Optimised PID-AVR controller design using Artificial Swarm Intelligence Algorithm

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Power system is consist of voltage regulator to maintain constant voltage. It regulates AC or DC voltages and it is designed as feed-forward and it may include negative feedback control loop. Load at this end changes continuously which requires to restructure the power system, this is carried out through tuned controllers. proportional–integral–derivative controller is commonly used controller in AVR system. It is also called as PID controller. Despite the popularity, tuning of PID control parameter is challenge to plant operators and researches. This research work has used Artificial Swarm Intelligence Algorithm (ASI) for tuning PID AVR parameters optimally. ASI is generally refer as human swarming. This algorithm creates network of all individuals in the group and Artificial intelligence is used to tune the control parameter. It enhances the prediction accuracy and it reduces the required number of iteration as well. This research work has compared the performance of ASI with Artificial bee colony (ABC), genetic algorithm (GA) and Particle Swarm Optimization(PSO) for optimisation of tuning PID controller. Five fitness functions were used to compare performance with existing algorithm. The results show best convergence of ASI algorithm.

Introduction

Now a days, many researches are going on towards increasing the accuracy of control methods. Artificial intelligence, decision trees, fuzzy system and various adaptive controls has developed to enhance the accuracy of predicting controller parameters. Structure of PID controller is simple as well as its implementation is cost and time effective, in parallel it provides high accuracy rate in variable operating conditions which makes it an in important and unreplaceable component in many industrial control system. In AVR system, management of power source of AC and DC supply is required, PID controller manages the control parameters and handles power supply. It has many applications in Generators and temperature control. However the tuning of control parameter may need to handle the disturbance and variable operating conditions of the system. Previously this tuning used be performed offline , this method was proposed by Ziegler-Nichols[2][3], However later on many system fails to tune the parameters using Ziegler-Nichols formula.

With the enchantment in prediction algorithm using fuzzy system and artificial intelligence, many researches were performed on the tuning of control parameters. Using fuzzy algorithm, PID control parameters of the non-negative water supply is managed [4]. It has been integrated with the stream turbines and using Artificial intelligence, control parameters were tuned [5]. Lab scaled helicopter system is also using Artificial intelligence to tune PID parameters [6].

Along with AI and genetic algorithm , PSO is also used in predicting the control variable for tuning. PSO Algorithms were built on social behaviour of group of individual. Artificial Bee colony (ABC) algorithm with enhanced version is used in improving the accuracy of PID-AVR control[7]. Like EABC , other PSO algorithm has also contributed in enhancing PID control [8]. PSO methods has proven a high accuracy rate with high convergence.

In this research an optimised algorithm based on PSO algorithm is applied to enhance the system performance, For this Human based Particle swarm optimization is configured. Fitness function is used to evaluate the performance of PID-AVR control[9]. Fitness function also improves the time complexity.

This research paper is organised as follow, Section II describes previous research in AVR PID control regulation. Section III describes the proposed Artificial Swarm intelligent algorithm integrated with AVR system. Section IV and V explains experimental analysis and conclusion of this research work.

Modelling of AVR system

PID controller is used in many industries because of simple architecture. Its role is to provide stable electrical power supply with good dynamic response and high efficiency. However PID controller has steady state error and fluctuation is performance of dynamic response. It is necessary to fix it. Additional pole configured at origin which is integrated with controller increases system type by one, and it helps to reduce the steady state error in PID-AVR system. By modification in open loop transfer function with addition of finite number of zero, response time of the system is improved. PID-AVR model is applied for performance testing proposed algorithm. This model is consist of four component. These components are generator, exciter, amplifier and sensor. This is illustrated in figure 1 with PID-AVR block diagram and transfer function.

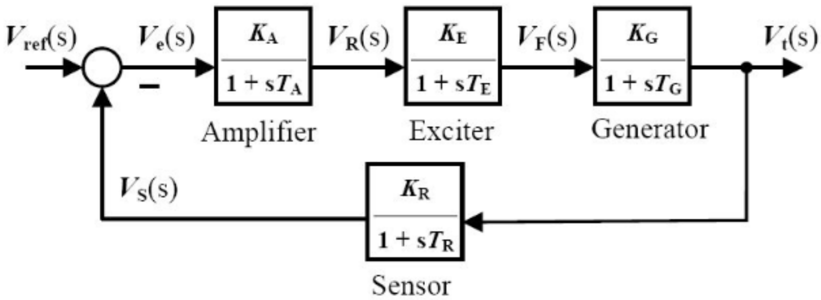


Figure 1 : Modelling of PID-AVR

As described in figure 1, based on error signal, controller generate control signal[10][11]. Deviation of generator output voltage and current voltage is called as error signal. Integral component is used to reduce the steady state error [10]. Oscillations were controlled by derivative [12].

Table 1 describes the Transfer function, Gain range , Time gain range , Gain and Time constant. In general, transfer function is describes relation between input signal and output signal of control system with considering all inputs. For example, I(s) is considered as an input , O(s) as system output,

$$G(s) = O(s) / I(s) \quad (1)$$

Where G(s) stands for Transfer function.

Gain is used to determine the amount of restoring force required to overcome position error. Gain for Amplifier, Exciter, generator and sensor is 10,1,1 and 1 respectively. PID control transfer function is measured with formula 2 in many researches [8].

$$C(s) = k_p + \frac{k_i}{s} + k_d s \quad (2)$$

As described in the figure 1 , for transfer function and mathematical modelling requires the components to be linearized. This section describes the transfer function.

Amplifier model transfer function uses K_A gain and Time constant , it is defined by :

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1+\tau_A s} \quad (3)$$

Exciter model transfer function is defined by K_E gain and Single time constant :

$$\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1+\tau_E s} \quad (4)$$

Generator model transfer function is defined by :

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1+\tau_G s} \quad (5)$$

Sensor model transfer function is defined by simple first-order transfer function as :

$$\frac{V_s(s)}{V_t(s)} = \frac{K_R}{1+\tau_R s} \quad (6)$$

for comparison of performance with existing algorithm, five fitness functions were used. These functions were previously used in many research related to PID-AVR control. In Comparative performance analysis of artificial bee colony algorithm for automatic voltage regulator (AVR) system, gozde has applied a fitness function to perform the analysis test. Integrated absolute error (IAE), Integral squared error (ISE) and Integrated of time weighted square error (ITSE) are mostly used parameters in the analytical performance measure [7]. As ISE and IAE require more time for analysis, ITSE is used in performance test. Formula for ITSE is described in equation 7,

$$ISTE = \int_0^{\infty} te^2(t)dt. \quad (7)$$

Donga in his research has proposed two fitness function for testing the performance of Genetic algorithm with other tuning algorithm [15]. This functions are described in equation 8 and 9. Integral of Time-weighted Absolute Error (ITAE) represented by

$$\int_{t=0}^{t=t_{\max}} t \times |e(t)|\, dt \quad (8)$$

e(t) represents the difference of calculated and descried value, value of Ma(t) is 1 second and B is 1.5

$$\frac{e^{-\beta} \times \frac{t_s}{\max(t)}}{(1-e^{-\beta}) \times \left|1-\frac{t_r}{\max(t)}\right|} + e^{-\beta} \times O_{sh} + E_{ss} \quad (9)$$

Zwe-Lee has used time constant based equation to perform the analysis. This is described in equation 10 [14].

$$(1 - e^{-\beta}) \times (O_{sh}+E_{ss}) + e^{-\beta}(t_s - t_r) \quad (10)$$

Mukherjee and Ghoshal has proposed an equation for fitness function, In this Osh is an overshoot and , ts is express settling time. max_dev denotes maximum-deviation of voltage

$$(O_{sh} \times 10000)^2 + t_s^2 + \frac{0.001}{(max\_dev)^2} \quad (11)$$

This fitness functions are mostly used to enhance the prediction accuracy.

PROPOSED ALGORITHM

Artificial swarming algorithm is based on parallel nature additionally it removes the social biasing problem. There exist no leader and follower concept in swarming algorithm, complete population contribute in the decision making. In swarming algorithm , all participant are active and contribute in decision making. In this algorithm, participants explore completes decision space and converge towards a common prediction. Artificial swarming algorithm enhances the performance by amplify group intelligence.

In nature, swarm practices is present in many species, they usually hunts food or travels using this method. Fish, birds, bees and insects are well known example of swarm algorithm. In swarm algorithm real time participants are present which votes to a decision [1]. Participants together forms a sub-population which leads to a decision making. When all subpopulations level active a threshold value, algorithms try to make prediction using convergence technique.

Steps in Artificial swarming algorithm

1) Excitation or Enabling swarm participants

In this step, all the participants in the network were activated. Each member from the group acts and contribute in making decision. It is inspired by honeybees decision making principle. It enables participants to integrate the information present, it allows to compare the decision, and it converge whole votes into an optimised solution. Artificial intelligence based algorithm is used for this convergence and decision making. This step is also known as Excitation.

2) Contribution

In Artificial swarming algorithm, participants are voting for their decision and it keep updating similar to bird swarming algorithm. As it is a continuous process, it more like a Behaving instead of reporting. In this each participant is engaged and behave to the direction and magnitude of the decision. It also follow the leaky integrator model. In leaky integral model input is takes in primary step but as algorithm keep moving forward, algorithm gradually leaks a small amount of input over time.

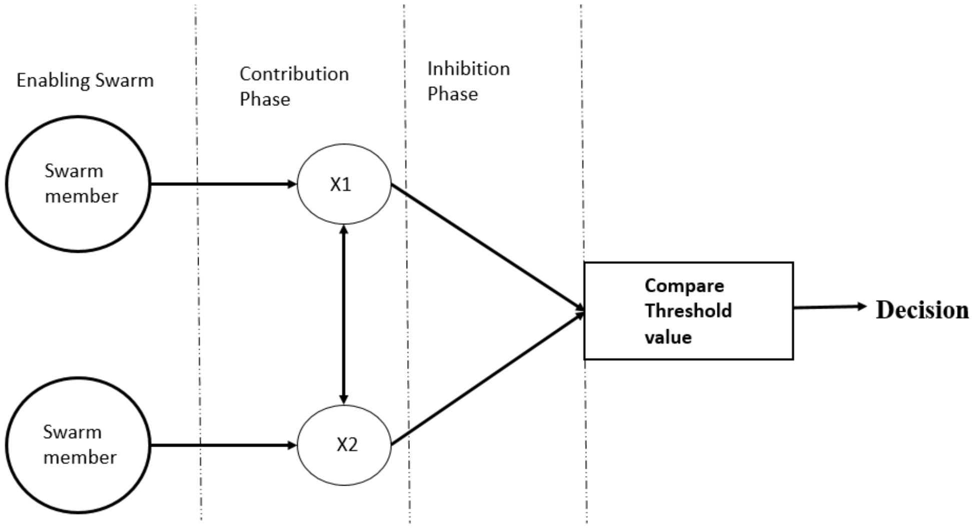


Figure 2 : Artificial swarming algorithm

3) Inhibition

In this step , instead of the individual decision, sub-population or group is dedicated for the voting step. This step comes after contribution of each individual. In the next phase threshold value is compared and which leads to final decision.

4) Threshold

In threshold value comparison, some predefined values are used to determine the central tendency of the swarm to accept one decision. If the decision among the group is similar then it leads to convergence, or else swarms diverges from central decision. As convergence grows, degree of convergence increases. This value is used to compare the threshold value.

5) Decision making

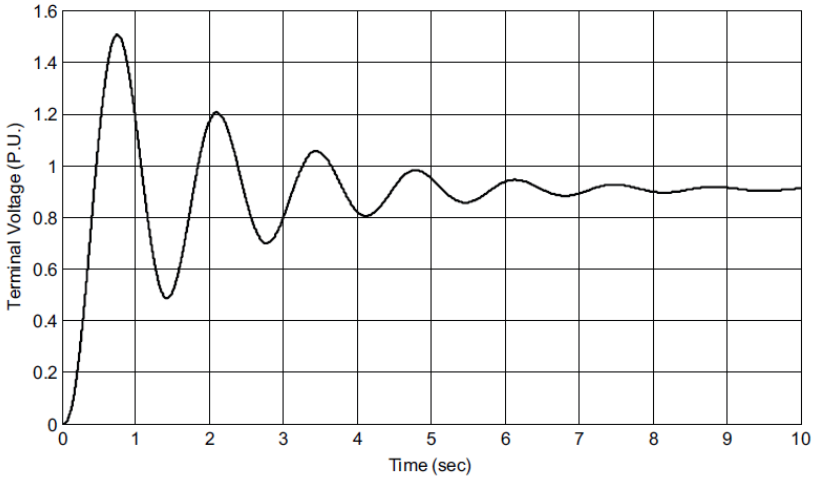
Brainpower is a metrics used in artificial Swarm Intelligence, it is computed by speed of convergence and participants alignment. Its value lie between 0 to 1. 1 indicates the strong convergence among participant which leads to decision making. Value of 0 indicates the divergence in the decision making and leads to no decision within allocated time. In the final step algorithm conclude a decision and the brainpower metrics which is used in performance analysis.

PERFORMANCE ANALYSIS

Performance of the proposed architecture and algorithm is tested using fitness function as discussed in section II, overshoot, time complexity for searching the parameter, AVR voltage output with and without proposed algorithm, and the comparison with the existing algorithms.

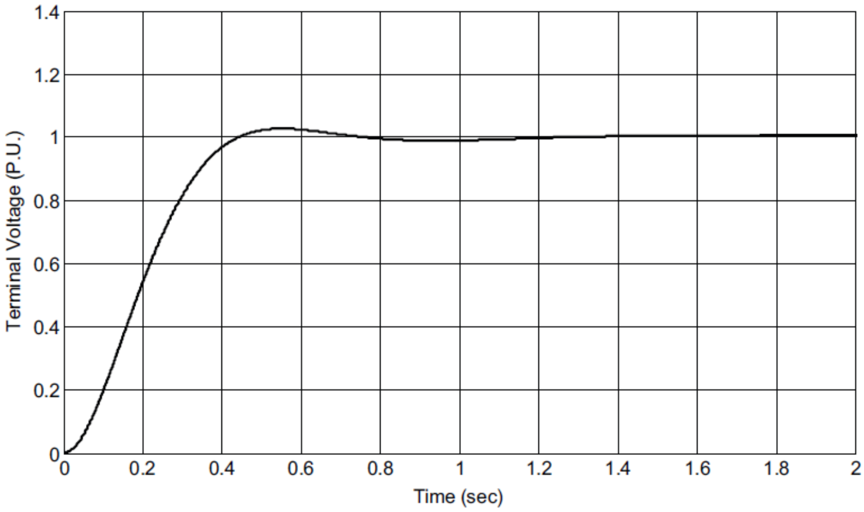
For voltage analsyis purpose, α is set to 3, β is set to 1, population size is fixed to 50. Graph 1 , represents the response of without PID controller. The overshoot (Mp), rise time (tr), settling time (ts), and steady-state error (Ess) is used to measure the effect of output voltage with and without PID controller. According to graph 1, overshoot =49.5%, steady-state error

= 0.034, rise time =0.27 sec, and settling time = 6.9 sec. It is clearly observed that overshoot is large and oscillations are not steady, this is unsafe situation for power system.



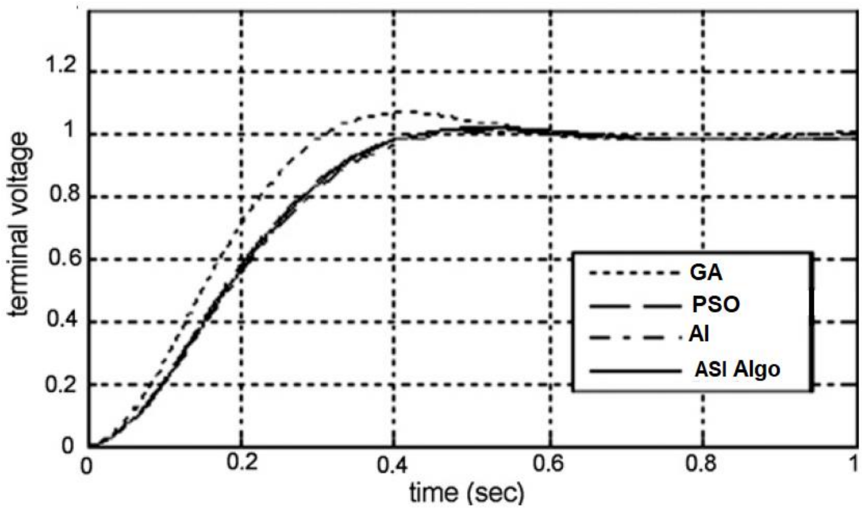
Graph 1 : Output voltage of AVR without PID controller

Graph 2, describes the voltage variation in AVR system without PID controller, where ts= 0.4018 sec, Ess= 0, Mp=1.12%,, tr=0.2762 sec



Graph 2 : Output voltage step response

Along with Proposed algorithm , the response of the system is compared with other existing algorithm and the step response of PID controller is measured. Graph 3 illustrates the comparison of proposed algorithm with existing algorithm.



Graph 3 : Comparsion with existing system

Graph 3 shows the comparison of step response with existing system including Genetic algorithm, partical swarm algortihm , Artifical inteligance and it is observed that Artifical swam intellignece has more stable output as compare to other algorithms. Terminal votage of prposed algorithm is more stable and safe as comapre to other system

As discussed in previous section, fitness function is used to compare the existing algorithm and the chart is prepared to measure the performance. Time domain analysis is used for performance testing. Mp, tr, ts and Ess variable were measured and analysed. tr is a time which is required for final value to increase from 10 to 90%. Settling time is a time need to damp out 2% oscillation. Overshoot is present in percentage and it is a measure by comparing the original output with desired output. output and real output at ten seconds is measured as steady state error.

1) Integrated of time weighted square error comparison

	tr	**ts**	**Mp**	**Ess**
Genetic Algorithm	0.4246	0.5019	0	5.75E-07
PSO	0.3486	0.5520	0	8.00E-07
AI	0.3436	0.7943	0	1.98E-05
Proposed Algorithm	**0.3131**	**0.4917**	0	**1.65E-07**

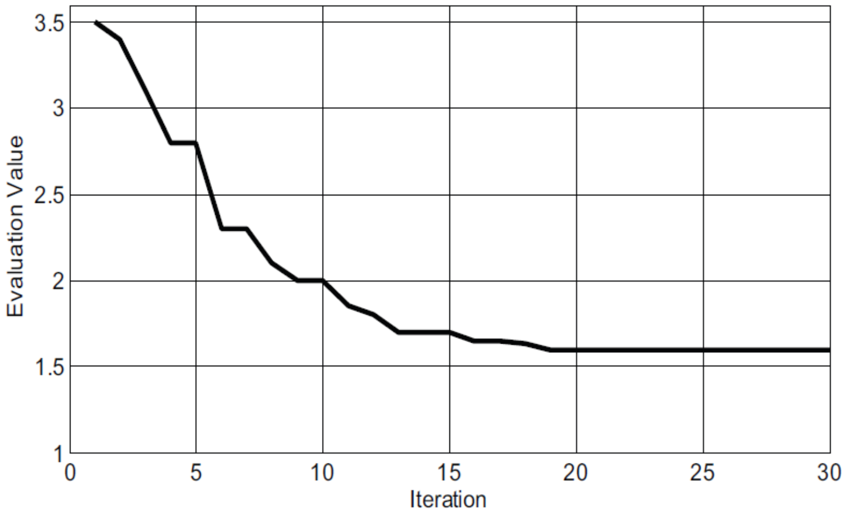
2) ITAE

	tr	**ts**	**Mp**	**Ess**
Genetic Algorithm	0.0958	0.945	28.448	3.85E-06
PSO	0.0964	0.948	27.98	3.12E-06
AI	0.0958	0.945	28.448	3.85E-06
Proposed Algorithm	0.1124	0.7733	17.65	4.94E-07

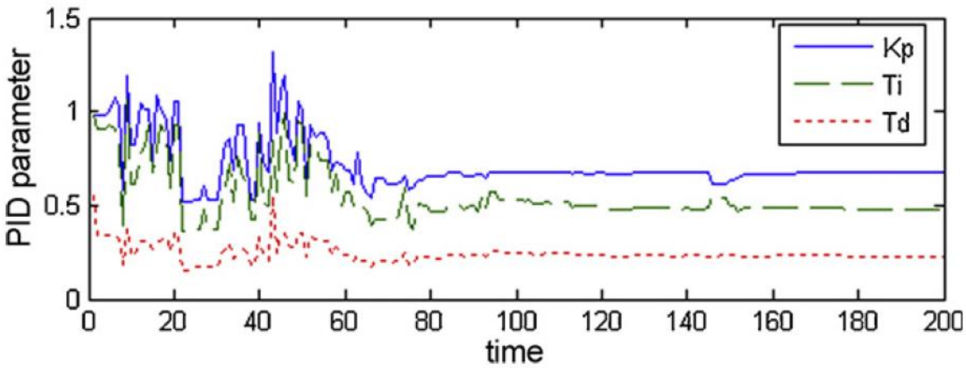
3) Max Deviation based fitness function

	tr	**ts**	**Mp**	**Ess**
Genetic Algorithm	0.1884	0.9189	10.425	4.14E-07
PSO	0.1495	0.7832	22.529	2.02E-08
AI	0.1354	0.7472	22.676	1.07E-07
Proposed Algorithm	0.1193	0.7007	17.038	3.63E-07

Convergence chart of algorithm is described in graph 4, As illustrated in graph 4, variable predictions from the subpopulation tires to convergence which eventually increases the brainpower and hence the tendency towards a one decision. IT is also observed that convergence occurs in less time as compare to other algorithms.



Graph 4 : Convergence graph



Graph 5 : parameter search time graph

Graph 5, explains the time vs parameter, which indicates the time required for searching the variable for PID regulation. It is observed that time required for finding the optimised control parameter reduces with time.

CONCLUSION

In this research work a new PSO is proposed to increase the time complexity and accuracy of finding the optimised control parameter for AVR-PID controller. Performance of analysed using fitness function as discussed in section II, overshoot, time complexity for searching the parameter, AVR voltage output with and without proposed algorithm, and the comparison with the existing algorithms. In performance analysis it is found that the output voltage of AVR PID controller with Artificial swarm algorithm is better than without PID controller. Voltage step response is also compared with PID tuned parameters using Genetic algorithm, Artificial intelligence, practical swarm algorithm and proposed algorithm, it is observed that the output ts of proposed algorithm is more steady. ITSE, IAE and maximum deviation is also compared. Convergence graph of proposed algorithm were studied along with time complexity of tuning the control parameters. Performance of the system increases with Artificial swarm intelligence as compare to other existing algorithms.

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