Enhancement of AVR response based on Intelligent Fuzzy-Swarm-PID Controller

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Abstract

Automatic voltage regulator is used to fix the output signal by correcting the voltage of the exciter and track the generator’s voltage. The improvement of automatic voltage regulator (AVR) response will reflected on the power system performance. In this paper two intelligent techniques fuzzy logic (FL) and Particle swarm optimization (PSO) are used to enhance the response of the Fourth order AVR system based on the merging between them and then the control action summed and coupled with PID controller action. Fuzzy controller has many benefits in design of AVR compared with conventional controllers, but the response of the AVR system still insufficient, therefore, the PSO and Fuzzy are used together for this purpose to produce Fuzzy-Swarm-PID controller (FSPID). Usually the cognitive (C1) and social acceleration (C2) are taken as a constant values in PSO algorithm, but here the Fuzzy logic system is used to get these accelerations to enhance the response.

تحسين اداء المنظم الاوتماتيكي للفولتيه بالاعتماد على المسيطر الذكي الضبابي- السرابي-الثلاثي

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ملخص

منظم الفولتيه الاتوماتيكي يستخدم في تثبيت ومتابعه فولتيه المولد والسيطره على استجابه الماكنه بواسطه تصحيح فولتيه المحفز . تحسين اداء المنظم سينعكس بشكل عام في تحسين اداء نظام السيطره، المسيطر الضبابي يستخدم بشكل واسع في تحسين اداء المنظم . هذا المسيطر لديه عدد من الفوائد مقارنه مع المسيطرات الاخرى ، ولكن استجابه المنظم تبقى غير كافيه ، لذا استخدمت تقنيه الامثله بواسطة التجمعات الجزئيه في تحسين اداء النظام بشكل افضل بكثير من المسيطرات التقليديه . في هذا البحث تم دراسه وتحليل المنظم الاتوماتيكي ذات درجه عاليه وبعد ذالك اختبر هذا المنظم بالخوارزميه المقترحه والتي هي عباره عن تهجين بين النظام الضبابي وتقنيه الامثله بواسطة التجمعات الجزئيه وجمع الاشاره الخارجه مع استجابه المسيطر الثلاثي للحصول على افضل اشاره سيطره ، الهدف من هذا العمل الحصول على اشاره سيطره مع اخذ فوائد كل مسيطر وجمعها في مسيطر واحد اطلق عليه (المسيطر الضبابي السربي الثلاثي). على الاغلب تؤخذ قيم التسارع المعرفي والتسارع الاجتماعي في تقنية الامثله بواسطه التجمعات الجزئيه كقيم ثابته ولكن في هذا البحث تم ايجادها عن طريق النظام الضبابي . النتائج بينت ان الخوارزميه المقترحه ذات كفائه عاليه ومؤثره على استجابه النظام .

1. Introduction

In power system, it is very hard to alleviate the effectiveness of the system by conventional controllers[1]. The automatic voltage regulator (AVR) represent the main part to fix and control on the voltage in any machine, therefore the response enhancements in this part will be reflected directly on the overall response enhancement. In recent years, many control algorithms worked to enhance AVR response [1, 2], such as the Intelligence methods, which are effective and suitable to improve overall stability of the machine system [3, 4] , compared with the conventional controllers which that implemented according to conservative theory. The PID tuned by artificial algorithms (AIs) have several advantages and stimulated by authors to make this connections to solve the problems in power system and to improve the response of the system and to avoid the limitations in classical and conventional theories [1]. Practical swarm optimization (PSO) and genetic algorithm (GA) algorithm are used to optimize the PID in different fields. PSO technique based on Ref. [5] is used for tuning and optimizing the power system gains and the results exposed that the PSO is a suitable algorithm for this purpose. Ref. [6] used GA to calculate the optimal gains of AVR system, real genetic algorithm is used to calculate the PSS gains [7] to enhance the overall system response.

2. High Order model of Automatic Voltage Regulator (AVR).

The closed loop system with AVR is explained in figure 1, the AVR formed by a grouping of a simple synchronous generator model. AVR system involves four blocks as shown in figure 1 [8, 9]: Amplifier; Exciter; Generator; and Sensor.

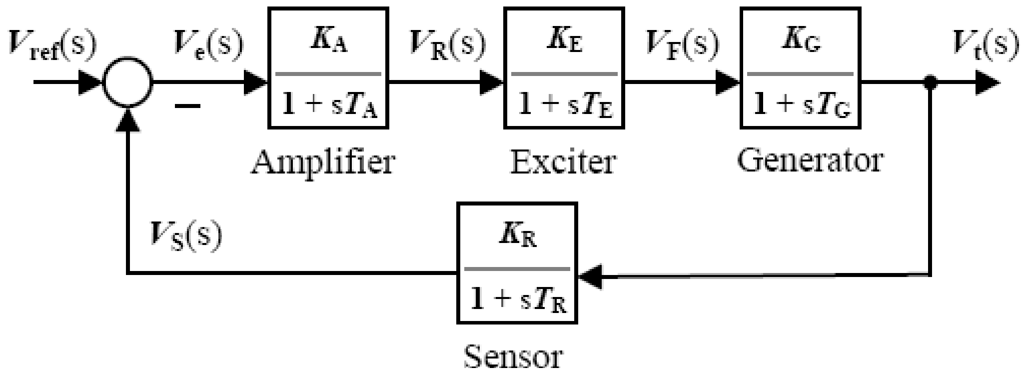

Figure 1 feedback control system with AVR

From figure 1, the transfer function connecting the generator output voltage $V_t(s)$ of the input voltage $V_{ref}(s)$ can be explained as follow:

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{K_A K_E K_G (1+sT_R)}{(1+sT_A)(1+sT_E)(1+sT_{G1})(1+sT_R) + K_A K_E K_G K_R} \quad (1)$$

Each block in figure 1 are showed in table 1. The values are selected according to many references [9-17].

Table 1: Functions, equations, parameters, and values of figure 1

Block	Function /value	Variable with its value
Exciter	$G_{Exc} = \frac{K_E}{1+sT_E}$	K_E =200; T_E=0.05
Generator	$G_{Gen} = \frac{K_G(1+sT_{z1})(1+sT_{z2})(1+sT_{z3})(1+sT_{z4})}{(1+sT_{p1})(1+sT_{p2})(1+sT_{p3})(1+sT_{p4})}$	K_G=1; T_{p1}=3.9517 ;T_{p2}=0.1481; T_{p3}=8.38e^{-3} ; T_{p4}=9.37e^{-4} ; T_{z1}=0.9087; T_{z2}=0.1257; T_{z3}=6.88e^{-3}; T_{z4}=7.75e^{-4}
Sensor	$G_{sen} = \frac{K_R}{1+sT_R}$	K_R =1 ; T_R=0.05

3. Fuzzy Logic

The fuzzy logic technique was suggested in 1965 by L. Zadeh at the California University, different aspects of control processing and problems are solved by fuzzy theory. The main operation of Fuzzy theory are: fuzzification, defuzzification and finally inference engine. The Fuzzification process is used to transforms the limited values into fuzzy set values. Fuzzy system is used to simulate thinking of human to control on the information or processing. Fuzzy system or fuzzy logic is implemented from long time to solve or tune the complex problems. No need to mathematical expression by using Fuzzy therefore the operations are simpler from another methods. Figure 2 shows the main components of fuzzy logic controller [18].

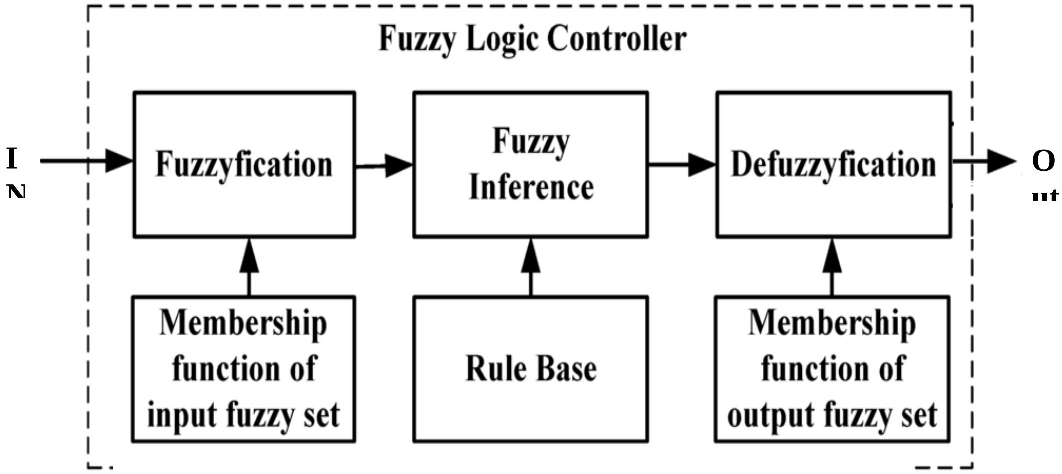

Figure 2 Fuzzy logic controller

4. Proposed Work: part 1: Fuzzy-Swarm Algorithm (FSA)

Fuzzy system with two input and two output is used to obtain and tune the best cognitive (C1) and social (C2) accelerations. Five triangular membership function are used with 25 rules and centroid defuzzification method are used in fuzzy system.

The velocity (vel) and position (k) of the PSO algorithm are described as follow **[19, 20]:**

$$vel_{i,j}(t+1) = vel_j(x) + c_1 r_{1j}(x)\left[y_{i,j}(x) - k_{i,j}(x)\right] + c_2 r_{2j}(x)\left[\acute{y}(x) - k_{i,j}(x)\right] \quad (2)$$

$$k_{i,j}(x+1) = k_{i,j}(x) + vlo_{i,j}(x+1) \quad (3)$$

Where r_{1j} (t) and r_{2j} (t) are limited between (o and 1). In classical PSO algorithm C1 and C2 are taken as constant values, but in the proposed work these values are represent fuzzy values and changed based on fuzzy system and can be calculated as follow:

$$C1 = \frac{\sum_{z=1}^{mc1} \omega_z^{c1}(C1z)}{\sum_{z=1}^{mc1} w_z^{C1}} \tag{4}$$

$$C2 = \frac{\sum_{z=1}^{mc2} \omega_z^{c2}(C2z)}{\sum_{z=1}^{mc2} w_z^{C2}} \tag{5}$$

Where mc1 and mc2 are the number of the rules in fuzzy corresponding to C1 and C2, C1z and C2z represent the output results for rule number z corresponding to C1 and C2, finally *w* is represent the membership function of z rule. The Fuzzy-Swarm algorithm (FSA) is explained in the figure 3

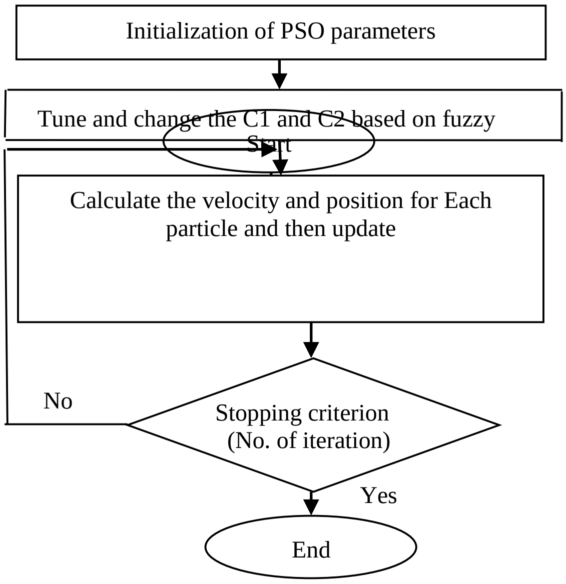

Figure 3. Flowchart of the proposed Fuzzy-Swarm algorithm (FSA).

Part 2: using conventional PID controller coupled with above controller to get the optimum control action, the advantage of each controller with be collected in the proposed controller to enhance the response of fourth order AVR system, as shown in the figure 4.

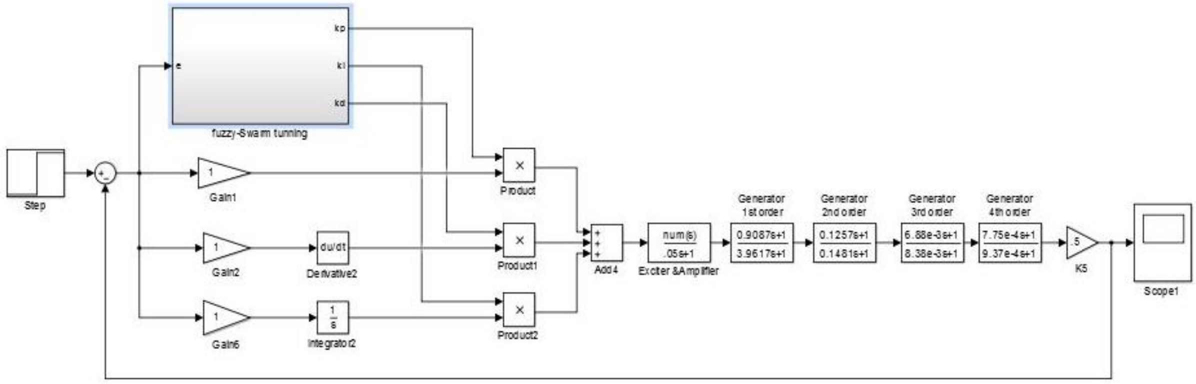

Figure 4. Feedback control system for 4th order AVR with proposed controller. (Fuzzy-Swarm-PID controller (FSPID) simulate in MATLAB simulink

4. Results

PSO and Fuzzy logic system are very suitable choose to solve many complex problems in any complex control systems with very good enhancement [21]. Fuzzy system is used to enhance the PSO algorithm by tune and change the C1 and C2 and then the response of this controller is summed with the control action from PID controller as shown in figure 4 to enhance the overall response by minimizing the error signal. Fourth order AVR is tested to check the performance of the proposed work and then compared with the classical controllers. A unite step signal of 1 (p.u) is applied as a voltage reference (input) to check the response. Figure 3 shows the simulation of AVR with 4th order model by MATLAB Simulink. Scope terminal voltage with and without controllers are shown in Figures 5, 6, and 7. The fourth order model of AVR system is used by many researchers such as [14, 22].

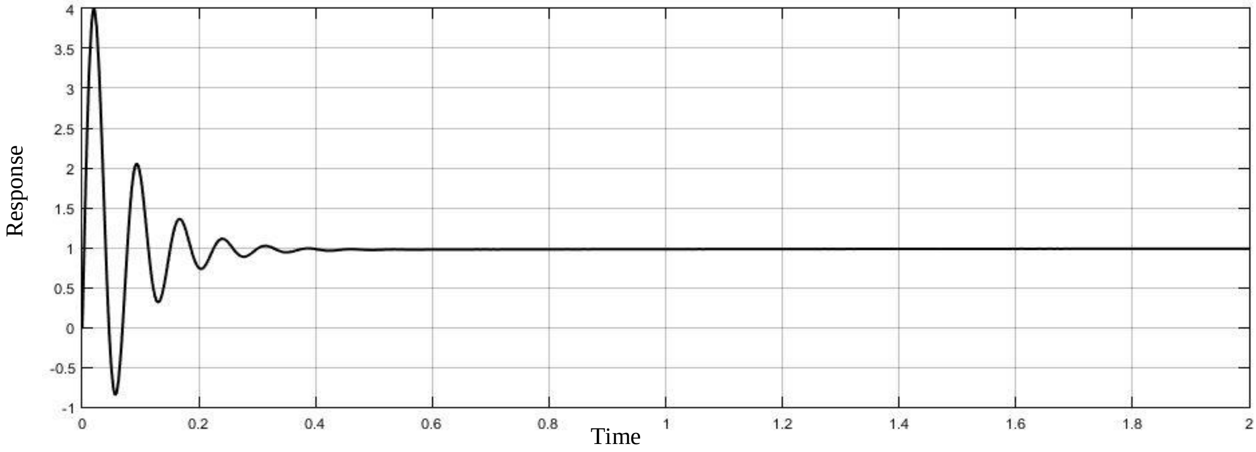

Figure 5 closed loop response without Controller

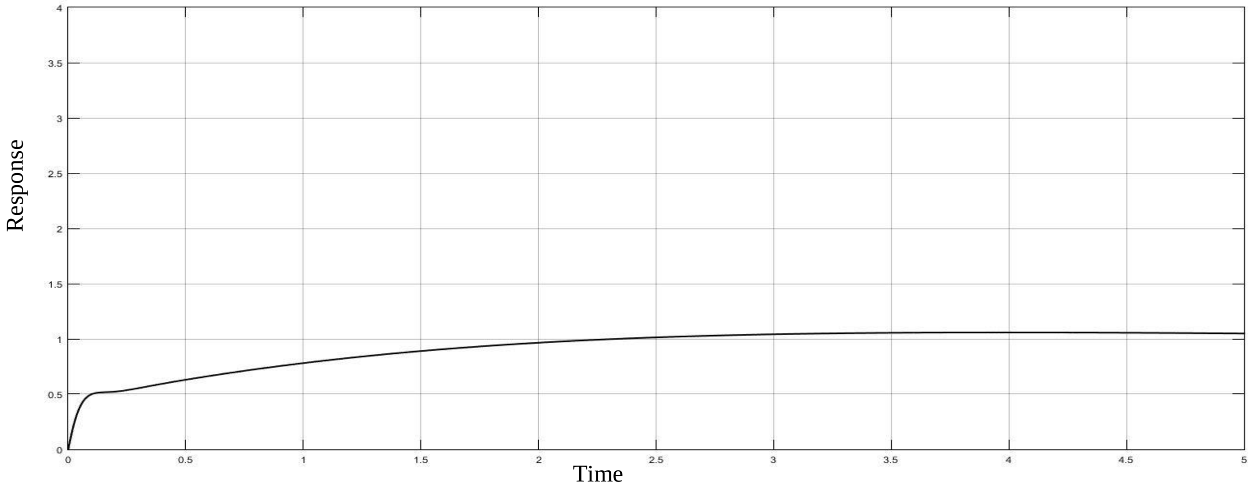

Figure 6 closed loop system response with PID Controller

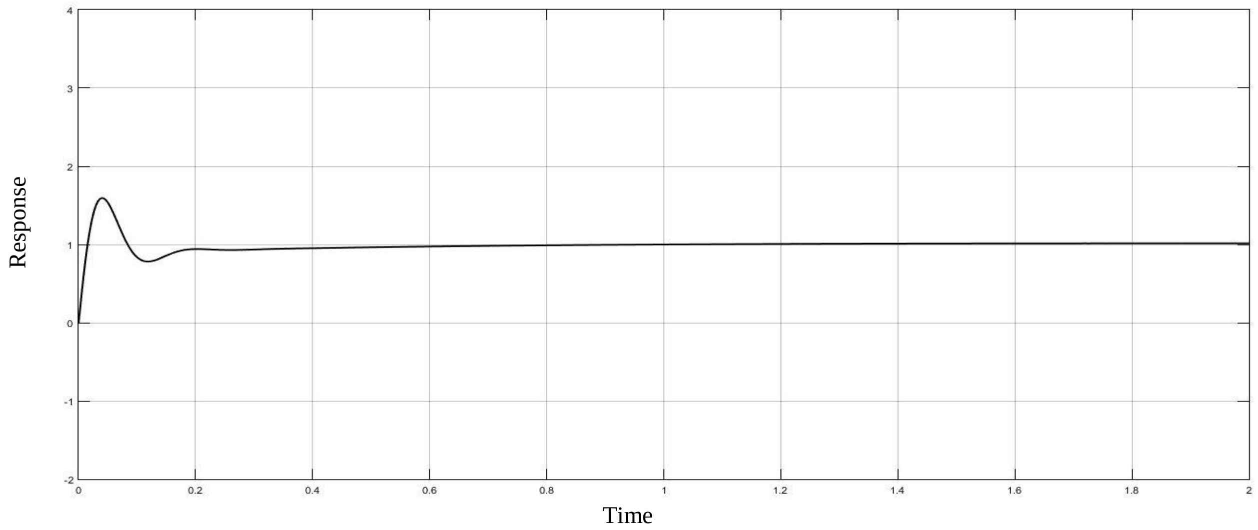

Figure 7 Closed loop system response with Fuzzy logic controller

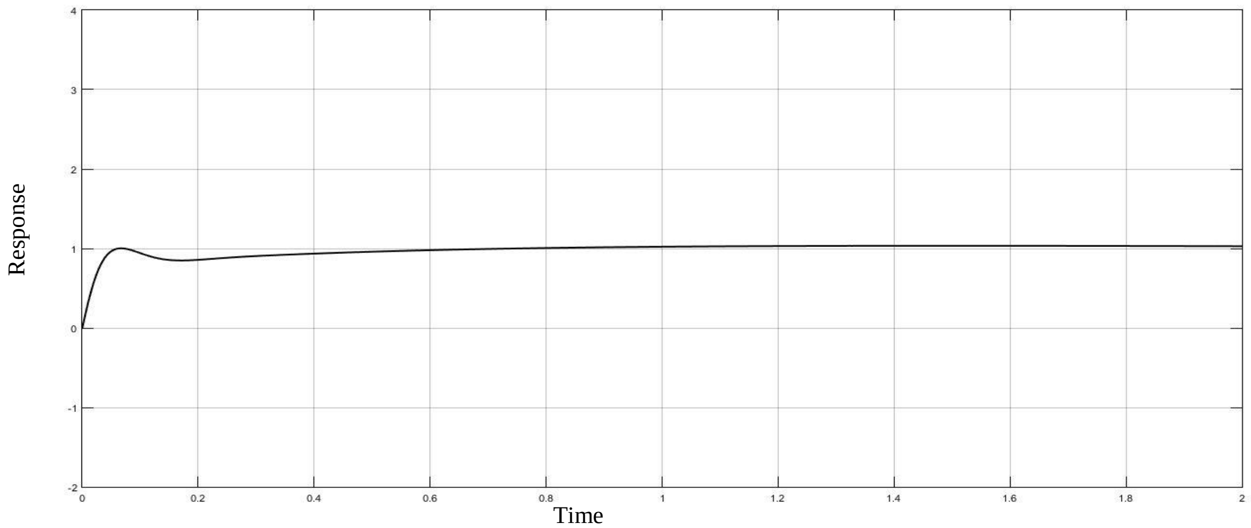

Figure 6 Closed loop system response with Fuzzy-Swarm-PID controller (FSPID)

Table 1 ISE and PID parameters for 4th order model

Type of Controller	**ISE**	**Time response parameters**			
		Overshoot	**tr**	**tp**	**ts**
Without controller	28.217	3	0.04	0.05	0.3
PID	6.183	/	1.6	/	1.7
Fuzzy	1.582	0.69	0.4	0.8	0.25
Fuzzy-Swarm-PID	1.256	0.01	0.03	0.1	0.23

Sudden high disturbance signal is applied on the system as explained in figure 7 to check the performance of the proposed work. The output responses are shown in Figures 8, 9, and 10.

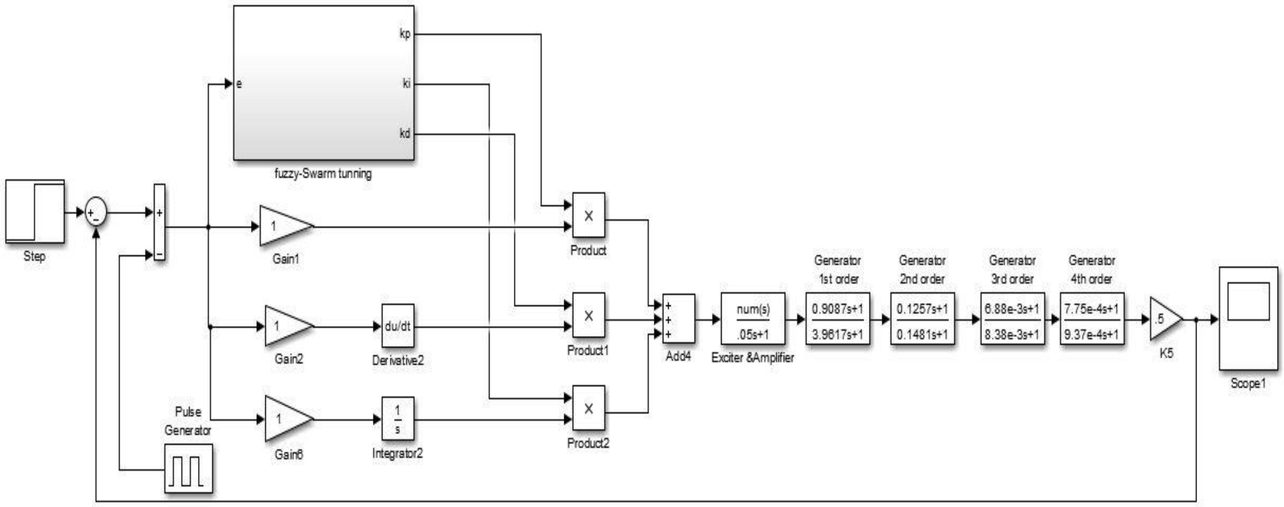

Figure 7 Closed loop system response of AVR system subjected to disturbance simulated in Matlab-

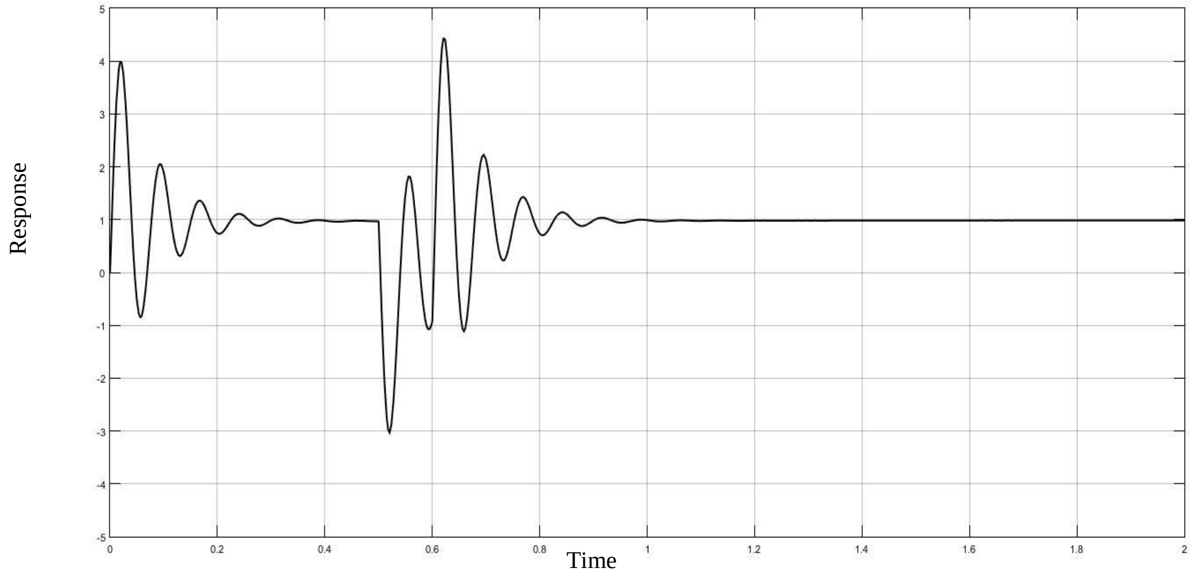

Figure 8 System response with disturbance without controller

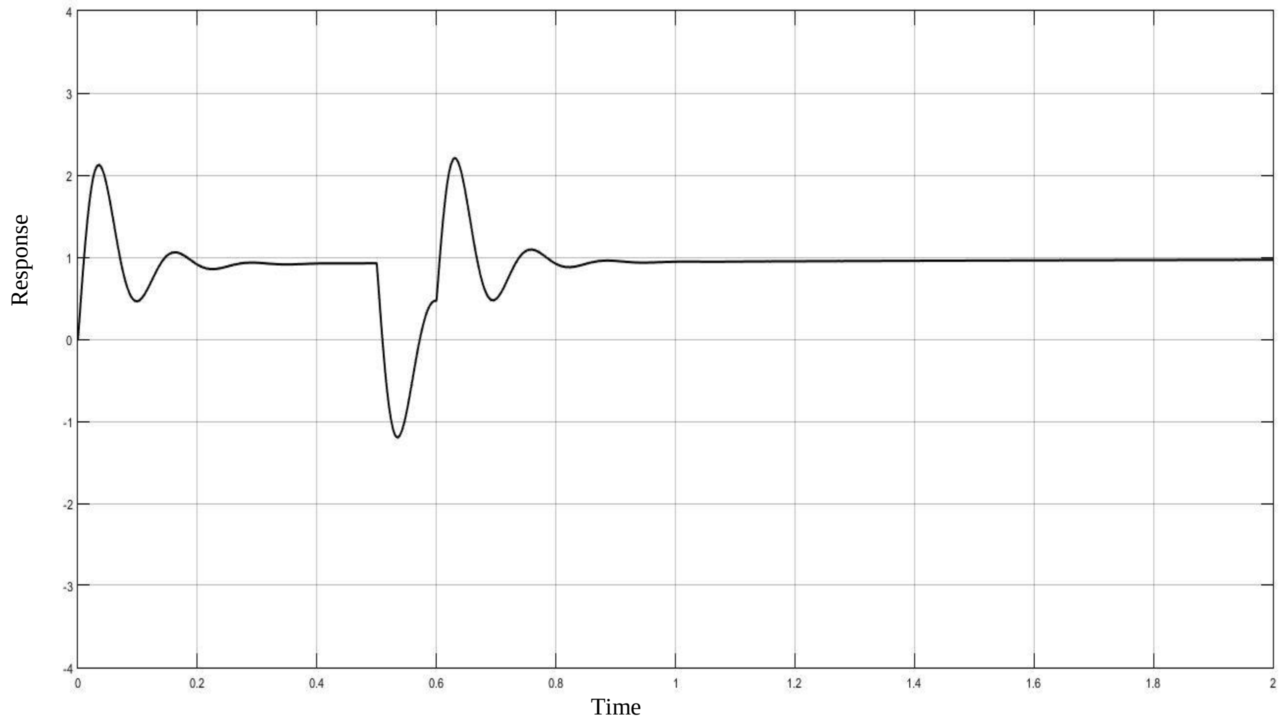

Figure 9 System response with disturbance by Fuzzy logic controller

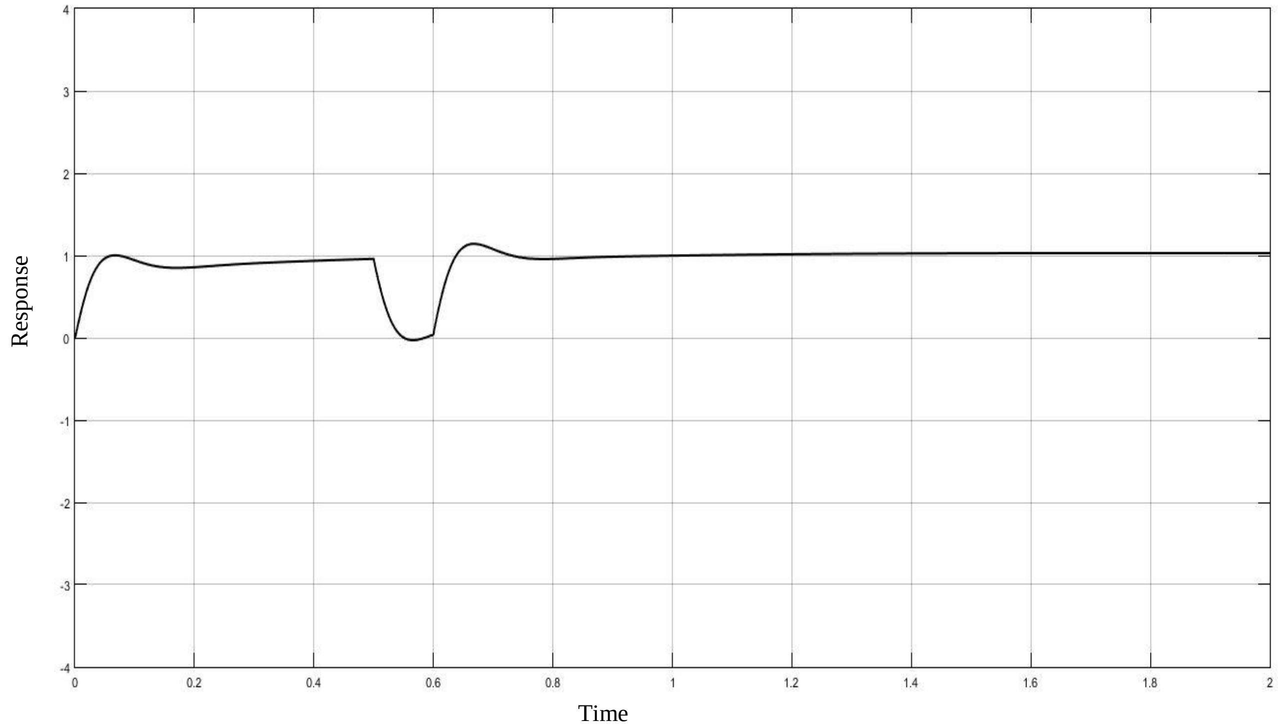

Figure 9 System response with disturbance with Fuzzy-Swarm-PID controller (FSPID)

5. Conclusion

The main function of AVR is used to fix the machine voltage response at limited level. This paper is focused on the mixing between PSO, Fuzzy, and conventional PID controller as famous intelligent technique in control system to enhance the output response of the system. The main goal is to enhance the performance of the voltage transient response of high order AVR system. This work is powerful to improve the response as shown in Table 2. According to the results, this work is a novel techniques compared with classical PID and fuzzy logic controller or fuzzy tuned by PSO.

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