Design Of PID Controller In Automatic Voltage Regulator (AVR) System Using PSO Technique

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ABSTRACT

In this paper, an evolutionary computing approach for determining the optimal values of the proportional-integral-derivative (PID) controller has been proposed. Proper tuning of such controllers is obviously a prime priority as any other alternative situation will require a high degree of industrial expertise. This paper demonstrated in detail how to employ the PSO method to search efficiently the optimal PID controller parameters of an AVR system. The proposed algorithm has been applied in the PID controller design for the AVR system. A MATLAB simulation has been performed and a comparative study between the proposed algorithms with the PID Controller Tuner has been studied in the presented work. In continuation of this, the proposed method was indeed more efficient and robust in improving the step response of an AVR system.

KEYWORDS - AVR system, Particle Swarm Optimization (PSO), PID Controller, PID Controller Tuner.

I. INTRODUCTION

A voltage regulator is designed to automatically maintain a constant voltage level. A voltage regulator may be a simple "feed-forward" design or may include negative feedback control loops. It may use an electromechanical mechanism, or electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages.The role of an AVR is to keep constant the output voltage of the generator in a specified range. A simple AVR consists of amplifier, exciter, generator and sensor. The block diagram of AVR with PID controller is shown in Figure 2.

Theory of particle swarm optimization (PSO) has been growing rapidly. PSO has been used by many applications of several problems. There are three coefficients: proportional coefficient, differential coefficient, and integral coefficient in the PID controller. By tuning these three parameters (coefficients), the PID controller can provide individualized control requirements.

In recent years, many intelligence algorithms are proposed to tuning the PID parameters. Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart, is one of the modern heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems [1]–[5]. The PSO technique can generate a high-quality solution within shorter calculation time and stable convergence characteristic than other stochastic methods [4]–[6]. which has many applications in engineering fields. In the PID controller design, the PSO algorithm is applied to search a best PID control parameters [7]–[8].

The PSO algorithm has been proposed to generate the optimum Proportional, Integral and Derivative gains of the controller. These values are sent to workspace and shared with the simulink model for simulation under different loads and regulation parameters.

The natural TUNER operations would still result in enormous computational efforts. The premature convergence of TUNER degrades its performance and reduces its search capability. Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart, is one of the modern heuristics algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-linear optimization problems[9].

II. AVR MODELING

The role of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a specified level. A simple AVR system comprises four main components, namely amplifier, exciter, generator, and sensor. For mathematical modelling and transfer function of the four components, these components must be linearized, which takes into account the major time constant and ignores the saturation or other nonlinearities. The reasonable transfer function of these components may be represented, respectively, as follows [6].

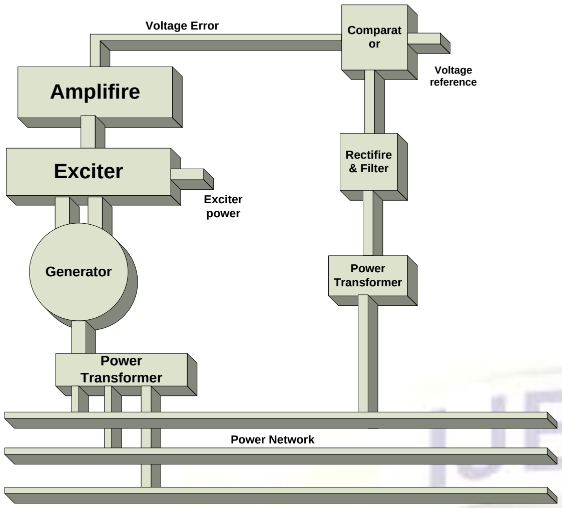

Fig 1. Schematic diagram of AVR System[13].

The generator excitation system maintains generator voltage and controls the reactive power flow using an automatic voltage regulator (AVR) [11]. The role of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a specified level. Hence, the stability of the AVR system would seriously affect the security of the power system. In this paper, a practical high-order AVR system with a PID controller is adopted to test the performance of the proposed PSO-PID controller.

III. AVR MODEL WITH PID CONTROLLER

The PID controller is used to improve the dynamic response as well as to reduce or eliminate the steady-state error. The derivative controller adds a finite zero to the open-loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady-state error due to a step function to zero. The PID controller transfer function is[11]

$$C(S) = k_p + \frac{k_i}{s} + k_d s \tag{1}$$

The block diagram represent of AVR model with PID controller is shown in figure 2.

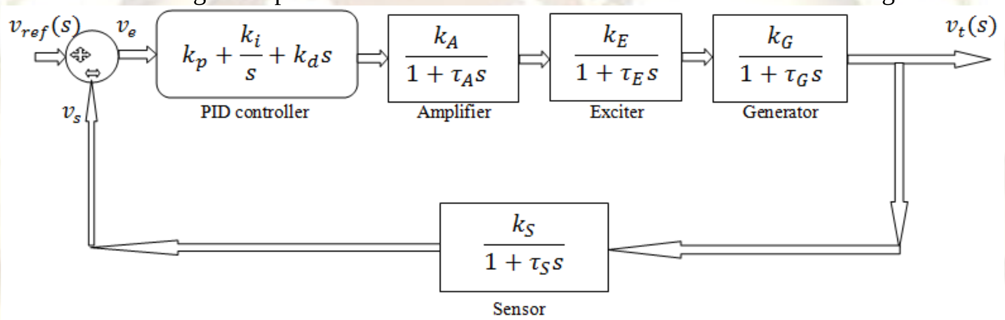

Fig 2. Block diagram of an AVR system with a PID controller.

A change in terminal voltage $\Delta V_t(s)$ with an incremental change in reference input voltage $\Delta V_{ref}(s)$ is given by

$$\Delta V_t(s) = \left[\Delta V_{ref}(s) - \left(\frac{K_A}{1+J_A s}\right)\Delta V_t(s)\right] \times \left[\left(\frac{K_A}{1+J_A s}\right)\left(\frac{K_E}{1+J_E s}\right)\left(\frac{K_G}{1+J_G s}\right)\left(k_p + \frac{k_i}{s} + k_d s\right)\right] \tag{2}$$

IV. PSO ALGORITHM

The structure of each particle in PSO algorithm for designing PID controller is

$$X = [k_p, k_i, k_d]\ n*3 \tag{3}$$

Where

k_p , k_i and k_d = the coefficient of PID controller which are to be designed using the PSO algorithm.

n= Number of population.

In order to coefficient of PID controller using PSO algorithm the following Constant.

Inspired from practical requirements, the lower bounds of the three controller parameters are zero and their upper bounds are set to $k_{p\,max}$ = 1.5, $k_{i\,max}$=1.5 and $k_{d\,max}$= 1.5.

The following parameters are used for carrying out the

PSO-PID design:

- The members of each particle are k_p, k_i, and k_d.
- Population size = 50.
- Inertia weight factor ω where ω_{max} = 0.9 and ω_{min} = 0.4.
- The limit of change in velocity is set to maximum dynamic range of the variables on each dimension.
- Acceleration constants C1 = 1.4 and C2 = 1.4.
- Maximum iteration is set to 50.

ω_{max}, ω_{min} Initial and final weights,
T_{max}, Maximum iteration number

TABLE I. Parameters of PID controller and AVR model with transfer function and parameter limits[11]

Item	Transfer Function	Parameter Limits
PID controller	$k_p + \frac{k_i}{s} + k_d s$	$0.2 \le k_p, k_{i,} k_d \le 2.0$
Amplifier	$TF_{amplifire} = \frac{k_A}{1+\tau_A s}$	$10 \le k_A \le 40$, $0.02s \le \tau_A \le 0.1s$
Exciter	$TF_{exciter} = \frac{k_E}{1+\tau_E s}$	$1 \le k_E \le 10$, $0.4s \le \tau_E \le 1.0s$
Generator	$TF_{generator} = \frac{k_G}{1+\tau_G s}$	k_G depends on load (0.7–1.0) $1.0s \le \tau_G \le 2.0s$
Sensor	$TF_{sensor} = \frac{k_S}{1+\tau_S s}$	$0.001s \le \tau_S \le 0.06s$

TABLE II - Gain Constant and Time Constant of AVR System [12].

Gain Parameter	**Constant Value**	**Time Parameter**	**Constant Value**
Amplifier gain constant (k_A)	10	Amplifier time constant (τ_A)	0.1
Exciter gain constant (k_E)	1	Exciter time constant (τ_E)	0.4
Sensor gain constant (k_R)	1	Sensor time constant (τ_S)	0.01

The value of Generator gain constant (k_G) varying between 0.7 to 1.0 and Generator time constant (τ_G) are varying between 1.0 to 2.0

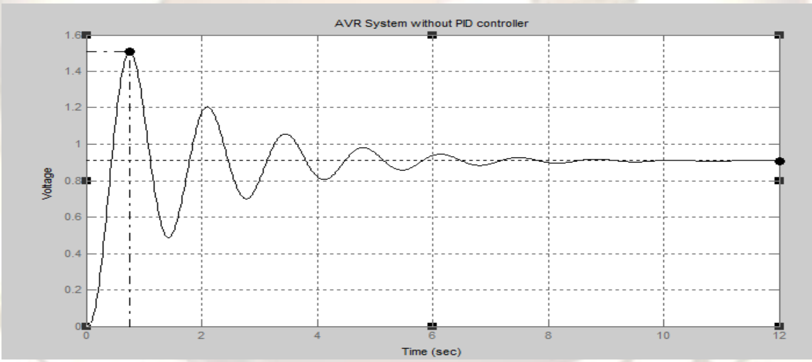

Fig 3.Terminal Voltage Step Response AVR System without PID controller ($k_G = 1, \tau_G = 1$)

V. SIMULATION RESULTS AND DISCUSSION

Generator Gain	Time constant	Type of controller	k_p	k_i	k_d	Rise time	Settling time	Overshoot	peak Volt.
k_G= 0.7	τ_G=1.0	PID_TUNER	0.2940	0.3444	0.0373	0.637	2.200	8.56%	1.09v
		PID_PSO	0.6845	0.4427	0.2341	0.436	1.510	0%	3.92v
	τ_G=1.5	PID_TUNER	0.2865	0.2358	0.0728	0.973	3.230	8.99%	1.09v
		PID_PSO	0.6125	0.4197	0.2013	0.684	3.087	3.80%	1.90v
	τ_G=2.0	PID_TUNER	0.2736	0.1723	0.1150	1.360	4.400	9.16%	1.09v
		PID_PSO	0.6458	0.4446	0.2215	0.787	3.967	7.66%	2.08v

k_G= 0.8	τ_G=1.0	PID_TUNER	0.2572	0.3013	0.0327	0.637	2.200	8.56%	1.09v
		PID_PSO	0.6644	0.4794	0.2454	0.361	1.218	0.32%	2.17v
	τ_G=1.5	PID_TUNER	0.2507	0.2063	0.0637	0.973	3.230	8.99%	1.09v
		PID_PSO	0.6785	0.4785	0.2458	0.516	2.862	3.27%	1.03v
	τ_G=2.0	PID_TUNER	0.2394	0.1507	0.1006	1.360	4.400	9.16%	1.09v
		PID_PSO	0.6482	0.4456	0.2158	0.681	3.630	7.60%	1.07v
k_G= 0.9	τ_G=1.0	PID_TUNER	0.2286	0.2678	0.0290	0.637	2.200	8.56%	1.09v
		PID_PSO	0.6648	0.4784	0.2486	0.307	1.162	0.20%	1.00v
	τ_G=1.5	PID_TUNER	0.2229	0.1834	0.0566	0.973	3.230	8.99%	1.09v
		PID_PSO	0.6456	0.4255	0.2165	0.901	2.309	2.64%	1.02v
	τ_G=2.0	PID_TUNER	0.2128	0.1340	0.0894	1.360	4.400	9.16%	1.09v
		PID_PSO	0.6548	0.4458	0.2326	0.599	3.487	6.40%	1.76v
k_G= 1.0	τ_G=1.0	PID_TUNER	0.2058	0.2410	0.0261	0.637	2.200	8.56%	1.09v
		PID_PSO	0.6570	0.4512	0.2458	0.274	1.179	0.13%	0.51v
	τ_G=1.5	PID_TUNER	0.2006	0.1651	0.0509	0.973	3.230	8.99%	1.09v
		PID_PSO	0.6475	0.4254	0.2456	0.412	0.699	1.98%	1.01v
	τ_G=2.0	PID_TUNER	0.1915	0.1206	0.0805	1.360	4.400	9.16%	1.09v
		PID_PSO	0.6658	0.4448	0.2345	0.524	3.238	5.78%	1.05v

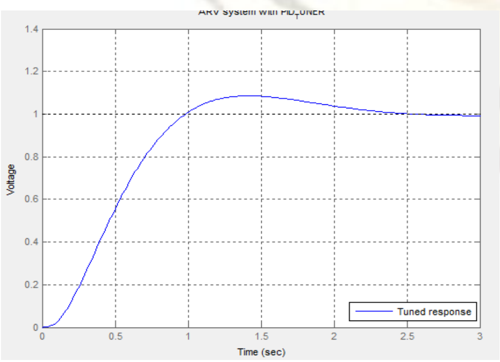

Fig 4. AVR system with PID_TUNER $(k_G = 1, \tau_G = 1)$

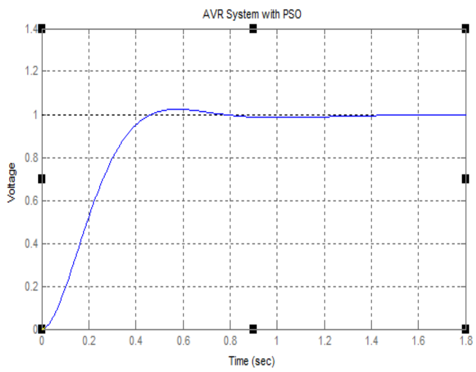

Fig 5. AVR system with PID_PSO $(k_G = 1, \tau_G = 1)$

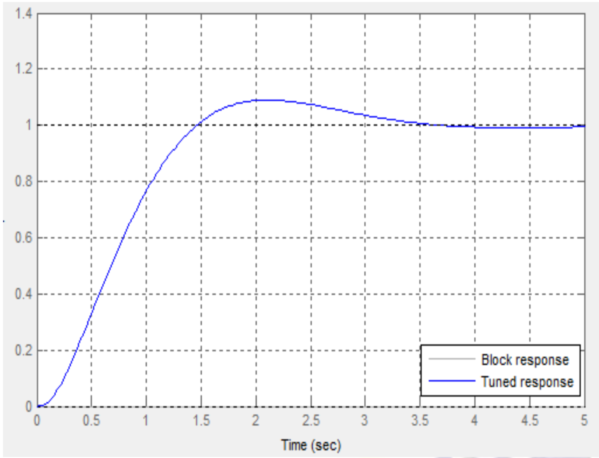

Fig 6. AVR system with PID_TUNER ($k_G = 1, \tau_G = 1.5$)

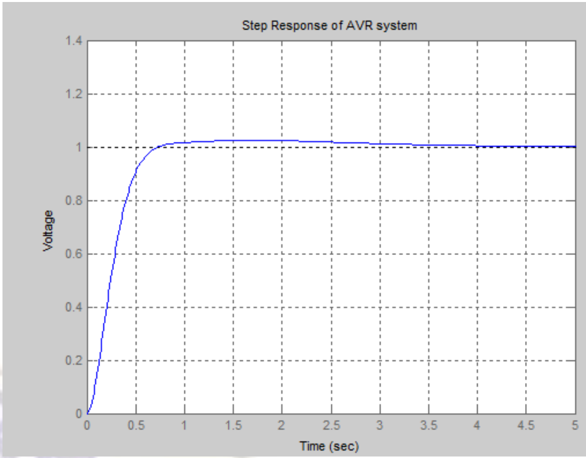

Fig 7. AVR system with PID_PSO ($k_G = 1, \tau_G = 1.5$)

There were two simulation output of AVR system with PID controller and input unit step response of the system are shown in figure 4 and figure 5. It is clearly show that unit step output response of PID PSO ($k_G = 1, \tau_G = 1$) controller are is more stable than PID TUNER ($k_G = 1, \tau_G = 1$) and Settling time of PID TUNER is 2.2 second and the settling time of PID PSO is 1.179 second. the comparison between both result in section 5.

In similarly, figure 6 and figure 7 are show that output of AVR system with PID controller and input unit step response of the system with PID PSO ($k_G = 1, \tau_G = 1.5$) controller are is more stable than PID TUNER ($k_G = 1, \tau_G = 1.5$) and Settling time of PID TUNER is 0.973 second and the settling time of PID PSO is 0.412 second. In this two example it has clearly that the proposed method (PID PSO) has better performance than the PID TUNER method.

In this section, AVR system with the specifications given in table 1 are simulated. . The comparison between the PSO algorithm and PID TUNER for the AVR system is performed in Section 5. The results of the simulation for this system are also illustrated in Figures 4 to Figures 7. Comparing the results of simulation the two AVR systems demonstrates that the PSO TUNER is not sensitive to the parameter variations of the system.

V. CONCLUSION

There were two simulation examples to evaluate the performance of both the PSO PID and the TUNER PID controllers. In each simulation example, The simulation results that showed the best solution were summarized in Result. As can be seen, both controllers could give good PID controller parameters in each simulation example, providing good terminal voltage step response of the AVR system. Table III also shows the four performance criteria in the time domain of each example. As revealed by the above four performance criteria, the PSO PID controller has better performance than the TUNER PID controller.

Comparison with recent work of PSO-PID controlled AVR system: In [10], Gaing optimized the parameters of PID controller in AVR system using particle swarm optimization technique. The PSO used in [10] has been termed as PSO in [6] except the concept of selection ratio. The detailed algorithm has also been discussed in [6]. With the same input data and parameters as in [10] and selection ratio = 0.3, The superiority of PSO in terms of step response profile of incremental change in terminal voltage is clear.

AVR system, many performance estimation schemes are performed to examine whether the proposed method has better performance than the PID TUNER method in solving the optimal PID controller parameters.

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