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Grey wolf optimizer algorithm based Fuzzy PID controller for AGC of multi-area power system with TCPS

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Abstract

In this paper, a meta-heuristic optimization algorithm has been applied to interconnected Hydro-thermal power system for automatic generation control (AGC). The optimal gains of the fuzzy based proportional, integral and derivative (PID) controllers are obtained by employing the proposed Grey Wolf Optimizer (GWO) algorithm. The generation rate constraint of 3% per minute for thermal power plant and 270% up and 360% down per minute for hydro plant have been considered. The dynamic performance of a two-area interconnected Hydro-thermal power system is investigated and compared with particle swarm optimization (PSO) and differential evolution (DE) techniques by incorporating a Thyristor Controlled Phase Shifter (TCPS) in series with the tie-line. The overall performance of the considered system has been significantly improved by controlling the phase angle of TCPS with the help of proposed Fuzzy PID controller. It is revealed that the frequencies of both area and tie-line power oscillations are quickly damped out by the proposed scheme under step load perturbations. Furthermore, the robustness of the proposed system is analysed when subjected to different loadings without recalculating the gains of the controller.

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Keywords: automatic generation control (AGC); hydro-thermal system; thyristor control phase shifter (TCPS); particle swarm optimization (PSO) algorithm; differential evolution (DE) algorithm; grey wolf optimizer (GWO)

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1. Introduction

Electric power systems are interconnected to generate, exchange and control of electric energy with nominal frequencies and tie-line power interchange at their respective scheduled values. The principal aspects of Automatic generation control (AGC) in power system is to maintain system frequency of each area and tie line power flow between areas during normal operating condition as well as during the variation in load demands [1-3]. Literature survey shows that considerable works have been carried out for AGC of interconnected power system, including the pioneering works by Elgerd and Fosha [4-5]. In past two decade following the advent of modern intelligent techniques such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Fuzzy Logic (FL) and Artificial Neural Network (ANN), new ideas have been emerged for the design of AGC controller to improve the system dynamics under the occurrence of the load perturbation [6-14]. Further, improvement of system dynamics have been revealed with inclusion of Flexible AC Transmission Systems (FACTS) based controller. These FACTS devices are capable of enhancing power system stability by controlling the power flow in an interconnected power system [15]. Thyristor Controlled Phase Shifter (TCPS) belongs to the family of FACTS devices. It is installed in series with the transmission lines. It is possible to regulate the power flow by connecting a TCPS in series with the tie-line in between two areas of an interconnected power system. It controls the real power flow by controlling the phase angle of system voltages [16]. It also reduces the frequency of oscillations of power flow following a sudden change in load in either of areas.

Followed by introduction the paper is organized as follows: system investigated is presented in section 2. Section 3 presents modeling of TCPS in AGC. Controller structure and objective function is described in section 4. In section 5, GWO algorithm is proposed. Results and discussions are presented in section 6. Finally conclusion is given in section 7.

Nomenclature

P_{R1}, P_{R2}	Rated area capacities $(a_{12} = -P_{R1}/P_{R2})$	R_1, R_2	Governor speed regulation parameter of thermal and hydro area respectively
T_{P1}, T_{P2}	Power system time constants	D_1, D_2	$\Delta P_{Di}/\Delta f_i$
K_{P1}, K_{P2}	Power system gains	B_1, B_2	Frequency bias constant of thermal and hydro area respectively
T_t	Steam turbine time constant	X_{12}	Transmission line reactance
T_G	Governor time constant in thermal area	K_φ	Gain parameter of TCPS
K_r	Steam turbine reheat constant	T_{PS}	Time constant of TCPS
T_r	Steam turbine reheat time constant	ϕ_{max}, ϕ_{min}	Maximum and minimum phase angle variation of TCPS
T_{12}	Synchronizing coefficient	ΔF_1, ΔF_2	Deviation of frequency in area1 and area2 respectively
T_1, T_2, T_R	Governor time constant of hydro area	ΔP_{tie12}	Tie-line power deviation
T_w	Water time constant	J	Objective function

2. System investigated

The system investigated for AGC is a two area interconnected hydro-thermal system with TCPS in series with the tie-line [16-17]. A schematic of the two area interconnected hydro-thermal power system is shown in Fig. 1. Area 1 comprising a reheat thermal system with generation rate constraint (GRC) of 3% per minute is considered. Area 2 comprising a hydro system and GRC of the order of 270% per minute (4.5%/second) for rising in generation and 360% per minute (6%/second) for lowering in generation is considered. The detail transfer function model is given in Fig. 1. The nominal parameters of the system are given in Appendix. For analysis of the system, 1% step load perturbation has been considered in thermal area.

3. Modeling of TCPS in AGC

The TCPS is connected in series with the tie line and is placed near area 1. Resistance of the tie-line is neglected. Without TCPS, the incremental tie-line power flow from area 1 to area 2 can be expressed as,

$$\Delta P^0_{tie12}(s) = \frac{2\pi T^0_{12}}{s}(\Delta f_1 - \Delta f_2) \quad (1)$$

When a TCPS is placed in series with the tie-line [16], power flow becomes,

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] + T_{12}\frac{K_\varphi}{1+sT_{PS}}\Delta F_1(s) \quad (2)$$

Now, $\Delta P_{tie12}(s) = \Delta P^0_{tie12}(s) + \Delta P_{TCPS}(s)$ (3)

Where, $\Delta P_{TCPS}(s) = T_{12}\frac{K_\varphi}{1+sT_{PS}}\Delta F_1(s)$

The TCPS is a frequency stabilizer. The gain K_φ and time constant T_{PS} of the TCPS are collected from reference [16].

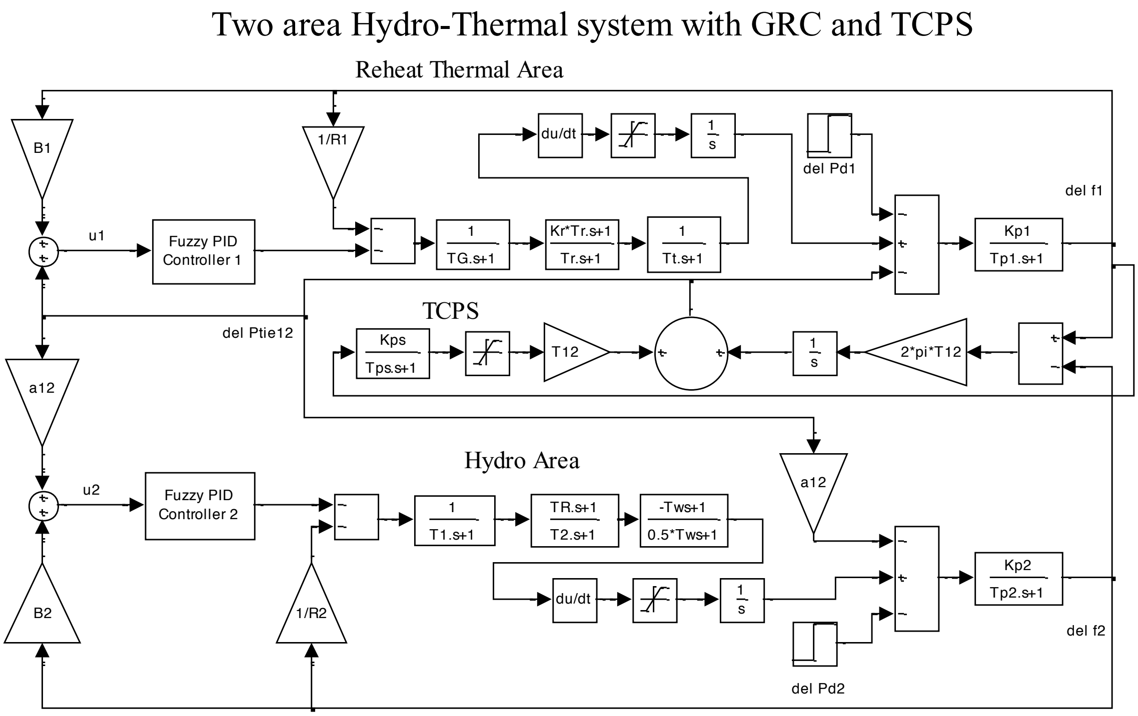

Fig. 1 MATLAB/Simulink model of two area Hydro-thermal system with GRC and TCPS

4. Controller structure and objective function

The structure of the Fuzzy PID controller is adopted from reference [18]. An identical controller is employed in each area. The error inputs to the controllers are the respective area control error (ACE). Fuzzy PID controller is a combination of fuzzy proportion-integral (PI) and fuzzy proportional-derivative (PD) controllers. The input scaling factors are K_1 and K_2 and the output scaling factors are K_3 and K_4. Triangular membership functions are used with five fuzzy linguistic variables such as NB (negative big), NS (negative small), Z (zero), PS (positive small) and PB (positive big) for both the inputs and the output. Mamdani fuzzy inference engine is selected for the present work. The two-dimensional rule bases for error, error derivative are inputs and u as output to fuzzy model.

Integral of time multiplied absolute error (ITAE) is used as objective function to find the optimum value of the controller parameters [19]. The objective function J for controller parameters optimization of the interconnected power system is depicted below.

$$J = ITAE = \int_0^{t_{sim}} (|\Delta F_1| + |\Delta F_2| + |\Delta P_{tie}|).t.dt \quad (4)$$

In the above equation, ΔF_1 and ΔF_2 are the system frequency deviations; ΔP_{tie} is the incremental change in tie line power. t_{sim} is the time range of simulation.

5. Overview of GWO algorithm

Grey Wolf Optimizer (GWO) is a new meta-heuristic algorithm proposed by Mirjalili et al. in 2014 for solving many multi-modal functions [20]. It is inspired by grey wolves. Four types of grey wolves such as alpha (α), beta (β), delta (δ) and omega (ω) are employed to derive the leadership of hierarchy of grey wolves. The main steps are hunting, searching for prey, encircling prey and attacking prey.

4.1 ***Social hierarchy***

For modeling of the social behavior of the grey wolf, alpha (α) is considered to be the fittest solution followed by beta (β) and delta (δ), respectively, and the rest of the candidate solutions are grouped under omega (ω). In GWO, the hunting (optimization) process is guided by alpha (α), beta (β) and delta (δ), where as omega (ω) wolves always follows these three wolves.

4.2 ***Encircling prey***

Grey wolves encircle prey during the hunt. In order to mathematically model encircling behavior the following equations are presented.

$$\vec{D} = \left|\vec{C}.\vec{X}_p(t) - \vec{X}(t)\right| \text{ and } \vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad (5)$$

Where t indicates the current iteration. $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_p$ is the position vector of the prey, and $\vec{X}$ indicates the position vector of a grey wolf. The vectors $\vec{A}$ and $\vec{C}$ are calculated as follows:

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a}\,;\ \vec{C} = 2.\vec{r}_2 \quad (6)$$

Where the components of $\vec{a}$ are linearly decreased from 2 to 0 over the course of iterations and $\vec{r}_1, \vec{r}_2$ are random vectors in $[0,1]$.

4.3 ***Hunting***

The following formulas are proposed in this regard.

$$\vec{D}_\alpha = \left|\vec{C}_1.\vec{X}_\alpha - \vec{X}\right|,\ \vec{D}_\beta = \left|\vec{C}_2.\vec{X}_\beta - \vec{X}\right|,\ \vec{D}_\alpha = \left|\vec{C}_3.\vec{X}_\delta - \vec{X}\right|; \quad (7)$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1.\left(\vec{D}_\alpha\right),\ \vec{X}_2 = \vec{X}_\beta - \vec{A}_2\left(\vec{D}_\beta\right),\ \vec{X}_3 = \vec{X}_\delta - \vec{A}_3.\left(\vec{D}_\alpha\right) \quad (8)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad (9)$$

4.4 ***Attacking prey (exploitation)***

In the above sections, it is discussed that how the grey wolves finish the hunt by attacking prey when it stops moving. In order to mathematically express the model approaching the prey, two parameters, as described below are considered. $\vec{a}$ is linearly decreasing from 2 to 0 and fluctuations of $\vec{A}$ is also decreased with $\vec{a}$.

4.5 ***Search for prey (exploration)***

Optimum search in grey wolf algorithm is based on the positions of alpha, beta and delta. They diverge from each other when they search for prey and converge during attacking the prey. Mathematically, when the random value of $\vec{A}$ is greater than 1 or less than -1 then search agent diverges to prey. This emphasizes exploration behavior in GWO algorithm. Thus, GWO shows more random behavior throughout the optimization and favoring exploration and local optima avoidance. Finally, the algorithm steps of GWO may be summarized as follows:

(a) The search process is started with random initialization of candidate solutions (wolves) in the search space.

(b) Alpha, beta and delta wolves are estimated based on the position of prey.

(c) To find the optimum location of prey, each wolf updates its position.

(d) A control parameter $\vec{a}$ linearly decreases from 2 to 0 for better exploitation and exploration.

(e) Candidate solutions tend to diverge when $\vec{A} > 1$ and to converge when $\vec{A} < 1$ and at the end GWO gives the optimum solution.

6. Results and discussions of the simulated test system

For DE algorithm the optimal gains are K_P =0.186 and K_I =0.7061 (thermal); and K_P =1.2853 and K_I =0.0651(hydro). Similarly, for PSO algorithm the optimal gains are K_P= -0.3043 and K_I =0.1136 (thermal); and K_P =1.6057 and K_I =0.6068 (hydro). For GWO algorithm the PI controller gains are K_P = 0.3032 and K_I =0.3618 (thermal); and K_P=1.6975 and K_I = -0.0584 (hydro). For GWO algorithm the gains of Fuzzy PID controllers are K_1 =0.66, K_2 =0.4591, K_3 =0.979, K_4 =0.8317(thermal) and K_1 =0.0, K_2 =0.5134, K_3 =0.1464, K_4 =0.2786 (hydro). K_1 and K_2 are weight coefficients[18].

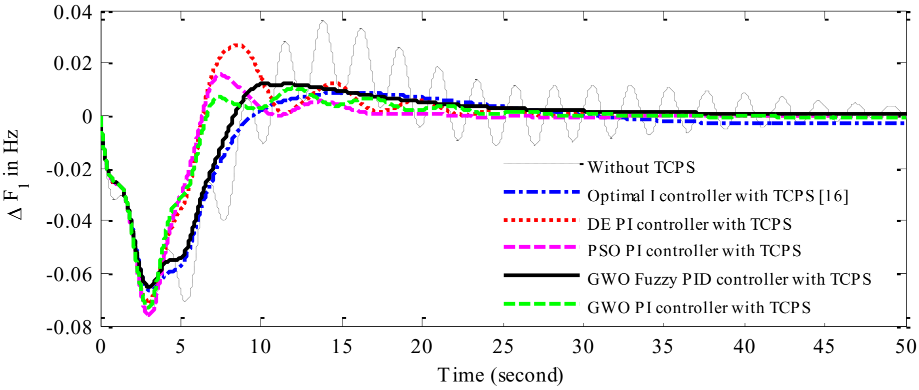

Fig. 2 Frequency deviation of area 1 under a step load perturbation of 0.01pu in area 1

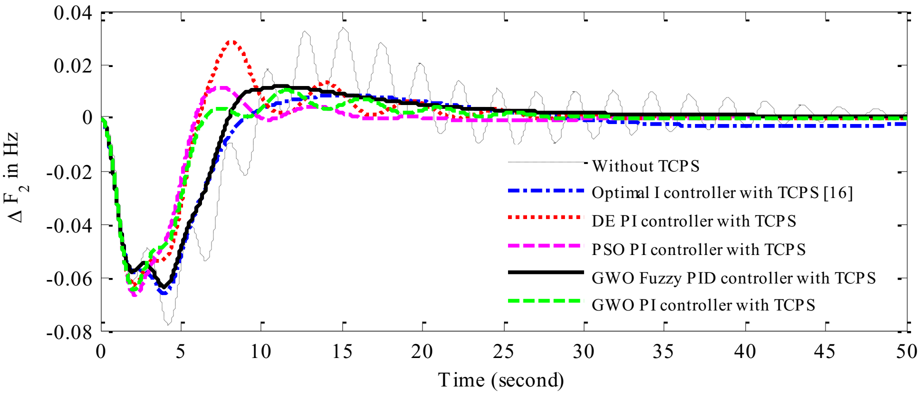

Fig. 3 Frequency deviation of area 2 under a step load perturbation of 0.01pu in area 1

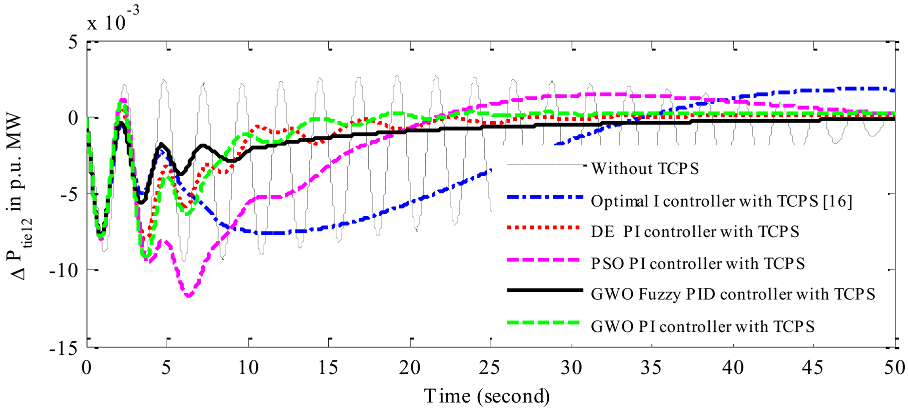

Fig. 4 Tie line power deviation of system under a step load perturbation of 0.01pu in area 1

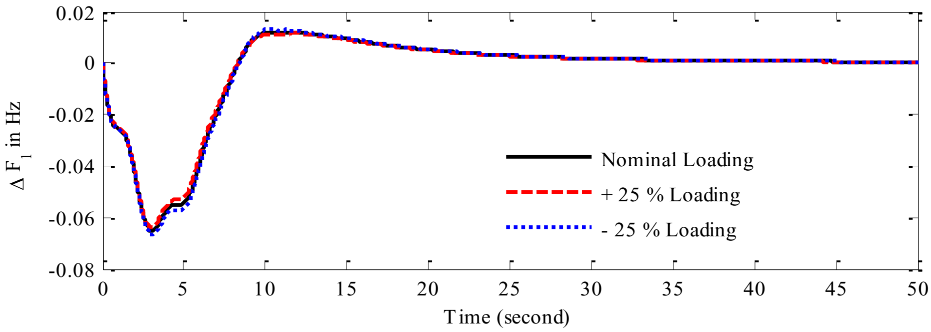

Fig. 5 Frequency deviation of area 1 under different loading conditions

The dynamic performance of the two-area interconnected hydro-thermal power system is investigated with proposed GWO optimized Fuzzy PID controller and compared with PSO, DE and GWO optimized PI controllers by incorporating a TCPS in series with the tie-line and with a step load perturbation of 1%. Simulation results of the system frequency deviations and tie-line power deviation are shown in Figs. 2 – 4. The system is simulated for 50 seconds. The results show that the performance of the system in terms of overshoots and settling time is better with the proposed controller. The effect of variations of operating loading condition by ± 25 % from their nominal values taking one at a time is shown in Fig, 5. It is proved form Fig. 5 that there is negligible effect on variation of loading conditions on the deviation of frequency response which validates the robustness of proposed controller.

7. Conclusion

In this paper, the GWO optimized Fuzzy PID controller is proposed for the AGC study of two area nonlinear hydro-thermal system with TCPS. The simulation results are compared with optimal integral controller, PSO optimized PI controller, DE optimized PI controller and GWO optimized PI controller for the similar system. The results obtained from simulation confirm the effectiveness of the proposed controller. Also the robustness of the system is verified by varying the loading condition of +25% and -25% from their nominal value without changing the gains of controller.

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