Hybrid Differential Algorithm of Linear and Non-Linear Systems for PID Controller Optimization

Dr B Mouli Chandra,
Professor and HoD, Department of EEE, QIS College of Engineering and Technology, Ongole
email:bmoulichandra@gmail.com
Dr B Venkata Prasanth,
Professor in EEE, QIS College of Engineering and Technology, Ongole, email:
bvenkataprasanth@gmail.com
Dr P. Lakshmi Narayana,
Associate Professor, Dept. of EEE, Vignan University, Guntur India email:
p.lakshminarayanaeee@gmail.com
N. Nagaraju,
Department of EEE, QIS College of Engineering and Technology, Ongole

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Abstract
This paper presents the implementation of HDE algorithm for PID controller tuning for automatic voltage regulator systems so that more expeditious settling to rated voltage is ascertained and AVR is closed loop system compensated with a PID controller. In this paper two AVR examples are considered. In one plant saturation non-linearity is neglected and second plant saturation non-linearity is considered. Hybrid Differential algorithm is habituated to tune the parameters of PID controller, to procure optimal solution. Optimal control parameters (proportional gain, integral gain, derivative gain) are obtained by minimizing the objective function ITAE (integral time absolute error). Simulations are done to show the performance of PID controlled AVR system tuned utilizing z-n method and differential evolutions are utilized.

Keywords:- PID, saturation non-linearity, Hybrid differential Algorithm, AVR System.

I. INTRODUCTION

The AVR system is a closed loop control system compensated with a PID or PSS controller. Power system stabilizer (PSS) has two drawbacks one is six tuning parameters and high gain is required, so PID controller utilized because three tuning parameters and low gain is required. The AVR is a component of synchronous machine. The AVR maintains the generator terminal voltage level under mundane operating conditions at different load levels. Automatic voltage regulator is mainly used where the supply voltage fluting and supply voltage not stable. The engenderer excitation system maintains engenderer voltage as required and controls the reactive power flow utilizing AVR. AVR consists of amplifier, sensor, exciter, and engenderer. Amplifier may be magnetic, rotating, or electronic and electronic amplifier is characterized by a gain may withal include a time constant as shown in fig1. The engenderer exaltation system maintains engenderer voltage constant and regulates supply line voltage. Sensor senses the output voltage and feedback to input. Any ac component present output voltage is rectified by sensor. Among conventional PID tuning methods Ziegler-Nichols[2] is most popular method however, this may engender immensely colossal overshoot. Soft computing technique has been proposed to find the optimal control parameters. Rudimentary differential evolution optimization Technique proposed by storn and prince. DE is a puissant soft computing technique simple evolutionary algorithm for optimization of authentic valued, multi modal functions. DE is generally considered as reliable, precise and robust optimization technique. In general the advantages of de are 1. Able to locate the precise ecumenical optimum irrespective of the initial parameter values 2. Has rapid convergence 3. Utilize few control parameters thus facile and simple to utilize. 4. Efficacious in non linear constraint optimization quandaries with penalty functions. 5. Efficient algorithm without matrix multiplication. 6. Parallel operating nature. 7. Facility to find the non differential able, strepitous and time dependent functions.

Now a day's computing techniques play paramount role for tuning PID controller. For tuning PID controller there are so many techniques example fuzzy logic[6],[17], chaotic ant swarm (cas), chaotic optimization [12], artificial bee colony (abc)[10],[11], fruit fly optimization algorithm[15] genetic algorithms[16],[20], Particle swam optimization (PSO)[5],[8],[19], differential evolutions[3] and other methods[9],[18]. Other then soft computing techniques one heuristic method is Ziegler-Nichols method. In PSO we engender the particles and velocities, velocities are integrated to particles to we get incipient position of particles. In differential evolution we engender the three desultory vectors, and weighted differences of two vectors are integrated to the third vector. Differential evolution is iteration sensitive. The DE algorithm withal utilizes a uniform crossover that can take child vector parameter from one parent more often than it does from others. It have feature of parallel operating nature.

In PID controller incrementing proportional gain rise time and study state error decreases, peak overshoot and settling time increase and stability degraded. Incrementing integral gain rise time and study state error decrease, overshoot and settling time increase, stability degraded. Incrementing derivative gain rise time, overshoot and settling time decreases and integral operation, so that integral operation have more expeditious settling feature, but the integral operation gives peak overshoot, this drawbacks overcome by derivative action. PID controller is better Using above table mentioned nominal parameters of plants. The closed loop transfer function for automatic voltage regulation system is shown below.

than individual of PID controllers like P, PI, PD controllers. Because of PID controller have better performance than individual of PID controllers.

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{0.1s + 10}{0.0004s^4 + 0.0454s^3 + 0.555s^2 + 1.51s + 11}$$

After the introduction, modeling of AVR system in section II, plant specifications in section III, controller design and, Ziegler-Nichols method differential evolution are explained in section IV, simulation results in section V, conclusion in section VI.

II. MODELING OF AN AVR SYSTEM [13], [14]

A simple AVR system contains four main components, namely amplifier, exciter, generator [7], and sensor. For mathematical modeling and transfer function of the four components, these components must be linearized, which takes into account the major time constant and ignores (the saturation in plant1 and considered in plant2 or) other nonlinearities. The transfer function model of each component consists of a gain and a time constant and is given as

PLANTS SPECIFICATIONS [1] ,[4]

Table.1

Model Transfer function	Parameters Limits	PLANT-1 Parameters Nominal values	PLANT-2 Parameters Nominal Values
Amplifier $\frac{K_A}{sT_A+1}$	$10 \le K_A \le 40$ $0.02 \le T_A \le 0.1$	$K_A=10$ $T_A=0.1$	$K_A=10$ $T_A=0.1$
Exciter $\frac{K_E}{sT_E+1}$	$1 \le K_E \le 10$ $0.4 \le T_E \le 1$	$K_E=1$ $T_E=0.4$	$K_E=1$ $T_E=0.4$
Generator $\frac{K_G}{sT_G+1}$	$0.7 \le K_G \le 1$ $1 \le T_G \le 2$	$K_G=1$ $T_G=1$	$K_G=1$ $T_G=1$
Sensor $\frac{K_S}{sT_S+1}$	$K_S=1$ $0.001 \le T_S \le 0.06$	$K_S=1$ $T_S=0.01$	$K_S=1$ $T_S=0.01$
Saturation	-3 to +3	Neglected	considered

Transfer function model of an amplifier is: T.F$_A$= $\frac{K_A}{sT_A+1}$

Transfer function model of an exciter is: T.F$_E$= = $\frac{K_E}{sT_E+1}$

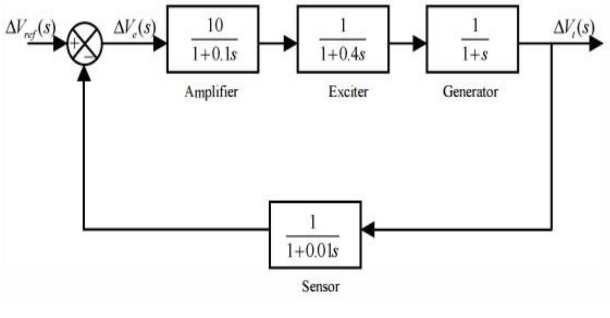
Transfer function model of a generator is: T.F$_G$= $\frac{K_G}{sT_G+1}$

Transfer function model of a sensor is: T.Fs= $\frac{K_s}{sT_s+1}$

The transfer function of AVR system with PID controller is shown in below. Where □V_t (s) is change the terminal voltage.

□V_{ref} (s) Is change reference voltage.

I. CONTROL STRATEGY



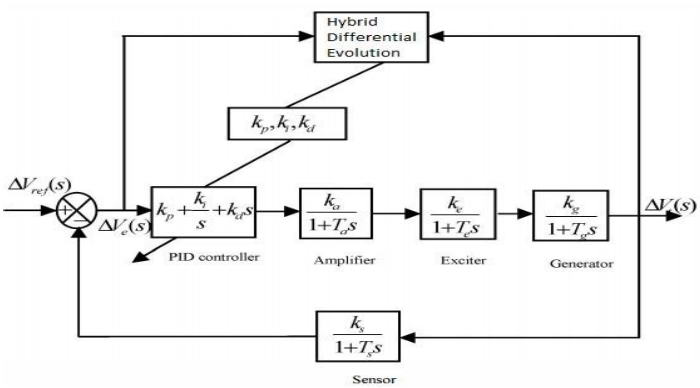


Fig 1. Block diagram of an AVR system without PID controller

Fig 2. Bock diagram of an Linear System

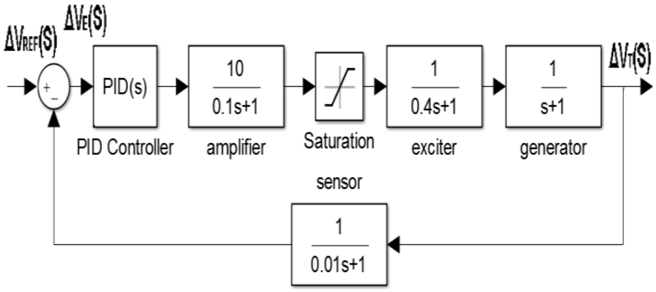


Fig.3 Block diagram of Non Linear System

The block diagram of AVR with PID has shown in fig.2 AVR consists of amplifier, exciter, generator, and sensor. Amplifier may be magnetic, rotating, or electronic and electronic amplifier is characterized by a gain may also include a time constant as shown in fig.1. Tuning of PID controller is using

$$\frac{\Delta V_t(s)}{} = \frac{0.1k_d s^3 + (0.1k_p + k_d)s^2 + (0.1k_i + 10k_p)s + 10k_i}{}$$

Ziegler-Nichols method and differential evolution integral operation, so that integral operation have more expeditious settling feature, but the integral operation gives peak overshoot, this drawbacks overcome by derivative action. PID controller is better Using above table mentioned nominal parameters of plants. The closed loop transfer function for automatic voltage regulation system is shown below.

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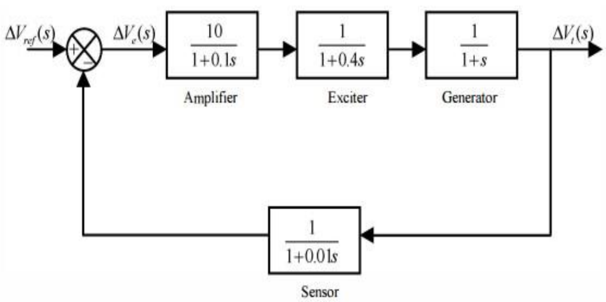

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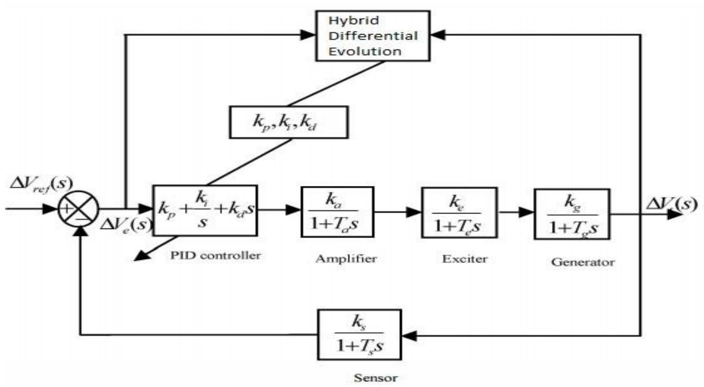

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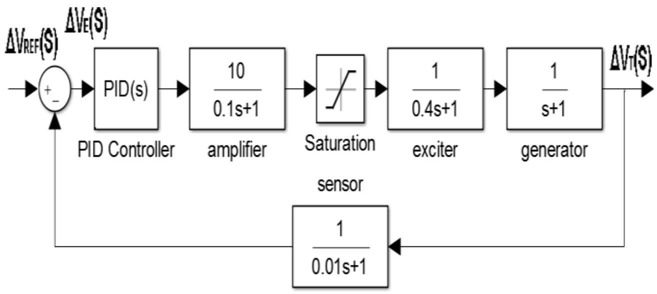

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3 2

□$V_t(s)$ □ $0.1k_d s$ □$(0.1k_p$ □$k_d)s$ □$(0.1k_i$ □$10k_p)s$ □$10k_i$

Ziegler-Nichols method and differential evolution

5 4 3 2

1) PID CONTROLLER DESIGN [1]

A PID controller calculates the error value, the difference between a measured process variable and a desired set point. The controller parameters adjusted minimize error those are proportional gain kp, integral gain ki, derivative gain kd. The transfer function of PID controller is shown below.

$$\frac{u(t)}{u(t)} = kp + \frac{ki}{s} + kds\, e(t)$$

Step 1- Initialization

Here we initialize upper and lower bounds of each control variables [Xmin, Xmax] and size of the population denoted with "N". The initial population is chosen randomly in the interval [Xmin, Xmax] by uniform probability distribution. Fitness value or cost value is calculated for each set of control variables. By using below formula generate the control variables as shown below.

$$e(t)\; kp\; 1 \quad TiS \; TdS$$

$$X^{G}_{i} = X_{i(L)} + rand_i[0,1].(X_{i(H)} - X_{i(L)}),\; i = 1,2,\ldots N$$

2) ZIGULAR-NICHOLAS METHOD [2]

For determining PID parameters The Ziegler-Nichols method is a heuristic method. It was introduced by John G. Zeigler and Nathaniel B. Nichol. Following steps

Step1: First we set the Ki and Kd to zero.

Step2: And then the Kp gain is increased (from zero) until it reaches the critical ultimate gain Ku, at that point the output of the loop begins to oscillaterand is a random number lies between 0 and 1. The initial process produces population Np individuals of X_i randomly.

Fitness Function:

$$ITAE = \int_0^T t\,|e(t)|\,dt$$

with a constant amplitude.Where $e(t) = V_{ref}(t) - V_t(t)$

Step3: The three gains of PID are set by using only ultimate gain Ku and oscillation of period Tu. Calculate the Kp, Ki, Kd depends on the type of controller used as shown in the Table.2.

Table.2

Controller type	K_P	K_I	K_D
P	0.5Su	---	---
PI	0.45Su	1.2/Pu	---
PID	0.6Su	2/Pu	Pu/8

3) *DIFFERENTIAL EVOLUTION [3]* $V_{ref}(t)$ □ Reference voltage

$V_t(t)$ □ Terminal voltage

The performance index ITAE tuning gets systems which settle much more quickly. Time is multiplied with absolute error and integrates within the limits 0 to T. We get integral time absolute error (ITAE).

Step2- Mutation Operation

Mutation operation increases the search space. A new vector is generated based on the present

individual G

Differential evolution is a stochastic, population-predicated optimization algorithm for X_i

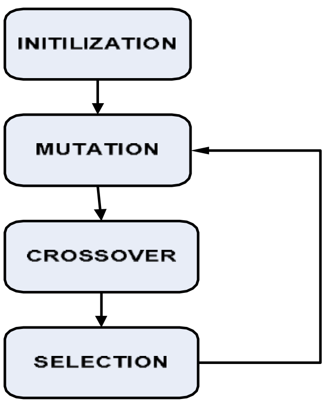
$$Y_i^{G □ 1} □ X_I^G \text{ as fallows}$$

$$+ \quad F((X_{r1}^G □ X_{r2}^G) □ (X_{r3}^G □ X_{r4}^G))$$

solving nonlinear optimization quandaries the algorithm was developed by Storn and Price in 1996. In differential evolution four main operations there are initialization, mutation, crossover and cull. Mutation, crossover, cull perpetuated until ceasing criterion is reached as shown in Fig.4. The mutation factor was selected as F □[0,1.2] , and the upper limit of 1.2 for F was selected depending on convenient; r1, r2, r3 and r4 are selected randomly and those are should not be same.

Step 3- Crossover Operation

Mutant vector and a present individual are culled by a binomial distribution to progress the crossover operation to engender a progeny. The diversity of population has been increased. Each gene of the



j^{th}

individual is reproduced from the new vector

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$G \square 1 \square (G \square 1, G \square 1, ..., G \square 1)$

Y_i $Y_{1i} Y_{2i}$

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□

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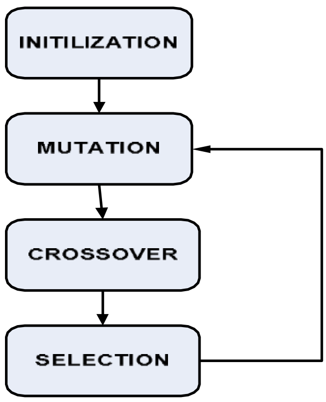

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otherwise

genes; and the crossover factor is set to be C_r □[0,1] .

Step 4- Estimation and Selection:

The parent vector is superseded by its scion if the fitness or cost of the scion is better than that of the parent. Similarly, if the fitness of the scion is cost than that of the parent then parent is retained for the next generation. Two forms are presented as follows

$X^{G□1}$ □ arg min{F (X^G), F ($Y^{G□1}$)}

Table.4

	PEAK AMPLITUDE(V)	SETTLING TIME (SEC)	RISE TIME (SEC)	PEAK TIME (SEC)
open loop system[1]	1.51	6.99	0.261	0.75
ZN tuned system[1]	1.52	2.95	0.232	0.604
PSO tuned system[1]	1.14	2.56	0.536	1.364
MOL tuned system[1]	1.03	1.2	0.372	0.778
APSO tuned system[1]	1.01	0.564	0.346	1.98
Proposed method	1.01	0.489	0.321	0.64

COMPARISON WITH OTHER METHODS FOR PLANT1

hi *i* *i*

$X^{G□1}$ □ argmin{F ($X^{G□1}$)}

b *i*

Where arg min means the argument of the minimum

X and$G$ □1 $i$is the best individual.

Step5- Repeat step 2 to step 4 until desired ITAE is reached as shown in Fig. 2.

IV. SIMULATION RESULTS

COMPARISON OF TUNING VALUES

	TUNNING METHOD	KP	KI	KD
PLANT-1	Z-N METHOD[1]	1.08	1.98	0.1469
	PSO[1]	0.3452	0.4778	0.1017
	MOL[1]	0.5523	0.4418	0.1572
	APSO[1]	0.5536	0.4369	0.1940
	Proposed method	0.5845	0.4214	0.1840
PLANT-2	Z-N METHOD[4]	1.05	1.4	0.1968
	Proposed method	0.8492	0.2045	0.2036

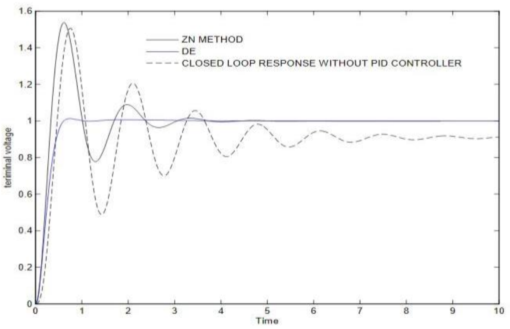

TABLE 3

Fig5.Responses of plant 1

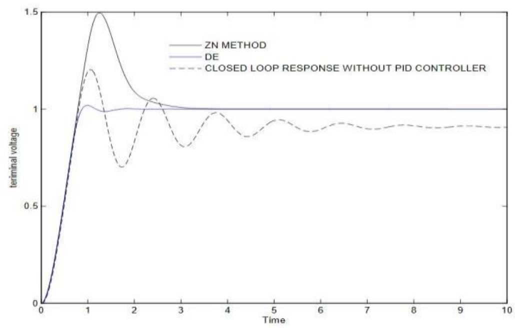

Fig6.Responses of plant 2

COMPARISON WITH OTHER METHODS FOR PLANT2

Table.5

	SETTLING TIME (sec)	OVER SHOOT (%)
Z-N METHOD[4]	2.68	49.55
GA Tuned ANN Like PID[4]	4	8.88
GA Tuned Fuzzy Like PID Using ANFIS[4]	4	0
GA Tuned Fuzzy Like PID[4]	2.25	0
GA Tuned PID[4]	1.3	0.3
Proposed method	**0.9**	**0.1**

CONCLUSION

For plant 1 and plant 2 are controlled utilizing PID controller. The PID controller is tuned utilizing DE algorithm is designed for an Automatic Voltage Regulator system to proved the tuning preponderating of the DE algorithm, compared with other methods. Differential evolution gives the better results. DE algorithm shows the better results for the performance measure integral time absolute error (ITAE). In plant 1 the particle size is lies between 0 to 1, mutation factors is 0.5, crossover ratio 0.7. Population size 100. In plant 2 the particle size is lies between 0 to 1.5, mutation factors is 0.5, crossover ratio 0.8. Population size 100.

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