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TECHNICAL PAPER

Design of MI fuzzy PID controller optimized by Modified Group Hunting Search algorithm for interconnected power system

Jyoti Ranjan Nayak[1] · Binod Shaw[1] · Sudeepa Das[2] · Binod Kumar Sahu[3]

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Abstract

This paper is validated the multi inputs (two inputs) fuzzy PID (MIFPID) controller as automatic generation control (AGC) over two disparate consolidation of single input FPID (SIFPID-1 and SIFPID-2) controller for a two area interconnected power system. The objective function is formulated by concerning undershoot, overshoot, and settling time of frequency and tie-line power deviation of the power system by implementing two different SIFPID and MIFPID controllers individually as AGC in each area. Modification of Group Hunting Search optimization (MGHS) is proposed to optimize the gain parameters of controllers to minimize the multi-objective problem with constraint. All the performances of these controllers as AGC are examined by implementing a load disturbance of 1% (0.01 p.u.) in area-1. Finally, MIFPID controller optimized by MGHS algorithm contributes better performance in the proposed system.

1 Introduction

In complex power system, interconnection between two areas enhances the quality of the supply power, stability of the system and capability to utilize the generating plant. Load deviation arises numerously which affects the power and system frequency deviation all over the power system. Primary controllers (rotating mass of such as governor and turbine of the system) may not overcome the large deviations (Kundur 1994). These enormous load deviations may be taken care by secondary controller like proportional (P), integral (I), derivative (D), PID, fuzzy, and etc. proportional (P), integral (I), derivative (D), PID, fuzzy, and etc. are used as secondary controller to enhance the capability to handle the load fluctuations in the power system. The primary purposes of the AGC are to:

1. Achieve the system frequency equal to its scheduled frequency (i.e. $\Delta f = 0$).
2. Achieve the power through tie-line equal to its scheduled value (i.e. $\Delta P_{tie} = 0$).
3. Achieve a superior control to minimize the objectives (settling time, undershoot, and overshoot) of the system after any load fluctuation.

To enhance the ability of the AGC to achieve better regulation over these specifications, fuzzy PID is one of the superior controller. In this work two different consolidations of FLC and PID are implemented in each area of the power system. Transfer function model of thermal with GRC and hydro power plant are used as generation units in area-1 and area-2 respectively. Controller's gain parameters are another decisive aspect also to enhance the transient performance of the system. So selection of optimization technique is a significant aspect to grab the optimal solution of the gain parameters to lessen objective function (ITAE).

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✉ Jyoti Ranjan Nayak
bapi.jyoti.2@gmail.com

Binod Shaw
binodshaw2000@gmail.com

Sudeepa Das
sudeepa.das1992@gmail.com

Binod Kumar Sahu
binodsahu@soauniversity.ac.in

[1] Department of Electrical Engineering, National Institute of Technology, Raipur 492010, India

[2] Department of Computer Science Engineering, Hi-Tech College of Engineering, Bhubaneswar 751025, India

[3] Department of Electrical Engineering, Siksha O Anusandhan University, Bhubaneswar 751030, India

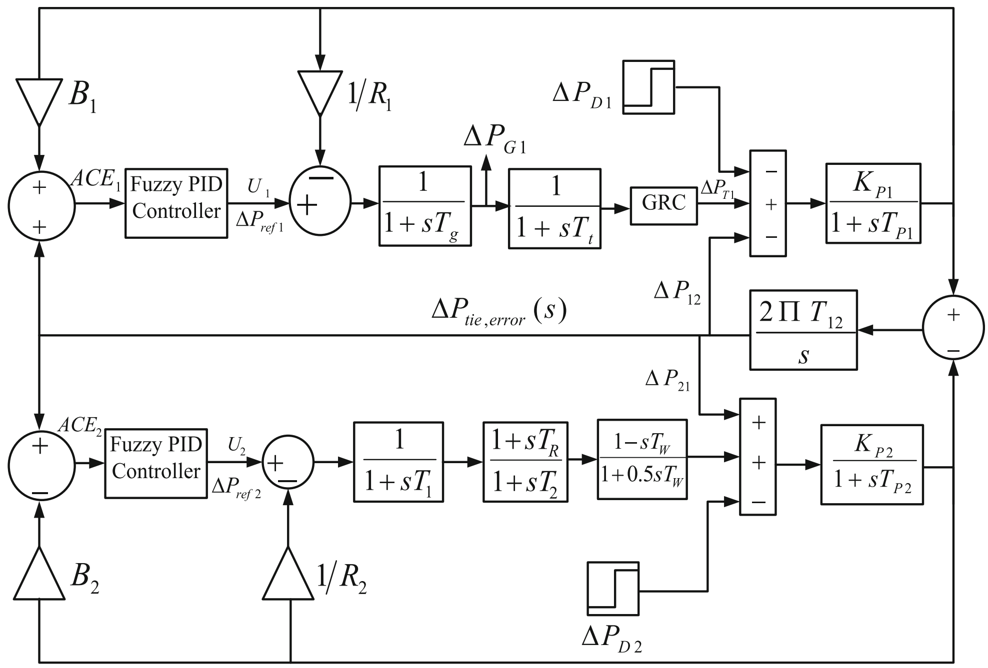

Fig. 1 Power system model (Nayak et al. 2017)

AGC is the most indispensable strategy in the power system which concerns the economic and stable power generation. To enhance the power quality many ideas have implemented to enhance the secondary controller as AGC. Some researchers (Ibrahim and Kothari 2005) have portrayed a relative analysis of various schemes implemented as AGC. The adequacy of superconducting magnetic energy storage (SMES) over integral controller used as AGC in a two area interconnected hydro-thermal system is distinguished by (Abraham et al. 2007). GA optimized PID controller has successfully implemented in an interconnected power system with thermal units (Singh and Sen 2004). Cascade controller titled as PI-PD controller optimized by FPA is introduced in four area interconnected reheat thermal power plants (Dash et al. 2016). Fuzzy logic controller (FLC) has convinced as a very robust and intelligent controller used as AGC (Indulkar and Raj 1995; Cam and Kocaarslan 2005; Oftadeh et al. 2010). The robustness of FPID controller is enhanced with the assemblage of advantages from both PID and FLC controller. FPID controller (Pande and Kansal 2015) optimized by different powerful algorithms have depicted (Sahu et al. 2016; Nayak et al. 2015; Pati et al. 2014, 2015). PSO (Kennedy and Eberhart 1995) is applied to optimize PID controller as AGC (Ghoshal 2004). Application of various novel metaheuristic techniques and hybridization among them like BF (Nanda et al. 2009), BFOA-PSO (Panda et al. 2013), DE (Rout et al. 2013), FA-PS (Sahu et al. 2015a, b), FPA (Madasu et al. 2016), TLBO (Sahu et al. 2015a, b), ALO (Satheeshkumar and Shivakumar 2016) and CS (Sikander et al. 2017) to optimize the parameters of different controllers adequately.

In this paper, the GHS algorithm is modified by replacing the worst candidates by randomly generated candidate. The probability to hunt optimum solution is enhanced by this process. The multi inputs fuzzy PID controller is validated over two distinct combinations of single input fuzzy PID controllers. The two different combinations of SIFPID controllers are SIFPID-1 and SIFPID-2. In SIFPID-1, ACE is the only input of the controller and in SIFPID-2, ACE and ΔACE are the inputs to two FLCs. The novelties of this paper are:

1. The MIFPID controller is validated over two distinct combinations of SIFPID controller in AGC.
2. The GHS algorithm is modified to enhance the capability to hunt optimum pair of controller gains.
3. The effect of non-linearity in power system.

Finally, MGHS technique optimized MIFPID controller is validated over other combinations of SIFPID controllers.

2 Power system modelling

The proposed system is a two area interconnected hydro-thermal power system. Area-1 consists of thermal power plant with generation rate constraints (GRC) and area-2 consists of a hydro power plant as delineated in Fig. 1. The transfer function parameters are mentioned in Appendix 1. Implementation of a load disturbance of 1% (0.01) in thermal area propagates error in each area titled as area control errors (ACE_1 and ACE_2). ACEs concerning deviations of frequency and tie-line power has to be minimized and may be defined as:

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie}, \quad (1)$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{tie}, \quad (2)$$

where B_1 and B_2 are the bias factors of frequency. The deviations of frequency with respect to nominal value in area-1 and area-2 are Δf_1 and Δf_2 respectively. The deviation of power in tie-line is ΔP_{tie} and is characterized as:

$$\Delta P_{tie} = \frac{2\pi T_{12}}{s}(\Delta f_1 - \Delta f_2). \quad (3)$$

SIFPID-1, SIFPID-2 and MIFPID controllers are executed in both the areas individually to examine the controller effectiveness to enhance the system performance. Intelligent MIFPID controller is observed as superior controller over SIFPID-1 and SIFPID-2 controllers. Compilation of advantages of both PID and FLC causes the FPID controller more precious and novel. The objective function for this system by concerning tie-line power deviation and frequency deviation is characterized in Eq. (4):

$$ITAE = \int_0^T t(\Delta f_1 + \Delta f_2 + \Delta P_{tie}) \quad (4)$$

$$\text{Subject to } 0.01 \le K_i \le 2,$$

where i = 1, 2, 3, …, n. 'n' is the numbers of design parameters.

3 Controller structure

The performance of the power system is primarily rely upon the controller design. Fuzzy logic controller (FLC) is adopted by many researchers as controllers from last few decades. In this purposed system, three distinct combinations of PID and FLC (SIFPID-1, SIFPID-2 and MIFPID) are adopted as controllers as portrayed in Fig. 2. The membership functions of all FLCs portrayed in Fig. 3 are adopted for all the controllers. Five MFs titled as negative high (NH), negative low (NL), zero (Z), positive low (PL), and positive high (PH) as delineated in Fig. 3 are adopted for all the controllers.

In SIFPID-1 controller, ACE is adopted as the only input of the controller as portrayed in Fig. 2a. In SIFPID-2 controller, two FLC are adopted in which ACE and ΔACE are the corresponding inputs of the two FLCs as shown in Fig. 2b. The rules for both SIFPID-1 and SIFPID-2 are as follows.

If input is NH then output is NH.
If input is NL then output is NL.
If input is Z then output is Z.
If input is PL then output is PL.
If input is PH then output is PH.

In MIFPID controller, ACE and ΔACE are adopted as two inputs to the FLC as illustrated in Fig. 2c. Table 1 encloses the rules of MIFPID controller.

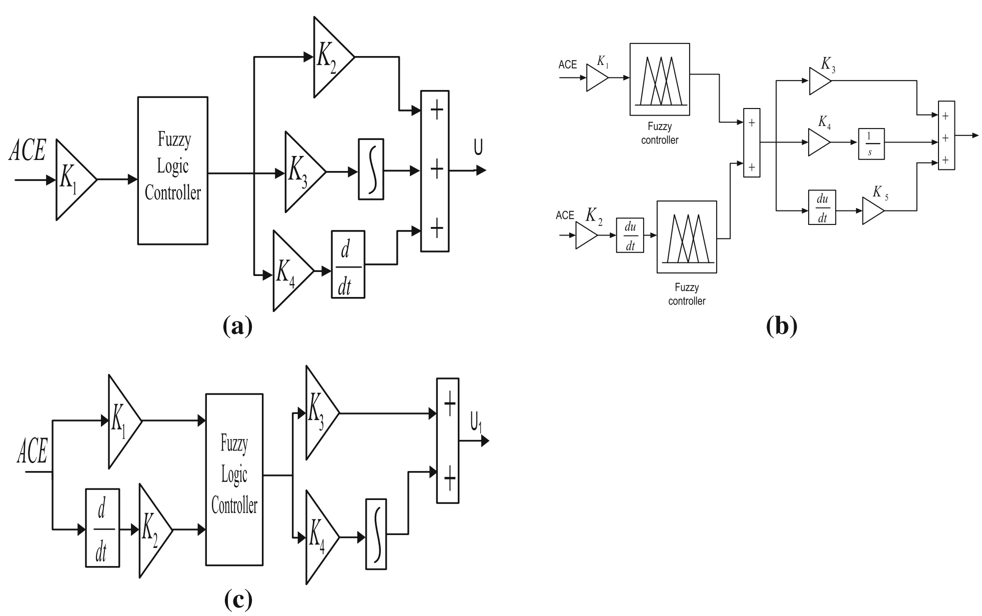

Fig. 2 **a** SIFPID-1 controller structure, **b** SIFPID-2 controller structure, **c** MIFPID controller structure

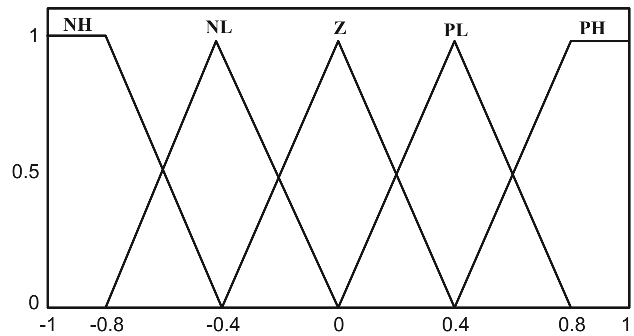

Fig. 3 Membership function structure of FLC

Table 1 Rule base

e	ė				
	NH	NL	Z	PL	PH
NH	NH	NH	NL	NL	Z
NL	NH	NL	NL	Z	PL
Z	NL	NL	Z	PL	PL
PL	NL	Z	PL	PL	PH
PH	Z	PL	PL	PH	PH

4 Modified Group Hunting Search (MGHS) algorithm

The relation between predator (group hunters i.e. lions, wolves etc.) and prey is beautifully expressed as optimization technique (Oftadeh et al. 2010). GHS algorithm is derived from the strategy of hunting a prey by concerning the group hunting technique. Unity of group members adopt an approach to trap the prey by circumscribing it. The member of the group near to the prey is adopted as leader and all other member follows leader to move towards the prey (optimum solution). If any of the group member amends by a better position compared to the recent leader then it becomes leader in the next generation. The hunters in each generation follows the leader by concerning maximum moments towards the leader (MML). MML affects the algorithm to maintain the balance between exploration and exploitation. If the MML value is large then the algorithm may skip over the optimum point and small value of MML may reduce the diversity factor of algorithm. In MGHS, the MML value is decaying constantly with iteration. The worst hunters in the group are replaced by other random numbers to enhance the probability to get optimum point. The stride of the MGHS are as:

1. Initialize the population randomly of size $X_{[NP\times D]}$ within the limit 0.01–2.
2. The best fitted hunters among the group is adopted as leader.
3. The hunter's positions are refurbished towards the leader. The mathematical expression is defined in Eq. (5):

$$X_i^{k+1} = X_i^k + rand \times MML \times (X_i^L - X_i^k). \tag{5}$$

$$MML = 0.6 - \left(it \times \left(\frac{0.6}{iter\max} \right) \right),$$

where 'it' is the current iteration, itermax is the maximum iterations and X_i^L is the position of leader.

4. The position of hunters are corrected as in Eq. (6) by concerning hunter's group consideration rate (HGCR) and distance radius (R_a):

$$X_i^{k+1} = \begin{cases} X_i^{k+1} \in \{X_i^1, X_i^2, \ldots, X_i^{HGS}\}\, with probability\, HGCR \\ X_i^{k+1} \pm R_a\, with probability\, (1 - HGCR) \end{cases}, \tag{6}$$

$$Ra(it) = Ra_{\min}(\max(X_i) - \min(X_i)) \exp\left(\frac{\ln\left(\frac{Ra_{\min}}{Ra_{\max}}\right) \times it}{iter\max} \right), \tag{7}$$

Ra is an exponential decay function expressed in Eq. (7).

5. Identify the group to avoid the algorithm to be trapped into local optima. It may be defined as in Eq. (8):

$$X_i^{k+1} = X_i^L \pm rand(\max(X_i) - \min(X_i)) \times \alpha \exp(-\beta \times EN), \tag{8}$$

Table 2 GHS and MGHS optimized gain parameters of different controllers

Controllers	Gains	Optimum values of gains			
		GHS		MGHS	
		Area 1	Area 2	Area 1	Area 2
SIFPID-1	K_1	0.7465	1.0939	1.4733	0.7399
	K_2	1.0064	0.3884	0.6076	0.3168
	K_3	1.4768	0.2902	0.9599	0.266
	K_4	1.6133	1.0696	0.3545	1.4670
SIFPID-2	K_1	1.3000	0.0100	2.0000	2.0000
	K_2	1.1254	2.0000	0.0128	2.0000
	K_3	1.7562	0.0100	1.5233	0.0100
	K_4	1.3943	0.0100	2.0000	0.0100
	K_5	1.0444	0.4349	0.8099	0.2395
MIFPID	K_1	0.9243	0.1936	**1.6675**	**0.0865**
	K_2	0.8923	1.1021	**0.5047**	**1.7871**
	K_3	0.4925	0.9031	**1.4966**	**0.6354**
	K_4	1.3338	0.1388	**1.5032**	**0.1055**

The best values are shown in bold

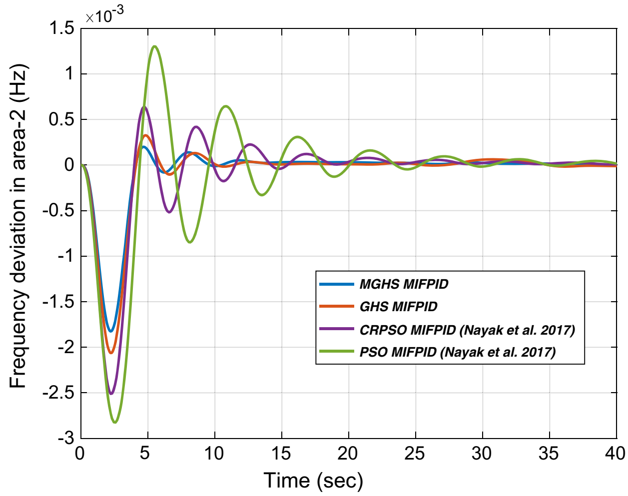

Fig. 4 Frequency deviation in area-2 of hydro-thermal power system without GRC

where EN is the numbers of epochs. EN is estimated by matching the difference of leader and worst hunter with a small value.

6. The worst hunters are replaced by the random numbers to enhance the probability to extract optimum point as expressed in Eq. (9):

$$count = find((f(X_i^L) + M) < f(X_i))$$
$$X_i(count) = \min(X_i) + rand \times (\max(X_i) - \min(X_i)). \quad (9)$$

7. Repeat steps 3–6.

In Appendix 2 all the specifications of MGHS are portrayed.

5 Results and discussion

GHS and MGHS algorithms are executed for 100 iterations to resolve the steps to discover the optimal gain parameters of SIFPID-1, SIFPID-2 and MIFPID controllers. Variables K_1, K_2, K_3, and K_4 are adopted as the design variables for SIFPID-1 and MIFPID as portrayed in Fig. 2a, c. K_1, K_2, K_3, K_4 and K_5 are the design variables of SIFPID-2 controller. The values of the above mentioned parameters are characterized within the perimeter 0.01–2. Table 2 represents the gain parameters of the different controllers optimized by GHS and MGHS algorithm. The GHS and MGHS algorithm is validated by comparing with PSO and CRPSO described in Nayak et al. (2017).

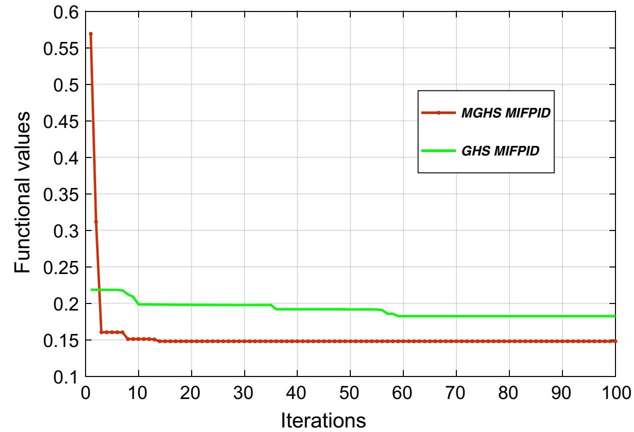

Fig. 5 Convergence plot

The deviation of frequency in area-2 of interconnected hydro-thermal power system without GRC is illustrated in Fig. 4 to contrast the proposed algorithm over PSO, CRPSO and DECRPSO algorithm to optimize FPID controller. The controller gain parameters of the system without GRC is tabulated in Table 3.

The convergence plot to validate the GHS and MGHS algorithms optimized different controllers is illustrated in Fig. 5. The power deviation in tie-line and frequency deviations of both areas by implementing different controllers optimized by different algorithms are portrayed in Figs. 6, 7 and 8.

The settling time (T_s), peak overshoot (O_{sh}), and peak undershoot (U_{sh}) are the objectives which are used to discriminate the performances of the controllers. Settling time is evaluated by considering a dimension of $\pm$ 0.002% (2×10^{-5}) of final value. T_s, U_{sh}, and O_{sh} of the system are minimum with MIFPID controller optimized by MGHS algorithm as reported in Table 4.

MIFPID controller optimized by MGHS algorithm is validated as the better controller over SIFPID controller.

Table 3 Optimal values of gains of MIFPID controller to validate the GHS and MGHS over (Nayak et al. 2017) without GRC

Algorithms	Optimum values of gain							
	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8
PSO (Nayak et al. 2017)	1.3665	1.5616	1.0616	1.7623	0.8316	1.8389	0.3828	0.0100
CRPSO (Nayak et al. 2017)	2.0000	1.1263	1.8302	1.3248	0.2496	1.0202	1.1404	0.0926
GHS	1.8268	1.5945	1.5136	1.8595	0.0948	1.5565	0.6945	0.0100
MGHS	1.9984	1.6230	1.7350	1.9969	0.0227	1.5579	0.7426	0.0100

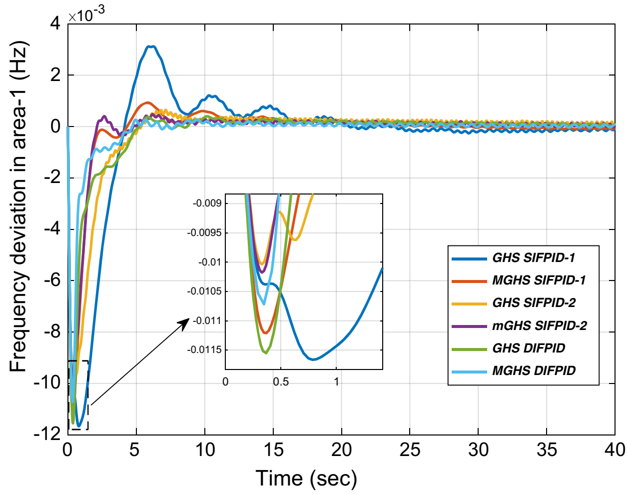

Fig. 6 Frequency deviation in area-1

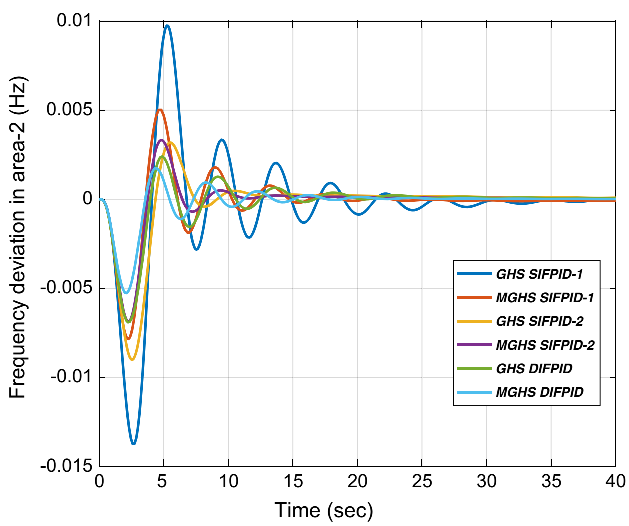

Fig. 7 Frequency deviation in area-2

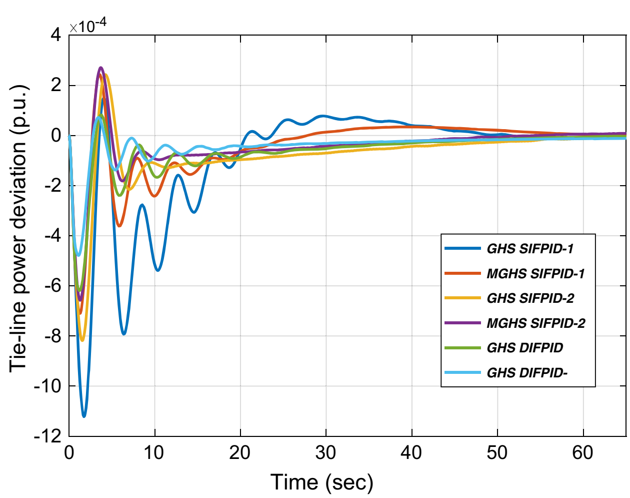

Fig. 8 Tie-line power deviation

Table 4 peak undershoots (u_{sh}), peak overshoots (o_{sh}) and settling time (t_s) of Δf_1, Δf_2 and ΔP_{tie}

Controllers	Transient responses	Δf_1 (Hz)	Δf_2 (Hz)	ΔP_{tie} (pu)
GHS	U_{sh} ($\times 10^{-3}$)	− 11.6654	− 13.7369	− 1.1218
SIFPID-1	O_{sh} ($\times 10^{-3}$)	3.1219	9.7464	0.2435
	T_s	36.6754	24.7560	50.4008
MGHS	U_{sh} ($\times 10^{-3}$)	− 11.2111	− 7.8495	− 0.7102
SIFPID-1	O_{sh} ($\times 10^{-3}$)	0.9336	5.0159	0.1496
	T_s	21.6668	30.6251	44.3766
GHS	U_{sh} ($\times 10^{-3}$)	− 10.0352	− 9.0095	− 8.1835
SIFPID-2	O_{sh} ($\times 10^{-3}$)	6.5032	3.1812	0.2429
	T_s	21.3658	24.5251	42.3666
MGHS	U_{sh} ($\times 10^{-3}$)	− 10.1854	− 6.9670	− 6.5764
SIFPID-2	O_{sh} ($\times 10^{-3}$)	4.0665	3.3191	0.2708
	T_s	20.8658	22.4254	42.0245
GHS	U_{sh} ($\times 10^{-3}$)	− 11.5519	− 6.9102	− 0.6189
MIFPID	O_{sh} ($\times 10^{-3}$)	0.3963	2.4027	0.0821
	T_s	20.4387	29.5224	41.0284
MGHS	U_{sh} ($\times 10^{-3}$)	**− 10.7164**	**− 5.2701**	**− 0.4785**
MIFPID	O_{sh} ($\times 10^{-3}$)	**0.2833**	**1.7515**	**0.0720**
	T_s	**20.1545**	**18.5962**	**37.9825**

The best values are shown in bold

6 Conclusion

The purpose of this paper is to validate the MIFPID controller optimized by hybrid DECRPSO algorithm as an improved secondary controller of the interconnected hydro-thermal power system. For this purpose MIFPID, and SIFPID controllers are applied separately in each area as AGC optimized by GHS, and MGHS algorithm. With 1% load disturbance in area-1, MIFPID controller is validated better than SIFPID controller to enhance the ability to get better control over tie-line power deviation and frequency deviation by considering their settling time, undershoot, and overshoot. The supremacy of MGHS algorithm over GHS is validated by optimizing both MIFPID and SIFPID controllers.

Appendix 1 (power system parameters)

$K_{p1} = K_{p2} = 120$ H_Z/p.u. MW,
$T_{P1} = T_{P2} = 20$ s, $B_1 = B_2 = 0.4249$;
$R_1 = R_2 = 2.4$ H_Z/p.u. MW; $T_g = 0.08$ s;
$T_t = 0.3$ s; $T_1 = 41.6$ s; $T_2 = 0.513$ s;
$T_R = 5$ s; $T_W = 1$ s; $T_{12} = 0.0866$;
$D_1 = D_2 = 8.333 \times 10^{-3}$ p.u. MW/Hz.

Appendix 2 (assumptions of algorithms)

$\mathrm{HGCR} = 0.3$; $\mathrm{Ra}_{\max} = 0.0001$; $\mathrm{Ra}_{\min} = 1\times10^{-6}$.

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