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Review Article

Design of Disturbance Observer for Third- Order Interval Plants

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ABSTRACT: -
This paper outlines the development of a disturbance observer (DOB) specifically tailored forthird-order interval plants, which are distinguished by uncertainties in their parameters. Utilizing an interval-based modeling approach, this design effectively captures variations in system dynamics, providing robust control solutions for plants with parameter uncertainties. The key focus is creating a disturbance observer capable of real-time estimation and compensation for external disturbances and model uncertainties. The proposed DOB is engineered using a nominal model of the third-order plant, carefully considering the interval uncertainties. The paper includes simulation results that effectively illustrate the effectiveness of the disturbance observer in achieving disturbance rejection and robust control performance of third-order interval plants. The method notably enhances system stability and robustness, especially in significant model variations and external disturbances, making it a compelling choice for applications demanding precise control under uncertain conditions. Here, the third-order interval plants are chosen by considering the uncertainty associated with each parameter,and all possible plants are designed based on the Kharitonov polynomial approach. A disturbance observer is designed for a third–order interval plant and the disturbances are identified using a disturbance observer and such system is regulated using PID Controller. Fora third-order plant the PID controller is designed which effectively regulates the uncertain plant, when this plant is subjected to the disturbances the plant is unregulated. The disturbance observer is designed for these plants to estimate the external disturbance, and this signal is added as feedback signal to counteract the external effects of the disturbances. Simulations are performed by considering third–order interval plants in the MATLAB environment and the uncertainties are taken in the respective parameters. Here, the reference and disturbance signalslike step, sine, square, sawtooth, and stair generator signals are considered for simulation.

Keywords: - Proportional-integral derivative control, Low Pass Filter, Disturbanceobserver (DOB), Third order interval plants, Kharitonov polynomial method

INTRODUCTION:

The development of disturbance observers (DOB) is a critical area within control engineering, particularly for systems that are prone to external disturbances and internal uncertainties. Real-world applications are often subjected to factors such as changes in the environment, sensor noise, and variations in parameters. This challenge is further compounded in interval plants, where system parameters fluctuate within predetermined bounds. As a result, controlling higher-order systems such as third-order plants become particularly demanding. The systems typically represent processes involving multiple energy storage elements, such as mass, capacitance, orinductance, and find wide-ranging applications in mechanical, electrical, and aerospace engineering. An interval plant is an uncertain system characterized by parameters, such as thecoefficients in the transfer function, that are not precisely known but instead lie within specificranges. These ranges represent the inherent uncertainty in the system and can result from various sources, including manufacturing variabilities, component aging, or fluctuations in operating conditions. Unlike traditional fixed-parameter systems, the dynamic behavior of an interval plant can exhibit significant variation within the specified bounds, leading to a wide range of potential system behaviors. Consequently, control systems designed for interval plants must demonstrate robustness to effectively address the diverse, dynamic behaviors and uncertainties present within the specified parameter ranges.

In the context of third-order systems, which are characterized by transfer functions containing cubic polynomials in the denominator, the challenges related to control and disturbance rejection become notably intricate. Due to their inherent complexity, third-order systems are particularly susceptible to dynamic uncertainties and often demonstrate intricate responses to external disturbances. This underscores the critical need for the development of robust and adaptive control strategies to effectively address these complexities. Disturbance observers (DOBs) play a pivotal role in control systems by accurately estimating and counteracting the impact of disturbances on a system. The fundamental concept behind a DOB involves estimating disturbances and these signals are added at the control terminal to counteract the disturbances, subsequently mitigate these disturbances. This capability allows the controller toadapt its actions to nullify the effects of disturbances, thereby enhancing the overall system performance. DOBs are particularly effective in mitigating the impact of unknown and time- varying disturbances, and they can also address certain types of model uncertainties, making them well-suited for controlling interval plants.

LITERATURE REVIEW: -

A disturbance observer (DOB) is a type of state observer used in control systems. Unlike traditional state observers, which estimate the states of a system, a disturbance observer measures and reimburses for the effects of disturbances on the system. By actively estimating and compensating for disturbances, DOB can enhance disturbance rejection, improve system stability, and reduce sensitivity to model uncertainties. In linear systems, disturbance observers can be designed using linear techniques such as state-space modeling, pole placement, or frequency domain analysis. The observer's performance can be analyzed using stability and performance metrics from linear control theory. In nonlinear systems, disturbance observers need to be designed with consideration for the system's nonlinearities. This typically involves using nonlinear observers, such as sliding mode observers [1],[2] extended Kalman filters or nonlinear adaptive observers. These observers are designed to estimate and compensate for disturbances in the presence of nonlinearities.

The work of disturbance observers is common in many domains, including robotics. By adjusting for external disturbances like friction, the observer in robotic systems [3],[4] may improve the trajectory tracking accuracy. In mechanical systems like servo motors and actuators to enhance position control and reduce the effects of disturbances such as friction andload variations [5],[6]. In aircraft control systems [7],[8] it enhances stability and control performance, particularly in the presence of atmospheric disturbances. DOBs can be used in process control systems to improve the regulation of variables such as temperature, pressure, and flow rate by compensating for disturbances in the process [9],[10]. In this work, the design of disturbance observers is designed for estimating the disturbances and a PID controller is regulating the third order interval plants. The following paragraph discusses the interval of plants.

In 1978, the Russian Mathematician Vladimir L. Kharitonov developed the Khaitonov polynomial method. The Kharitonov polynomial method is used to analyze the stability of a higher-order (or) third-order system. When its characteristic polynomial's coefficients are uncertain and vary within specific intervals. The research on third-order interval system stabilization. By stabilizing a group of eight extreme plants that can be derived from the highest and lower values of uncertain parameters, a constant gain controller is demonstrated to stabilize an interval plant family in [11]. It was shown in [12] that if a first order controller stabilizes the set of extreme plants, it would also stabilize an interval plant. It was shown in [13] that a first order controller can only stable an interval plant when it also stabilizes the family of sixteen Kharitonov plants. The Hermite-Biehler theorem's generalized form was applied to the stabilization of interval systems in [14]. This section uses the stability boundary locus to find all the values of the parameters of a PID controller for which the given interval plant is Hurwitz stable, rather than the Routh tables that were used in [12] to characterize all the parameters of a first order controller that stabilizes an interval plant.

OBJECTIVES OF STUDY (ADDRESSING GAPS): -

Third - order interval plants whose coefficients vary in the specific intervals are considered. Using Kharitonov polynomials all possible plants are generated considering these uncertain parameters. Regulation of third-order interval plants in a disturbance region are considered where the plant dynamics are affected by the disturbances. Here the objective is to regulate the plant under these disturbance conditions. To regulate these plants a conventional PID Controller is designed. The conventional PID controller is a robust controller which can reject/reduce the effect of disturbances. If the disturbance or uncertain signal magnitude is morethan a certain value, then it may be unable to regulate the plant dynamics. To regulate this plant under these different disturbance conditions a disturbance observer is designed to estimate thedisturbance signal. This estimated disturbance signal is subtracted from the original disturbance signal to as to nullify its impact on the plant.

ORGANIZATION OF PAPER: -

Section II discusses the concept of the disturbance observer. Section III discusses the design aspects of low-pass filter. Section IV discusses the Kharitonov family of plants of an interval system. Section V discusses the detailed block diagram used in the MATLAB environment. Section VI discusses simulation results. In section VII references are given.

CONCEPT OF DISTURBANCE OBSERVER: -

The concept of the Disturbance Observer (DOB) was first introduced by Japanese scholar Ohnishi in 1987 (Ohnishi) [15] and has since been a subject of significant interest. The general structure of DOB, as illustrated in Fig.1, encompasses various key components.

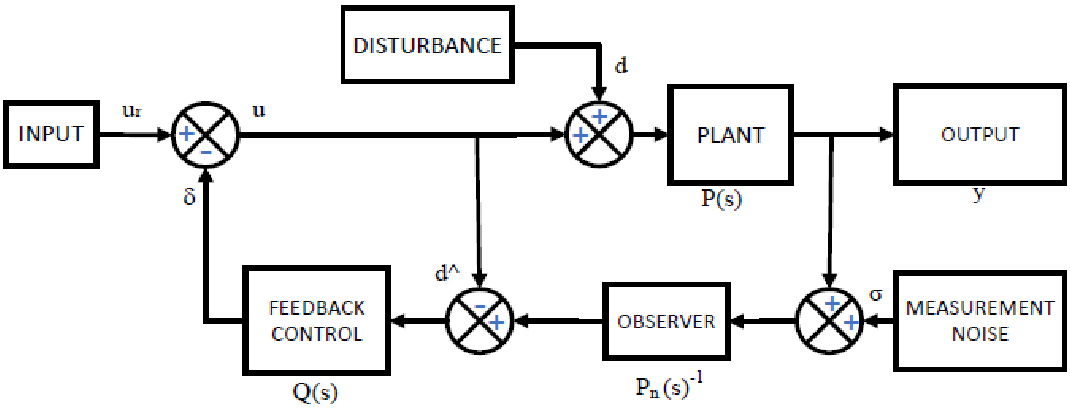

Fig.1 GENERAL STRUCTURE OF DOB

The reference input, denoted as u_r, represents the desired output, while d represents the external disturbance, σ represents the measurement noise, and y represents the output of plant P(s). The nominal model is denoted as $p_n(s)$, is typically a causal system, meaning that the denominator's order is typically higher than the numerators. External disturbances d are influenced by the intrinsic characteristics of the external environment, system nonlinearity, anduncertainty. It's worth noting that the disturbance signal 'd', is typically a low-frequency signal.The control signal, u, which denotes the difference between the reference input signal and the disturbance compensation signal d, is obtained by filtering through Q(s). It generally represents a causal system, wherein the order of the denominator is typically greater than the order of thenumerator. On the other hand, is a non-causal system, which poses practical challenges in real- world implementation. To address this, the structure is equivalently represented as shown in fig 2.

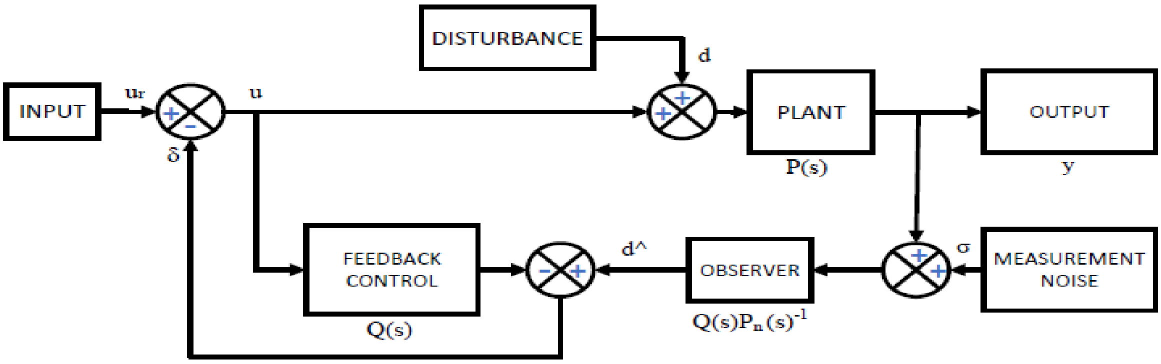

Fig. 2. EQUIVALENT STRUCTURE OF DOB

The output of a plant due to the three input signals are derived using signal flow graph theory and represented using equation (1). The sensitivity and complementary sensitivities of the closed-loop plant is denoted using equation (2) and equation (3).

$$y = \frac{P(s)P_n(s)}{P_n(s)+[P(s)-P_n(s)]Q(s)}u_r + \frac{P(s)P_n(s)[1-Q(s)]}{P_n(s)+[P(s)-P_n(s)]Q(s)}d - \frac{P(s)Q(s)}{P_n(s)+[P(s)-P_n(s)]Q(s)}\sigma \qquad (1)$$

$$S_{DOB} = \frac{P(s)P_n(s)[1-Q(s)]}{P_n(s)+[P(s)-P_n(s)]Q(s)} \qquad (2)$$

$$T_{DOB} = \frac{P(s)Q(s)}{P_n(s)+[P(s)-P_n(s)]Q(s)} \qquad (3)$$

The sensitivity function (SDOB) and compensatory sensitivity function (TDOB) clearly describe the closed loop response of the system due to low-frequency disturbances and high- frequency noise measurement respectively. The closed-loop system is clearly rejecting the disturbances/noises means the magnitude of the closed-loop response due to these signals should be small in the respective frequency region. As the filter absolute magnitude Q(s) approaches 1, the system's capability to suppress external disturbances at the input terminal is significantly enhanced (SDOB=0), as indicated by it. Conversely, when the system effectively attenuates measurement noise at the input terminal as the Q(s) approaches 0. The distinct values play a pivotal role in determining the system's performance in suppressing disturbance and noise. Therefore, the selection of appropriate values of the filter Q(s) is instrumental in simultaneously suppressing low-frequency disturbances and high-frequency noise. In an ideal scenario, the filter Q(s) should exhibit characteristics of a low-pass filter, approaching 1 at low frequencies to combat low-frequency disturbances at the input, and approaching 0 at high frequencies to counter high-frequency noise at the output.

DESIGN OF LOW PASS FILTER Q(s): -

The analysis underscores the critical role of the low-pass filter Q(s) in the DOB. The design ofthe filter is primarily focused on two key considerations (i) the orders of the numerator and denominator, and (ii) the bandwidth of the filter. Assuming the numerator order of Q(s) is ‘m’and the denominator order is ‘n’ then, the low pass filter can be expressed as $Q_{mn}(s)$, the corresponding system model is

$$P(s) = \frac{(s+z_1)\ldots\ldots\ldots\ldots(s+z_m)}{s^l(s+p_1)\ldots\ldots\ldots(s+p_n)} \qquad (4)$$

Where $p_i > 0, z_i > 0, l + n > m$.

Umeno and Hori [4] give the regular form of a low-pass filter (Umeno et al.,[4]) for thesystem represented in the equation (4):

$$Q(s) = \frac{1+\sum_{k=1}^{N-r} a_k(\tau s)^k}{1+\sum_{k=1}^{N} a_k(\tau s)^k} \qquad (5)$$

Where N is the maximum exponent power in the denominator polynomial, a_k is the coefficients of each term, s is the complex variable,τ is the time constant of the filter, and r is the variance between the structure of the numerator and numerator of the Q(s). In equation (5),the value of L is represented using N-r, and a_k with $a_k=c_k/\tau^k$, where τ is the time constant, these modifications are given using equation (6).

$$Q(s) = \frac{1+\sum_{k=1}^{L} c_k(\tau s)^k}{1+\sum_{k=1}^{N} c_k(\tau s)^k} \tag{6}$$

DESIGN OF THIRD-ORDER INTERVAL PLANT BY USING KHARITONOV POLYNOMIAL METHOD: -

The Kharitonov polynomial method is used to analyze a third-order system when its characteristic polynomial coefficients are uncertain and vary within specific intervals. Let usconsider a third-order plant which is described using G(s), where the coefficients varyin the specific intervals.

$$G(s) = \frac{N(s)}{D(s)} = \frac{q_3 s^3+q_2 s^2+ q_1 s+ q_0}{p_3 s^3+p_2 s^2+p_1 s+p_0} \tag{7}$$

Where $q_i \in [q_i^u, q_i^l], i = 0, 1, 2,3$ and $p_i \in [p_i^u, p_i^l], j = 0, 1, 2,3$ Let the Kharitonov polynomials of associated with numerator N(s) and denominator D(s) of the third order system (described by equation (7)) be denoted by Ni(s) and Dj(s), where i, j=1,2,3,4.

$$\begin{aligned}
N_1(s) &= q_3^u s^3 + q_2^u s^2 + q_1^l s + q_0^l. & D_1(s) &= p_3^u s^3 + p_2^u s^2 + p_1^l s + p_0^l\ .\\
N_2(s) &= q_3^l s^3 + q_2^u s^2 + q_1^u s + q_0^l. & D_2(s) &= p_3^l s^3 + p_2^u s^2 + p_1^u s + p_0^l\ .\\
N_3(s) &= q_3^u s^3 + q_2^l s^2 + q_1^l s + q_0^u. & D_3(s) &= p_3^u s^3 + p_2^l s^2 + p_1^l s + p_0^u\ .\\
N_4(s) &= q_3^l s^3 + q_2^l s^2 + q_1^u s + q_0^u. & D_4(s) &= p_3^l s^3 + p_2^l s^2 + p_1^u s + p_0^u\ .
\end{aligned} \tag{8}$$

By taking all combinations of the Ni(s) and Dj(s) considering i, and j, = 1,2,3,4, the following sixteen Kharitonov plant families can be obtained

$$G_k(s) = Gij\ (s) = \frac{N_i(s)}{D_j(s)} \tag{9}$$

For these systems stabilizing PID controller is designed, and simulations are performed without DOB.

DESIGN AND ANALYSIS OF DOB FOR THE THIRD ORDER SYSTEM: -

Consider a linear third-order interval plant in a disturbance region where the plant dynamics are affected by the disturbances. Here the objective is to regulate the plant under these disturbance conditions. To regulate these plants a conventional PID Controller is designed/tuned. The conventional PID controller is a robust controller which can reject/reducethe effect of disturbances. If the disturbance or uncertain signal magnitude is more than a certainvalue, then it may be unable to regulate the plant dynamics. To regulate this plant under these different disturbance conditions a disturbance observer is designed to estimate the disturbance signal. This estimated disturbance signal is subtracted from the original disturbance signal to as tonullify its impact on the plant.

The objective of the disturbance observer is to identify the exact size and shape of the disturbance signal. For this a disturbance observer is designed. This observer identifies the size and shape of the disturbance signal. This estimated signal is added properlyat the location where the plant is affected by the disturbance signal, and it is added in such a manner to nullify the effect of the disturbance signal. Hence, the resultant disturbance is equalto the zero at the input of the plant. Now the PID Controller is effectively regulating the plantdynamics.

The step-by-step procedure to design DOB is given in following paragraph.

1. Consider a third- order interval plant where the coefficients vary in the specific intervals.
2. Using Kharitonov polynomials generates all possible plants using these uncertainparameters.
3. Design a PID Controller for this interval plant to attain desired specifications. (settling-time ts= peak overshoot % M_p).
4. Ensure this PID Controller is regulating the interval plant as shown in figure 3.

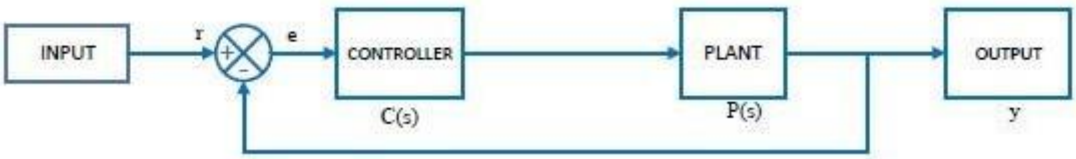

Fig.3. PID Controller along with Interval plant

5. Now verify whether the designed PID Controller is regulating the plant in the presence of disturbances as shown in figure 4.
   5.1. If the PID controller is regulating the plant along with disturbance signal, then there isno – need of designing the disturbance observer as it is robust controller. This system is simulated using the following block diagram.

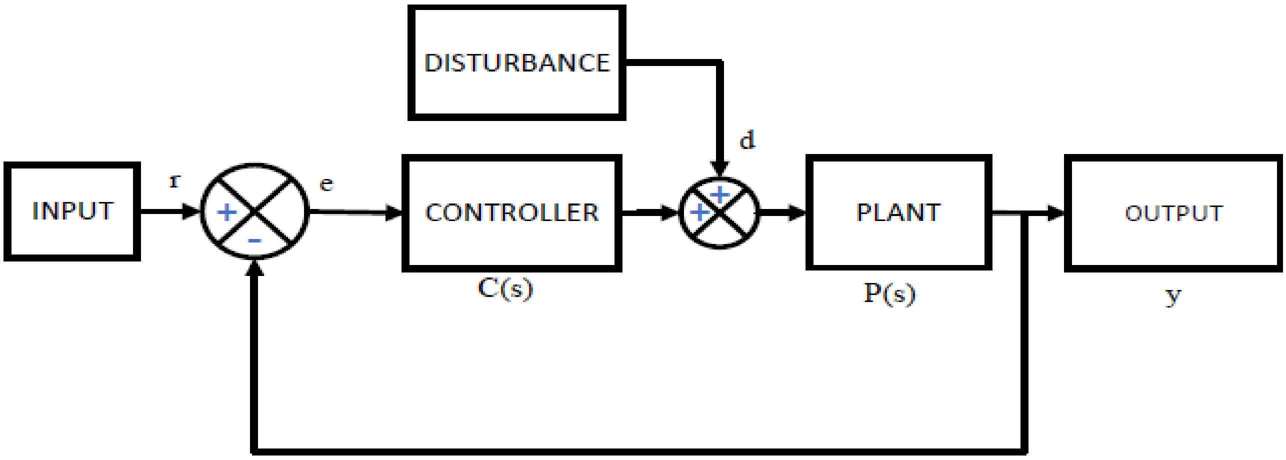

Fig.4.PID controller along with disturbance

   5.2. If the PID controller is not regulating the plant, here the plant is affected by uncertainsignals, then design an appropriate disturbance observer. The purpose of DOB is to estimate the size and type of disturbance signal.

6. After designing the disturbance observer, the disturbance signal is estimated. Now comparethe estimated signal with the actual disturbance signal. If there is any small difference between these two then filter is redesigned. This process is continued till the two signals are exactlyequal.

Then observed disturbance signal is subtracted at the appropriate location (or added with opposite sign). This estimated disturbance signal is subtracted from the original disturbance signalto as to nullify its impact on the plant.

7. Now ensure the effect of disturbances is nullified at the input of the plant.
8. The effectiveness of PID controller performance as shown in figure 5 along with DOB in regulating the dynamics of the third-order plants are verified in the MATLAB simulation environment.

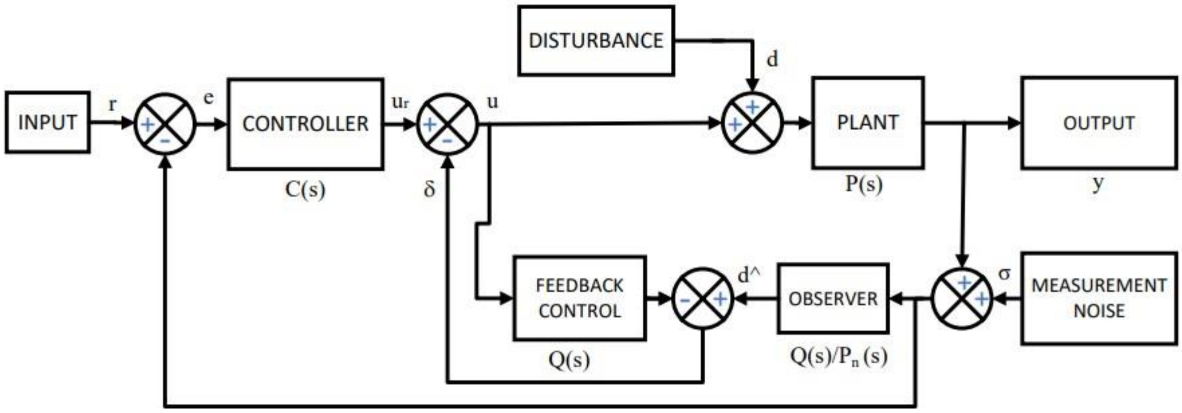

Fig.5. PID controller along with the disturbance observer

9. SIMULATION RESULTS: -

Consider a third-order transfer function described $P(s) = \frac{q_3 s^3 + q_2 s^2 + q_1 s + q_0}{p_3 s^3 + p_2 s^2 + p_1 s + p_0}$, the interval coefficients of this transfer function are defined as follows

$q_3 \in$ [1.8 2.2], q_2 = [4.5 5.5], q_1 = [2.7 3.3], q_0= [5.4 6.6], p_3 = [0.9 1.1] p_2 = [5.4 6.6], p_1 = [9.9 12.1], p_0 = [5.4 6.6].

Here, for this system, the nominal transfer function is described

$P_{nom}(S) = \frac{2S^3+5S^2+3S+6}{S^3+6S^2+11S+6}$.

Thus, the numerator and denominator Polynomials of an interval plant are,

N(S) $\in$ [1.8 2.2] s^3+ [4.5 5.5] s^2+ [2.7 3.3] s+ [5.4 6.6],

D(S) $\in$ [0.9 1.1] s^3+ [5.4 6.6] s^2+ [9.9 12.1] s+ [5.4 6.6]

Using the Kharitonov theorem, the sixteen possible plants for this system are defined and given using the equation.

$$Q(s) = \frac{1}{10^{-6}s^2+0.002s+1} \tag{10}$$

Q(s) is a second-order low-pass filter, the time constant of the filter, $\tau = 0.001$, Pn(s) is the nominal model, is generally a causal system, namely the order of the denominator is generally greater than the order of the numerator. The PID Controller designed for this system is, $C(s) = 10 + \frac{40}{s} + 0.2s$; simulation Time = 40 s, $P_n(s) = \frac{1.53}{0.0254s^2+s}$.

TABLE. NO.1 SIXTEEN POSSIBLE PLANTS OF THIRD-ORDER INTERVAL PLANTS.

Sl. No.	PLANT EQUATIONS	Sl. No.	PLANT EQUATIONS
1	$G_1(s) = \frac{2.2\,s^3 + 5.5\,s^2 + 2.7\,s + 5.4}{1.1\,s^3 + 6.6\,s^2 + 9.9\,s + 5.4}$	9	$G_9(S) = \frac{2.2s^3+4.5s^2+2.7s+6.6}{1.1s^3+6.6s^2+9.9s+5.4}$
2	$G_2(S) = \frac{2.2s^3+5.5s^2+2.7s+5.4}{0.9s^3+6.6s^2+12.1s+5.4}$	10	$G_{10}(S) = \frac{2.2s^3+4.5s^2+2.7s+6.6}{0.9s^3+6.6s^2+12.1s+5.4}$
3	$G_3(S) = \frac{2.2s^3+5.5s^2+2.7s+5.4}{1.1s^3+5.4s^2+9.9s+6.6}$	11	$G_{11}(S) = \frac{2.2s^3+4.5s^2+2.7s+6.6}{1.1s^3+5.4s^2+9.9s+6.6}$
4	$G_4(S) = \frac{2.2s^3+5.5s^2+2.7s+5.4}{0.9s^3+5.4s^2+12.1s+6.6}$	12	$G_{12}(S) = \frac{2.2s^3+4.5s^2+2.7s+6.6}{0.9s^3+5.4s^2+12.1s+6.6}$
5	$G_5(S) = \frac{1.8s^3+5.5s^2+3.3s+5.4}{1.1s^3+6.6s^2+9.9s+5.4}$	13	$G_{13}(S) = \frac{1.8s^3+4.5s^2+3.3s+6.6}{1.1s^3+6.6s^2+9.9s+5.4}$
6	$G_6(S)= \frac{1.8s^3+5.5s^2+3.3s+5.4}{0.9s^3+6.6s^2+12.1s+5.4}$	14	$G_{14}(S) = \frac{1.8s^3+4.5s^2+3.3s+6.6}{0.9s^3+6.6s^2+12.1s+5.4}$
7	$G_7(S) = \frac{1.8s^3+5.5s^2+3.3s+5.4}{1.1s^3+5.4s^2+9.9s+6.6}$	15	$G_{15}(S)= \frac{1.8s^3+4.5s^2+3.3s+6.6}{1.1s^3+5.4s^2+9.9s+6.6}$
8	$G_8(S) = \frac{1.8s^3+5.5s^2+3.3s+5.4}{0.9s^3+5.4s^2+12.1s+6.6}$	16	$G_{16}(S) = \frac{1.8s^3+4.5s^2+3.3s+6.6}{0.9s^3+5.4s^2+12.1s+6.6}$

CASE- I :- STEP INPUT AND SINE DISTURBANCE:-

A PID controller is designed for this interval plant, here, this system is excited by a step input, the response of the system is shown in Fig.6. It shows that under the presence of disturbances the controller is unable to regulate the plant. Therefore, a disturbance observeris designed for this system. And this process requires the design of a filter andthe time constant of the filter is considered 0.001. It is given using equations (10). Now the simulations have been performed by considering reference input of step, and disturbance input of sinusoidal. Simulations are performed by considering four different combinations generated using PID controller as well as a DOB. The response of the interval plant with disturbance observer along with the PID controller is shown on Fig.6.

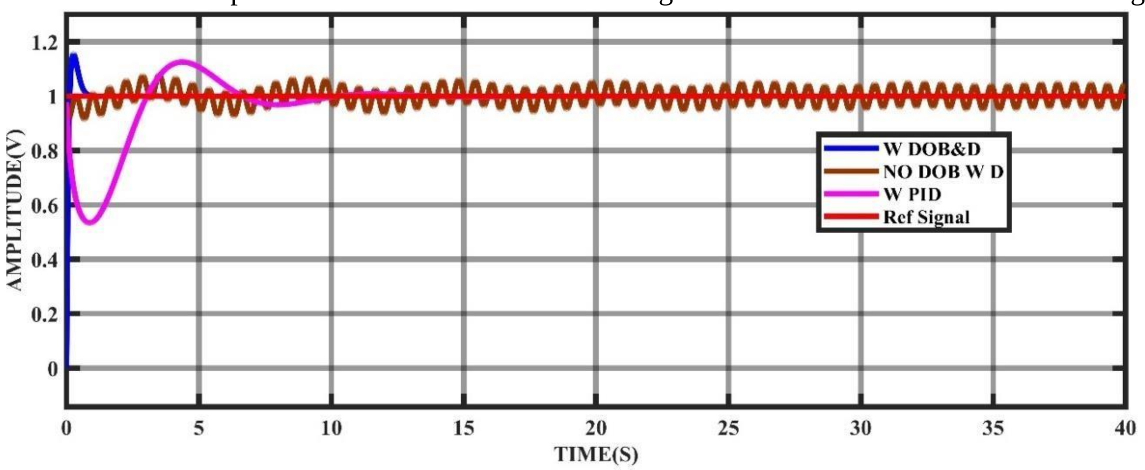

FIG.6.THE STEP RESPONSE WITH SINE DISTURBANCE

CASE- II: - STEP INPUT AND STEP DISTURBANCE: -

A PID controller is designed for this interval plant here this system is excited by a step input the response of the system is shown in Fig.7. It shows that under the presence of disturbances the controller is unable to regulate the plant. Therefore, a disturbance observeris designed for this system. And this process requires the design of a filter andthe time constant of the filter is considered 0.001. It is given using equations (10). Now the simulations have been performed by considering reference input of step, and disturbance input of step. Simulations are performed by considering four different combinations generated using PID controller as well as a DOB. The response of the interval plant with disturbance observer along with the PID controller is shown in Fig.7.

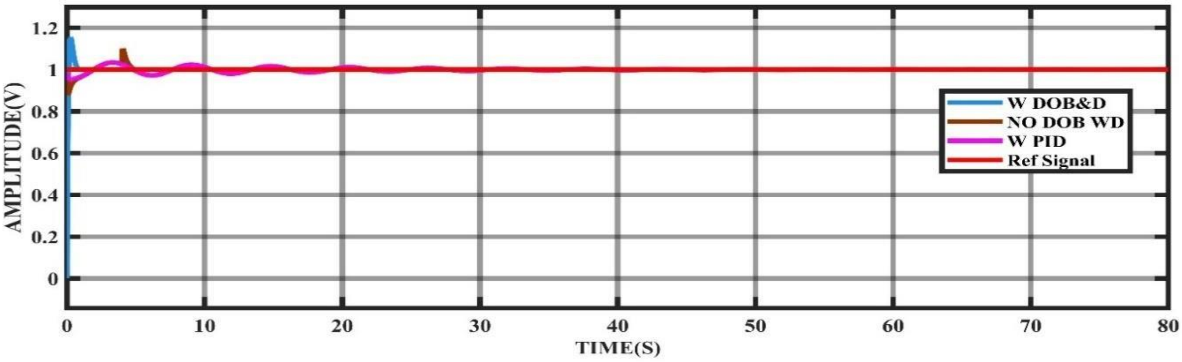

FIG.7.THE STEP RESPONSE WITH STEP DISTURBANCE

CASE- III :- STEP INPUT AND RANDOM DISTURBANCE:-

A PID controller is designed for this interval plant here this system is excited by a step input the response of the system is shown in Fig.8. It shows that under the presence of disturbances the controller is unable to regulate the plant. Therefore, a disturbance observer is designed for this system. And this process requires the design of a filter and the time constant of the filter is considered 0.001. It is given using equations (10). Now the simulations have been performed by considering reference input of step, and disturbance input of random. Simulations are performed by considering four different combinations generated using PID controller as well as a DOB. The response of the interval plant with disturbance observer along with the PID controller is shown in Fig.8.

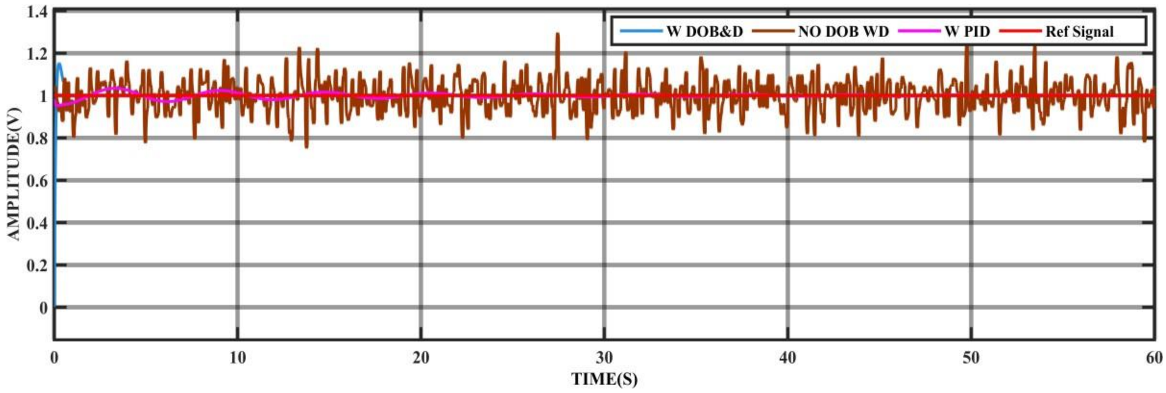

FIG.8.THE STEP RESPONSE WITH RANDOM DISTURBANCE

CASE- IV:- SINE INPUT AND SINE DISTURBANCE:-

A PID controller is designed for this interval plant here. This system is excited by a Sine input the response of the system is shown in Fig.9. It shows that under the presence of disturbances the controller is unable to regulate the plant. Therefore, a disturbance observer is designed for this system. And this process is requires the design of a filter andthe time constant of the filter is consider 0.001. It is given using equations (10). Now the simulations have been performed by considering reference input of sine, and disturbance input of sine. Simulations are performed by considering four different combinations generated using PID controller as well as a DOB. The response of the interval plant with disturbance observer along with the PID controller is shown in Fig.9.

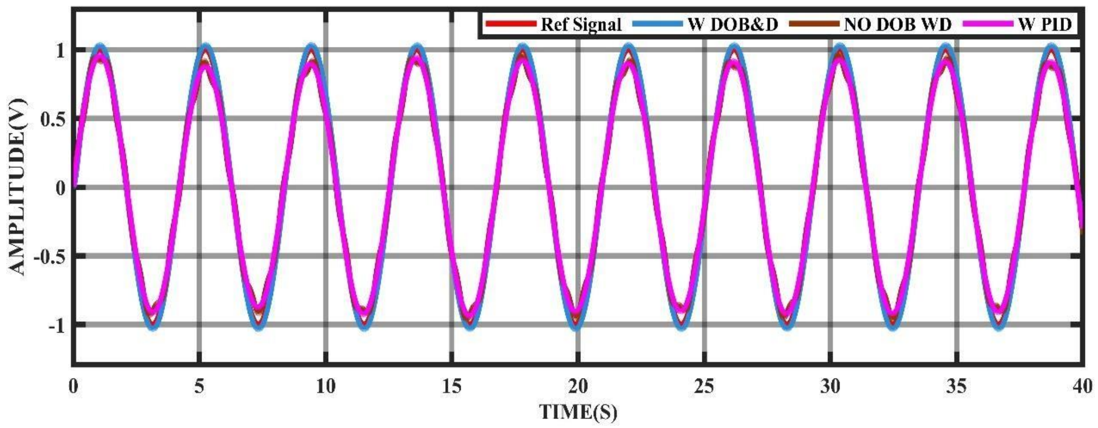

FIG.9.THE SINE RESPONSE WITH SINE DISTURBANCE

CASE- V:- SQUARE INPUT AND SQUARE DISTURBANCE:-

A PID controller is designed for this interval plant here this system is excited by a square input the response of the system is shown in Fig.9. It shows that under the presence of disturbances the controller is unable to regulate the plant. Therefore, a disturbance observer is designed for this system. And this process requires the design of a filter and the time constant of the filter is considered 0.001. It is given using equations (10). Now the simulations have been performed by considering reference input of square, and disturbance input of square. Simulations are performed by considering four different combinations generated using PID controller as well as a DOB. The response of the interval plant with disturbance observer along with the PID controller is shown in Fig.9.

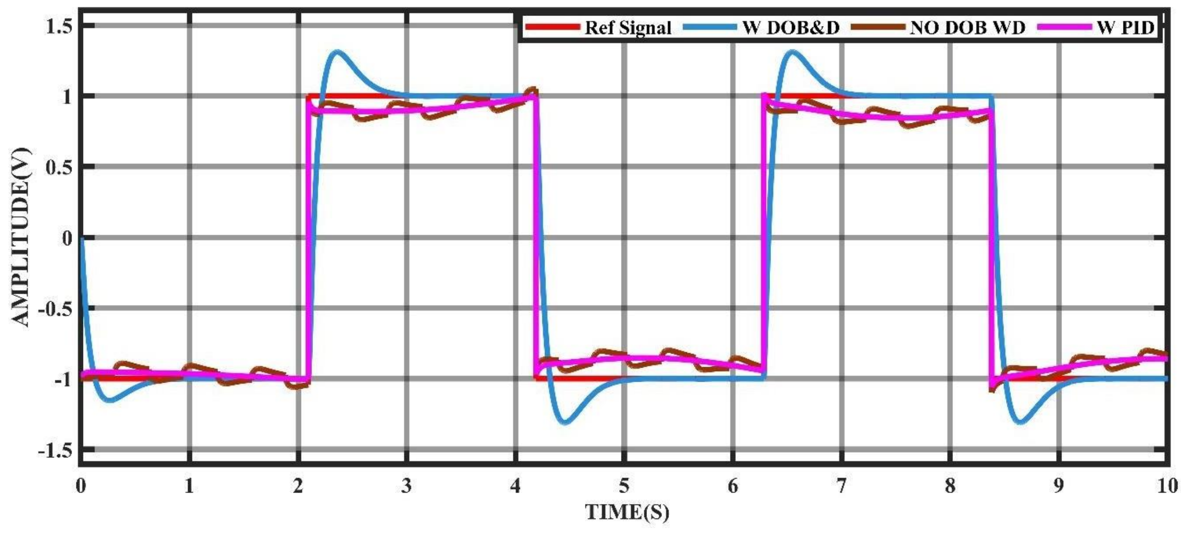

Fig.9.The Square Response with Square Disturbance

CASE- VI:- Sawtooth Input and Sawtooth Disturbance:-

A PID controller is designed for this interval plant here. This system is excited by a sawtooth input the response of the system is shown in Fig.10. It shows that under the presence of disturbances the controller is unable to regulate the plant. Therefore, a disturbance observeris designed for this system. And this process requires the design of a filter and the time constant of the filter is considered 0.001. It is given using equations (10). Now the simulations have been performed by considering reference input of sawtooth, and disturbance input of step. Simulations are performed by considering four different combinations generated using PID controller as well as a DOB. The response of the intervalplant with disturbance observer along with the PID controller is shown in Fig.10.

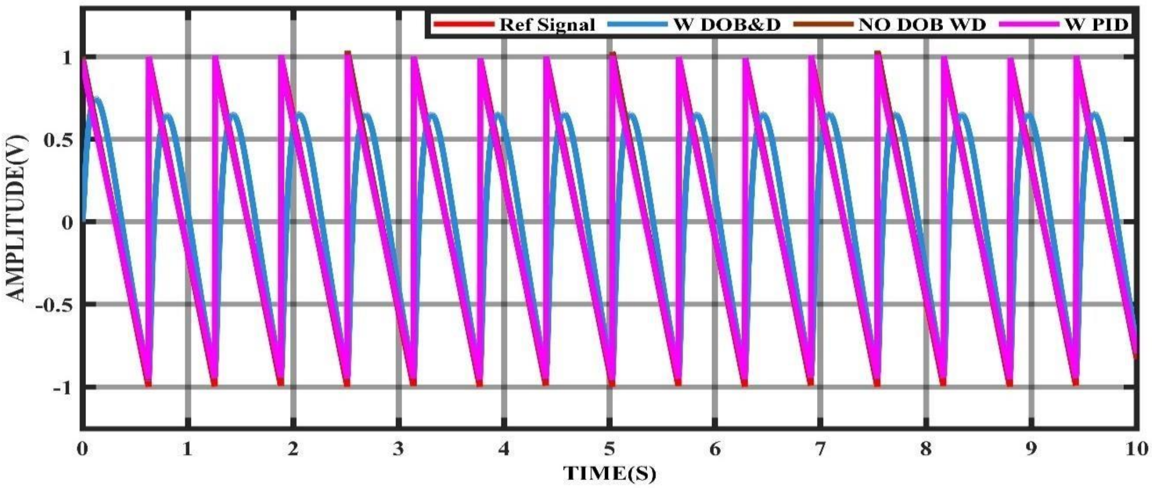

FIG.10.The Sawtooth Response with Sawtooth Disturbance

CASE- VII: - Stair Generator Input and Random Disturbance:-

A PID controller is designed for this interval plant here is excited by a Stair input the response of the system is shown in Fig.11. It shows that under the presence of disturbances the controller is unable to regulate the plant. Therefore, a disturbance observeris designed for this system. And this process is requires the design of a filter and the time constant of the filter is consider 0.001. It is given using equations (10). Now the simulations have been performed by considering reference input of stair generator, and thedisturbance of random is considered. The response of the interval plant with disturbance observer along with the PID controller is shown in Fig 11.

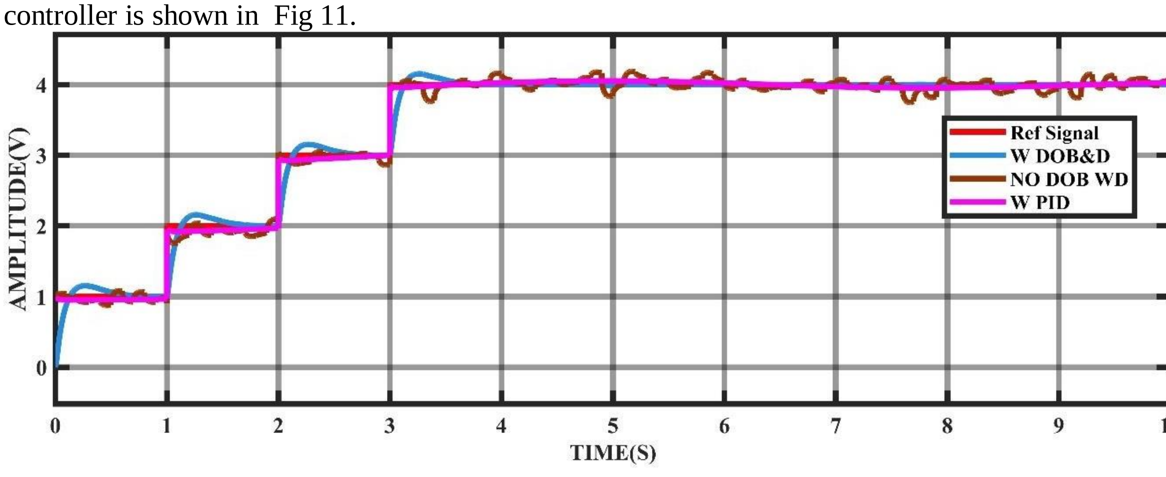

Fig.11.The Stair Generator Response with Random Disturbance

CONCLUSION: -

In this work, the disturbance observer is designed for third-order interval plants. The plant coefficients(or) polynomial coefficients of the third-order coefficient system are varied within the specific interval i.e., varied within the limits. For such a system, a PID controlleris designed and here, the uncertain interval plant is subjected to the unknown signals (or) unknown exogenous signals. If the designed PID controller is unable to regulate the plant with exogenous signals. A disturbance observer is designed by considering a second-order filter and also simulations are performed using this disturbance observer along with the PID controller. Here, a wide variety of simulations are performed by considering (i) the differenttypes of input signals like step, sine, square, sawtooth, and stair generator and (ii) the different types of disturbance signals like step, sine, square, sawtooth, and random signal. Seven different cases are considered for a third-order interval system. Simulations are performed by considering (i) step input with step disturbance, (ii) step input with sine disturbance, (iii) sine input with sine disturbance, (iv) square input with square disturbance, (v) sawtooth input with sawtooth disturbance, (vi) step input with random signal, and (vii)stair generator input with random signal disturbance. For all these cases, the PID controller along with DOB is exhibiting better time-response characteristics.

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