PID Controller Tuning using ACO Algorithm for AVR Systems

Harsha S Anantwar, Anirudh Suresh Ramachandran

Abstract: This paper features an effective technique to device the parameters of PID controllers for utilization together with an Automatic Voltage Regulator System (AVR). The quintessential goal is to acquire a good load disturbance response by minimizing the performance index/(Integral time square error). Simultaneously, the transient response is assured by limiting maximum overshoot, settling time and rise time of the step response to minimal values. For achieving these goals, optimum and quick tuning of the parameters (Kp, Ki, and Kd) is essential. In an effort to accomplish the aforementioned, the paper put forth an algorithm developed based on the Ant Colony Optimization technique (ACO) to decide optimal gains of PID controller and for getting optimal performance within an AVR system. Simulation results establish superior control response may be accomplished in comparison with methods like conventional tuning method (trial and error) and built-in genetic algorithm (GA) took-kit.e.

Keywords : ACO, AVR and PID

I. INTRODUCTION

Proportional-integral-derivative controllers are typically employed to regulate and stabilize the time domain behavior of dynamic plants and systems. These controllers are widely accepted owing to their simple structure, good performance characteristics for a broad range of conditions and environments Despite the straightforward structure of this controller there is necessity is to tune its parameters; proportional gain (Kp), integral gain (Ki), and derivative time constant gain (Kd) effectively and suitably [1]. Conventionally, the problem has been handled by a trial and error method or by using older algorithms such as the Ziegler-Nichols method. However, it is often problematic and tiresome to obtain optimal PID parameters with these methods. In order to reduce the complication compared to traditional method of tuning the PID controller parameters, many optimization methods have already been developed, like, fuzzy logic [2]-[3], self-tuning methods [4]-[5],particle swarm optimizations[6],artificial bee optimization[7], and pattern recognition [8] genetic algorithm (GA) [9], particle swarm optimization [10]. These techniques tend to be quite effective during their tuning of the PID controller. Better methods not only enable a quicker tuning, in addition, provide us with better performance and enable for

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widespread utilization of the controller Within this research, we have developed the challenge of design PID controllers , for usage within the AVR system by applying the ant colony optimization algorithm (ACO) [11].The algorithm works on the closed feedback loop that is formed by the AVR and the PID controller. Researchers have confirmed the promising potential of ACO to competently explore and locate an optimal solution. The procedure followed influenced by examining the proven fact that ants can discover the shortest path between their nest and as well as a food source [12]

ACO is basically a metaheuristic approach suited for finding solutions of complex optimization problems. Some of the examples include the traveling salesman problem, quadratic assignment problem, vehicle routing, scheduling [13]. Natural ants inspire a lot of the behavior used in this algorithm .some of main traits are listed here: (1) artificial ants prevail in colonies of cooperating individuals, (2) communicates indirectly by the dumping chemical pheromone. Simililary in ACO ,a colony of artificial ants work together to search and explore solutions in given domain in order, to find the optimal solution

II. AVR SYSTEM

AVR comprises of four main components the amplifier, exciter, sensor.PID controller is added so as to help control the AVR which in turn regulates the reactive power and voltage magnitude. An AVR system mainly regulates the fluctuations in voltage, these mainly happen because of the variation within the load. This variation might lead to severe impairment of the system and equipment. To prevent the variation in the voltage and mitigate damage to equipment, AVR is provided in more than one point in the system. Now, the generator voltage in the AVR is sensed by direct connection to the terminals of the generator. This sensed voltage is then fed to a measurement unit which converts it into a low-value direct voltage proportional to the generator voltage. Further, the terminal voltage of a generator obtained through a potential transformer which is then rectified, filtered and compared with a reference voltage. Thus, the AVR system detects the difference between these two and generate an error voltage. The AVR can be tuned effectively by making use of a PID controller, which in turn is optimally tuned by ACO algorithm. Controller output gives an appropriate signal to the main exciter, then the exciter adjusts the field current of the machine, to bring system voltage nearer to the reference value. This helps to reduce the overvoltages which occur due to the sudden loss of load on the system or any other types of fluctuations which may occur due to variations in the load [14].The AVR system components are modeled using transfer functions, which considers only the time constant ignoring the saturation or other nonlinearities. These components can be in Fig.1 [15].
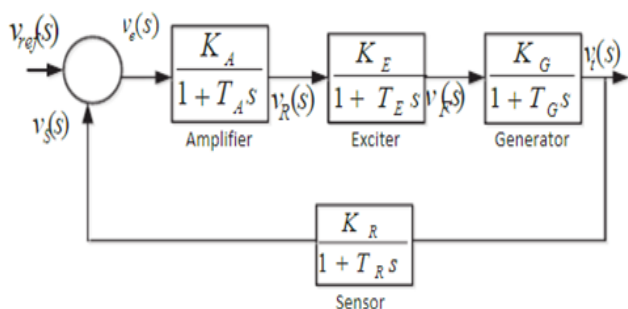
Fig.1-Simplified block diagram of an AVR system

III. OPTIMIZATION PROBLEM

An optimization problem is defined as selecting optimal values of PID controller parameter to enhance the response of the AVR system under varying load condition. In this work Kp, Ki and Kd gains controller are optimally tuned using the ant colony algorithm. The transient state of system is important since the system must reach steady-state quickly and the time response of the system must be kept within the endorsed limits. [1,16]] Hence, three key performance evalution criterias are utilized to characterize the performance systems ,these include: ITSE(integral time square error), overshoot, and settling time.

IV. ANT COLONY OPTIMIZATION

ACO is an evolutionary meta-heuristic algorithm. It is a graphical method of solving the problem and has been proven successful and effective to handle various hard combinatorial optimization problems. Main insight of ACO is to create a graphical model of the problem and search for the path the shortest path and best the cost. Artificial ants' traverse across the various nodes. A single ant has a very straightforward behavior and would be unable to find good paths or solutions on their own but with the help of cooperation among a number of them, they are able to find out the best path and hence the best solution. This cooperation happens because of deposition involving a chemical substance known as pheromone.

As the best way to find the solution is to test all the possibilities one by one, the ants as they roam through the paths deposit this chemical substance which the other ants can follow. Firstly, the way the ants choose a certain path is dependent on Pseudo-Random-Proportional Action Choice Rule which gives us the probability of which node the ants might choose the next step. An ant will move from node x to node y with probability .

$$P_{ij} = \frac{[\tau_{xy}]^{\alpha}[\eta_{xy}]^{\beta}}{[\tau_{xy}]^{\alpha}[\eta_{xy}]^{\beta}} \qquad (1)$$

Where 'α' represents the relative importance of the pheromone trace in the problem and 'β' represents heuristic factor. The Eq.(1) , the probability equation is a requital between the heuristi factor and the pheromone factor. Two types of different process that occur in the following algorithm is first because of the pheromone factor if there is a lot of ants taking a similar path then this then creates an autocatalytic process whereas due to the heuristic factor closer nodes are chosen with higher probability thus creating a greedy constructive heuristic process. Thus, Ants allocate the next elections in accordance with possibility equation. A

round orientation is finished considering that all the nodes within the problem are visited and traveled . After this , amount of pheromone trace is updated in accordance with Eq. (2) and Eq.(3) given below. In other words, pheromone updation is intended to allocate a larger quantity of pheromone to paths with a lower cost (small tours). This value is assessed when the ant has completed a tour which consists of a cycle of' 'n' iterations . Then, it is used to update the amount of substance beforehand put down on the path, based on the subsequent rules

$$\tau xy(t + a) = (1 - E)\tau xy + \Delta \tau xy \qquad (2)$$

$$\Delta \tau xy(t) = \sum_{k=1}^{a} \Delta \tau xy \qquad (3)$$

where a is number of ants . E is the persistence of the trail in the generations. The pheromone-updating rule was focusing on trying to simulate the transition in the total sum of pheromone stemming from both the addition of latest pheromone deposited by ants upon visiting the edges plus some lost as a consequence of pheromone evaporation. The algorithm terminates iterating either when an ant finds a solution or whenever the maximum number of generations has been executed. [17,18]

V. TUNNING OF PID CONTROLLER USING ACO ALGORITHM

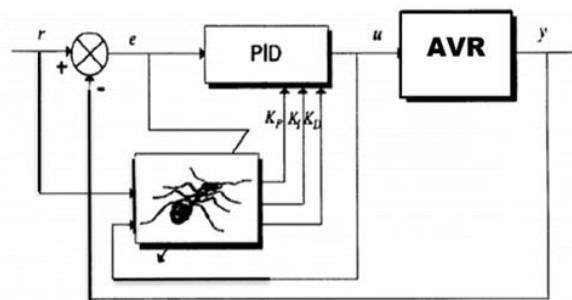The PID controller is developed using ACO to the optimally control AVR system can be seen in Fig.2

Fig2- ACO optimized of PID controller

The optimal design of PID controller means to select the best parameters Kp, Ki and Kd such that the performance indexes of the step response of the system are kept minimal. . To develop graph representation involving an optimal problem, the vectors are considered as paths between the nests. All the paths are considered as nodes .Start and end node are also considered. Within the tour, the ant must visit all of the nodes by selecting a pathway from the start node to the end node. The purpose of ACO would be to search for the best tour having the lowest value of the cost function or objective function amongst all the three paths. All of the of ants deposit pheromone onset of each new path. Subsequently the pheromones are updated in pheromone updating rule [17,18].

Now the pseudo-code of the algorithm for use in PID -AVR system is presented below :
The ACO pseudo-code for the optimal design of PID is as follows
Set parameters and initialize pheromone trail
Start iteration from node 1 to 1000
Determine the probability distribution of the nodes

Determine the probability sum
The cost function is calculated
Best cost is determined
Pheromone trails updated
End iteration
Display parameters with the best cost
Larger the nodes gives more precise results. Trails are updated only after having constructed complete path and the solution . Each path represents the performance indexes (cost function) on the load disturbance response and transient response for a set of parameters (Kp, Ki& Kd). The). The ACO parameters used are: α=0.8 ,β=0.2 , Evaporation Rate =0.2, nodes = 1000, number of ants = 10, number if iterations = 10. In this paper as stated the number nodes used are 1000, a greater number of nodes produced better accuracy, though the solution is found much slower. Fig.3 represents the graphical movement by which the ant colony algorithm works. Each column represents the PID parameters, while each graphical node represents a numerical solution for corresponding parameters (Kp, Ki, and Kd). Ants as stated move about these nodes trying to discover the best solution. Trails are updated only after creating complete path and the solution found.
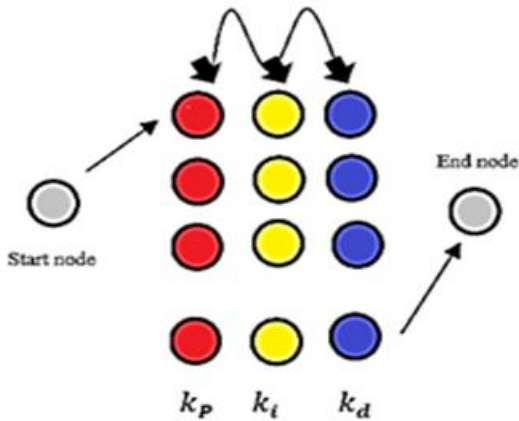

Fig3-Ant movement

VI. SIMULATION RESULTS

The simulation results of ACO based optimal tuned AVR is presented in this section. To implement the ACO algorithm we design a Simulink model of AVR [1] is presented in Fig.4
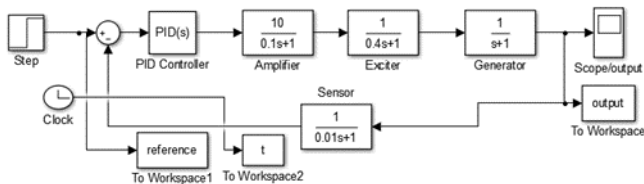

Fig4- Simulink model

The ACO algorithm is tested for various performance indices (objective function) such as ITSE, IAE, ISE and ITAE employed for solving an optimization problem (optimal tuning of controller parameter) is tabulated in Table 1. From TableI, it is seen that the objective function is consistently minimum in case of the ITSE compared to all the other performance indexes.

TABLE I: Performance index tabulation

S/NO	ITSE	IAE	ISE	ITAE
1	**10.61**	269.2051	109.10	251.82
2	**10.27**	231.1285	103.67	231.16
3	**10.91**	274.6025	106.12	237.22

4	**11.64**	220.2894	104.38	232.32
5	**11.56**	223.5646	105.12	251.32
6	**12.46**	214.9676	105.16	218.13
7	**12.80**	215.8716	109.96	220.60
8	**11.96**	224.4941	105.14	215.12
9	**11.43**	216.0378	108.80	220.40
10	**10.36**	230.6225	107.23	230.12

Comparison of AVR response for various performance indices is illustrated in Fig.5, From that, we can notice that the ITSE gives us the best response characterizes giving the fastest settling time and overshoot
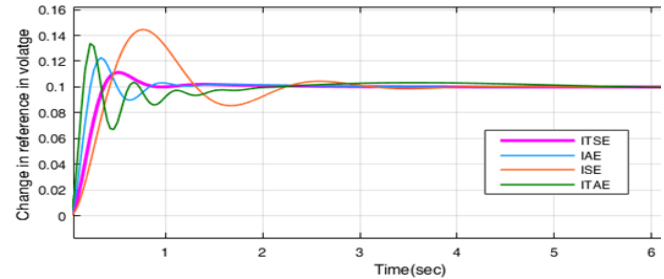

Fig5- Comparison of AVR response for various performance indices for 1%(0.1 p.u 0 step disturbance condition

The results obtained through the ACO algorithm and two other methods for validating the effectiveness of ACO. The results obtained by using the GA algorithm and a conventional method (trial and error) are presented in Fig. 6
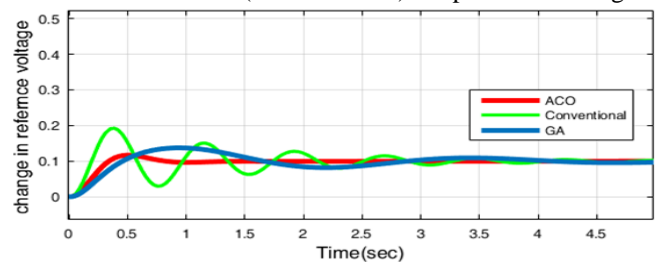

Fig6- Comparison of AVR response with ACO ,GA and Conventional method optimal tuned PID controller for 1% step disturbance condition. citation [8].

Table II presented controller parameters obtained by the three above mentioned methods for 1% step change in reference voltage change to the AVR system.
Table III summarizes time domain specification of AVR response for 1% change in reference voltage for GA, ACO and Conventional method

TABLE II : Optimal PID Controller parameters

Specification	GA	Conventional	ACO
Kp	2.7	0.4661	**0.88402**
Ki	8	1.4671	**0.56358**
Kd	0.34	0.1490	**0.21913**

TABLE III: Time domain specification of AVR response

Specification	Conventional	GA	ACO
Settling Time (Sec)	5	4	**3.5**
ITSE	186.65	97.98	**0.10466**

Overshoot	220%	38.1%	**25.94%**

paper.

VII. CONCLUSION

In this work, an improved concept to design and model the PID controller for usage in an AVR system in order to optimize and enhance its response is featured. The optimization of the PID controller is made by using three key performance indexes namely maximum overshoot, settling time, and ITSE. It is realized that for the particular usage the ITSE proves to be a better fit compared to IAE, ISE, and ITAE. The results obtained by using genetic algorithm(GA) and conventional method are also featured for comparison and contrast. It can be concluded that the proposed method, the ant colony algorithm provides a better response on the three Performance indexes compared to the other methods. The characteristic feature of the presented algorithm unique include that it can be (i) it can be implemented relatively easy, (ii) flexible in nature and hence upon changing a few parameters allows for use in different applications (iii) search in parallel provides a guaranteed and definitive converge.

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