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Applying of PID, FPID, TID and ITID controllers on AVR system using particle swarm optimization (PSO)

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***Abstract*—Some methods are available to optimize problems such as Particle Swarm Optimization (PSO) -which is a computational method- by having a population of candidate solutions. In this paper we presented four PID, FPID, TID and ITID controllers and applied each one on four different error functions in an AVR system by means of PSO algorithm. This performance led us to a specific conclusion and also a comprehensive result was drawn out of the system's response and diagrams. According to rising time, settling time and overshoot percentage, we gathered a presentation that helps everyone to find the best controller easily while working with different error functions.**

***Keywords*—particle swarm optimization;pso; pid; fpid; tid; itid; avr system**

I. INTRODUCTION

During the past decades while the world was becoming more industrial and modern, the need for modern controllers became more essential. As the old controllers were not suitable for new systems, therefore engineers tried to find new methods to reduce the instability of systems in order to reduce cost and time and in the other hand to increase the efficiency. To achieve this goal, research in the field of control increased, insofar as we see some great advances in control methods such as modern control, fuzzy control, neural control and adaptive control. The three basic controllers were Proportional, Integral and Derivative, that the combination of these controllers could result new ones for new purposes. Although PI controller made advances, it was not efficient in some fields. So a new controller (PID) was designed. PID controller is one of the common samples of feedback control algorithm which is used in many control processes like. DC motor speed, pressure control and etc. It is formed of three proportional, integral and derivative controllers that each of them do specific operations. The PID controller transfer function is:

$$C(s) = K_p + \frac{K_i}{s} + K_d s \tag{1}$$

As K_p increases the system speed increases too, and steady state error decreases approximately by zero. (Ess ≠ 0)

In presence of K_i, steady state error becomes zero (Ess = 0) and overshoot adds a bit to transient response. The derivative controller weakens the fluctuations of transient response and brings the step response to ideal [1]. The Fractional Order PID, after PID controllers, was designed to enhance the operations. Afterwards Podlubny improved the PID controller to Fractional Order PID (FOPID) in 1999.
Considering the transfer function:

$$C(s) = K_p + \frac{K_i}{s^{\lambda}} + K_d s^{\mu} \tag{2}$$

brings us to appoint that in addition to three parameters of PID controller (K_p, K_i, K_d) there are two other parameters (λ and μ) which are in fractional order to create a new method [2], [3]. One of the feedback system controllers introduced for PID controller is Tilted Integral Derivative controller (Lune, 1994). In this controller the proportional component was replaced by tilted component that enhances the operation of transfer function than in PID. The TID is another commonly used fractional calculus based controller [4], [5], [6].I-TI controller has a better phase lead characteristic than TI and it consumes less energy and decreases the error, and also it increases system speed [7].

II. FRACTIONAL ORDER OPERATOR

A lot of definitions of fractional operators are available in the Literature. Riemann–Liouville definition which is mentioned below is a commonly used definition of the fractional integration

$$D^{-\alpha} f(t) = \frac{1}{\Gamma(\alpha)} \int_0^t (t-\tau)^{\alpha-1} f(\tau) d(\tau) \tag{3}$$

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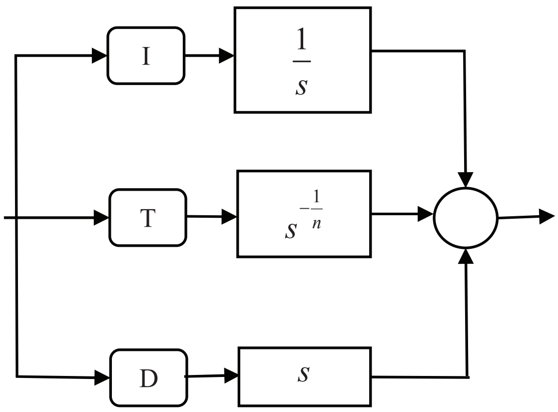

Fig. 1. *Conventional Tilted Integral Derivative.* [8]

while the fractional derivative definition is

$$D^{\beta} f(t) = D^{m}[D^{-\gamma} f(t)] \tag{4}$$

where

$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-x} dx \tag{5}$$

is the Gamma function, α is the order of the integration, m is an integer number, and $\gamma = m - \beta$.

The Laplace transform method can be employed to analyze the system and synthesize the controller in the frequency domain. Under zero initial conditions, the Laplace transform of the fractional integral given by Riemann–Liouville for order α is:

$$L(D^{-\alpha} f(t)) = s^{-\alpha} F(s) \tag{6}$$

where F(s) is the normal Laplace transformation f (t) [7].

III. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is an algorithm to optimize a non-linear and multi-dimensional problem which makes better solutions in case of minimal parameterization requirement. James Kennedy and Russell Ebhart in 1995 introduced the algorithm and its idea of "Particle Swarm Optimization". Creating a swarm of particles is the basic concept of the algorithm moving in the space around them (the problem space) searching for their goal, the place which best suits their needs given by a fitness function [9].

$$\begin{aligned} x_{id}(t+1) &= \omega v_{id}(t) + b_1 r_1 (p_{id}(t) - x_{id}(t)) \\ x_{id}(t+1) &= x_{id}(t) + v_d(t+1) \end{aligned} \tag{7}$$

IV. LINEARIZED MODEL OF AN AVR SYSTEM

The main role of an AVR is to keep the terminal voltage magnitude of synchronous generator at a specific level. An AVR system which meant to be simple consists of four main components, namely amplifier, exciter, generator and sensor. These four components must be linearized because of their mathematical modeling and transfer function, which takes into account the time constant and rejects the saturation or other nonlinearities. The transfer function of these four components is represented as below and the block diagram is presented in Fig. 2.

- *Amplifier Model*

The amplifier model is known by a gain K_A and a time constant T_A and the transfer function is:

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1+\tau_A s} \tag{8}$$

The range of 10 to 400, are the common values of K_A and the amplifier time constant is in the range of 0.02 to 0.1 s, which is very small.

- *Exciter Model*

Here is the transfer function of a modern exciter which is represented by a gain K_E and a single time constant T_E.

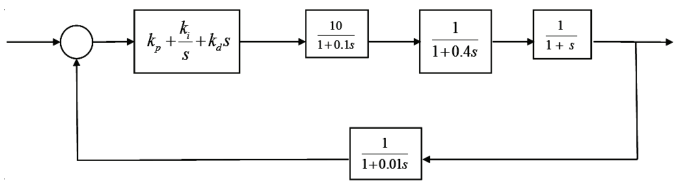

Fig. 2. Block Diagram of an AVR System with a PSO-PID Controller

$$\frac{V_F(s)}{V_R(s)} = \frac{K_A}{1+\tau_E s} \tag{9}$$

The range of 10 to 400, are the common values of K_E and the amplifier time constant is in the range of 0.5 to 0.1 s.

- *Generator Model*

The transfer function of a generator terminal voltage which related it to its field voltage, in the linearized model is as below, by a gain K_G and a time constant T_G.

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1+\tau_G s} \tag{10}$$

These constants are depended on load. K_G may vary among 0.7 to 1.0, and T_G can vary in the range of 1.0 and 2.0 s from full load to no load.

- *Sensor Model*

The sensor is presented by a simple transfer function as below

$$\frac{V_s(s)}{V_t(s)} = \frac{K_R}{1+\tau_R s} \quad (12)$$

T_R is ranging from 0.001 to 0.06 s, which is very small [10].

V. Estimating The Performance of Controllers

The four controllers' (PID, FPID, TID and ITID) method design is using integrated absolute error (IAE), integrated absolute time-weighted-error, integral of squared-error (ISE), and integrated of time-weighted-squared-error (ITSE). The IAE, IATE, ISE and ISTE formulas are as below:

$$IAE = \int_0^\infty |e(t)|\, dt$$

$$IATE = \int_0^\infty t\,|e(t)|\, dt \quad (13)$$

$$ISE = \int_0^\infty e^2(t)dt$$

$$ISTE = \int_0^\infty te^2(t)dt$$

The optimization block diagram consisted of controllers, system and PSO is presented in Fig. 3 and the range of the parameters used in whole system is presented in Table. 1.

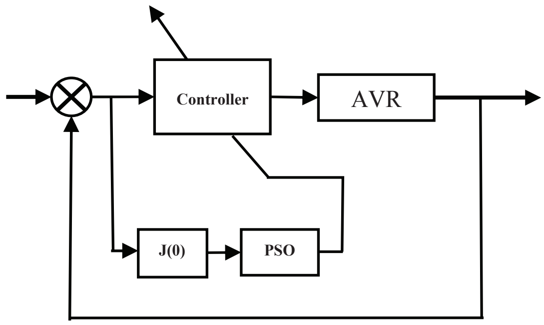

Fig. 2. *Control Parameter Optimization Diagram.* [2]

TABLE I. RANGE OF PARAMETERS

Controller Parameters	Min. Value	Max. Value
K_p	-2	8
K_i	0	3.5
K_d	0	1.5

VI. Results

After applying the four PID, FPID, TID and ITID controllers on AVR System using four error functions (IAE, IATE, ISE and ISTE) by PSO algorithm we collected and presented the whole responses in four diagrams and four tables (tables II to IV and figures 4 to 7) in order to determine the difference clearly and then a conclusion is extracted from diagrams which guide us to know which controller is suitable for each error function.

TABLE II. RESULTS FOR IAE

Controllers	K_p	K_i	K_d	n	λ	μ	d.o.	T_r	T_s	M_p(%)	IAE
PID	0.8402	3.5	0.3315	-	-	-	-	0.1988	1.2109	1.3035	0.3198
FPID	-2	3.5	1.5718	-	0.7	0.4	-	0.2408	NaN	1.3061	0.6801
TID	8	3.5	1.1869	5	-	-	-	0.1936	2.0010	4.0029	0.2849
ITID	0.0879	3.5	0.1487	-	-	-	0.2	0.5102	0.8138	1.0681	0.3312

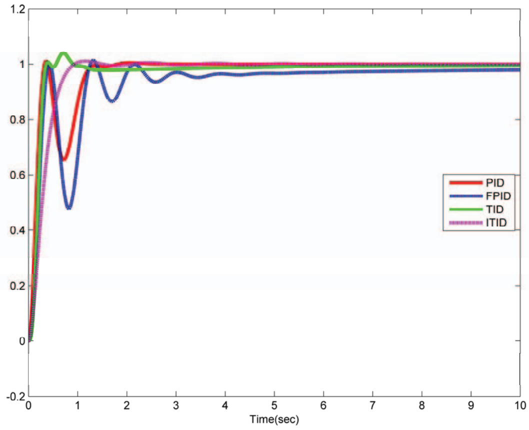

Fig. 4. *IAE Diagram*

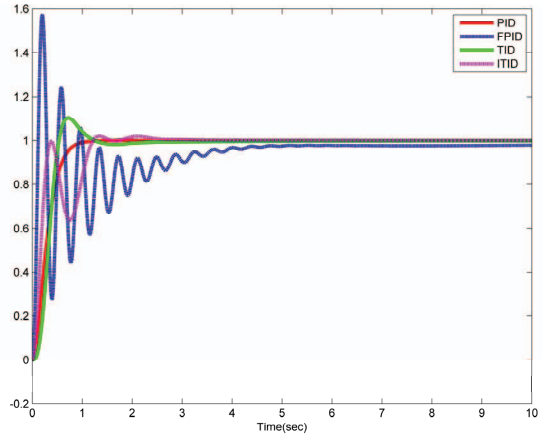

Fig. 5. *IATE Diagram*

TABLE III. RESULTS FOR IATE

Controllers	K_p	K_i		K_d	n	λ	µ	d.o.	T_r	T_s	M_p(%)	IATE
PID	0.1321	3.5		0.1575	-	-	-	-	0.5004	0.8634	0.0918	0.0750
FPID	-1.0185	3.5		0.4095	-	0.7	0.65	-	0.0742	NaN	57.4987	1.1879
TID	1.7153	3.5		0.4670	5	-	-	-	0.3146	1.1017	10.3094	0.1768
ITID	0.6130	3.5		0.2586	-	-	-	0.2	0.2191	1.3575	2.0207	0.1895

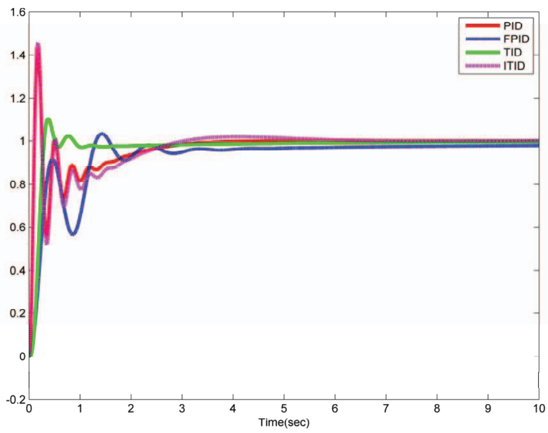

Fig. 6. *ISE Diagram*

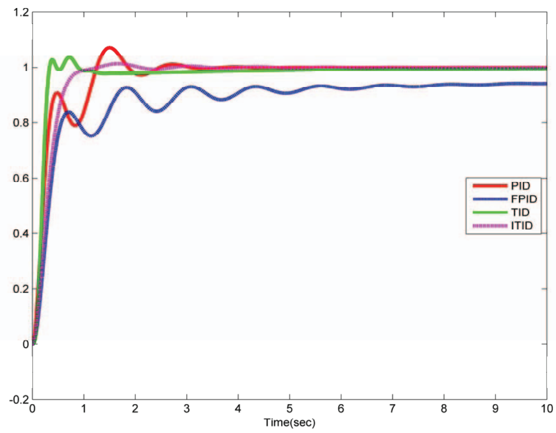

Fig. 7. *ISTE Diagram*

TABLE IV. RESULTS FOR ISE

Controllers	K_p	K_i	K_d	n	λ	μ	d.o.	T_r	T_s	M_p(%)	ISE
PID	3.2035	3.5	1.4678	-	-	-	-	0.0665	2.8700	44.1612	0.1187
FPID	-2	3.5	1.397	-	0.7	0.4	-	0.3196	NaN	3.3034	0.2549
TID	8	3.5	1.0318	5	-	-	-	0.1707	2.4935	10.3315	0.1504
ITID	2.2263	3.5	1.362	-	-	-	0.2	0.0668	2.6828	45.4967	1.1361

TABLE V. RESULTS FOR ISTE

Controllers	K_p	K_i	K_d	n	λ	μ	d.o.	T_r	T_s	M_p(%)	ISTE
PID	0.4117	3.5	0.2166	-	-	-	-	0.3548	2.2676	7.0539	0.0334
FPID	-2	3.5	0.7342	-	0.5	0.5	-	1.5267	NaN	0	0.2885
TID	8	3.5	1.1511	5	-	-	-	01872	2.1548	3.6337	0.1686
ITID	0.0993	3.5	0.1143	-	-	-	0.6	0.4901	0.8532	1.3475	0.0303

In some situations, the conclusion made from minimum cost is not enough and we should take a look at energy diagrams in order to find if the energy usage is not above the expected range. So the four energy diagrams (figures 8 to 11) are presented.

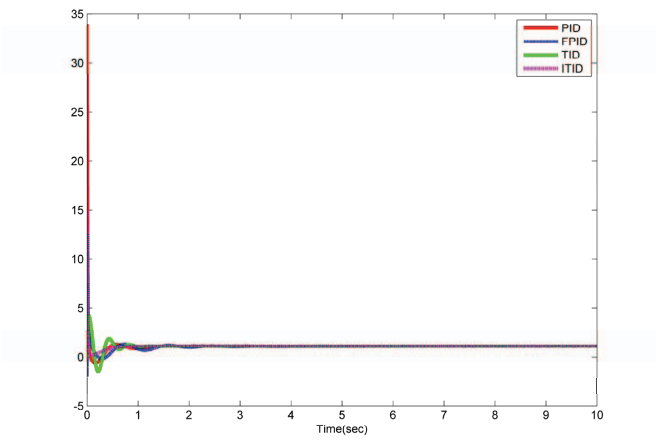

Fig. 8. *IAE Energy Diagram*

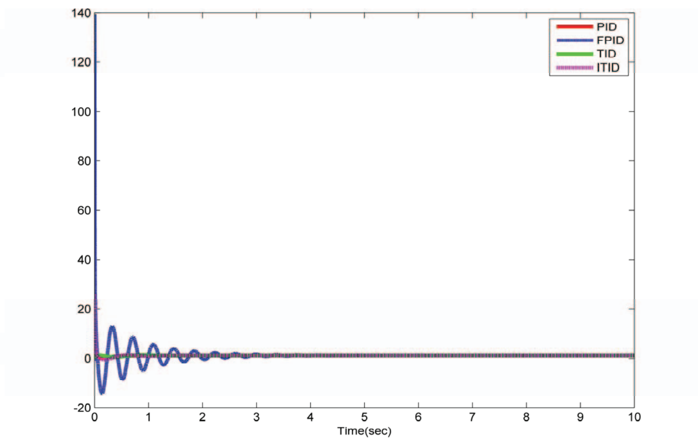

Fig. 9. *IATE Energy Diagram*

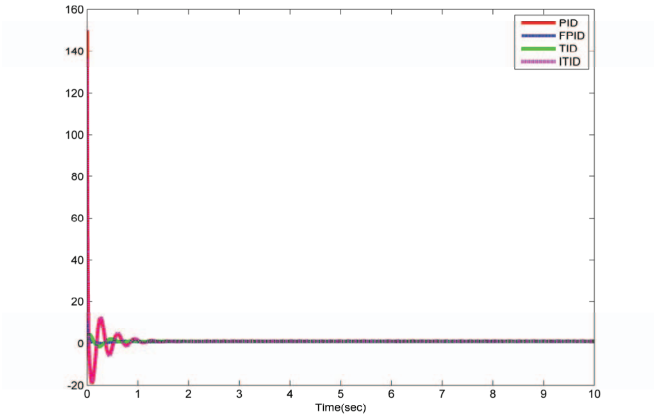

Fig. 10. *ISE Energy Diagram*

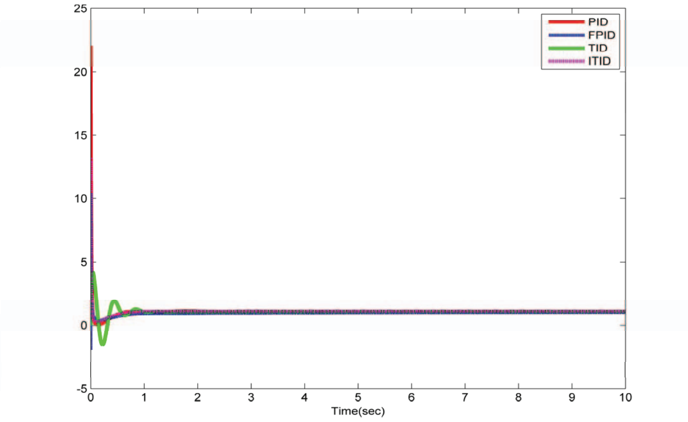

Fig. 11. *ISTE Energy Diagram*

VII. CONCLUSION

As discussed earlier in this paper we tried to gather a complete overview of common controllers and also presented their error diagrams, energy diagrams and each one's vital information in separated tables in order to give the reader a brief view to select the appropriate controller for each error function. According to Fig.4 and the min cost from Table.II, it is obvious that TID controller is showing a better result for IAE error function and also Fig.5 and Table.III, lead us to select PID controller for IATE error function. Results from Fig.6 and Table.IV show the PID controller as the appropriate one for ISE error function and meanwhile ITID controller is better for ISTE error function according to Fig.7 and Table.V. As seen in figures 8 to 11 energy diagrams are not changing much which means that there is no anxiety about energy consumption.

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