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Meta-heuristic Approach to Design Controller for AVR System

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Abstract

In this paper, Firefly Algorithm (FA) based design of the optimal PID controller is proposed for the benchmark Automatic Voltage Regulator (AVR) system. The best possible solution (Kp, Ki, Kd) for the PID controller is obtained by minimizing the multi-objective cost function. In this work, the FA explores the three dimensional search space, till it discovers the optimal PID parameters. This paper also presents a comprehensive study various search assisted FA, such as Brownian, Levy and chaotic exploration. The simulation work is implemented using the traditional and modified form of PID controllers. The performance of PID is computed based on the time domain values and the error values. The performances of chosen FA are also assessed based on its run time. From this research work, it can be observed that, all the search techniques tender similar time domain and error values. The iteration time taken for the Chaotic FA is relatively lesser than other FAs. Proposed approach is also authenticated against the other related works existing in the literature and it is noted that, FA based PID controller offers better result.
Keyword- PID Controller; AVR; Firefly Algorithm; Performance Analysis

I. INTRODUCTION

Recent research work evident that, soft computing approach guided optimization is emerged as an important technique to determine best solutions for a class of engineering problems [1]. In the literature, a considerable amount of soft computing procedures are invented and implemented by the researchers [2-7]. Choice of a particular soft computing technique relies on the following constrains: (i) Engineering trouble to be resolved; (ii) Search space dimension; (iii) Value of cost function (single or multiple); (iv) Adaptability of the algorithm and its parameters; (v) Simplicity in execution; (vi) Optimization accurateness and (vii) Flexibility.

Normally, a particular soft computing methodology is chosen by the researchers based on his experience and the need of the advanced procedures to solve the considered problem. In this paper, recent soft computing procedure known as the Firefly Algorithm (FA) is adopted to find the best possible PID controller value for the Automatic Voltage Regulator (AVR) control problem.

In the literature, traditional and modified FA was widely considered by the researchers [8-10]. A detailed description of the FA and its implementation can be accessed from [11]. In this work, the traditional FA and its modified versions such as the Brownian walk FA and the chaotic FA are considered to find the PID values for the AVR system.

Proposed work implements the best possibly tuned PID parameters for the benchmark Automatic Voltage Regulator (AVR) unit existing in the literature. Even though a considerable amount of advanced controller structures are existing [12, 13], traditional and modified forms of PIDs are simple to adjust and employ [1]. Hence, in this paper traditional PID and PID with pre-filter considered and employed to get the desired response from the benchmark AVR unit.

The remaining part of the paper is as follows: section 2 outlines the construction of the benchmark AVR and its linear model, section 3 discusses about the firefly algorithms and its implementation to solve the problem, and section 4 presents the experimental results and the related discussion. Finally, conclusion of the present research work is discussed in section 5.

II. PROCESS DESCRIPTION

This section presents the details of the benchmark AVR system existing in the literature [2]. During the power production, necessary instability such as deviation of load, parameter dissimilarity in transmission line, and turbine fluctuations may begin oscillatory productivity in synchronous generator. This class of electro-mechanical fluctuation influences the stability of power unit. Therefore, in contemporary power producing stations, to improve the dynamic stability and to promise the power superiority, most of the synchronous generators are equipped with an excitation system, which is monitored by an AVR and a Power System Stabilizer (PSS) [3, 4].

Figure.1 depicts the detailed block representation of the AVR system with related components, such as amplifier, exciter, generator and sensor. The process delay time of this AVR system is very small and implementing an appropriate controller for this unit needs the subsequent guesses: (i) entire unit is always linear, (ii) exterior disturbance performing on the unit is insignificant and (iii) the sensor part is free from the measurement noise.

The whole unit is an open-loop stable system and requires a suitable controller to obtain the desired output voltage based on the set point. During the closed loop implementation, the PID is mainly dependable to preserve the robustness and also to maintain smooth set point tracking operation and disturbance rejection operation.

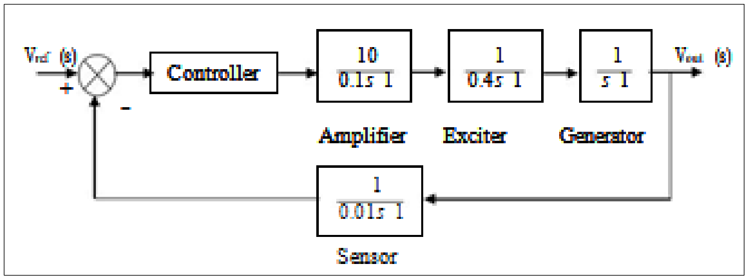


Fig. 1: Block representation of AVR unit

Because of its importance in power generation, AVR unit is broadly discussed by most of the researchers. The previous research works widely implemented various soft computing procedures, such as Particle Swarm [2,6], hybrid methodology [7], Firefly [4], and Teaching-Learning Optimization [3]. Most of the previous PID controller design for the AVR unit was implemented and validated for the reference tracking operation.

In the proposed work, traditional and improved structures of PID controllers are chosen to standardize AVR unit and the controller design process in done using traditional and enhanced FAs.

III. IMPLEMENTATION

This section presents the details regarding chosen soft computing approach and its implementation to solve the problem.

A. Firefly Algorithm

FA was invented by Yang in 2009 [9, 10]. It is based on the arithmetical replica of flashing illumination prototype emitted by creatures, such as firefly and glow worm. Comprehensive explanation and working principle of FA and its modifications can be found in the literature [14-16].

The foremost working attitude of the FA depends on the light intensity created by the insect due to a chemical reaction. In FA, it is assumed that, at any moment, the light concentration of a firefly *I* at distance *d* can be related as I $1/d^2$ (the light intensity with respect to d from the brightness source t follows inverse square law). At this Xi situation, the association of fascinated firefly i near a brilliant firefly j can be found using position update equation;

$$X_i^{t\ 1} \quad X_i^t \quad \beta_0 e^{\gamma d_{ij}^2}(X_j^t \quad X_i^t) \quad .\ sign(rand - ½) \quad SM \quad (1)$$

Where, $X_i^{t\ 1}$ is reorganized location of firefly, X_i^t is the initial position of firefly, $\beta_0 e^{\gamma d_{ij}^2}(X_j^t\ X_i^t)$ is the attraction between fireflies, the symbol signifies entry wise multiplication and SM is the search methodology.

In the proposed work, the FA was considered with various search methodologies, such as Levy flight (LF), Brownian Walk (BW) and the chaotic search known as the Ikeda Map (IM).

$$X_i^{t\ 1} \quad X_i^t \quad \beta_0 e^{\gamma d_{ij}^2}(X_j^t X_i^t).\ sign(rand - ½) LF \qquad (2)$$

$$X_i^{t\ 1} \quad X_i^t \quad \beta_0 e^{\gamma d_{ij}^2}(X_j^t X_i^t).\ sign(rand - ½) \qquad BW \quad (3)$$

$$X_i^{t\ 1} \quad X_i^t \quad \beta_0 e^{\gamma d_{ij}^2}(X_j^t \ X_i^t).\ sign(rand - ½) \qquad IM \quad (4)$$

LF is the most famous search procedure widely adopted by the researcher to enhance various soft computing approaches [8].The BW approach is also attracted few researchers because of its robustness [17-20]. The chaotic IM is recently considered to enhance the cuckoo search [21] and the bat algorithm [22]. In the proposed work, the IM is used to speed up the FA search process.

B. Execution

A generalized close loop system is shown in Figure 2. Here, $G_c(s)$ denotes the PID controller and $G_P(s)$ denotes the AVR.

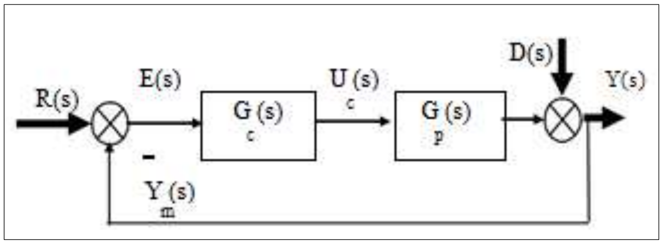


Fig. 2: Block diagram of a closed loop control system

Closed loop response of the above system with set point '*R(s)*' can be expressed as;

$$Y(s) = \frac{G_p(s)G_C(s)}{1 + G_p(s)G_c(s)} R(s) \quad (5)$$

To achieve a satisfactory reference tracking and disturbance rejection operation, the controller should have optimal values of K_p, K_i and K_d. In this study, parallel PID controller is considered to achieve the preferred response [1].
The parallel PID structure is given below:

$$G_C(s) = K_p e(t) + K_i \int_0^T e(t)\,dt + K_d \frac{de(t)}{dt} \quad (6)$$

$$G_{PID}(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s\right) \quad (7)$$

where $K_p / T_i = K_i$; $K_p * T_d = K_d$.
In the proposed work, the considered Objective Function (OF) is given below:

$$J_{min}(K_p, K_i, K_d) = (w1.ISE) + (w2.IAE) + (w3.M_p) + (w4.t_s) \quad (8)$$

where w1=w2=w3=1, and w4= 0.5, ISE = Integral Square Error, IAE = Integral Absolute Error, M_p = overshoot, and t_s = settling time.

IV. RESULTS AND DISCUSSIONS

This section presents the experimental results obtained for the AVR system with the chosen FAs. The following algorithm parameters are assigned for FA: search dimension D = three, number of fireflies (n) = 25, $\beta_0 = 1$, $\gamma = 5$, $\alpha_0 = 0.5$ (gradually reduced to 0.01 in steps of 0.01 as iterations proceed), and the total number of run is chosen as 500. The search procedure is repeated ten times for every FA and the best value among the search is chosen as the optimized controller parameter.

The search dimension is assigned with the following boundaries: 0% < K_p < +50%, 0% < K_i < +50% and 0% < K_d < +50% [3].

Firstly, the FA based PID tuning is proposed with LF strategy. Figure 3 shows the traces made by the i^{th} firefly. From this figure, one can observe that, number of iterations taken by the LF based FA is comparatively smaller than BD based FA. The traces made by the IM based FA is similar to the traces discussed in [11].

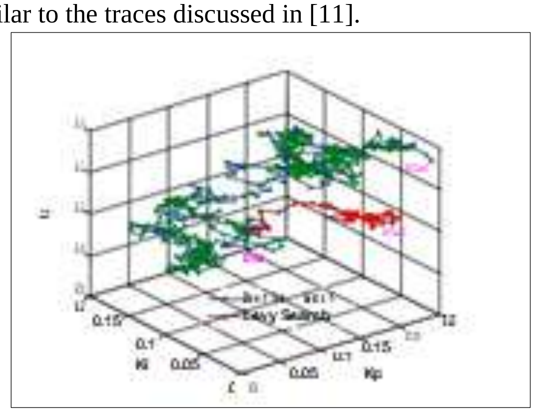


Fig. 3: Traces made by a single firefly on three dimensional search space

The performance of considered FAs are evaluated using well know qualitative measures as given in Table 1. In this paper, FA1 represent LF based search, FA2 represents BW search, FA3 is for IM. The obtained results show that, even though the IM based FA shows a slower convergence when compared to LF based FA approach; it offers better t_s, M_p, ITAE and J_{min} when compared to FA1 and FA2.

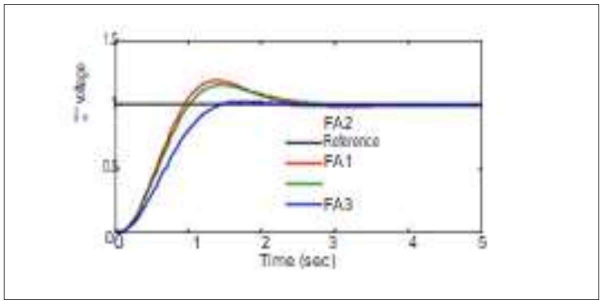
	Controller parameter			Iteration	J_{min}
	K_p	K_i	K_d		
FA1	0.2885	0.2001	0.2947	63	2.645
FA2	0.2700	0.1894	0.3308	115	2.832
FA3	0.2093	0.1254	0.2777	82	2.562

Table 1: (A). Optimal PID Values for AVR

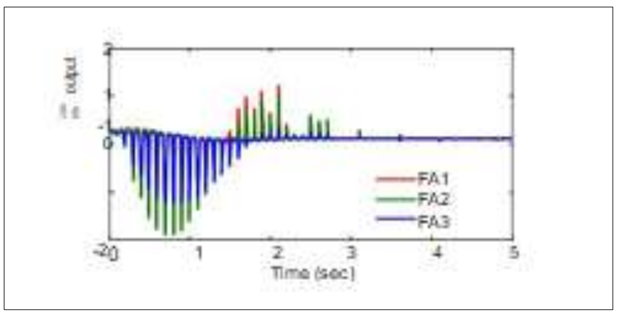
	$t_r(s)$	$t_s(s)$	M_p	ITAE	ITSE
FA1	0.946	2.500	0.187	0.5606	0.1744
FA2	1.024	2.931	0.151	0.5286	0.1756
FA3	1.454	2.300	0.020	0.4593	0.2061

Table 1: (B). Performance Values of AVR with PID Controller

Figure 4 (a) shows the reference tracking response of AVR system with the PID controller. Where, FA1 and FA2 shows overshoot compared to FA3. The controller output shown in Figure (b) also shows more oscillatory response.



(a) AVR output with Filter + PID

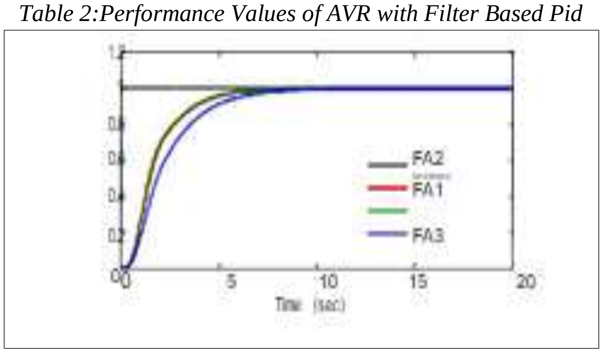


(b) Controller response with PID
Fig. 4: Performance of FA designed PID for AVR

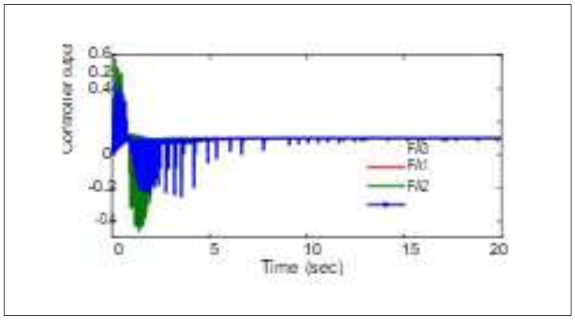
The AVR model is then controlled with a setpoint filter based PID (Filter + PID) controller discussed in [12, 13, 23]. In this method, when the filter time constant τ_f is set equal to integral time constant T_i, the controller offers a smooth reference tracking performance as shown in Figure 6 (a) and (b). From this figures and Table 2 values, it is noted that, the response by the filter based PID is extremely sluggish compared to the conventional PID structure.

	Tf =Ti	tr(s)	ts(s)	Mp	ITAE	ITSE
FA1	1.4418	0.946	2.500	0.00	0.8674	0.0881
FA2	1.4255	1.024	2.931	0.00	0.8994	0.1008
FA3	1.6690	1.454	2.300	0.00	1.9840	0.2130

Table 2:Performance Values of AVR with Filter Based Pid



(a) AVR output with Filter + PID



(b) Controller response with Filter + PID
Fig. 5: Process output and controller output with modified PID structure

Reference	*Algorithm*	*Controller parameter*			*ITAE*	*ITSE*
		Kp	*Ki*	*Ki*		
Kim [7]	*GA*	*0.8282*	*0.7143*	*0.3010*	*5.645*	*1.957*
	PSO	*0.6445*	*0.5043*	*0.2348*	*2.513*	*0.6908*
	GA+PSO	*0.6794*	*0.6167*	*0.2681*	*3.191*	*0.9676*
	BF+GA	*0.6728*	*0.4787*	*0.2299*	*2.643*	*0.7157*
Wong et al. [5]	*GA*	*0.7722*	*0.3196*	*0.7201*	*0.9413*	*0.2405*
	PSO	*0.6751*	*0.2630*	*0.5980*	*0.9621*	*0.2139*
	RGA	*0.0222*	*0.2451*	*0.2913*	*15.32*	*6.468*
Omar [4]	*CFA*	*0.6537*	*0.4742*	*0.2467*	*2.310*	*0.6281*

Table 3: Various Algorithm Based PID Values and Its Performance Measure

The reference tracking performance of AVR system with the proposed PID controller is then validated with the existing PID controllers in the literature. Kim [7] proposed a PID controller design for the AVR system using hybrid algorithm (GA+BF) and compared the result with the existing heuristic algorithms. The PID gains and the corresponding error values are presented in Table 3. The PID parameters and error values attained by Wong et al. [5] with GA, PSO, and Real-value GA (RGA) is also presented in the table. The table also depicts the work of Omar [7] with continuous FA. The ITAE and ITSE value obtained with the proposed work (Table 1 and Table 2) is better compared with the existing methods shown in Table 3. Hence, in future soft computing approach with the chaotic IM search can be considered to enhance the heuristic algorithm performances.

V. CONCLUSIONS

In this research work, Firefly Algorithm (FA) assisted PID and PID with pre-filter tuning design is discussed for the benchmark AVR unit. The various forms of search procedures, such as Levy flight, Brownian walk and Ikeda map are considered to improve the search efficiency of the FA and its performance are validated against the other approaches existing in the literature. The experimental work confirms that, the controller values acquired with the FAs are approximately similar and all the algorithms shows approximately similar Jmin value, time domain values and error values with the traditional PID and FPID controllers. In addition, the proposed study depicts that, the performance of PID with pre-filter is better than the traditional PID structure. The IM based FA offers enhanced result compared with the other procedures considered in this study.

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