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Differential Evolutionary Algorithm Based PID Controller Design for Antenna Azimuth Position Control System

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Abstract: *In this paper, antenna azimuth position control system with PID controller was proposed. PID controllers are mainly used because of its simplicity, robustness and successful practical implementations. Many PID controllers tuning methods are available like Ziegler-Nichols (ZN) method, Modified Ziegler-Nichols without overshoot (MZN-NOOS) method, Modified Ziegler-Nichols with overshoot (MZN-OS) method and Tyreus- Luyben (TL) method. All the methods are simulated in MATLAB environment and the results are compared with differential evolutionary algorithms based PID controller which has less overshoot and smooth response.*

Keywords: *Ziegler-Nichols (ZN), Modified Ziegler-Nichols without overshoot (MZN-NOOS), Modified Ziegler-Nichols with overshoot (MZN-OS), Tyreus- Luyben (TL), Differential Evolution (DE, Proportional Integral Controller (PID).*

1. Introduction

The Azimuth Position control system obtains an output response from input command signal. This control system is used mainly used in antennas, robot arms, rocket fire and computer disk drives. The position of antenna is mainly controlled by using gears and feedback potentiometer. For a better response PID controller is used before the preamplifier but after the power amplifier. Output angle of the antenna θ_o (t) is get from the input angle of the potentiometer θ_i (t). Fig 1 shows the pictorial view of azimuth control system. In this system angular displacement is an input command signal. The potentiometer converts the angular displacement in to a voltage. In the same way potentiometer in the output path converts the output angular displacement into the voltage. The signal and power amplifiers boost the difference between the input and output voltages. The amplified actuating signal drives the plant [1].

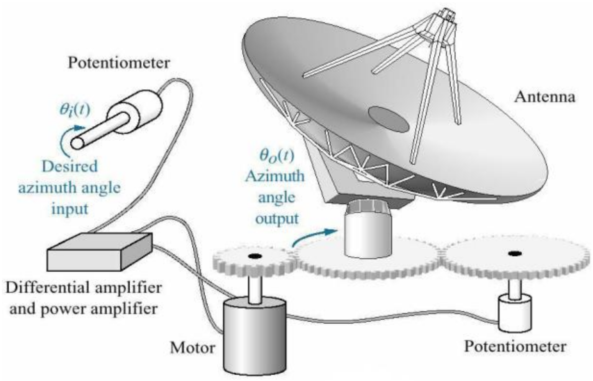

Fig1. *Layout of Antenna Azimuthal position control system*

Fig 2 shows the components of antenna azimuth control system. In this the potentiometer which is placed at the top most position is controlled by the operating personnel. The signal is first received by the differential preamplifier and then it goes to the power amplifier. The output signal from the power amplifier goes to the motor and then to the gear. This gear is connected to another gear for the movement of antenna. Finally the antenna's signal is connected to potentiometer and another gear. The feedback signal is going from the potentiometer back into the differential amplifier. After that differential amplifier check how much the obtained signal is different from the given signal and also find the error. Power amplifier amplifies the input signal. Motor will run until the error approaches to zero.

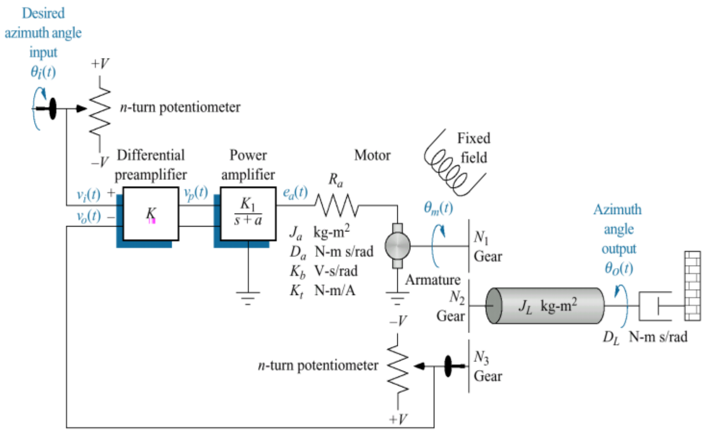

Fig2. *Components of Antenna Azimuthal position control system*

2. Modeling of Azimuth Position Control System

Block diagram of Azimuthal position control system consists of two potentiometers one at input side and other at the output side, preamplifier, power amplifier, motor, load and gears. Transfer function of moor and load is

$$\frac{\phi_m(s)}{E_a(s)} = \frac{Km}{s(s+a_m)}$$

The equation for inertia and damping components are given as

$$J = J_A + J_L(K_g)^2$$

$$D_m = D_A + D_L(K_g)^2$$

In below equation, N1 and N2 represent the gear teeth ratio

$$K_g = \frac{N_1}{N_2}$$

Motor and load block's pole and zero is represented as

$$a_m = \frac{D_m R_a + K_b K_t}{JR_a} \qquad K_m = \frac{K_t}{JR_a}$$

Where R_a is the resistance of the motor, K_b and K_t are the back EMF and torque constant of the motor respectively.

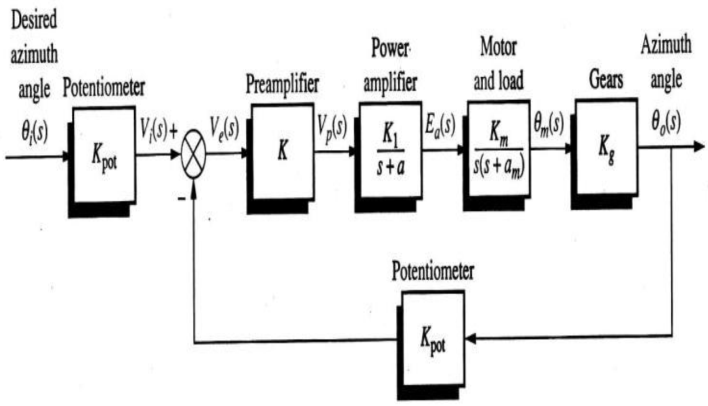

Fig3. *Block diagram of Azhimuthal position control system*

The closed loop control system for controlling the azimuthal position control is given by

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{KK_1K_gK_m}{s(s+a)(s+a_m)}$$

Table1. *Shows the parameters of block diagram*

Parameters	Value
K	1
K_1	100
a	100
K_m	0.8
a_m	1.32
K_g	0.2

3. PID Controller

A PID controller is a control loop feedback mechanism commonly used in industrial control systems. PID controller involves three separate constant parameters and therefore it is said to be three-term control. They are P stands for the proportional term I for the integral term and D for the derivative in the controller. An "error value" is calculated by the PID controller as the difference between a measured process variable and a desired set point. The error is minimized by PID controller by adjustment of a control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de}{dt}$$

Where K_p, K_i and K_d all non-negative, denote the coefficients for the proportional, integral, derivative and terms, respectively. PID controllers perform well for a broad range of processes and they will give resilient presentation for a wide range of working conditions and are easy to execute using analog or digital hardware. Fig 4 shows the block diagram of PID controller.

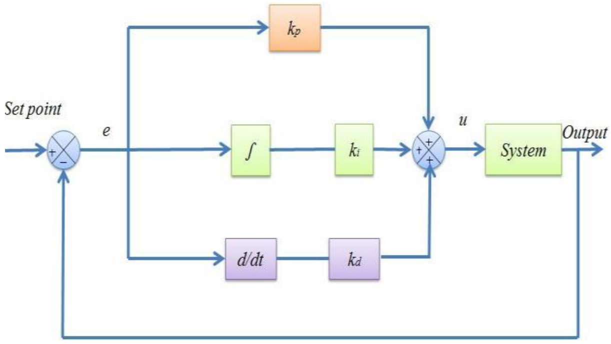

Fig4. *Block diagram of PID controller*

The system model is given by,

$$G_c(s) = \frac{K_d s^2 + K_p s + K_I}{s}$$

4. Tuning Methods

The PID controller tuning methods are classified into two main categories such as closed and open loop methods. The closed loop tuning methods are Ziegler-Nichols method, Modified Ziegler-Nichols with and without overshoot method, Tyreus- Luyben method and Damped oscillation method. Table 2 shows the tuning rules for various closed loop tuning methods of PID controllers.

Table2. *Various tuning rule of PID controller*

Methods	K_P	T_i	T_D
ZN	$0.6\ K_u$	$P_u/2$	$P_u/8$
MZN-NOOS	$0.2K_u$	$P_u/2$	$P_u/2$
MZN-OS	$0.33\ K_u$	$P_u/2$	$P_u/3$
TL	$0.45\ K_u$	$2.2\ P_u$	$P_u/6.3$

5. DIFFERENTIAL EVOLUTION ALGORITHM

Differential Evolution (DE) algorithm is a simple evolutionary algorithm for optimization of multidimensional real valued functions. DE optimizes a problem by maintaining a population of candidate solutions and creating new candidate solutions by combining existing ones according to its simple formulae, and then keeping whichever candidate solution has the best score or fitness on the optimization problem at hand. The optimization process is preceded by means of three main operations: mutation, crossover and selection. DE was a heuristic optimization algorithm and the pseudo-code of DE [4-5] was given below in section 5.1

5.1. DE Algorithm

1: Select P, F and CR and Set G= 1

2: P_G = initialize population randomly

3: **while** termination criteria not satisfied **do**

4: **for** each individual ${x_G}^i$ in P_G do

5: Select auxiliary parents ${x_G}^{r1}$ ${x_G}^{r2}$ ${x_G}^{r3}$ 6: Create offspring ${x_G}^{child}$ using mutation and crossover

7: $P_{G+1} = P_{G+1}\ U\ Best({x_G}^{child}, {x_G}^i)$

8: **end for**

9: Set $G = G + 1$

10: **end while**

5.2. Objective Function

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

$$\text{Min } F(K_P, K_I, K_D) = (1 - e^{-\beta})(M_P + E_{ss}) + e^{-\beta}(t_s - t_r$$

The above optimization problem is subjected to the following constraints

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

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

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

PID controller is tuned by tuning methods and the values of $\mathbf{K_P}$, $\mathbf{K_I}$, $\mathbf{K_D}$, $\mathbf{t_r}$, $\mathbf{t_s}$, $\mathbf{t_p}$, **are shown in table 3 .**

Table3. *Bound value of PID controller*

Parameters	Min.Value	Max.Value
K_P	0	3
K_I	0	1
K_D	0	3

Table4. *K_P K_I K_D Value of various methods and measured value of system response*

Parameters / Methods	K_P	K_I	K_D	t_r	t_s	t_p	Peak value	% Peak value
ZN	157.7151	579.7789	10.7815	0.1063	3.7160	0.4987	1.6767	67.6401
MZN-NOOS	52.5717	192.2596	14.3753	0.1601	3.2803	0.8325	1.3354	33.5359
MZN-OS	86.7433	317.2284	15.81279	0.1274	2.4093	0.8285	1.3782	37.8167
TL	118.2863	98.3146	10.2681	0.1310	1.3984	0.8758	1.4171	41.7089
DE	2.5077	0.1686	1.3572	1.8891	20.5905	0.9021	1.0657	6.5739

6. RESULTS AND DISCUSSION

The rise time, settling time, peak time and peak value are considered in real time operations but all this specifications are not achieving in any conventional methods and any optimization techniques. In this work, peak value is only considered and the minimum value is achieved in DE algorithm but it has high settling time, Peak time and rise time as compared with conventional methods. Fig 5 shows the comparison of settling time of various methods. Of that TL has fast settling time. Fig 6 shows the comparison of peak time of various tuning methods and it is observed that ZN has minimum peak time. Fig 7 shows Rise time comparison of various methods and it is clear that ZN has low rise time compared to other methods. Fig 8 and 9 shows the comparison of peak value and its percentage value and it is proven that DE has minimal value compared to other conventional methods. Fig 10. Shows the Bode plot of different methods which are used to find the gain margin. Fig 11 and 12 shows the step response characteristics.

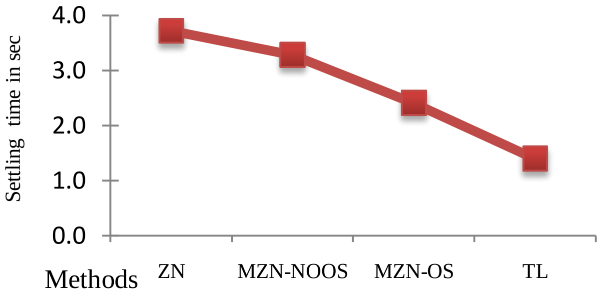

Fig5. *Settling time comparison of various methods*

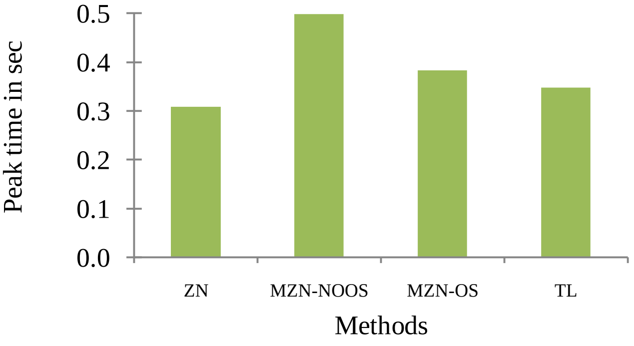

Fig6. *Peak time comparison of various methods*

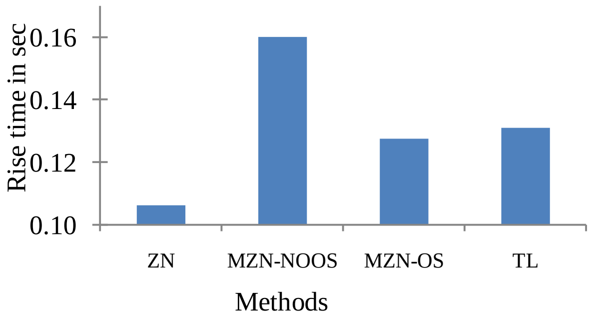

Fig7. *Rise time comparison of various methods*

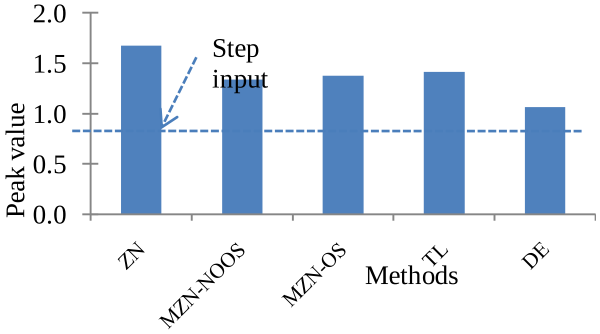

Fig8. *Peak value comparison of various methods*

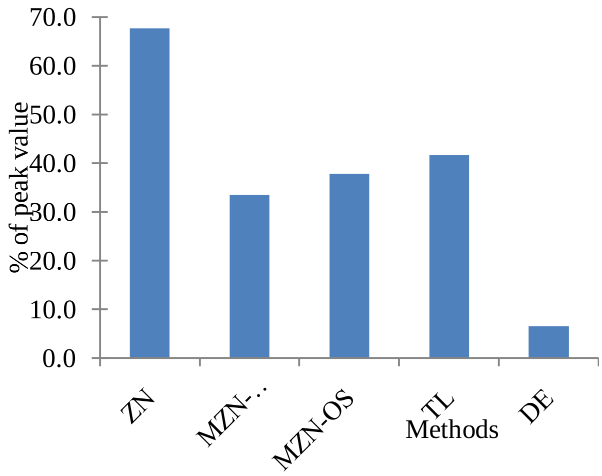

Fig9. *% Peak Value comparison of various methods*

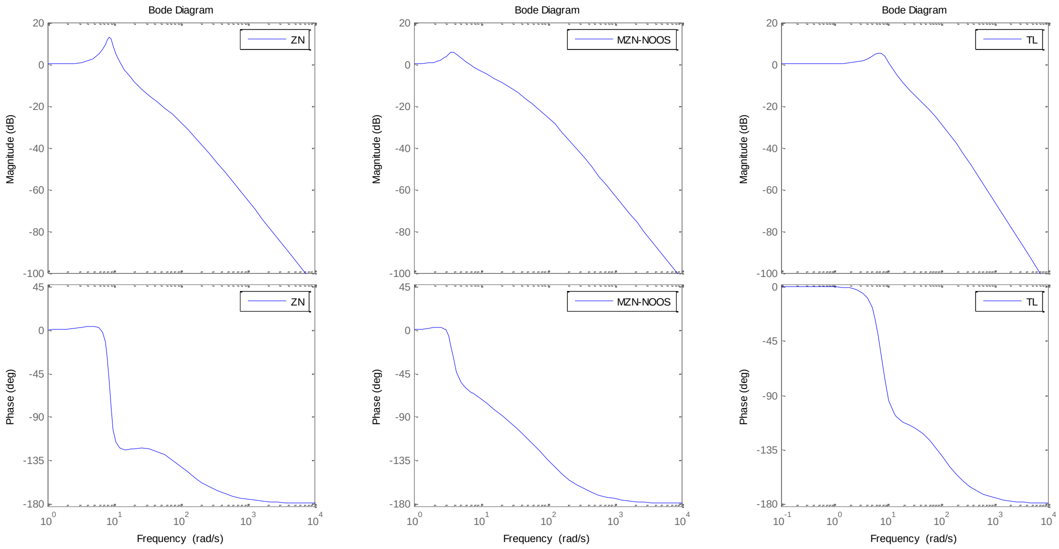

Fig10. *Bode plot for ZN, MZN-NOOS and TL methods*

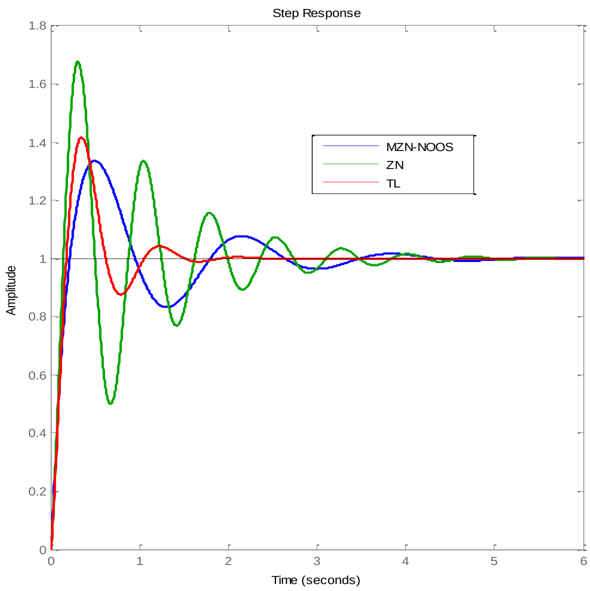

Fig11. *Step response of various tuning methods*

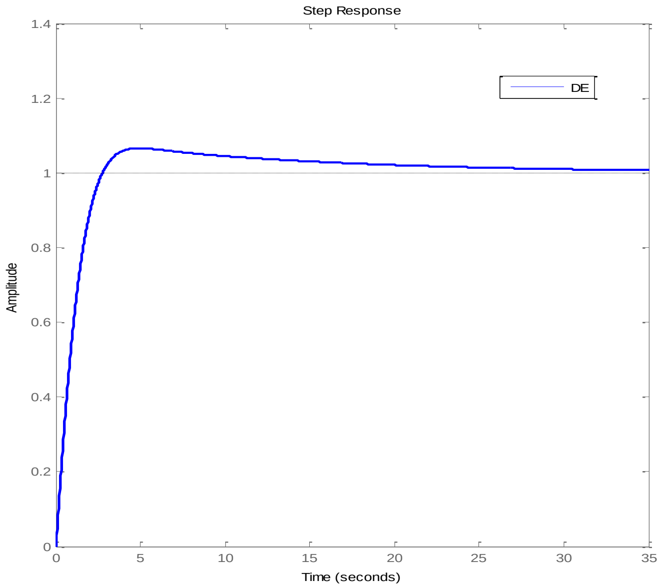

Fig12. *Step response of Differential algorithm based PI controller method*

7. Conclusion

Antenna azimuth position control system with DE based PID controller provided minimum peak value and smooth response as compared with conventional tuning methods. All the works are carried out in MATLAB environment. The optimization technique provides Kp, Ki and Kd values are minimum as compared with conventional tuning which leads easy to implement the PID controller for real time applications.

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