Performance Comparison of Various Classical Controllers in LFC of Hydro-Thermal Power System with Time Delays

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***Abstract*—This paper presents the application of an artificial electric field algorithm (AEFA) optimized classical PID plus double derivative (DD) gain (PIDD) for load frequency control (LFC). Two-area realistic hydro thermal (TARHT) power system is considered and an investigation is carried out by subjugating the disturbance of 10% step load on area-1 (10%SLD). Efficacy of AEFA tuned PIDD is revealed with other classical PI and PID regulator performances. TARHT is analyzed for the conditions with and without deliberating the constraint of time delays (TDs). Simulation results reveal the predominance of TDs on TARHT system performance and the importance of its consideration is accentuated.**

Keywords—TARHT system, PIDD controller, AEFA algorithm, 10%SLD, time delays.

I. Introduction

Due to fast-growing industrialization in developing nations like India, the demand for electric power is rising rapidly. Diverse generation sources (DGS) are integrating with the interconnected power system (IPS) to meet the rapid demand. The integration of several DGS made the IPS complex and hence the governing becomes difficult. In IPS, the generation utilities are segregated into control areas and each area is intended to be linked with the other through the transmission line called tie-lines. Tie-lines facilitaes the exchange of power among the control areas from surplus to deficit generation regions. Demand for electrical power on IPS varies continuously and to keep the system stable the generation must be in synchronize with fluctuating demand [1]. Otherwise, the real power mismatch arises thereby variations in control area frequency. Thus, a regulator is necessitated to synchronize the electric power generation with fluctuating load automatically to keep the IPS stable. Every generation unit is provided with a speed governor as the primary regulator at the turbine location to regulate the generation. However, the governor's action was limited to only a certain extent. Hence a secondary regulator is necessary to govern the power generation automatically.

Various secondary regulators that are widely implemented in LFC of IPS, available in the literature are classical PI, PID, robust type control techniques of (H α) [2], model predictive controller (MPC) [3], degree-of-freedom (DOF) [4], tilt-integral-derivative (TID), and fractional order (FO) [5] type traditional regulators. Moreover, the proper functioning of the aforementioned regulators requires optimization algorithms. Various algorithms like seagull optimization algorithm (SOA) [6], dragonfly algorithm (DFA), biogeography-based optimizer (BBO), elephant herd optimization (EHO) approach [7], grasshopper optimizer (GO) [8], gravitational search algorithm (GSA), coefficient diagram algorithm (CDA) [9], ant lion optimization (ALO), lightning search algorithm (LSA) [10], bacterial foraging algorithm (BFA), artificial bee colony (ABC) [11] approach, slap swarm algorithm (SSA), backtracking search algorithm (BSA) [12], water cycle algorithm (WCA) etc. are utilized in optimal LFC of multi-area IPS models.

Further, fuzzy regulators are also prominently presented by the researchers as a secondary regulators for automatic frequency regulation. However, the design of a fuzzy system involves many approximations that might degrade its performance. Furthermore, fuzzy aided classical controllers like fuzzy-PI, fuzzy-PID based on optimization algorithms like grey wolf optimizer (GWO), leveraged multi-verse approach (LMVA) [13], big-bang big-crunch (BBBC) [14], hybrid genetic-fuzzy (HGFT) [15] technique, cuckoo search algorithm (CSA), volleyball algorithm (VBA) [16], teaching learning-based (TLBO) optimization etc. are reported. Numerous nature-inspired global optimization techniques are emerging every day and each algorithm had its advantages and drawbacks. Thus, new optimization algorithms are always finding their way to the application of LFC for secondary regulator optimization. In this paper, the AEFA approach is implemented to optimize the PIDD regulator. Moreover, the investigative model deliberated in this work is the TARHT system and the realistic constraint of TDs is perceived. Literature survey reveals that researchers had given less preference to considering the non-linearity constraint of TDs with the system, even though their effect on system performance is more. Thus, this work focuses on revealing the TD's effect on the performance of the TARHT system.

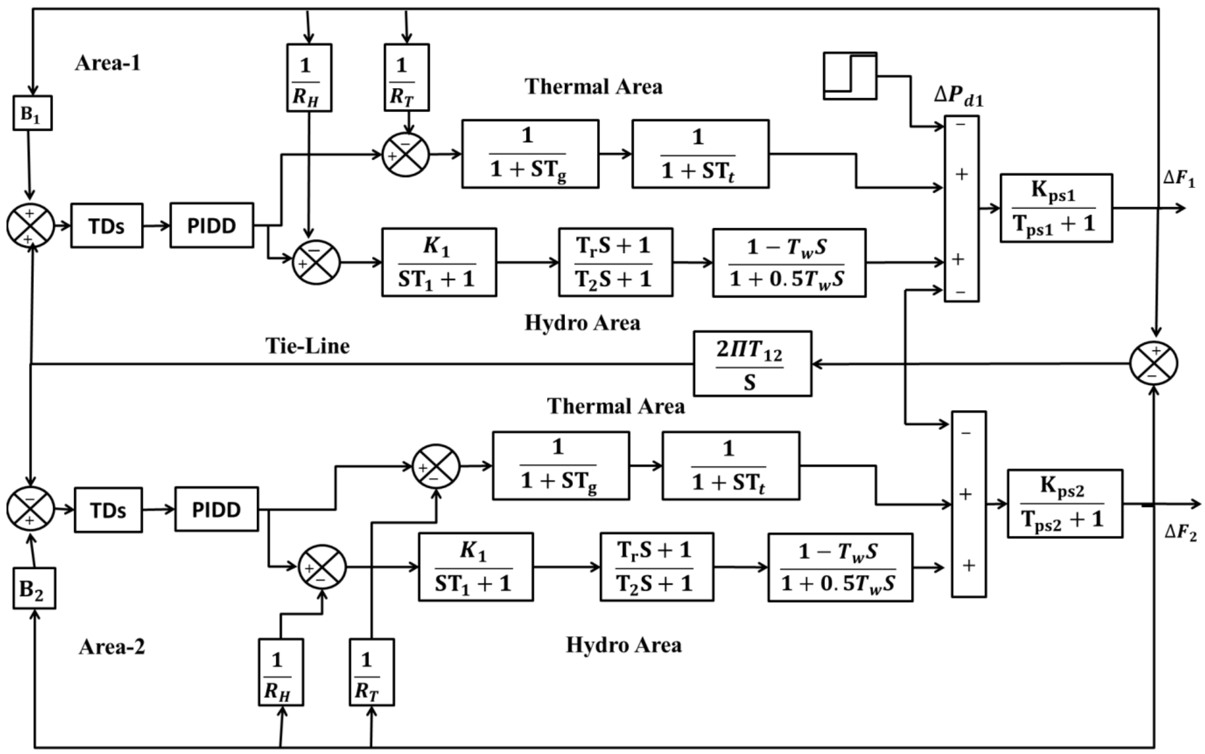


Fig.1. Model of TARHT system with time delays.

Given the above literature, the contributions of this paper are

a) AEFA tuned PIDD is suggested as a regulator for the LFC study.
b) Efficacy of AEFA-based PIDD is revealed with PI and PID performances.
c) 10%SLD is laid on area-1 of the TARHT for investigation.
d) The predominance of TDs on the TARHT performance is demonstrated.
e) The importance of taking TDs with a power system in the LFC study is addressed clearly.

II. POWER SYSTEM UNDER INVESTIGATION

The simple model of the TARHT power system depicted in Fig.1, is deliberated for study in this paper. Area-1 is laid with a perturbation of 10%SLP to analyse TARHT transient behaviour. Each area of TARHT comprises hydro-thermal units with equal generation capacity. The modelling of the turbine and governor of the thermal unit is as provided in (1-2).

$$G_{TG} = \frac{1}{1+ST_g} \tag{1}$$

$$G_{TT} = \frac{1}{1+ST_t} \tag{2}$$

The hydro plant governor, turbine and penstock are modeled as given in (3-5).

$$G_{HG} = \frac{K_1}{1+ST_1} \tag{3}$$

$$G_{HT} = \frac{T_r S+1}{1+ST_2} \tag{4}$$

$$G_{HP} = \frac{1-T_w S}{1+0.5ST_w} \tag{5}$$

Moreover, the TARHT system is accompanied with TDs to furnish the analysis close to the standards of realistic practice. A practical TD parameter of 0.12seconds is perceived with the TARHT for analysis. IPS employs several devices for measurement and sensing purposes at different locations. The information or the data from the measuring devices are transmitted to the control centre through communication channels. From the control centre, a command signal will be generated which can be transmitted through the communication peripherals to the controller situated at generation utilities. The peripherals inherits the TD nature and hence the information transfer might not be performed instantly among various devices located at distant positions. Hence, the signal received by the controller situated at generation with the delays leads to the delaying of changing the generation of power by the generating unit. Thus, TDs are prominent in the performance of IPS under load disturbances. The modelling of TDs [17] in this work is provided in (6).

$$e^{-s\tau_d} = \frac{1-\frac{\tau_d}{2}s}{1+\frac{\tau_d}{2}s} \tag{6}$$

III. CONTROLLER AND OBJECTIVE FUNCTION

Selection of regulator in secondary position for LFC of IPS is the key to regulating the system frequency effectively. PIDD regulator is chosen in this paper based on the population-based optimization of AEFA. Considering the design and economical aspects, PIDD is more close to the PID. Moreover, the additional DD gain provides better scope in dampening the variations and facilitates the variations in reaching the zero psotion. The parameters of PIDD are found with AEFA optimally in this paper concerning the integral square error (ISE) index minimization. The formulation of ISE given in (7) is formulated with deviation in frequency at

(Δf_1) area-1, (Δf_2) area-2 and (ΔP_{tie12}) [18] power flow in the tie-line.

$$J_{ISE} = \int_0^{T_{Sim}} (\Delta f_1^2 + \Delta P_{tie,12}^2 + \Delta f_2^2)dt \quad (7)$$

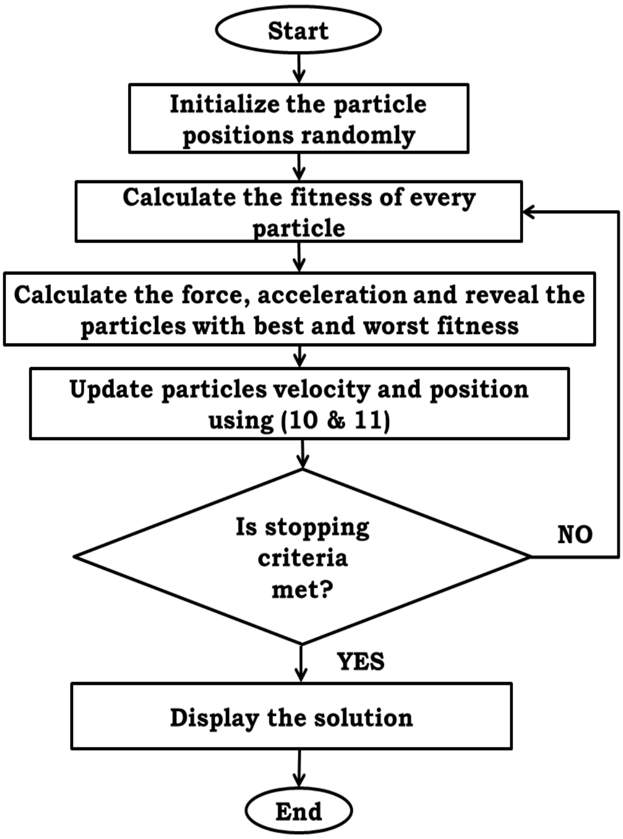


Fig.2. AEFA flowchart

IV. Artificial Electric Field Algorithm

AEFA is the newest algorithm presented by the researchers in [19], as a solution to the constraint optimization problem. AEFA is implemented to get the gains of the PIDD regulator optimally for the LFC problem in this work. AEFA works on the principle of attraction and repulsion of charged particles which themselves act as searching agents. Initially, the PIDD parameters are randomly initialized in d-dimensional space as follows:

$$K_{PIDD} = \begin{bmatrix} K_{P1} & K_{I1} & K_{D1} & K_{DD1} \\ K_{P2} & K_{I2} & K_{D2} & K_{DD2} \\ --- & --- & --- & --- \\ K_{PN} & K_{IN} & K_{DN} & K_{DDN} \end{bmatrix} \quad (8)$$

These parameters are intended to be fed into the PIDD regulator one after the other and the simulation will be done for each particle. The fitness value is evaluated using (9) after evaluating the objective index using (7) for each particle.

$$\text{Fitness} = \frac{1}{1 + \text{Objectivevalue}} \quad (9)$$

The velocity and position of k^{th} charged particle in d^{th} iteration are modelled as follows:

$$V_k^{(d+1)} = rand() * V_k^d + a_k^d + rand() * (P_{Best} - P_{Present}) \quad (10)$$

$$X_k^{(d+1)} = X_k^d + V_K^{(d+1)} \quad (11)$$

Where the parameter P_{Best} indicates the best particle position and 'a_k' represents the acceleration. The parameter acceleration is calculated taking the parameters of electric field (E) and charge (Q) and mass (M) of the particle 'k' as follows:

$$a_k^d = \frac{Q_k^d * E_k^d}{M_k^d} \quad (12)$$

$$E_k^d = \frac{F_k^d}{Q_k^d} \quad (13)$$

Later, the force (F) implied on k^{th} particle due to j^{th} particle in d^{th} iteration as

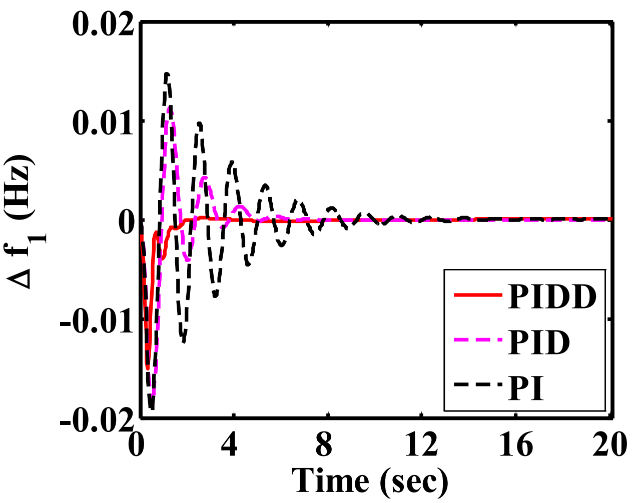
$$F_k^d = rand() * F_{kj}^d \quad (14)$$

After that, the charged particles with best and worst fitness values are revealed based on the procedure illustrated in [19], and the particles of fittest value are displayed as optimal gains of the PIDD regulator. The procedure of AEFA is depicted in Fig.2.

V. Simulation Results

A. Case-I: Analysis of TARHT system without considering TDs.

In this case, TARHT considered system is investigated upon omitting the realistic constraint of TDs under different regulators. Controllers like PIDD, PID and PI are enacted in both the areas of the TARHT system as secondary regulators one by one. To get a comparative performance evaluation, all the regulators are rendered optimally using the AEFA mechanism for 10%SLD on area-1. Dynamical behaviour of TARHT under load disturbances is analysed in terms of (Δf_1), (Δf_2) and (ΔP_{tie12}) and are rendered in Fig.3, and is clear that PIDD is more efficacious in dampening the peak undershoots as well as oscillations. Moreover, the deviations under AEFA-based PIDD are quickly mitigated and reach steady-state early compared to PI and PID. Further, the objective function is minimized effectively with PIDD and is improvised by 38.46%with PID and 60.54%with PI. Responses settling time and regulators optimal parameters that are found using AEFA are provided in Table I and Table II.



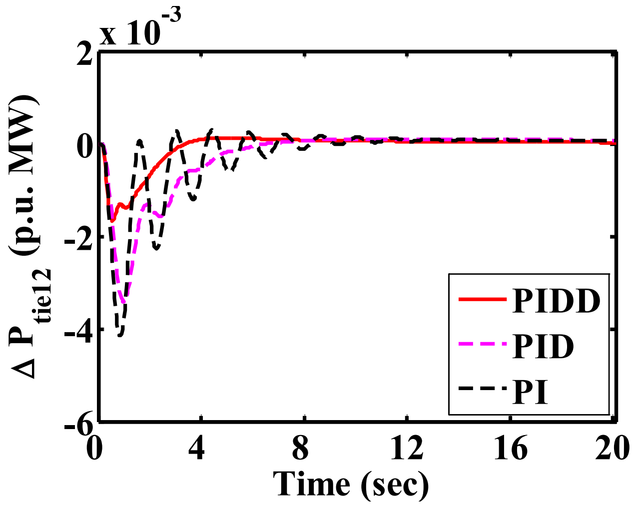
(a)

TABLE I. RESPONSES SETTLING TIME

Settling time (Sec)	Case-1			Case-2		
	Δf_1	Δf_2	ΔP_{tie12}	Δf_1	Δf_2	ΔP_{tie12}
PI	14.38	13.64	16.30	20.41	20.24	21.90
PID	8.01	9.76	11.22	13.99	13.29	17.08
PIDD	4.52	5.64	9.27	11.26	10.44	12.36

TABLE II. CONTROLLER OPTIMAL GAINS

Parameters		Case-1			Case-2		
		PIDD	*PID*	*PI*	*PIDD*	*PID*	*PI*
Area-1	K_P	0.316	0.455	0.672	0.419	0.548	0.672
	K_I	0.270	0.196	0.458	0.316	0.365	0.549
	K_D	0.273	0.313	--	0.632	0.284	--
	K_{DD}	0.365	--	--	0.476	--	--
Area-2	K_P	0.353	0.413	0.582	0.517	0.691	0.718
	K_I	0.159	0.208	0.374	0.411	0.291	0.432
	K_D	0.304	0.299	--	0.513	0.198	--
	K_{DD}	0.286	--	--	0.298	--	--
$ISE*10^{-3}$		26.19	42.56	66.38	53.82	98.61	131.76



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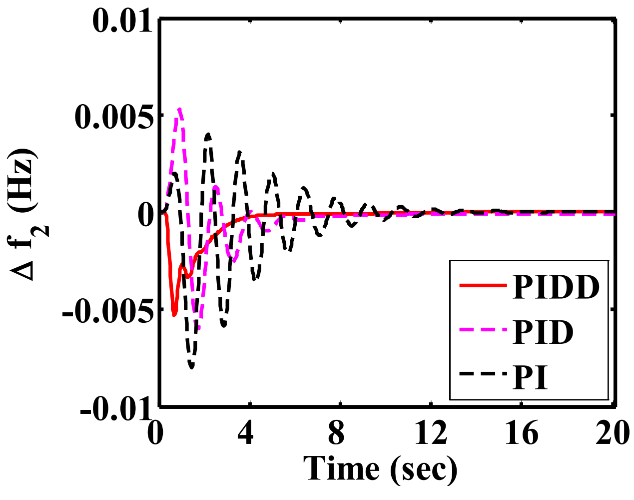
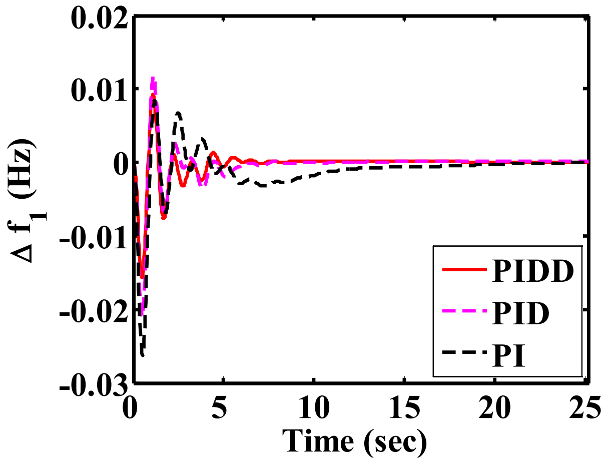


(c)

Fig.3. Case-I responses. (a).Δf_1, (b).ΔP_{tie12}, (c).Δf_2.

B. Case-II: Analysis of TARHT system with considering TDs.

In this case, the realistic constraint of TDs is perpetuated with the TARHT system for analysis purposes under the same disturbance conditions. Different regulators such as PIDD, PID and PI fine-tuned using the AEFA algorithm are used as secondary regulators and the responses are compared in Fig.4. Pointing out the system behavior shown in Fig.4, it is concluded that PIDD facilitates better mitigation in both control area frequency and power flow in the line. Moreover, ISE with PIDD is enhanced by 45.42%with PID and 59.15%with PI. Further, peak deviations are effectively addressed by the PIDD compared to PI and PID. The peak undershoots is numerically interpreted for PI as (Δf_1=0.026Hz, Δf_2=0.006Hz, ΔP_{tie12}=0.0066Pu), for PID as (Δf_1=0.020Hz, Δf_2=0.0162Hz, ΔP_{tie12}=0.0059Pu), and for PIDD as (Δf_1=0.0151Hz, Δf_2=0.0118Hz, ΔP_{tie12}=0.0045Pu).



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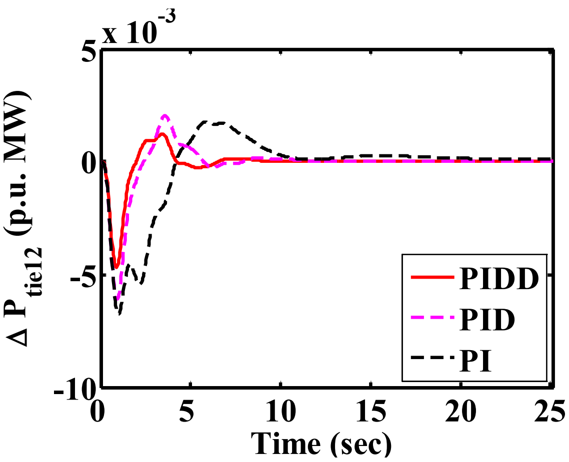

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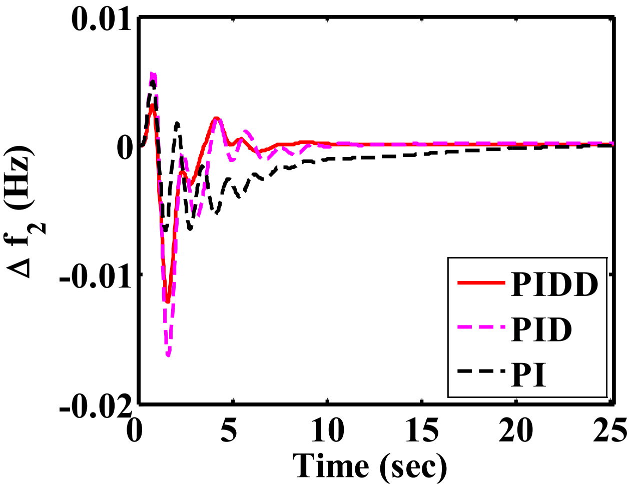

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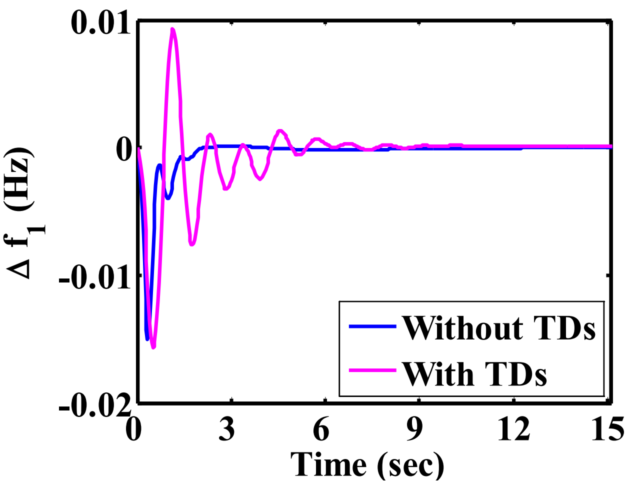
Fig.4. Case-II responses. (a).Δf_1, (b).ΔP_{tie12}, (c).Δf_2.

C. *Case-III: Effect of TDs on TARHT system performance*

PIDD based on the optimization of the AEFA algorithm is disclosed as the supreme regulator, and responses of the TARHT system for the situation of taking and omitting TDs are compared for better vicinity. The responses in Fig.5, disclosed that the transients of the TARHT with TDs are more deviated when coming to the situation of omitting the TDs. Further, the responses concede little bit excess time to reach zero position for the case of taking TDs into cosnideration. Considering the time delays, resulting in time lag for the signals that are transmitted and received among various devices that are located at remote places. Due to this, the generation of the control signal concerning the area control error has been generated with delay. This control signal is interned and acts as input to the regulator situated in plant to change the power system operating point (PSOP). The PSOP is needed to be varied following varying load demands to keep real power mismatch at a minimum. Thus, with the delay in altering the PSOP, there will be more deviations in the system frequency. This work strongly suggests considering TDs with a power system in the LFC study so that the suggested controller would be more robust enough in grabing the stability even in the situations of unpredictable TDs injected with the system.



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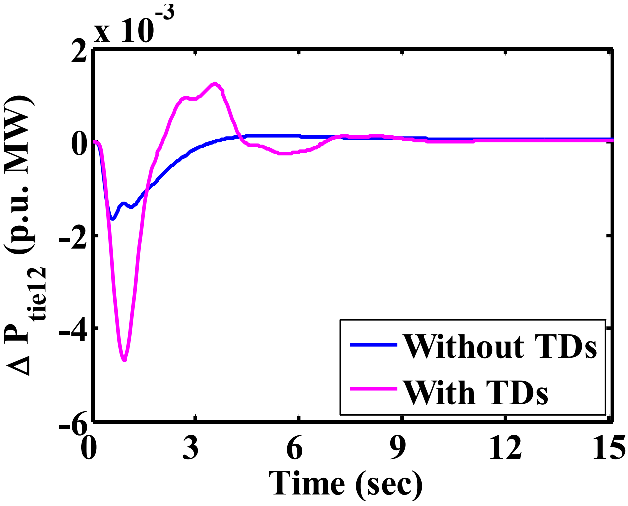

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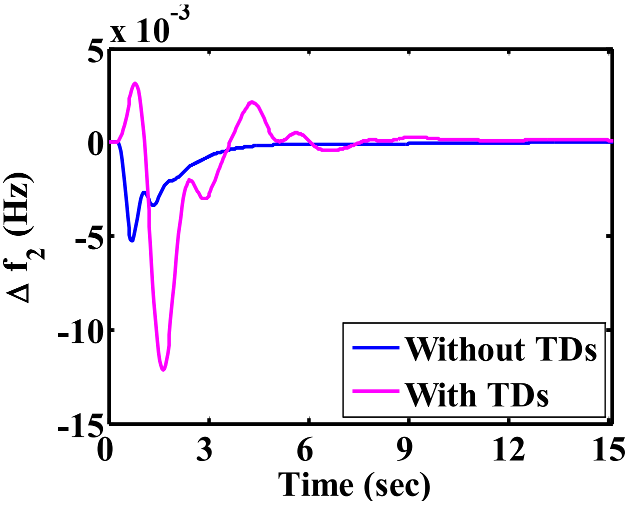

(c)

Fig.5. Case-III responses. (a).Δf_1, (b).ΔP_{tie12}, (c).Δf_2.

VI. Conclusion

This work spotlights the sovereignty of the AEFA optimized PIDD regulator in handling TARHT system stability with practical constraints of TDs. Transient analysis of the TARHT system is undergone by targeting area-1 with 10%SLD disturbance. Supremacy of presented PIDD regulator fine-tuned using AEFA approach is demonstrated with PID and PI. The significance of TDs on TARHT is showcased clearly in analysing the system dynamical behaviour for the cases of taking and omitting the constraint of TDs with the power system. Investigation discloses the predominance of TDs on TARHT performance and the system responses are more deviated due to delay in altering the system operating point.

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