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# Comparison of PID Tuning by Different PSO Algorithms for an AVR System

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***Abstract:*** In this paper, different Particle Swarm Optimization (PSO) based optimal designs for Proportional-Integral-Derivative (PID) controller parameters in an Automatic Voltage Regulator (AVR) system have been compared. Integral of Time-Weighted-Squared-Error (ITSE) criteria has been considered for checking the performance of control systems. First Classical Particle Swarm Optimization (CPSO) is applied for determining the step response characteristics of optimal PID controller parameters in an AVR system. Then Natural Exponent Inertia Weight (NEIW) algorithm and Moderate Random Search PSO (MRPSO) algorithm are used to reach the optimal PID controller parameters in order to improve the step response of automatic voltage regulator. Conducted simulations show the effectiveness and the efficiency of the proposed MRPSO approach.

***Index Terms* - CPSO, NEIW, MRPSO, PID Controller, AVR, Integral of Squared Error (ISE), Integrated Absolute Error (IAE), Integral of Time-weighted Squared Error (ITSE), Overshoot Method**

## I. INTRODUCTION

During last few decades, alternators are playing an important role in supplying energy for electrical networks. As alternators are largely responsible for maintaining stability and security of the systems, the effective control of alternators is very essential. Different control methods such as adaptive control, neural network control, and fuzzy control have already been developed [1-2]. But, because of its simple structure and robustness, PID controller has been widely used in the industry. In the optimal design of a PID controller, it is required to determine its proportional gain, integral gain, and derivative gain. Many approaches have already been developed to tune PID controllers. A comparison of some established PID tuning techniques is discussed in [3]. Generally, there are mainly four integral performance criteria which are used in control system design namely ISE, IAE, ITSE, and Overshoot Method. The first three criteria are used in control system design because they can be developed analytically in the frequency domain. Overshoot method used in [4] is in time domain which includes the overshoot $M_p$, settling time $t_s$, rise time $t_r$ and steady-state error $E_{ss}$.

Different intelligent control techniques such as fuzzy logics, neural networks and Genetic Algorithms (GA) have been applied to design PID controllers for automatic voltage regulator [1-2, 5]. Although GA method has widely been used to different control systems, recently it has been identified some deficiencies in GA performance. It has been found in [6] that the chromosomes of a population have similar structures and their average fitness is high toward the end of the evolutionary process. But, the crossover and mutation cannot always give better fitness of offspring.

Particle Swarm Optimization (PSO) is swarm intelligence based robust optimization technique to find a solution for continuous nonlinear optimization problem in a search space [4]. Generally, CPSO method performs better than other algorithms in terms of solution quality and accuracy. But, NEIW-PSO and MRPSO have much better performance in comparison with CPSO [7].

Maity et al. in [7] compared NEIW-PSO and MRPSO to CPSO algorithm. The comparison reveals that the MRPSO is a relatively better optimization technique. It has almost similar performance as PSO and better performance than GA in term of success rate and solution quality and its processing time.

The performance and the robustness considerations have been involved to show the stability and efficiency of the system in both algorithms. Optimized parameters obtained in both algorithms, are compared with each other.

## II. SYSTEM MODEL

### 2.1 Basic Model of an AVR System with PID Controller:

The main role of an AVR is to hold the terminal voltage magnitude of an alternator at a specified level. The AVR system contains four major parts, namely: amplifier, exciter, generator and sensor. The block diagram of an AVR system with PID controller and amplifier limitation is shown in Figure 1.

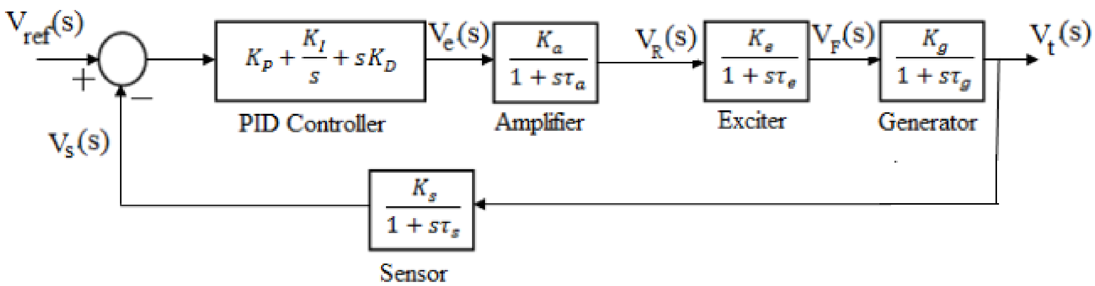


Figure 1: Block diagram of an AVR system with PID controller.

The terminal voltage drop causes an increase in the reactive power. The voltage is sensed through a potential transformer on one phase. After rectification, this voltage is compared to a dc set point signal. After amplification, error signal controls the exciter field and helps to increase the terminal voltage of exciter. Thus, the generator field current is increased, which results in an increase in the generated e.m.f. The generated reactive power is increased to a new equilibrium state, raising the terminal voltage to the preferred value.

In order to model the four major components and to determine their transfer functions, each component must be linearized taking into account the major time constant. The approximate transfer functions of these components are given as following Table I.

Table 1: Transfer function of AVR components

| MODEL | TRANSFER FUNCTION | PARAMETER LIMITS |
|---|---|---|
| Amplifier | $\frac{V_R(s)}{V_e(s)} = \frac{K_a}{1 + s\tau_a}$ | $10 \leq K_a \leq 400$; $0.02 \leq \tau_a \leq 0.1$ |
| Exciter | $\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1 + s\tau_E}$ | $10 \leq K_E \leq 400$; $0.5 \leq \tau_E \leq 1$ |
| Generator | $\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1 + s\tau_G}$ | $0.7 \leq K_G \leq 1$; $1 \leq \tau_G \leq 2$ |
| Sensor | $\frac{V_s(s)}{V_t(s)} = \frac{K_s}{1 + s\tau_s}$ | $0.001 \leq \tau_R \leq 0.06$ |

### 2.2 PID controller:

The PID controller transfer function is given in equation (1):

$$C_s = K_P + \frac{K_I}{S} + K_d s \qquad (1)$$

The derivative controller adds a finite zero in the open-loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin and increases the type of system by one and reduces the steady-state error to zero. Range of PID controller parameters are shown in Table 2.

Table 2: Range of Three controller parameters

| CONTROLLER PARAMETERS | MIN. VALUE | MAX. VALUE |
|---|---|---|
| $K_P$ | 0 | 1.5 |
| $K_D$ | 0 | 1 |
| $K_I$ | 0 | 1 |

In literature review, many techniques have been implemented to evaluate the performance of the PID controllers. The four evaluating performance criteria defined in [4], are ISE, IAE, ITSE and Overshoot method. Overshoot method includes the overshoot $M_P$, rise time $t_r$, settling time $t_s$ and steady state error $E_{SS}$. All of these criteria have their own advantages and disadvantages. The evaluation performance criterion formulas are as follows:

$$ITSE = \int_0^{\propto} te^2(t)dt$$

$$W = \left(1 - e^{-\beta}\right).(M_P + E_{SS}) + e^{-\beta}.(t_s - t_r)$$

$$IAE = \int_0^{\propto} |r(t) - y(t)|dt = \int_0^{\propto} |e(t)|dt$$

$$ISE = \int_0^{\propto} e^2(t)\, dt$$

In order to evaluate the performance of PID controller in the AVR system, here ITSE method is considered for CPSO, NEIW-PSO and MRPSO optimization process.

## III. OVERVIEW OF DIFFERENT PSO METHODS

A number of different PSO strategies are being applied here for tuning PID controller in AVR system. The significant developments are presented which will serve as a performance measure for the MRPSO technique [8] applied in AVR system.

### A. Particle Swarm Optimization (PSO):

PSO is a nature inspired optimization method developed by Eberhart and Kennedy in 1995 based on the social behaviors of birds flocking and fish schooling.

**Particle (X):** It is a candidate solution represented by an m-dimensional vector, where m is the number of optimized parameters.

**Population:** Pop (t) is a set of n particles at time t, i.e.

Pop(t) = [ $X_1$(t), $X_2$(t), ……………… $X_n$(t) ]

**Swarm:** It is a random population of moving particles that tend to group together towards a common optimum while each particle seems to be moving in a random direction.

**Personal best ($P_{best}$):** The personal best position linked with i-th particle is the best position that the particle has visited and select the highest fitness value for that particle.

**Global best ($G_{best}$):** The best position linked with i-th particle that any particle in the swarm has visited and select the highest fitness value for that particle. This is the best fitness of all the particles of a swarm at any point of time.

**Formulation of PSO:**

$$V_i^{u+1} = w * V^u + C_1 * rand * (P_{best} - P_i) + C_2 * rand * (g_{best} - P_i) \quad (2)$$

$$P_i^{u+1} = P_i^u + V_i^{u+1} \quad (3)$$

Where $C_1 = C_2 = 2$, cognitive & social acceleration constants respectively and w = 0.7, inertia weight.

### B. Natural Exponent Inertia Weight (NEIW)

In this technique, the inertia weight is varied exponentially.

$$w = w_{min} + (w_{max} - w_{min}).* e^{(iter/(itermax/10))} \quad (4)$$

Suitable selection of inertia weight in equation (4) provides a balance between local and global explorations. It requires less number of iterations to find the optimal solution. Inertia weight decreases from about 0.9 to 0.4 during simulation.

### C. Moderate Random Search PSO (MRPSO)

MRPSO was first proposed by Hao Gao and Wenbo in the year 2011 [9]. In MRPSO, the global search ability of the PSO is improved without compromising its convergence rate. A Moderate Random Search technique is used in this new PSO technique. Only position is updated and but velocity in not changed.

The position $P_i^{u+1}$ of i-th particle at (u+1)th iteration can be calculated by the following formula

$$P_i^{u+1} = P_{di} + \alpha\lambda(m_{besti} - P_i^u) \quad (5)$$

$$m_{besti} = \frac{\sum_{i=1}^{n} P_{besti}}{n} \quad (6)$$

Where, n denotes the population size. The parameter α is achieved by changing its value from 0.45 to 0.35 with the linear decreasing method during iteration, $P_d$ is the attractor moving direction of particles. It is given as

$$P_{di} = rand1 * P_{besti} + (1 - rand1) * g_{best} \quad (7)$$

Where, rand1 is a uniformly distributed random variable within [0, 1] and $\lambda = (rand2 - rand3)/rand4$ (8)

Where, *rand2* and *rand3* are two random variables within [0, 1] and *rand4* is a random variable within [−1, 1]. [9]

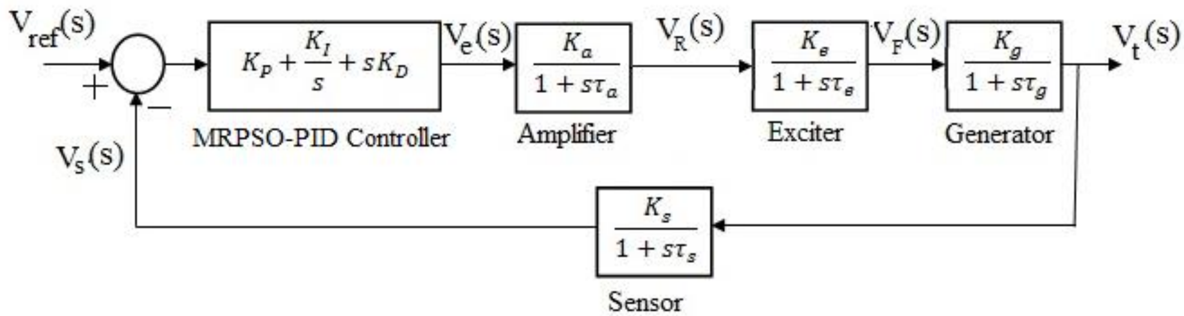


Figure 2: Block diagram of an AVR system with MRPSO-PID controller.

## IV. SIMULATION RESULTS

The proposed approach is implemented in MATLAB language on the Intel(R) Core(TM) i3 CPU 3.30 GHz PC and preliminary numerical tests are used to set the values of the MRPSO control parameters. The best obtained results are presented in Table 3.

Table 3: MRPSO control parameters values

| DESIGNATION | VALUE |
|---|---|
| Population size | 10 |
| Number of generation | 30 |
| $C_1$ , $C_2$ | 2 |

To examine the efficiency and the performance of the proposed approach, a practical high-order AVR system as shown in Figure 2, is tested. The parameters of the block diagram are taken as:

$K_a = 10$, $K_e = K_g = K_s = 1$, $\tau_a = 0.1$ s, $\tau_e = 0.4$s, $\tau_s = 0.01$ s, $\tau_g = 1$ s

### 4.1 Performance of Different types of PSO-PID controller

First, step response of the AVR system without any PID controller is considered. The result is shown in Figure 3. In this case the system an un-desirable oscillatory behavior with large overshoot, long settling time is found.

Then AVR system with CPSO-PID controller is considered. The corresponding step response is shown in Figure 3. It can be seen from this figure, that the system response has relatively small overshoot and short settling time with no oscillatory behavior.

Table 4: Solutions using CPSO-PID, NEIW PSO-PID and MRPSO-PID controllers.

| | $K_P$ | $K_I$ | $K_D$ | $M_P$ | $t_s$ | $t_r$ |
|---|---|---|---|---|---|---|
| Without Controller | - | - | - | 65.7226 | 6.9865 | 0.2607 |
| CPSO-PID | 1.4356 | 0.8779 | 0.9211 | 27.2053 | 1.3954 | 0.0918 |
| NEIW PSO-PID | 1.4274 | 0.9115 | 0.3476 | 22.7317 | 0.9485 | 0.1656 |
| MRPSO-PID | 1.1685 | 0.7993 | 0.4147 | 14.5666 | 0.8518 | 0.1607 |

Then AVR system with Natural Exponent Inertia Weight PSO-PID controller is considered. The corresponding step response is shown in Figure 3. The system response has relatively small overshoot and short settling time with no oscillatory behavior.

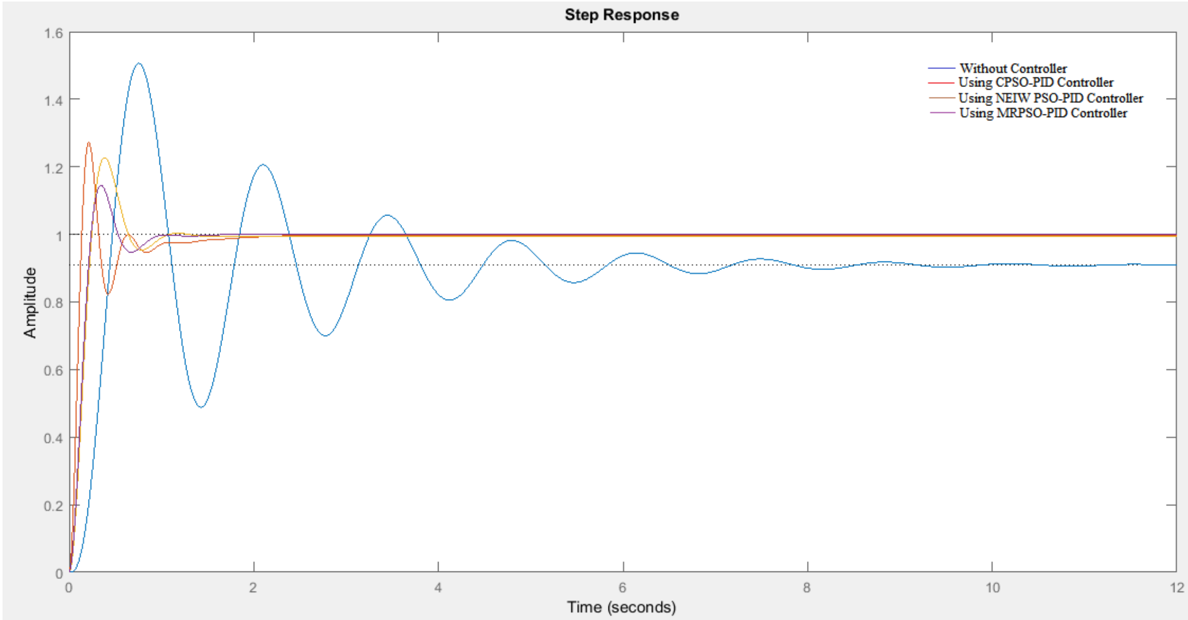


Figure 3: Step Response of AVR System with different types of PSO-PID Controllers.

At last AVR system with MRPSO-PID controller is considered. The corresponding step response is shown in Figure 3. The system with MRPSO-PID controller has superior performance than systems with other PSO-PID controller. The system with MRPSO-PID controller has very small overshoot and settling time with no oscillatory behavior.

The comparative study of this AVR system with different controllers are shown in Table 4.

## V. CONCLUSION

In this paper, different PSO techniques have been successfully implemented and tested for tuning the PID controller parameters in an AVR system. The results obtained through simulations on a practical higher order AVR system shows that the MRPSO method has superior performance than other PSO techniques. MRPSO can perform efficient search for the optimal tuning of PID controller parameters in AVR systems. Furthermore, this approach can improve the control system performance in terms of time domain specifications and set point tracking compared with other PSO based techniques.

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