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Synergistic DE-PS Approach for Fuzzy PID Control in Multi-Area Power System AGC

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Abstract:- This paper suggests a Fuzzy Proportional Integral Derivative (FPID) controller for Hybrid Differential Evolution Pattern Search-based Automatic Generation Control (AGC) of a multi-area power system. The effectiveness and performance of the HDEPS-FPID controller are evaluated through extensive simulations on a multi-area power system and compared with fuzzy PI and PID controller to demonstrate the superiority of the proposed approach. The performance metrics considered include settling time and undershoot. The simulations show that the HDEPS-FPID controller outperforms the other controllers in terms of dynamic responses and robustness under various operating conditions. The results indicate that the proposed controller can effectively regulate the system frequency and tie-line power deviations.

Keywords: AGC, Fuzzy PID controller, HDEPS, Multi-Area Power System.

1. Introduction

AGC is an essential aspect of power system control that is responsible for maintaining the balance between the generation and load demand in the system. AGC ensures that the frequency and voltage of the power system remain within acceptable limits, and prevent blackouts. In a power system, the load demand is constantly changing, and it is the responsibility of AGC to ensure that the power generation is adjusted to match the demand [1, 2].

AGC is achieved through a combination of primary and secondary control systems that work together to maintain the equilibrium among generation and demand. Primary control responds to changes in the load demand in real-time, usually within a few seconds, and adjusts the power generation to maintain a balance between the two. However, primary control is not enough to maintain the stability. On the other hand, secondary control provides a slower response but it is used to correct any long-term imbalances between generation and load demand. Overall, AGC is a critical component of power system control, ensuring that the power system operates reliably and efficiently, while also preventing blackouts [3-6].

2. Literature Review

Several researchers have studied and analyzed about the AGC problem under various loading conditions. Out of them, some are suggested few optimization techniques and the others recommended the design of control structures. Putra et al. [7] have studied AGC concept by employing PID controller. The authors tuned the PID parameters by using Bat technique. Feleke et al. [8] analysed two-area power system for frequency regulation by employing PID controller.

The authors also shown the superior performance of DE based PID controller over PSO based PID controller. Boopathi et al. [9] has proposed a new optimization technique Mayfly Algorithm (MA) based PID controller for frequency regulation of a microgrid which comprises of PV and wind systems. The simulation results proved that MA-PID technique performs better than Genetic Algorithm GA), PSO and DE based PID controller. Gozde et al. [10] has designed two-area power system for AGC by employing Artificial Bee Colony (ABC) algorithm for PID controller.

3. Proposed method and Control Structure

A reheat thermal power system encompassing two areas has been studied. The model, created using MATLAB SIMULINK, is illustrated in Fig. 1. Each area consists of a reheat turbine, generator, governor and a reheater. The system dynamics are described using transfer functions and differential equations that represent the physical components and their interactions. A fuzzy PID controller is a type of controller that combines the conventional PID control with fuzzy logic. Fuzzy logic is a mathematical approach that enables the representation and handling of uncertain and imprecise information. By integrating fuzzy logic into the PID control algorithm, the resulting controller is capable of handling non-linear systems and can achieve better control performance in some cases.

The basic structure of a fuzzy PID controller consists of three components: the fuzzy inference system, the PID controller, and the defuzzification process. The fuzzy inference system takes the input signals from the system and generates the appropriate control signal based on a set of fuzzy rules. The fuzzy rules are defined based on expert knowledge and experience with the system. The output of the fuzzy inference system is then fed to the PID controller, which computes the control signal based on the error signal between the desired and actual outputs. The proportional, integral, and derivative components of PID controller are then used to modify the control signal, which is then sent to the system. Fig. 2 shows arrangement of fuzzy PID and the shapes of membership functions are provided in Fig. 3.

The defuzzification process transforms the fuzzy output from the fuzzy inference system into a precise control signal that can be used within the system. This is done by selecting a single output value that represents the weighted average of the fuzzy output values. Fuzzy PID controllers have been applied in various fields, including temperature control, speed control of motors, and control of robotic systems. Their primary benefit lies in their capacity to manage non-linear systems and adapt to fluctuating operating conditions. However, designing fuzzy PID controllers can be intricate, and their performance is significantly influenced by the choice of fuzzy rules and membership functions.

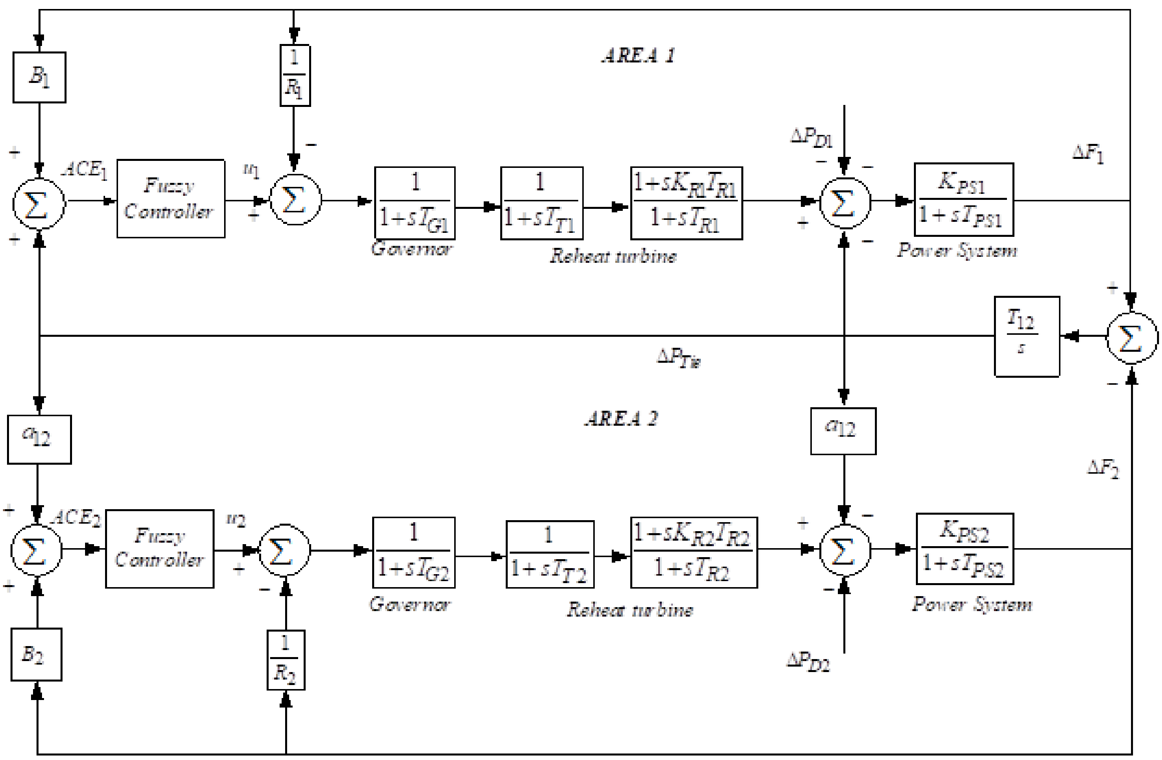

Fig. 1 SIMULINK model for 2-area power system

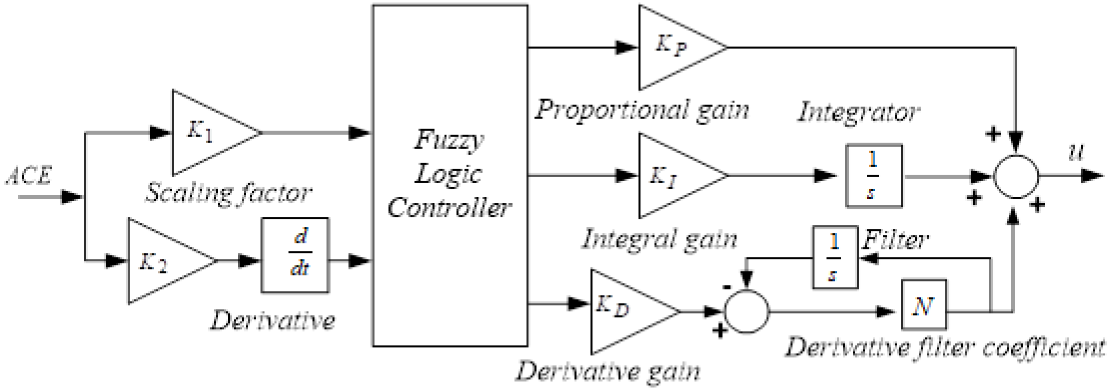

Fig. 2: Structure of proposed fuzzy PIDF controller

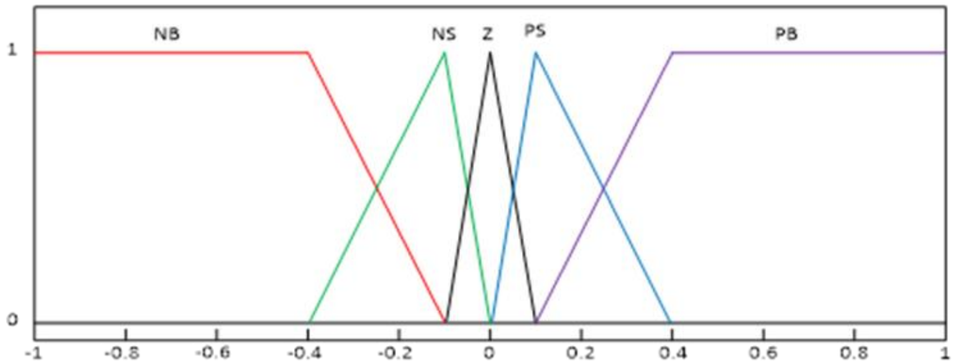

Fig. 3: Triangular MFs

4. Proposed Algorithm

HDEPS is a metaheuristic optimization algorithm that combines the strengths of Differential Evolution (DE) and Pattern Search (PS) algorithms. The goal of HDEPS is to find the global optimum of a function by iteratively improving a candidate solution. The DE algorithm is a stochastic, population-based optimization method that employs mutation and crossover operators to produce new candidate solutions. In contrast, the PS algorithm is a deterministic optimization technique that explores the solution space by iteratively moving in predefined search directions. In HDEPS, the DE algorithm is used to generate a population of candidate solutions, and the PS algorithm is used to refine these solutions by iteratively improving their quality. The population generated by DE is divided into subpopulations, and the PS algorithm is applied to each subpopulation separately. The PS algorithm is used to refine the candidate solutions generated by DE by moving them along a set of predefined search directions [14-16].

HDE-PS has several advantages over other optimization algorithms. It is robust, can handle a wide range of functions, and has a low computational cost. Additionally, HDEPS can be easily parallelized, allowing it to solve complex optimization problems in a reasonable amount of time. HDEPS has been utilized for various optimization problems across multiple disciplines, such as engineering, economics, and computer science. Some examples of applications of HDEPS include optimal power flow in power systems, parameter estimation in nonlinear dynamic models, and feature selection in machine learning [17-19]. The flowchart of HDEPS is provided in Fig. 4.

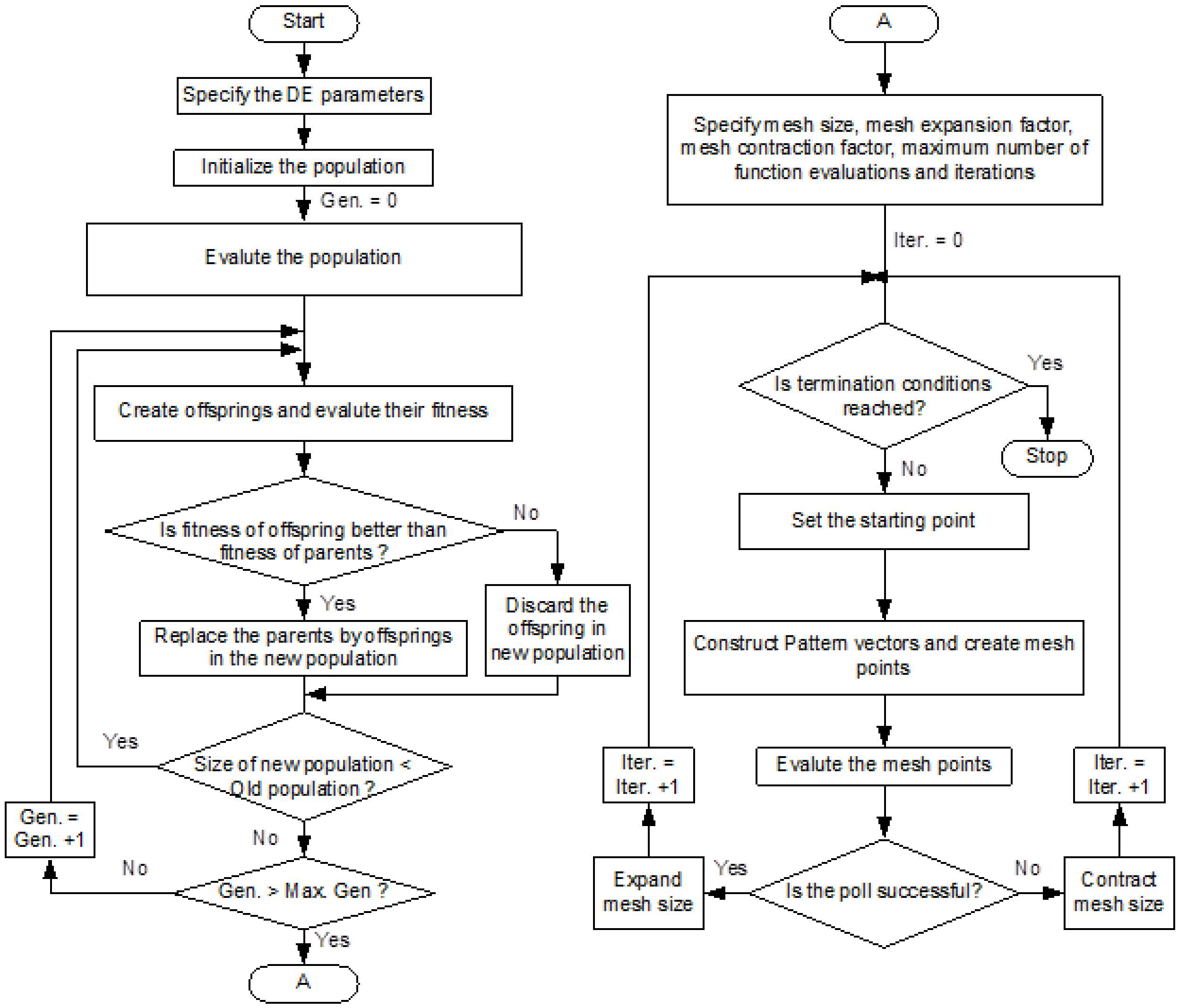

Fig. 4 Flow chart of proposed HDEPS algorithm

5. Results

Initially, a step load of 1% as disturbance is considered in area-1 for the analyzing the performance of the system. The Fuzzy PID controller is used as a secondary controller to improve the system's transient responses. The controller's gains are adjusted using the DE technique, and the resulting gains are listed in Table 1. The responses of the fuzzy PID are compared with ABC tuned PID controller which was published result and DE based fuzzy PI controller. The objective function ITAE is minimum for fuzzy PID (0.0143) when compared to DE: Fuzzy PI (0.0170), ABC: PID (0.0691), ABC: PI (0.9210) and PSO: PI (0.6092). For further improvement of the transient responses, local optimization is also added to the global optimization i.e. pattern search is incorporated to DE technique and then the ITAE further reduced to 0.0082. The corresponding system responses are displayed in Fig. 5(a-c), and performance indices like settling time and undershoot are recorded in Table 2.

The capability of fuzzy PID controller is further verified by doing robustness analysis. The robustness has examined by varying the system parameters. The nominal values of loading conditions, turbine time constant (TT), Synchronizing Coefficients for Tie Lines (T12) and Regulations of Governors (R) are varied from +25% to -25% and then responses are drawn without changing gain values. The related figures are shown in Figs. 6(a-c) to 9(a-c). It was confirmed from the results that, fuzzy PID is robust and performs better even there are changes in the system parameters. Furthermore, the eigen values are also determined which are shown in Table 3 and got all the eigne values are negative which means that the system is stable.

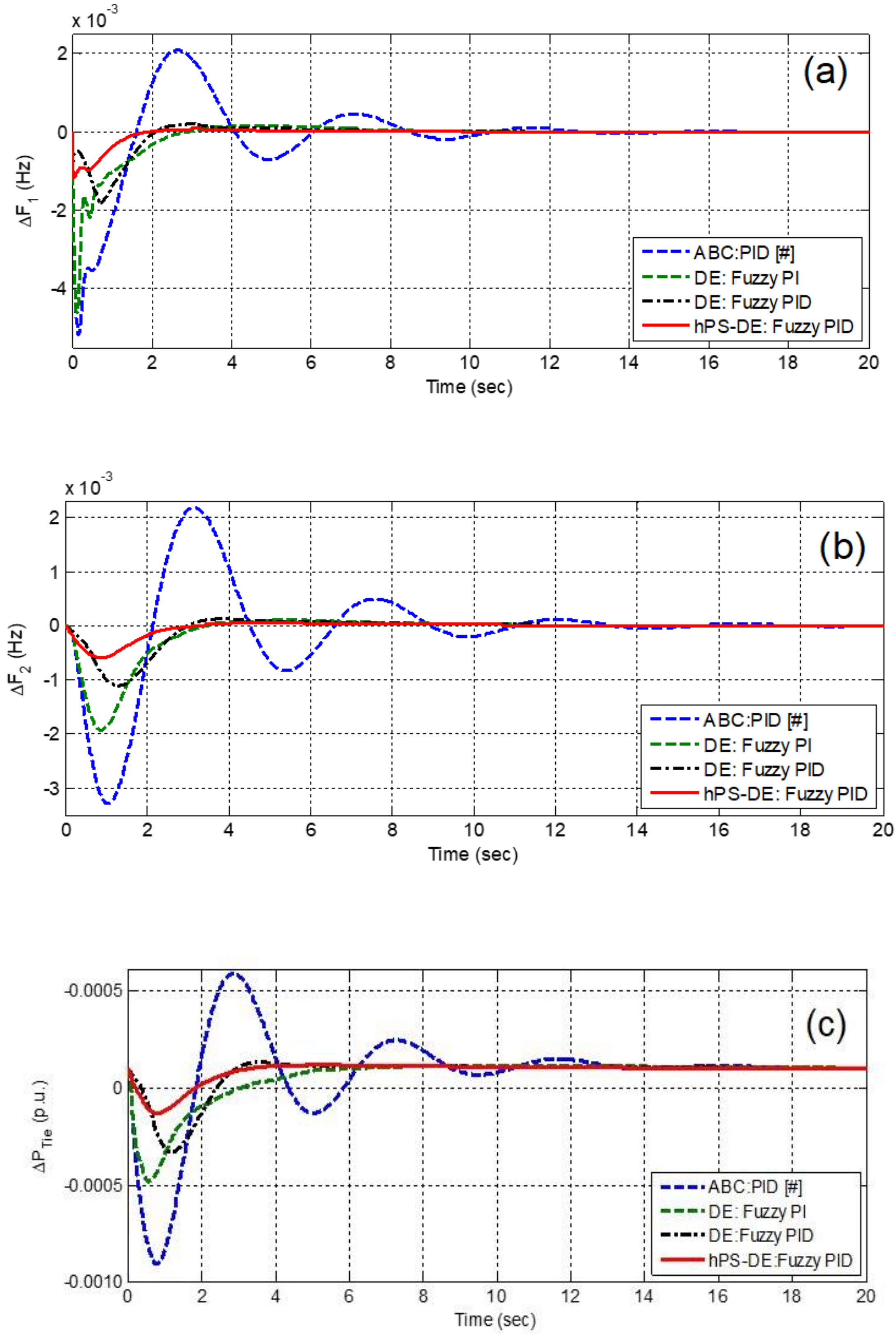

Fig. 5 (a-c) Responses for 1% change in area 1
[#] indicates reference [10]

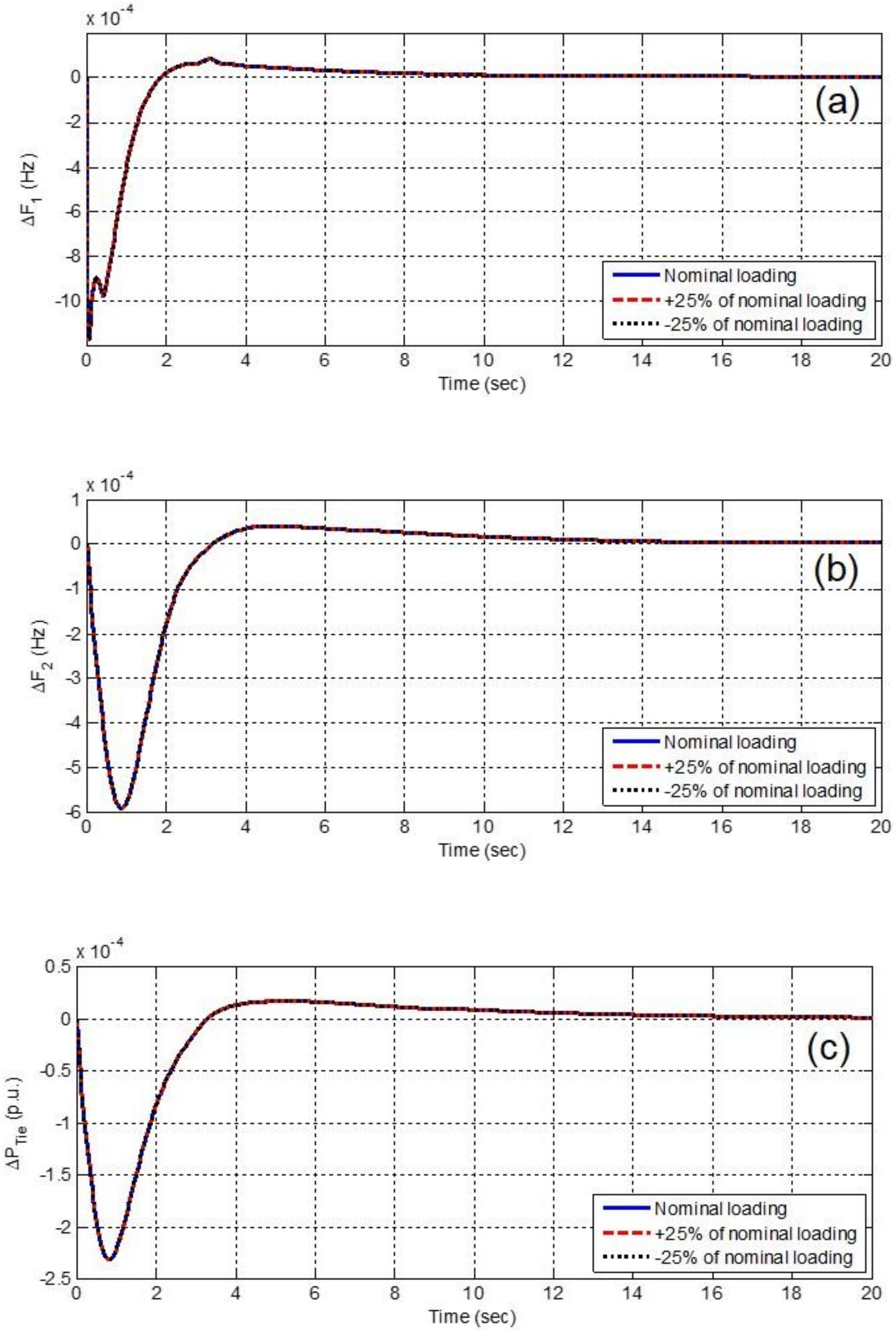

Fig. 6 (a-c) Responses for the variation of loading

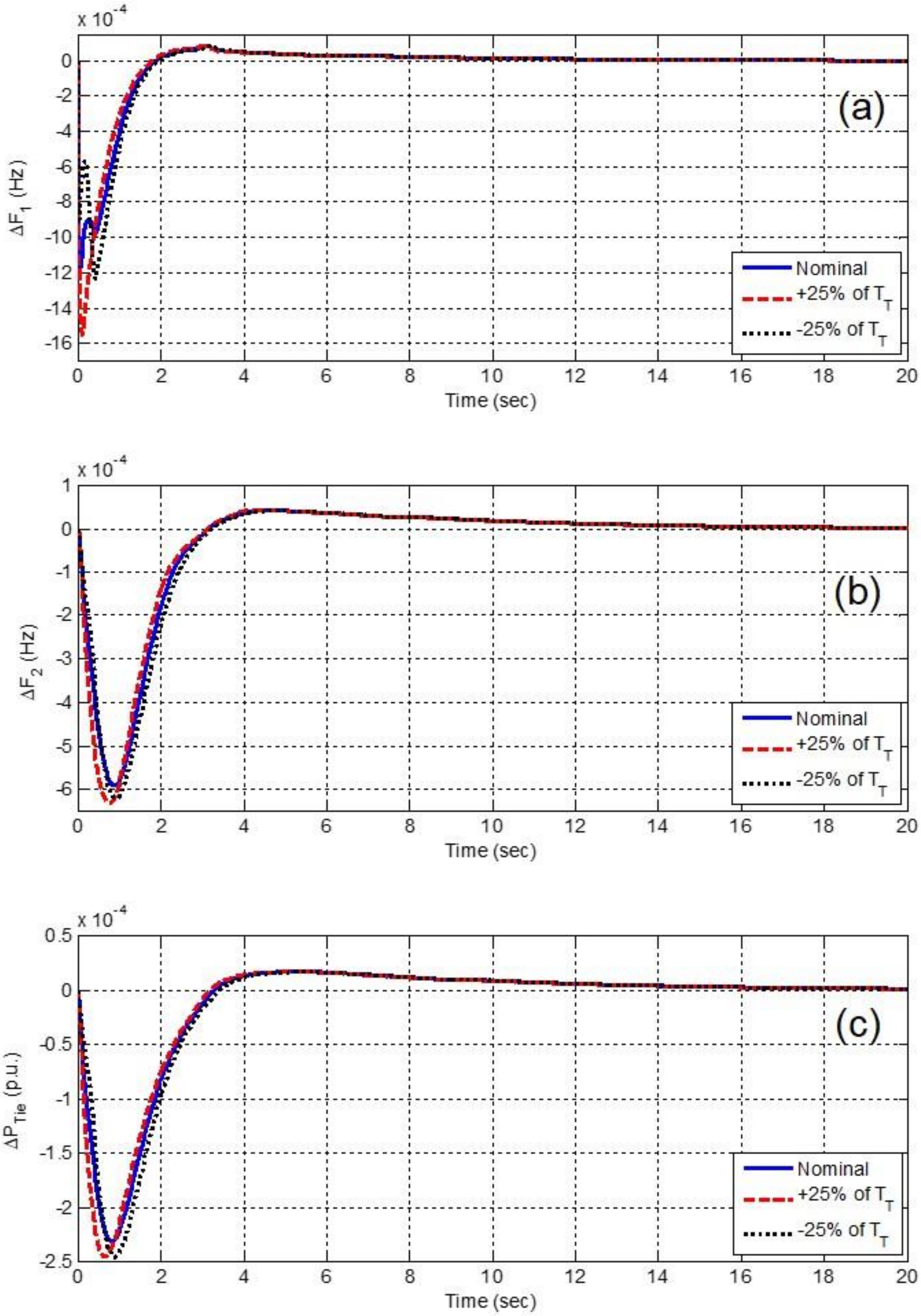

Fig. 7 (a-c) Responses for variation of T_T

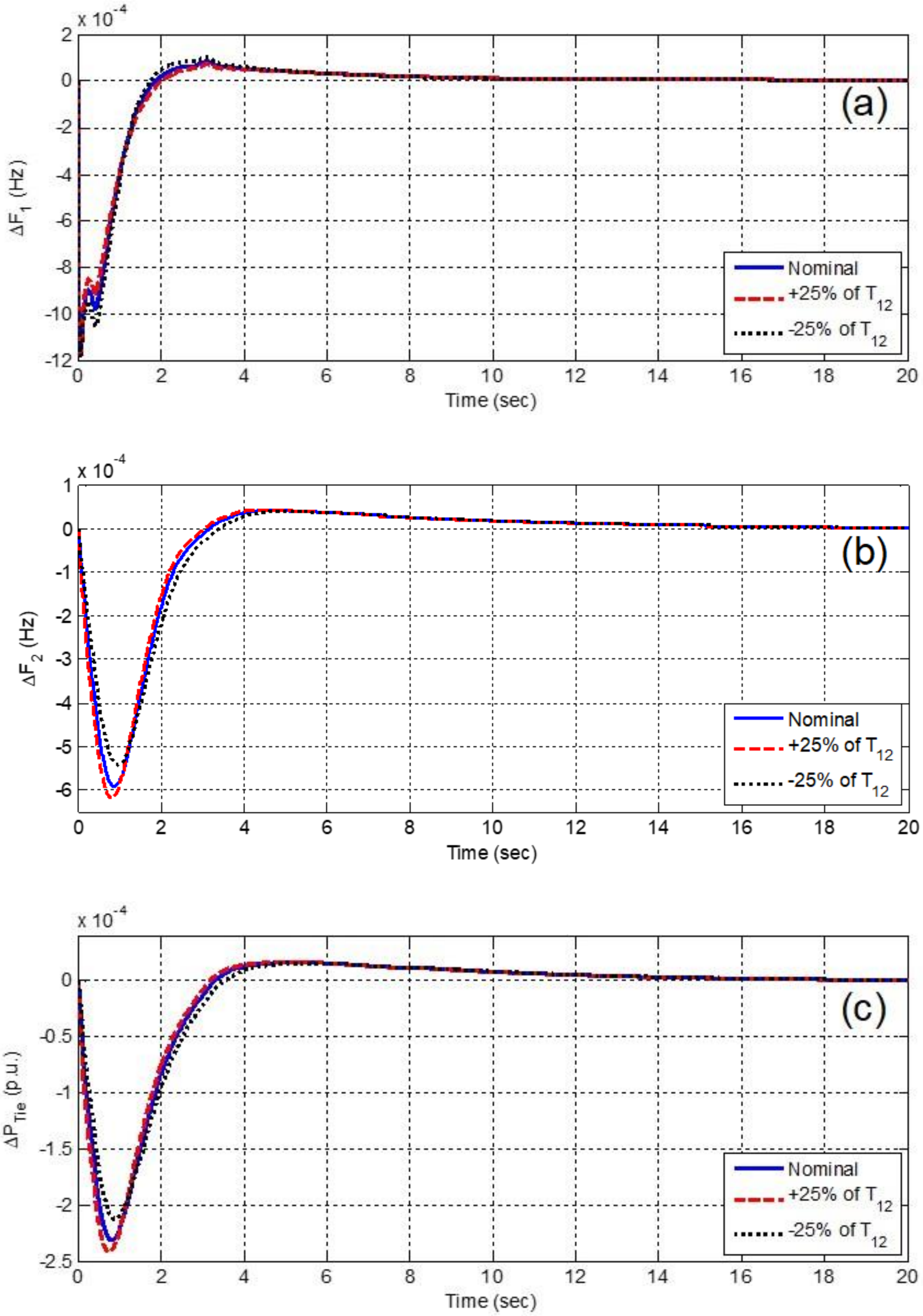

Fig. 8(a-c): Rresponses for variation of T_{12}

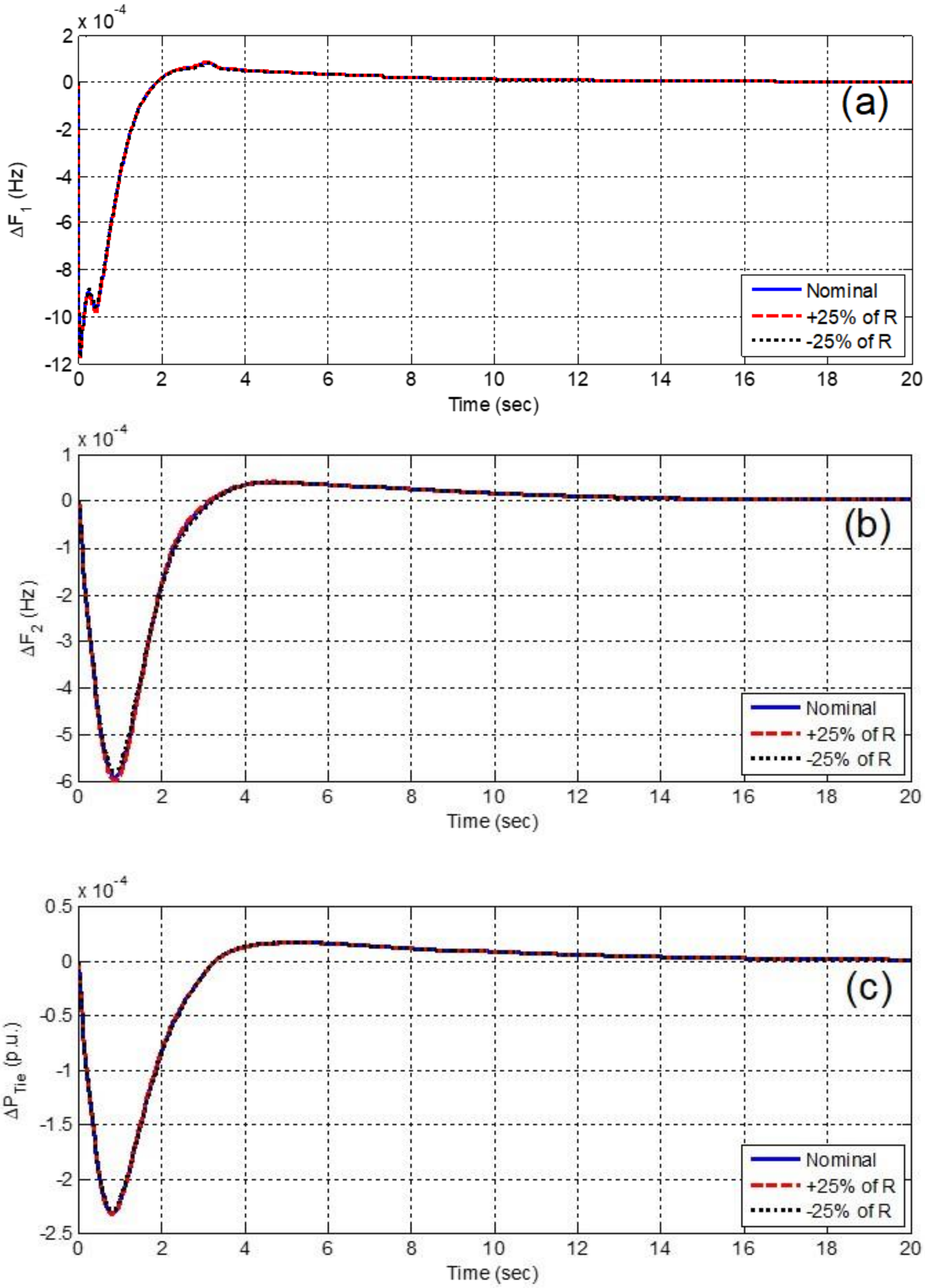

Fig. 9 Rresponses for variation of R

Table 1: Tuned controller parameters

Controller parameters		DE: Fuzzy-PI	DE: Fuzzy-PID	hDE-PS: Fuzzy-PID
Area 1	K_1	1.2147	1.7178	1.7178
	K_2	1.0861	0.8927	0.3927
	K_{P1}	1.3598	0.7812	1.7812
	K_{I1}	1.7168	1.4073	1.9073
	K_{D1}	---	0.2813	0.2813
Area 2	K_3	0.3246	0.7668	1.7668
	K_4	0.0113	1.1907	1.1907
	K_{P2}	0.2733	0.8009	0.3009
	K_{I2}	0.3997	0.2362	1.2362
	K_{D2}	---	0.1237	0.1237

Table 2: Performance index values

Parameters	Settling time T_s(Sec)			Under shootx10^{-3}			ITAE
	ΔF_1	ΔF_2	ΔP_{Tie}	ΔF_1	ΔF_2	ΔP_{Tie}	
PSO:PI [10]	21.14	22.26	19.86	-26.2	-29.0	-7.5	0.6092
ABC:PI [10]	27.85	26.95	19.76	-23.1	-23.0	-0.0	0.9210
ABC:PID [10]	12.36	12.80	8.42	-5.1	-3.2	-1.0	0.0691
Fuzzy PI (DE)	8.29	8.03	4.11	-4.19	-1.78	-0.56	0.0169
Fuzzy PID (DE:)	7.01	7.26	2.59	-1.79	-1.08	-0.39	0.0145
hPS-DE: Fuzzy PID	**4.15**	**2.58**	**2.38**	**-1.29**	**-0.63**	**-0.21**	**0.0084**

Table 3: System eigen values

Loading condition		T_T		T_{12}	
+25%	-25%	+25%	-25%	+25%	-25%
-12.9193	-12.9185	-12.8189	-13.1090	-12.9189	-12.9189
-12.9046	-12.9038	-12.8073	-13.0890	-12.9007	-12.9078
-0.3164 $\pm$ 2.9919i	-0.3023 $\pm$ 2.9905i	-0.2300 $\pm$ 2.9620i	-0.4244 $\pm$ 3.0000i	-0.2610 $\pm$ 3.2767i	-0.3763 $\pm$ 2.6656i
-1.4320 $\pm$ 1.3564i	-1.4187 $\pm$ 1.3391i	-1.1422 $\pm$ 1.3426i	-3.0587	-1.4254 $\pm$ 1.3480i	-1.4254 $\pm$ 1.3480i
-2.3603	-2.3645	-1.9514	-1.8857 $\pm$ 1.2224i	-2.4622	-2.2256
-0.2124	-0.2150	-0.2134	-0.2140	-0.2137	-0.2137
-0.0980	-0.0980	-0.0980	-0.0980	-0.0984	-0.0973

6. Conclusion

In this article, the outer performance of fuzzy PID controller was observed and verified by comparing with other published papers. From the Fig. 5(a-c) and Table 2 was apparent that, transient responses are better for fuzzy PID based AGC system. In the next step, the robustness of the proposed controller was observed by changing parametric values of the system. From Fig. 6(a-c) and Table 3, it was confirmed that the waveform was more or less is same and indices values are also very close to the nominal values. Finally, it was also confirmed from Table 4 is that, all the eigen values are negative and some of the values are far way from imaginary axis which indicates that the system is more stable.

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