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# Hybrid Differential Evolution Based Tuning Of PID Controller for Automatic Voltage Regulation System

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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 work two AVR examples are considered. In first plant saturation non-linearity is neglected and second plant saturation non-linearity is considered. Hybrid Differential Evolutions are acclimated to tune the parameters of PID controller, to procure optimal solution. Optimal control parameters 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, differential evolution and hybrid differential evolutions are utilized.

**KEYWORDS:** PID controller, Z-N method, DE, HDE.

## I.INTRODUCTION

The AVR is a contrivance which is utilized for regulating supply line voltage where the supply line voltage is unstable or fluctuating. For controlling the AVR system we can utilize PID controller or power system stabilizer (PSS), in our work PID controller is utilized because PSS requires six tuning parameters and high gain thyristers are required. PID controller requires 3 tuning parameters and low gain is required. So we utilize PID controller for controlling the AVR system. The AVR system is closed loop system compensated with PID controller as shown in fig2. The other consequential reason for AVR control is that the authentic line losses depend on authentic and reactive power flow. Because the reactive power flow greatly depends on terminal voltages in the potency system. The AVR controls the terminal voltage by adjusting the exciter voltage of the generator. The proportional-integral-derivative (PID) controller is the most famous and prominent among them. The PID controllers have been utilized in many control applications due to the robustness of these controllers and they offer a wide stability margin. Many methods have been utilized for fine tuning the PID controller parameters. The PID controller parameters are tenacious by utilizing the Ziegler-Nichols method. Moreover, many artificial astuteness (AI) techniques, such as neural network technique, and neuro-fuzzy system, fuzzy logic, have been proposed to fine tune the PID controller parameters. In Comparative performance analysis of artificial bee colony (ABC) algorithm for automatic voltage regulator (AVR) system has been proposed for tuning of the control parameters. DE was invented by Rainer Storn and Kenneth Price. DE is utilized to find approximate solution for nonlinear and non differentiable functions. This paper presents development of an optimal PID controller for AVR system and composition control system utilizing DE and HDE techniques. This paper additionally compares the transient performance of the two AVR systems utilizing DE and HDE tuning methods with Ziegler-Nichols method.

## II. MODELLING OF AN AVR SYSTEM

The AVR consists of four components exciter, amplifier, sensor and generator. The amplifier amplifies the input signal amplifier output is given for input exciter, the excitation system voltage maintains the generator terminal voltage constant and the generator engenders electrical power.

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Table.1 PLANTS SPECIFICATIONS

| Model Transfer function | Parameters Limits | PLANT-1 Parameters Nominal values | PLANT-2 Parameters Nominal Values |
|---|---|---|---|
| Amplifier $\frac{K_A}{sT_A+1}$ | $10 \le K_A \le 40$<br>$0.02 \le T_A \le 0.1$ | $K_A=10$<br>$T_A=0.1$ | $K_A=10$<br>$T_A=0.1$ |
| Exciter $\frac{K_E}{sT_E+1}$ | $1 \le K_E \le 10$<br>$0.4 \le T_E \le 1$ | $K_E=1$<br>$T_E=0.4$ | $K_E=1$<br>$T_E=0.4$ |
| Generator $\frac{K_G}{sT_G+1}$ | $0.7 \le K_G \le 1$<br>$1 \le T_G \le 2$ | $K_G=1$<br>$T_G=1$ | $K_G=1$<br>$T_G=1$ |
| Sensor $\frac{K_S}{sT_S+1}$ | $K_S=1$<br>$0.001 \le T_S \le 0.06$ | $K_S=1$<br>$T_S=0.01$ | $K_S=1$<br>$T_S=0.01$ |
| 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: $T.Fs = \frac{K_S}{sT_S+1}$

## III.CONTROL STRATEGY

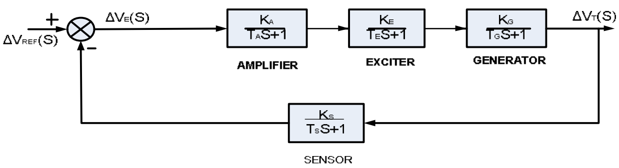


Fig 1.block diagram of an AVR system without PID controller

Now a day's PID controller is utilized for many applications because of robustness and wide stability margin. PID controller has three tuning parameters they are proportional gain (kp), integral gain (ki) and derivative gain (kd). For tuning the PID controller parameters the tuning methods are discussed in section-I. The closed loop AVR system is shown in fig1.

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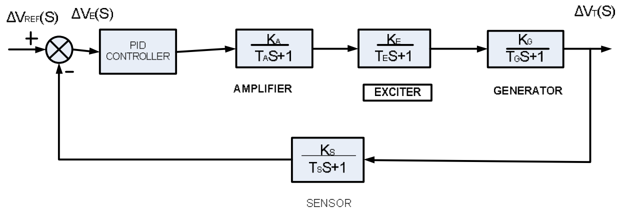


Fig 2.block diagram of an AVR system with PID controller for plant 1

The AVR system is compensated with PID controller is fig.2 and the PID controller compensated AVR system including saturation non linearity is shown fig.3

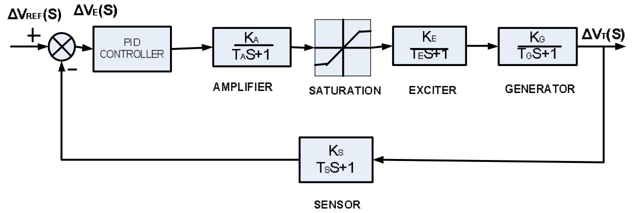


Fig.3 Block diagram with saturation and PID controller for plant 2

**1) PID controller design:** The PID controller calculates the error between input and output of plant. The parameters present in PID controller are proportional gain (kp), integral gain (ki), and derivative gain (kd). The transfer function PID is

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

$$\frac{u(t)}{e(t)} = kp\left(1 + \frac{1}{TiS} + TdS\right)$$

**2) zigular-nicholas method:** 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

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 |

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 oscillate with a constant amplitude.
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

**3. a. Differential Evolution:** DE is a stochastic population predicated search technique. The algorithm has been utilized in many practical causes because of its good convergence and ecumenical optimization capability. DE can probe for the optimal condition very expeditious with minimal control parameters such as initialization, mutation, crossover and cull. All these operations are briefly described in HDE technique. Mutation, crossover, cull perpetuated until stopping criterion is reached as shown in Fig. 4. The main disadvantage of DE is premature convergence. HDE surmounts this constraint by performing migration operation

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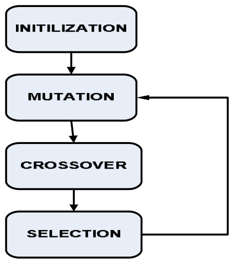


Fig.4 flow chart of differential evolution

**3. b. Hybrid Differential Evolution:** Migration strategy is mainly integrated to pristine DE to perform Hybrid Differential Evolution by Chiou and Wang. HDE is an efficacious reliable optimization technique to obtain the optimum control parameters of the controller where the fitness value ITAE is minimized.

**Fitness Function:**

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

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

$V_{ref}(t) =$ Reference voltage

$V_t(t) =$ Terminal voltage

The performance index ITAE makes the more expeditious settling time.
The proposed method is described briefly below

**Step 1. Initialization:**

Initialize upper and lower bounds of each control variables and size of the population. The initial populations are culled desultorily in the interval [Xmin, Xmax] by uniform probability distribution. Fitness value has been calculated for each set of control variables. Generation of control variables has been made utilizing below formula.

$$X_i^G = X_{i(L)} + rand_i[0,1].(X_{i(H)} - X_{i(L)}), i = 1,2,...N$$

Where $\rho_i \in [0,1]$ is desultory number. The initial process engenders Np individuals of desultorily.

**Step 2. Mutation Operation:**

Mutation expands the search space. A mutant vector is engendered predicated on the present individual as fallows

$$Y_i^{G+1} = X_i^G + F((X_{r1}^G - X_{r2}^G) + (X_{r3}^G - X_{r4}^G))$$

The mutation factor was culled as F □ [0, 1.2], and the upper limit of 1.2 for F was resolute empirically; r1, r2, r3 and r4 are arbitrarily culled and distinct.

**Step 4. Crossover Operation:**

Mutant vector $Y_i^{G+1}$ and a present individual $X_i^G$ are culled by a binomial distribution to progress the crossover operation to engender a scion. The diversity of population has been incremented. Each gene of the $j^{th}$ individual is reproduced from the mutant vector $Y_i^{G+1} = (Y_{1i}^{G+1}, Y_{2i}^{G+1}, ....., Y_{Ki}^{G+1})$ and the present individual $Y_i^{G+1} = (Y_{1i}^{G+1}, Y_{2i}^{G+1}, ....., Y_{Ki}^{G+1})$. That is

$$Y_{hi}^{G+1} = \begin{cases} X_{hi}^G, & if\ a\ random number > C_r \\ Y_{hi}^{G+1}, & otherwise \end{cases}$$

Where i=1, 2. . . $N_p$; h=1,2, . . . , $n_c$; $n_c$ is the dimension of decision parameters; K is the no of genes; and the

Crossover factor is set to be $C_r$ □$[0,1]$.

**Step 5. Estimation and Selection:**
The parent is superseded by its progeny if the fitness of the scion is better than that of the parent. Contrarily, if the fitness of the scion is worse than that of the parent then parent is retained for the next generation. Two forms are presented as follows

$$X_{hi}^{G+1} = \arg\min\{F(X_i^G), F(Y_i^{G+1})\} \;\&$$
$$X_b^{G+1} = \arg\min\{F(X_i^{G+1})\}$$

Where arg min means the argument of the minimum and $X_i^{G+1}$ is the best individual.

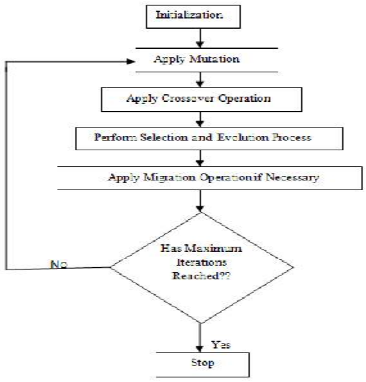


Fig.5 Flow chart of Hybrid Differential Evolution

**Step 6. Migration If Necessary:**
Migration strategy is to diversify a population that failed in certain tolerance besides eluding from local optimal and averts premature convergence. The incipient populations are predicated on the best individuals. The h[th] gene of the it[h] individuals as fallows

$$X_{hi}^{G+1} = \begin{cases} X_{hb}^{G+1} + \rho_1 (X_{h\min} - X_{hb}^{G+1}), & if \;\; \rho_2 < \dfrac{X_{hi}^{G+1} - X_{h\min}}{X_{h\max} - X_{hb}^{G+1}} \\ X_{hb}^{G+1} + \rho_1 (X_{h\max} - X_{hb}^{G+1}), & otherwise \end{cases}$$

Where $\rho_1, \rho_2$ are desultorily engendered numbers uniformly distributed in the range of [0, 1]; h= 1, . . . ,nc. The migration in HDE is executed only if quantification fails to match the desired steadiness of population diversity. This quantification is defined as fallows

$$\rho = \sum_{\substack{i=1 \\ i \neq b}}^{N_p} \sum_{j=1}^{n_c} X_{ji} \Big/ n_c (N_p - 1) < \varepsilon_1$$

Where

$$X_{ji} = \begin{cases} 1, \; if \; \left| \dfrac{X_{ji}^{G+1} - X_{jb}^{G+1}}{X_{jb}^{G+1}} \right| > \varepsilon_2 \\ 0, \; otherwise \end{cases}$$

$\varepsilon_1 \in [0,1]$ and $\varepsilon_2 \in [0,1]$ respectively express the desired steadiness for the population diversity and the gene diversity with deference to the best individual. If ρ is more diminutive than Ɛ1, then the HDE performs the migration to engender an incipient population to elude the local point; otherwise, the HDE breaks off the migration and keeps a mundane search direction.
STEP 7: Reiterate step 2 to step 5 until desired ITAE is reached as shown in Fig.5

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## IV.SIMULATION RESULTS

TABLE3. COMPARISON OF TUNING VALUES

| | TUNNING METHOD | KP | KI | KD |
|---|---|---|---|---|
| PLANT-1 | Z-N METHOD[3] | 1.08 | 1.98 | 0.1469 |
| | PSO[3] | 0.3452 | 0.4778 | 0.1017 |
| | MOL[3] | 0.5523 | 0.4418 | 0.1572 |
| | APSO[3] | 0.5536 | 0.4369 | 0.1940 |
| | DIFFERENTIAL EVOLUTION[12] | 0.5290 | 0.4 | 0.1631 |
| | **Proposed method** | 0.52 | 0.4 | 0.1633 |
| PLANT-2 | Z-N METHOD[6] | 1.05 | 1.4 | 0.1968 |
| | DIFFERENTIAL EVOLUTION[12] | 1.2 | 0.2091 | 0.2541 |
| | **Proposed method** | 1.2 | 0.2059 | 0.2706 |

In plant 1 the particle size is lies between 0 to 1, mutation factors is 0.5, crossover ratio 0.8. $\varepsilon_1$&$\varepsilon_2$=0.4, 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. $\varepsilon_1$&$\varepsilon_2$=0.4, Population size 100.

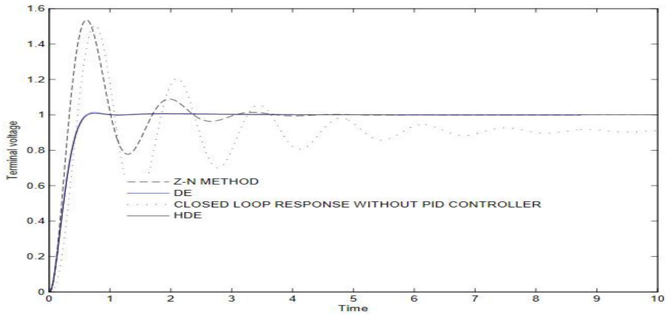


Fig.6.Responses of plant1, are zigular-nicholas method, differential evolution and hybrid differential evolution zigular-nicholas method gives large over shoot than DE&HDE, showing graphs HDE get better results than DE. Zoomed subplot pant 1 shown in fig.7

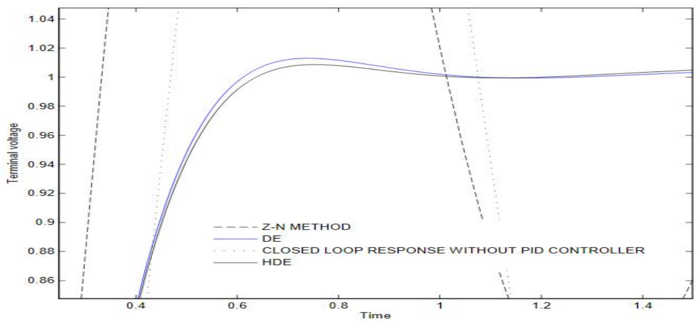


Fig.7 subplot of fig6

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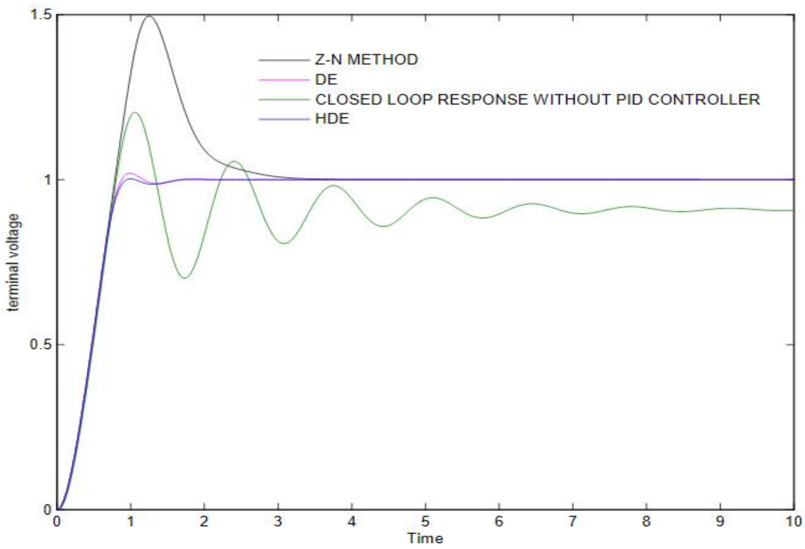


Fig.8.Responses of plant 2 are zigular-nicholas method, differential evolution and hybrid differential evolution zigular-nicholas method gives large over shoot than DE&HDE, showing graphs HDE get better results than DE.

Table.4 Comparison with other methods for plant1

| | PEAK AMPLITUDE(V) | SETTLING TIME (SEC) | RISE TIME (SEC) | PEAK TIME (SEC) |
|---|---|---|---|---|
| open loop system[3] | 1.51 | 6.99 | 0.261 | 0.75 |
| ZN tuned system[3] | 1.52 | 2.95 | 0.232 | 0.604 |
| PSO tuned system[3] | 1.14 | 2.56 | 0.536 | 1.364 |
| MOL tuned system[3] | 1.03 | 1.2 | 0.372 | 0.778 |
| APSO tuned system[3] | 1.01 | 0.564 | 0.346 | 1.98 |
| Differential evolution[12] | 1.01 | 0.554 | 0.358 | 0.74 |
| **Proposed method** | 1.01 | 0.486 | 0.316 | 0.64 |

Plant 1 responses compared those are peak amplitude, settling time, rise time and peak time Shown in table4. And plant 2 responses are compared those are settling time and over shoot are shown in table.5.

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Table.5 Comparison with other methods for plant2

| | SETTLING TIME (sec) | OVER SHOOT (%) |
|---|---|---|
| Z-N METHOD[6] | 2.68 | 49.55 |
| GA Tuned ANN Like PID[6] | 4 | 8.88 |
| GA Tuned Fuzzy Like PID Using ANFIS[6] | 4 | 0 |
| GA Tuned Fuzzy Like PID[6] | 2.25 | 0 |
| GA Tuned PID[6] | 1.3 | 0.3 |
| Differential evolution[12] | 0.8358 | 1.9224 |
| **Proposed method** | 0.8639 | 0.2467 |

## V.CONCLUSION

In plant 1 and plant 2 are controlled utilizing PID controller. It has been demonstrated that the tuning of PID controller utilizing Hybrid Differential Evolution technique for automatic voltage regulator system is highly efficacious over other comparison methods and over Differential Evolution. From simulation results PID is more efficacious than other PID controller tuning in all performance aspects and the relative stability of the resultant closed loop system has been greatly ameliorated.

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