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Modified Approach for Tuning Fractional Order PID Controller (FOPID) Using Intelligent Control Techniques

طريقة معدلة لتنغيم المسيطر التكاملي التناسبي المشتق الجزئي باستخدام تقنيات السيطره الذكية

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Abstract:

Many controllers are used to enhance the output responses for the complex system but there are several problem appear when classical controller are used therefore the world directed toward the intelligent control techniques to solve complex problem. In this paper the intelligent techniques are integrated with Fractional order PID controller (FOPID), to enhance the output response for the overall system. FOPID is a PID controller but its derivative parameter and integral parameter are fractional numbers not integers and it is consists of five parameters (K_P, K_I, K_d, α, β), these parameters are extracted and tuned by genetic algorithms, new performance criterion is used in this paper, by collecting the time response parameter (rise time , peak time, settling time) with integral squire error ISE to produce good performance index ,finally the proposed approach has been tested and compared with another controllers. The simulation has been performed using MATLAB.

Key Words:
Intelligent Controller ,FOPID, AVR , Genetic Algorithms,

المستخلص

عده مسيطرات استخدمت لتحسين استجابة الانظمه المعقدة ولكن هناك مشاكل ظهرت عندما استخدمنا المسيطرات التقليدية او الكلاسيكية لذا أنتجه العالم باتجاه تقنيات السيطره الذكية لحل مشاكل الانظمه المعقدة في هذا البحث التقنيات الذكية عشقت مع المسيطر الجزئي التناسبي التكاملي التفاضلي(FOPID) لتحسين استجابة النظام الكلية.المسيطر المفترح الجديد هو بالحقيقة مسيطر ثلاثي ولكن متغيرات المشتقة والتكامل ليس شرط ان تكون أرقام صحيحة وكذلك يحوي على خمس متغيرات بدل من ثلاثة متغيرات وهي ((K_P, K_I, K_d, α, β) وهذه المتغيرات الخمسه استخلصت من الخوارزميات الجينية . بالاضافه الى ذلك فقد تم تكوين معامل جديد للمقارنه يعتمد على جمع الأخطاء بالاشاره الخارجه مع متغيرات الاستجابه . وأخيرا قورنت النتائج مع مسيطر كلاسيكي ثلاثي وبدون استخدام مسيطر واثبتت النتائج قوه هذا المسيطر الجديد والحصول على استجابه جيده ومتغيرات زمنيه صغيره . واستخدم برنامج الماتلاب لتمثيل ورسم النظام.

1-Introduction:

PID controller is a one of the earliest industrial controllers. It has many advantages: Its cost is economic, simple easy to be tuned and robust. This controller has been proven to be remarkably effective in regulating a wide range of processes [1]. More than 90% of industrial controllers are still implemented based around PID algorithms, particularly at lowest levels. With its three-term functionality covering treatment to both transient and steady-state responses, proportional- integral-derivative (PID) control offers the simplest and yet most efficient solution to many real-world control problems[2].Fractional Order PID (FOPID) controller is a convenient fractional order structure that has been employed for control purposes [3,4,5]. An FOPID is characterized by five parameters: the proportional gain, the integrating gain, the derivative gain, the integrating order and the derivative order. 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 ,genetic programming and evolutionary strategies [6]

2- Fractional Order PID Controller (FOPID)

The differential equation of a fractional order PID controller is described by [3]:

$$u(t) = K_p e(t) + K_I D_t^{-\lambda} e(t) + K_D D_t^{\beta} e(t) \text{ ---------(1)}$$

The continuous transfer function of FOPID is obtained through Laplace transform and is given by [3]:

$$G_c(S) = K_p + K_I S^{-\lambda} + K_D S^{\beta} \quad \text{---------(2)}$$

Design of an FOPID controller involves design of three parameters *(K_p ,K_I,K_D)* and two orders(λ ,β) which are not necessarily integer [3]. Several method used for enhance the out put response for FOPID such as Particle Swarm Optimization Algorithm as explained in reference [3].
The new approach in this work involves an integrate genetic algorithms instead of classical method for tuning and extracting the five parameters.

3- Intelligent Control Techniques

In this section the general introduction about intelligent control technique are explained
3-1:Fuzzy Logic Controller
Figure (1) shows the block diagram of a typical fuzzy logic controller (FLC) [7].

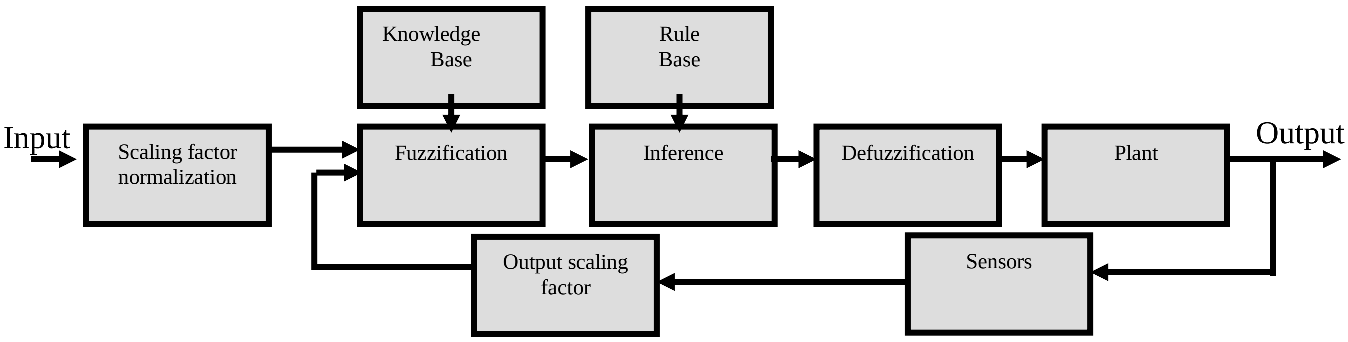

Figure. (1) Block diagram of a typical fuzzy logic controller [9]

There are five principal elements to a fuzzy logic controller:
- **Fuzzification (fuzzifier)**: change crisp value to linguistic variable .
- **Knowledge base**: provides all the necessary definitions for the Fuzzification process .
- **Rule base**: It is usually obtained from expert knowledge.
- **Inference engine**:.
- **Defuzzification**: change linguistic variable to crisp value.

3-2: Neural Network

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the network function is determined largely by the connections between elements. You can train a neural network to perform a particular function by adjusting the values of the connections (weights) between elements. Commonly neural networks are adjusted, or trained, so that a particular input leads to a specific target output. Such a situation is shown below. There, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target. Typically many such input/target pairs are needed to train a network. Neural networks have been trained to perform complex functions in various fields, including pattern recognition, identification, classification, speech, vision, and control systems. Figure (2) show the basic configuration of ANN [8]

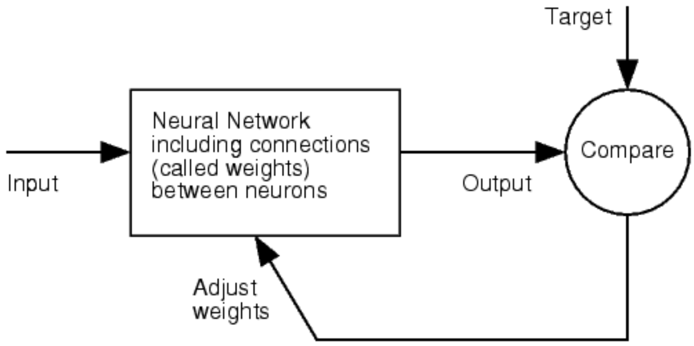

Figure (2): Basic configuration of ANN

3-3: Genetic Algorithm (GA)

This section outlines the operation of a basic genetic algorithm (GA). A basic GA consists of five components. These are a random number generator, “fitness” evaluation unit and genetic operators for “reproduction”. “crossover” and “mutation” operation. The algorithm is summarized in Figure (3) The initial population required at the start of the algorithm, is a set of number strings generated by the random generator. Each string is a representation of a solution to the optimization problem being addressed. Binary strings and real string are commonly employed. Associated with each string is fitness value as computed by the evaluation unit. A fitness value is a measure of the goodness of the solution. The aim of the genetic operators is to transform this set of strings into sets with higher fitness. Typically, the GA starts with little or no knowledge of the correct solution depending entirely on responses from interacting environment and their evolution operators to arrive at optimal or near optimal solutions. In general, GA include operations such as reproduction, crossover, and mutation. Reproduction is a process in which a new generation of population is formed by selecting the fittest individuals in the current population. Crossover is the most dominant operator in GA. It is responsible for producing new offsprings by selecting two strings and exchanging portions of their structures. The new offsprings may replace the weaker individuals in the population. Mutation is a local operator which is applied with a very low probability. Its function is to alter the value of a random position in a string [6,9]

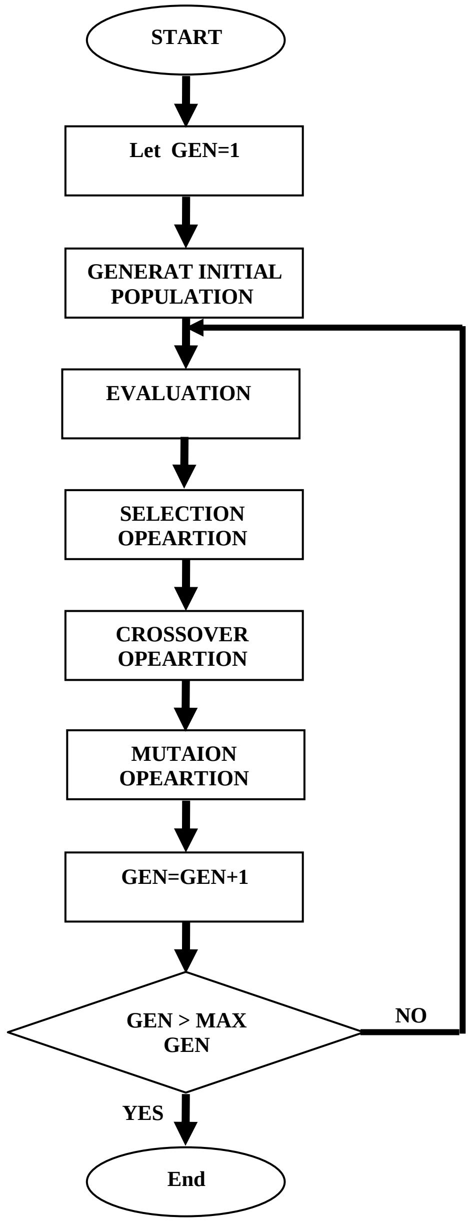

Figure (3): Basic genetic algorithms

4- Intelligent Fractional Order PID Controller (FOPID)

In this section the main block diagram for intelligent fractional order PID controller is demonstrated in figure (4)

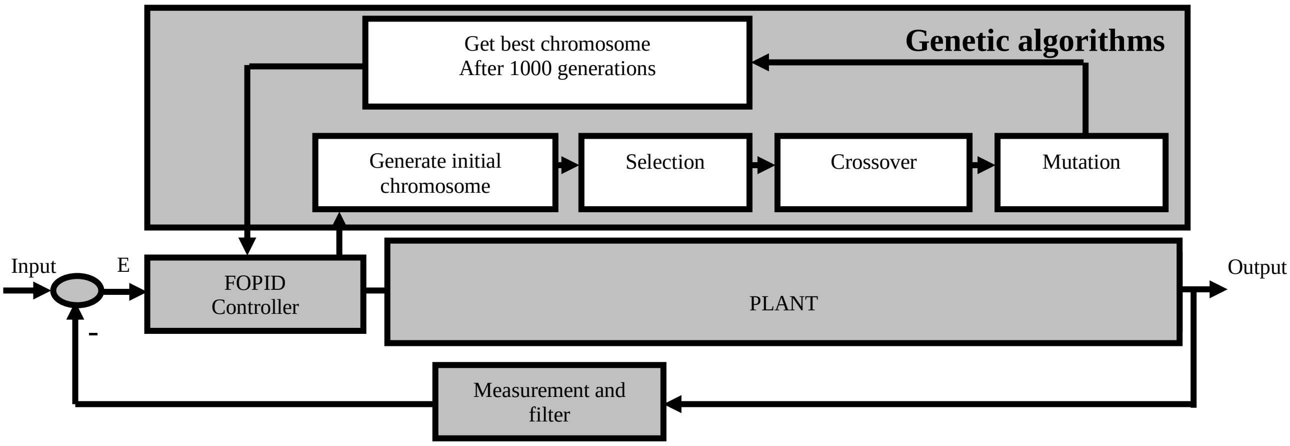

Figure (4):Block diagram of Intelligent FOPID controller

The genetic algorithm (GA) is used here to design the controller parameters (obtain five controller parameters K_P , K_I , K_D , α and β) such that the system exhibits desired output response and robust stability as evaluated by the proposed performance criterion.
Now we express the design steps as follows.
The outline for this intelligent controller is proposed by these steps:

Step 1:Generate initial population
- -Population size (No. of Population) = 500
- -Length of each chromosome (No. of Parameters) L = 5 as shown in figure (5)

K_P	K_I	K_D	α	β

Figure (5):chromosome structure

Step 2:Calculate fitness value for each chromosome and arrange the initial population in descending form (from high fitness to lower fitness),
Fitness Function =1/(performance criteria +0.0001)
Performance criteria(P.C.) = ISE + rise time (tr) + peak time (tp) + settling time(ts) -----(3)

$$ISE = \int e(t)\, dt \qquad \text{------------(4)}$$

Step 3: Select the best chromosomes using (roulette Wheel Selection method)
Step 4:Crossover each two chromosome to produce new chromosomes (multi point crossover method used with probability = 0.95)
Step 5: Mutate each chromosome with 0.05 probability
Step 6: Arrange in descending form the new population and calculate the fitness value for each chromosome also compare the fitness value with specified value or satisfy the number of generation condition .
Step 7: Calculate the control action value from the transfer function for FOPID ,finally calculate the overall response .
Step 8: Plot the output response.

5- Simulation Result

In this section, the complete system is tested under different type of controllers The simulation results showed that the intelligent controller provide an improvement in the responses of the system. The effect of the new controller can be realized from decrement of steady state error (ess), setting time(ts), rise time (tr), and integral of squared error (ISE). The proposed approach are tested for Automatic voltage regulator(AVR) plant ,the AVR is the central controller within the excitation system that maintains the terminal voltage of a synchronous generator at a specified level. Depending on the method of supplying DC power, different types of excitation systems exist [3,10]. As an example, we consider an alternator supplied controlled rectifier excitation system . The dc regulator holds constant generator field voltage and is commonly referred to as manual control. It is primarily for testing, start-up and to cater to situations where the ac regulator is faulty. Closed loop voltage control is carried out through the ac regulator. In addition to the AVR, this loop comprises five main components, namely amplifier, exciter, excitation voltage limiters, generator and measurement and filtering [3,11].Figure (6) show block diagram of an AVR with FOPID controller

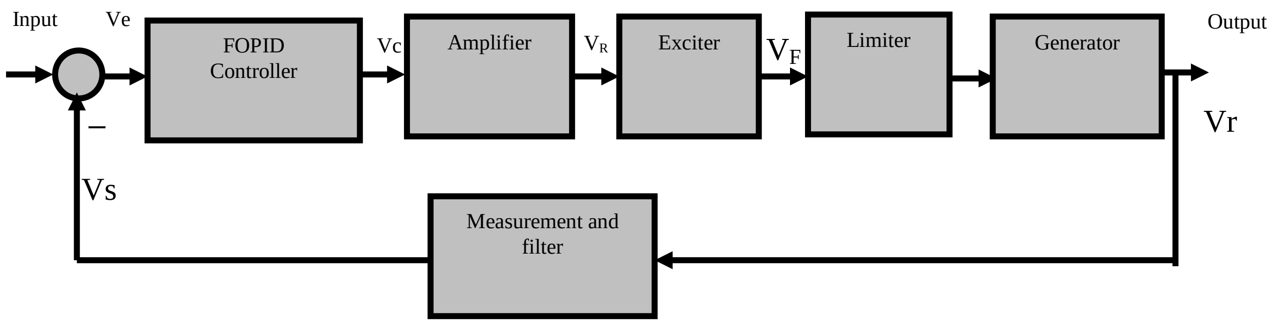

Figure (6):Block diagram of AVR with FOPID controller

Each part in figure (6) will be explained bellow:

5-1:Amplifier model.

The amplifier model is given by Typical values of k_A are in the range of 10 to 400. The amplifier time-constant often ranges from (0.02 to 0.1 s).

$$\frac{V_R(S)}{V_C(S)} = \frac{K_A}{1+\tau_A S} \qquad \text{-------(5)}$$

5-2:Exciter model .

Exciter model and parameters greatly depend on its type A simplified transfer function of a modern exciter is:

$$\frac{V_F(S)}{V_R(S)} = \frac{K_E}{1+\tau_E S} \qquad \text{-------(6)}$$

Typical values of k_E are in the range of 0.8 to 1 and the time-constant τ_E for an AC exciter in the range of 0.5 to 1.0 s.

5-3:Generator model.

The transfer function relating the generator terminal voltage to its field voltage can be simplified to:

$$\frac{V_t(S)}{V_F(S)} = \frac{K_G}{1+\tau_G S} \qquad \text{-------(7)}$$

The constants are load dependent, k_G may vary between 0.7 and 1.0, and τ_G between 1.0 and 2.0 s from full load to no load.

5-4 Measurement model.

The voltage measurement block, including PT, rectifier and filter, is often modeled with a single time constant.

$$\frac{V_s(S)}{V_t(S)} = \frac{K_R}{1+\tau_R S} \qquad \text{-------(8)}$$

τ_R ranges over 0.001 to 0.06 s

5-5: Excitation voltage limiters.

AVR and exciter output voltages are limited by windup and non-windup limiters Also, dedicated over excitation and under excitation limiters are employed to assure safe operation of the generator. A practical high-order AVR is used to verify the efficiency of the proposed FOPID controller. The system parameters are shown in this table (1) [3] :

Table(1): AVR system parameters

K_A	K_E	K_G	K_R	τ_A	τ_E	τ_G	τ_R	V_{fo}
10	1	1	1	0.1	0.5	1	0.06	1

Table two show the first ten optimum chromosomes from final population with its fitness function

To find overall transfer function for this system:

-Plant transfer function(AVR):

$$G_P(S) = \frac{Vr(S)}{Vc(S)} = \frac{K_A K_E K_G}{(1+\tau_A S)(1+\tau_E S)(1+\tau_G S)} = \frac{10}{(1+0.1S)(1+0.5S)(1+S)} \qquad \text{------(9)}$$

-FOPID controller transfer function :

$$G_c(S) = \frac{V_C(S)}{V_E(S)} = K_p + K_I S^{-\lambda} + K_D S^{\beta} = \frac{K_P S^{\lambda} + K_I + K_D S^{(\lambda+\beta)}}{S^{\lambda}} \qquad \text{------(10)}$$

-Sensor or measurement transfer function:

$$H(S)\frac{V_s(S)}{V_t(S)} = \frac{K_R}{1+\tau_R S} = \frac{1}{1+0.06S} \qquad \text{------(11)}$$

-Overall transfer function without controller:

$$\frac{V(out)}{V(in)} = \frac{Vr(S)}{Vi(S)} = \frac{G(S)}{1+G(S)H(S)} = \frac{G_P(S)}{1+G_P(S)\,H(S)}$$
$$= \frac{10(1+0.06S)}{(1+10S)(1+0.5S)(1+S)(1+0.06S)+10} \qquad \text{-------(12)}$$

-Overall transfer function with FOPID controller

$$\frac{V(out)}{V(in)} = \frac{Vr(S)}{Vi(S)} = \frac{G(S)}{1+G(S)H(S)} = \frac{G_C(S)\,G_P(S)}{1+G_C(S)\,G_P(S)\,H(S)}$$
$$= \frac{10(1+0.06S)(K_P S^{\lambda} + K_I + K_D S^{(\lambda+\beta)})}{S^{\lambda}(1+10S)(1+0.5S)(1+S)(1+0.06S) + 10(K_P S^{\lambda} + K_I + K_D S^{(\lambda+\beta)})} \qquad \text{------(13)}$$

The final 10 chromosomes in the final geneartion (after 1000 generation) shown in table (2), Since the best chromosome has 11.424 performance index ,the new performance index give us good indication about the final response , the good response must be low time response parameters and low in summation of error .

Table (2): chromosomes value at the end of iteration (at Generation no=1000) with its performance index

No	Chromosome parameters					Time Response parameters with ISE				P.C
9991	K_P	K_D	K_I	α	B	Tr	tp	ts	ISE	
9992	2.02	2.678	1.891	0.869	1.437	0.89	2.12	5.13	1.19	9.33
9993	2.02	2.678	1.891	0.869	1.437	0.89	2.12	5.13	1.19	9.33
9994	2.02	2.678	1.891	0.869	1.437	0.89	2.12	5.13	1.19	9.33
9995	2.02	2.678	1.891	0.869	1.437	0.89	2.12	5.13	1.19	9.33
9996	2.02	2.678	1.891	0.869	1.437	0.89	2.12	5.13	1.19	9.33
9997	2.02	2.678	1.891	0.869	1.437	0.89	2.12	5.13	1.19	9.33
9998	3.09	2.583	2.193	0.723	2.819	0.99	2.22	6.89	1. 324	11.424
9999	3.09	2.583	2.193	0.723	2.819	0.99	2.22	6.89	1. 324	11.424
1000	3.09	2.583	2.193	0.723	2.819	0.99	2.22	6.89	1.324	11.424

Figure (7) show the step and impulse responses for the system when without controller is used, since the high overshot and high rise time is appear,

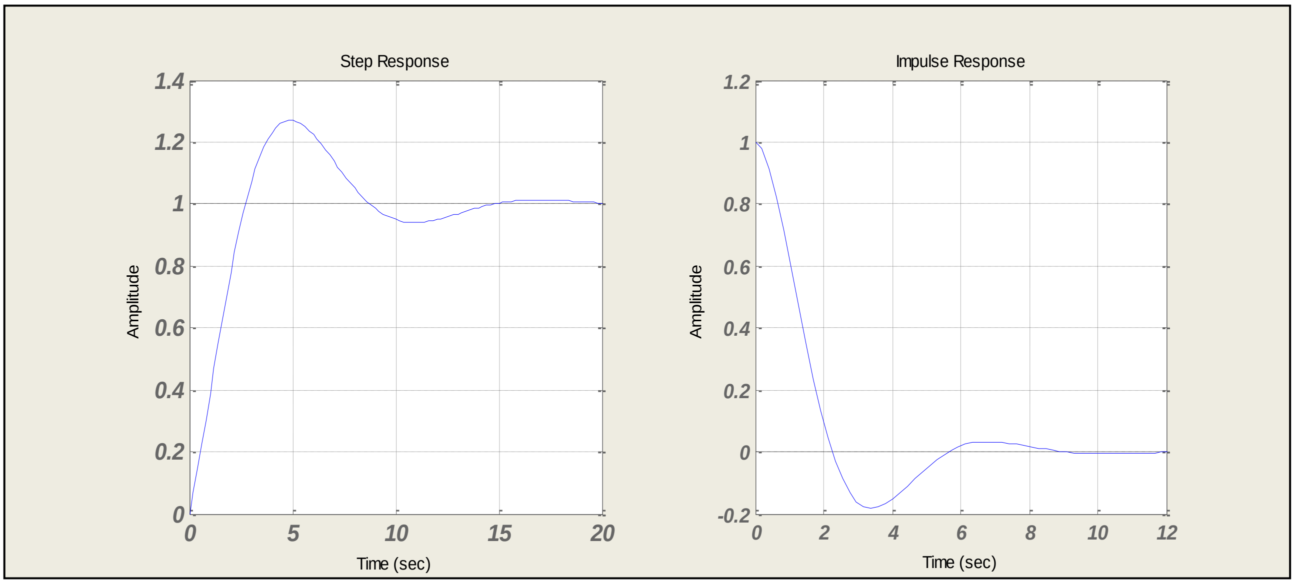

Figure (7): step and impulse output response for AVR without controller

Figure(8) show the step and impulse responses for closed loop AVR system with classical PID controller ,some enhancement is appear in this figure, but not sufficient therefore the intelligent controller is used to obtain response in figure (9)

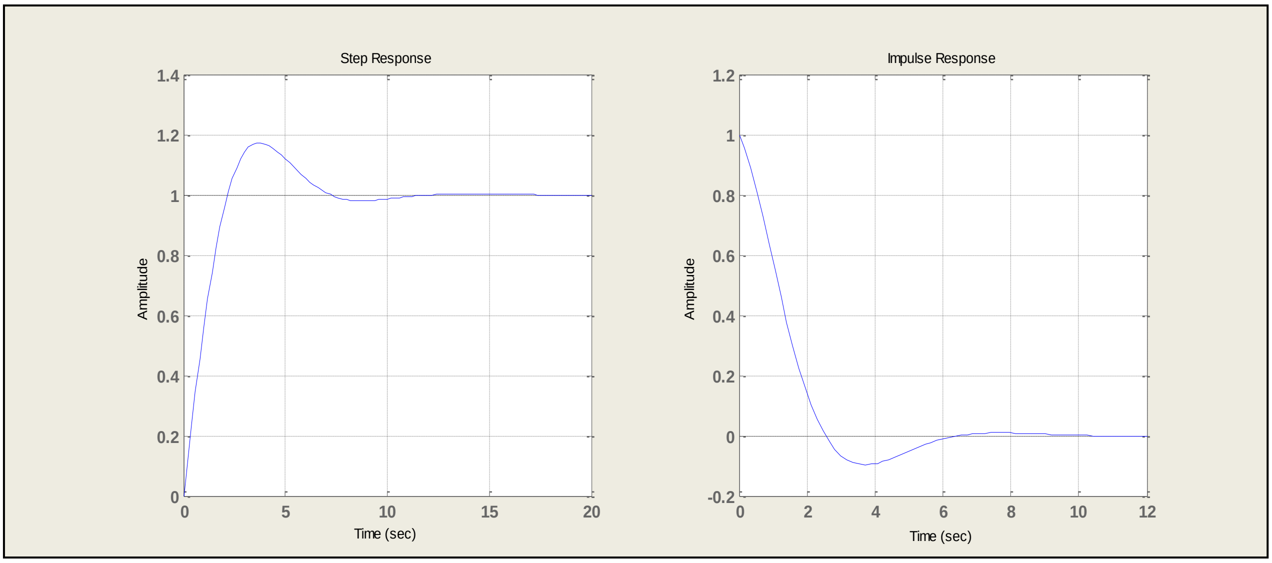

Figure (8): step and impulse output response for AVR with PID controller

figure (9) show the output responses for the AVR system when step and impulse inputs are applied with intelligent controller used , good responses are obtained when its used, small overshoot, small rise time, small settling time ,and finally the small ISE is obtained .

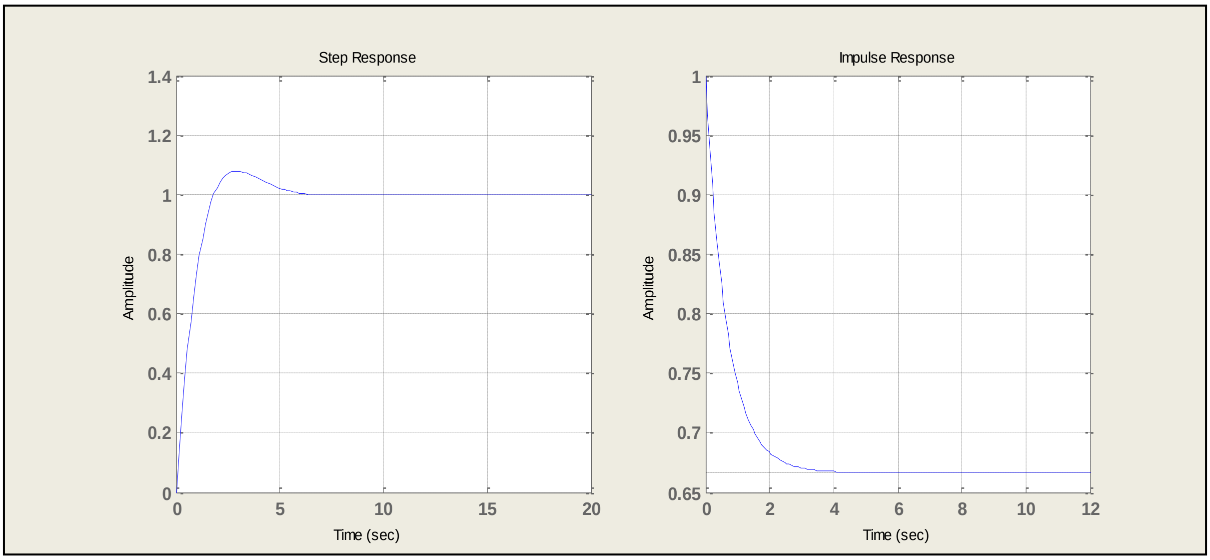

Figure (9): step and impulse output response for AVR with intelligent FOPID controller

Table (3), the performance of this controller is compared with another controller for step input

Table(3): controller types with its performance criteria(P.C) when step input is applied

Controller Type	Time response Parameters & ISE				P.C = SUM (ISE + tr + tp + ts)
	tr(sec)	tp(sec)	ts(sec)	ISE	
Without Controller	2.23	4.05	15.45	2.651	24.381
Classical PID	1.51	2.2	7.5	1.574	12.784
FOPID	1.09	2.12	5.01	1.15	9.37

6- Conclusion

The simulation result shows some important points about the modified intelligent controller (FOPID-GA), these are:
- From table (3), the output response for the different controllers shown that the proposed controller (FOPID-GA) is very efficient controller, since the time response parameters are decreased to min. value and small performance index
-More robust stability and good performance characteristic than another controllers such as classical PID
-The proposed new performance index (ISE + tr + tp + ts) gives more accuracy than ISE only .
-Can be use multi FOPID for MIMO systems(multi input /multi output systems)
-The genetic algorithms really good search optimization algorithms ,since it give optimal five parameter for FOPID controller
-In GA, the multipoint crossover is more efficient than single point crossover

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