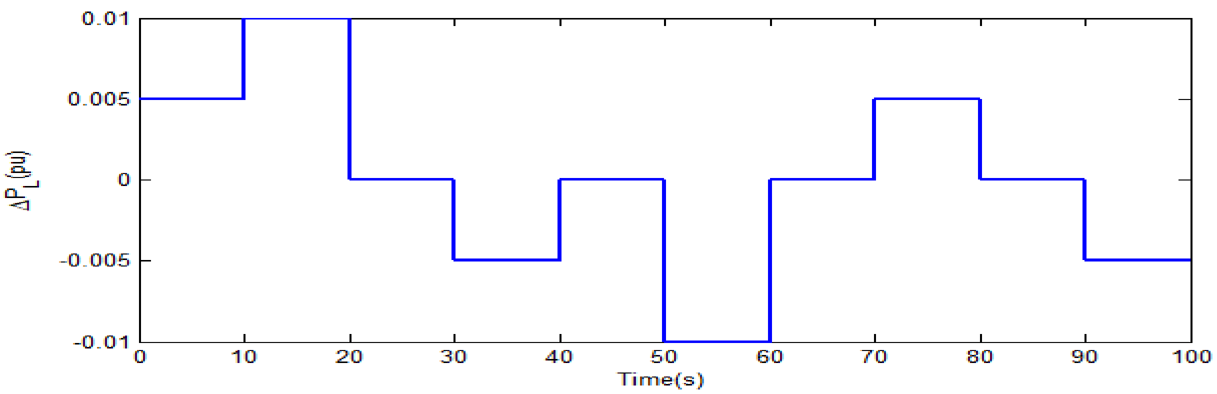


Fig.7(a) Random load pattern

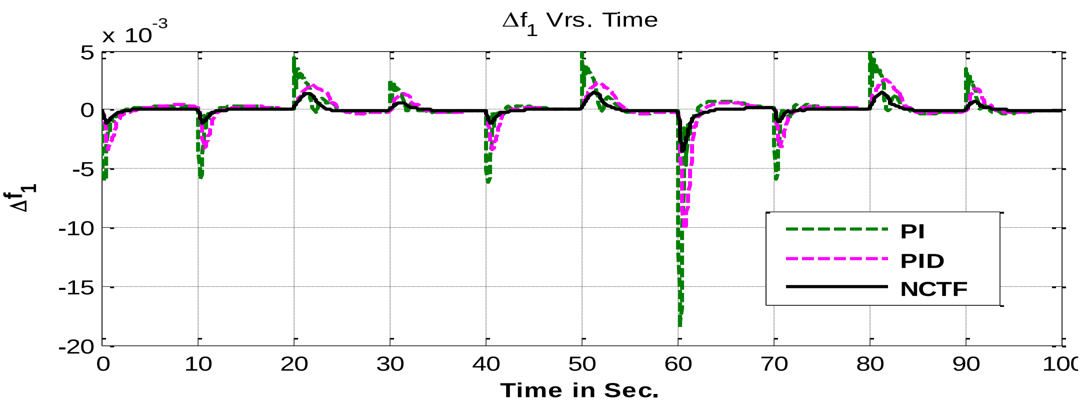


Fig.7(b) Deviation of frequency in area.3 due to RLP at area.1 onl

Table1: Optimized values of different controller parameters with MFOTechnique

Controller	NCTF Controller			PID Controller			PI Controller	
Parameters	K_P	K_I		K_P	K_I	K_D	K_P	K_I
AREA1	-1.9986	1.9767		-1.6156	-1.9215	-1.9013	0.3034	-1.1639
AREA2	-0.2353	1.8408		-0.5681	-0.0327	-0.4573	-0.4668	-0.0350
ITAE value	41.68×10^{-2}			86.97×10^{-2}			131.54×10^{-2}	

The optimized gain values of different controllers implemented for this research work is given in table.1 which helps to develop different dynamic responses through MATLAB simulink environment. Ithas been observed different depicted values in table.2 that optimized NCTF controller provides LEAST OVERSHOOT , UNDERSHOOT AND MINIMUM SETTLING TIME.

Table2: Performance analysis of different optimization techniques with different signals and fitness function

Technique/ Performance	NCTF (SSO)			PID(SSO)			PI(SSO)		
	Settling Time in Sec.	Over Shoot in Pu. $*10^{-3}$	Under Shoot in Pu $*10^{-3}$	Settling Time in Sec.	Over Shoot in Pu. $*10^{-3}$	Under shoot in Pu $*10^{-3}$	Settling Time in Sec.	Over Shoot in Pu. $*10^{-3}$	Under shoot in Pu $*10^{-3}$
ΔF1	8.4523	0.4500	-1.9200	9.2020	1.2202	-3.1200	12.2747	2.6502	-5.3224
ΔF2	12.1634	0.3264	-0.6256	12.8788	0.6244	-2.6200	15.2530	1.4166	-3.8644
ΔP12	8.3244	0.8654	-6.6232	9.6086	0.9264	-8,4090	10.6208	1.1088	-11.1022
ITAE value	41.68×10^{-2}			42.80×10^{-2}			102.74×10^{-2}		

VI. Conclusion

The AGC analysis in two interconnected Thermal, Hydro and Gas unit based area has been considered for AGC analysis. Here the frequency and tie line power are kept within their rated values with the application of suitable control mechanism. The non linearity constraints make system real and complex due to which different dynamic responses took larger time to settle and especially in tie line power there is more oscillation and also took more time to settle. It has been observed that the optimized NCTF controller develops least overshoot and minimum settling time based responses in comparison with implemented other PID and PI controllers. For performance analysis in technique level the proposed SSO technique behaves as supremacy in response with PSO and GA and has been shown through convergence curves. Finally it has been justified that proposed SSO optimized NCTF controller exhibits superior performance for AGC of multi area system.

APPENDIX

P_{ri} = 2000MW(Each area rating) ; P_L^0 = 1740 MW (Avg. load on each area); f = 60hz, H= 5MWsec/ MVA(Inertia), D = 0.0145 pu MW/ Hz; K_{PS} = 68.9655 Hz/pu MW, T_{PS} = 11.49 sec; T_{SG} = 0.06 sec, T_T = 0.3 sec, T_{12} = 0.0433; R_i= 2.4 Hz/ pu MW (Regulation); B= 0.4312, a_{12} = -1, K_g = 0.3, T_g = 10.2 sec; T_W = 1.1 sec, T_{RS} = 4.9 sec, T_{RH} = 28.749 sec; b_g = 0.049sec; T_{GH} = 0.20 SEC, X_G = 0.60 sec, Y_G = 1.10 sec; C_g = 1, T_F = 0.239 sec; T_{CR} = 0.010 sec, T_{CD} = 0.20 sec;

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