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GWO optimized FOPID controller for AGC of nonlinear hydro thermal system with HVDC line

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ABSTRACT

This paper presents the fractional order (FO) PID controller (FOPID) for stabilizing the frequency of two similar areas of hydro thermal with constraints of non-linearity. The system is investigated by applying 10% step load burden on area-1. The parametric gains of FOPID controller are optimized with grey wolf optimization (GWO) subjected to error multiplied with time over the integral (ITAE) performance index. Moreover, the superiority performance of FOPID is established by putting system responses with those of conventional controllers under comparison and the GWO algorithms performance is also tested with other algorithms available in literature. Furthermore, the HVDC line is incorporated with the existing AC line in parallel to further damp out system oscillations under load disturbances..

Index Terms – *Automatic generation control, FOPID controller, GWO algorithm, Non linearity's.*

1.INTRODUCTION

The load on the power system will never be constant, which results in real power mismatch between generation and demand. Due to this system frequency get deviated from nominal value and sometimes may even leads to instability. In order to overcome this Load frequency controller (LFC) is employed .LFC plays prominent purpose in maintaining the modern day interconnected power system stability under load disturbances. LFC comprises of two control loops. Among which one is Primary control loop, deals with regulating the speed governor which was not adequate to control the system disturbances. So, the secondary controller comes in to the action by regulating the system performance variations upon minimizing the area control error (ACE).

A volume of articles are available on AGC in literature and some of them are mentioned here. The concept of LFC was first proposed by authors in [1] on thermal power plant. Later it was extended and implemented to several test systems like multi-area thermal units, hydro-thermal systems [2], incorporation of renewable energy generation sources to conventional power generation sources with out and with considering system non linearity's [3]. Moreover, the secondary controller acts significant role in regulating the system performance. The classical controllers like PI/PID, FO controllers like FOPI/FOPID [4], intelligent Fuzzy-PID controllers [5], with and without considering derivative filters and neural network based controllers etc. are available in literature. However, the process of optimizing the controller parameters using optimization algorithms is the most recent trend of research. The optimization algorithms like particle swarm optimization (PSO) [6], grey wolf optimization (GWO) [7], sine-cosine algorithm (SCA), and cuckoo search algorithm (CSA) [8] etc. are implemented by researchers in literature. In this present work, a widely accepted and highly efficient FOPID controller is supposed to be acted as secondary controller and the gains are optimized with GWO algorithm.

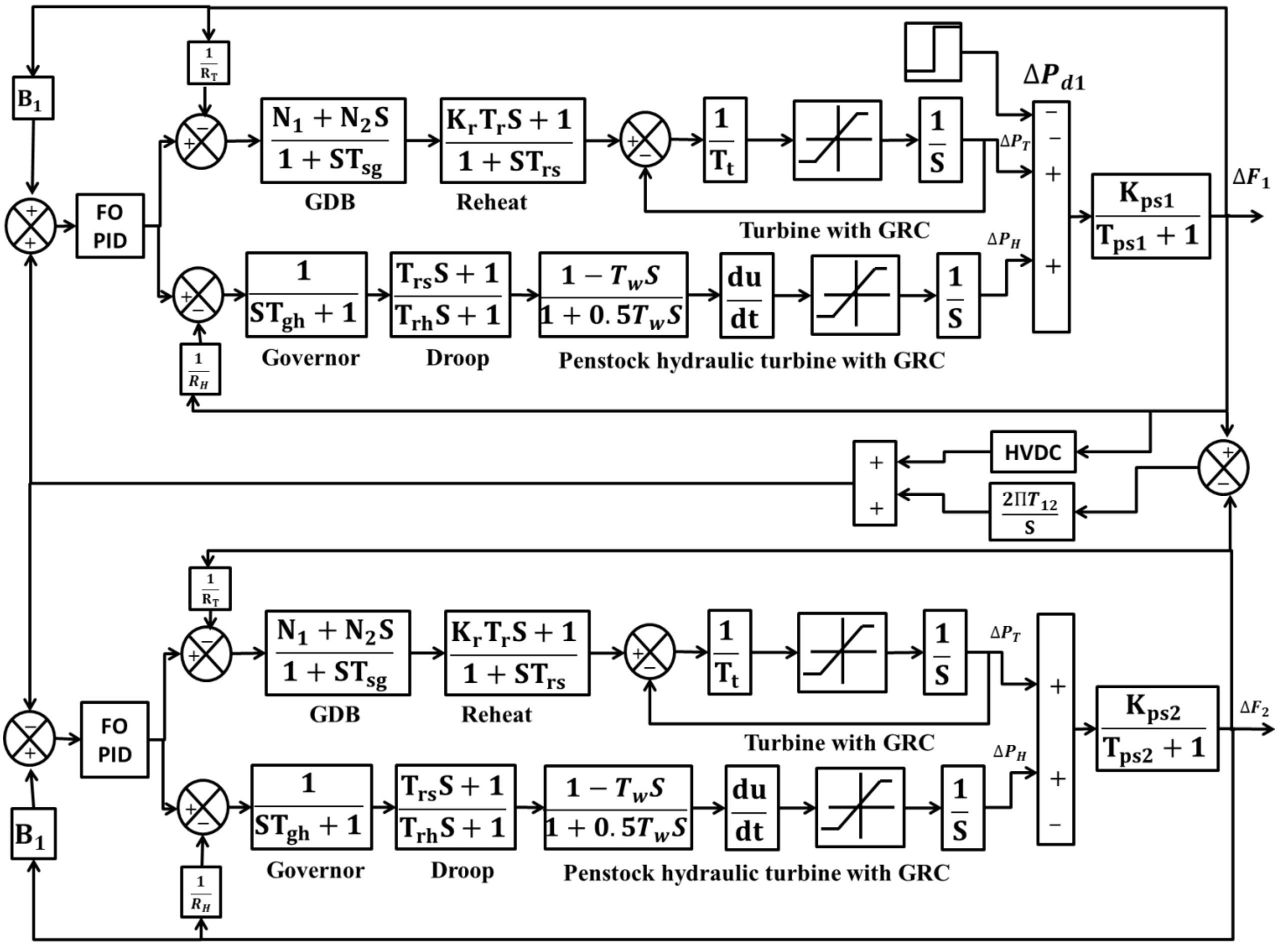

Fig.1 Two area transfer function model

2. INVESTIGATED TEST SYSTEM

Two similar areas of hydro-thermal generation units in each area with equal generation capacities are considered for investigation. System non linearity's like GDB and GRC are taken in to account to get the most realistic approach. The test system model is depicted in Fig.1. The system is investigated by impressing area-1 with10% SLP. The time and gain constant parameters of the system are directly considered from [4].

3. OBJECTIVE FUNCTION

FOPID controller is employed in this paper to drag down the ACE close to zero in order to dampen frequency oscillations of the system based on integral time area error (ITAE) objective function. The two additional knobs in FOPID controller inspire the authors to investigate its performance in AGC domain. The mathematical model of FOPID controller is modeled as

$$G(S) = K_P + \frac{K_I}{S^{\lambda}} + K_D S^{\mu}$$

The ITAE performance index is modeled as

$$ITAE = \int_{0}^{T_{sim}} T * (\Delta f_1 + \Delta P_{tie12} + \Delta f_2) dt$$

4. GREY WOLF OPTIMIZATION (GWO)

The searching strategy of this GWO algorithm is inspired from the hunting and leader ship mechanism of grey wolf in nature. Grey wolves occupies top place in the list of predators food chain. These are usually lives as a group with an average of 5-12 members consisting both males and females, and carry the hunting mechanism. The wolves in these groups are classified as alpha, beta, delta and omega. Out of these alpha wolfs are most dominant and performs crucial place in taking the decisions on hunting and all the other activities. The beta wolves are the second level ones and they can pass the information to the remaining and also help the alpha wolfs in making the decisions. Omega wolves are the lowest ranking wolves and are more likely to eat the prey at the last only. The wolves that are not come under the category of alpha, beta and omega are the delta wolves which are responsible for submitting the data to all categories of wolves except the omega. The step by step phases in hunting mechanism are tracing, and attacking the prey, encircling the prey and harassing until it stops moving. The mathematical modeling of the GWO algorithm is considered from [7].

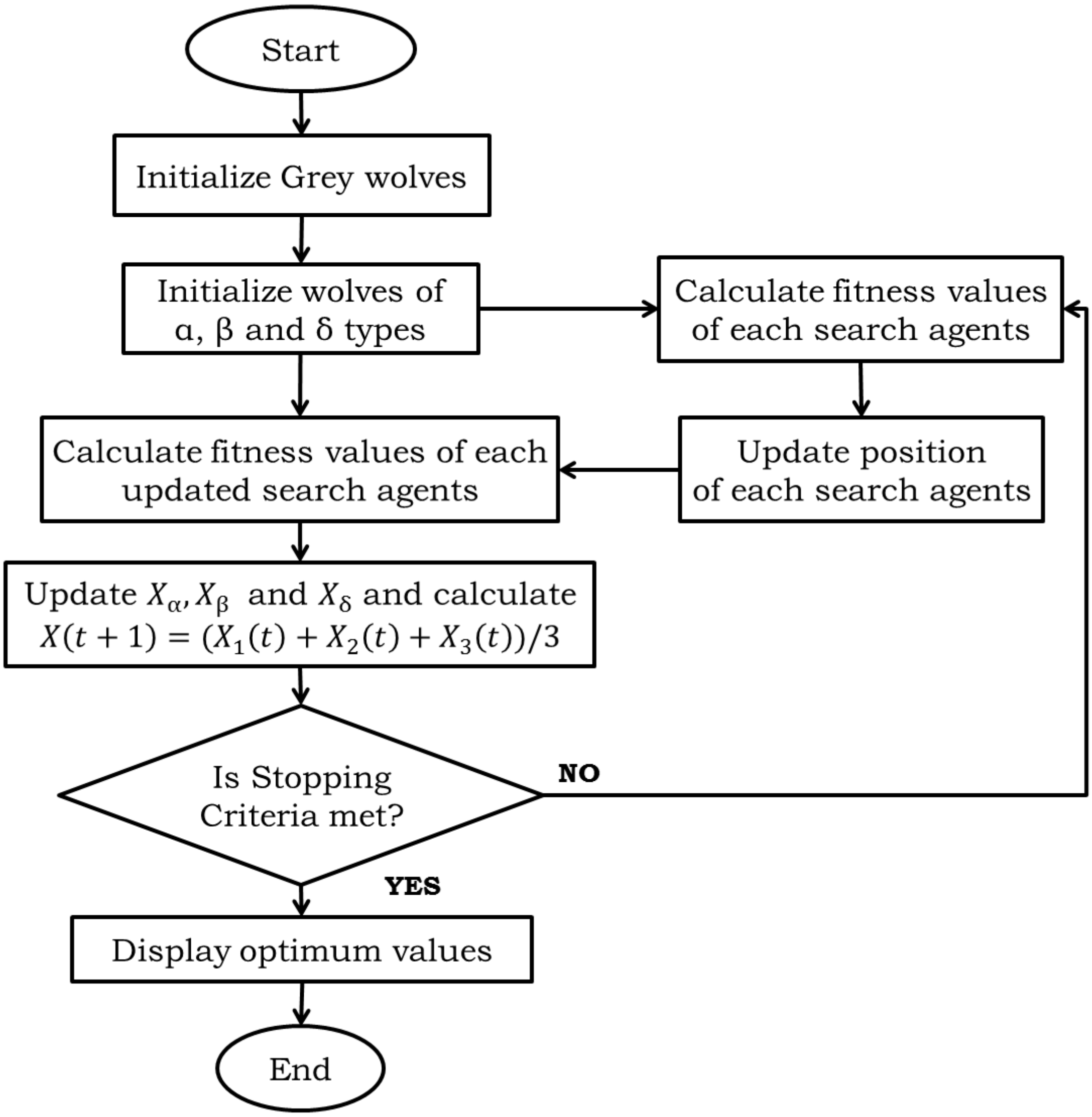

Fig.2 GWO algorithm flow chart

5. SIMULATION RESULTS

Case-1: system performance with GWO optimized different controllers

In this sub section, the performance of FOPID along with various classical controllers like PI, PID are analyzed with system for applying 10%SLP on area-1 one at a time. The parametric gains are found with GWO. Responses of system are compared in Fig.3, and the settling time (TS) is noted in Table 1. On analyzing Fig.3, it is elucidated that the system responses are greatly improved with FOPID based controller when compared to other controllers. The controller parameters are noted in Table 2.

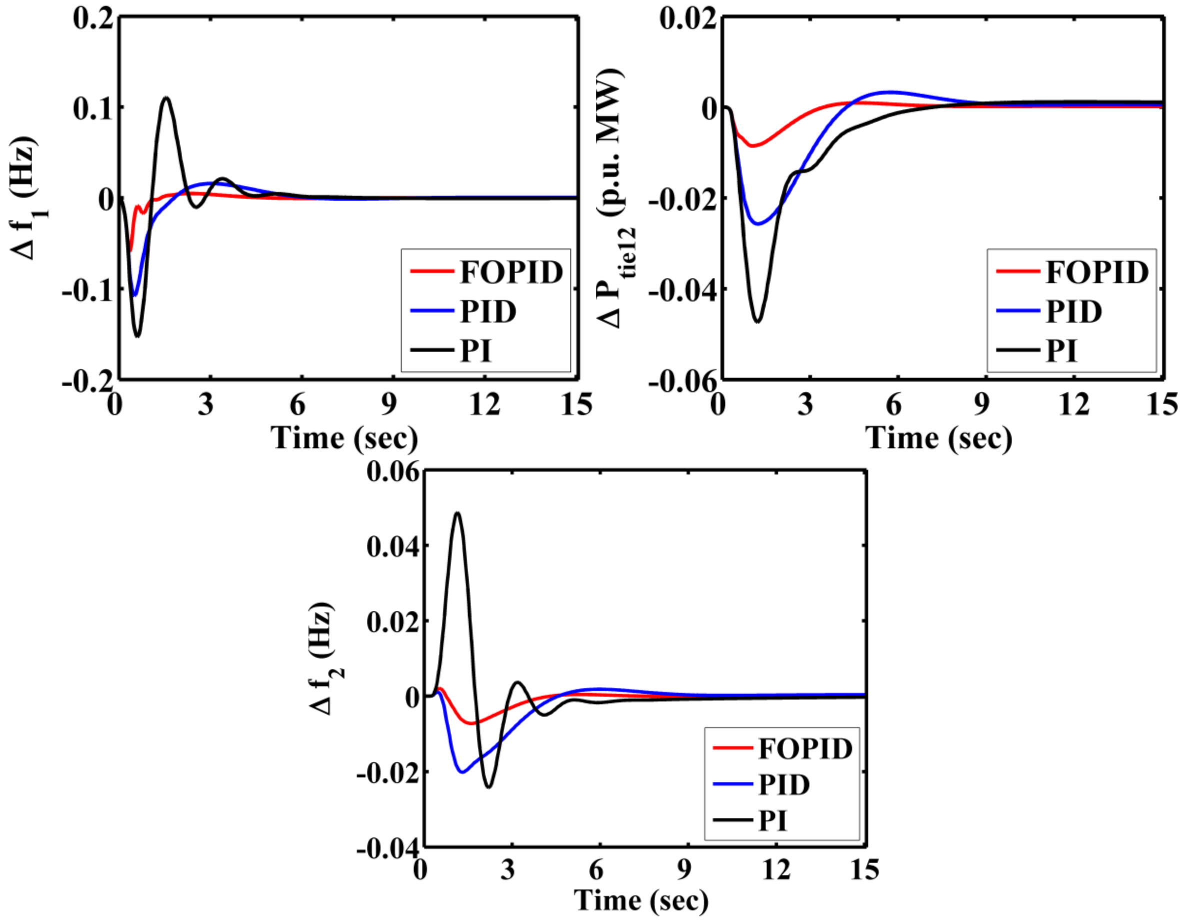

Fig.3 System responses under various controllers optimized with GWO algorithm

Table 1. Settling time of the responses under various cases

Parameters	**Settling time (T_S)**			
	PI:GWO	**PID:GWO**	**FOPID:GWO**	**FOPID:GWO with HVDC incorporation**
Δf_1	9.56	7.62	6.69	5.45
ΔP_{tie12}	10.39	8.78	5.85	5.04
Δf_2	8.93	8.87	5.96	4.97

Table 2. Optimal gains of the controller

Controller	**PI:GWO**	**PID:GWO**	**OPID:GWO**	**OPID:GWO with HVDC incorporation**
Area-1	K_P=3.0972 K_I=1.9361	K_P=4.0132 K_I=2.7610 K_D=1.9972	K_P=3.0936 K_I=1.9784 K_D=2.0135 λ=0.7084 μ=0.1026	K_P=3.8745 K_I=2.0137 K_D=1.9803 λ=0.6728 μ=0.0976
Area-2	K_P=2.6850 K_I=1.7894	K_P=3.7609 K_I=2.7581 K_D=1.7894	K_P=3.0862 K_I=1.6850 K_D=2.2060 λ=0.6978 μ=0.1343	K_P=3.8992 K_I=2.1098 K_D=1.7904 λ=0.7180 μ=0.2117

Case-2: System performance with FOPID optimized with different algorithms

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The superiority of GWO optimizer is showcased up on comparing with other algorithms that are covered in literature like PSO, ABC and CSA algorithms performance. The dynamic responses under FOPID controller optimized with the above algorithms are compared in Fig.4, and it is revealed that the system responses are better with GWO optimized FOPID and the performance objective index value is also improved and is compared in Fig.5.

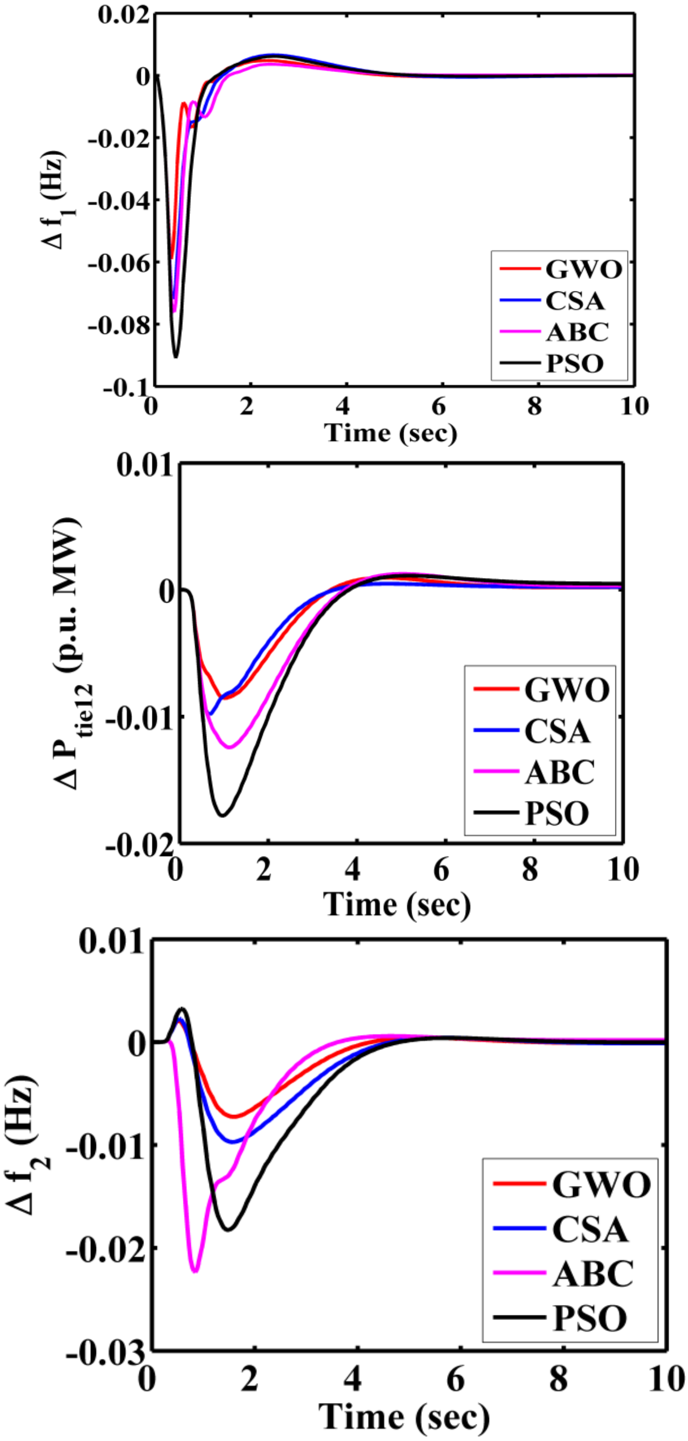

Fig.4 System responses with FOPID controller optimized with various algorithms

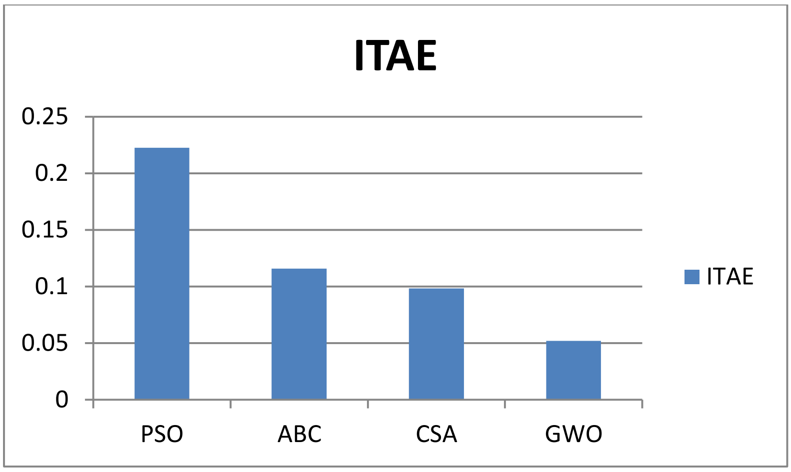

Fig.5 Comparison of objective function values with optimization algorithms

Case-3: System performance by incorporating HVDC line

Furthermore, the test system under investigation is integrated with HVDC in order to facilitate bulk power transfer capacity. The corresponding responses are depicted in Fig.6, and the settling time is noted in Table 1 and the gains are noted in Table 2. The deviations in tie-line along with the system frequency deviations are very much regulated by incorporating HVDC line with AC tie rather than AC line only.

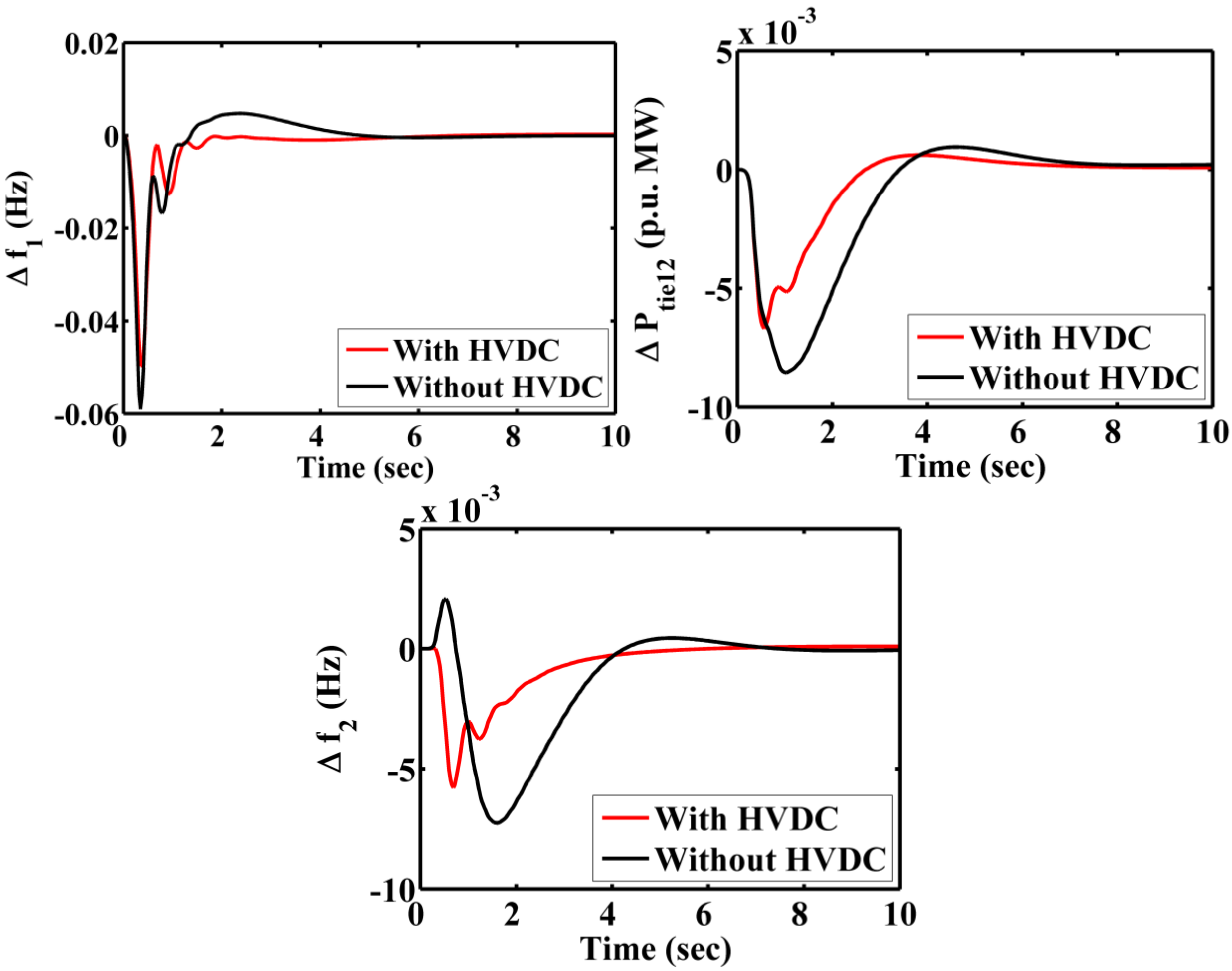

Fig.6. System responses with GWO optimized FOPID and incorporating HVDC line

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6.CONCLUSION

The performance of FOPID controller in AGC domain is investigated on two-area system with more practical constraints in this paper. 10%SLP is laid on area-1 for analysis purpose. The performance superiority of GWO optimized FOPID controller is demonstrated by comparing its performance with other classical controllers. Moreover, the algorithms efficacy is deliberated with performance of other algorithms like PSO, ABC and CSA. Furthermore, the test system is integrated with HVDC line along with existing AC line. Investigation reveals that, system performance is predominantly enhanced with HVDC line incorporation.

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