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SLIDING MODE GOVERNING SYSTEM CONTROL USING PID SURFACE AND SECOND AND THIRD ORDER PLANT

G Ganesh Gangadhar Kalyan[1], Mr. K Venkateswara Rao[2]

[1] M.Tech Scholar, PEED, Baba Institute of Technology and Sciences.

[2] Assistant Professor, Baba Institute of Technology and Sciences.

Introduction :

A control strategy known as PID Surface Sliding Mode Control (PID Surface SMC) blends the concepts of Sliding Mode Control (SMC) and Proportional-Integral-Derivative (PID) control. The goal of this hybrid strategy is to attain better control performance by utilizing the advantages of both approaches. Like traditional SMC, PID Surface SMC defines a sliding surface to direct the behaviour of the system. But PID Surface SMC integrates the continuous control adjustments characteristic of PID control, rather than depending only on discontinuous control actions like SMC. This combination preserves SMC's robustness and disturbance rejection capabilities while enabling accurate and seamless system control.

The PID component of the controller contributes to error correction over time (Integral), immediate error response (Proportional), and anticipatory control action based on the rate of error change (Derivative). Because of these features, PID Surface SMC is a good choice for applications like advanced robotics and industrial processes where precise control and disturbance rejection are crucial. The second and third order plants are subjected to the control methods that were discussed, and the plant stabilization is confirmed on these plants by applying the Kharitonov polynomials technique.

This study compares and contrasts four advanced control strategies that are used with DC motors and second and third order plants: PID (proportional-integral-derivative) controller, SMC (sliding mode control), M-SMC (modified sliding mode control), and PID (PIDsur-SMC) surface sliding mode control. PID control offers a simple method for optimizing systems to reduce system deviations from target setpoints. Three distinct types of SMC structures are designed: SMC, modified SMC (M-SMC), and SMC with a PID surface (PIDsur-SMC).

DC Motor simulation and its Interval plant stabilization simulation

2.1 DC motor simulation

The intrinsic transfer function of the DC motor system is described by equation (5.1). Within the MATLAB Simulink environment, a series of simulations are run under the direction of this transfer function. Evaluating the DC motor's performance in relation to particular speed responses is the goal. Notably, a wide range of control techniques are applied to the system, resulting in noticeable differences in performance outcomes, highlighting their unique impacts.

During the course of these simulations, a step response is started and a step disturbance is added at intervals of 15 milliseconds. Figure 5.1 provides a clear visual representation of the resulting system response and provides an understanding of the system's dynamic behavior. To provide more details, the exact requirements guiding this response are carefully gathered and organized
within Table (5.1)

$$P(s) = \frac{0.6}{0.00676S^2 + 0.1622S + 0.36} \quad (5.1)$$

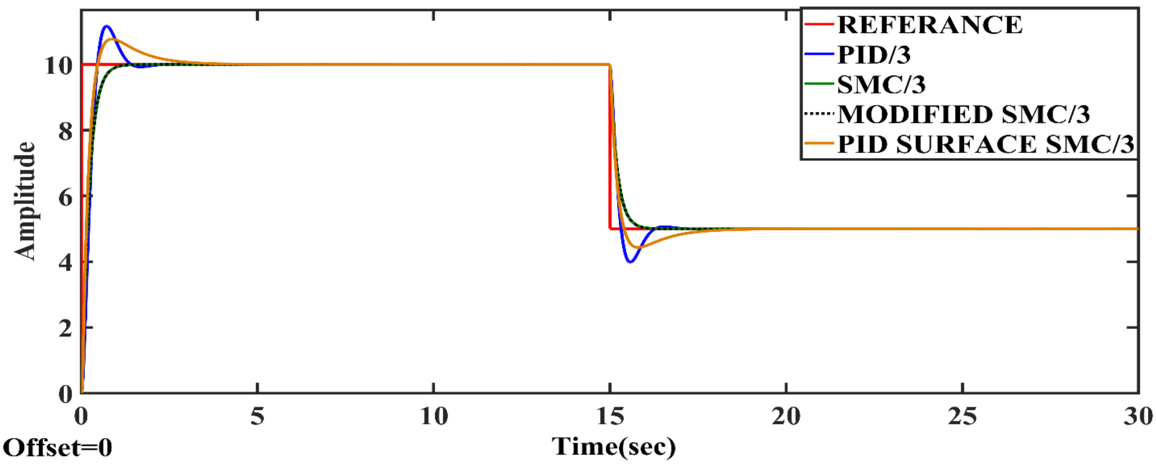

Fig .2.1 response of the dc motor

Controller	***Rise Time (sec)***	***Settling time (sec)***	***Overshoot(%)***
PID	0.3126	1.2267	11.7014
SMC	0.4392	0.8014	4.2e-05
M-SMC	0.4395	0.8016	0
PIDsur-SMC	0.2927	2.1671	7.7474

Table-2.1 Transient Response Specifications of DC Motor

The data analysis in Table (5.1) shows clear patterns among the various control methods. To be more precise, the PID controller exhibits more overshoot than the other control strategies. On the other hand, the PID-sur-SMC arrangement outperforms its PID, SMC, and Modified-SMC (M-SMC) counterparts, showing a regulated degree of overshoot despite a slightly longer settling time. All of the evaluated parameters show similar performance from the SMC and Modified-SMC techniques; the latter indicates that Modified-SMC is not much more accurate than SMC. Among all the controllers taken into consideration in this study with a small rise time, the PIDsur-SMC controller stands out particularly for providing the better response.**5.2.2 Interval Plant Stabilization of DC Motor**

The relevant transfer function of the DC motor system is defined by equation (5.1). The dynamics of the transfer function are improved by using interval plant stabilizing strategies. By using the Kharitonov polynomials approach, it is possible to derive an extensive family of eight Kharitonov plants, which provides a detailed comprehension of the behavior of the system. Equation (5.2), which neatly depicts the interval plant connected with the DC motor system, succinctly captures this intricate interplay.

$$P(s) = \frac{\left[0.51 \quad 0.69\right]}{\left[0.0057 \quad 0.0077\right]S^2 + \left[0.1378 \quad 0.1865\right]S + \left[0.306 \quad 0.414\right]} \quad (5.2)$$

Exploring a single Kharitonov plant within a family comprising eight interval second-order DC motor plants, the transfer function is elegantly depicted through equation (5.3). With a focus on comprehensive performance assessment, this specific system is subjected to simulation within the MATLAB environment, incorporating four distinct controllers. The outcomes are vividly represented in Figure 5.2, showcasing the system's responses. Detailed specifications of these responses are systematically presented within Table (5.2).

$$P(s) = \frac{0.69}{0.00774S^2 + 0.18653S + 0.306} \quad (5.3)$$

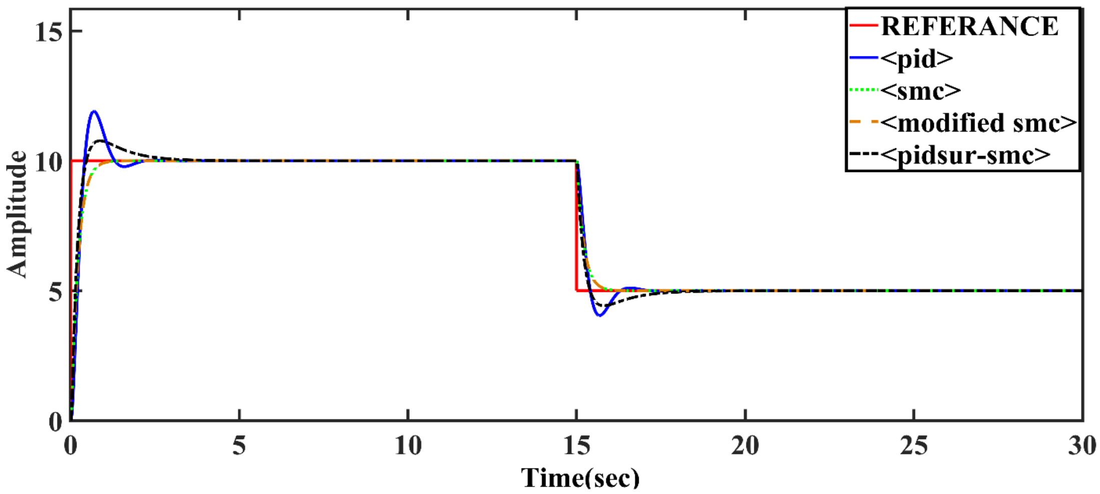

Fig .2.2 response of DC Motor interval plant

Table .2.2 Transient response of DC Motor Interval plant stabilization

Controller	*Rise Time (sec)*	*Settling Time (sec)*	*Overshoot(%)*
PID	0.2857	1.6908	18.0728
SMC	0.4394	0.8012	1.89e-06
M-SMC	0.4396	0.8017	0
PIDsur-SMC	0.2901	2.1599	7.640

Observations from Table (2.2) highlight the transient response of the DC Motor concerning Interval plant stabilization. Notably, the controllers exhibit analogous characteristics in comparison to the standard DC Motor simulations. However, the PID controller in this context displays a marginal increase in overshoot when contrasted with its performance in the previous scenario due to interval plant stabilization.

3 Second order plant simulation and its Interval plant stabilization

3.1Second order plant simulation

Examining the properties of a second-order plant, equation (3.4) elegantly captures its transfer function. In this regard, a thorough analysis of the performance of the particular system is carried out using simulations that are aided by four different control approaches. The results of these simulations, which take place in the MATLAB environment, are illuminating and are illustrated in Figure 3.3. The second order plant's response provides a precise estimate of the controller to choose depending on the application.

$$G(s) = \frac{8}{S^2 + 4S + 8} \quad (5.4)$$

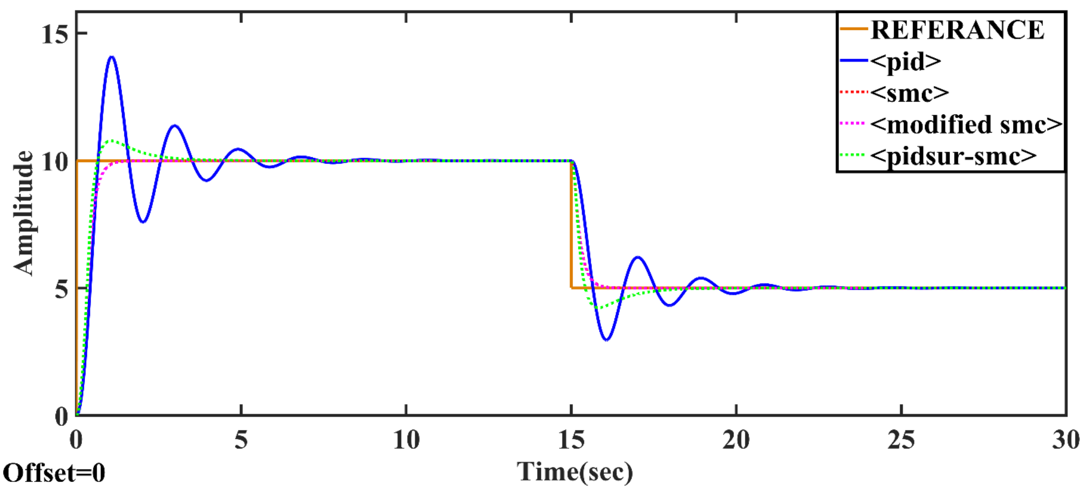

Fig .3.3 response of the second order plant

Table .3.3 Transient response comparison of second order plant controllers

Controller	*Rise Time (sec)*	*Settling Time (sec)*	*Overshoot(%)*
PID	0.4300	6.0574	40.80
SMC	0.5150	0.9731	5.45e-08
M-SMC	0.5139	0.9689	0
PIDsur-SMC	0.3453	2.3562	7.745

Table (3.3) shows that, in comparison to the other controllers, the PID controller has a relatively long settling period. Moreover, the PID controller exhibits a larger amplitude of overshoot than the other controllers. On the other hand, the transient response characteristics of the SMC and M-SMC controllers are similar, albeit the latter displays slightly better precision than the traditional SMC approach. Out of four controllers, PIDsur-SMC configuration has the fastest response time. This quicker reaction is accomplished without sacrificing the allowable overrun threshold.

.3.2 Plant Interval Maintenance of second-order plant stability

Considering the second-order plant, its encompassing transfer function is elegantly defined by equation (3.4). By using Kharitonov polynomials in conjunction with interval plant stabilization, a more comprehensive viewpoint becomes possible.

. Through this technique, a comprehensive family of eight Kharitonov plants is derived, symbolizing the system's behavior. Aptly summarized by equation (5.5), this interval plant encapsulates the attributes of the second-order plant. The ensuing results yield a set of eight distinct Kharitonov plants, thereby enriching and understanding of the system's intricate dynamics.

$$P(s) = \frac{[6.4 \quad 9.6]}{[0.8 \quad 1.2]S^2 + [3.2 \quad 4.8]S + [6.4 \quad 9.6]} \quad (5.5)$$

First Kharitonov plant of Interval plant stabilization of a second order system

Think about the interval plant of the second-order system, as expressed in equation (5.5). Out of the eight Kharitonov plants, one is highlighted in particular and is provided in equation (5.6). Based on this fine-tuned selection, four different control strategies are carefully simulated in MATLAB. The results of these simulations are graphically displayed in Figure.5.4, which tastefully displays each controller's response properties. To further elucidate these results, the exact response parameters are organized in a systematic manner in Table (5.4). It is possible to estimate the system performance based on the specs. It simplifies comparisons with the second-order nominal plant and sheds light on system stabilization when this Kharitonov plant is simulated.

$$G(s) = \frac{6.4}{0.8S^2 + 3.2S + 9.6} \quad (5.6)$$

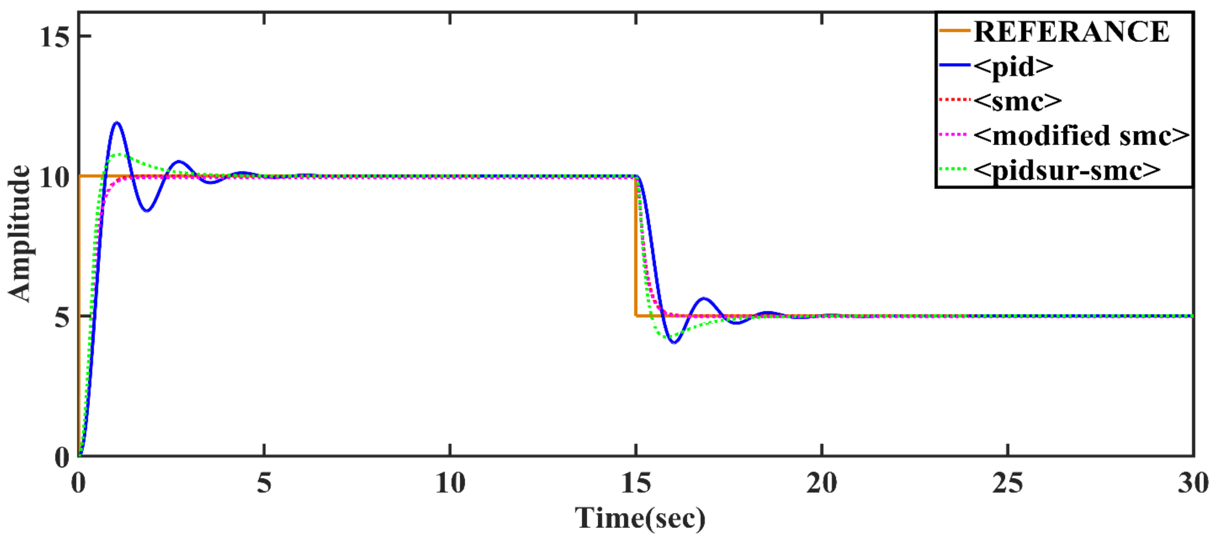

Fig .3.4Response of second order interval plant-1

Table .3.4 Transient response of second order interval plant-1

Controller	***Rise Time (sec)***	***Settling Time (sec)***	***Overshoot(%)***
PID	0.4722	3.7111	19.0714
SMC	0.5216	0.9800	4.901e-07
M-SMC	0.5153	0.9621	0
PIDsur-SMC	0.3933	2.3648	7.7436

The data encapsulated within Table (3.4) elucidates distinct performance trends among various control strategies. Specifically, the PID controller is characterized by elevated overshoot and extended settling time in comparison to alternative control methods. In contrast, both SMC and modified SMC strategies exhibit similar response patterns, with the latter showcasing zero overshoot and notably expedited settling by the modified SMC. Additionally, PID surface-SMC demonstrates early settling time in comparison to other controllers, alongside minimal overshoot as compared to PID.

Second Kharitonov plant of Interval plant stabilization of a second order system

Within the scope of the second-order interval plant described by equation (3.5), the focus is narrowed to the selection of the second Kharitonov plant within its coefficient range. MATLAB Simulink simulations are meticulously executed for this specific Kharitonov plant, employing an array of diverse control strategies. The outcomes of these simulations are visually represented through Figure .3.5, illuminating the response dynamics of the system under varied controls. Providing a more granular insight, the precise specifications of this particular response are systematically outlined within Table (3.5).

$$G(s) = \frac{9.6}{1.2S^2 + 4.8S + 6.4} \quad (5.7)$$

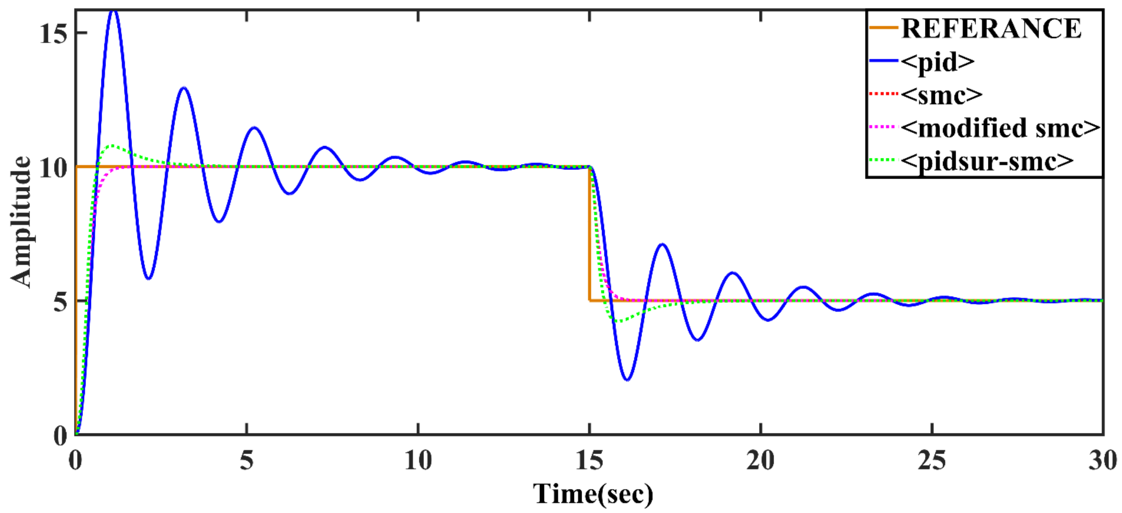

Fig .3.5Response of second order Interval plant-2

Table .3.5 Transient response of second order interval plant-2

Controller	***Rise Time(sec)***	***Settling Time(sec)***	***Overshoot(%)***
PID	0.4088	10.5588	59.2701
SMC	0.5116	0.9693	5.490e-08
M-SMC	0.5105	0.9670	0
PIDsur-SMC	0.3808	2.3516	7.7442

The data presented in Table (3.5) provides valuable insights into the performance characteristics of various control strategies. Specifically, it is evident that the PID controller achieves a reduced rise time, although not surpassing that of PID surface-SMC. However, the PID controller maintains its consistent behavior by displaying higher overshoot compared to other control methods. In contrast, the SMC strategy demonstrates minimal overshoot, which is negligible in practical terms, along with reduced settling time. Notably, the modified SMC approach attains a remarkable outcome with zero overshoot and even faster settling than SMC. Meanwhile, PID surface-SMC exhibits the least overshoot than PID and notably rapid rise time when contrasted with alternative control methodologies.

UncertainSecond Order arbitrary plant simulation

The selection of an Uncertain arbitrary plants involves a random sampling approach to assess the compatibility of specific plants with designated control strategies. In this investigation, an Uncertain second-order plant model is adopted as the benchmark. It represents a broad category of systems that can vary widely in terms of their characteristics, dynamics, and complexity.The dynamic behavior of this plant is scrutinized across all four control strategies, allowing for a comprehensive evaluation of their efficacy. By observing the system responses, the study aims to discern the variations in response specifications across the different strategies employed. This analysis contributes to a deeper understanding of the control strategies' performance in relation to the given second-order plant model.In the context of control systems, a second-order system is characterized by having at least one second derivative (acceleration) term in its mathematical description.

Uncertain Second Order arbitrary plant-1 simulation

The examination of anUncertain second-order system, as defined by equation (5.8), forms a fundamental aspect of this study. This system is characterized as uncertain arbitrary, encompassing a broad spectrum of potential scenarios. By subjecting this system to all four distinct controllers, the resulting output responses are graphically depicted in Figure 5.6. Moreover, the corresponding response specifications are meticulously itemized in Table (5.6). The insightful patterns derived from these response profiles facilitate an informed assessment of the performance exhibited by each control methodology when applied to the arbitrary second-order plant. This analysis stands to provide valuable insights into the comparative strengths and weaknesses of the control strategies under consideration.

$$G(s) = \frac{6}{S^2 + 2S + 10} \quad (5.8)$$

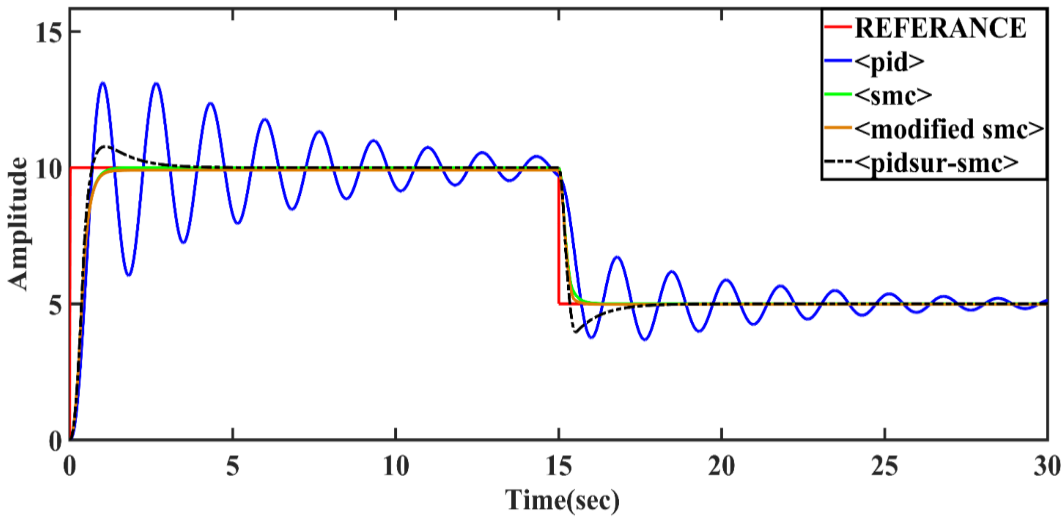

Fig .3.6 response of Uncertain second order arbitrary plant-1

Table .3.6 Transient response of Uncertain second order arbitrary plant-1

Controller	***Rise Time (sec)***	***Settling Time (sec)***	***Overshoot(%)***
PID	0.4358	17.8357	31.5271
SMC	0.5289	1.0035	1.87e-07
M-SMC	0.5144	0.9580	0
PIDsur-SMC	0.4013	2.3890	7.7437

From the Table (5.6) it is observed that the transient response details of a specific Uncertain second-order plant when applied through various control methods. Among these methods, PID exhibits extended overshoot and settling time compared to the other three. SMC displays minimal, practically negligible overshoot, while modified SMC attains zero overshoot. PID surface-SMC achieves an acceptable overshoot within safe limits while demonstrating remarkable speed, outpacing PID, SMC, and modified SMC responses. Notably, PID's overshoot is marginally lower than the PID. Its settling time is lower than the PI.

Uncertain Second Order arbitrary plant-2 simulation

The investigation extends to another Uncertain second-order arbitrary plant, as defined by equation (3.9), distinct from the one described by equation (3.8). Following a similar methodology, this unique plant is subjected to all four designated control strategies. The resultant output responses, specific to this second-order plant, are visually depicted in Figure 3.7. Further insight is gained by summarizing the response characteristics within Table (3.7). Through this comprehensive analysis, the study illuminates the performance of each control approach within the context of this particular Uncertainsecond-order plant. This comprehensive evaluation offers a nuanced understanding of how these control strategies operate, enriching the comparative discourse surrounding their respective strengths and limitations.

$$G(s) = \frac{10}{S^2 + 6S + 6} \quad (5.9)$$

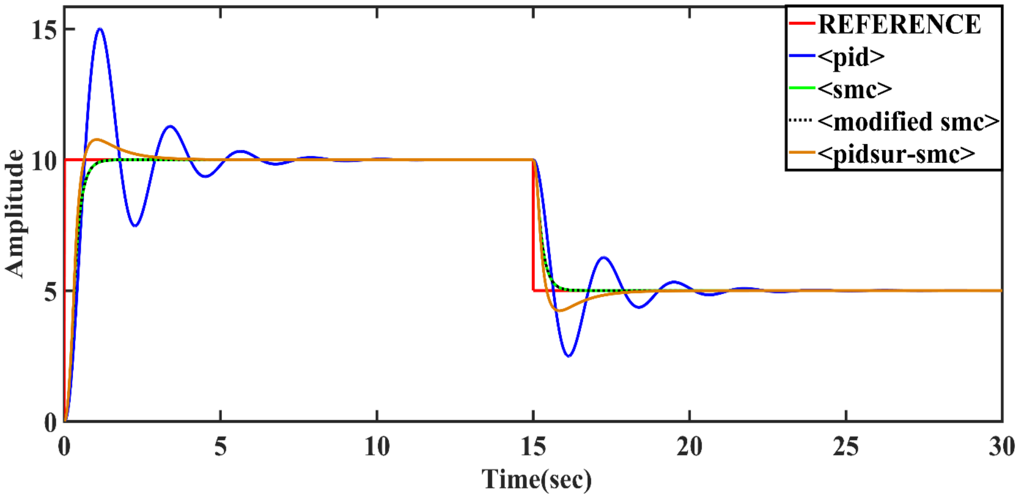

Fig .3.7Response of Uncertain second order arbitrary plant-2

Table .3.7 Transient response comparison of Uncertain second order arbitrary plant-2

Controller	***Rise Time (sec)***	***Settling Time (sec)***	***Overshoot(%)***
PID	0.4280	5.9644	50.1202
SMC	0.5068	0.9533	2.19e-05
M-SMC	0.5074	0.9539	0
PIDsur-SMC	0.3752	2.3349	7.7445

Table (3.7) provides insights into the transient response of another potential Uncertain second-order plant. Notably, the data indicates that in this context, PID exhibits increased overshoot in comparison to other controllers. Meanwhile, SMC and modified SMC exhibit parallel performance traits, with the latter achieving zero overshoot and marginally earlier operation than SMC. Notably, PID surface-SMC delivers a acceptable overshoot while also boasting the fastest response among all control methods considered.

3.4 Simulation Studies of Third order Interval plant and its stabilization

3.4.1 Third order plant simulation

Exploring the dynamics of a third-order plant, its transfer function is succinctly presented in Eq (3.10). Investigating into the evaluation of this specific system's performance, comprehensive simulations employing four distinct controllers are meticulously conducted within the MATLAB environment. The results of these simulations are thoughtfully visualized in Figure 5.8, offering a clear representation of the system's responses

$$G(s) = \frac{24}{S^3 + 9S^2 + 26S + 24} \quad (5.10)$$

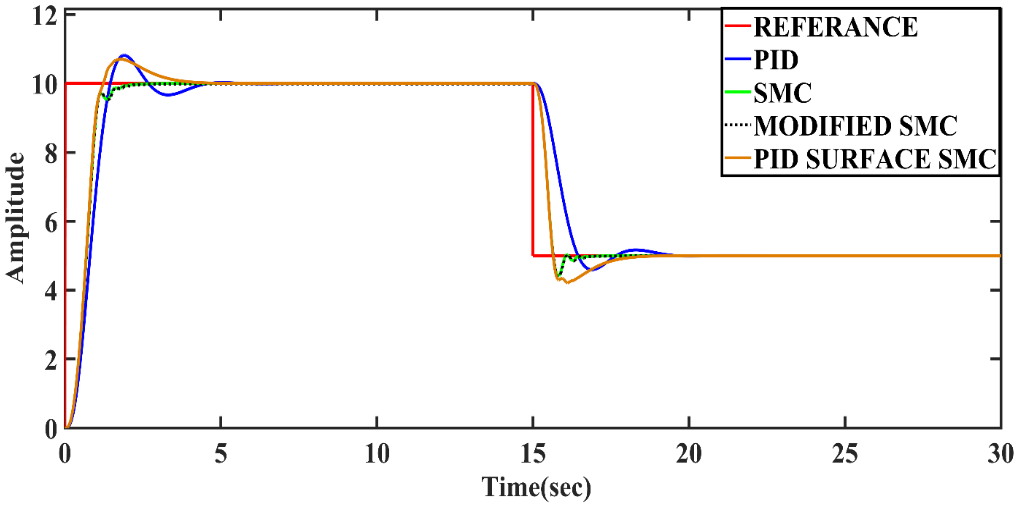

Fig .3.8 response of the third order plant

Table .3.8 Transient response of third order plant

Controller	***Rise Time (sec)***	***Settling Time (sec)***	***Overshoot(%)***
PID	0.8917	3.8540	8.1518
SMC	0.6627	1.5161	1.84e-05
M-SMC	0.6655	1.5397	0.0017
PIDsur-SMC	0.6502	3.0727	7.0494

Table (5.8) illustrates the transient response characteristics of a third-order plant. Analysis of the data reveals that PID exhibits extended settling time in contrast to the alternative control methodologies, while maintaining an acceptable level of overshoot. SMC, on the other hand, demonstrates virtually imperceptible overshoot, while modified SMC achieves a commendable zero overshoot and quicker settling time compared to SMC. Noteworthy is PID surface-SMC, exhibiting reduced rise time, swift operation, and diminished overshoot relative to the PID configuration.

3.4.2 Interval Plant Stabilization of third order plant

Considering a third-order plant delineated by equation (5.10), an interval plant stabilization approach is applied. Leveraging the Kharitonov polynomial technique, a comprehensive ensemble of eight Kharitonov plants is derived. These plants collectively establish the coefficient ranges characterizing the interval plant of the third-order system. Insight into the nature of this third-order interval plant is elegantly encapsulated within equation (5.11), affording a deeper understanding of the plant stabilization processes at play.

$$P(s) = \frac{[19.2 \quad 28.8]}{[0.8 \quad 1.2]S^3 + [7.2 \quad 10.8] + [20.8 \quad 31.2]S + [19.2 \quad 28.8]} \quad (3.11)$$

3.4.3 First Kharitonov plant of Interval plant stabilization of a third order system

Exploring the interval plant within the context of a third-order system, as articulated in equation (3.12), a specific focus is placed on a single Kharitonov plant. This chosen plant is one among the eight possibilities derived from the broader range of the interval plant. MATLAB simulations are conducted, considering four distinct control strategies. The results of these simulations are considerately illustrated through Figure 5.9, effectively showcasing the response dynamics across all controllers. Detailed specifications governing these responses are meticulously compiled within Table (5.9).

$$G(s) = \frac{19.2}{0.8S^3 + 10.8S^2 + 31.2S + 19.2} \quad (3.12)$$

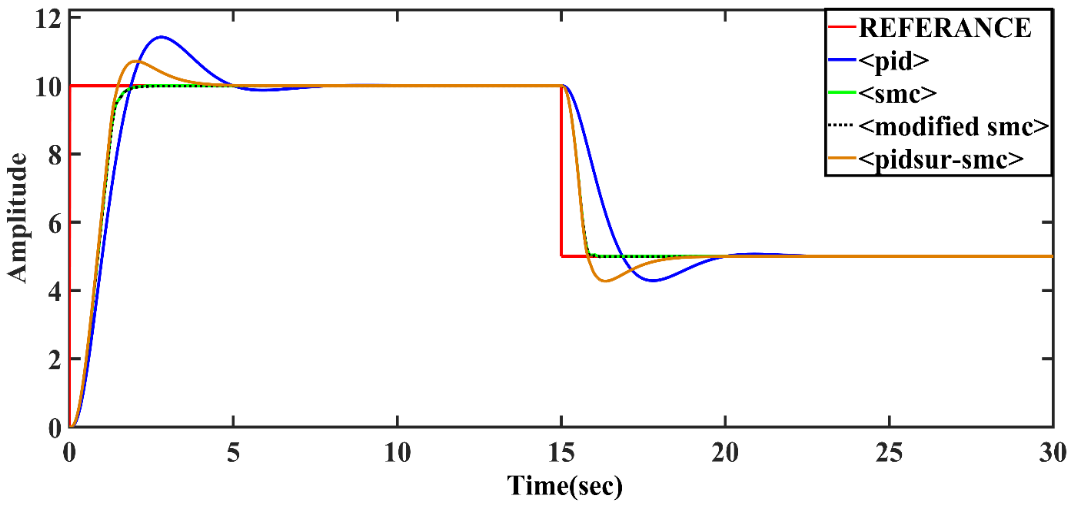

Fig .3.9 response of the third order Interval plant-1

Table .3.9 Transient response of third order Interval plant-1

Controller	***Rise Time (sec)***	***Settling Time (sec)***	***Overshoot(%)***
PID	1.2174	4.5465	14.2151
SMC	0.9471	1.6433	1.380e-05
M-SMC	0.9536	1.6534	6.664e-10
PIDsur-SMC	0.9122	3.2978	7.2003

Extracting insights from Table (3.9), it becomes evident that SMC and M-SMC strategies exhibit comparable response characteristics, characterized by notably small overshoots. Conversely, the PID controller manifests a pronounced overshoot, accompanied by extended settling and rise times. In contrast, PID surface-SMC (PIDsur-SMC) showcases swift initial response, comparing with controllers PID, SMC, and M-SMC. Although PIDsur-SMC entails an overshoot, it remains within acceptable bounds. Notably, each controller demonstrates response traits in line with the nominal transfer function of the third-order system, with the exception of PID.PID responds to the system parameters and changes the response according to the parameters like resistance and inductance.

3.4.4 Second Kharitonov plant of Interval plant stabilization of a third order system

Focusing on the second Kharitonov plant extracted from the ensemble of eight Kharitonov plants derived from the third-order interval plant defined by equation (3.13), a systematic investigation is undertaken. This investigation involves the application of four distinct control methods to the selected plant. The ensuing responses, intricately influenced by the respective controllers, are meticulously evaluated. The simulation outcomes, thoughtfully showcased in Figure 3.10, provide a visual representation of the system's behavior under varying control strategies. Further detailing these outcomes, the response specifications are meticulously tabulated within Table (3.10).

$$G(s) = \frac{28.8}{1.2S^3 + 7.2S^2 + 20.8S + 28.8} \quad (3.13)$$

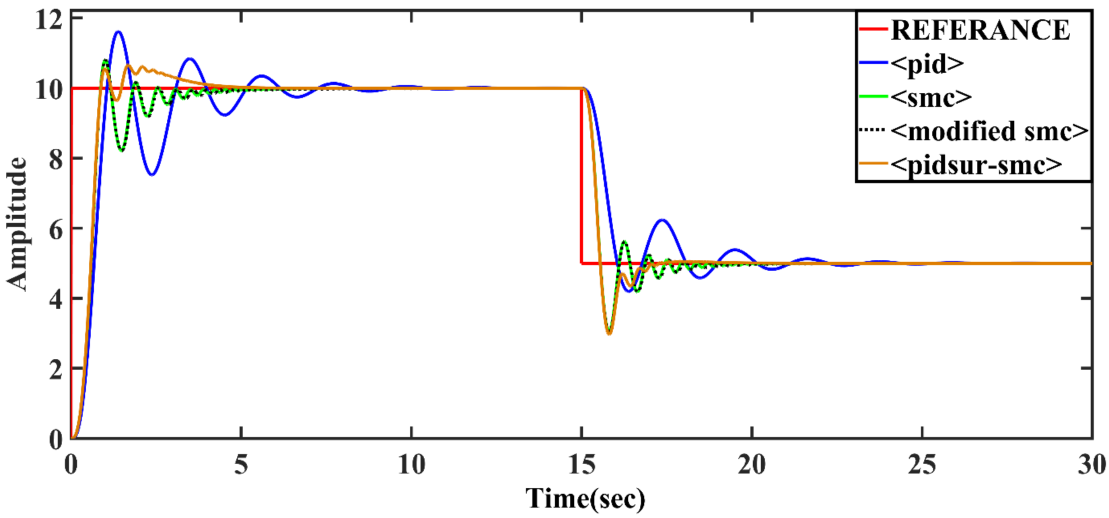

Fig .3.10 response of the third order Interval plant-2

Table .3.10 Transient response of a third order Interval plant-2

Controller	***Rise Time (sec)***	***Settling Time (sec)***	***Overshoot(%)***
PID	0.6239	6.8703	16.184
SMC	0.4916	3.7337	8.0855
M-SMC	0.4931	3.8182	8.2507
PIDsur-SMC	0.4893	3.4134	6.6401

Table. (3.10), presents a comprehensive overview of the system behaviors under various control strategies. It is evident from the table that the Proportional-Integral-Derivative (PID) controller exhibits a higher degree of overshoot compared to other strategies, accompanied by prolonged settling times. Both Sliding Mode Control (SMC) and Modified Sliding Mode Control (M-SMC) demonstrate similar response patterns, with M-SMC notably exhibiting reduced chattering phenomenon compared to standard SMC. The novel PID-Surface Sliding Mode Control (PIDSur-SMC) method stands out by successfully mitigating overshoot tendencies observed in traditional PID control. Furthermore, PID-Sur-SMC excels in achieving the shortest settling time among all considered control strategies. These findings underscore the effectiveness of the proposed PID-Surrogate approach in achieving improved control performance for the system at hand.

3.4.5UncertainThird order arbitrary plant simulation

This research delves into the realm of an uncertainthird-order arbitrary plants, specifically selected in an arbitrary manner, to systematically assess the diverse behaviors exhibited by four distinct controllers. Through this deliberate choice of plant using these control strategies, the nuanced responses generated within the system. This analysis facilitates to understand the controller dynamics and their response on the overall system's behavior. The findings gleaned from this study offer a comprehensive understanding of controller efficacy and the corresponding system responses, thereby yielding precise and well-defined response specifications. Such insights hold valuable implications for optimizing control strategies in practical applications.When dealing with an Uncertainarbitrary plant, control engineers and researchers need to design a suitable controller that can effectively manipulate the plant's inputs to achieve the desired control objectives. These systems are characterized by having three poles in their transfer functions, which influence their behavior and response to inputs or disturbances in a more intricate manner.

3.4.6 UncertainArbitrary third order plant-1

In this study, the dynamics of anUncertainarbitrary third-order plant as depicted in equation (3.14). Theselection of this specific plant model is made with a degree of randomness to ensure a comprehensive assessment of control strategies.UncertainThird-order plant is subjected to four distinct control strategies and observe their individual responses within the system. The outcomes of these strategies are then utilized to evaluate how well the system adheres to predetermined specifications. The graphical representation of the system's response can be observed in figure 3.11, while a comprehensive breakdown of its response characteristics is provided in table 3.11. This investigation aims to provide valuable insights into the effectiveness of various control strategies, contributing to a more informed understanding of system behavior and performance.

$$G(s) = \frac{18.6}{S^3 + 9.9S^2 + 23.4S + 26.6} \quad (3.14)$$

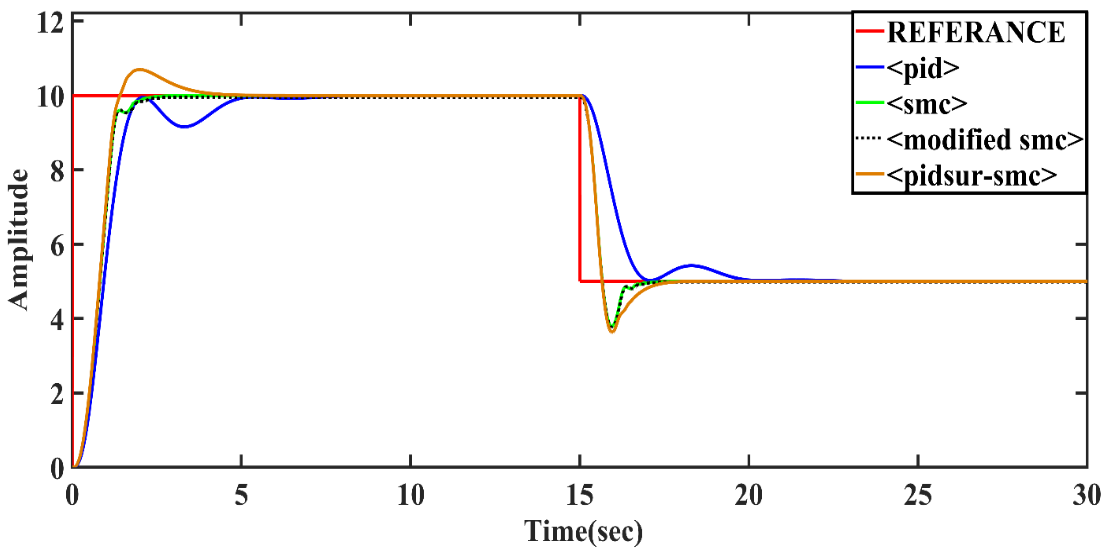

Fig .3.11Response of Uncertain third order Arbitrary plant-1

Table .3.11 Transient response of Un certain third order Arbitrary plant-1

Controller	***Rise Time (sec)***	***Settling Time (sec)***	***Overshoot (%)***
PID	1.1317	4.5763	0
SMC	0.8367	1.8041	2.02e-05
M-SMC	0.8383	1.8410	0.0056
PIDsur-SMC	0.8074	3.2770	6.9859

The insights gleaned from Table (3.11) underscore distinct control behaviors of all the four controllers for Un certain third order plant. Notably, PID achieves precise control with zero overshoot and extended settling time. SMC, in contrast, exhibits negligible overshoot, while modified SMC displays a similarly slight overshoot and quicker rise time than PID. However, PID surface-SMC demonstrates reduced overshoot, reduced rise time when compared to PID, SMC, and modified SMC.

3.4.7 UncertainArbitrary third order plant-2

In this study, the second uncertainarbitrary plant model within the domain of third-order systems, as described by equation (3.15). This particular plant configuration is regulated using four distinct controllers: Proportional-Integral-Derivative (PID), Sliding Mode Control (SMC), Modified Sliding Mode Control (M-SMC), and PID with Surface Sliding Mode Control (PIDsur-SMC). Each of these controllers contributes to an output response in the context of the given system. The resulting output responses are visually represented in figure 3.12, while comprehensive response specifications are systematically outlined in table (3.12). The amalgamation of this information serves to unveil the operational performance of these controllers, shedding light on their effectiveness and behavior. These insights hold considerable promise for enhancing controller selection and design strategies in practical scenarios.

$$G(s) = \frac{28.6}{S^3 + 8.1S^2 + 23.4S + 21.6} \quad (3.15)$$

The PID control system is highly responsive to changes in system parameters, such as resistance and inductance. It dynamically adjusts its response based on these parameters. However, this adaptability can lead to increased overshoot in the system's response. Overshoot beyond a certain limit is undesirable for the system's stability and performance. Additionally, the system may exhibit slower settling times under certain conditions, resulting in higher setting times. In Figure 3.12, presenting a visual representation of the response characteristics for all four control strategies, shedding light on their respective behaviors and trade-offs.

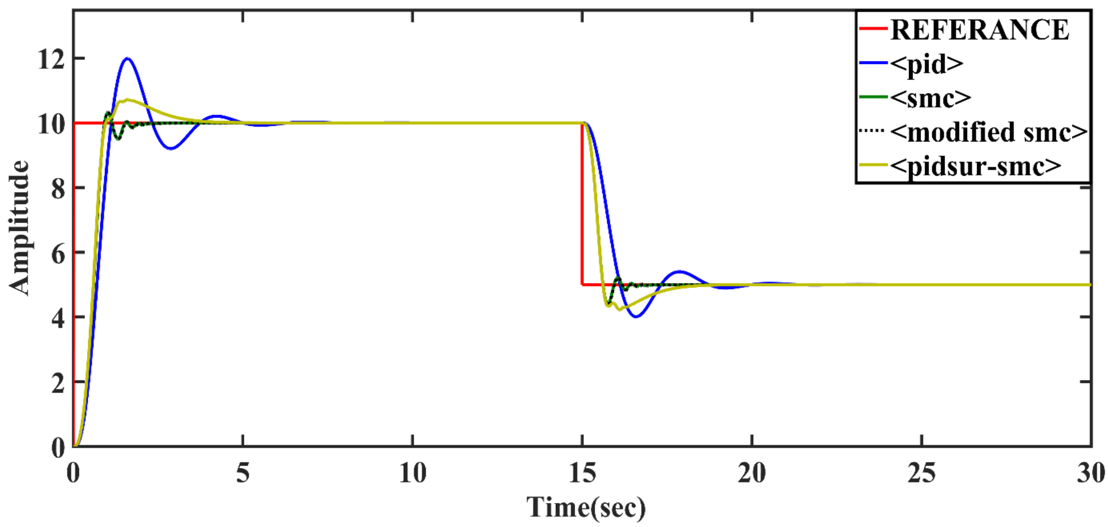

Fig .3.12Response ofUncertainthird order Arbitrary plant-2

Table .3.12 Transient response of Uncertainthird order Arbitrary plant-2

Controller	***Rise Time (sec)***	***Settling Time (sec)***	***Overshoot(%)***
PID	0.6814	4.2902	19.8617
SMC	0.5274	1.4374	3.2285
M-SMC	0.5296	1.4552	3.4177
PIDsur-SMC	0.5260	2.8976	7.2051

From Table (3.12), it becomes evident that PID control manifests increased overshoot and extended settling time relative to alternative control strategies. Meanwhile, both SMC and modified SMC implementations showcase acceptable overshoot along with reduced rise times when contrasted with PID. Notably, the PID surface-SMC configuration demonstrates diminished
overshoot in comparison to PID, along with reduced rise time when compared to PID, SMC, and modified SMC.

Through careful analysis of the simulations, discernible variations emerge in the response patterns exhibited by distinct control methodologies. Notably, the PIDsur-SMC approach stands out by yielding superior outcomes in comparison to the alternative methods. It demonstrates rapid response characteristics and notably minimized overshoot than the normal PID. Conversely, the PID approach displays consistent overshooting tendencies across response scenarios. Additionally, the Sliding Mode Control strategy, while effective, lags behind in terms of response speed when contrasted with the agility showcased by the PIDsur-SMC technique. These findings, drawn from empirical observations, highlight the advantageous attributes of the PIDsur-SMC method, offering valuable insights for informed control method selection and application.