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Optimal Tuning of PID Controller for Automatic Voltage Regulator System Using Dragonfly Algorithm

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ABSTRACT: This paper presents an evolutionary computation-based approach for optimal tuning of Proportional–Integral–Derivative (PID) controller parameters in an Automatic Voltage Regulator (AVR) system using the Dragonfly Algorithm (DFA). The primary objective is to enhance the dynamic performance of the AVR system by improving transient response characteristics, minimizing overshoot and settling time, and reducing steady-state error. The proposed GA-based optimization technique is employed to determine the optimal PID controller gains, namely proportional gain (Kp), integral gain (K), and derivative gain (Kd). The performance of the proposed controller is evaluated using standard time-domain response characteristics and compared with the conventional Ziegler–Nichols (Z-N) tuning method. The results demonstrate the potential of the DFA-based PID controller to provide improved dynamic response and enhanced voltage regulation performance compared with conventional Z-N tuning. Thus, the proposed approach offers an effective optimization strategy for improving the stability and transient performance of AVR systems.

INDEX TERMS— Automatic Voltage Regulator (AVR), Dragonfly Algorithm (DFA), Proportional–Integral–Derivative (PID) Controller, Optimal Controller Tuning, Ziegler–Nichols (Z-N) Method, Evolutionary Optimization

I. INTRODUCTION

The main objective of an Automatic Voltage Regulator (AVR) system is to maintain the terminal voltage of a synchronous generator at a desired reference value under varying load conditions. The AVR plays an important role in maintaining voltage stability and improving the overall security and reliability of the power system.

However, the conventional AVR system may exhibit oscillatory behaviour, excessive overshoot, and prolonged settling time in its open-loop or uncompensated step response, thereby affecting its dynamic performance.

To overcome these limitations, an appropriate control technique is required to improve the transient and steady-state response of the AVR system. Among various control strategies, the Proportional–Integral–Derivative (PID) controller is widely employed because of its simple structure, ease of implementation, and effective control performance. In a conventional AVR configuration, the PID controller is incorporated into the feedback control loop to regulate the excitation system and maintain the generator terminal voltage at the desired level.

Several conventional PID tuning techniques have been developed to obtain suitable controller parameters. The most commonly used methods include the Ziegler–Nichols, Cohen–Coon, and Åström–Hägglund methods. However, conventional tuning techniques may not provide satisfactory performance for all operating conditions and system parameter variations. Therefore, optimization-based tuning techniques have gained considerable attention for determining optimal PID controller parameters.

In recent years, intelligent optimization algorithms inspired by natural evolutionary processes have been widely applied to control system design. The Dragonfly Algorithm (DFA) is one such evolutionary optimization technique based on the principles of natural selection, reproduction, crossover, and mutation. It provides an effective search mechanism for finding optimal solutions in complex optimization problems.

In this paper, a DFA-based optimization approach is proposed for determining the optimal proportional gain (Kp), integral gain (Ki), and derivative gain (Kd) of a PID controller for a conventional Automatic Voltage Regulator system.

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The optimization process aims to improve the dynamic response of the AVR system by minimizing transient performance indices and enhancing voltage regulation. The performance of the proposed DFA-based PID controller is evaluated and compared with that of the conventional Ziegler–Nichols tuning method using MATLAB simulation.

II.MODEL OF AVR SYSTEM

The role of Automatic voltage regulator (AVR) of the synchronous generator is to provide stable electrical power service with high efficiency and good dynamic response. A simple AVR consist of amplifier, exciter, generator and sensor. The block diagram of AVR with PID controller is shown in Figure 1. Previously, the analog PID controller is generally used for the AVR. Because, of its simplicity and economic. However, the tuning of PID parameter is not easy. This paper proposed a method to search these parameters by using a Dragonfly algorithm. The AVR system model is controlled by PID controller can be expressed in Fig.1. Where V_t is the output voltage of the system, V_e is the error voltage between the V_s and reference input voltage $V_{ref(s)}$, V_r is an amplify voltage by amplifier model, V_F is the output voltage by exciter model, and Vt is the output voltage of synchronous generator. There are five components: (a) PID controller model, (b) Amplifier model, (c) Exciter model, (d) Generator model, and (e) Sensor model.

The range of parameters limit and used parameter in this paper is shown in Table 1.

Table 1: Range of AVR Parameters

Block	Parameters Range	Used Parameter
Amplifier	$10 \le K_a \le 40$	$K_a = 10$
Exciter	$1 \le K_e \le 10$ $0.4 \le \tau_e \le 1$	$K_e = 1, \tau_e = 0.4$
Generator	K_g depend on load,(0.7-1), $1 \le \tau_g \le 2$	$K_g = 1, \tau_g = 1$
Sensor	$0.001 \le \tau_s \le 0.01$	$K_s = 1, \tau_s = 0.05$

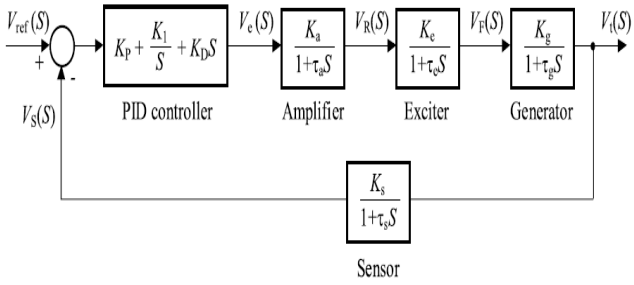


Fig.1: Block Diagram of AVR System with PID Controller.

In this paper, DFA is applied to search a best PID parameters so that the controlled system has good dynamic control performance. Fig.2 Shows the DFA based PID controller with AVR system.

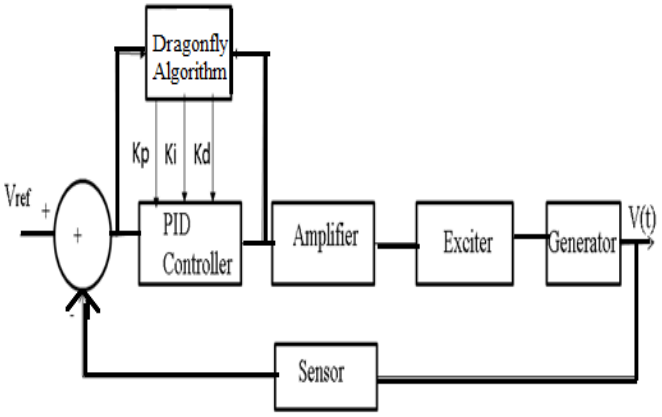


Fig.2: The Block diagram of GA based PID controller.

III DRAGONFLY ALGORITHM:

The Dragonfly Algorithm (DFA) is a nature-inspired metaheuristic optimization algorithm. It is based on the collective behavior of dragonflies during hunting and migration. The algorithm is used to find the optimum solution to complex engineering and mathematical optimization problems.

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The algorithm mathematically represents five basic behavioral characteristics.

(1) Separation (S):

Separation prevents dragonflies from colliding with neighbouring individuals.

It is calculated as:

$$S_i = -\sum_{j=1}^{N}(X_i - X_j) \text{----------(1)}$$

Where:
X_i = Position of the current dragonfly
X_j = Position of neighbouring dragonfly
N = Number of neighbouring dragonflies

(2) Alignment(A):

Alignment represents the matching of flight velocity with neighbouring dragonflies

$$A_i = \frac{\sum_{j=1}^{N} V_j}{N} - - - - - - - - - - - - - (2)$$

Where:
V_j = Velocity of neighbouring dragonfly
N = Number of neighbours

(3) Cohesion (C):

Cohesion represents the tendency of dragonflies to move towards the Centre of neighbouring individuals.

$$C_i = \frac{1}{N}\sum_{j=1}^{N} X_j - X_i - - - - - - - - (3)$$

(4)Food Attraction (F):

Dragonflies move towards the food source, which represents the best solution found so far.

$$F_i = X^+ - X_i - - - - - - - - - - - (4)$$

Where:
X^+ = Position of the food source
X_i = Current position

(5) Enemy Distraction (E):

Dragonflies move away from enemies to avoid dangerous regions.

$$E_i = X_i - X^- - - - - - - - - (5)$$

Where:
X^- = Position of enemy

X_i = Current Position

The algorithm follows these steps:

a) **Initialize population:** Generate a group of dragonflies with random positions.
b) **Initialize parameters:** Assign separation, alignment, cohesion, food, enemy and inertia wights.
c) **Calculate fitness:** Evaluate the objective function for every dragonfly.
d) **Find best solution:** Select the dragonfly with best fitness as the food source.
e) **Find worst solution:** Select the dragonfly with the worst fitness as the enemy.
f) **Calculate behaviour:** Determine the five behavioural factors.
g) **Update movement:** Calculate the new step vector.
h) **Update position:** Calculate the new position of each dragonfly.
i) **Check constraints:** Ensure all parameters remain within specified limits.
j) **Repeat:** Continue until the maximum number of iterations is reached.
k) **Obtain result:** Return the best solution and its fitness value.

IV.DFA BASED TUNING OF PID CONTROLLER

The main objective of this work is to use the DF algorithm in order to obtain best PID controller settings for AVR, which is non-linear in nature and to minimize the error between the reference voltage and actual generator terminal voltage.

$$e(t) = V_{ref}(t) - V_t(t) - - - - - - - - - - - - (6)$$

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For AVR optimization, the Integral of Time multiplied by Absolute Error (ITAE) is a suitable objective function

$$ITAE = \int_0^{T_{sim}} t|e(t)|dt \quad ----------(7)$$

A lower ITAE indicates that the controller reduces persistent voltage error more effectively. However, minimizing ITAE alone does not always guarantee minimum overshoot or a stable control of every operating condition.

$$J = \omega_1 ITAE + \omega_2 M_p + \omega_3 T_s + \omega_4 E_{ss} \quad --------(8)$$

Where:

M_P = Peak overshoot
Ts = Settling time
Ess = Steady -state error

$\omega_1, \omega_2, \omega_3$ and ω_4 = Weighting coefficients,

The weights should be selected based on the design priorities and normalization of the individual.

V.RESULT AND DISCUSSION

The closed loop transfer function of AVR system without PID controller is given in Equation and step response of system is shown in Figure 3.

$$G(s) = \frac{0.5s + 10}{0.002s^4 + 0.067s^3 + .615s^2 + 1.55s + 11} \quad --------(9)$$

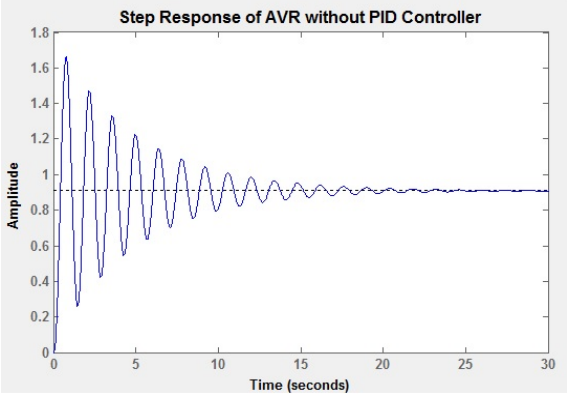


Fig.3: Step Response of AVR System without PID Controller

The transfer function of AVR system with PID using Ziegler-Nichols (Z-N) tuning method is shown in Equation and step response of AVR system using Ziegler-Nichol's tuning is shown in Figure.4.

$$G(s) = \frac{5s^2 + 8s + 8.66}{0.002s^5 + 0.067s^4 + 0.615s^3 + 6.55s^2 + 9s + 8.66} \quad --------(10)$$

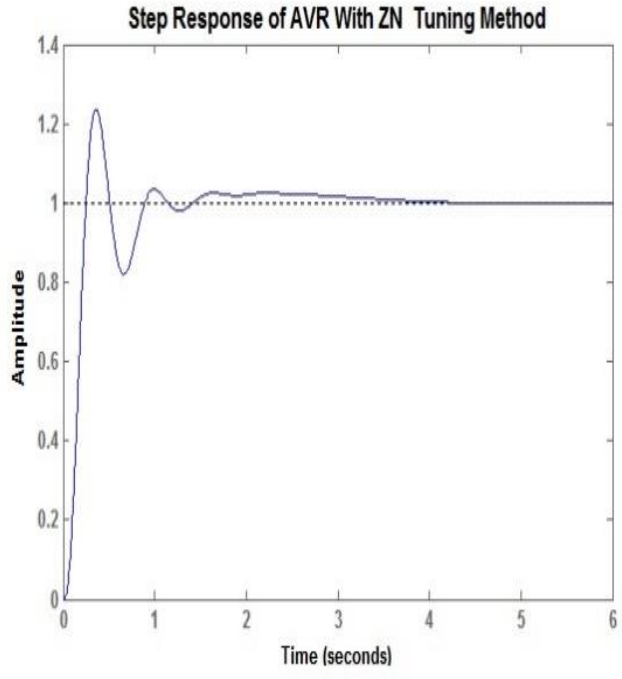


Fig.4: Step response of AVR system with PID controller using Ziegler-Nichols Tuning Method

The transfer function of AVR system with PID - DFA method is shown in Equation (11) and step response of AVR system using PID-DFA method is shown in Figure.5

$$G(s) = \frac{2.18s^2 + 6.95s + 8.46}{0.002s^5 + 0.067s^4 + 0.615s^3 + 3.71s^2 + 7.93s + 8.45} \quad --------(11)$$

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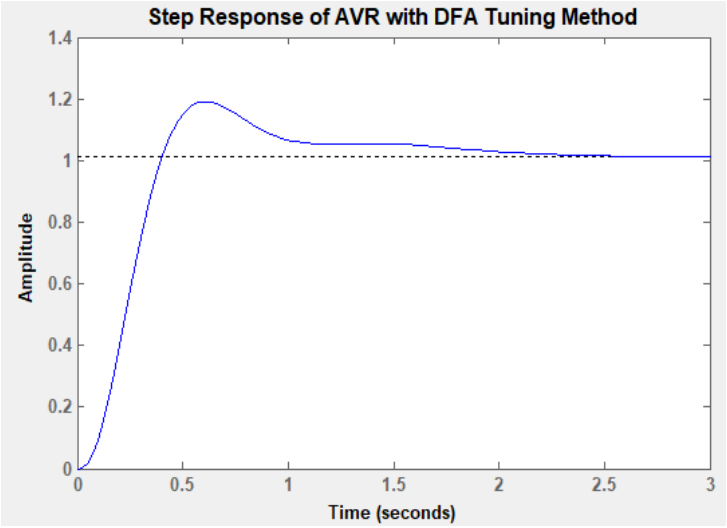


Fig.5: Step response of AVR system with PID controller using DFA tuning method

Simulation results and PID parameters obtained using Z-N , DFA methods are shown in Table 2.

Table 2: PID Parameters and results obtained Z-N & DFA tuning methods

Method/ Parameters	Z-N Tuning Based PID Controller	DFA Based PID Controller
Kp	0.80	0.690
Kd	0.5	0.214
Ki	0.866	0.843
Peak Overshoot Mp(%)	23.70% @0.358 sec	17.6% @0.61 sec
Settling time t_s(sec)	2.73	1.9
Rise time t_r(sec)	0.153	0.257

From the above results, it shows that the tuning PID parameter using DFA technique gives good results than Z-N tuning method.

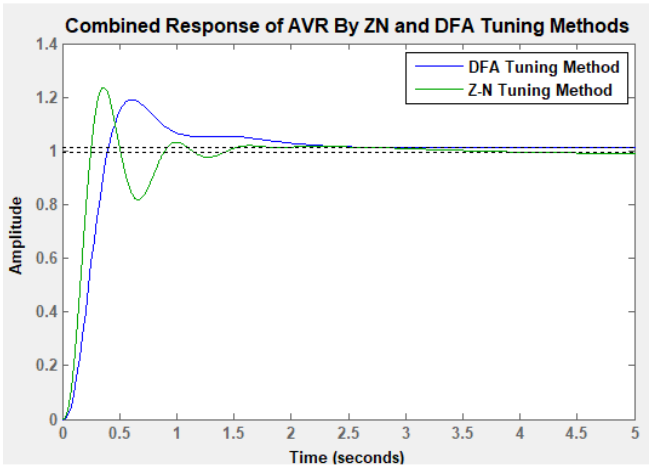


Fig.6: Comparative Analysis of Z-N and DFA tuning method

Conclusion:

Various tuning techniques, such as the conventional Ziegler–Nichols (Z-N) method and Dragonfly Algorithm (DFA), have been proposed for determining the optimal parameters of Proportional–Integral–Derivative (PID) controllers. Although these techniques aim to improve controller performance, their effectiveness varies depending on the system characteristics and optimization criteria. The main objective of this paper is to determine the optimal PID controller parameters using an optimization-based approach and evaluate their performance against conventional tuning techniques.

In this study, two PID tuning methods, namely the Ziegler–Nichols method and the Dragonfly Algorithm-based optimization method, are investigated and compared for a conventional Automatic Voltage Regulator (AVR) system. The DFA-based PID controller is designed to obtain optimal proportional, integral, and derivative gains by minimizing the selected performance index. The simulation results are used to evaluate the effectiveness of both tuning methods in terms of rise time, peak overshoot, settling time, and steady-state error. The proposed DFA-based PID controller is expected to provide improved dynamic performance compared with the conventional Z-N tuning method. The effectiveness of the proposed approach is demonstrated through MATLAB simulation of the AVR system.

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