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Research paper

GWO tuned multi degree of freedom PID controller for load frequency control

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Abstract

In order to enhance the control action, in this article multi degree of freedom PID controllers (MDFPID) like 2DOF-PID and 3DOF-PID controllers are suggested for frequency control in a multi-unit hydro-thermal interconnected system. The finest gains of the recommended MDFPID controllers are achieved with Grey Wolf Optimization (GWO) Technique considering a time based evaluative function. The dom-inating performance of the suggested control technique is validated by relating the outcomes with a pre-published journal results. The robust behavior of the MDFPID controller is also validated by abruptly amplifying the loading of the system. The system dynamic responses are analyzed in consideration with time response parameters like minimum undershoots, settling time and peak overshoots.

Keywords: *Keywords: Hydrothermal System; Grey Wolf Optimization, Load Frequency Control; Multi Degree Freedom of Proportional-Integral-Derivative Controller.*

1. Introduction

Automatic generation control is the most vital part of an interlocked power system, which is the solution to many problems in the mod-ern management systems. AGC helps in maintaining the frequency to its desired/nominal value as well as it also helps in transferring power in the scheduled value. There should be proper balancing be-tween the total power generated with the total load demand of a particular area thereafter the interconnected power system will be properly operating [1].

Comprehensive literature surveys have been carried out and many researchers have investigated and proposed large varieties of solu-tions on this particular area of concern over the few past years. Back in the year of 1970, NAPSIC or generally known as ''North Amer-ican Power Systems Interconnection Committee'' recommended that each region should set their frequency bias equaling the char-acteristics of the responses of the area frequencies [2]. Farahani used LCOA i.e. Lozi map-based chaotic technique to optimize the gains of the PID controllers in a two-area power system. The results have been compared with various other techniques in the paper [3].The proposed technique in the paper [4] is a self-tuning tech-nique which is used to tune the PI along with the PD types fuzzy-logic controllers, moreover it is compared on the basis of ITAE, IAE, settling time, rise time ,etc., with the conventional FLC's. An optimal feedback-output controller is used in a control system in-volving of thermal along with hydro & gas generating units, also taking into considerations about the generation rate-constraints in the paper [5]. The dynamic performances of the proposed controller are co-related with the full-state feedback controllers. Rabindra et al [6] designed and investigated about the differential evolution al-gorithm basing upon the PI controller, considering a non-reheat thermal system for a two-area system and the outcomes were also compared with the modern techniques such as BFOA & GA with the proposed controller. In the paper [7], a very efficient hybrid op-timization technique is used i.e., Genetic Algorithm with Particle-Swarm Optimisation (HGAPSO) for optimally tuning the FPI con-trollers of a multi-area control system. Paper [8] deals with the in-tegral/proportional-integral type controller in AGC of thermal type and hydrothermal type system. The superior characteristics of the electrical hydro governor are highlighted against mechanical hydro governor. Saroj Pradhan et al [9] investigated and highlighted the superiority of the firefly algorithm optimization technique over other optimization methods for the two areas containing thermal type system. The investigations also further include the multi-area type thermal system comprising generation rate constraints. Paper [10] considers listing about the thermal-hydro two-area system. PID controllers are used to be tuned by the hybrid firefly algorithm and pattern search technique where the output is compared with the other methods. Proportional-integral-double derivative controller or simply PIDD controller is used in paper [11] for the control of frequency of a two-area power system considering thermal-reheat type system, implementing the Teaching & learning based optimi-zation method for optimization process. Furthermore, the investiga-tion is also extended on a three-area but unequal system. Paper [12] highlights about the maiden application of a hybrid technique, LUS-TLBO or Local Unimodal sampling-Teaching & Learning based optimization basing upon the fuzzy-PIDF for LFC in a hybrid power system. A simple and new optimization algorithm known as GWO algorithm in paper [13] is applied for AGC to solve many problems regarding the proper management of power system. Sasmita et al [14] investigated as well as designed a hybrid yet very superior optimization technique, stochastic fractal Search-Pattern Search technique basing upon cascaded PI-PD controller on a hy-brid powr system. To overcome the challenges and problems cre-ated by the growing percentage wind energy for the instability in the grid which is stated in paper [15], an automatic online gain estimation algorithm using the PSO technique is implemented to optimize the controller gains so as to maintain a uniform frequency. The work in the paper [16] reflects about the application of FPA or flower-pollination algorithm, which is used to optimize the parameters of the PID controller gains of an interconnected structure having multi areas.

The above research study indicated that adequate numbers of research work were carried on single loop control action but in this research work emphasis has been given to develop two and three independent control loop to regulate frequency in control area during disturbances.

2. System investigated

An investigation has been carried out over a two area of hydro-thermal type power system of 2000 MW interconnected to each other through tie line. Fig.1 signifies the transfer function model of the recommended system. The rated values of the parameters of the scrutinized model are taken from article [10]. Distinct controllers are employed for each unit of the power system. The ACE (Area control error) of each area behaves as the input signal to the suggested GWO tuned MDFPID controller. This described system is surveyed with abrupt perturbations of 0.15pu in area 1 and further also studied by incremental load demand. The ACE can be mathematically expressed as:

$$ACE_i = B.\Delta f_i + \Delta p_{tie}$$

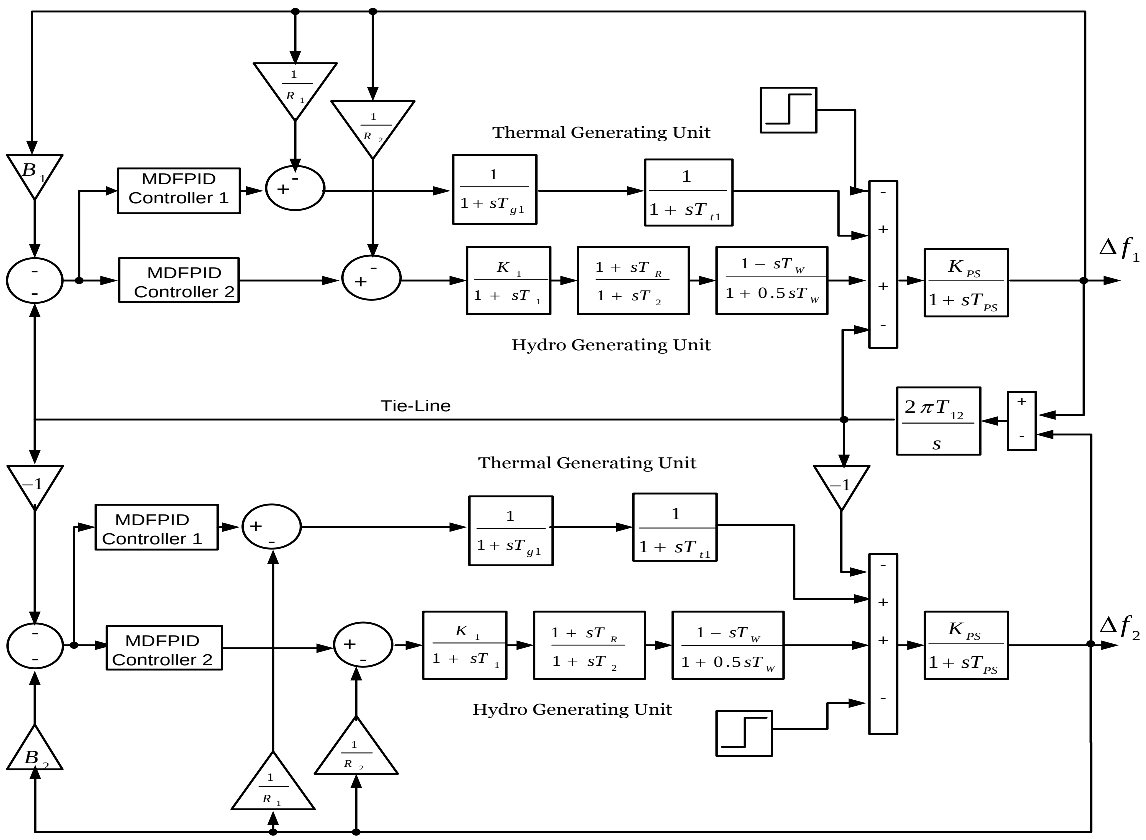

Fig. 1: Two-Area Two-Unit Hydrothermal System Represented by Transfer Function.

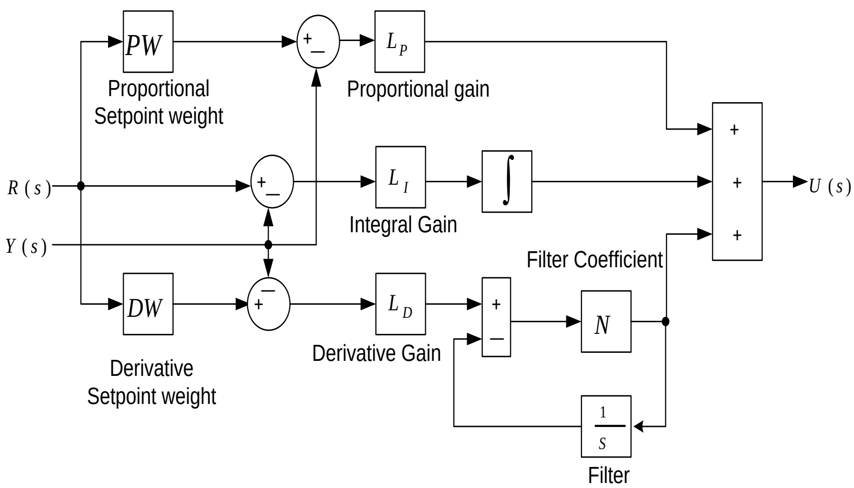

Fig. 2: Organization of Two Degree of Freedom PID (2DOF-PID) Controller.

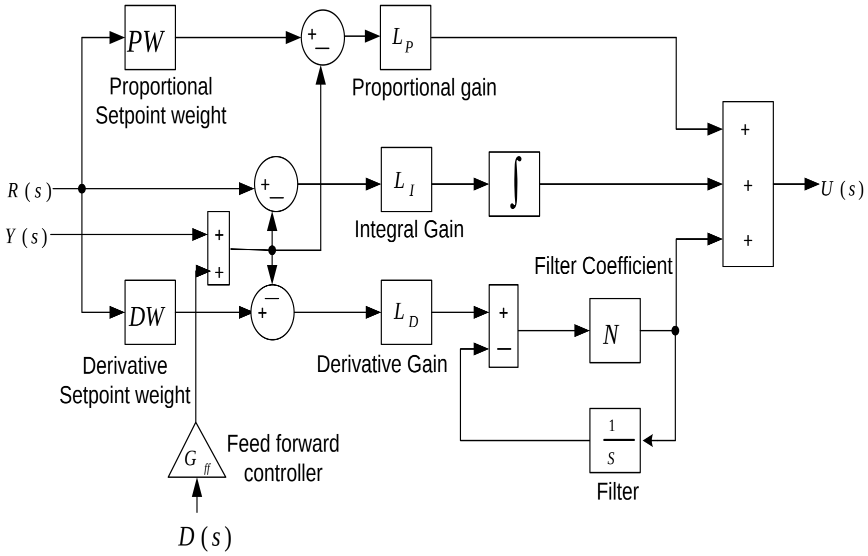

Fig. 3: Design of Three Degree of Freedom PID (3DOF-PID) Controller.

3. Proposed approach

3.1. Design of controller

The number of control loops which can be controlled independently while performing the control action is known as degree-of-freedom. This paper details about the implementation of 2DOF-PID controller along with 3DOF-PID controller. Both the controllers include multiple control loops like 2DOF-PID consists of double control loops and 3DOF-PID consists of triple control loops. The output signal which is produced by the 2DOF controller is the difference between reference valued signal and system measured output. The properties of the three loops of 3DOF controller comprises: i) elimination of disturbances ii) shaping the response of closed loop iii) improving the stability of the closed loop. The inside structures for both the controllers are shown in the Fig. 2-3 where, $R(s)$ is denoted for the reference input signal, $Y(s)$ is the feedback signal from the system measured output & $U(s)$ represents for the input to the generating unit. The extra loop in the 3DOF-PID controller denoted as $D(s)$ represents for the disturbances in the system. G_{ff} stands for feed forward controller gain in the 3DOF controller. The 3DOF-PID controller unveils having seven parameters as seen from the architectural design of the controller. In the outlined figures for both the controllers; the derivative, integral as well as proportional control gains are denoted as $K_D, K_I \,\&\, K_P$ respectively, N denoted for the coefficient of the derivative filter, finally PW & DW is proportional set-point weight and derivative set-point weight respectively.

3.2. Grey wolf optimization

Grey wolf optimization technique is a population based meta-heuristics algorithm that based on the leadership and hierarchy mechanism of gray wolves and suggested by Mirjalili et al. in 2014. Grey wolves come under the category of four levels of social dominant hierarchy and most likely live in a pack containing 5-12 members on average. The first level called as alpha (α) consider as leaders in a group and answerable for making decisions regarding sleeping place, time to walk and so on. All other levels of wolves have to obey their decisions by holding their tails down. The second level beta wolves are considered as the subsidiary wolves who deliver the command of alpha to all the member of pack and feedback to alpha. They also help alpha wolves for decisions making and also reflect the best aspirant when the alpha dies and get old. The third level delta wolves have to obey the decisions of alpha and beta but can rule the fourth level hierarchy omega wolves. Scouts, sentinels, elders, hunters and care takers wolves are belong to several categories of delta wolves in a group. The fourth level wolves named alpha have to follow all other leading wolves. The hunting process normally conducted by alpha and wolves encircle prey. The below mathematical model is used for enclosing the prey

$$D = |C.X_P(t) - A.X(t)|$$
$$X(t+1) = X_P(t) - A.D$$

Here t, X_P and X is known as current position, location vector of victim and location vector of wolf respectively. A and C is known as coefficient vectors and calculated as

$$A = 2a.r_1.a$$
$$C = 2.r_2$$

Alpha, beta and delta are first three best solutions and other wolves have to update their locations rendering to best search agents by ensuing the below equations.

$$D_\alpha = |C_1.X_\alpha - X|$$
$$D_\beta = |C_2.X_\beta - X|$$
$$D_\delta = |C_3.X_\delta - X|$$
$$X_1 = X_\alpha - A_1.(D_\alpha)$$
$$X_2 = X_\beta - A_2.(D_\beta)$$
$$X_3 = X_\delta - A_3.(D_\delta)$$
$$X(t+1) = \frac{X_1 + X_2 + X_3}{3}$$

The whole process of hunting is finished when the wolves attack prey and stop moving. The component 'a' linearly reduced from 2 to 0 and the random vectors varies in [0-1]. When |A|<1 the wolves attack towards the prey and |A|>one, the wolves are enforced to deviate from the prey and discover a fitter prey. The grey wolf finish the hunt by attacking the prey when its stop moving.

4. Result and analysis

A two area hydro thermal type power system is modeled and simulated in Matlab 2016 Simulink software. The nominal parameters of this model are taken from [10]. The MDFPID controllers are implemented in both areas as the secondary controller to maintain the stability. The parameters of the controllers are optimized by Grey wolf optimization technique. The Integral time absolute error is taken as the objective function which is expressed in below

$$ITAE = \int (|\Delta f_1| + |\Delta f_2| + |\Delta p_{tie}|) t.dt$$

To verify the supremacy, the performance of this recommended system is examined under two cases.

4.1. Case 1: A SLP of 1.5% in area 1

A step load disruption of 1.5% is implemented to area one consists of hydro-thermal system. The optimum gains of the MDFPID (2-DOF-PID and 3-DOF-PID) controllers are presented in Table I. Figures 3, 4 and 5 signify the frequency deviation of area 1, area 2 and the tie-line power respectively. The results are compared with the control action of PID controllers [10]. The plots clarify that the act of the MDFPID controller is faster than that of PID controllers [10]. The system robustness is further established by analyzing the vigorous performance of this suggested system concerning performance indices like maximum overshoot, settling time and least undershoot. Table 2 lists the values of the performance responses for PID and the proposed MDFPID controllers. The least values of each index clearly indicate the supremacy of the proposed controller.

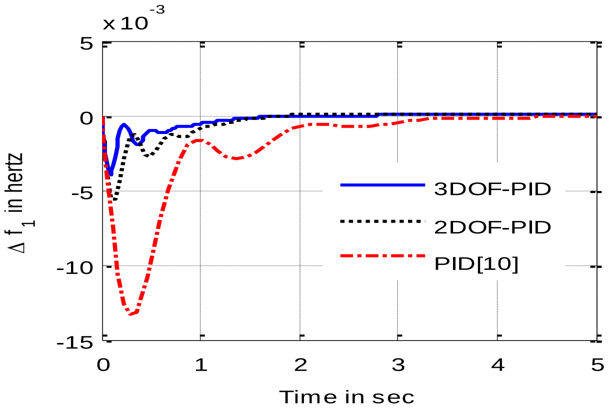

Fig. 3: Oscillations of Area 1 Frequency.

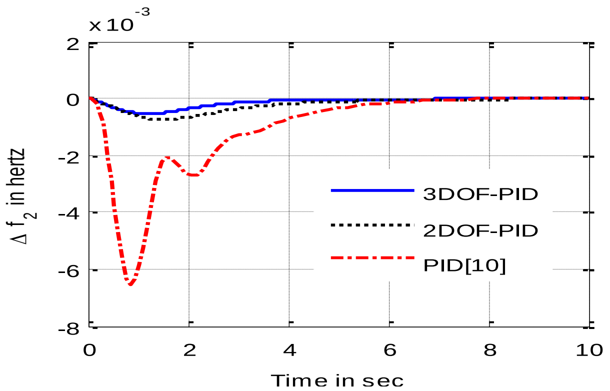

Fig. 4: Oscillations of Area 2 Frequency.

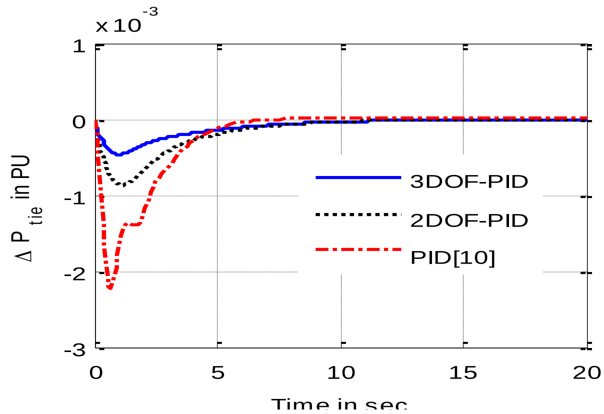

Fig. 5: Oscillations of Tie-Line Power.

4.2. Case 2: abrupt change in loading by 10%

This hydro-thermal system is now subjected to an abrupt increase of load in area 1 by 10%. Figures 6, 7 and 8 display the fluctuations in frequency in area one, area two and exchange of tie-line power respectively. The simulation outcomes are correlated with the pre-published PID controller [10].The minimum values of the settling time, maximum and minimum overshoot shows the preeminence of the projected controller over the traditional PID controller [10].

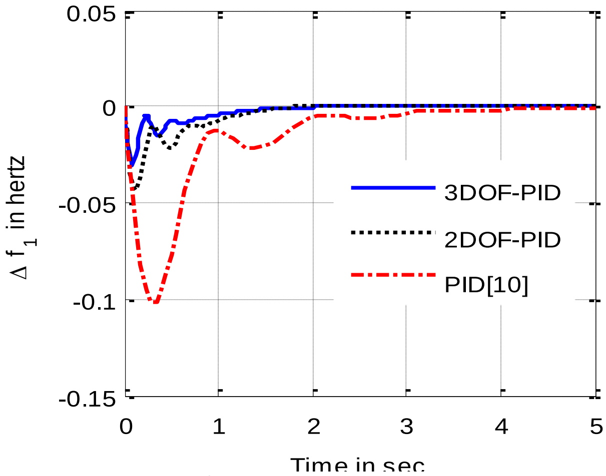

Fig. 6: Oscillations of Area 1 Frequency with Load Enhancement.

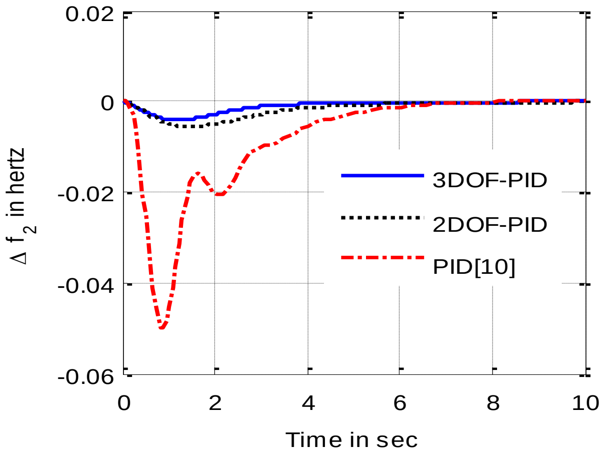

Fig. 7: Oscillations of Area 2 Frequency with Load Enhancement.

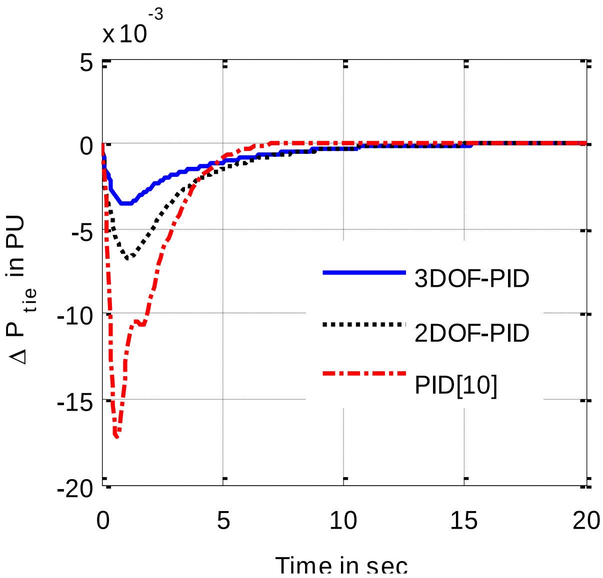

Fig. 8: Oscillations of Tie-Line Power with Load Enhancement.

Table 1: The Finest Gains of MDFPID/PID Controllers Obtained by GWO

3-DOF PID													
Thermal							Hydro						
G_{ff}	L_P	L_I	L_D	N	PW	DW	G_{ff}	L_P	L_I	L_D	N	PW	DW
0.001	3.349	3.869	2.399	199.9	2.798	0.997	0.001	0.010	0.012	0.0111	71.18	0.2395	1.412
2-DOF PID													
L_P	L_I	L_D	N	PW	DW		L_P	L_I	L_D	N	PW	DW	
3.0525	2.2810	1.7763	84.289	0.9920	0.1000		2.3980	0.0100	2.2955	11.968	3.6820	0.6116	
PID [10]													
L_P	L_I	L_D	L_P	L_I	L_D		L_P	L_I	L_D	L_P	L_I	L_D	
1.8457	1.6563	0.6109	-0.4525	0.1378	0.4120		1.292	1.8748	0.4041	-1.0720	-1.3785	0.4541	

Table 2: Settling Time, Peak Overshoots and Undershoot.

Change	Settling time (T_s) , Peak Overshoot(O_{sh}) & Undershoot	3-DOF PID	2-DOF PID	PID [10]
	T_s (sec)	1.9508	3.7416	5.5512
Δf_1	$O_{sh} \times 10^{-4}$	0	0	0.1358
	Undershoots	-0.0039	-0.0056	-0.0133
	T_s (sec)	5.0995	6.8760	7.0908
Δf_2	$O_{sh} \times 10^{-4}$	0	0	0.1322
	Undershoots	-0.0005	-0.0007	-0.0066
	T_s (sec)	8.1814	8.9839	5.7528
ΔP_{tie}	$O_{sh} \times 10^{-4}$	0	0	0.0683
	Undershoots	-0.0005	-0.0009	-0.0022

5. Conclusion

This work implemented MDFPID controllers like 2DOF-PID and 3DOF-PID controllers to regulate the frequency in each control area of the scrutinized unified system consisting of thermal and hydro generating units. It also demonstrated that the recommended MDFPID controllers exhibit superior performance as compared to existing PID controllers in terms of response indices like minimum undershoots, settling time and peak overshoots. After successful implementation of MDFPID controllers it can be indicated that by increasing the numbers of control loop the performance of the system also increases. Finally it also demonstrated that the proposed method is robust as it can successfully handle the deviations of frequency and interline power during abrupt load variations.

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