A PROPOSED APPROACH TO CONTROL OF AUTOMATIC VOLTAGE REGULATOR SYSTEM USING INTELLIGENT CONTROL TECHNIQUE+

Ahmed Karim Abdullah Albakri* **Ali Abdul Abbas Abdullah Albakri****

Abstract

In recent years, the world has moved toward the intelligent control to obtain the optimal solution for the big problems. The main aim of this paper is to obtain the best performance for the Automatic Voltage Regulator (AVR) system by using the fuzzy logic controller tuned by genetic algorithm. The genetic algorithm approach is used here to change the scaling gains at the inputs, output of fuzzy controller, and tuning the membership function with stay the fuzzy rules without changing. The proposed approach has been tested and compared with PID controller and without controller. The simulation has been performed using C++ programming language (version 5.02) along with MATLAB program that has been used for plotting time response.

المستخلص

في السنوات الاخيرة ، اتجة العالم باتجاة السيطرة الذكية للحصول على افضل الحلول لمشاكل السيطرة، الهدف الرئيسي من البحث هو الحصول على افضل اداء لمنظم الفولتية الاوتوماتيكي (AVR) بأستحدام مسيطر غامض منغنم بالخوارزميات الجينية، إذ استخدمت الجوارزميات الجينية هنا في تغيير وايجاد افضل قيم لمتغيرات الادخال والاخراج وكذلك تم التحكم بقاعدة الدوال الغامضة (fuzzy membership function) للحصول على مسيطر غامض معدل بالخوارزميات الجينية وبثبوت قواعد السيطرة والتي تعطي افضل استجابة للنظام ، واختبرت هذة الطريقة وقورنت مع المسيطر الثلاثي (PID)والطريقة القديمة(من دون مسيطر)، تم تمثيل وبرمجة هذه الطريقة بلغة (C++) وبرنامج MATLABفي رسم استجابة النظام.

2. Introduction

Fuzzy Logic was initiated in 1965, by Lotfi A. Zadeh. Fuzzy systems are particularly suitable for modeling and classification problems as a human expert [1].In the past years more researches have been devoted to augment the approximate reasoning method of fuzzy systems with the learning capabilities of neural networks and evolutionary algorithms [2].

In power system studies, there are many elements affecting stability of the system. These factors need be addressed before proceeding to design any simulation program for the power system. The AVR has a substantial effect on transient stability when varying the field voltage to try to maintain the terminal voltage constant [3].

There are a number of efficient search algorithms that have their origins in the field of biological evolutionary and are known as evolutionary computation, the field of evolutionary computation is comprised mainly of Genetic Algorithms (GAs), Genetic programming (GP) and Evolutionary Strategies (ES) [4].

+ Received on 5/12/2005 , Accepted on 8/2/2007
* Asst. Lecturer\ Technical Collage / Almusyeib\ Electrical Power Engineering Technique,Baghdad,Iraq.
** Asst. Lecturer\Technical Collage / Almusyeib\Electrical Power Engineering Technique ,Baghdad,Iraq.

In this work, these algorithms are used to tuning the inputs and output scaling parameters and fuzzy membership function bases of the fuzzy controller to obtain the optimal rules for control system under the condition of no expert.

This paper is organized as follows: after the introduction, Automatic Voltage Regulator (AVR) system is presented in section 3, a Genetic-Fuzzy Controller Design (GFC) is presented in section 4. Result of testing the proposed approach is addressed in section 4. Finally the conclusions are given.

3. Automatic Voltage Regulator System

A simple automatic voltage regulator (AVR) is shown in Figure (1)

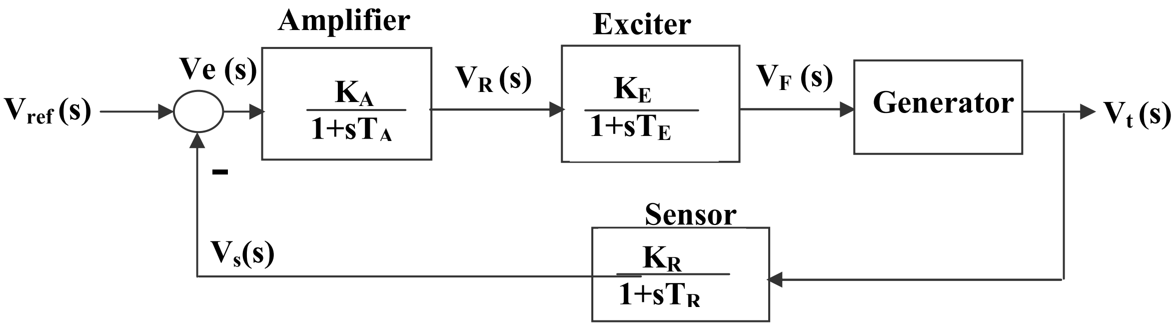

Figure 1: Block diagram of the proposed AVR system

First order model of synchronous generator is:

$$\frac{Vt(s)}{V_F(s)} = \frac{K_G}{1+sT_G} \qquad \text{-------(1)}$$

Fourth order model of synchronous generator is:

$$\frac{Vt(s)}{V_F(s)} = \frac{K_G\,(1 + sT_{z1})\,(1 + sT_{z2})\,(1 + sT_{z3})\,(1 + sT_{z4})}{(1 + sT_{p1})\,(1 + sT_{p2})\,(1 + sT_{p3})\,(1 + sT_{p4})} \qquad \text{-------(2)}$$

Each block in the figure 1 will be explained below

3.1 Exciter Model

The most important component other than the synchronous machine in the power system is the excitation system. The most basic form of expressing the exciter model can be represented by a gain K_E and a single time constant T_E as shown in equation (3) .

$$\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1+sT_E} \qquad \text{------------(3)}$$

where: K_E= Gain of the Amplifier (K_E=1)
T_E= Time constant of the pole (T_E=0.05)

There are many different types of excitation systems available some of which use ac power source through solid-state rectifiers such as SCR [3]. As a result, the output voltage of the exciter becomes a nonlinear function of the field voltage due to the saturation effects which occur in the magnetic circuit. However, the modern exciter can be estimated as a linearised model, taking account for major time constant and ignoring the saturation and other nonlinearities. Therefore, the simplest form of representing a basic exciter is expressed as equation (3) which will be used to represent the exciter model in the simulation.

3.2 Amplifier Model

The amplifier is represented similarly by a gain *K*A and a time constant *T*A. The transfer function of the amplifier is

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1 + sT_A} \qquad \text{-------(4)}$$

where: K_A= gain of the Amplifier (K_A=200)
T_A= time constant of the pole (T_A=0.05)

Typically, the time constant of the amplifier is very small and is often neglected. Therefore it is very often the case, to represent the amplifier (neglecting the time constant) and the exciter as a single block model since the time constant for the exciter is also very small.

3.3 Generator Model

The basic generator model will be similar to the exciter model in terms of its transfer function. A simple linearized model of generator can be expressed as shown in Figure (2) where *V*t is the terminal voltage of the synchronous generator. K_G and T_G are the generator gain and time constant of the generator. For this simple model, the typical value of K_G varies between **0.7** to 1, and T_G between 1 second to 2 seconds from full load to no-load since these constants are load dependent.

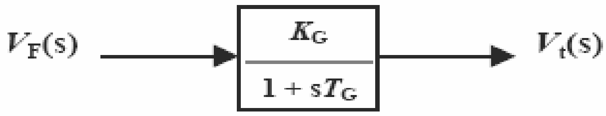

Figure 2: Block diagram of Generator model

A fourth order model of the synchronous machine consists of a generator gain plus four pairs of pole-zero time constants derived from the operational inductance. In terms of expressing it as transfer function, is :

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G\,(1+sTz1)\ (1+sTz2)\ (1+sTz3)\ (1+sTz4)}{(1+sTp1)\ (1+sTp2)\ (1+sTp3)\ (1+sTp4)} \qquad \text{------(5)}$$

K_G = Gain of the generator
*T*z = Time constant of the zero
*T*p = Time constant of the pole
*V*F = Field voltage of the synchronous generator
*V*t = Terminal voltage of the synchronous generator

Generally the over all transfer function for fourth order model after substituting all values (gains and time constants) is [3]:

$$\frac{Vt(s)}{V_F(s)} = \frac{(0.9067\ s + 1)(\ 0.1257\ s + 1)(\ 0.00688\ s + 1)(\ 0.000775\ s + 1)}{(3.962\ s + 1)(\ 0.1481\ s + 1)(\ 0.00838\ s + 1)(\ 0.000937\ s + 1)} \qquad \text{-----(6)}$$

3.3 Sensor Model

The terminal voltage of the synchronous generator is being feedback by using a potential transformer that is connected to the bridge rectifiers. The sensor is also being modeled, likewise as the exciter, by a first order transfer function

$$\frac{V_S(s)}{V_t(s)} = \frac{K_R}{1 + sT_R} \qquad \text{------} \qquad (7)$$

where V_S = output voltage of the sensor, i.e. the output of the bridge rectifiers.

K_R= Gain of the generator (K_R=1)

T_R= Time constant of the pole (T_R=0.05)

By combining the various models from Section 3.1 to 3.3, a simple automatic voltage regulator (AVR) is created [3].

4. Genetic-Fuzzy Controller Structure (GFC)

In order to design the simulation program, a block diagram of the closed-loop control system used , it is shown in Figure 3.

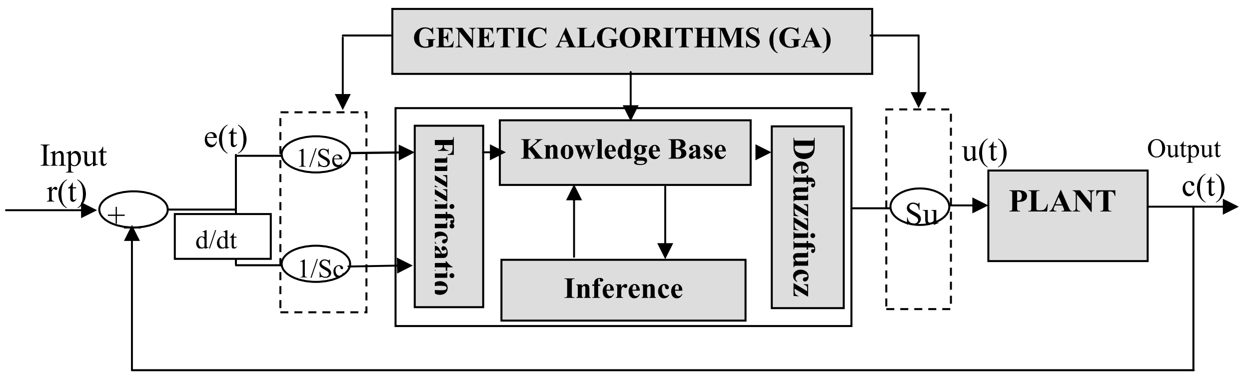

Figure 3: Closed loop Control with Genetic Fuzzy controller (GFC)

In general there are three popular types of FLC used in the paper, which are 25-Rule, 49-Rules, and 121-Rules controllers. However, the (25-Rules) fuzzy controller may not operate over wide range of conditioned, while using 121-Rules fuzzy controller needs more computational efforts [5], so 49-Rules have been used for simulation results.

The genetic algorithms are search optimization technique that evaluate more than one area of the search space and can discover more than one solution to problem .There are three main operators, namely (Selection, Crossover, and Mutation) used in genetic algorithms [4].

The integration of GAs and FLC with a main emphasis on tuning the membership function and the scaling gains at the inputs (Se, Sc) and the scaling gain at the output (Su) of fuzzy controller can have significant impact on the performance of the resulting fuzzy control system, and hence they are convenient parameter for tuning. In this work these gains and optimal membership function ships are found using GAs.

The flowchart for GA-FC is shown below:

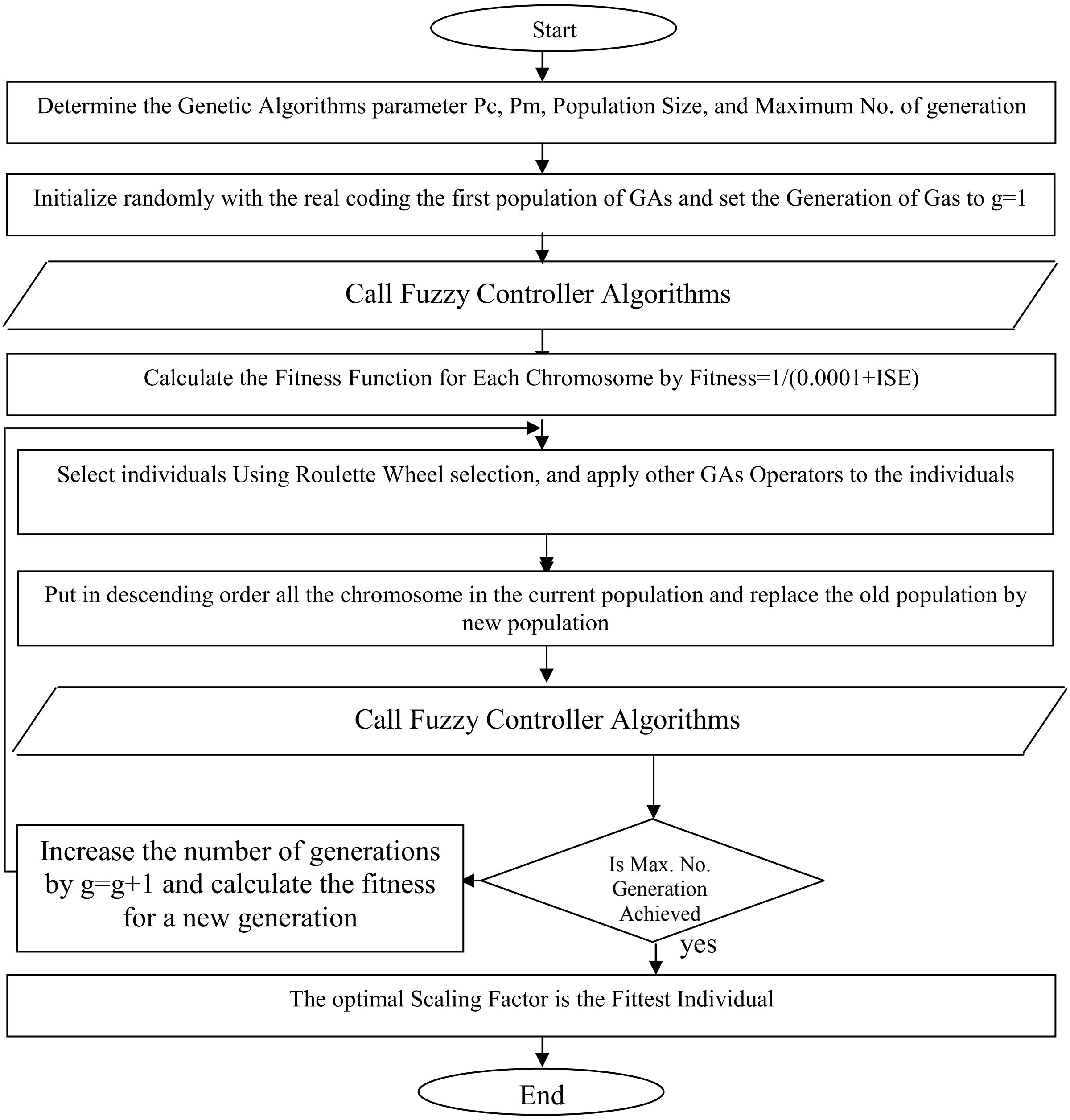

Figure 4: Flowchart of genetic learning scheme for GFC

To understand this approach the important steps in Figure (4) are explained below.
The parameters types for genetic algorithms used here are:

- **Type of Selection = Roulette Wheel Selection**

The Selection is a method for increasing the number of solution candidates having high fitness values. There are several types of selection such as (Roulette Wheel Selection (RWS), and Rank selection) [4].

- **Type of Crossover = Single point Crossover.**
  The GA is not only filling the population with the best of the first generation by choosing better solutions, but there are also created new solutions, are created from the original database which can be done by crossover operator .There are several types of crossover operator, some of these are (Single point crossover, Two Points Crossover, multi Point Crossover, and Arithmetic Crossover) [2]

- **Type of mutation = Uniform mutation**
  Mutation operator is another degree of freedom in search procedure, which is frequently used in GA, based design. The need for mutation is to keep diversity in the population. There are many ways of accomplishing mutation such as binary, Uniform, Non-Uniform and Boundary mutation [6].

- **Fitness function =1/(ISE+0.00001)**
  The fitness/objective function is chosen depending on the problem in hand such that the individuals having high fitness values are the good solution candidates for the optimization. Therefore, selection of the next generation will be dependent on the fitness measure [6].
  Since ISE=Integral of square error

- Probability of Crossover = 0.95
- Probability of Mutation =0.01
- Max. NO. of Generation =1000
- Population size = 100

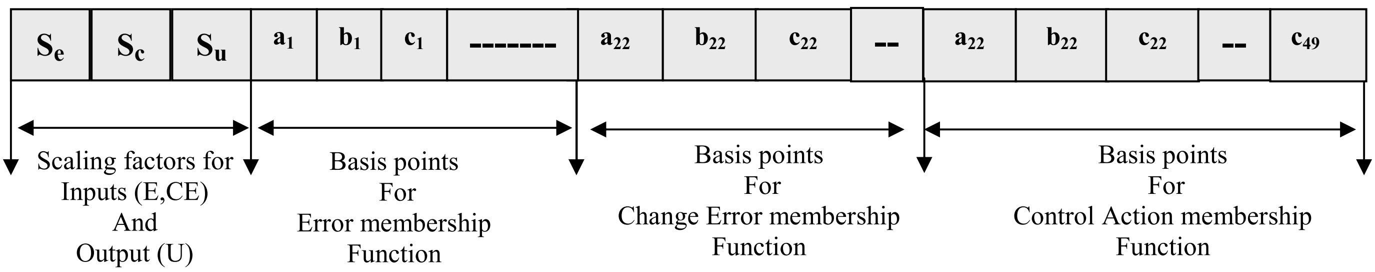

Figure 5: Chromosome Representation for the GFC

The block of **fuzzy controller algorithms** are illustrated through this steps:

<u>Step 1</u>: Define scaling factor (Se, Sc, and Su) and intervals for error (E), Change in error (Ce), and control action (U).

<u>Step2:</u> Compute the error (E and change in error (CE) :

Error (i)=Input (i)-Output (i)

Change in error (i)=Error(i)-Error (i-1)

<u>Step 3:</u> Compute the values of membership function for E and CE.

<u>Step4</u> **:**Compute the values for premise membership function for E and CE using minimum operator.

Step 5: Determine which rules to use and find the area under the membership function.
Step 6: Compute the control action (output value)
.

The base for this membership functions can be represented by 3 points (a, b, c) as shown in Figure 4.

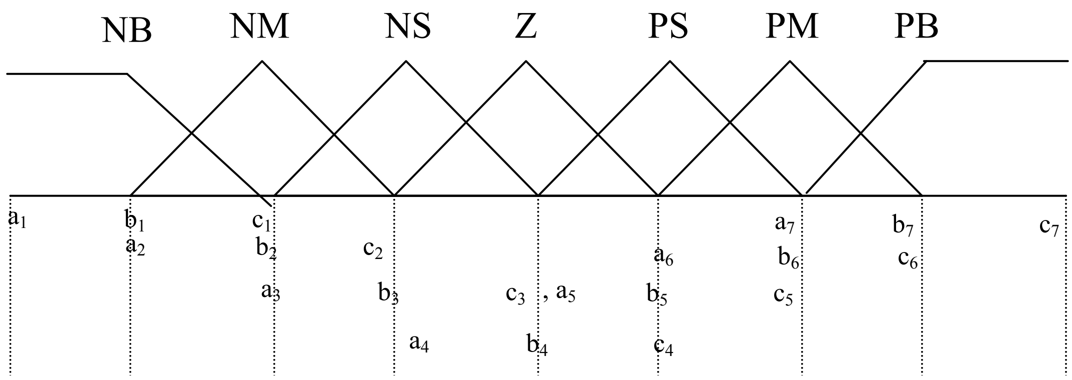

Figure 6: The membership function distribution

Also the same membership function distribution is for change in error and control action, since the 7 membership functions are used for Error (E), Change in Error (CE) and Control action (U), therefore the rules number is (7*7 = 49) rules stored in Knowledge Base as shown in Table (1)

Table 1:Rule –Base Matrix

	NB	NM	NS	Z	PS	PM	PB
NB	Z	PS	PM	NS	NM	PS	NM
NM	PS	Z	PS	PM	NS	NM	PS
NS	PM	PS	Z	PS	PM	PS	PM
Z	PS	PM	PS	Z	NS	NM	PS
PS	PS	PS	PM	NS	Z	NS	NM
PM	NS	PM	NS	NM	NS	Z	NS
PB	NM	NS	NS	NS	NM	NS	Z

5. Results and discussion

In this section, the Automatic Voltage Regulator (AVR) system is tested. The proposed AVR system block diagram for simulating synchronous generator with the rest of the appropriate excitation system Components is shown in Figure (7). Note that the amplifier block shown in Figure has merged with the exciter block in this figure.

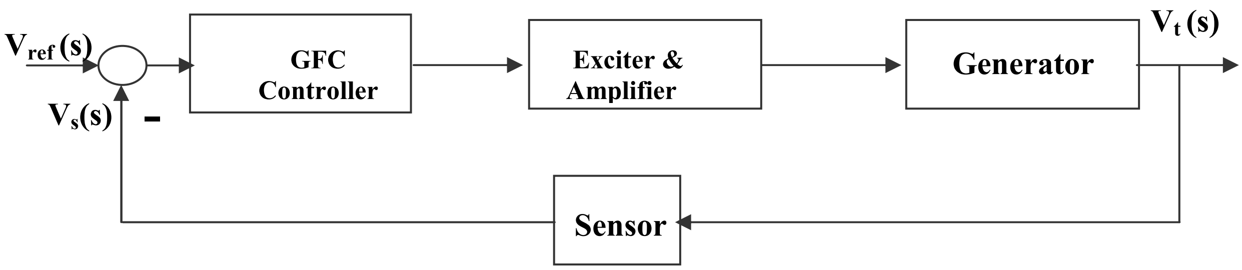

Figure 7: Block diagram of the proposed AVR system with GF controller

The simulation has been performed on Pentium 4(P4) personal computer with 2.4GHZ CPU speed, using C++ programming language (version 5.02) along with Matlab program that has been used for plotting the time response of different simulation where it is required that the plant output follows the desired input. The simulation results showed that the use GFC with AVR plant provide an improvement in the response.

The Automatic voltage regulator Has been controlled using GFC to follow the reference input, the comparison between GF controller, PID controller, and without controller is shown in table (2). The influence of stabilizing this system can be noticed from the unit step responses. Figure (8) and Figure (9) illustrated the response for the system when without controller is used for first order and fourth order generator modal respectively.

Figure (10) and Figure (11) show the effect of PID controller for the system since the controllable response are obtained but not sufficient and the significant overshot appears therefore the another controller must be used and the GFC is used to obtain the good response for the system as shown in Figure (12) and Figure (13). The error signals for first and fourth order model are illustrated in Figures (14 and 15) respectively when using GFC

For First order generator system, after a number of generation (50 generation) in genetic algorithm the ISE value equals (2.005601) with maximum overshot (0.35) since the scaling values for fuzzy controller is (Se=-7.286754, Sc=-9.432896 , Su= 2.08563) which are obtained from genetic algorithm but at the last generation the ISE = 1.003156 and the good characteristic for unit step response as shown in figure (12). The stopping criterion in the C++ program is the number of generation, since the execution screen is appearing when the generation number is arriving to 1000 generation .The fuzzy membership function distribution before and after tuning for control action is illustrated in Figure (16) and Figure (17).

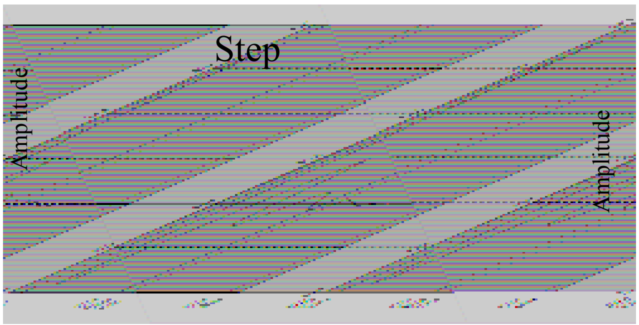

Figure 8: Response without controller for the First order model

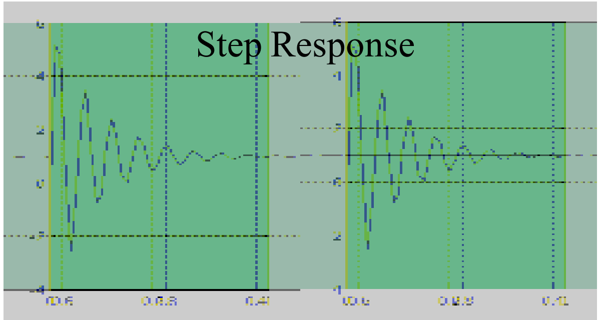

Figure 9: Response without controller for the Fourth

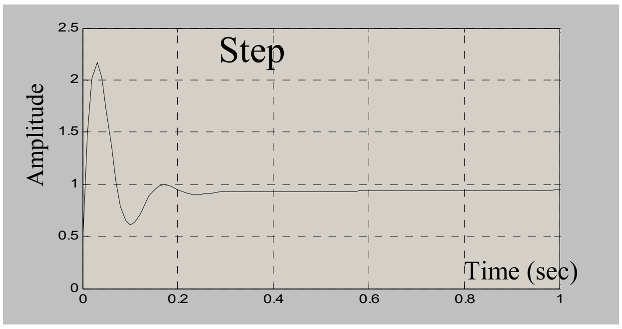

Figure 10: Response with PID for the First order

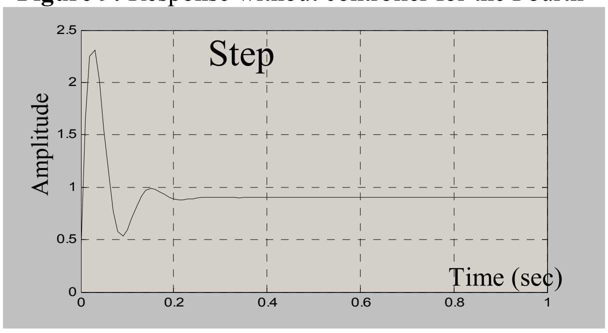

Figure 11: Response with PID for the Fourth order

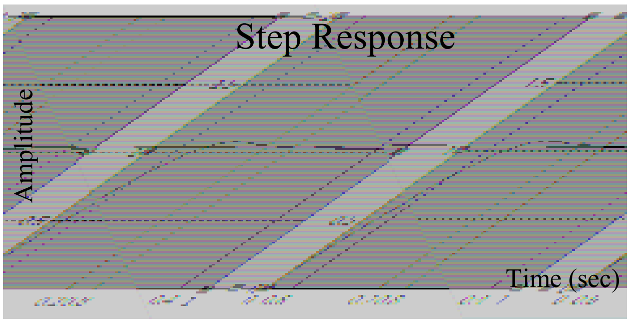

Figure 13 : Response with GF for the First order

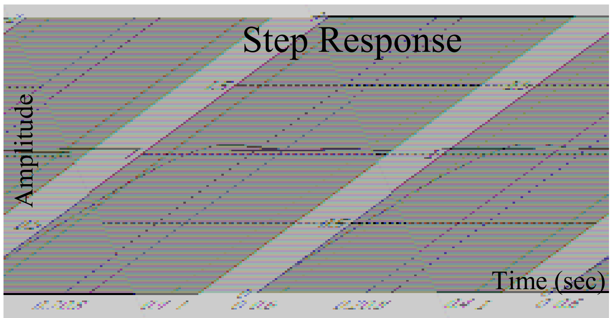

Figure 14 : Response with GF for the Fourth order model

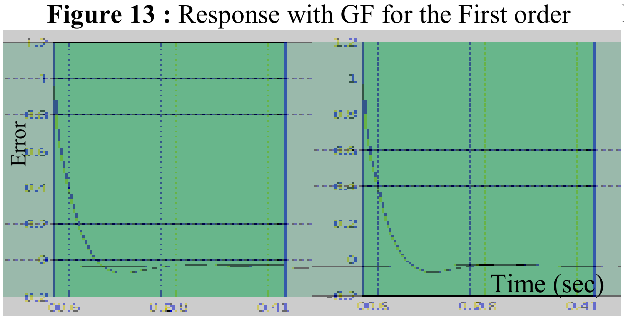

Figure 14: error signal with GF for First order model

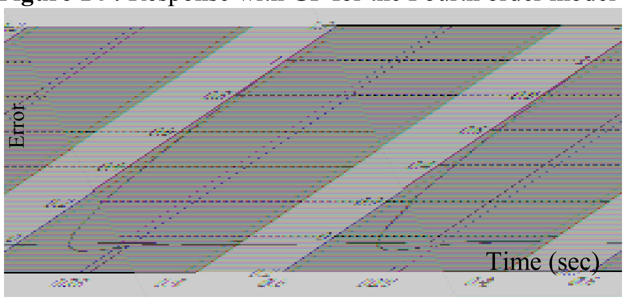

Figure 15: error signal with GF for Forth order

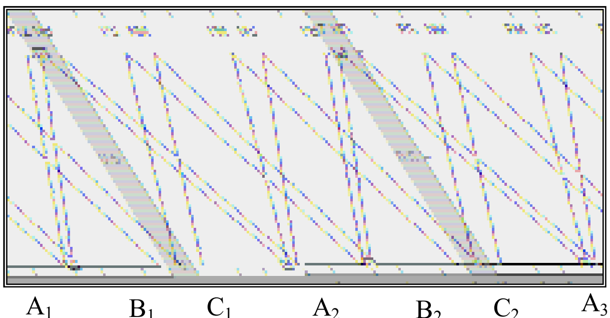

Figure 16 : The membership function distribution after tuning for Control Action

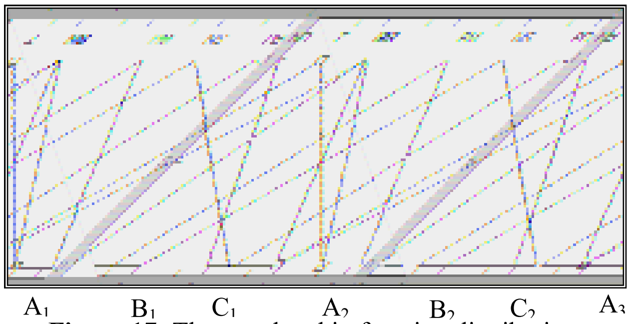

Figure 17: The membership function distribution after tuning for Control Action

Table (2): Time response specifications for first and Fourth Order model generator with Unit step input

enerator Model	Controller Type	Figure No.	ISE	IAE	ITAE	Fuzzy Scaling Factors (obtained Genetically)		
						Se	Sc	Su
First Order Generator	Without Controller	Fig.9	12.45	14.75	19.64			
	PID	Fig.11	2.320	4.67	7.381			
	GFC After 50 Generation		2.005	1.524	1.632	-7.286	-9.432	2.085
	GFC at the Last Generation	Fig.13	1.003	1.029	1.047	1.0003	-1.777	9.192
Fourth Order Generator	Without Controller	Fig.10	25.34	13.68	31.89			
	PID	Fig.12	3.289	3.875	4.989			
	GFC After 50 Generation		2.206	2.89	3.58	4.970	-0.67326	1.005438
	GFC at the Last Generation	Fig.14	1.091	1.18	1.92	2.890	0.04328	-1.87543

5.2 Conclusions

The simulation of the transient response of synchronous machine has been successful. The program in this dissertation is able to generate the responses of the first and fourth order synchronous machine correctly.

- When number of generation is increased the best result is obtained but the computation time for execution program is increased also.
- The computer simulation shows that the GFC is an effective controller to control on AVR systems, since the GFC with this systems provided an improvement in the responses, decrement in steady state error , decrement in rise time and decrement in setting time since table 2 and 3 show this effective
- The genetic algorithm is really search optimization algorithm since a good scaling gain for fuzzy controller is obtained when using this algorithm.
- There are several types of crossover but the multipoint crossover gives the significant result.
- PID controller with AVR system is a good but GFC is the best

6. References

1. Zadeh, L. *"Making computer think like people"*, *IEEE. Spectrum*, pp.26-32, 1984.
2. Herrera, F., Cordon, O., and Dejesus, M. J. "*Genetic learning of fuzzy rule-based classification systems cooperating with fuzzy reasoning methods", International Journal of Intelligent Systems*, vol.13, pp.1025–1053, Nov. 1998.
3. Klempner G. and Kerszenbaum I. " *Principle of Operation of Synchronous Machines*", John Wiley & Sons, Inc USA,2004
4. Mitcell, M.., *"An Introduction to Genetic Algorithms"*, First MIT Press Paperback edition ,United States of America, 1996.
5. Bezdek, J. C. *"Fuzzy models, what are they, and why?" , IEEE Trans*. Fuzzy Systems **1**, pp 1-6, 1993
6. Al Said I. A. M. , "*Genetic Algorithm Based Intelligent Control"* , Ph.D. Dissertation . Control and computer Engineering Department, University of Technology, Iraq. 2000.
7. Oscar, C., and Julyan H. E. *"Fuzzy control of chaos ", Int. J. Bifurcation and Chaos **8***, pp 1743-1747, 1998
8. Passino K. M. and Yorkovich S.," *Fuzzy Control*" , , Addison Wesley Longman, Inc, USA.,1998.
9. Wang L.X., *A course in Fuzzy Systems and Control* , Prentice –Hall, International, Inc., 1997.
10. Rashaeed F.K. *"Analysis of fuzzy model Reference Learning Controller"*. .M.SC. Dissertation. Electrical Engineering Department, Engineering Collage, University of Almustansiriyah, Iraq. 2000.
11. Reznik L.," *Fuzzy Controllers*", Imprint of Butterworth Heineman, Newnes, 1997.