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Optimal AVR Control System using Particle Swarm Optimization

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Abstract: This paper proposed a PSO with the constriction factor algorithm was used to tune PID-gains for an automatic voltage regulator (AVR) system. In the proposed approach, optimal tuning of PID-gains has very significant issue to perform the target value. Thus, a proposed algorithm has been used to get a better performance. The superiority of the PSO-PID controller is demonstrated through comparing the results with other techniques like Ziegler-Nichols method. Numerical results reveal that the PSO-PID controller has better dynamic response, fast convergence, and high-quality-solution than the other approaches based on rise and settling time of terminal voltage signal of generator.

Keywords: AVR system, PID-controller, PSO, constriction factor.

I. INTRODUCTION

Recently, the scale of the power grid has been expanded fast and complex to satisfy the increasing of the load demand with in nominal voltage. AVR system is used to improve power system equality over maintain the terminal voltage with in permit level. It has ineffectual dynamic response, so that to overcome this problem it will be insert in closed-loop with the controller [1].

Presently, many controllers can be used for AVR system. Among them, the PID-controller is simple structure and efficient performance in the industry process [2]. PID consists of three parameters: proportional, integral, and derivative gains which are to be tuning satisfactory. A numerous algorithms were used to set these parameters properly such as Evolutionary-algorithms, Fuzzy-Logic-System, and Neural-Network … etc. In [3] the authors proposed a PSO-PID for AVR system. The new fitness function was used to find optimality of PID-gains. In [4] the authors present a new hybrid algorithm consists of PSO and the Gravitational Search algorithm (PSOGSA) to obtain optimal values of PID-gains for AVR system. In [5] the authors present a teaching-learning based optimization algorithm (TLBO) for AVR system to get good performance and it was executed in MATLAB environment.

In this paper, a PSO with the constriction factor algorithm was proposed to set the PID-gains in the AVR system. A new objective function was used to achieve better dynamic response than the common performance indices firstly. And it's compared with conventional ZN-algorithm to emphasize effectiveness of the proposed-algorithm.

II. MODELLING OF THE AVR SYSTEM

A linearized model of AVR system is consists of four parts: Amplifier, Exciter, and Generator with the feedback of Sensor. The schematic diagram is demonstrated in figure (1) [6].

- Amplifier:

$$\frac{V_{R\ (s)}}{V_{E\ (s)}} = \frac{K_A}{1+\tau_A S} \quad (1)$$

- Exciter:

$$\frac{V_{F\ (s)}}{V_{R\ (s)}} = \frac{K_E}{1+\tau_E S} \quad (2)$$

- Generator:

$$\frac{V_{t\ (s)}}{V_{F\ (s)}} = \frac{K_G}{1+\tau_G S} \quad (3)$$

- Sensor:

$$\frac{V_{S\ (s)}}{V_{t\ (s)}} = \frac{K_R}{1+\tau_R S} \quad (4)$$

The transfer function of system is:

$$\frac{\Delta V_{t\ (s)}}{\Delta V_{ref\ (s)}} = \frac{0.1S+10}{0.0004S^4+0.045S^3+0.555S^2+1.51S+11} \quad (5)$$

Where:

K_A	Amplifier gain
τ_A	Amplifier time constant
K_E	Exciter gain
τ_E	Exciter time constant
K_G	Generator gain
τ_G	Generator time constant
K_R	Sensor gain
τ_R	Sensor time constant

Figure (2) illustrate the step terminal voltage response. It is obviously that is oscillatory stable and has a rise and settling time are (0.264, 6.985) respectively.

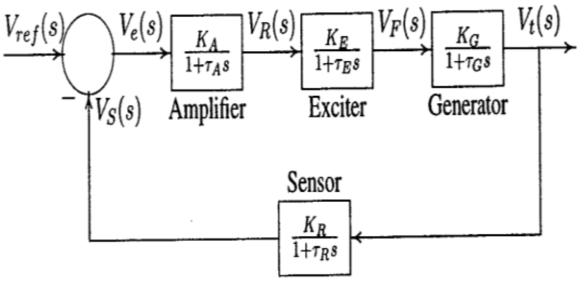

Figure (1) Linearized AVR system block diagram [6]

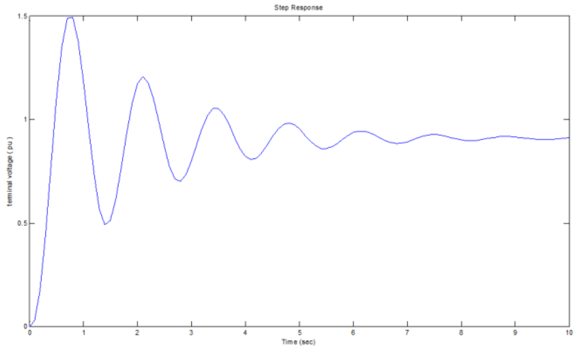

Figure (2) AVR system step terminal voltage response

Therefore, to enhance the dynamic response of system a PID-controller insert to the cooled-loop as shown in figure (3) and the transfer function of system will become:

$$\frac{\Delta V_{t\ (s)}}{\Delta V_{ref\ \ (s)}} = \frac{0.1K_d S^3+(0.1K_p+10K_d)S^2+(0.1K_i+10K_p)S+10K_i}{0.0004S^5+0.045S^4+0.555S^3+(1.51+10K_d)S^2+(1+10K_p)S+11} \quad (6)$$

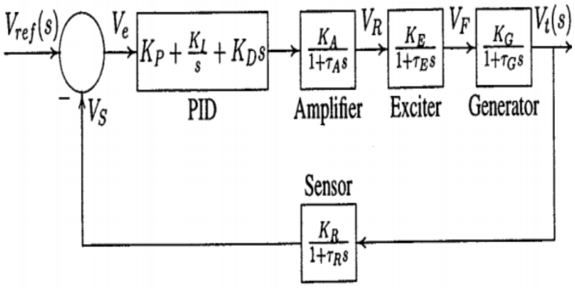

Figure (3) AVR-PID system [6]

III.PARTICLE SWARM OPTIMIZATION

The one of the swarm intelligent techniques is PSO-algorithm which developed by Eberhart and Kennedy depend on the simulation of bird flocking and fish pool [7]. It is randomly initialization of particles in D-dimension search space. The initial position and velocity is taken as the best one for start point of algorithm then the particles are updated the velocity and position according the following equations:

$$V_i^{k+1} = WV_i^k + C_1R_1 * \left(P_{best} - X_i^k\right) + C_2R_2 * \left(g_{best} - X_i^k\right) \ (7)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (8)$$

Where:

V_i^k	Velocity of particle I of iteration k.
W	Inertia weighting factor.
R_1, R_2	Random number between 0 and 1.
C_1, C_2	Acceleration constant.
X_i^k	Current searching point.
X_i^{k+1}	Modified searching point.
P_{best}	Best position of the ith particle.
g_{best}	The index of best particle among the entire particle in the population.

The 15th different strategies of inertia weight which modified the algorithm to enhance the convergence of algorithm as listed in Table (1) [8].

Table (1) Different Inertia Weight

#	**Name of inertia weight**	**Formula of inertia weight**
1.	Constant inertia weight	$W = constant$
2.	Random inertia weight	$W = 0.5 + \frac{Rand()}{2}$
3.	Adaptive inertia weight	$W_i(t+1) = W(0) + (W(n_t) - W(0))\frac{e^{m_i(t)}-1}{e^{m_i(t)}+1}$ $m_i(t) = \frac{gbest - current}{gbest + current}$
4.	Sigmoid increasing inertia weight	$W_k = \frac{(W_{start} - W_{end})}{(1+e^{u*(k-n*gen)})} + W_{end}$ $u = 10^{(\log(gen)-2)}$
5.	Sigmoid decreasing inertia weight	$W_k = \frac{(W_{start} - W_{end})}{(1+e^{-u*(k-n*gen)})} + W_{end}$ $u = 10^{(\log(gen)-2)}$
6.	Linear decreasing inertia weight	$W_k = W_{max} - \frac{W_{max} - W_{min}}{maxiter}\ x\ K$
7.	The chaotic inertia weight	$w = (w_1 - w_2)x\frac{Maxiter - iter}{Maxiter} + w_2 x\ z$ $z = 4x\ z\ x\ (1-z)$
8.	Chaotic random inertia weight	$w = 0.5x\ rand(\ ) + 0.5x\ z$ $z = 4x\ z\ x\ (1-z)$
9.	Oscillating inertia weight	$w(t) = \frac{W_{min} + W_{max}}{2} + \frac{W_{max} - W_{min}}{2}\cos(\frac{2\pi t}{T})$ $T = \frac{2S_1}{3+2k}$
10.	Global-local best inertia weight	$w_i = \left(1.1 - \frac{gbeat_i}{(pbest_i)}\right)$
11.	Simulated annealing inertia weight	$w_k = w_{min} + (w_{max} - w_{min})x\ \lambda^{(k-1)}, \quad \lambda = 0.95$
12.	Natural exponent inertia weight (e1)	$w(t) = w_{min} + (w_{max} - w_{min}).e^{(\frac{-\left[\frac{t}{Maxiter}\right]}{10})}$
13.	Natural exponent inertia weight (e2)	$w(t) = w_{min} + (w_{max} - w_{min}).e^{(\frac{-\left[\frac{t}{Maxiter}\right]^2}{4})}$
14.	Logarithm decreasing inertia weight	$w = w_{max} + (w_{min} - w_{max})x\log_{10}(a + \frac{10t}{T_{max}})$
15.	Exponent decreasing inertia weight	$w = (w_{max} - w_{min} - d_1).e^{(\frac{1}{1+\frac{d_2 t}{t_{max}}})}$

Newly, the constriction factor was used to ensure of algorithm according to the following [9]:

$$V_i^{k+1} = K[V_i^k + C_1R_1 * \left(P_{best} - X_i^k\right) + C_2R_2 * \left(g_{best} - X_i^k\right)] \ (9)$$

$$K = \frac{2}{\left|2-\varphi-\sqrt{\varphi^2-4\varphi}\right|} \quad (10)$$

Where:
$\varphi = C_1 + C_2$ and $\varphi > 4$

The PSO-algorithm with the constriction factor has efficient and high-quality-solution than traditional PSO-algorithm [9].

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IV. OPTIMAL CONTROL DESIGN OF AVR SYSTEM

The schematic diagram of the proposed-controller is illustrated in figure (3).

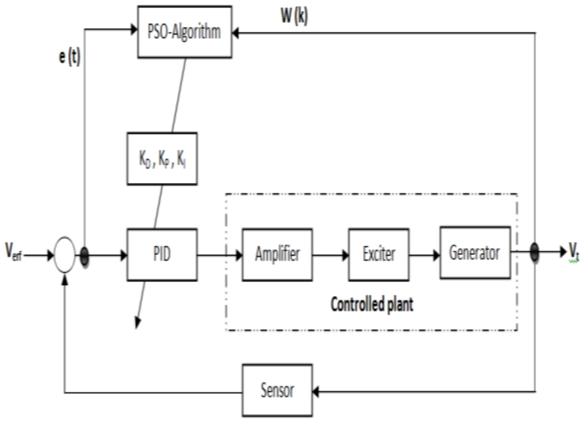

Figure (4) block diagram of PSO-PID

The performance algorithm depended on the objective function that be used. The common performance indices are listed in table (2) [10], minimization of objective-function is chosed according to:

Table (2) Mathematical description of different performance criteria

Performance Criteria	Symbol	Mathematical description of the error
Integral of Absolute Magnitude of the Error	IAE	$J_{IAE} = \int_0^T \lvert e(t) \rvert dt$
Integral of the Square of the Error	ISE	$J_{ISE} = \int_0^T e^2(t) dt$
Integral of Time multiplied by Square Error	ITSE	$J_{ITSE} = \int_0^T t.e^2 dt$

$$objective\ function = \frac{1}{J} \quad (11)$$

To improve the controller, a modification in the objective-function is requested. In [3], the performance index was described as follow:

$$W(k) = (1 - e^{-\beta})(M_p + e_{ss}) + e^{-\beta}(t_s - t_r) \quad (12)$$

And

$$objective\ function = \frac{1}{W_{(k)}\ x\ J} \quad (13)$$

Where:

$W(k)$	Performance function.
K	[Kp, Ki, Kd].
β	weighting factor
M_p	Maximum overshoot.
e_{ss}	Steady stat error.
t_s	Settling time.
t_r	Rise time.

Equation 13 can be improving the dynamic response and boost the accuracy and efficiency of the controller when β =1.5 that be determined experimentally. The PSO-PID-controller flow-chart is shown in figure (4).

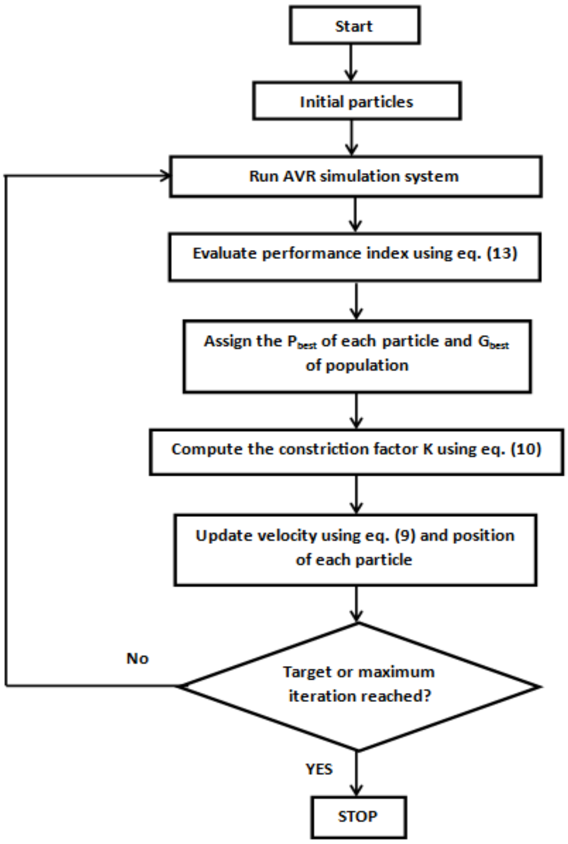

Figure (5) Flow-chart of the proposed algorithm

V. SIMULATION RESULTS

The AVR system structure and its performance of step response was shown in figures (1, 2) respectively. The nominal parameters values are given in appendix A and the proposed-algorithm parameters are given in table (3).

Table (3) The parameters of proposed-algorithm

Parameters		Value
Population size		80
Maximum iteration		100
Acceleration factors	C_1	2.5
	C_2	2.9
Search space of each particle		0 - 1

The simulation results demonstrated in figure (6) is carried out using common performance-indices and new objective-function in eq. (13). That showed ITSE performance index has a better dynamic response than the other performance-indices.

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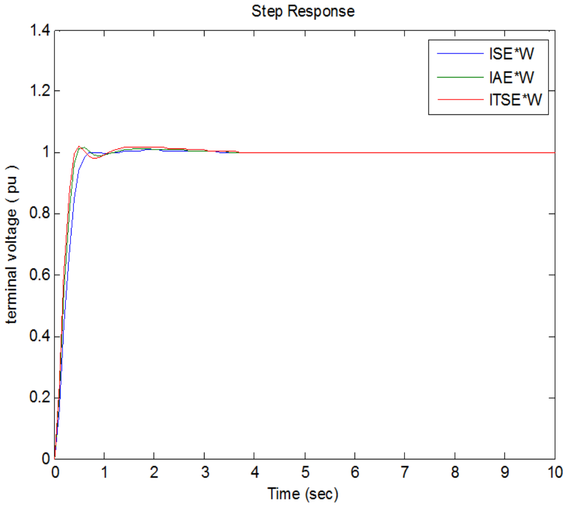

Figure (6) step response of AVR system using objective function using eq. (13)

Table (4) Comparing between ZN and proposed controller

Controller	K_P	K_D	K_I	Rise time (sec)	Settling time (sec)
ZN-PID	1.08	0.1469	1.98	0.232	2.95
PSO-PID$_{ITSE}$	0.6841	0.2679	0.6186	0.276	0.3761

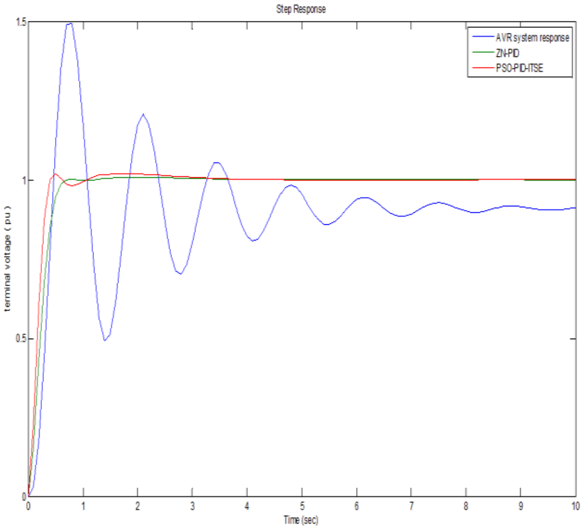

Figure (7) Voltage step response of AVR system

Table (5) Comparison of different schema controls

Controller	K_P	K_D	K_I	Rise time (sec)	Settling time (sec)
TLBO-PID [5]	0.4008	0.1017	0.2556	0.559	0.8296
PSOGSA-PID [4]	0.4783	0.1411	0.3420	0.431	0.691
APSO-PID [11]	0.5536	0.1940	0.4369	0.346	0.564
GA-PID [3]	0.6193	0.2228	0.4589	0.3	0.43
PSO-PID [3]	0.63	0.2276	0.4538	0.3	0.42
PSO-PID$_{ITSE}$	0.6841	0.2679	0.6186	0.276	**0.3761**

The different schema controls were used by the researches as listed in table (5) which seem the efficiency and robustness of the controller to return the terminal voltage of generator to its permit value with lowest rise time and shortest settling time.

VI. CONCLUSION

In this paper, a modify PSO-algorithm with new objective function have been successfully proposed for AVR system dynamic response improvement. The constriction factor helped the PSO-algorithm to converge fastly and accurately to the best point. Through the results, the PSO-PID controller can perform an efficient and precise approach to reach the optimal PID-gains compared to the other methods.

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APPENDIX

The nominal parameter values of AVR system are:

$K_A = 10$
$\tau_A = 0.1$
$K_E = 1$
$\tau_E = 0.4$
$K_G = 1$
$\tau_G = 1$
$K_R = 1$
$\tau_R = 0.05$

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