Simple Controller Approach with Smith Predictor for Long Time Delay Systems

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Abstract:

There are many approaches that are used for controlling or enhanced the performance of the time delay systems, one of the most popular approaches is smith predictor method, but this approach may give bad performance or make the system unstable if the time delay become very long. Kaya and Atherton controller method is one of an effective method to solve this problem.

In this paper, a simple controller approach is suggested with smith predictor in order to maintain the stability of the higher order plant in addition to improve the performance of the controlled system. This controller consist from two parts, the first part is PI_D controller, where the values of KP, K_I, and K_D are determine from the denominator equation of the reduce order plant mathematical equation. The second part (PD) is used to reject or reduce the effect of external disturbance. The second part is also used with Kaya and Atherton controller method to enhance the performance of this approach. Four linear stable examples with disturbance are tested by the suggested approach and by the control method Kaya and Atherton to compare the performance o f these controllers.

Keyword: Smith predictor, higher order system, long time delay, disturbance removal**.**

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الخلاصة:

هنـاك طرق عديدة التي تستخدم للسيطرة او لتحسين اداء الانظمة ذات التاخير الزمنـى ,احد هذه الطرق والاكثر شيوعاً هي طريقة (Smith Predictor) لكن هذه الطريقة ممكن ان تعطي اداء غير جيد او تجعل النظام غير مستقر اذا كان التاخير الزمنى كبير جداً. طريقة المسيطر الخاصة بـ (Kaya and Atherton) هي احدى الطرق الفعالة لحل هده المشكلة في هذا البحث,إقترح مسيطر بسيط مع (Smith Predictor) وذلك للمحافظة على استقرارية المنظومة ذات الدرجة العالية بالاضافة الى تحسين اداء المنظومة المسيطر عليها. هذا المسيطر يتكون من جزئين , الاول المسيطر PI_D, قيم المتغيرات $K_P, K_I, and K_D$ تم تحديدها من معادلة المقام للموديل (ذات الدرجة المختزلة) ,الجزء الثاني(PD) استخدم لتفادي او تقليل تاثير الضوضاء الخارجية .الجزء الثاني ايضاًاستخدم مع طريقة المسيطر الخاصة بـ (Kaya and Atherton) لتحسين الاداء لهذه الطريقة.

I. Introduction

The problem dead time in control systems is an everlasting problem which is of primary importance in process control [1]. Factors that affects enormously the performance and stability of a control system, either based upon a PID algorithm or any other, is the presence of a transportation delay or delay in the control loop. Many solutions have been tried in order to compensate the negative effect of the delay [2]. One of these solutions is smith predictor method.The smith predictor, shown in Fig.(1), is well known as an effective dead time compensates for a stable process with long time delay [3].
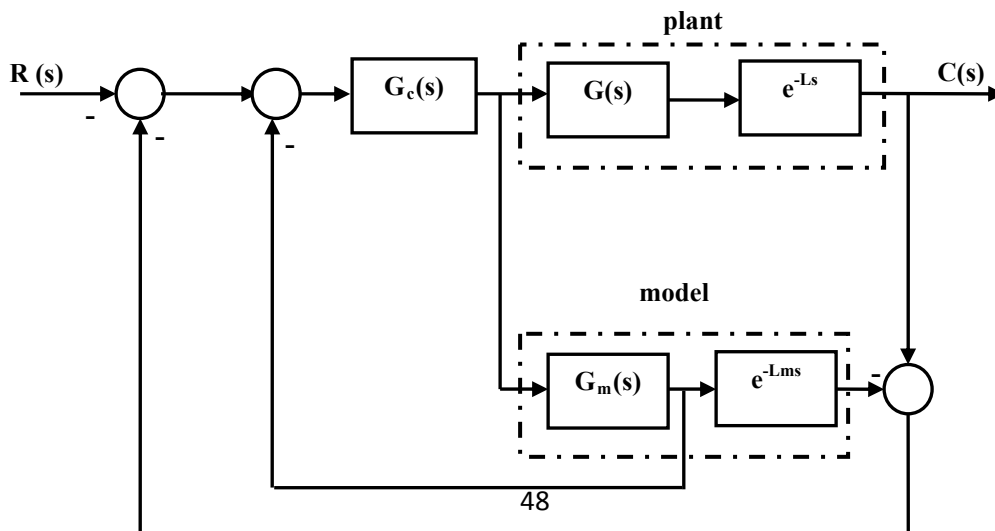

Fig.(1): The Smith predictor control scheme

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There are many approach which are used to improve the performance of the smith predicator, like **[1]** which proposed a method for controller tuning using an optimization method optimization method is based on dominating the gain of the minimum phase term in the open loop transfer function of the loop , such that non minimum phase effects of the model and process become dominated by the minimum phase charactiristics of the desired term.VersonsiMassimiliano**[4]** proposed a simple adaptive law for the automatic tuning of the model time delay the performanace of the smith predictor can decrease dramatically (become unstable) due to modeling errors, especially for the dead time which , contrary to what would be expected , can vary considerably depending on the working conditions. Wei Dong Zhang and You Xian Sun**[5]** proposed the method which is extended to the general integrator/time delay process. A clearer and more logical design procedure is formulated ,and simple tuning rules are developed the important improvement of the proposed modified smith predictor is that it provides an easier possibility of tuning the parameters, and the set point response and the disturbance response can be optimized by only one parameter , respectively, the two parameters have a direct relationship with the system . Band widths are equivalently the performance and robustness the closed loop system. Asim Voden carevic**[6]** presents a realization of a PLC-based smith predictor control scheme on the Siemens S7platform the process control represents a first order plus dead time approximation of the actual process dynamic. Even if the process to be controlled is not first order in its nature a FOPDT smith predictor still can be used to provide better loop response Zhu Hongdong,Li Ruixia and Shao Huihe **[7]** presents a modified smith predictor called cascade smith predictor (CSP) to control the integrating processes with long dead time , CSP has two smith predictors . The inner predictor keeps the actual process stable and converts the integrating process into a stable one, while the outer smith predictors reject the load disturbance. Kaya and Atherton **[8]** suggest an effective controller scheme to enhance the smith predictor performance when the time delay is large. This controller which is shown in **fig. (2)** consist from three controller G_{c1}, G_{c2}, and G_d.
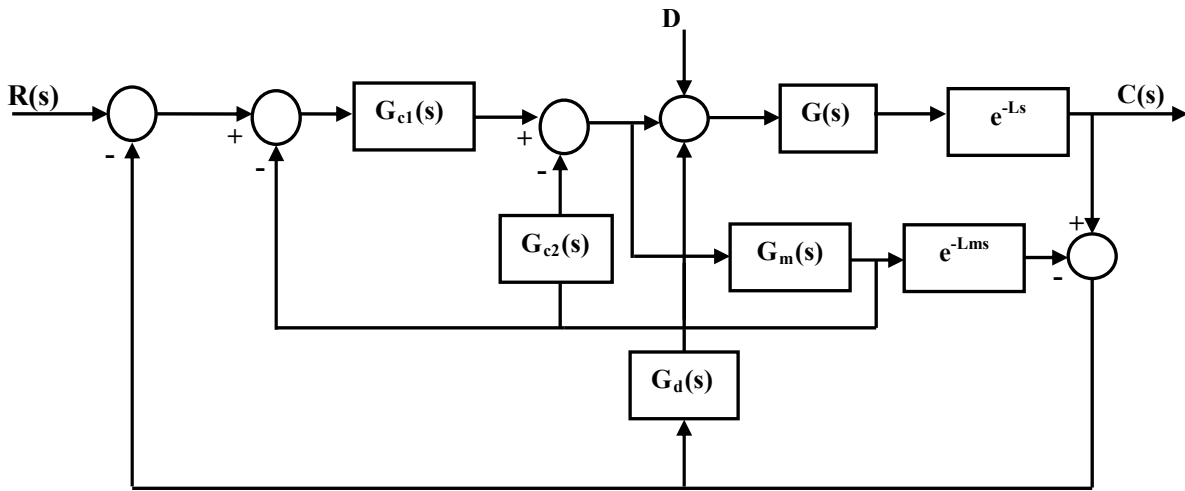
Fig (2).Kaya and Atherton controller with smith predictor

Where G(s) is higher order plant, $G_m(s)$ is reduced order plant model, L_s is the exact time delay L_{ms}

is the approximate time delay, G_{c1} is a PI controller, G_{c2} is a PD controller and G_d is the disturbance controller introduced by matausek and micic (1999) .assuming exact matching between the process and the model parameters then the set point and disturbance response are given by:

$$C(s) = T_r(s)R(s) + T_d(s)D(s)$$ …………………………………(1)

Where

$$T_r(s) = \frac{G_m G_{c1} \, e^{-l_{ms}}}{G_{m(G_{c1}} + G_{c2)}}$$ ....(2)

$$T_d(s) = \frac{G_m[1 + G_m(G_{c2} + G_{c1} - G_{c1}\, e^{-L_{ms}})]\ e^{-L_{ms}}}{[1 + G_m(G_{c1} + G_{c2})][1 + G_d G_m e^{-l_{ms}}]} \dots\dots\dots\dots(3)$$

The transfer function for the set point response, given by Eq**.(1)**, reveals that the parameters of the main controller G_{c1} and G_{c2} , may be determined using a model of the delay free part of the plant. Also it is seen that only the disturbance response is affected by the controller G_d. For more details see **[8].**

II. The Suggested Methods

In this section, two methods will be presented, the first one is a simple proposed controller, and the second one is a simple modification on the Kaya and Atherton method.

II.1 Simple controller Approach (first method):

The block diagram of PID controller that proposed by Kaya and Atherton**[8]** which is shown in **Fig.(2**) can be modified to more simple controller as we suggest in this paper as shown in **fig. (3**), where this approach consist from two controller $C_1(s)$ and $C_2(s)$.
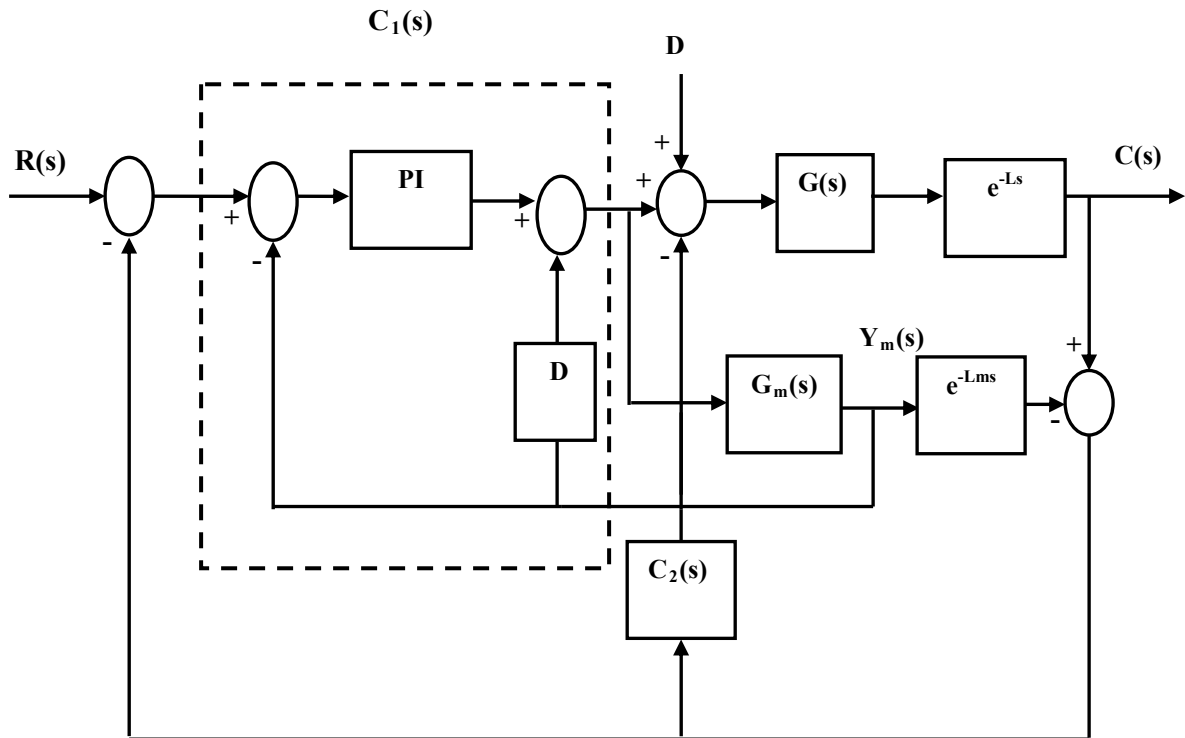
Fig.(3): The suggested controlled approach

The first controller $C_1(s)$ proportional integral-derivative (PI-D) is designed for reduced order plant by the following equation.

$$C_1(s) = PI\text{-}D = (K_P + K_I/s) \, E(s) - K_D s \, Y_m(s) \quad \dots\dots\dots\dots\dots\dots (3)$$

Where the values of KP, K_I, and K_D are determine from the denominator equation of the reduce order plant model $G_m(s)$ which has the form:

$$Gm(s) = \frac{e^{-l_{ms}}}{s(as+b)+c} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(4)$$

Where $a, b,$ and c are parameters of reduced order plant model.

Three state will be taken as following:

1-$a, b,$ and c are constant and not equal to zero then the $G_m(s)$ will be as in Eq. (4).

2-If a and b not equal to zero, and c equal 0 then the $G_m(s)$ will become as:

$$Gm(s) = \frac{e^{-l_{ms}}}{s(as+b)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(5)$$

3-If a not equal zero, b equal 0, and c equal 0 then the Gm(s) will become as:

$$Gm(s) = \frac{e^{-l_{ms}}}{s(as+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(6)$$

Table (1) explain the suggested method for selection the controller parameters (KP, K_I, and K_D).

Table (1) The design PI-D controller parameter

forms	Denominator equation	K_D	K_I	K_P
1	den=s(as+1)= $as^2 + s$	$\dfrac{a}{b}$	zero	$\dfrac{2 + K_D}{2}$
2	den=s(as+b)= $as^2 + bs$	$\dfrac{a/f}{b/f} = \dfrac{a}{b}$	zero	$b \ /f$

3	den=s(as+b)+c= $as^2 + bs + c$	$\dfrac{a/f}{b/f} = \dfrac{a}{b}$	$\dfrac{c}{f}$	$b \ /f$

Where f is suitable selected integer value.

The second $C_2(s)$ is used to eliminate or reduce the effect of the disturbance D, this controller has the following PD controller equation:

$$C_2 = K_p + K_d \ s \qquad\qquad ....(6)$$

The value of proportional gain $\mathbf{K_p}$ and derivative gain $\mathbf{K_d}$ are obtain from comparing the characteristic equation $1 + C_2 G_m$ with the following desired second order equation:

$$s^2 + 2\xi\omega_n s + \omega_n^2 \qquad\qquad ……. ....(7)$$

Where ξ is a damping ratio and ω_n is natural frequency, ξ and ω_n are user design parameters.

II.2 Simple Modification on Kaya and Atherton controller Approach(second method):

Kaya and Atherton method **[8]** is modified by replace the disturbance controller Gd(s) by $C_2(s)$ controller which is explained in the previous section.

III. Simulation Examples

The two suggested controller approaches and the controller approach of Kaya and Atherton**[8]** are used to controlling a four linear stable examples to compare the performance of the controlled system with these approaches .The example and the parameter for these controller are given as following:

Example (1)

The first example is a third order transfer function given by **[8]**

$$G(s) = \frac{e^{-10s}}{(3s+1)(2s+1)(s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots(8)$$

The reduce order SOPDT (second order plus dead time) transfer function is

$$G_m(s) = \frac{e^{-10.625}}{(2.7245+1)^2} \dots\dots\dots\dots\dots\dots\dots\dots(9)$$

In this example the value of *f*=2

The PID controller parameter for approach **[8]** is given in **table (2).**

Table(2): control parameter for kaya and Atherton method for Ex1.

| G_{c1}		G_{c2}		G_d	
K_p	T_i	K_f	T_f	K_0	T_d
2.401	2.724	1	1	----	2.724

The parameters for the suggested controller scheme are given in **Table (3).**

**Table (3): control parameter for the suggested method for Ex1**

PI-D			$C_2(s)$			
a	b	c	K_1	K_2	ξ	ω_n rad/sec.
7.42	5.448	1	.0652	.0708	1.6205	.625

The output result for **example (1)** and the control signal with the three controller are shown in **Fig(4)** , from this figure we can see that the performance of the suggested controller(first method) is nearly equivalent to that of the PID controller of suggested **[8]** and second method.
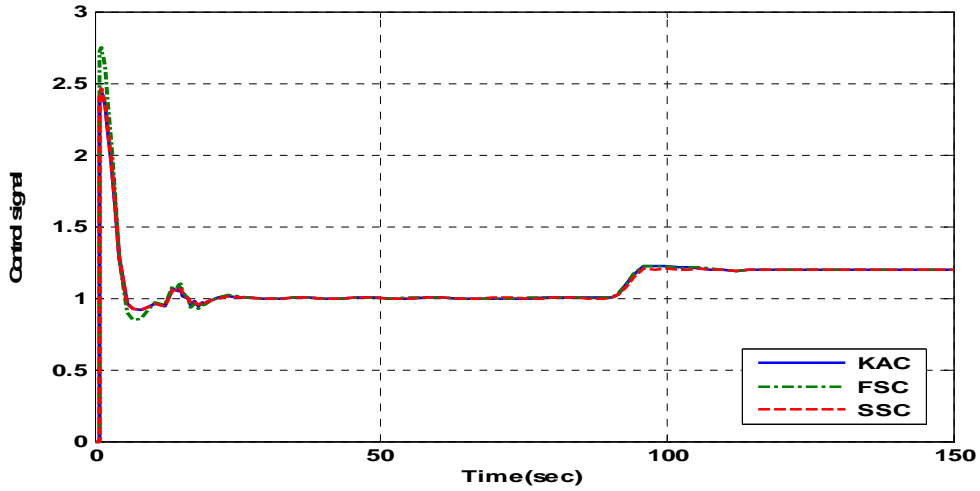
Fig (4) The output response for example 1 with unit step input
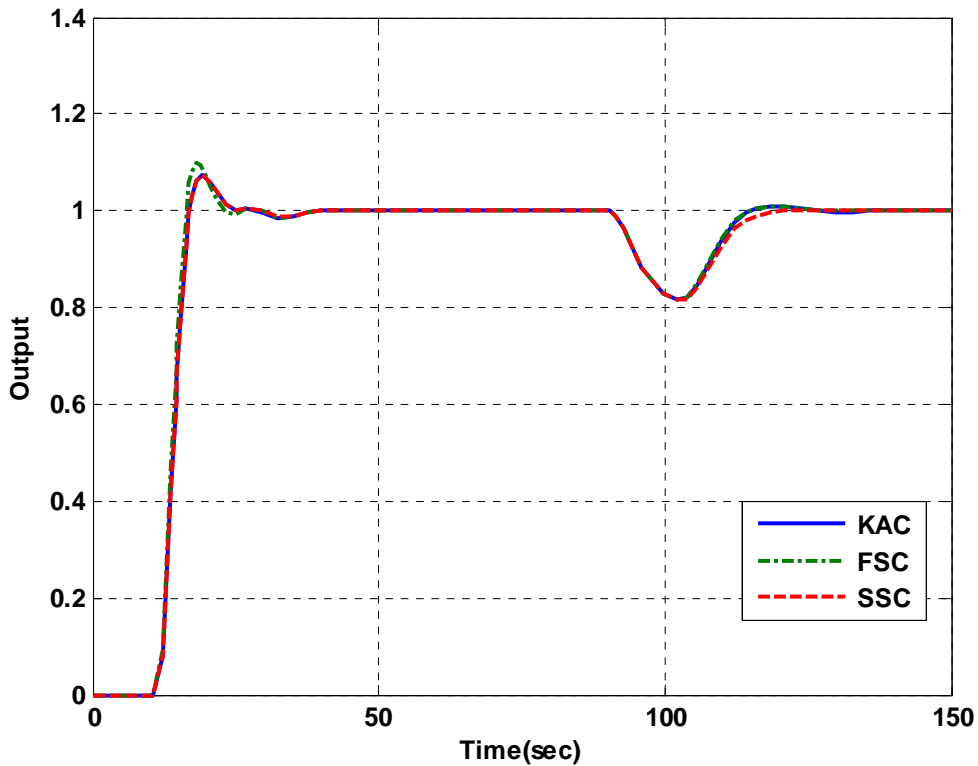
Fig (4) The output response for example 1 with unit step input

Example (2):

The second example is a second order transfer function given by **[8].**

$$G(s) = \frac{e^{-16s}}{(20s+1)(10s+1)} \ldots\ldots\ldots (10)$$

In this example the value of f=10

The PID controller parameters suggested by [8] is given in **table (4)**

**Table (4): control parameter for the Kaya and Atherton method for Ex2.**

G_{c1}		G_{c2}		G_d	
K_p	T_i	K_f	T_f	K_0	T_d
4.082	20	1	20	------	20

The parameters for the suggested controller scheme are given in **table (5).**

Table (5): control parameter for the suggested method for Ex2

PI-D			$C_2(s)$			
a	b	c	K_1	K_2	ξ	ω_n
200	30	1	.6	.416	.85	.089

The output response and control signal for this example shown in **fig (5),** its show that the performance of the suggested first and second method is more efficient than the Kaya and Atherton method in reaching to the set point and more fast in rejection the disturbance
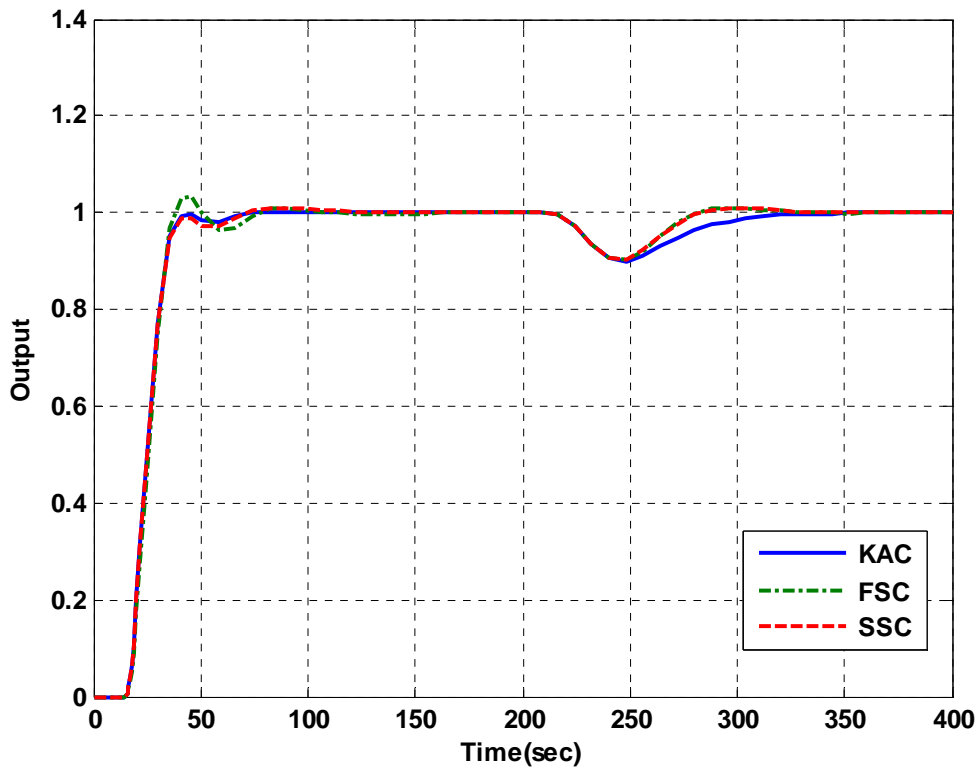
Fig (5) The output response for example 2 with unit step input
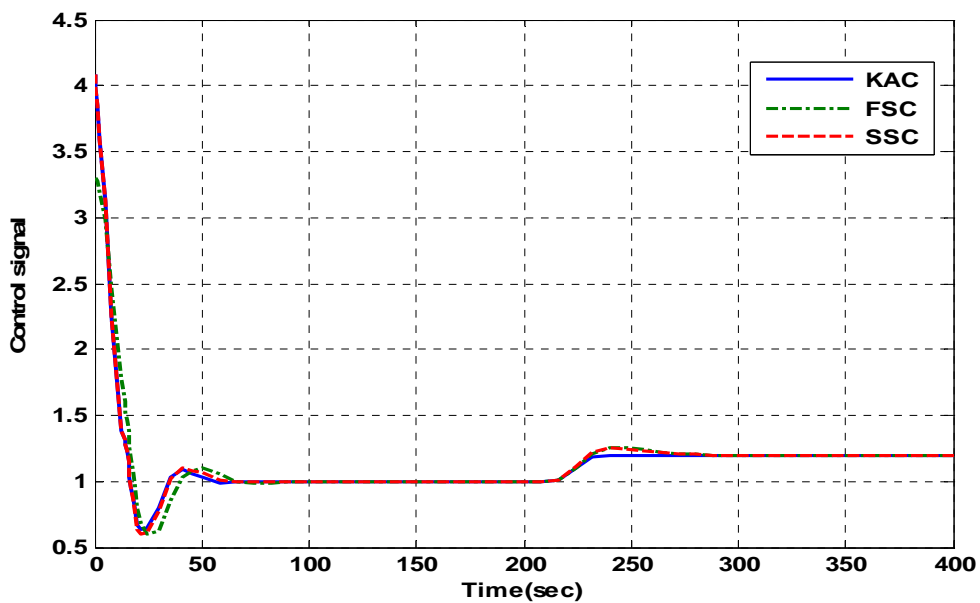
Fig (5)the control signal for example 2 with unit step input

Example(3): The third example is an integrating process given by **[8]**

$$G(s) = \frac{e^{-5s}}{s(s+1)(0.5s+1)(0.2s+1)(0.1s+1)} \quad ....(11)$$

The reduces order SOPDT transfer functional is

$G_n(s)$

G_{c1}		G_{c2}		G_d	
K_p	T_i	K_f	T_f	K_0	T_d
0.45	1.205	1	1.205	0.08	2.72

$$= \frac{e^{-5.6s}}{s(1.205s+1)} \quad ....(12)$$

The PID controller parameters suggested by [8] is given in **table (6).**

Table (6): control parameter for the Kaya and Atherton method for Ex3.

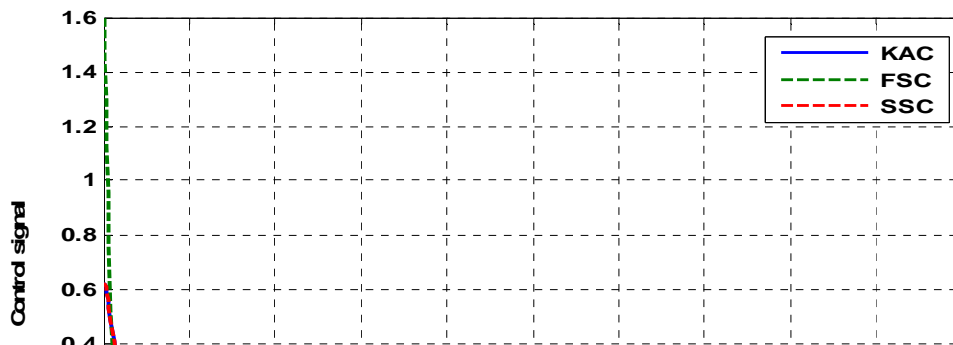The parameters for the suggested controller scheme are given in **Table (7).**

Table(7): control parameter for the suggested method for Ex3.

PI-D			$C_2(s)$			
a	b	c	K_1	K_2	ξ	ω_n
1.205	1	0	.128	.47	1.47	.326

The simulation result for the output response and the control signal in **fig (6),** from this result we can see that The suggested method gives slightly better results for both the set point response and disturbance rejection.
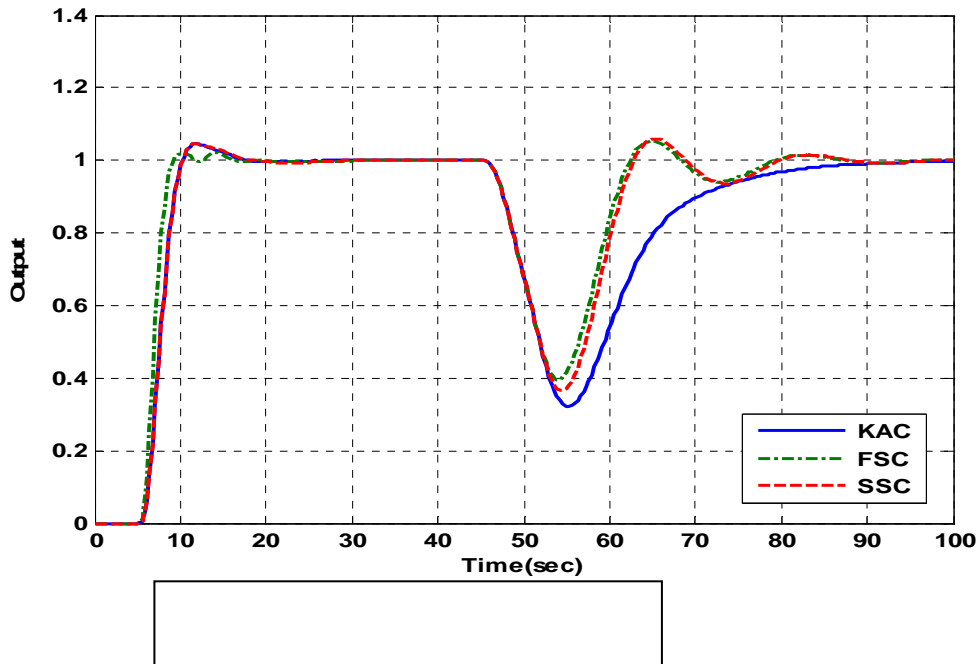
Fig (6) the output response for example3 with unit step input

Fig (6)The control signal for example3

G_{c1}		G_{c2}		G_d	
K_p	T_i	K_f	T_f	K_0	T_d
5.102	10	1	10	0.031	6.68

Example(4):

Consider

$$G(s) \ = \frac{e^{-6.95}}{s(10s+1)} \ ....(13)$$

The PID controller parameters suggested by **[8]** is given in **table (8).**

Table (8): control parameter for the Kaya and Atherton method for Ex4

The parameters for the suggested controller scheme are given in table (9).

**Table(9): control parameters for the suggested method
for Ex4**

PI-D			$C_2(s)$			
a	b	c	K_1	K_2	ξ	ω_n
10	1	0	.08	.8	1.006	.089

With this examples suppose that T_d=6.9 instead of 6.7. the simulation result for this example is shown in **fig (7)** as in the previous example the performance for this example with the suggested approach is faster in reduce the effect of the disturbance .
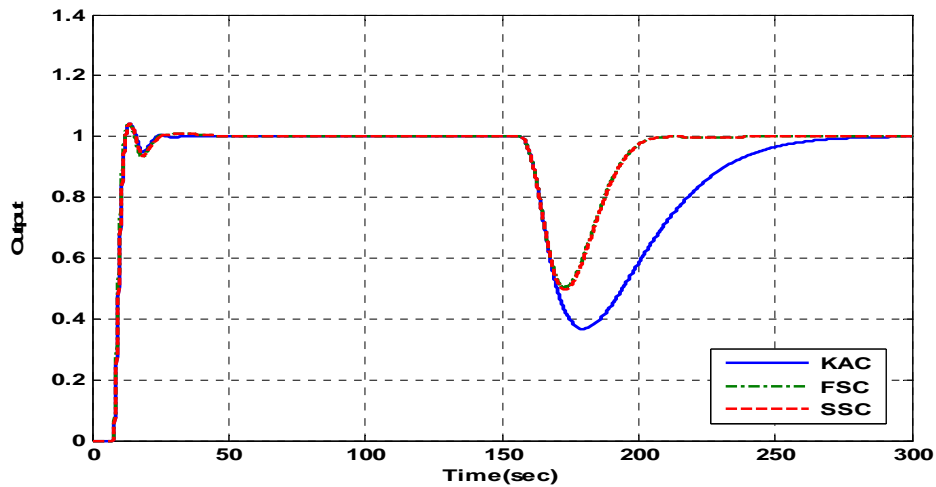
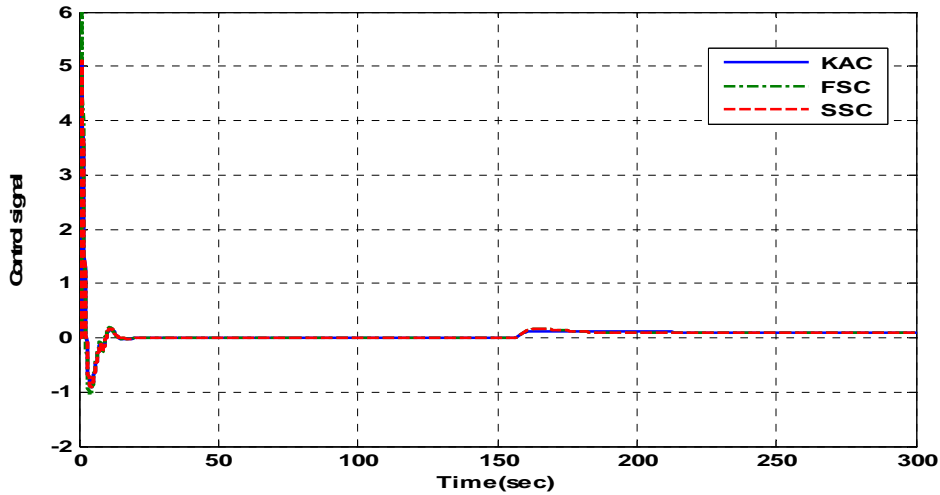**Fig (6) The output response for example 4 with unit step input**

Fig (7) the control signal for example 4 with unit step input

Conclusion

A simple controller scheme with smith predictor for long time delay system is suggested in this paper . This controller scheme consist of two controller the first one is used to maintan the stability for the controlled system and to enhance the performance of the system . The second controller is used to reduce the effect of the disturbance on the system. Since the suggested scheme is consider as an enhance to the method that is proposed by **[8],** therefore it is applied on the same simulated examples that are presented in **[8].** The simulation results with this suggested show more accurate and faster space for the tested scheme examples.

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