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Research paper

Control of Antenna Azimuth Position using Fractional order Lead Compensator

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Abstract

This paper addresses the position control of antenna azimuth using proportional and integral (PI) controller and lead compensators. The fractional order calculus plays an important role for designing the robust control. The fractional order lead compensator is proposed for enhancing the closed loop performance of azimuth position control of antenna system. From the comparison of the closed loop responses, the proposed lead compensator delivers a superior closed loop performance when compared with PI controller and lead compensator.

Keywords: *Control of Antenna Azimuth Position, fraction order calculus, fractional order lead compensator, lead compensator, PI controller.*

1. Introduction

Modern world and the surrounding applications are using the concepts of control systems. A position control system is used to convert an input position to an output position with desired values. The applications of position control systems are antennas, computer disk drives, robot arms, hydraulic piston of a car and many other real life applications [1]. The antenna position control system is mathematically modelled based on time domain approach. It will give the clear explanation of system response with the analytical calculations and Matlab/Simulink [1].
An angular measurement of azimuth is represented as a spherical coordinates. An observer to an argument of interest is projected perpendicularly onto a reference plane. The angle of azimuth position is difference between the projected vector and a reference vector on the reference plane. Azimuth angle of an antenna which is rotated clockwise direction from the geographical north to bring the direction of a signal of interest of the coordinate's plane [2]. The techniques for the control of azimuth position are investigated towards enhancing the closed loop performance [3].
An antenna azimuth position is controlled using designed proportional-integral-derivative (PID) controller and fuzzy logic controller (FLC). From the closed loop response, FLC delivers the finest closed loop response compared with PID controller [4]. The firing angle of the motor is adjusted, it drives the antenna due changing the output angle. The fuzzy controller is used and achieved the position control of antenna by regulating the firing angle of the motor [5]. The lead compensator is used for the position control of an antenna azimuth.
The compensated system delivers with minimization of settling time, which increases the closed loop performance [2]. This work aims to further enhancement of the closed loop performance of position control of an antenna azimuth, which is improved by using the fractional order lead compensator.
In this work, fractional-order based lead compensator is designed for the control antenna position. Fractional order is a more powerful tool for designing robust control systems and it has more flexibility in altering the characteristics of gain margin and phase margin [6, 7].
The paper is deliberate as follows. Section two describes the antenna azimuth position control system. Section three is about the design of PI, Lead and fractional order lead compensator for control of antenna azimuth position. Simulation results are given in Section four. Conclusions are drawn in Section five.

2. Antenna Azimuth Position Control System

The control of antenna azimuth system is described as a servo controlled mechanism by the use of gears and feedback potentiometers. The compensator is designed for the control of such a system and it provides control with stability. The antenna control system physical layout is shown in Fig.1 [2].

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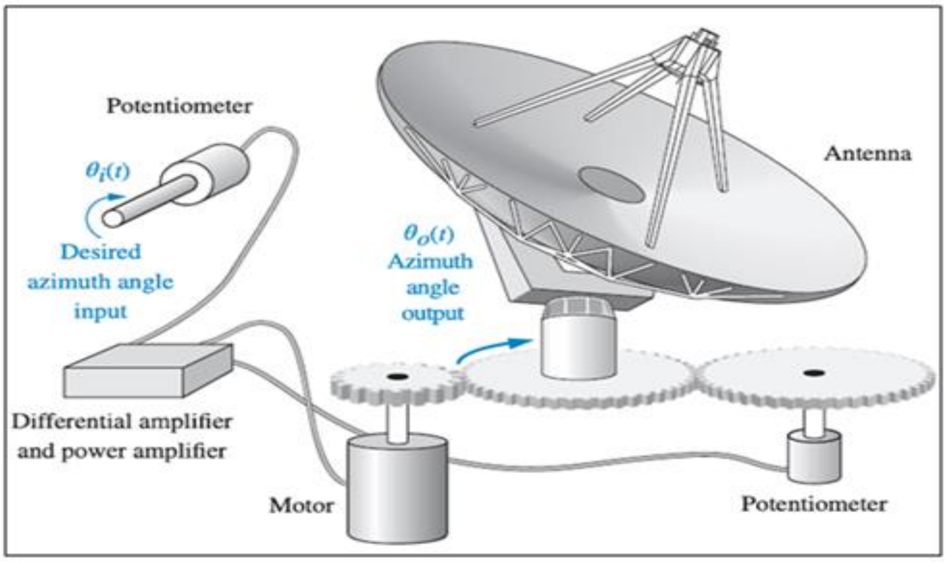

Fig. 1: Layout of the Antenna Azimuth control system

A block diagram of above system is converted form physical layout to and it revealed in Fig. 2.

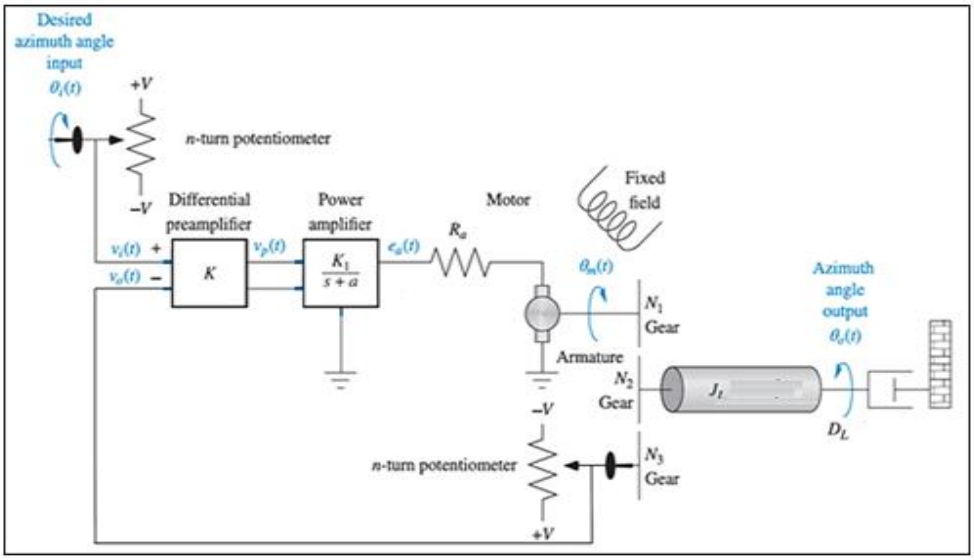

Fig. 2: Representation of the Antenna Azimuth system

From the above representation, the potentiometer that the operator controls is at the very top. The signal is directed to the preamplifier then power amplifier. The result is sent to a motor then to a gear, which is connected to another gear to change the position of the antenna. Finally the antenna signal is connected to another gear and a potentiometer. The feedback is going back from the potentiometer into the differential preamplifier. The feedback is crucial in determining whether our antenna is in the correct position. This schematic diagram is used to derive the block diagram of the system and it is given in Fig. 3. The mathematical model and controllers are obtained by using the block diagram.

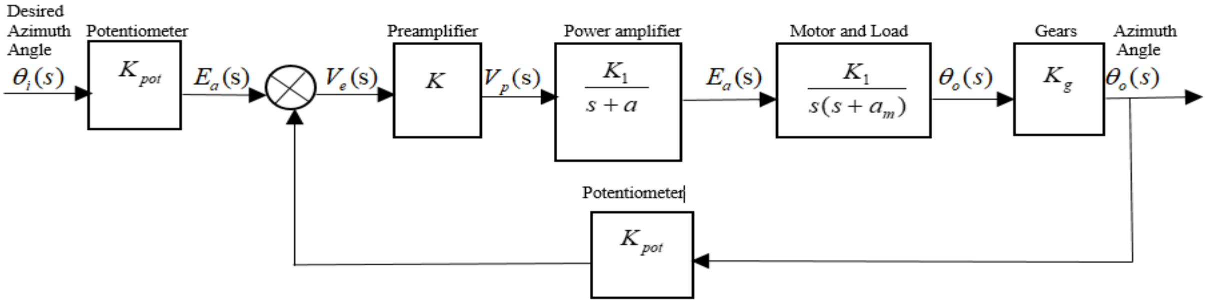

Fig.3: The Closed- Loop Antenna Azimuth system

The input and output a voltage of preamplifier is connected with the power amplifier. The preamplifier output voltage is converted and it is usable by the motor. The various transfer function of the antenna azimuth position control system is obtained by using the values of the schematic parameters [2] and it is given in Table 1.

Table 1: Schematic Parameters

Parameters	Definition	Values
V	Output voltage of potentiometer [V]	10
n	Potentiometer turns	10
K_1	Gain of power amplifier	100
a	Pole of power amplifier	100
R_a	Resistance of motor [ohms]	8
J_a	Inertial constant of motor [kg-m2]	0.02
D_a	Damping constant of motor [N-m s/rad]	0.01
K_b	Back EMF [V-s/rad]	0.5
K_t	Torque constant of motor [N-m/A]	0.5
N_1, N_2, N_3	Gear teeth	25,250,250
J_L	Load inertial constant [kg-m2]	1
D_L	Load inertial constant [N-m s/rad]	1
K_{pot}	Potentiometer gain	0.318
K_m	Load gain with motor	2.083
a_m	Pole of motor and load	1.71
K_g	Gear ratio	0.1

3. Mathematical Modelling

Many variables are used to represents as inputs and outputs signals. The input and feedback potentiometer have a transfer function with the form of a gain. The potentiometer changes the input angle, which is an input voltage, $V_i(s)$, and it is represented as Eq. 1. The value applied voltage and number of turns the potentiometer is used to gain and it is given below.

$$\frac{V_i(s)}{\theta_i(s)} = \frac{10}{10\pi} = \frac{1}{\pi} \tag{1}$$

Using the preamplifier, amplify the input voltage by gain K and it is an output voltage. The resulting equation is,

$$\frac{V_p(s)}{V_e(s)} = K \tag{2}$$

The power amplifier is amplifying the preamplifier voltage and it is given to the motor. The power amplifier transfer function is represented as,

$$\frac{E_a(s)}{V_p(s)} = \frac{K_1}{s+a} \tag{3}$$

The motor is attached to the gears and load, which is an antenna for this work. The transfer function of an armature controlled DC servo motor is considered and Fig. 4 shows that the general circuit of motor.

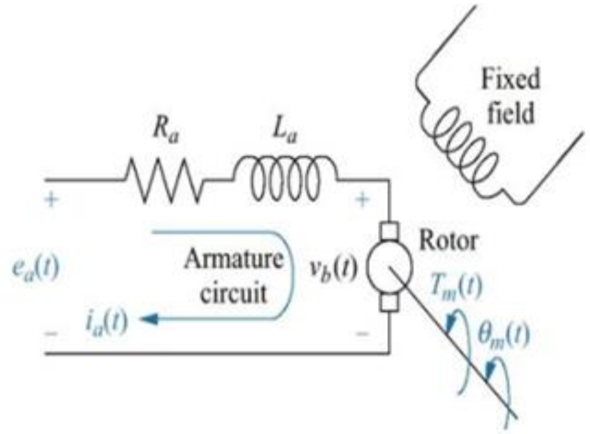

Fig.4: Armature circuit

The transfer function of this subsystem is obtained with the voltage law equation. The input voltage and output position of the armature is relates the below equation,

$$V_b(t) = K_b \frac{d\theta_m(t)}{dt} \tag{4}$$

Apply the Laplace transform of the above equation is,

$$V_b(s) = K_b S\theta_m(s) \tag{5}$$

Now, substitute the value for K_b as 0.5, it gives,

$$V_b(s) = 0.5s\,\theta_m(s) \tag{6}$$

Applying the Kirchhoff's Voltage Law (KVL) for the armature circuit,

$$R_a I_a(s) + L_a s I_a(s) + V_b(s) = E_a(s) \tag{7}$$

The value of R_a and Eqn. 5 are used in the above Eqn. (7), it gives,

$$8I_a(s) + L_a s I_a(s) + 0.5s\theta_m(s) = E_a(s) \tag{8}$$

The motor torque is directly proportional to armature current,

$$T_m(s) = K_t I_a(s) \tag{9}$$

The mechanical load consists of moment of inertia and frictional elements. The torque of a motor depends on these elements and the torque equation is,

$$T_m(s) = (J_m s^2 + D_m s)\theta_m(s) \tag{10}$$

The following equations are used to determine the values of J_m and D_m by using the gear mechanism connected to the load.

$$J_m = J_a + J_L\left(\frac{N_1}{N_2}\right)^2 \tag{11}$$

$$D_m = D_a + D_L\left(\frac{N_1}{N_2}\right)^2 \tag{12}$$

The Table 1 parameters are used in the above equations and it gives the values of J_m and D_m are 0.03 and 0.02 respectively. The above equations are used to determine transfer function of the motor, which is relation between input voltage $E_a(s)$ and output position $\theta_o(s)$.

$$\frac{\theta_o(s)}{E_a(s)} = \frac{N_1}{N_2}\left[\frac{\frac{K_t}{R_a J_m}}{S\left[S + \frac{1}{J_m}\left(D_m + \frac{K_t K_b}{R_a}\right)\right]}\right] \tag{13}$$

The Table 1 parameters are used in the above equations and it gives the transfer function of the motor.

$$\frac{\theta_o(s)}{E_a(s)} = \frac{20.83}{S(S+1.71)} \tag{14}$$

Using Fig. 5, the open loop transfer function of the antenna azimuth position control system is obtained. It is obtained by connecting the subsystems to get the overall open-loop system.

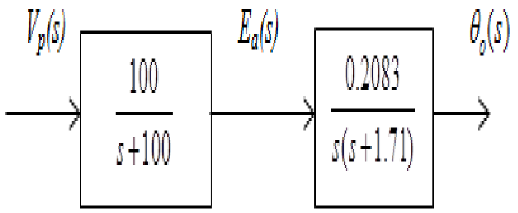

Fig. 5: Open loop system model

The overall transfer function of system is obtained by cascade connection of the above blocks. The equivalent transfer function of the open-loop system,

$$\frac{\theta_0(s)}{V_p(s)} = \frac{20.83}{s(s+100)(s+1.71)} \tag{15}$$

The above equation can be written as,

$$\frac{\omega_o(s)}{V_p(s)} = \frac{20.83}{(S+100)(S+1.71)} \tag{16}$$

4. Controller Design

The relation between angular speed $\omega_o(s)$ and $V_p(s)$ is the second order transfer function of position control of antenna azimuth. The open loop response of this transfer function is obtained by the excitation of step input. From this response, determine the first order plus delay time (FOPDT) model by using the two point method [8]. In this method, the standard transfer function is modelled with standard step input form the obtained the process reaction curve. Using the open loop response, system gain K_P is determined form the values of steady state. The values time t_1 and t_2 are calculated by using response corresponds to the 35.3% and 85.3% respectively. These time values are used to calculate the parameters τ and L using the following equations [8].

$$\tau = 0.67(t_2 - t_1) \tag{17}$$

$$L = 1.3t_1 - 0.29t_2 \tag{18}$$

The FOPDT model of the system is obtained by using two point method and it consists of system gain K_P, time constant τ and dead time L.

4.1 The conventional PI Controller Design

A PI controller consists of proportional (P) and integral (I) terms. The P control output is proportional to the error signal, it is represented as [9, 10],

$$u(t) = K_P\, e(t) \tag{19}$$

The P and I control action is represented as,

$$u(t) = K_P\left(e(t) + \frac{1}{T_i}\int e(t)\,dt\right) \tag{20}$$

Where, K_P is proportional gain or constant
T_i is integral time constant.

The integral gain, $K_i = \frac{K_p}{T_i}$

The above relations are used the determine the integral and derivative constants.

The parameter of above PID controller is obtained by using Ziegler-Nichols open loop method [11]. The tuning equations of PI controller are given below. The proportional gain of PI controller is,

$$K_p = \frac{0.9\tau}{LK} \tag{21}$$

The integral and differential time constants are obtained using the below equations [11],

$$T_i = 3.125L \tag{22}$$

Using Eqn. 20, obtain the final form of PI controller equation. The obtained process parameters K_P is 0.1218, τ is 0.59 and L is 0.01 are used in the above Eqn. (21) and (22) tuning the PI controller. The tuned value of proportional gain is 450 and the value of integral gain is 125.125.

4.2 Lead Compensator Design

Compensators are applied in electrical circuits in the structure of feed forward path. To improve system performance and increase the forward gain to reduce steady-state error by suing compensators. In this work, addresses the phase lead compensators for control of antenna azimuth position. It increases the phase margin, which is improves the closed loop performance. The transfer function of Lead compensator $G_c(s)$ is represented as,

$$G_c(s) = \alpha\frac{Ts+1}{\alpha Ts+1} \tag{23}$$

The phase lead compensator is designed by using the following steps [12].

1. Using the system transfer function G(s), get the bode plot for and determine the phase margin and gain margin for the plot.
2. The lead compensator $G_c(s)$ is designed with the desired phase margin.
3. The maximum phase lead angle, ϕ_m is obtained by using the desired phase margin (γ_d) and actual phase margin (γ)

$$\phi_m = \gamma_d - \gamma + 5^o \tag{24}$$

4. Using the below relation, determine the parameter α .

$$\alpha = \frac{1-\sin\phi_m}{1+\sin\phi_m} \tag{25}$$

5. The compensator parameter T is determined with maximum phase lead angular frequency (ω_m)

$$T = \frac{1}{\omega_m\sqrt{\alpha}} \tag{26}$$

Where, $\omega_m = -20\log_{10}\left(\frac{1}{\sqrt{\alpha}}\right)$ in db. (27)

6. The lead compensator $G_c(s)$ is represented as,

$$G_c(s) = \alpha\frac{Ts+1}{\alpha Ts+1} \tag{28}$$

Using the above steps, find the compensator parameters and determine the lead compensator transfer function is of the Antenna Azimuth position system is,

$$G_c(s) = 0.61\frac{12.56s+1}{7.68s+1} \tag{29}$$

4.3 Proposed fractional order Lead Compensator

In the field of control applications, fractional order calculus plays more important role. It provides more flexibility in the control system design [13-17], which is gained significant interest from the industrial and academic communities. Fractional calculus is a generalization of integration and differentiation of non-integer order operator ${}_aD_t^{\mu}$, where a and t denote the limits of the operation and μ denotes the fractional order such that [18],

$$ {}_aD_t^{\mu} = \begin{cases} \dfrac{d^{\mu}}{dt^{\mu}} & R \in \mu, \mu > 0 \\ 1 & R \in \mu, \mu > 0 \\ \int_a^t (dt)^{-\mu} & R \in \mu, \mu > 0 \end{cases} \quad (30) $$

From Riemann-Liouville definition [19], the fractional integral operator is given by,

$$ {}_aD_t^{-\mu} f(t) = \frac{1}{\Gamma(\mu)} \int_a^t (t-\tau)^{\mu-1} f(\tau)\, d\tau \quad \text{for } t > a \quad (31) $$

Where, μ is a positive real number, and the fractional derivative operator is,

$$ {}_aD_t^{\mu} f(t) = \frac{1}{\Gamma(m-\mu)} \left(\frac{d}{dt}\right)^m \int_a^t \frac{f(\tau)}{(t-\tau)^{\mu-m+1}} d\tau \quad (32) $$

Where, $m-1 < \mu < m, m \in \mathbb{N}, \mu \in \mathbb{R}^+$ and $\Gamma(\bullet)$ is Euler's gamma function.

The proposed fractional order lead compensator is denoted as,

$$ G_f(s) = \alpha \frac{T s^{0.25(1-\lambda)} + 1}{\alpha T s^{\lambda} + 1} \quad (33) $$

Where, $\lambda = \dfrac{\alpha T}{2(\alpha + T)}$

The obtained values of α and T are 0.612 and 12.56 respectively. These two parameters are used to determine the fractional order value λ and the value is 0.3. The resultant proposed fractional order lead compensator is represented as,

$$ G_f(s) = 0.612 \frac{12.56 s^{0.1} + 1}{7.68 s^{0.3} + 1} \quad (34) $$

Using the proposed fractional order lead compensator for enhancing the closed loop performance of antenna azimuth position control system.

5. Results and Discussion

The relation of antenna position and input voltage is represented in Eqn. 15. The position of antenna is controlled by using the designed PI controller and the closed loop response is shown in Fig. 7.

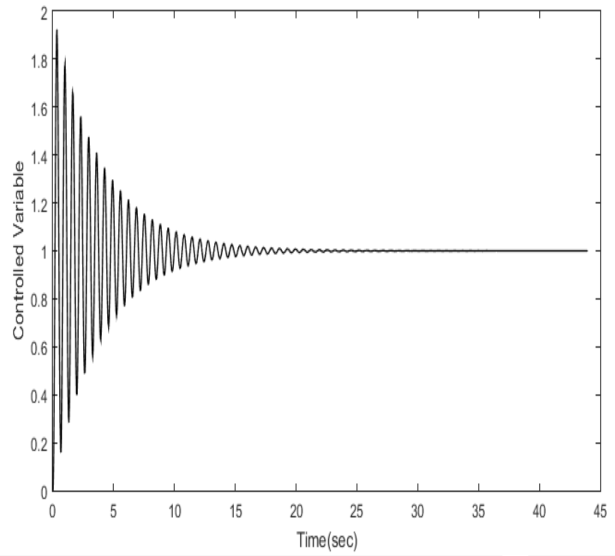

Fig. 7: Closed loop response with PI controller

From the above Fig. 7, it contains the more oscillation and peak overshoot. The closed loop performance is degraded, when using PI controller for the control of azimuth antenna position control system. The corresponding performance indices integral of the squared error (ISE) and integral of absolute error (IAE) are 10.11 and 25.71 respectively.

The lead compensator is used for the control of antenna azimuth system, for enhancing the closed loop performance. The closed loop response of lead compensator and it is shown in Fig. 8.

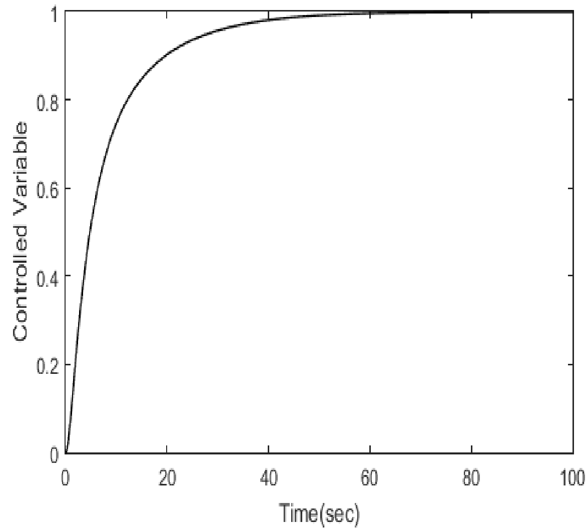

Fig. 8: The closed loop response with lead compensator

From the above Fig. 8, the closed loop response does not contain peak overshoot and oscillating behavior. The lead compensator is suitable for effective control of antenna azimuth position control system. The values of ISE and IAE are 4.874 and 8.584 respectively.

For further enhancing the closed loop performance, the fractional order lead compensator is proposed for the control of antenna azimuth position. The proposed compensator is used for obtain the closed loop response and it is shown in Fig. 9.

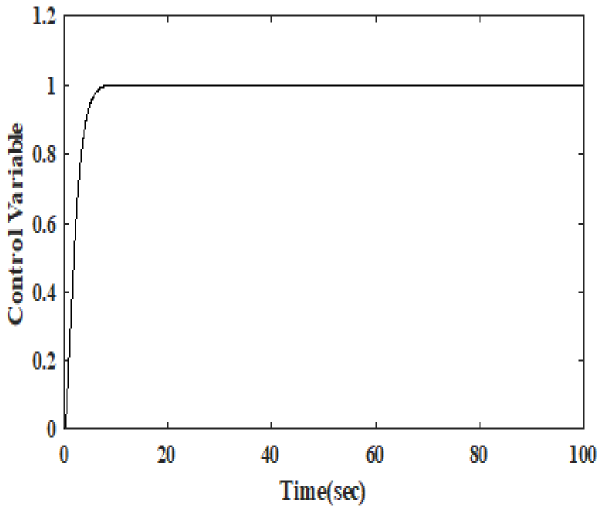

Fig. 9: The closed loop response with proposed fractional order leads compensator

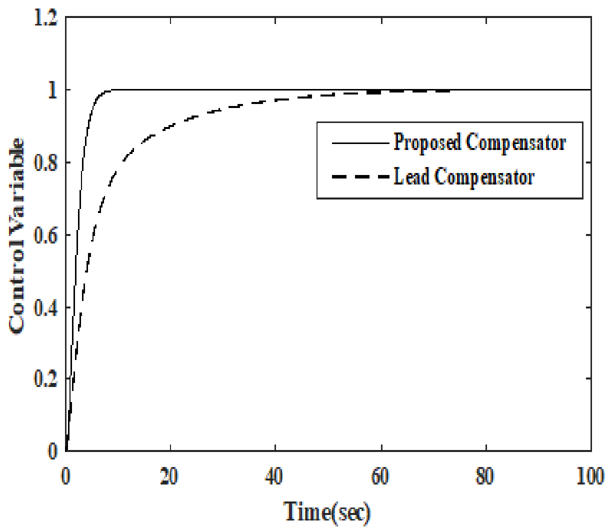

Fig. 10: Comparison of the closed loop responses

From Fig. 9, it can be noted that the speed of the response is increased and settling time is reduced. Also, the response does not contain the oscillations and peak overshoot. This enhancement of closed loop performance is achieved, when control the position of antenna by using proposed fractional lead compensator. It can be noted that, the fractional calculus play an important role for the enhancement of the closed loop response. The values of ISE and IAE are 1.407 and 2.216 respectively. The closed loop responses of the conventional lead compensator and proposed fractional order lead compensator are given in Fig. 10.

6. Conclusion

The proposed lead compensator is designed by using fractional order calculus for the control of Antenna azimuth position. The response of the fractional order lead compensator is compared with PI controller and conventional lead compensator. Using Ziegler-Nichols method tunes the parameters of PI controller and the lead compensator is designed based on the desired phase margin. The closed response containing peak overshoot and more oscillations when PI controller is used to control. The proposed fractional order lead compensator is used and the control of antenna position. It gives the better closed loop performance with factors of speed of the response and settling time. The fractional order lead compensator is delivers more closed loop performance when compared with PI controller and lead compensator.

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