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Research paper

Performance enhancement in AGC of multi-area power system with WOA optimized fo-2dof controller and facts controllers

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Abstract

This research article aims to develop Load Frequency Control (LFC) of equal three area with individual area comprises single thermal sys-tem and wind system and appropriated 3% of Generation rate constraint (GRC) is considered for thermal system to make non-linearity to overall system. For automatic generation control (AGC) the proposed secondary controller is a two degree of freedom (DOF) based frac-tional order Proportional, Integral, Derivative (PID) controller and used to reduce error for this study. For optimizing the gains of this pro-posed controller in a suitable manner a newly deterministic algorithm called Whale Optimization algorithm (WOA) is applied. Comparative performance analysis of different controllers like FO-2DOF-PID, 2DOF-PID, and PID is done in respect of settling time and peak over-shoot. Apart from this to improve quality of different dynamic responses some FACTS devices like Interlined power flow controller(IPFC), Static synchronous series compensator (SSSC) and Thyristor controlled series capacitor (TCSC) are implemented with FO-2DOF-PID controller and for superiority analysis a comparison is made between above optimized controllers.

Keywords: *Automatic Generation Control (AGC); Fractional Order Two Degree of Freedom (FO-2DOF)); Interline Power Flow Controller (IPFC); Whale Optimization Algorithm (WOA); Flexible AC Transmission System (FACTS).*

1. Introduction

The system frequency and tie-line power exchange are responsible for reliable and economic operation of an interconnected power. According to this there will be a reliable and successful operation of an interconnected power system when system frequency and tie-line power exchange are kept with their nominal values. To achieve nominal values of area frequency and tie-line power research in the area of AGC[1-3] is carried out. So research in AGC of multi-area [4-5] with both isolated and interconnected system is carried out successfully. According to Elgerd et.al.(6) literature survey is developed in multi-area system and based on this research is carried out in different areas tremendously [7]. The classical controller like PID [8]is in the category of single order secondary controller of AGC. There is a concept of 2 degree of freedom (2DOF) in controller, which Mituhiko Araki et. al.[9] has shown as 2DOF-PID controller in first time. But to get better dynamic response and robust nature of 2DOF-PID controller, again the controller is modified to get orders (exponent) in fraction. Such proposed controller name is Fractional order 2DOF-PID(FO-2DOF-PID) controller. In this research article FO-2DOF-PID controller is implemented with different FACTS devices [10]. In present research scenario Genetic Algorithm(GA)[11] and Particle Swarm Optimization(PSO)[12] have been implemented for optimizing the controller gains. BFO[13] having better performances like convergence and low operating time in comparing with GA and PSO. Saikia et.al. developed another met heuristic algorithm called Firefly algorithm(FA) and applied in the area of AGC for better stabilization. Besides this in this article a proposed newly developed algorithm based on nature known as Whale Optimization algorithm (WOA)[14] is implemented in the area of multi-area AGC for improving dynamic response of system. This method is most robustness and accurate for solving multilevel optimization problem. the performance of WOA technique is analyzed in response with GA, PSO and BFO algorithm for superiority analysis.

Introduction of Flexible AC Transmission (FACTS) devices in interconnected power system increases the stability of Power System Operation. According to Bhatt et al.[15] the FACTS devices like Static Synchronous Series Compensator(SSSC) and Thyristor Controlled Phase Shifter(TCPC) have been utilized in series with tie-line along with Super Conducting Magnetic Energy Storage(SMES) for stabilizing area frequency in two area AGC system. Chidambaram et. al.[16] proposed use of special type batteries in addition with some FACTS devices for improvement of inter area frequency stability and tie-line power in two-area interconnected power system.

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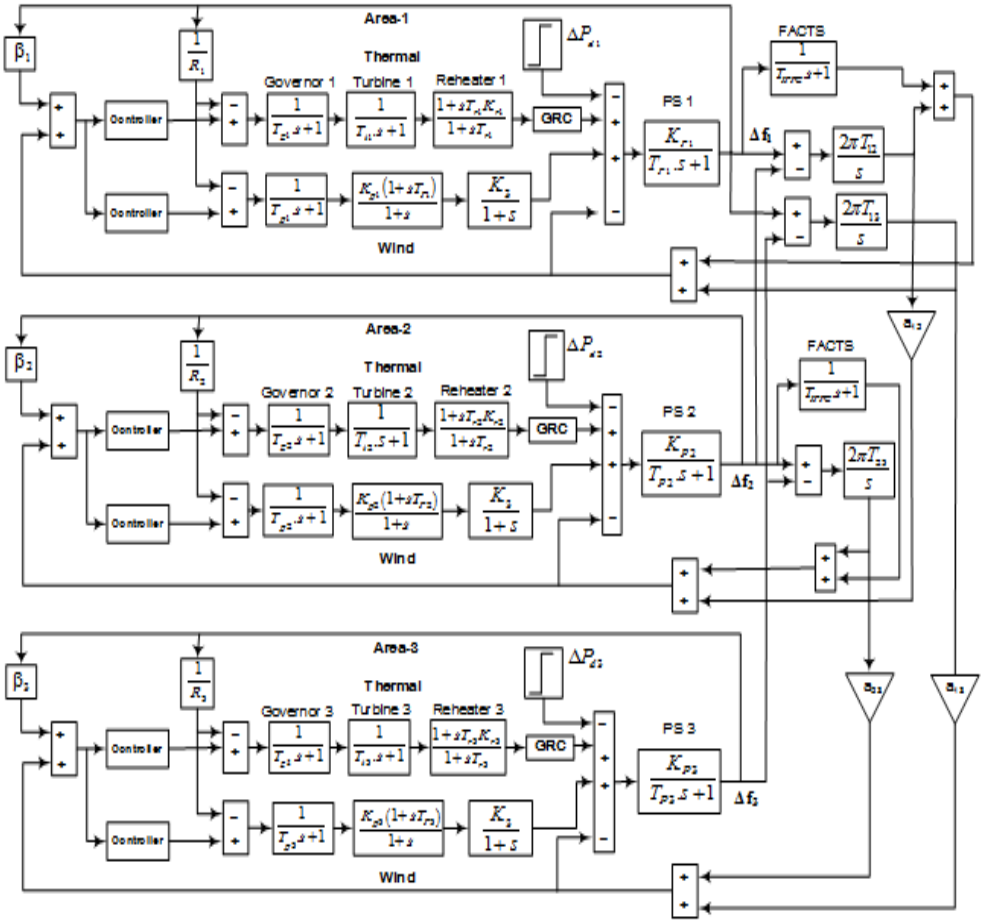


Fig. 1: Thermal and Wind Based Three Area Power System.

2. Proposed controller structure

2.1. Fractional order (FO) 2-degree of freedom Controller (FO-2DOF)

For any arbitrary number mathematically fractional oriented calculus is the modification of integer order type differentiation and integration. In fractional calculus ${}_aD_t^{\alpha}$ is a fundamental operator which shows non-integer-order differentiation and integration . Here a and t are bounds and α ε R is the order. The above operator is expressed in eq(1) and transfer function of controller is expressed in equation(2).

$$ {}_aD_t^{\alpha} = \begin{bmatrix} \int_a^t (d\tau)^{\alpha}, \alpha < 0 \\ 1, \alpha = 0 \\ \frac{d^x}{dt^x}, \alpha > 0 \end{bmatrix} \quad (1) $$

$$ C(s) = K_P + \frac{K_I}{S^{\lambda}} + K_D S^{\mu} \quad (2) $$

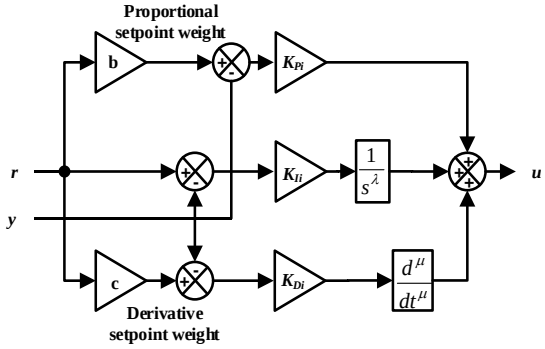


Fig. 2: Fractional Order 2DOF-PID Controller.

Combining phenomena of Fractional Calculus with two degree of freedom (2DOF) principle in PID controller that results fractional order (FO) 2DOF-PID controller and is shown in Fig 2.

2.2. Facts devices and objective function

SSSC is a static oriented series type FACTS device which is capable of amalgamating Line voltage of three phase supply system in quadrature with respective line current. To achieve this SSSC utilizes the principle of self commutated voltage source converter. IPFC is an advance type power flow(Inter-line) controlled type FACTS device, which is implemented in this article for controlling power flow by injecting an adequate amount of series voltage in an interconnected transmission line. IPFC also possess the characteristic of series reactive compensation. Another semiconductor device based FACTS device known as TCSC, which is a series type FACTS device and helps to control line impedance and hence able to control power flow. The different above said are taken for this research article for controlling purposes. Fig1 shows the connection of IPFC in series with the interconnected power system.

For this research article ITAE (Integral of Time Multiplied Absolute Error) has been implementing as objective function and which is described as

$$J = \int_0^{tsim} \left(|\Delta f_1|\right) + \left(|\Delta f_2|\right) + \left(|\Delta f_3|\right) + \left(|\Delta P_{tie}|\right) t.dt \quad (3)$$

2.3. Whale optimization algorithm (WOA)

Whale Optimization Algorithm (WOA) is a metaheuristic algorithm which was first introduced by Mirjalili and Lewis [14]. Whales having very much response towards motion and recognized as most clever animal with motion. There is a special type whale known as humpback whale, whose hunting technique is the inspiration of whale optimization algorithm. Normally humpback whales like to hunt small fishes and krills in sea when they (fishes) are just below the water surface.. The hunting technique of whale specially follows a unique method termed as 'bubble net' method. Basic principle of bubble net method is that while whales moving around the prey they produce numbers of bubbles in a circular path.

The modeling of WOA technique follows three basic principles. These are

- Encircling Prey
- Bubble Net
- Search the Prey

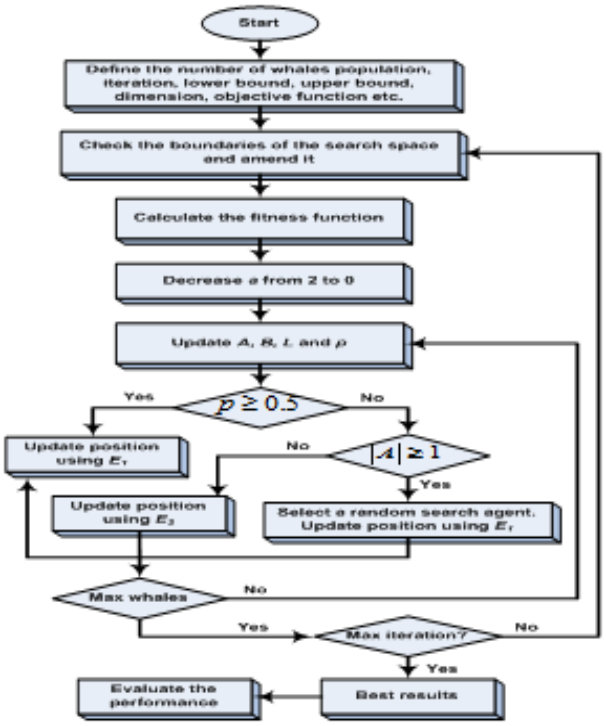


Fig. 3: Flow Chart of Whale Optimization Algorithm

3. Simulation results and analysis

Comparison of Performances of PID controller, 2 degree of freedom based PID controller and proposed Fractional Order-2DOF PID controller along with different optimization techniques like WOA, BFA, PSO and GA are discussed briefly in this section. Besides this comparison in performances of different FACTS devices likes IPFC, TCSC and SSSC are briefly discussed while improving stability of different dynamic responses. . The optimized values of WOA based proposed FO-2DOF controller gains obtained are provided in tableI. For this research work the model was run in simulink of MATLAB 2014b environment and the coding was written in .m file.

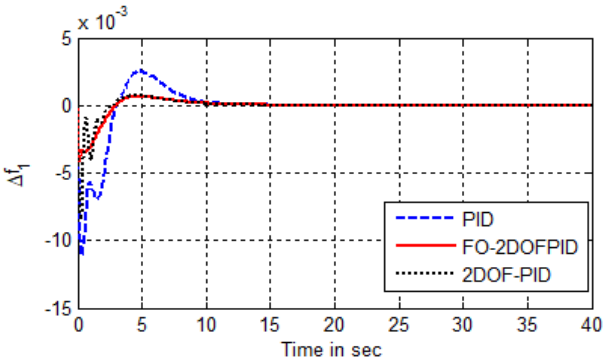


Fig. 4: (A).

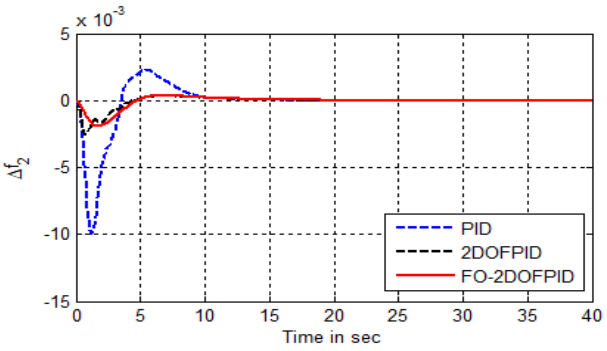


Fig. 4: (B).

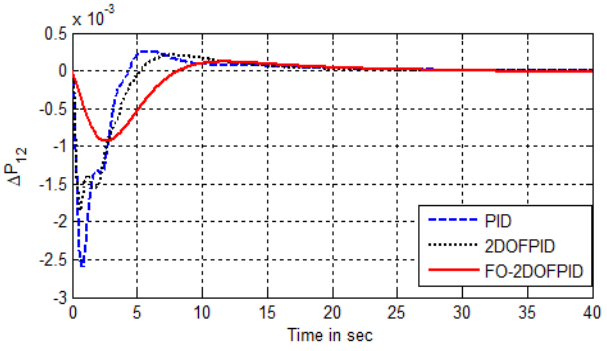


Fig. 4: (C).

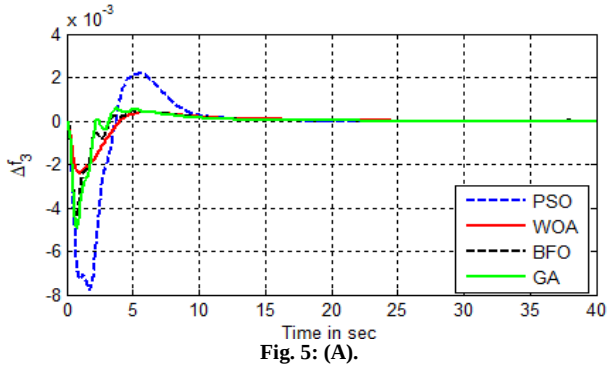


Fig. 5: (A).

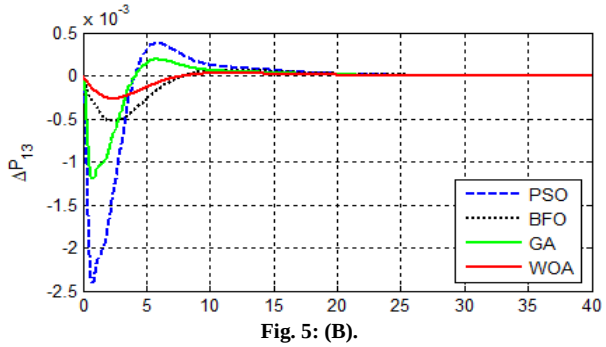


Fig. 5: (B).

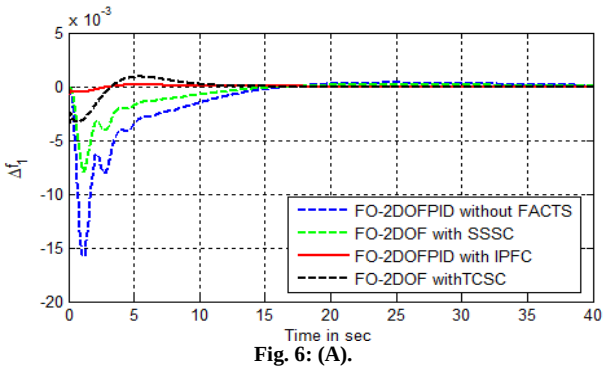


Fig. 6: (A).

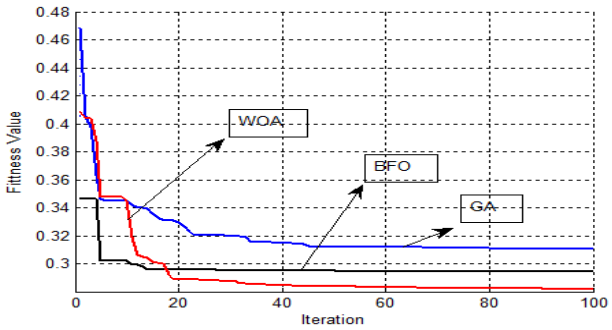


Fig. 7:

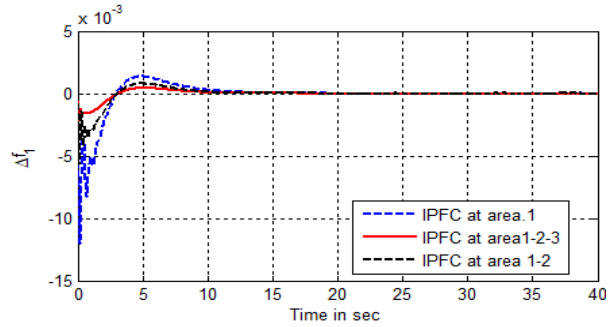


Fig. 6: (B).

Table 1: Optimal Value of Gain Parameters of Different Controllers

Controller Area Gains Genco.		FO-2DOFPID	2DOFPID	PID
		K_P, K_I K_D, b_i, ci , λ , μ	K_P, K_I, K_D, bi, ci	K_P, K_I, K_D
Area-1	Thermal	0.0092; 0.0022; 0.9898; 1.2020;-1.8080; 0.8200; 0.6644	-0.1012; 1.0028; -2.0000; 1.00; 1.0000	-2.0000;1.9800; 1.00;
	Hydro	-2.0000;1.2212;1.9000; 1.0000;1.7762; 0.0212; 0.1050	-1.8000; -1.0044; -1.8600; 2.00; 2.0000	-1.9800;2.0000; 2.00
Area-2	Thermal	-1.0212;0.0022;1.6442; 1.8600;1.8750; 0.1000; 0.4210	-1.9898; -1.0098;1.7860; 1.00; 1.0200	1.9512; -1.8600; 1.98
	Hydro	0.0034; 1.0932; 0.0022; 2.0000;1.5000; 0.4020; 0.3500	1.0030;2.0000;2.0000; 1.80;1.0400	1.0000; -2.0000; 1.68
Area-3	Thermal	-2.0000;2.0000;1.0000; 1.7856;2.0000; 0.0080; 0,6060	-1.0000; -1.6800; 1.8080; 2.00; 2.0400	-1.9800; -1.9800; 1.12
	Hydro	-1.1212;1.9500;1.5664; 1.2080;1.9200; 0.3534; 0.1212	-2.0000; 1.8234; 2.0000; 1.66; 2.0000	-2.0000;2.0000; 0.92

Table 2: Ssettling Time, Peak Overshoot, Peak Undershoot of Different Responses

Technique	FO-2DOFPID (WOA)			2DOF-PID(WOA)			PID(WOA)		
	Settling Time in Sec. $*10^{-3}$	OverShoot in Pu. $*10^{-3}$	UnderShoot in Pu$*10^{-3}$	Settling Time in Sec. $*10^{-3}$	Over Shoot in Pu. $*10^{-3}$	Undershoot in Pu $*10^{-3}$	Settling Time in Sec. $*10^{-3}$	Over Shoot in Pu. $*10^{-3}$	Under shoot in Pu $*10^{-3}$
ΔF1	8.4523	2.450	-3.9200	9.2020	3.2202	-4.1200	12.2747	4.6502	-9.3224
ΔF2	12.1634	2.326	-3.6256	12.878	3.6244	-4.6200	13.2530	1.4166	-9.8644
ΔF3	13.6218	2.382	-0.8256	14.200	0.9234	-2.5466	16.3288	1.4286	-9.9654
ΔP12	16.3244	0.465	-6.6232	18.608	0.4264	-8,4090	20.6208	0.4888	-11.102
ΔP23	17.0876	0.329	-2.1004	18.654	0.4876	-2.2200	20.9876	0.3244	-2.8654
ITAE	41.68 x 10-2			42.80 x 10-2			102.74 x 10-2		

It is evident from fig.4 that WOA optimized FO-2DOF-PID develops well settling time and least overshoot and undershoot based dynamic responses. While comparing different optimization techniques WOA exhibits superiority than other implemented optimization technique and is shown through different dynamic responses in fig.5

In this research article the main focus is on FACTS devices. It is clearly observed from fig.6 that FACTS devices also help to improve stability of different dynamic responses. It also observed that IPFS gives better dynamic responses in comparing wit TCSC and SSSC. FACTS devices applying simultaneously in all areas having better dynamic responses than applying in limited areas.

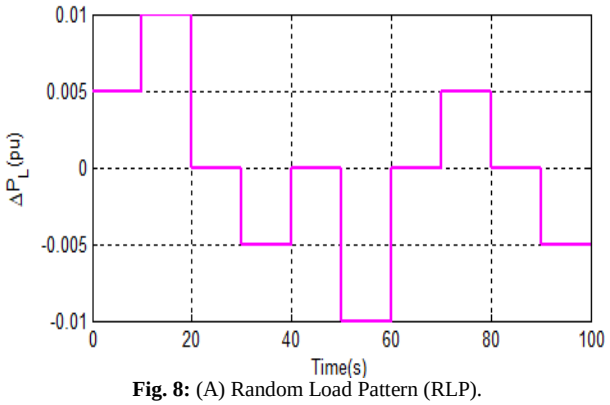


Fig. 8: (A) Random Load Pattern (RLP).

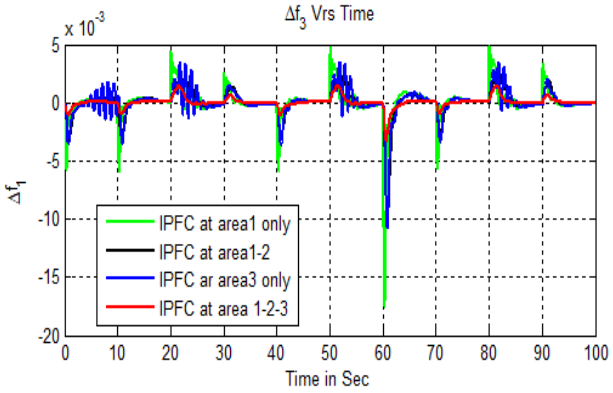


Fig. 8:(B) Deviation of Frequency in Ar,1 Due to RLP.

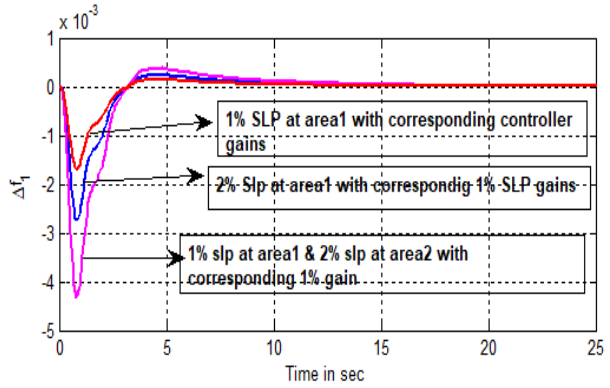


Fig. 9: (A) Frequency Deviation Due to Different SLP.

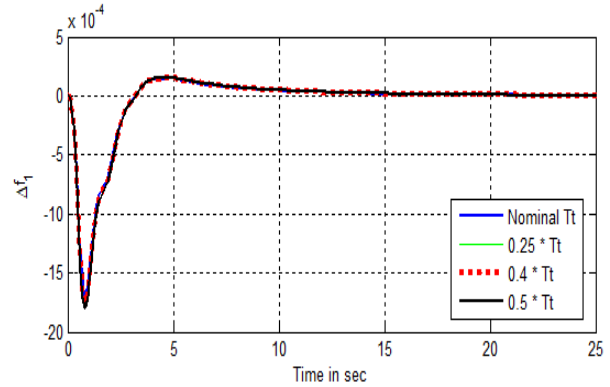


Fig. 9:(B) Frequency Deviation Due to Different Turbine Timeconstant.

It is observed from fig.8 that characteristic of a dynamic response produced due to Random Load Pattern vary according to the location of IPFC. From the response shown in fig.8 it suggests response having better dynamic quality when IPFC is present in more area.

For sensitive analysis of above proposed controller it is tested with varying magnitude and location of SLP. Fig.9(a) suggests response of deviation of frequency in area exhibits least settling time and undershoot when SLP is 1%(least) and applied in area1(single area) only. Also the robustness of the controllers are checked by varying some system constant parameters, like governor time constant, turbine time constants etc. Here only the turbine time constant (T_t) is taken in to consideration. Here large change in turbine time constant is taken, the time constant is changed to $0.5xT_t$, $0.4xT_t$ and $0.25xT_t$. The dynamic responses are given in fig. 9 (b).

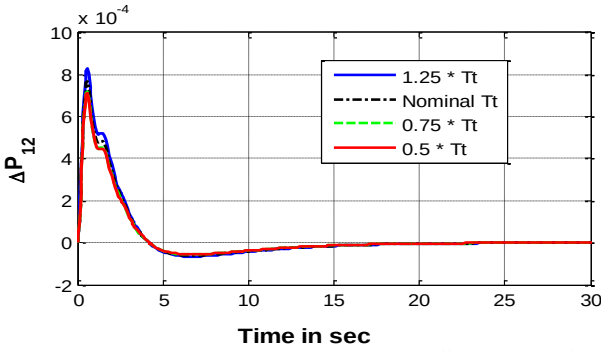


Fig. 10: (A) Deviation in Tie-Line Power Due to Different Value of Tt.

Here it is observed that all the four changes overlap with each other which confers us that the variation of turbine time constant has no impact in frequency deviation, tie line power deviation and generator output power change. It imposes that the proposed controller is most robust in nature.

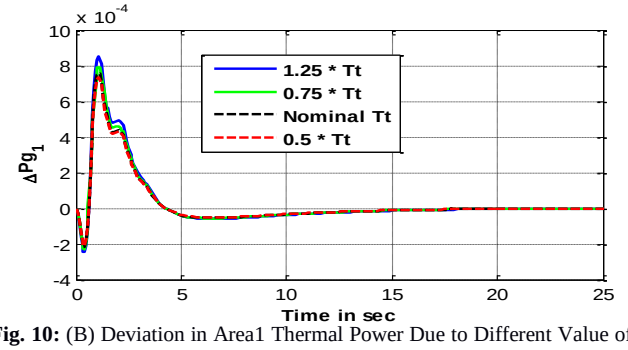


Fig. 10: (B) Deviation in Area1 Thermal Power Due to Different Value of Tt.

Responses shown in fig.10 give more idea about the robustness of above proposed FO-2DOFPID controller. It shows the above two different responses are overlapping each other and concludes that the proposed controller is most robust in nature. It is more clear from these responses that the optimized gain parameters of proposed FO-2DOFPID are need not to be changed again to develop better quality different dynamic responses even if at large variation of magnitude of different system parameters(here the case T_t). The sensitive analysis may be carried out also by regulating the value of system parameters like governor time constant (T_g), power system gain (K_P) and power system time constant(T_P).

While developing different dynamic responses and resulting different gain parameters initially the research has been done in MATLAB software and simulink environment. Specially the above proposed power network model and controller was created in simulink environment and required optimization technique and other required programmes are written in MATLAB2014b .m file by 4GB ram desktop.

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4. Conclusion

In this paper, a WOA technique is proposed to tune the FO-2DOF-PID controller parameters for AGC of three area multi source nonlinear power system. The nonlinearities like GRC is introduced in the proposed model. It is observed that proposed WOA optimized FO-2DOFPID controller gives good results through different dynamic responses in comparing with 2DOF-PID and PID controllers. Proposed algorithm is also tested by different standard bench mark functions for observing capability of this proposed algorithm. It is found from the result that the proposed WOA optimized FO-2DOFPID controller exhibits better performance in terms of average value, best value and standard deviations obtained in 30 runs. while optimizing different gain parameters an objective function of Integral of Time Multiplied Absolute Error (ITAE) has been taking into consideration for obtaining better performances different dynamic responses as ITAE has the ability to produce least overshoot and settling time responses. Again the stability of different dynamic responses are improved with the application of different FACTS devices. Among all FACTS devices IPFC along with proposed controller shows better performance with the application in increased area. The performance of different dynamic responses is improved with the location of FACTS devices. Whenever the FACTS devices are allocated in all areas that case the system provides good dynamic responses in respect of settling time and overshoot.

5. Appendix

Nominal parameter of the system f =frequency= 60 Hz; Tgi = Governor time constant=0.08sec; Tti = Turbine time constant=0.3 s; Tri = Time constant of reheat type turbine= 10 s; Kri = Gain of reheat type turbine= 0.5; Kpi = power system gain=120 Hz/pu MW; Tpi =power system time constant= 20 s; T12 = 0.086 pu MW/rad; Hi= Inertia constant= 5s; Di = Damping coefficient= 8.33 * 10-3 pu MW/Hz; βi = frequency biasing factor=425*10-3 pu MW/Hz; Ri = Regulation=2.4 pu Hz/MW; loading = 50%; TSSSC =Time constant of SSSC= 3*10-2 s; KSSSC= Gain of SSSC= 180.2*10-3; KU = 1.5 rad/Hz; TPS = 0.1s;TTCSC=Time constant of TCSC=0.015s;TIPFC= Time constant of IPFC=0.01s.;K3=1.40;KDi=1.25;TDi=0.6s;

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