ISSN: 0974-8571 Vol.13 No. 1 June, 2021

International Journal of Computational Intelligence in Control

VOLTAGE CONTROL OF AN AVR WITH TUNED PID CONTROLLER WITHANT COLONY OPTIMIZATION

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ABSTRACT

The intention of this work signifies about the tuned PID controller with ANT Colony Optimization for the output voltage control of an AVR. The non-linear behaviour of the system causes some external as well as internal disturbances due to which the stable performance of the system gets affected. The employment of an adaptive control techniques to achieve better system stability enrichment further. In present environments, Proportional + Integral + Derivative controllers are predominantly used in many production units because of its architecture, efficient, reliable, and robust performance. To improve the system stability in addition with minimum error, overshoot and settling time etc., an optimization method based on Ant Colony Optimization (ACO) is deployed in this exertion for tuning the PID parameters at optimum by means of modelling an Optimal PID tuned controller with AVR system in Matlab /Simulink environment. The results are validatedwith AVR system in comparison with conventional PID controller as well as its study in terms of step response.

Keywords—*PID controller, Adaptive control, Automatic voltage regulator, Genetic algorithm,* Ant Colony *optimization.*

I.INTRODUCTION

The voltage of a power source is able to sustainwithin tolerance bandand attainswith the help of electrical device labelled as voltage regulator and the objective is to maintain a constant voltage even in the presence of perturbations also. AVR with the synchronous drive implemented to sustain constant terminal voltage of the generator in normal operational conditions at abundant load levels [1]. There is a chance to deviate the constant voltage level of the voltage regulator i.e., output of the system from the setup point caused by occurrence of fluctuations in the input voltage levels. To quickly reach the setup point level from its deviated voltage level, the adoption of controller is needed. Largelyconstant terminal voltage at the desired value achieved with AVR closed loop control system. It controls the terminal voltage by regulating the exciting voltage of the generator [3].

The principal objective of the controller is to preserve the firm voltage level. The typical Proportional+Integral+Derivative controller (PID) is the greatestinfluential and well-known because of its structural simplicity, toughness, cost-effective and also offer a wide stability margin etc. These are used in numerous control practices [1]. This controller is of right choice for the AVR structure. For satisfactory operation of it, vital tuning of parameters involved in the controller is must. Ziegler–Nichols, Cohen-coon methods etc., have been used to govern PID parameters for many years. It is most challenging one by conventional methods to flourish the best. Therefore, Engineers / Designers have to be reliant on their knowledge for attaining the optimumperformance characteristics. The objective of thework carried out in this is to recommend an optimum PID controller constructed on Ant Colony Optimization (ACO) technique for clever control of voltage in a self-regulating power generating unit. The problemdiscussed in this is put into words as an Optimization control and ant colony optimization technique is working to exploration for best controller parameter gains K_p, K_i&$K_d$aimed at the better performance of AVR system [4].

II. MODELING OF AN AVR

The main objective of this structural unit is to uphold the constant voltage at the alternator.Stability of an AVR has crucial impact on the power system quality and reliability. In order to achieve stable operation and good power quality, it is utmost significant to control the excitation of a synchronous generator. Fig.1 shows a simple real prototype of an Automatic Voltage Regulator unit. The sub modules of AVR are in the order of sequence namely comparator, amplifier, exciter, generator and measuring device (sensor). The output of an AVR system without any controller unit when subjected to unit step input has some oscillations which diminishes the regulation performance [5].

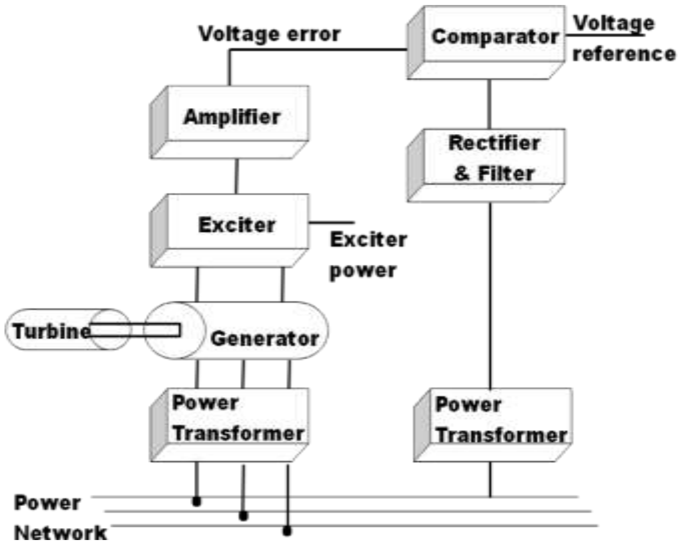

Fig 1: A simple real model of AVR system

The voltage drop occurs in the generator terminals when the reactive power demand is increased at the load side. Alternator or generator unit that generates the voltage is sensed at regular intervals of time by a potential transformer (PT). The output of PT unit is AC and converts to DC by means of a rectifier unit and further smoothens it by means of a filter circuit to get required output. Next, the error detector (comparator) unit generates an appropriate voltage error signal output based on the output of smoothing circuit and DC reference signal. The error voltage is amplified by amplifier unit. The amplified signal which controls the field of excitation / exciter unit that rises the terminal voltage of exciter. Hence increased the field current of the generator due to which the generated EMF also increased [3]. Then the reactive power increases to a new equilibrium value which then mains the terminal voltage to ananticipated value.

AVR sub components are characterized based on their mathematical models and the concern transfer functionof sub components are presumedto be linear that proceeds into relation the major time constant and castoffs saturation or other non-linearities. The general block diagram of AVR is shown in Fig 2 with all the transfer functions of individual units of it. The particulars of sub-units are given as follows:

i) The transfer function of amplifier model is represented in terms of gain (K_a) and time constant (T_a) and is given by $TF_A = \frac{K_a}{1+sT_a}$ ... (1) ;

ii) The transfer function of an exciter model is expressed in terms of gain (K_e) and time constant (T_e) and is given by $TF_E = \frac{K_e}{1+sT_e}$ ... (2) ;

iii) Generator transfer function is expressed in terms of gain (K_g) and time constant (T_g) which are load dependent and is specified by $TF_E = \frac{K_e}{1+sT_e}$ ... (3) ;

iv) A measuring device i.e., sensor element characterized as a simple transfer function whose order is one and expressed in terms of gain (K_S) and time constant (T_S) which is specified as $TF_S = \frac{K_s}{1+sT_s}$ ... (4)

v) Comparator generates appropriate error signal from reference to terminal voltage. It is modelled by voltage error signal

$V_e = V_{ref} - V_s$ ... (5)

$V_s = \frac{K_s}{1+sT_s} V_t$ ... (6)

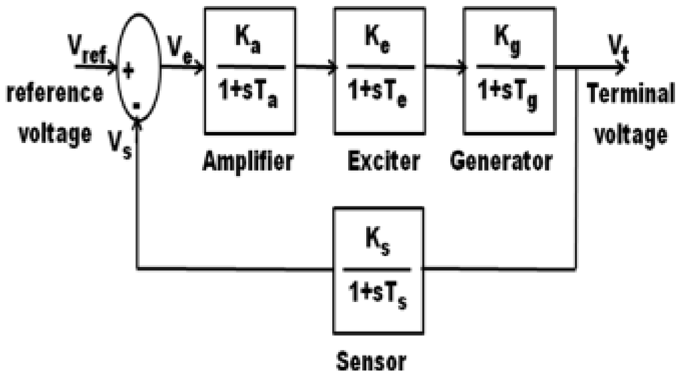

Fig 2: Block diagram of the AVR system

Gain and time constant values of sub units in AVR system model are selected asK_a=20.0, T_a=0.05S, K_e=1.0, T_e=0.8S, K_g=1.0, T_g=1.0S, K_s=1.0 and T_s=0.01S.Now with these values the overall AVR system transfer function [3] turn out to be

$$TF_{AVR}=V_t/V_{ref} = \frac{V_t}{V_{ref}} = \frac{0.2S+20}{0.0004S^4+0.0489S^3+0.9085S^2+1.86S+21} \quad ... (7)$$

III. PID CONTROLLER WITH AVR UNIT

Proportional + Integral + Derivate controller unit finds widespread usageduring few decades in industrial era. It is simple in structure, easily understood, robust in performance which can affordoutstanding performance even a process unit subject to dynamical deviances also. The theme of a controller is to diminish the steady state error as well as to improve further system dynamic behaviour. A controller with three basic actions like proportional, integral and derivative actions[2] are required as per the mentioned. The following are achieved with respective basic control actions.

With Proportional Control action:

- This affords comprehensive control action in proportion to the error signal.
- If the controller gain is very high, the system changes from stable to unstable area.

- It has the effect of decreasing the rise time, but impotent to reduce the steady-state error

With Integral Control action:

- The controller adds a pole adds at the origin that enhances system type to one and reduces the steady state error to zero.
- Large integral gain can cause overshoot and lower value will make the system performance slow.

With Derivative Control action:

- The transient response improved with this controller because this adds a finite zero to the transfer function.
- D- controller improvestransient response, reduces overshoot as well as improves system stability.
- Larger derivative gain yields system unstable.

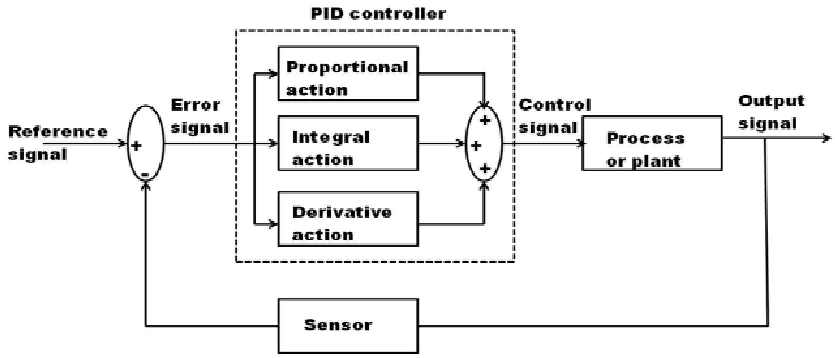

Fig 3: Pictorial outlook of a PID controller with plant

To get estimated response from closed loop system, tuning of three gains (proportional, integral and derivative) are significant in the design fragment of a controller. The closed loop system output has better settling time with insignificant / zero overshoot to a step signal [2]. For a PID controller, the input and output are related routinely by a transfer function is as follows:

$$U(t) = K_p e(t) + k_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \quad \ldots (8)$$

$$\frac{U(S)}{E(S)} = K_p + \frac{k_i}{S} + K_d S$$

$$TF_{PID} = K_p + \frac{k_i}{S} + K_d S \quad \ldots (9)$$

An outlook of a PID unit coupled in cascade with AVR sub modules as shown in Fig. 4 is to sustain the steady terminal voltage and further enrichment in dynamic response for a step input to AVR.

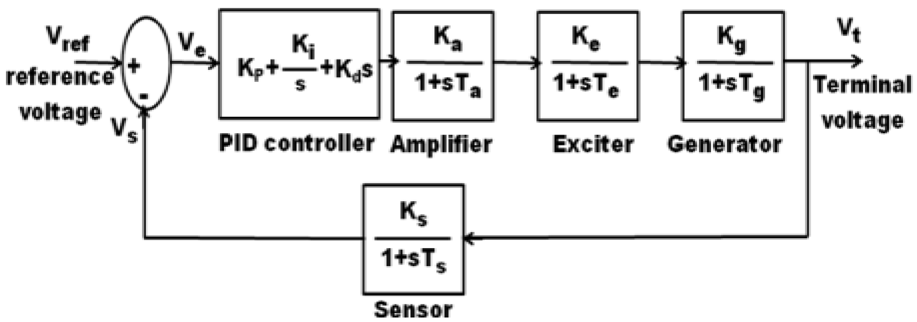

Fig 4: Pictorial representation of a PID unit with AVR sub modules

Table I: AVR sub units/blocksTransfer function and boundaries of parameters

BLOCK NAME	PID CONTROLLER	AMPLIFIER	EXCITER	GENERATOR	SENSOR
Transfer function	$K_p+(K_i/s)+K_ds$	$K_a/(1+sT_a)$	$K_e/(1+sT_e)$	$K_g/(1+sT_g)$	$K_s/(1+sT_s)$
PARAMETER					
Boundaries	$0.2\leq K_p, K_i, K_d\leq 2.0$	$10\leq K_a\leq 40$, $0.02\leq T_a\leq 0.1$	$1\leq K_e\leq 10$, $0.4\leq T_e\leq 1.0$	(0.7-1.0) K_g depends on load $1.0\leq T_g\leq 2.0$	$0.0001 \leq T_s\leq 0.06$
Values - Used	K_p,K_i,K_doptimum	$K_a=20$, $T_a=0.05$	$K_e=1,T_e=0.8$	$K_g=1,T_g=1$	$K_s=1,T_s=0.01$

By utilizing the above parametric values, the cascaded AVR with PID controller units, the attained transfer function [4] is given by

$$\frac{V_t}{V_{ref}}=\frac{0.2K_dS^3+(20K_d+0.2K_p)S^2+(20K_p+0.2K_i)S+20K_i}{0.0004S^5+0.0489S^4+0.9085S^3+(20K_d+1.86)S^2+(20K_p+1)S+20K_i} \quad \text{... (10)}$$

At this point unknown parameters (three gains) of PID controller must be calculatedon the way tovalidate the stability of AVR system. To diminish the steady state error, upgrading in the transient response of AVR unit a tuning algorithm is preferred to attain best parameter values during design of a controller unit.

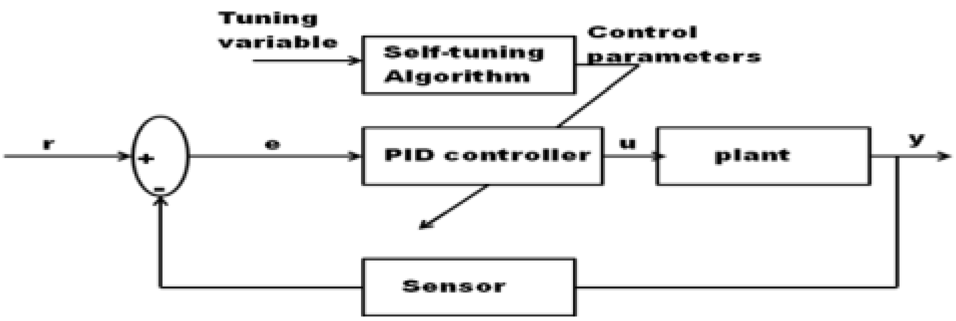

Fig 5: Pictorial view of self-tuning PID controller

IV. CONTROLLER PROPOSAL USING ANT COLONY ALGORITHM

An Optimization Technique is preciselycompatible for better solutions to different optimization problems one among them the technique is based on Ant Colony algorithm.A collection of artificial ants collaborates to determineuprightdeterminations, which standsapromisingassets of the ant's helpful interaction. ANT algorithm can be applied to diverse problems due to their resemblances. Each ant individual can accomplish minor portion or comprehensive solution to optimization problem. The Optimal solution attained when many ants work together only. On demand basis to solve a precise optimization problem statement, artificial ants have been developed with extra capabilities that are not present in real ants.

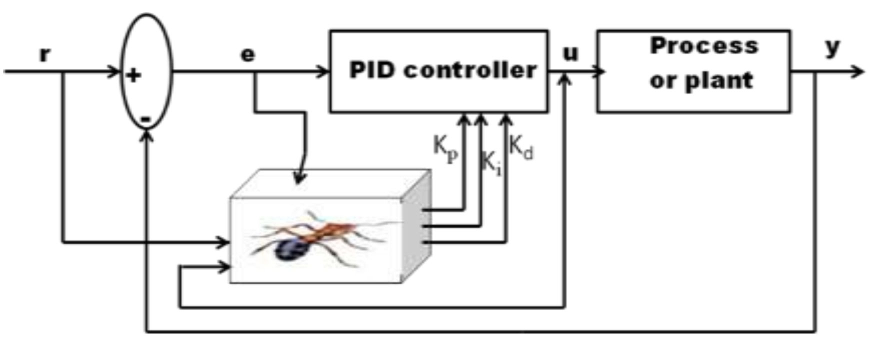

Fig 6: Block diagram of ACO based PID controller

For a designated plant, the gain values of proportional, integral and derivative units of controller are generated with the help of multi objective ACO algorithm. A matrix is of order 100 * 3 labelled as population, where the ant select the finest parameters of PID unit by minimizing the objective function L^A. Each parameter of K_p, K_i, and $K_d$units is coded by 100 numbers (nodes) respectively. As a result, one particular node only denotes the optimalanswer of the parameters. A simple step is to pick the optimization conditions that are used to estimate fitness values.The transient response indexes performancepool into singleindependent function poised of the weighted sum of objectives.

L^A=*min* (*Φ*F) ...(11)

Where F and Φ stands for fitness function, non-negative weights.

Routinely there is not a single best solution being better than the remainderwith respect to each individual objective.

Consequently, we lookfor the "Pareto front" which affords a set of answers which are better than remainder results. Among all possible solutions, a non-dominated solution is a solution that belongs to Pareto front and the remainder solutions are termed as dominated ones.

The ACO algorithm depends on pheromone matrix τ= {τ_{ij}} to build the proper solutions. The preliminary values of τ are

Usually$\tau_{ij} = \tau_0$, where $\tau_0 > 0$

The probability $P_{ij}^{A}(t)$ of taking a node *j*at node *i*which is definedby equation (12).

Starting at source node, the ant constructs a complete solution from above mentioned equation at eachgeneration stage of the algorithm.

$$P_{ij}^{A}(t) = \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{ij \in T^A} [\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}} ; i, j \in T^A \quad \text{... (12)}$$

Where $\eta_{ij} = \frac{1}{kj}, j = [p, i, d]$ characterizes the heuristic function. α and β are coefficients that determine the relative influence of the pheromone and the heuristic values on the decision part of an ant. The path effectuated by the ant A at a given time denoted as T^A.On each path,the quantity of pheromone $\Delta\tau_{ij}$may be defined as

$$\Delta\tau_{ij}^{A} = \begin{cases} \frac{L^{\min}}{L^A} & i, j \in T^A \\ 0 & else \end{cases} \quad \text{... (13)}$$

Where L^Abe the value of the objective function obtained by the ant A. L^{min}be the optimum solution carried out by the set of ants until the current iteration. Pheromone evaporation is a way to avoid unlimited upsurge of pheromone trails as well as it also allows the obliviousness of the bad selections.

$$\tau_{ij}(t) = \rho\tau_{ij}(t-1) + \sum_{A=1}^{NA} \Delta\tau_{ij}^{A}(t) \quad \text{... (14)}$$

Where *NA* = number of ants.

ACO Algorithm steps:

i. Initialize arbitrarilypossible solutions of the parameters K_p, K_i, and K_d by uniform distribution. Initialize the Pareto set to an empty set and also initialize the pheromone trail and heuristic values.

ii. Place the A^{th} ant on the node. Work out the heuristic value associated on the objective function L^A (minimize the error). Choose the successive node with probability:

$$P_{ij}^{A}(t) = \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{ij \in T^A} [\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}};\, i, j \in T^A$$

Where $\eta_{ij} = \frac{1}{kj}, j = [p, i, d]$ denotes the heuristic function. T^A is the path effectuated by the ant A at a given point of time.

iii. Use pheromone evaporation given by the equation

$$\tau_{ij}(t) = \rho\tau_{ij}(t-1) + \sum_{A=1}^{NA} \Delta\tau_{ij}^{A}(t)$$

to avoid unlimited increase ofPheromones trail and allow the obliviousness of bad selections.

iv. Evaluate the attained solutions according to the objectives.Update the Pareto archive with the non-dominated ones and if necessary reduce the size of the archive.

v. Optimum values of the parameters K_p, K_i, and $K_d$to be displayed.

vi. Generally, update the pheromone, according to the optimized parameters calculated in previous step. Iterate from step 2 until the maximum of iterations is touched.

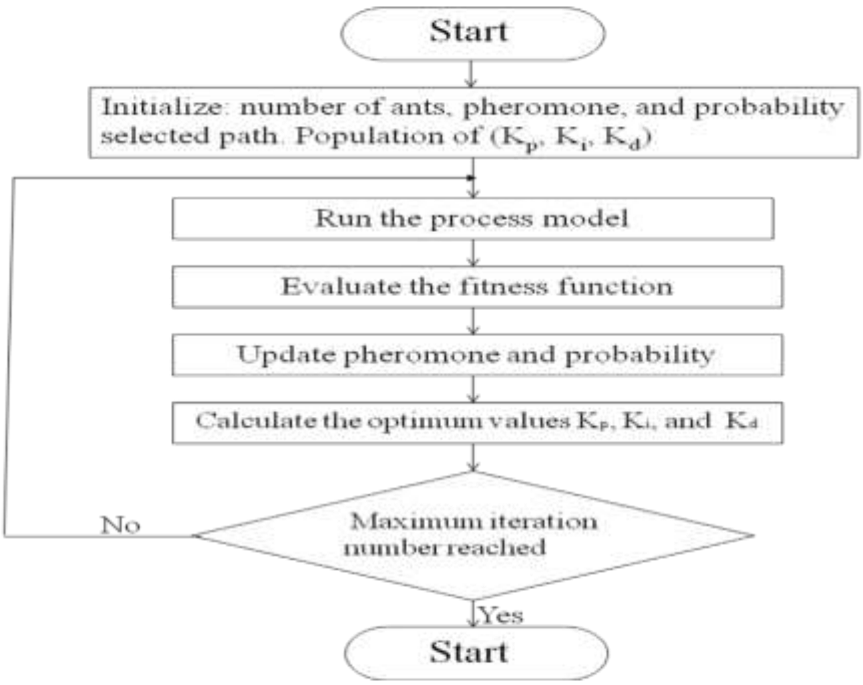

Fig 7: Flow chart of ACO based PID controller

V.SIMULATION RESULTS

The work carried out here is about the employment of following different PID controller tuning practices for AVR model. Fig 8. Shows step response of AVR system model without controller that exhibits oscillations as well as it took more time to settle down. To achieve stable output PID controller is amended.

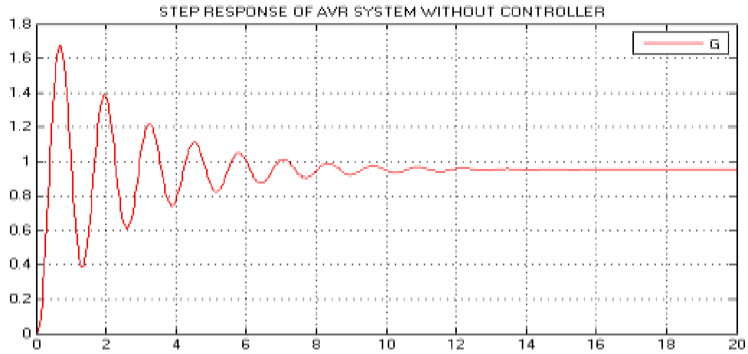

Fig 8: Step response of an AVR system without controller

i). Ziegler– Nichols method: The constraints of proposed PID controller for an AVR system are evaluated with conventional technique Ziegler– Nichols method. The parameters of ZN method are, ultimate gain K_u=1.6485, ultimate period of oscillations P_u=6.16,T_i=3.08 T_d=0.77. The gains of the PID controller are determined using Z-N tuning rules table shown in Table II. For the AVR system, the values of K_p, $K_i$and K_d are 0.9697, 0.3148& 0.746 respectively. Fig 9 shows the output of an AVR system for step input with Z-N tuned PID controller as well as error minimization response shown in fig 10.

Table II: Ziegler-Nichols Tuning Rules

Controller	K_p	T_i	T_d
P	$K_u/2$	∞	0
PI	$K_u/2.2$	$P_u/1.2$	0
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

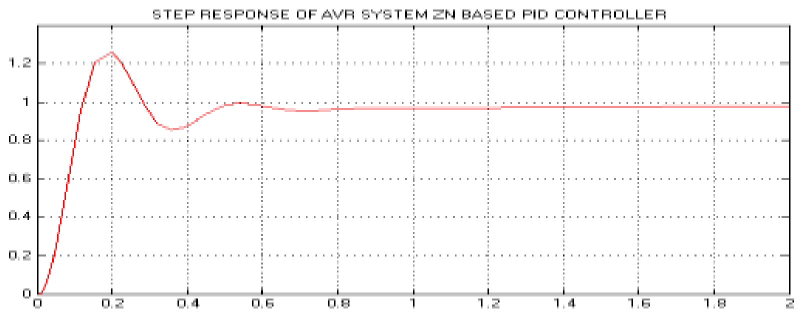

Fig 9: Step response of AVR system with ZN method based PID controller

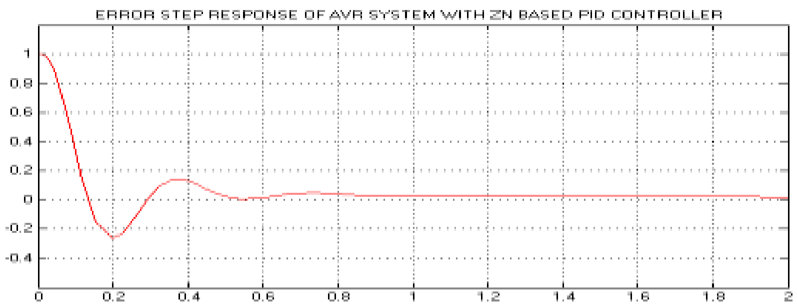

Fig 10: Error minimization response of AVR system with ZN based controller

Step response of an AVR system model with Z-N based PID controller is under damped as well as settling time also large. Consequently, requires tuning of PID controller's parameters by optimization method.Fig 8. Shows step response of AVR system model without controller that exhibits oscillations as well as it took more time to settle down. To achieve stable output PID controller is amended.

ii).Genetic Algorithm: The gains of PID controller for the proposed model calculatedwith Genetic Algorithm methodology. The parameters of GA , population size=100, Max iterations=100,Tournament selection, Arithmetic Crossover with probability =0.5,Uniform mutation with probability =0.02.The gain values of PID controller unit for the AVR system respectively are K_p=0.578, K_i=0.351 and K_d=0.264. Fig 11 shows the output of an AVR system for step input with GA tuned PID controller as well as error minimization response shown in fig 12.

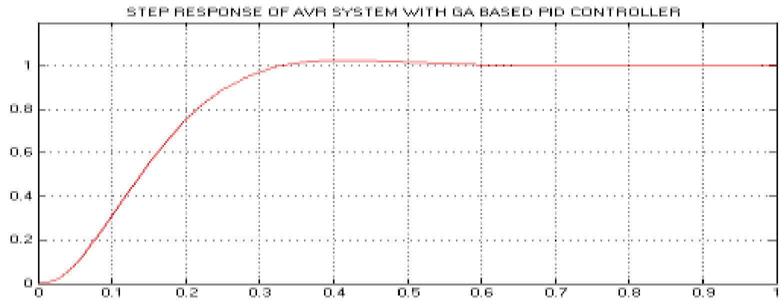

Fig 11: AVR system response for a step unit with GA based PID controller

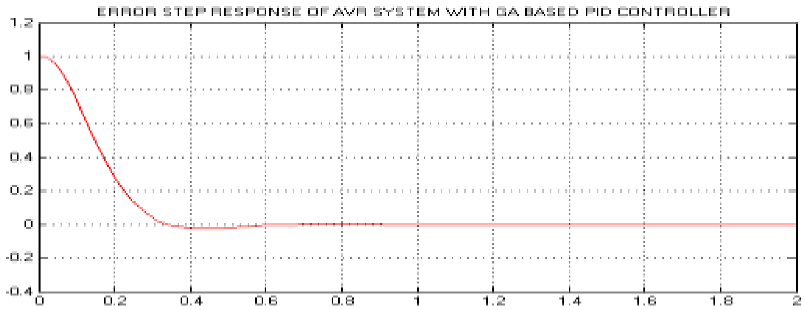

Fig 12: Error minimization response of an AVR with GA based PID controller

The output of an AVR system model with GA based PID controller for step unit is somehow without any overshoots, good rise time and settling time is not that as much as minimum. Further, tune the Controller parameters by Ant Colony Optimization method.

iii).Ant Colony Optimization

The gains of the proposed controller are evaluated and optimized by Ant Colony Optimization algorithm for an Automatic Voltage Regulator(AVR) system withnumbers of ants m=100 , α = 0.5, β = 0.5, ρ = 0.5, and maximum generation = 100. In Matlab/Simulink environment the results are carried out. The response of AVR system with GA based tuned PID controller, error minimization response for a step unit are shown in Fig. 13 and 14. Fig. 15 shows the comparison of responses of proposed system with GA and ACO based tuned PID controllers. Fig. 16 and 17 shows the comparison of step responses and error signal minimization responses of three controllers such as Z-N method, GA method and ACO based PID controllerof proposed system.

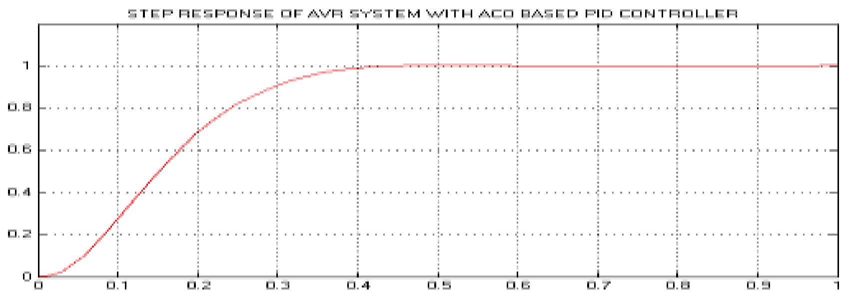

Fig 13: Step response of AVR system with ACO based PID controller

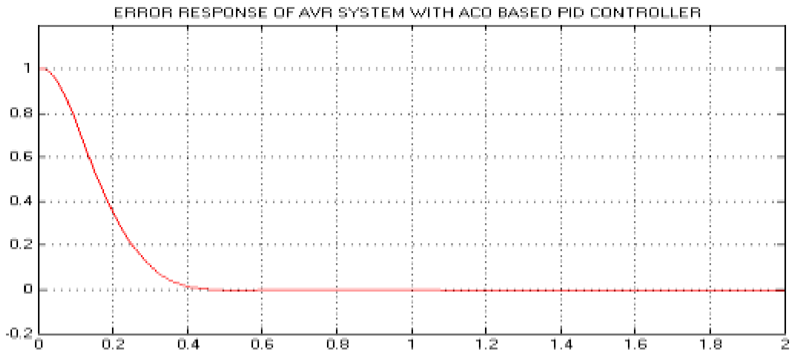

Fig 14: Error response of AVR system with ACO based PID controller

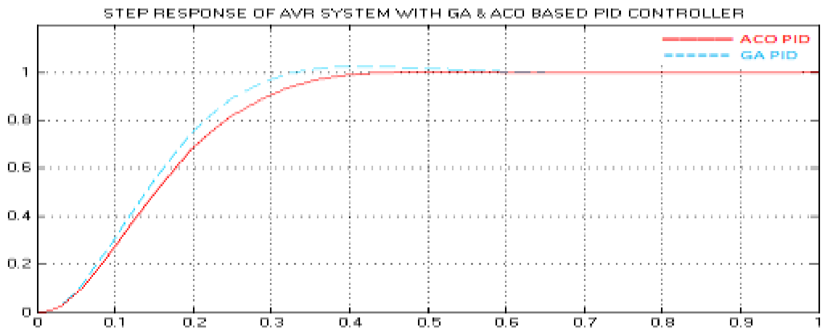

Fig 15: Step response of AVR system with GA & ACO based PID controller

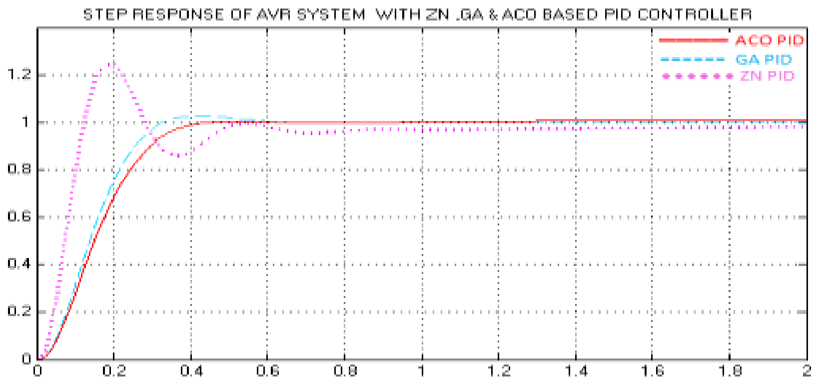

Fig 16: Step response of AVR system with ZN, GA & ACO based PID controller

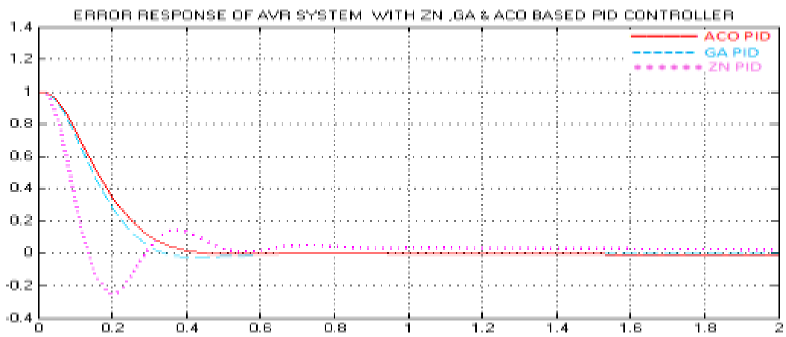

Fig 16: Error response of AVR system with ZN, GA & ACO based PID controller

Table III: PID parameters using ZN, GA & ACO

	K_p	K_i	K_d
ZN	0.9697	0.3148	0.7466

GA	0.578	0.351	0.264
ACO	0.4974	0.3179	0.2341

Table IV: Time domain specifications of AVR system using ZN, GA & ACO- PID controller

	t_d	t_r	t_p	M_p	t_s
AVR system	0.3	0.38	0.7	0.7	20(∞)
ZN	0.078	0.141	0.205	0.25	5
GA	0.15	0.265	0.39	0.03	0.64
ACO	0.17	0.312	0.42	0	0.46

PID controllers' gains for different techniques tabulated in Table III and time domain specification also tabulated in Table IV. The performance of ACO tuned parameters of a controller for AVR system is better in comparison with Z-N, GA based controllers as well as zero over shoot, good rise, peak times and also desirable settling time.

VI. CONCLUSIONS

In this exertion, the optimal PID control approach is established on the multi-objectiveAnt Colony Optimization in order to achieve enhanced performance of AVR system in additionto optimummodified PID constraints / parameters. The ultimatepurpose of multi-objective ACOstandson the way to provide the feasible results to optimal control problems also to recognize the Pareto optimumresult. Simulation results of AVR system validates that the control approachestablished on the multi-objective ACOthat improvesthe overall betterment in control system performance when compared with conventional approaches. Development of a new optimization approaches based control strategy by using Artificial intelligence is future work.

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