©2006-2019 Asian Research Publishing Network (ARPN). All rights reserved.

DESIGN AND ANALYSIS OF HYBRID FUZZY PID CONTROLLER FOR DIVERSE SOURCE OF POWER SYSTEM USING DE OPTIMIZATION TECHNIQUE

Pratap Chandra Pradhan[1] and Jyoti Ranjan Sahoo[2]
[1]Department of Electrical Engineering, Dhaneswar Rath Institute of Engineering and Management Studies, Cuttack, Odisha, India
[2]Department of Electrical Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India
E-Mail: pratap_pin@yahoo.com

ABSTRACT

A differential evolution algorithm optimized hybrid FPID controller is considered in this research article for Load Frequency Control of multi area interconnected systems. Each area consists of three plants like gas, hydro and thermal. DE algorithm is used to optimize the parameters of PID/hybrid FPID controllers by employing ITAE as objective function. The system performances are evaluated with single and double disturbances respectively. The simulation result indicate that the hybrid FPID controller exhibit better performance compare to PID controller.

Keywords: fuzzy PID (FPID) controller, fuzzy logic control (FLC), load frequency control (LFC), integral time of absolute error (ITAE), differential evolution (DE).

1. INTRODUCTION

Electrical power systems (EPS) are designed to operate safely in the face of the most probable contingencies. In most cases the EPS's have the capacity to support simple contingencies, and some multiple contingencies, through protection and control systems. One of the permanent objectives of the operation of a EPS is to maintain an established level of security during its operation. If the security level falls below a certain value, preventive measures must be taken to restore security to acceptable levels.

The Power-Frequency control plays a fundamental role in the generation and distribution of power in a multi-unit power system. On the other hand, it is also vital when it comes to guaranteeing the stability of a system and its correct operation in real time. As is well known electric power must be consumed at the same time it is generated. The lack of knowledge, lack of control and over demand complicates the control of this balance in optimal conditions. The changes in active power mainly influence the frequency of the system, while the reactive power changes are directly related to the voltage. This research work will therefore focus on the study of frequency control and real power, generally known as LFC.

Literature review signifies the research work already done in a particular area and various scope to work in that area. Already many researchers have applied optimization technique to control frequency; still there is an opportunity to propose new controller and optimization technique to achieve better result.

The purpose of AGC in an interconnected system is to regulate the frequency of each area, and restore the tie-line power to its scheduled value. It is difficult to keep up the balances between demand and generation without control [1, 2]. LFC used to keep the system frequency and tie line power flow at their scheduled values both under normal and small disturbance condition [3].The author discussed about automatic generation control (AGC) in decentralized environment in multi-unit power systems. PID parameter controlling method is given by Hongxia Zhang (2012) w.r.t. no flow of tie-line power [4]. B. Paramasivam (2013) represents the AGC for a multi area system. BFO algorithm is used to maximize the gain of controller [5]. K.P. Singh (2014) proposed a modified automatic generation control method for deregulated power environment consisting of six unit two area system [6]. R.K. Sahu (2015) extended the research further by using DE optimized fuzzy-PID controller for AGC in deregulated environment [7]. R. K. Sahu (2016) proposed TIDF for LFC of interconnected system [10]. P.C. Pradhan (2016) discussed FA tuned FPID controller for AGC of multi area system with UPFC and SMES [11]. Author discussed about the closed loop performance of different controller with FLC [12]. LC Saikia [13] proposed AGC of a hydrothermal system with neural network. Vijaya Chandrakala and Balamurugan [14] proposed SA optimized optimal controller for regulating frequency and controlling terminal voltage of interconnected system. R.K. Sahu (2015) discussed the design of hFA-PS optimized fuzzy FPID controller for LFC of multi area power systems [15]. Keyhani and Chatterjee [16] proposed an AGC control structure by accommodating intermittent, non dispatchable distributed energy resources penetrations. P. K. Ray (2015) proposed fuzzy-sliding mode controller for hybrid power system. This controller is used for the automated load frequency control in a wind-hydro- thermal system [17].

In perspective of the above, an effort has been made in this study to use DE algorithm to optimize the scaling factors of controller. Here a hybrid FPID controller is used for the LFC of gas-thermal-hydro systems. The supremacy of DE optimized FPID controller is discussed and compared with PID controller.

2. SYSTEM EXAMINED

The hybrid-source transfer function model comprises of two areas. Each area having three generating

ARPN Journal of Engineering and Applied Sciences
©2006-2019 Asian Research Publishing Network (ARPN). All rights reserved.

unit as shown in Figure-1. The three generating units are gas turbine power plant, hydro power plant and thermal power plant with reheat turbine. Each unit is represented with their transfer function.

3. CONTROL METHODOLOGY

3.1 Hybrid fuzzy PID controller

In this research article a FPID controller is used. FPID controller handles non linearity input in a better manner in control system. FLC having two inputs as error and derivative of error. FLC divides the error into different sets from small to big called fuzzy set. FLC output multiplied with gain of PID parameter to give total output of controller. Basically triangular membership function is used to design controller, which is economic as compared to others. Membership functions are associated with five variables. These variables are N_B (Negative_Big), N_S (Negative_Small), Z_E (Zeros), P_S (Positive_Small), P_B (Positive_Big). Output is controlled by using method of centroid defuzzification.

4. OBJECTIVE FUNCTION

The main aim of objective function is to optimize the gain of the controller. In this research article Integral Time Absolute Error is used as objective function**.** Benefits of ITAE are: the settling time is much quicker than Integral Squared Error (ISE) and it drastically reduces the overshoot in the system. So, because of the above reasons performance index ITAE is used in this case.

$$J = ITAE = \int_0^{t_{sim}} (|\Delta F_1| + |\Delta F_2| + |\Delta P_{Tie}|).t.dt \qquad (1)$$

Where, ΔF_1 is change of frequency in area 1,ΔF_2 is change of frequency in area 2, ΔP_{Tie} is change in tie-line power and t_{sim} is time period of simulation.

ITAE is minimized as per the following conditions:

$K_{P_{min}} \le K_P \le K_{P_{max}}$, $K_{I_{min}} \le K_I \le K_{I_{max}}$, $K_{D_{min}} \le K_D \le K_{D_{max}}$, $k_{1min} \le k_1 \le k_{1max}$
$k_{2min} \le k_2 \le k_{2max}$.

5. DIFFERENTIAL EVOLUTION (DE) OPTIMIZATION

This method was introduced by R. Storn and K. Price [8]. This technique uses the difference between two random vectors to produce a new solution vector. For each solution in the original population, a desired solution is generated by performing the crossover procedure. The old (parent) solutions and the new ones are compared and the best ones will appear in the next generation. The DE algorithm will perform the following steps**:**

Step 1: The initial population generation which consists in creating an initial population vector of N_p individuals (solutions). The initial population is intended to give birth to successive generations. The initial population vector is randomly selected as follows:

$$X_{j,i}^G = X_{jmin} + rand[0.1] \times \left(X_{jmax} - X_{jmin}\right) \qquad (2)$$

$i = 1,2, \ldots .N_p\ ; j = 1,2, \ldots$
Where,N_p: No. of parameters of the objective function.

Step 2: The mutation that is seen as the first step towards generating new solutions. The formula for a mutation vector $V_i^{(G+1)}$ is as follows:

$$V_i^{(G+1)} = X_a^G + F \times (X_b^G - X_c^G) \qquad (3)$$

Where: x_a, x_b and x_c are vectors randomly selected with $a \neq b \neq c \neq i$. F is the scaling constant used to adjust the disturbance size in the mutation operator and is determined by the user, and its typical value is in the interval (0.4, 1) [9].

ARPN Journal of Engineering and Applied Sciences
©2006-2019 Asian Research Publishing Network (ARPN). All rights reserved.
www.arpnjournals.com

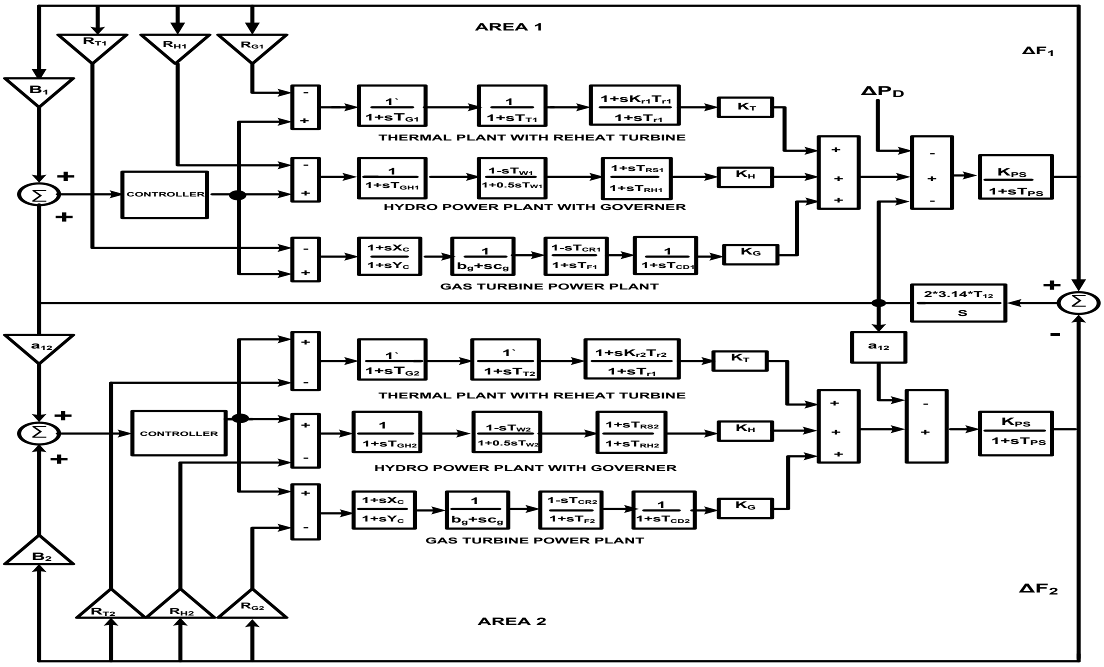


Figure-1. The hybrid-source power system model with its transfer function.

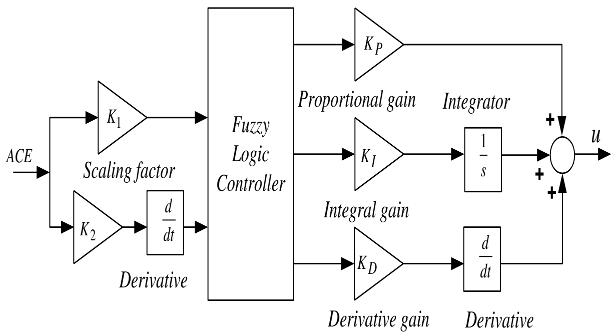


Figure-2. Structure of proposed hybrid FPID controller.

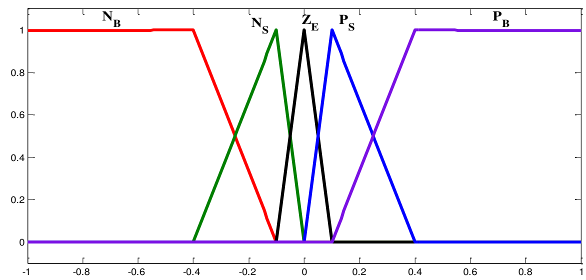


Figure-3. Membership function for error, change in error and controlled output [7].

Table-1. Input and output rules.

E \ dE / dt	N_B	N_S	Z_E	P_S	P_B
N_B	N_B	N_B	N_S	N_S	Z_E
N_S	N_B	N_S	N_S	Z_E	P_S
Z_E	N_S	N_S	Z_E	P_S	P_S
P_S	N_S	Z_E	P_S	P_S	P_B
P_B	Z_E	P_S	P_S	P_B	P_B

Step 3: The crossing, which is applied to the population of the vector resulting from mutation and the population of the parent vector (initial population), where a new vector called the desired vector is generated. The crossing operation is carried out according to the following criterion:

$$U_{j,i}^{G+1} = \begin{cases} V_{j,i}^{G+1} & if\ (rand, [0,1]) \leq CR \\ X_{j,i}^{G} & if\ (rand, [0,1]) > CR \end{cases} \tag{4}$$

Where CR is the crossover factor which is at a constant value between 0 and 1 also determined by the user. If $rand_j[0,1]$ is less than or equal to CR the new solution is a combination of the three vectors chosen randomly (x_a, x_b and x_c), otherwise this new solution is only the old solution (parents), as shows the Figure-4.

©2006-2019 Asian Research Publishing Network (ARPN). All rights reserved.

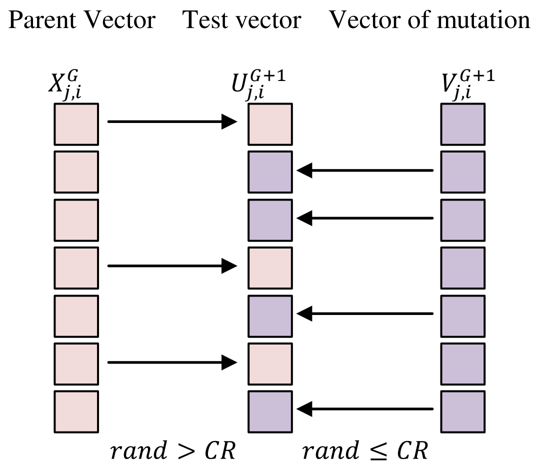


Figure-4. Crossing example (D = 7).

Step 4: The selection that must be applied to find out the individuals to participate in the next generation. Selection in this technique is made by comparing the function of the vector of the initial population (parent vector) with the function of the test vector, and the one that gives better results must participate in the next generation. The new population must then replace the current population and a new loop will be launched.

Figure-5 shows the flow diagram of Differential Evolution algorithm.

6. RESULTS AND DISCUSSIONS

In this research work two area six unit systems is modelled on MATLAB/SIMULINK environment. DE algorithm is used to optimize gain of controllers. In Table-2 Optimized gain of PID and FPID controller are given.

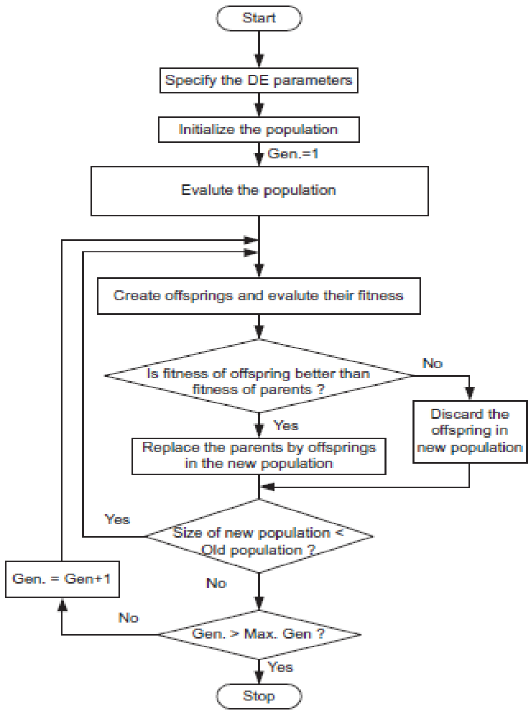


Figure-5. Flow dia. of DE algorithm [10].

Table-2. Gains of the optimized controller.

Parameters		DE optimized PID controller	DE optimized FPID controller
Thermal	K_{P1}	1.7183	1.7281
	K_{I1}	1.8272	1.8700
	K_{D1}	1.7410	0.6058
	K_1	-	1.8923
	K_2	-	1.7580
Hydro	K_{P2}	1.5410	0.7985
	K_{I2}	1.4948	1.1238
	K_{D2}	1.4087	0.2428
	K_3	-	1.4033
	K_4	-	0.8472
Gas	K_{P3}	1.1975	0.5164
	K_{I3}	1.3588	1.7096
	K_{D3}	0.6001	0.3575
	K_5	-	1.2449
	K_6	-	1.8932

Result of ΔF and ΔP_{tie} are shown in Figure-6, Figure-7 and Figure-8 respectively.

©2006-2019 Asian Research Publishing Network (ARPN). All rights reserved.

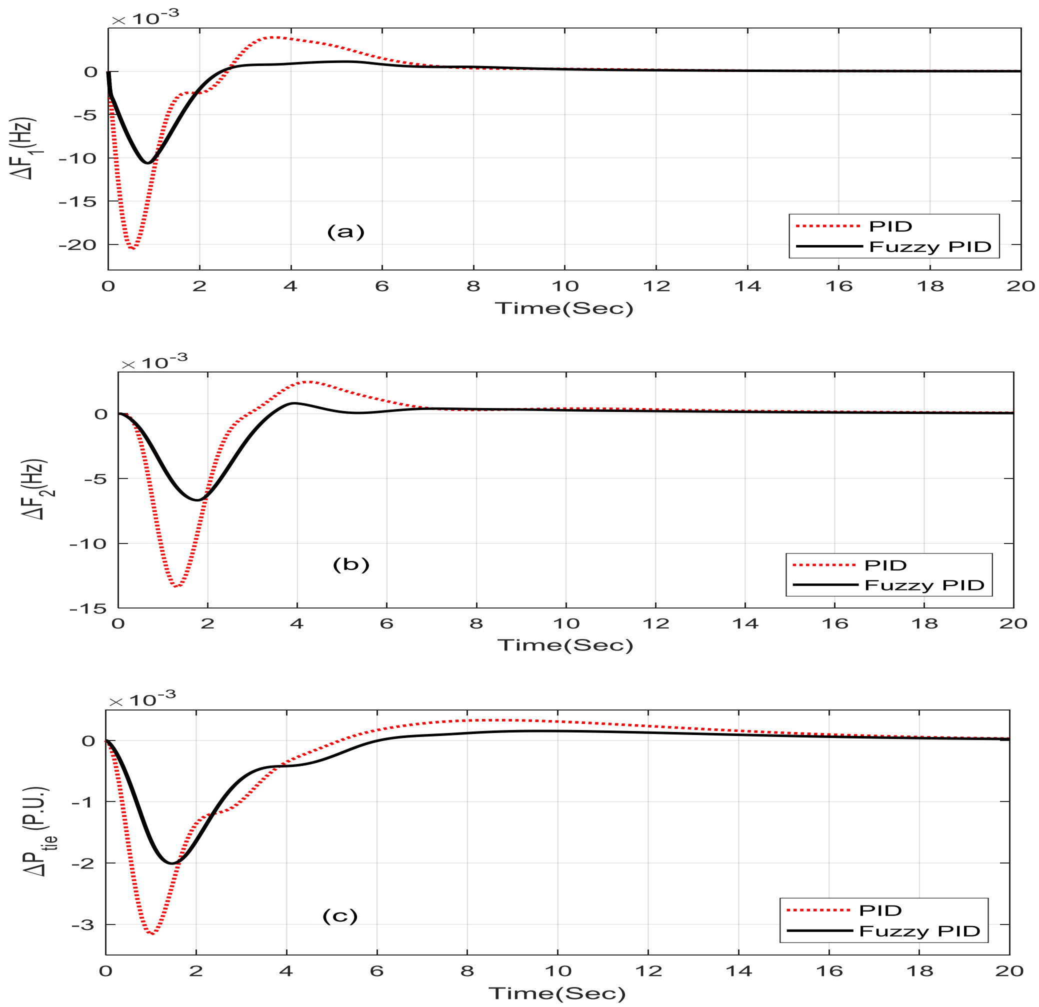
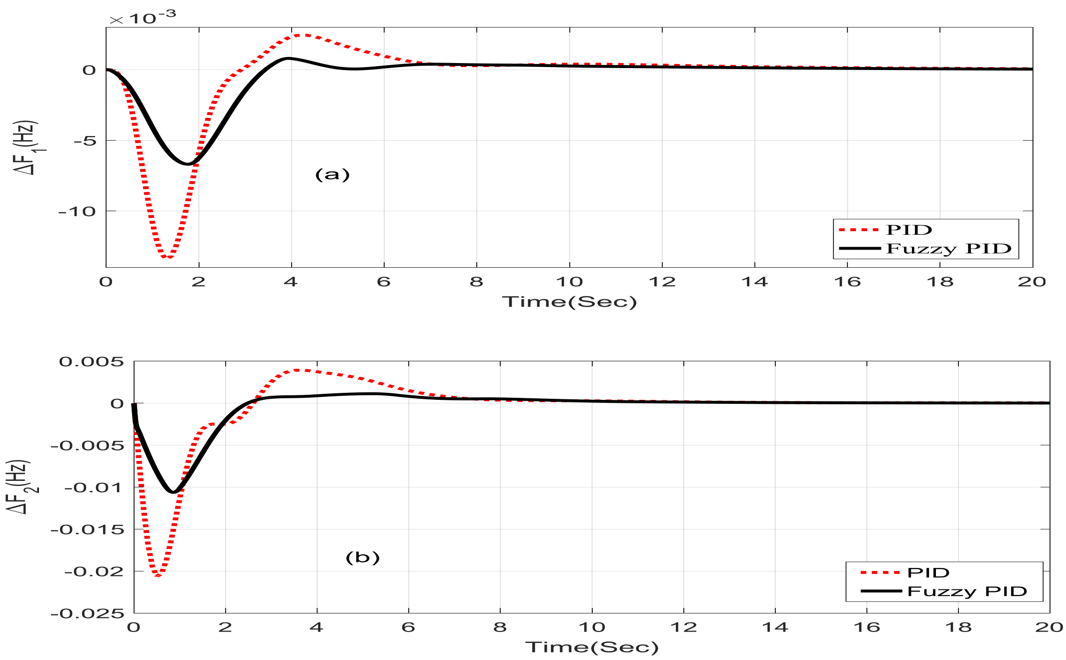


Figure-6. ΔF_1, ΔF_2 and ΔP_{tie} for the test system after step load demand of 1% in area-1.



ARPN Journal of Engineering and Applied Sciences
©2006-2019 Asian Research Publishing Network (ARPN). All rights reserved.
www.arpnjournals.com

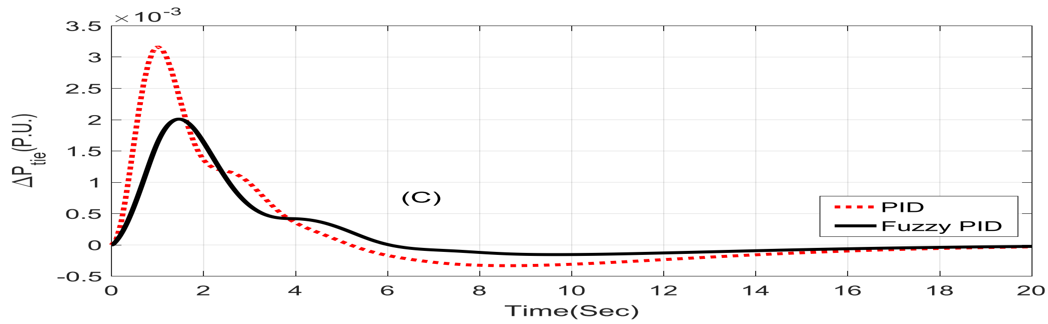


Figure-7. ΔF_1, ΔF_2 and ΔP_{tie} for the test system after step load demand of 1% in area-2.

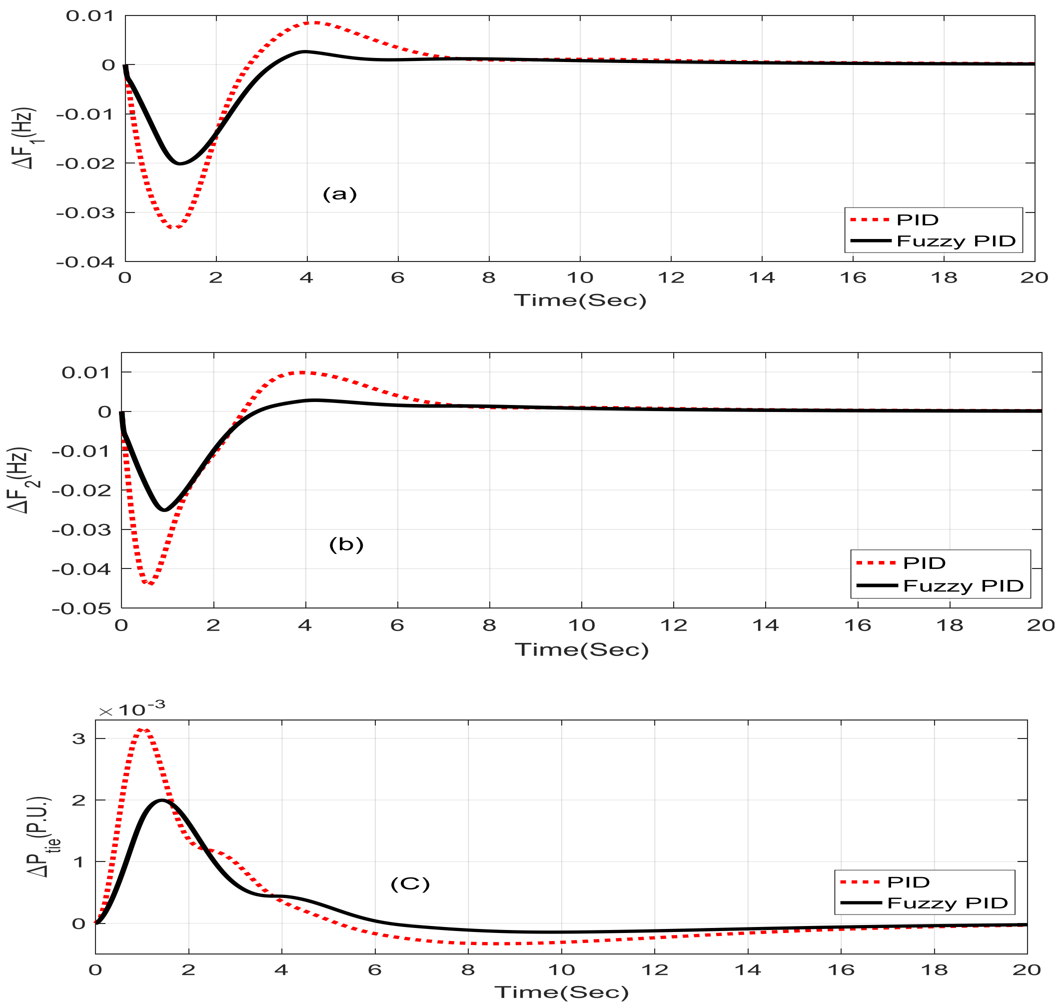


Figure-8. ΔF_1, ΔF_2 and ΔP_{tie} for the test system after simultaneous disturbance (step load demand of 1% in area-1& step load demand of 2 % in area-2).

Table-3. Comparison of error in PID and FPID controller.

Techniques/controller	ITAE
DE PID	0.2289
DE FPID	0.1397

Figures 6, 7 and 8 shows the ΔF_1, ΔF_2 and ΔP_{tie} for the test system with single and double disturbances of load respectively. From the above observation (Table-3), it is found that the system with DE optimized hybrid FPID controller has less ITAE value as compared to PID controller. Hence hybrid FPID controller outperforms PID controller.

System stability reduces due to complexity and nonlinearities in the system. In case of nonlinearity disturbance, PID controller have larger overshoot/undershoot as compared to hybrid FPID controller. Hybrid FPID controller can handle the nonlinearities in a smooth manner.

ARPN Journal of Engineering and Applied Sciences
©2006-2019 Asian Research Publishing Network (ARPN). All rights reserved.

The above analysis clearly demonstrates that the DE optimized FPID has less ITAE value than PID controller. Hence the system with less ITAE value gives better result i.e. provides a much better transient response.

7. CONCLUSIONS

For the minimization of area control error (ACE), this research paper proposes a FPID controller, which is used in multi area six unit interconnected system. DE algorithm is used to optimize the parameters of FPID controller. The proposed controller is tested and compared. It is observed that DE optimized FPID controller has less ITAE value, which provides better response over PID controller in terms of settling time, peak overshoot/undershoot subjected to load disturbance of 1% in area1 and area2 separately and 1% in area1 and 2% in area2 simultaneously**.** Controller which is proposed here exhibit good performance.

REFERENCES

[1] P.Kundur. 2009. Power System Stability and control. Tata McGraw-Hill, 8th reprint.

[2] H.Bevrani. 2009. Robust Power System Frequency Control. Springer.

[3] Ibraheem, P. Kumar, D.P. Kothari. 2005. Recent philosophies of automatic generation control strategies in power systems. IEEE Trans. Power Syst. 20: 346-357.

[4] Tan, Wen, Hongxia Zhang and Mei Yu. 2012. Decentralized load frequency control in deregulated environments. International Journal of Electrical Power & Energy Systems. 41(1): 16-26.

[5] I. A. Chidambaram and B. Paramasivam. 2013. Optimized load-frequency simulation in restructured power system with redox flow batteries and interline power flow controller. International Journal of Electrical Power & Energy Systems. 50: 9-24.

[6] K.P. Singh Parmar, S. Majhi and D. P. Kothari. 2014. LFC of an interconnected power system with multi-source power generation in deregulated power environment. International Journal of Electrical Power & Energy Systems. 57: 277-286.

[7] Rabindra Kumar Sahu, GT Chandra Sekhar, and Sidhartha Panda. 2015. DE optimized fuzzy PID controller with derivative filter for LFC of multi source power system in deregulated environment. Ain Shams Engineering Journal. 6(2): 511-530.

[8] R. Storn and K. Price. 1997. Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces. Journal of global optimization. 11(4): 341-359.

[9] Swagatam Das, Sankha Subhra Mullick and Ponnuthurai N. Suganthan. 2016. Recent advances in differential evolution-an updated survey. Swarm and Evolutionary Computation. 27: 1-30.

[10] Rabindra Kumar Sahu, Sidhartha Panda, Ashutosh Biswal and GT Chandra Sekhar. 2016. Design and analysis of tilt integral derivative controller with filter for load frequency control of multi-area interconnected power systems. ISA transactions. 61: 251-264.

[11] Pratap Chandra Pradhan, Rabindra Kumar Sahu and Sidhartha Panda. 2016. Firefly algorithm optimized fuzzy PID controller for AGC of multi-area multi-source power systems with UPFC and SMES. Engineering Science and Technology, an International Journal (JESTCH), Elsevier. 19(1): 338-354.

[12] K.R. Mudi, R.N. Pal. 1999. A robust self-tuning scheme for PI-and PD-type fuzzy controllers. IEEE Trans. on Fuzzy Syst. 7(1): 2-16.

[13] L.C. Saikia, S. Mishra, N. Sinha, J. Nanda. 2011. Automatic generation control of a multi area hydrothermal system using reinforced learning neural network controller. Int. J. Elect. Power & Energy Syst. 33(4): 1101-1108.

[14] K.R.M. Vijaya Chandrakala, S. Balamurugan. 2016. Simulated annealing based optimal frequency and terminal voltage control of multi source multi area system. International Journal of Electrical Power and Energy Systems. 78: 823-829.

[15] Rabindra Kumar Sahu, Sidhartha Panda, Pratap Chandra Pradhan. 2015. Design and analysis of hybrid firefly algorithm-pattern search based fuzzy PID controller for LFC of multi area power systems. International Journal of Electrical Power & Energy Systems (IJEPES), Elsevier. 69: 200-212.

[16] A. Keyhani, A. Chatterjee. 2012. Automatic Generation Control Structure for Smart Power Grids. IEEE Transactions on Smart Grid. 3(3): 1310-1316.

[17] Prakash K. Ray, Pratap C. Pradhan, Rabindra K. Sahu, Aurojyoti Das, Saswat Satpathy, Asit Mohanty. Automated Frequency Control using Fuzzy-Sliding

ARPN Journal of Engineering and Applied Sciences
©2006-2019 Asian Research Publishing Network (ARPN). All rights reserved.

Mode in Wind-Thermal-Hydro Hybrid System. In 2015 IEEE Power, Communication and Information Technology Conf. pp. 889-894.

APPENDIX

Parameters of the test system are:

B_1= 0.43120 p.u.MW/Hz, T_{SG}=0.080 sec, T_T=0.30 sec, K_R=0.30 sec, T_R= 10 sec, B_2=0.43120 p.u.MW/Hz, K_{PS}=68.956 Hz/p.u., T_{PS}=11.490 sec, R_2=2.40 Hz/p.u, T_{12}=0.0433, a_{11}= 0.543478, a_{12}=0.326084, a_{13}=0.1304381, T_W=1.0 sec, T_{RH}=28.750 sec, T_{GH}=0.20 sec, Y_G=1.0 sec, C_G=1.0, B_G=0.050 sec, T_F=0.230 sec, T_{CD}=0.20sec, R_1= 2.40 Hz/p.u, T_{RS}=50.0 sec, X_G=0.60 sec, T_{CR}=0.010 sec.