Optimal Tuning of Fractional Order PID Controller for Automatic Voltage Regulator System through Genetic Algorithm

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***Abstract* -In this paper a Fractional order PID controller is proposed for AVR system and its parameters are optimised through Genetic Algorithm. Results are obtained by simulation in MATLAB/SIMULINK environment with FOMCON software. The results show that the AVR system with fractional order PID controller is faster and robust compared to integer order PID controller.**

Key words: Fractional order PID controller, Genetic Algorithm, $PI^{\lambda}D^{\mu}$, AV $PI^{\lambda}D^{\mu}$

I. INTRODUCTION

It was in 1695, L'Hopital coined the word fractional order calculus[1]. There after the scientists, Euler,Laplace,Fourier,Able,Riemann,and Lurel, worked on fractional order calculus. It is reasonable to say that the order of the system need not to be always integer, it could be fractional also. This is true in the case of the systems with memory and hereditary characteristics. From 1884 the research on fractional order calculus is flourished. At present fractional order calculus is playing vital role in control system applications. Fractional Order PID controller (FOPID) is one of the advancements in control systems for last decade. Many scientists have done research in this area and proved the performance of FOPID ($PI^{\lambda}D^{\mu}$)is good compared to integer order PID controller.

$PI^{\lambda}D^{\mu}$ controller has five parameters need to be tuned (Kp,Ki,Kd,λ,μ). This makes the tuning of the $PI^{\lambda}D^{\mu}$ controller most difficult. Till now there is no one step tuning procedure established for $PI^{\lambda}D^{\mu}$ as in the case of integer order PID controller. Many researchers presented different evolutionary optimisation methods to tune these five parameters for optimum performance of various systems[2],[10]-[12].

In this paper an evolutionary optimisation procedure Genetic algorithm (GA) is chosen to obtain optimum $PI^{\lambda}D^{\mu}$ parameters for Automatic Voltage Regulator (AVR) system [3]. The AVR system performance with FOPID is obtained through FOMCON (Fractional Order Modelling and Control) software[4]. Generally the generator parameters of AVR system depends on the load. Optimum $PI^{\lambda}D^{\mu}$ controller parameters are obtained for the entire parameter variation range. It was shown that the performance of AVR system against parameter variation with $PI^{\lambda}D^{\mu}$ controller is robust, when the $PI^{\lambda}D^{\mu}$ parameters set fixed to average of the parameters obtained for generator parameter variations.

II. FRACTIONAL ORDER CALCULUS

Fractional order calculus is in existence since the regular calculus in development. It is meaning less to say that the order of the differentiation or integration only integer. Some of the practical system could be well described with fractional order differential equations. The basic operator used in fractional order differential equations is integro-defferential (differintegral) operator as defined in (1).

$$ {}_aD_t^r = \begin{cases} \frac{d^r}{dt^r} & R(r) > 0 \\ 1 & R(r) = 0 \\ \int_a^t (d\tau)^{-r} & R(r) < 0 \end{cases} \quad (1) $$

Where 'a' and 't' are the limits of the operator. The operator 'r' is the order of the operation and belongs to R (any rational number) but 'r' could also be a complex number[3]. Two definitions used for the general fractional differintegral are the Grunwald-Letnikov (GL) definition and the Riemann-Louville (RL) definition [5]-[7]. The GL is given here

$${}_aD_t^r f(t) = \lim_{h\to 0} h^{-r} \sum_{j=0}^{\frac{t-a}{h}} (-1)^j \binom{r}{j} f(t-jh) \quad (2)$$

The fractional differintegral defined by RL is

$${}_aD_t^r f(t) = \frac{1}{\Gamma(n-r)} \frac{d^n}{dt^n} \int_a^t \frac{f(\tau)}{(t-\tau)^{(r-n+1)}} d\tau \quad (3)$$

for $(n-1 < r < n)$ and $\Gamma(.)$ is the *Gamma* function.

III. FRACTIONAL ORDER PID CONTROLLER ($PI^{\lambda}D^{\mu}$)

For last one decade fractional order PID controllers became very popular among researchers, because its robust performance and fast response .The fractional order PID controller is defined as in (4).

$$C(s) = Kp + Kis^{-\lambda} + Kds^{\mu} \quad (4)$$

Where Kp →Proportional gain

Ki → Integral gain

Kd→ Derivative gain

λ → order of the integrator

μ → order of the differentiator

The fractional order PID controller needs the tuning of above five parameters appropriately to make the system performance as desired.

IV. LINEARISED MODEL OF AN AVR SYSTEM

An AVR system contains mainly four components, namely Amplifier, exciter, sensor and synchronous generator to control the terminal voltage of the synchronous generator . Block diagram of an AVR system with nominal values of the parameters of the components is shown in Fig.1. The terminal voltage of the generator mainly depends on the reactive power of the load. The main role of an AVR system is to maintain terminal voltage at set value irrespective of load changes, by controlling the field excitation. The PID controller is normally used to control the excitation based on the error (deviation).

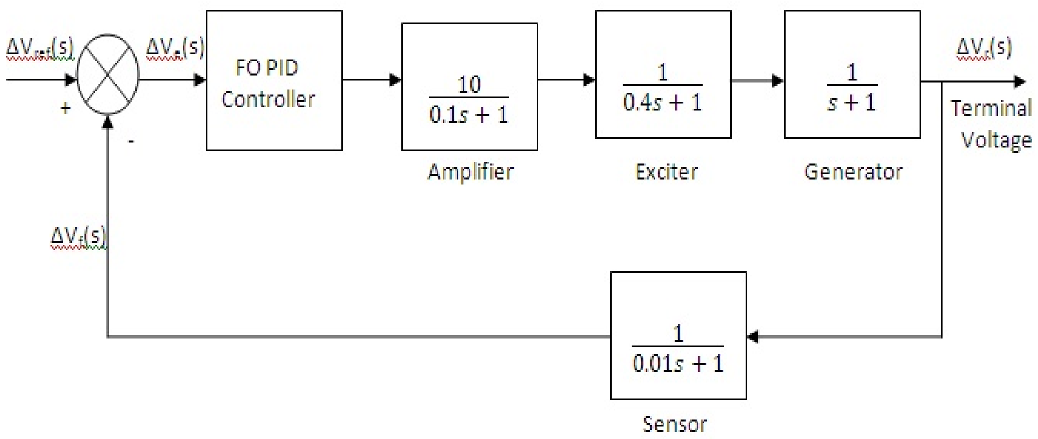

Fig.1: Block diagram of an AVR system

In this paper a Fractional Order PID controller (FOPID) has been used to give better performance than ordinary PID controller. Generally parameters of the generator changes with load and the parameters of other components also changes with design. The limits of the parameters of the components and generator are shown in Table1 [8].

TABLE 1. Transfer function of the components

Component	Transfer function	Limits of parameters
Amplifier	$T(s)_{amplifier} = K_a/(\tau_a s+1)$	$10 < K_a < 40$; $0.02s < \tau_a < 1s$
Exciter	$T(s)_{exciter} = K_e/(\tau_e s+1)$	$1 < K_e < 10$; $0.4s < \tau_e < 1s$
Generator	$T(s)_{generator} = K_g/(\tau_g s+1)$	K_g depends on the load ($0.7 < K_g < 1$); $1s < \tau_g < 2s$
Sensor	$T(s)_{sensor} = K_s/(\tau_s s+1)$	$0.01s < \tau_s < 0.06s$

V. OPTIMIZATION OF FOPID PARAMETERS THROUGH GENETIC ALGORITHM

In this paper the parameters of FOPID are optimised through binary coded genetic algorithm. The performance criterion is chosen as in (5).The genetic algorithm mainly have three operators, namely reproduction, crossover, and mutation operators to progress the optimisation [3]. Roulette wheel selection is used as reproduction operator, cross over operation is performed with probability of 0.125 and mutation operator is applied with probability of 0.25.

$$Obj = \beta(Osh + Ess) + (1-\beta)(Ts + Tr) \quad (5)$$

Where Obj → Objective function

Ts → Settling time

Tr → Rise time

Osh → Overshoot

Ess → Steady state error

β → Weighting factor

The β value is chosen such that the overshoot is minimised at maximum extent. the β value is found best when its value is 0.93. Since the optimisation problem is a minimisation problem, the fitness function (F) is taken as in equation (6).

$$F = \frac{1}{Obj} \quad (6)$$

The parameters of FOPID for system shown in Fig.1 are optimised through GA using MATLAB/FOMCON environment and the results are compared with RGA tuned PID (RGAPID) [9] and PSO tuned PID (PSOPID) [8]. The Fig.2 represents the progress of optimisation for 100 generations with population size of 20. The results show that the response of GA $PI^{\lambda}D^{\mu}$ is faster than RGAPID and PSOPID. Table2 and Fig.3 shows the performance of RGAPID, PSOPID and Genetic Algorithm tuned FOPID (GAFOPID).

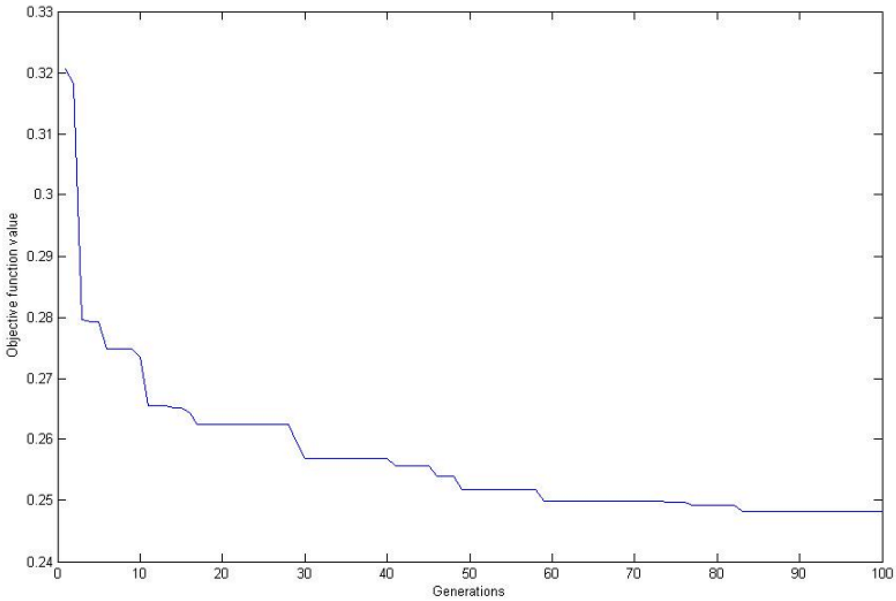

Fig.2 : Convergence of objective function while optimization.

TABLE 2. performance comparison of RGAPID, PSOPID and $GAPI^{\lambda}D^{\mu}$

Method	Kp	Ki	Kd	λ	μ	Ts(s)	Tr(s)	Osh(10^{-4})	Ess(10^{-5})
RGAPID	0.6820	0.2660	0.1790	1	1	1.2682	1.0668	4.00	4.3386
PSOPID	0.6570	0.5389	0.2458	1	1	0.4025	0.2767	1.16	-
$GAPI^{\lambda} D^{\mu}$	5.5294	1.0235	0.7216	1.4471	1.5	0.3500	0.0800	4.88	4.2200

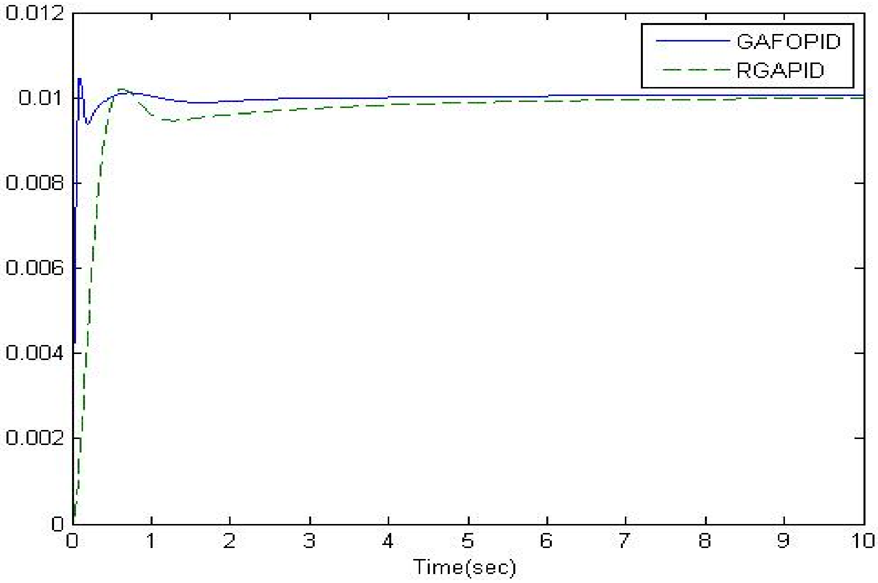

Fig.3: Time response of $GAPI^{\lambda}D^{\mu}$ and RGAPID

VI. SIMULATION RESULTS

The optimum parameters of FOPID are obtained through Genetic algorithm for generator parameter variation as given in table1. Here the parameters of generator K_g and τ_g are quantised as {0.7, 0.8, 0.9,1} and {1, 1.2, 1.4, 1.6, 1.8, 2} respectively. Optimum controller parameters are obtained for the 24 (4*6) combinations in generator parameter variation range. Obtained controller parameters and time response parameters are given in the Table3..

TABLE 3. Optimum FOPID controller parameters obtained by GA for generator parameter variation

S.No.	Generator Parameters		Controller Parameters					Time Response Parameters			
	K_g	τ_g	Kp	Ki	Kd	λ	μ	Ts(s)	Tr(s)	Osh(10^{-4})	Ess(10^{-5})
1	0.7	1	6.6824	1.8118	0.9020	1.1529	1.5	0.37	0.09	2.17	1.13
2	0.8	1	6.6824	2.4118	0.9255	1.0941	1.5	0.34	0.08	5.00	0.49
3	0.9	1	4.8000	1.1765	0.7059	1.2882	1.5	0.44	0.09	1.44	2.70
4	1	1	5.5294	1.0235	0.7216	1.4471	1.5	0.35	0.08	4.88	4.22
5	0.7	1.2	7.3412	1.9412	1.1294	1.2471	1.5	0.42	0.09	2.50	1.80
6	0.8	1.2	7.3882	1.5647	1.0118	0.9765	1.5	0.34	0.08	3.70	1.70
7	0.9	1.2	6.0706	1.2706	0.8154	1.2882	1.5	0.36	0.10	1.99	2.40
8	1	1.2	4.9647	1.1647	0.7529	1.3294	1.5	0.42	0.10	1.85	2.74
9	0.7	1.4	7.6471	1.7176	1.2784	0.9882	1.5	0.45	0.09	1.85	1.39
10	0.8	1.4	7.7647	1.3765	1.0667	1.3588	1.5	0.35	0.10	2.40	3.00
11	0.9	1.4	6.0706	1.3882	0.9804	1.0059	1.5	0.42	0.09	2.00	1.00
12	1	1.4	5.7882	1.1882	0.9020	1.0412	1.5	0.41	0.09	2.40	0.80
13	0.7	1.6	9.3882	1.5059	1.4588	1.2471	1.5	0.40	0.09	2.50	1.56
14	0.8	1.6	8.6118	1.1647	1.2627	1.3588	1.5	0.37	0.09	2.70	2.79
15	0.9	1.6	5.4588	2.4824	1.1451	0.2000	1.5	0.40	0.09	2.27	1.00
16	1	1.6	7.0118	1.3882	1.0980	1.2118	1.5	0.39	0.08	3.97	1.27
17	0.7	1.8	8.4235	2.1176	1.6784	0.5647	1.5	0.47	0.09	2.10	6.80
18	0.8	1.8	9.0118	1.6588	1.5137	1.2706	1.5	0.42	0.08	3.45	1.84
19	0.9	1.8	8.0471	2.8588	1.5216	0.2741	1.5	0.34	0.07	5.90	7.80
20	1	1.8	7.9059	1.0353	1.2627	1.1000	1.5	0.38	0.08	4.50	1.09
21	0.7	2	9.4118	1.0471	1.7961	1.2765	1.5	0.51	0.09	1.59	1.15
22	0.8	2	8.8235	1.1882	1.5922	1.0765	1.5	0.46	0.09	2.32	1.36
23	0.9	2	8.1412	2.0706	1.4510	0.1706	1.5	0.35	0.09	3.60	9.40
24	1	2	9.3176	1.5294	1.4824	1.1000	1.5	0.35	0.07	5.62	2.21
Average values of $PI^{\lambda}D^{\mu}$ ($AVPI^{\lambda}D^{\mu}$)			7.3451	1.5868	1.1856	1.0445	1.5				

The average values of the controller parameters obtained for the 24 sets are given in the Table3. Table4 shows that when these average values are fixed irrespective of the load (parameter) variations, the system response is better as when tuned with RGA for that particular parameter set[9]. This indicates that the system is more robust with FOPID.

TABLE 4. Time response parameters for off nominal values

Kg	τ_g	Method	Kp	Ki	Kd	λ	μ	Ts(s)	Tr(s)	Osh (10^{-4})	Ess (10^{-5})
0.77	1.50	RGA PID	0.7246	0.3601	0.1643	1	1	1.19	0.81	2.16	6.11
		AV$PI^{\lambda}D^{\mu}$	7.3451	1.5868	1.1856	1.0445	1.5	0.97	0.1	2.07	0.58
0.79	1.15	RGA PID	0.6598	0.2927	0.1743	1	1	1.11	0.94	0.29	7.54
		AV$PI^{\lambda}D^{\mu}$	7.3451	1.5868	1.1856	1.0445	1.5	0.42	0.07	6.34	0.69
0.85	1.30	RGA PID	0.7379	0.2862	0.1643	1	1	0.90	0.84	6.33	8.01
		AV$PI^{\lambda}D^{\mu}$	7.3451	1.5868	1.1856	1.0445	1.5	0.41	0.07	5.69	0.59
0.75	1.67	RGA PID	0.6321	0.3601	0.2643	1	1	1.80	1.07	0.06	2.00
		AV$PI^{\lambda}D^{\mu}$	7.3451	1.5868	1.1856	1.0445	1.5	1.11	0.53	2.56	0.53
0.99	1.45	RGA PID	0.7080	0.3601	0.1652	1	1	0.77	0.77	1.96	4.90
		AV$PI^{\lambda}D^{\mu}$	7.3451	1.5868	1.1856	1.0445	1.5	0.38	0.07	6.79	0.46
0.99	1.96	RGA PID	0.6030	0.3601	0.1757	1	1	1.41	0.99	0.04	1.39
		AV$PI^{\lambda}D^{\mu}$	7.3451	1.5868	1.1856	1.0445	1.5	1.1	0.10	2.60	0.31

VII. CONCLUSIONS

This work has been simulated using MATLAB in combination with FOMCON software, which is designed to work with fractional order systems. The simulation results show that the response of the AVR system with fractional order PID controller is faster compared to integer order PID controller, when tuned with GA and RGA respectively. Further the fractional order system is more robust against generator parameter variations due to load changes. When the controller parameters are set fixed to average values of the parameters obtained with variation of the generator parameters , still it shows that the performance of the system is better than RGA tuned PID controller. When fractional order PID controllers are used , without retuning we can obtain better performance than RGA tuned PID controller .The better results could be obtained by tuning $PI^{\lambda}D^{\mu}$ controller through Particle Swarm optimization (PSO) .

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