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Chaotic Differential Evolution Algorithm based PID Controller for Automatic Voltage Regulator system

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Abstract- This paper presents a genetic based method to design a PID controller for Automatic Voltage Regulator system. Many practical problems have objective functions that are non-differentiable, non-continuous, non-linear, noisy, flat, and multi-dimensional or have many local minima, constraints or stochasticity. The proposed algorithm is applied to those fields and the design of PID controller. The result from the algorithm shows the proposed method will able to give better performance and higher speed of convergence. Performance of our proposed algorithm is compared with other famous algorithms and the simulation results clearly indicate that our proposed approach is more efficient and improving the performance of an AVR system.

Index Terms- AVR System, Chaotic DEA, PID Controller, TL Method, ZN Method.

I. Introduction

Automatic voltage regulator plays a vital role in power system in order to regulate the output voltage at a nominal constant voltage level. The main functions of AVR are to detect terminal voltage, compare with the voltage setter and regulate field current via the exciter. The stability of the AVR system is of great concern because it can seriously affect the security of the power system. The excitation system must contribute for the effective voltage control and enhancement of the system stability. It must be able to respond quickly to a disturbance enhancing the transient stability and the small signal stability [1]. The excitation system controls the generated EMF of the generator and therefore controls not only the output voltage but the power factor and current magnitude also. In many of the exciter system is a dc generator supplied to the exciter and the increasing use of solid state devices such as thyristor based excitation systems are also used to give a controlled output voltage to the exciter. The proportional-integral-derivative (PID) controller is the most popular controller, which has been widely used in the industry because of its simple structure, easy implementation and robust performance in a wide range of operating conditions. However, proper tuning of the parameters of PID controllers has been quite difficult because many industrial plants are often hampered with problems such as high order, time delays, and nonlinearities [2]-[4]. The first method used the classical tuning rules proposed by Ziegler and Nichols. But in reality, it is often hard to optimize PID parameters with Ziegler-Nichols method in many industrial plants. So in order to increase the performance of controller several soft computing techniques such as fuzzy logic, neural network, evolutionary computing were used. Fast and accurate controlling is obtained by incorporating soft computing algorithms.

Differential Evolution (DE) is a vector population based stochastic optimization method which has been introduced in 1995 by Storn and Price. Like genetic algorithm (GA), this method is able to optimize objective functions which are function of discrete variables. Differential Evolution (DE) algorithm [5] belongs to Evolutionary Algorithms (EAs) and now-a-days it is considered one of the most powerful tools in EAs. One of the advantages of DE algorithm compared to GA is that this method does not require the transformation of the variables into binary strings. Since 1996 differential evolution has been used in a wide spectrum of scientific problems such as physics [6], computer science, shape optimization, signal processing, control science, traffic control, manufacturing, management and even economics. Fig.1 shows the general diagram of AVR system. In includes Amplifier, exciter, Governor and Sensor.

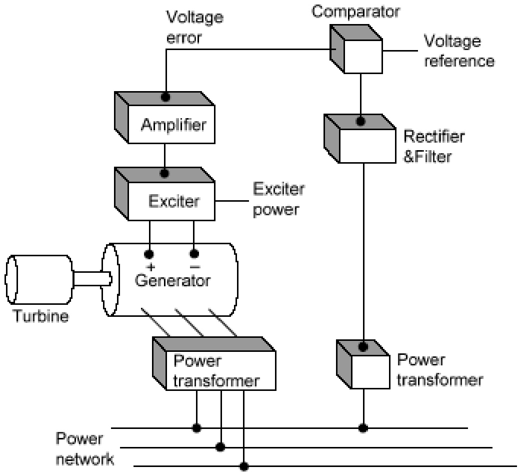

Fig.1 Model of AVR System

II. DESCRIPTION OF THE AVR SYSTEM

The AVR model consists of the amplifier model, exciter model, generator model and the sensor model. An AVR is used to hold the terminal voltage magnitude of a synchronous generator at a specified level. The block diagram of the whole system is given in Figure2. A sensor senses the voltage magnitude and this voltage is compared with a dc set point signal to generate the error signal. A PID controller is used to decrease the error and to get better the dynamic response.

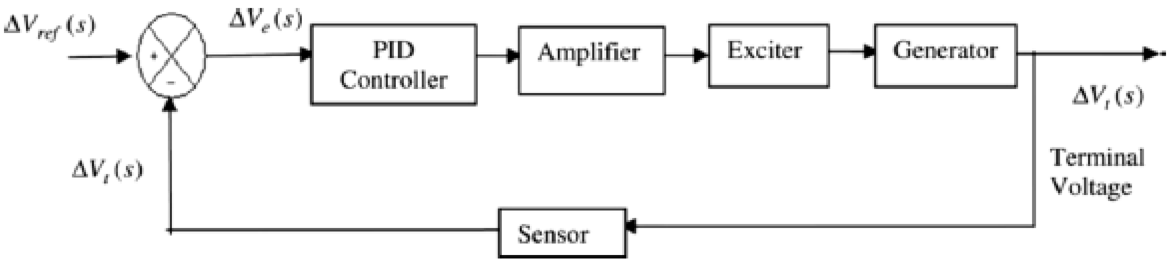

Fig.2 Block diagram of AVR system with PID controller

The PID controller improves the dynamic response of the system and also reduces the steady state error by rearranging the poles and zeros of the closed loop transfer function. The derivative controller adds a finite zero to the open-loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady-state error due to a step function to zero. For mathematical modeling and determining transfer functions of the four components, these components must be linearized, which takes into account the major time constant and ignores the saturation or other nonlinearities. The transfer function of AVR is given by the equation

$$\mathrm{TF} = \frac{(K_D s^2 + K_P s + K_I)(1 + sT_s)(K_a\, K_e\, K_g)}{s(1 + sT_a)(1 + sT_e)\left(1 + sT_g\right)(1 + sT_s) + (K_D s^2 + K_P s + K_I)(K_a\, K_e\, K_g K_s)}$$

Where

K_P -Proportional gain of PID controller, K_I -Integral gain of PID controller, K_D -Derivative gain of PID controller K_a -Amplifier gain, K_e-Exciter gain, K_g-Generator gain, K_s -Sensor gain, T_a -Amplifier time constant, T_e -Exciter time constant, T_g -Generator time constant, T_s -Sensor time constant.

The following table represents the approximate transfer function and parameter limits of amplifier, exciter, generator and sensor. [7]

Model	Transfer Function	Parameter limits	Used parameter value
PID controller	$K_P + \frac{K_I}{s} + K_D s$	$0 \le K_P \le 1$ $0 \le K_I \le 1$ $0 \le K_D \le 1$	K_P, K_I, K_D = optimum values
Amplifier	$\frac{K_a}{1 + sT_a}$	$10 \le K_a \le 400$ $0.02 \le T_a \le 0.1$	$K_a = 10$ $T_a = 0.1$
Exciter	$\frac{K_e}{1 + sT_e}$	$1 \le K_e \le 200$ $0.4 \le T_e \le 1$	$K_e = 1$ $T_e = 0.4$
Generator	$\frac{K_g}{1 + sT_g}$	$0.7 \le K_g \le 1$ $1 \le T_g \le 2$	$K_g = 1$ $T_g = 1$
Sensor	$\frac{K_s}{1 + sT_s}$	$K_s = 1$ $0.01 \le T_s \le 0.06$	$K_s = 1$ $T_s = .01$

Table 1: T/F and parameter limits of AVR system

III. PROPOSED ALGORITHM

Differential Evolution (DE) algorithm is one of the population-based stochastic optimization algorithm. Advantages of DE are: simplicity, efficiency & real coding, easy use, local searching property and speediness. DE works with two populations; old generation and new generation of the same population. The size of the population is adjusted by the parameter *NP*. The optimization process is conducted by means of three main operations: mutation, crossover and selection. In each generation, individuals of the current population become target vectors. For each target vector, the mutation operation produces a mutant vector, by adding the weighted difference between two randomly chosen vectors to a third vector. The crossover operation generates a new vector, called trial vector, by mixing the parameters of the mutant vector with those of the target vector. If the trial vector obtains a better fitness value than the target vector, then the trial vector replaces the target vector in the next generation.

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A) Objective function:

The problem of PID controller parameter selection is formulated as an optimization problem, the objective function of which is given by

$$\mathrm{MinF}(K_P, K_I, K_D) = \left(1 - e^{-\beta}\right)(M_P + E_{ss}) + e^{-\beta}(t_s - t_r)$$

The above optimization problem is subjected to the following constraints

$$K_P^{min} \le K_P \le K_P^{max}$$

$$K_I^{min} \le K_I \le K_I^{max}$$

$$K_D^{min} \le K_D \le K_D^{max}$$

B) Bound value of PID controller:

The individuals initialized by randomly choosing values from a uniform distribution having lower bound and upper bound of the values of the parameters. The range of the parameter values is given below.

Controller Parameters	Min.Value	Max.Value
K_P	0	1.5
K_I	0	1
K_D	0	1

Table 2: Bound Value

C) Parameters of DE, JDE and CDE:

The following table gives the various parameter values of algorithms.

DE	JDE	CDE
G_{max} =100 NP =20 F=0.6 CR=0.9	G_{max} =100 NP =20 F_L=0.1 F_U=0.2 T_1=0.1 T_2=0.1 CR=0.7867 F= 0.6242	G_{max} =100 NP =20 μ=4 CR= 0.9703 F= 0.7935

Table 3: Parameters of Algorithm

D) K_P, K_I, K_D of PID controller:

The tuning of a PID controller is mainly based on the proper selection of Proportional, Integral and derivative gain values. The following table shows these values.

Parameters / Methods	K_P	K_I	K_D
Without controller	0	0	0
ZN	0.4673	0.8801	0.0620
MZN (No OS)	0.1589	0.2992	0.0843
MZN(OS)	0.2621	0.4938	0.0928
TL	0.3575	0.1530	0.0602
DE	0.3807	0.2779	0.1220
JDE	0.5813	0.3788	0.1846
CDE	0.5716	0.4748	0.2028

Table 4: Values of K_P, K_I, K_D

IV. SIMULATION RESULTS

The simulation of AVR with PID controller was done by MATLAB R2012a. It is a powerful tool to analyze the model of various parts of the plant.

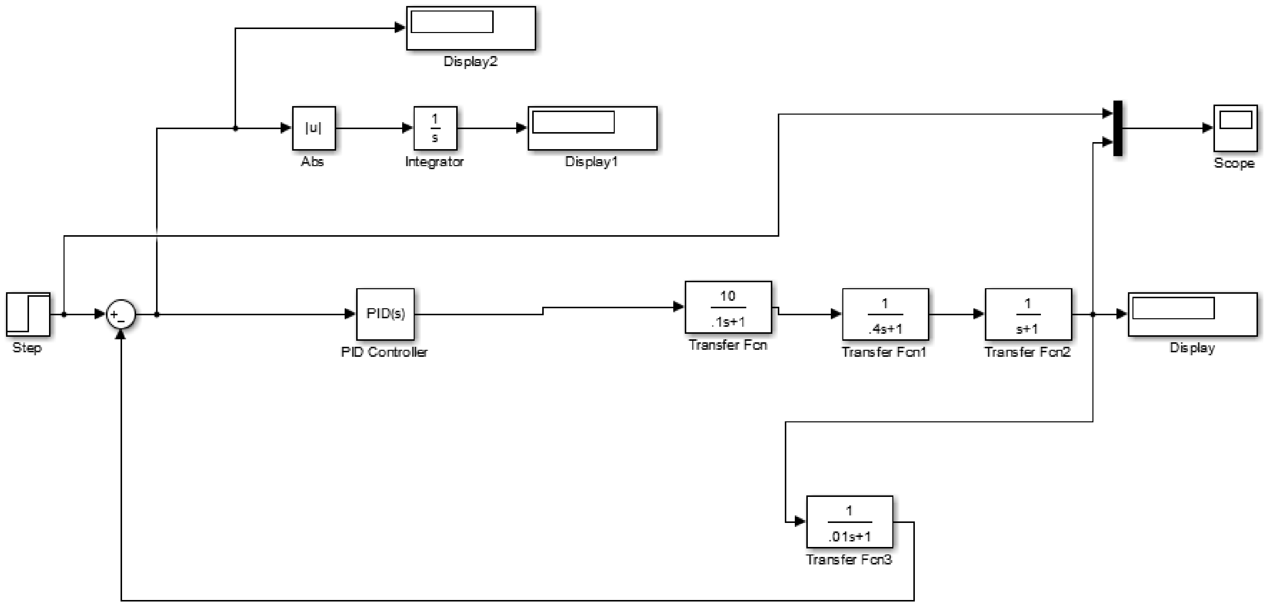

Fig.3 Simulink model of AVR with PID controller

The results obtained from the simulation shown in Fig.4 and Fig.5. It is observed that the response of AVR system is better by introducing CDE optimization technique. Fig.6 clearly shows the plant steady state response with CDE algorithm.

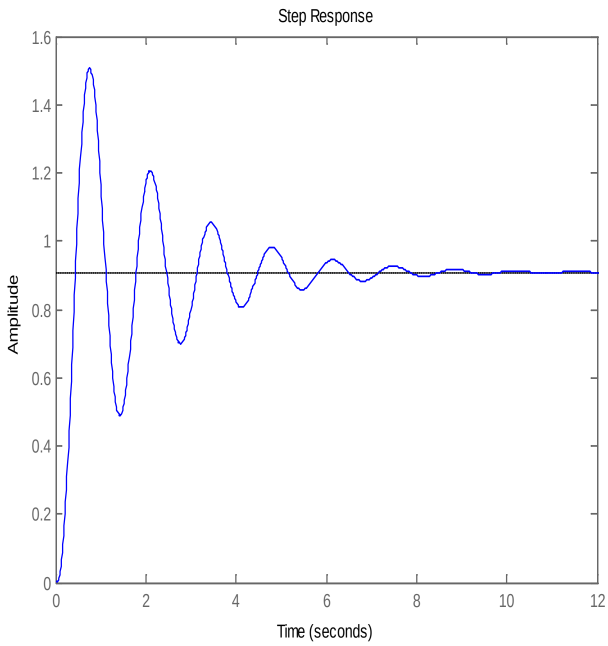

Fig.4 Plant response without controller

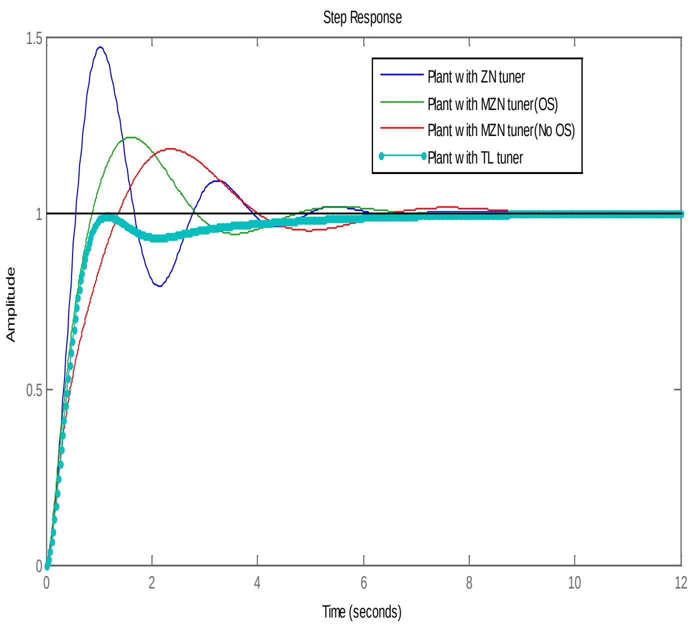

Fig.5 Plant response with conventional tuning

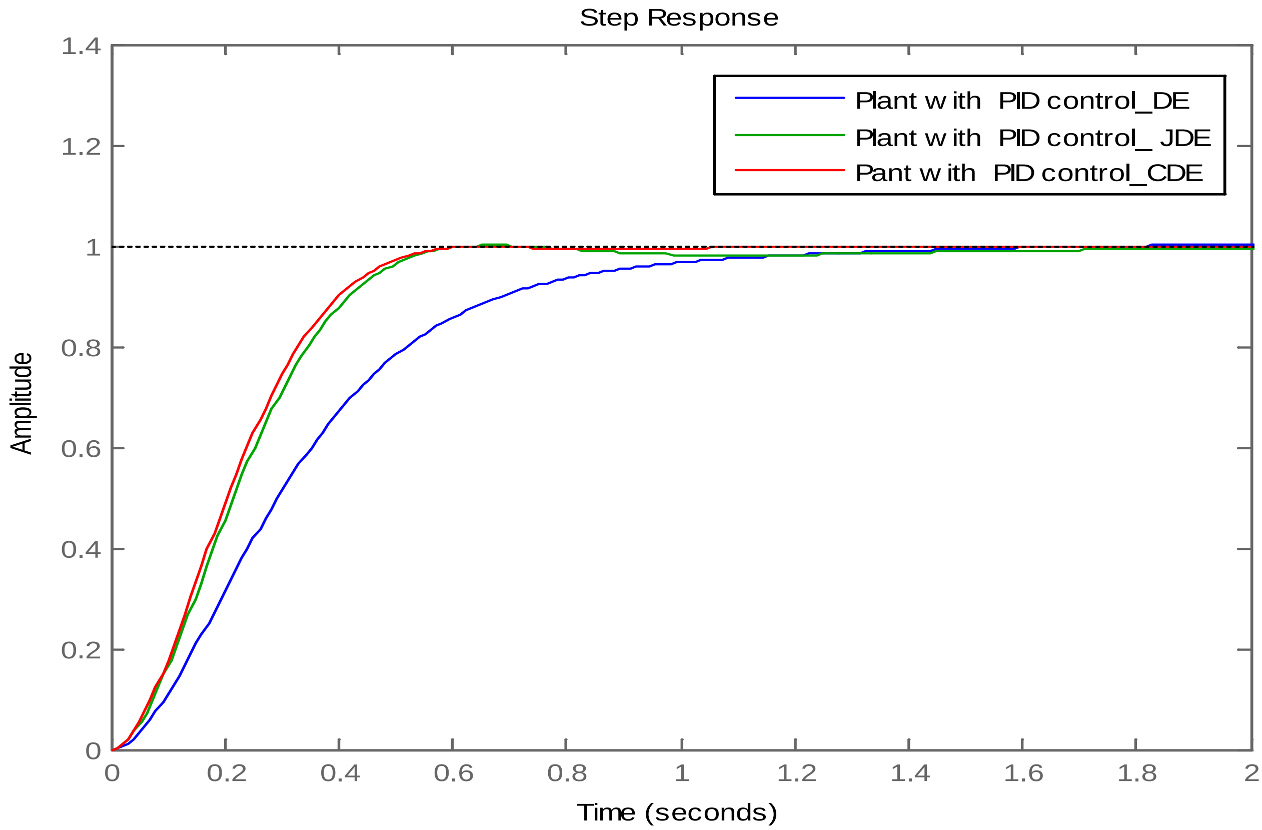

Fig.6 Plant response using optimization algorithm

The values of rise time, settling time and maximum peak overshoot are tabulated. From the table 5 it is understood that with CDE algorithm the maximum peak overshoot is reduced to zero.

Measured value / Methods	t_r(s)	t_s(s)	M_P (%)	Peak value
Without controller	0.2608	6.9865	65.7149	1.5065
ZN	0.3890	4.7526	46.9002	1.4690
MZN (No OS)	1.0116	6.0492	18.0335	1.1803
MZN(OS)	0.6215	4.4462	21.4856	1.2149
TL	0.6477	5.0695	0	0.9997
DE	0.5917	1.1766	0.1943	1.0019
JDE	0.3437	0.5345	0.0431	1.0004
CDE	**0.3291**	**0.5200**	**0**	**0.9977**

Table 5: Rise time, Settling time and Peak overshoot

V. CONCLUSION

This article represents an efficient algorithm used to determine the parameters of PID controller for AVR system. The aim was to improve the control performance using a genetic algorithm for PID controller tuning. The tuning new controller parameters using genetic algorithm was succeeding very good results. The performance of the algorithm in obtaining the optimal values of PID controller parameters under various operating conditions has been analyzed through computer simulation The result obtained from the simulation shows the proposed algorithm gives better performance than the conventional tuning methods.

APPENDIX

Appendixes, if needed, appear before the acknowledgment.

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