Report on the setpoint overshoot method (supplementary material)

M. Shamsuzzoha and S. Skogestad
Department of Chemical Engineering
Norwegian University of Science and technology (NTNU)
Trondheim

August 2010

Section: 1, Step setpoint responses with various overshoots for E1-E33 (P-only controller).

Section: 2, Responses for PI-control for E1-E33.

Section: 3, Comparison of proposed PI controller performance with Yuwana and Seborg (AIChE, 1982) for E1-E32.

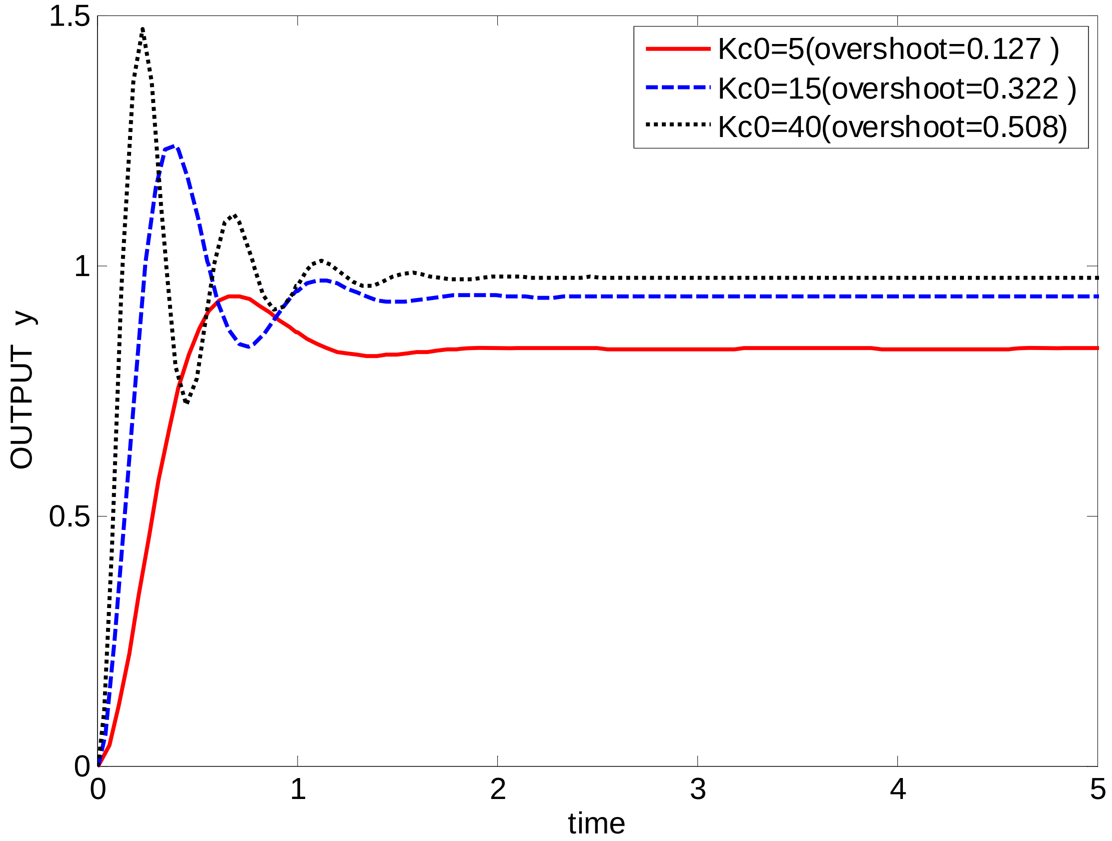
Yuwana and Seborg [10] is a two-step procedure, based on a closed-loop setpoint experiment with a P-controller. They identified a first-order with delay model by matching the closed-loop setpoint response with a standard oscillating second-order step response that results when the time delay is approximated by a first-order Pade approximation. They identified from the setpoint response the first overshoot, first undershoot and second overshoot. We have identified the process model using Yuwana and Seborg method and then obtain the PI setting with SIMC rules and compared with the proposed method.

Section: 4, Table 1: Parameters identification and SIMC PI setting: Yuwana and Seborg (AIChE, 1982) E1-E32.

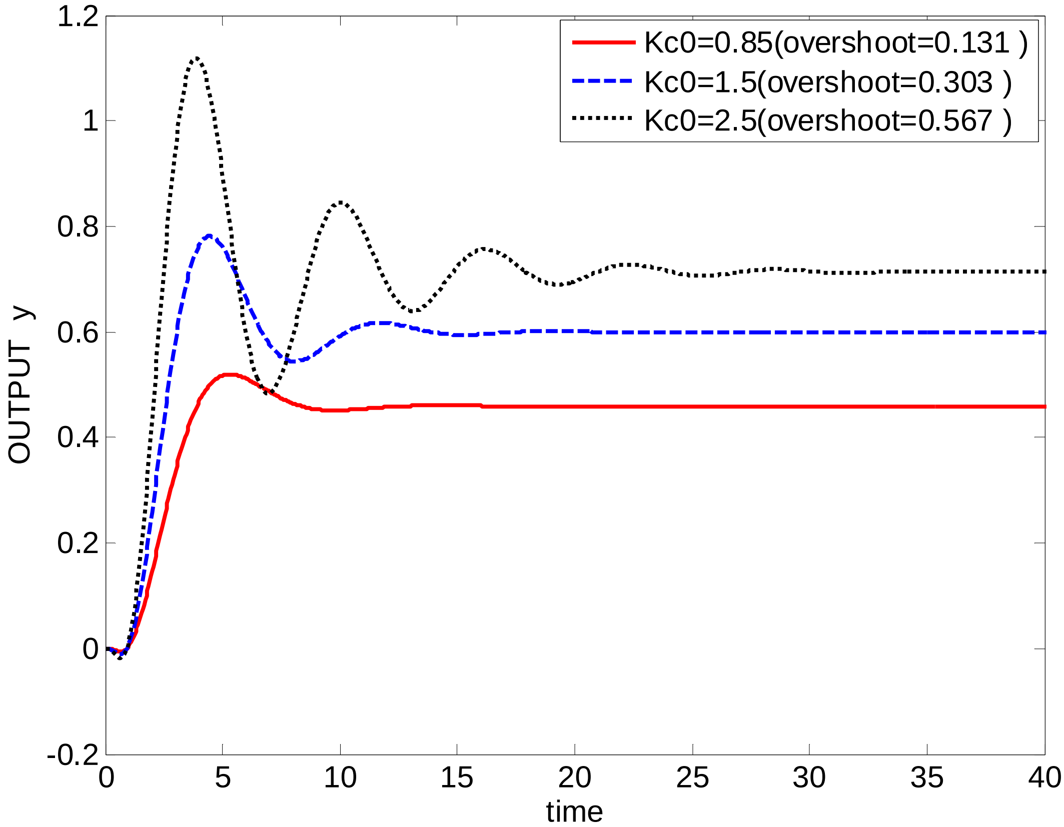
Section: 5, Table 2, the correlation has been further tested on the 33 processes from Table 1 for $\Delta y_\infty = 0.895(\Delta y_p + \Delta y_u)/2 \approx 0.45(\Delta y_p + \Delta y_u)$ and result is listed for different overshoot for E1-E33.

Section: 1

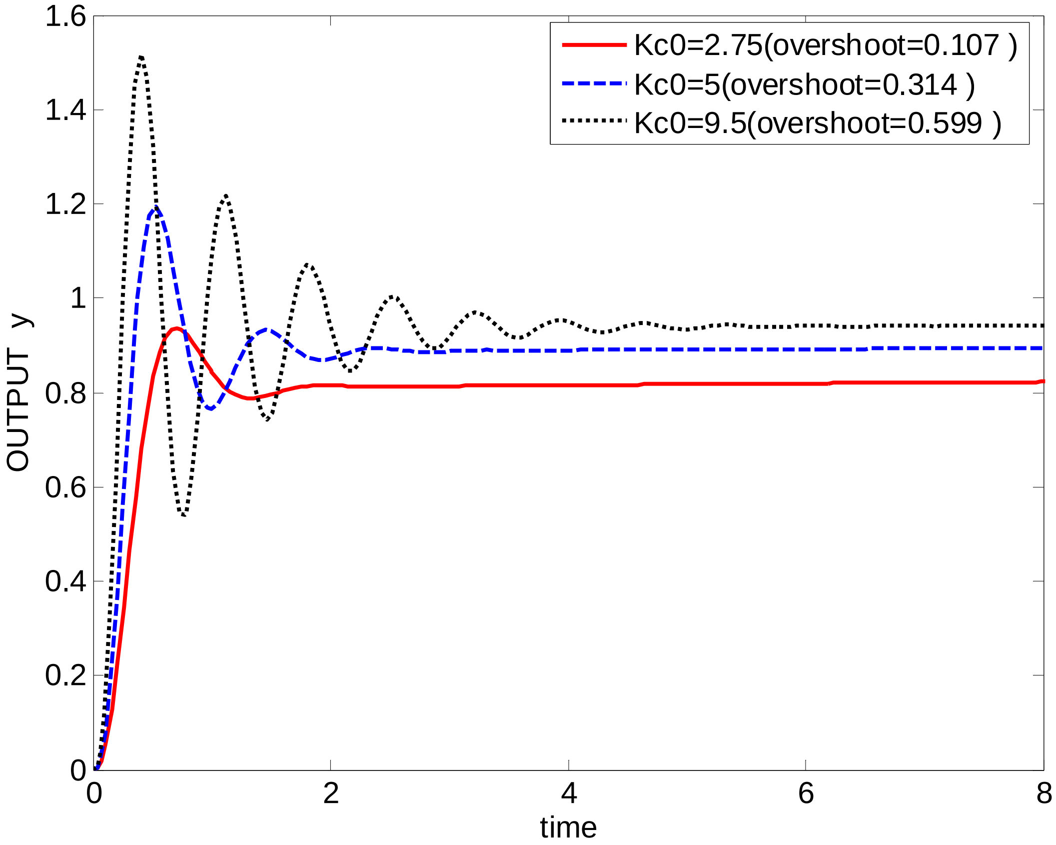
Simulation results for E1-E33 (P-only controller).



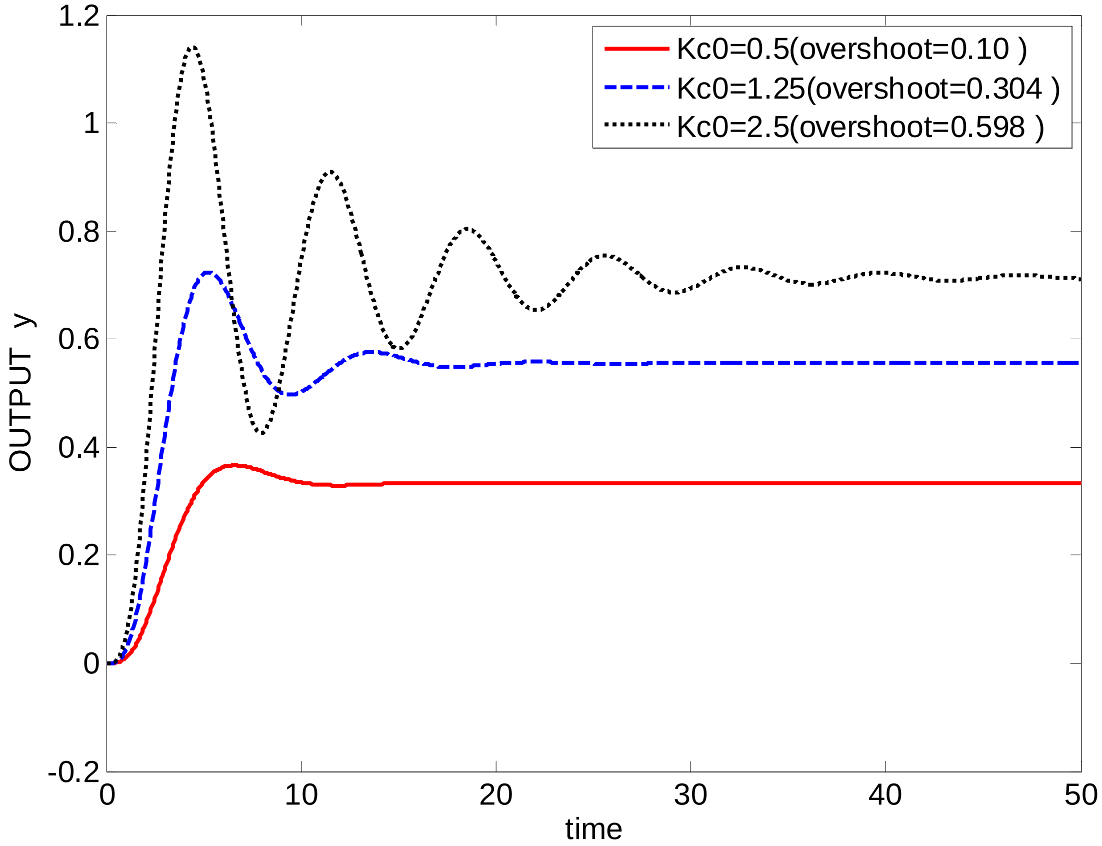
E1 $\frac{1}{(s+1)(0.2s+1)}$



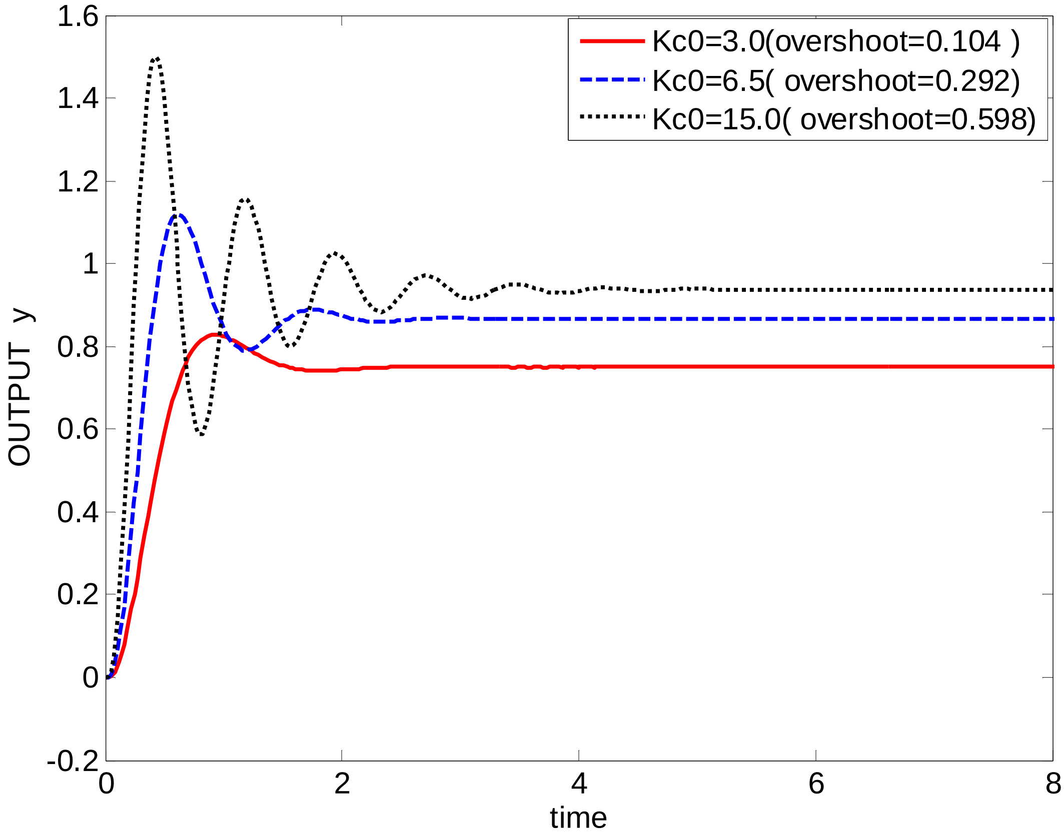
E2 $\frac{(-0.3s+1)(0.08s+1)}{(2s+1)(s+1)(0.4s+1)(0.2s+1)(0.05s+1)^3}$



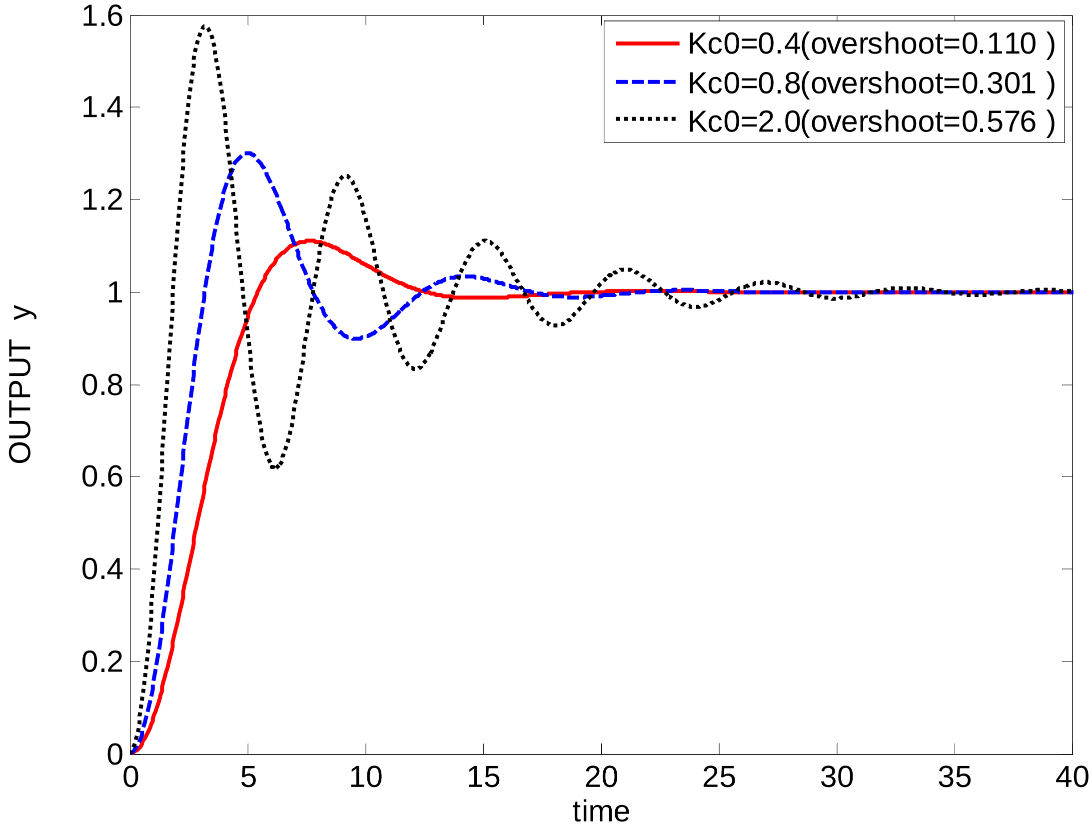
E3 $\frac{2(15s+1)}{(20s+1)(s+1)(0.1s+1)^2}$



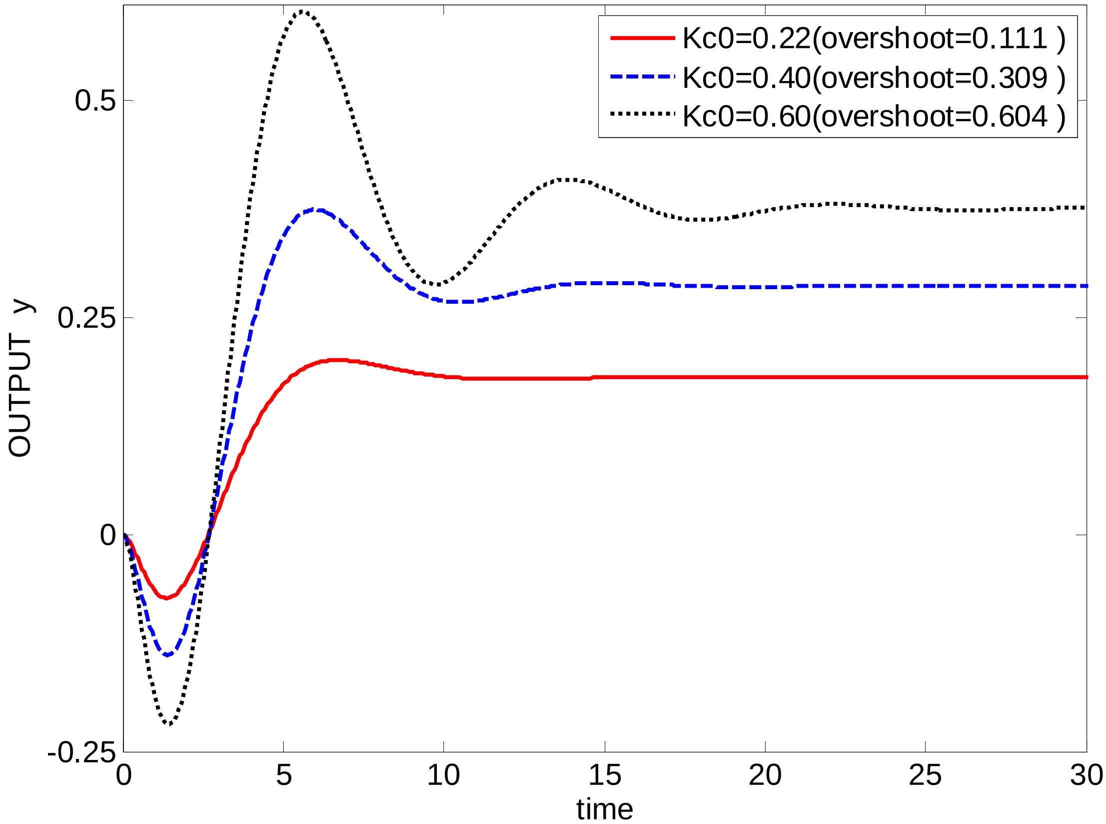
E4 $\dfrac{1}{(s+1)^4}$



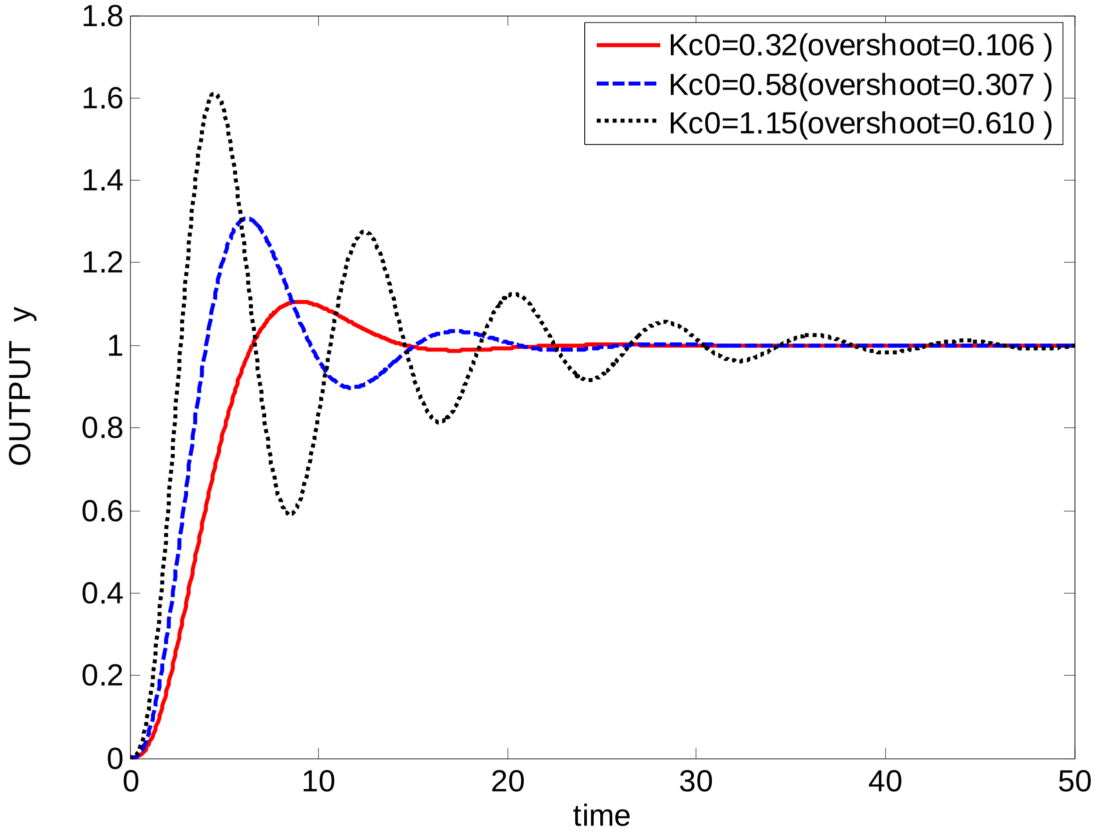
E5 $\dfrac{1}{(s+1)(0.2s+1)(0.04s+1)(0.008s+1)}$



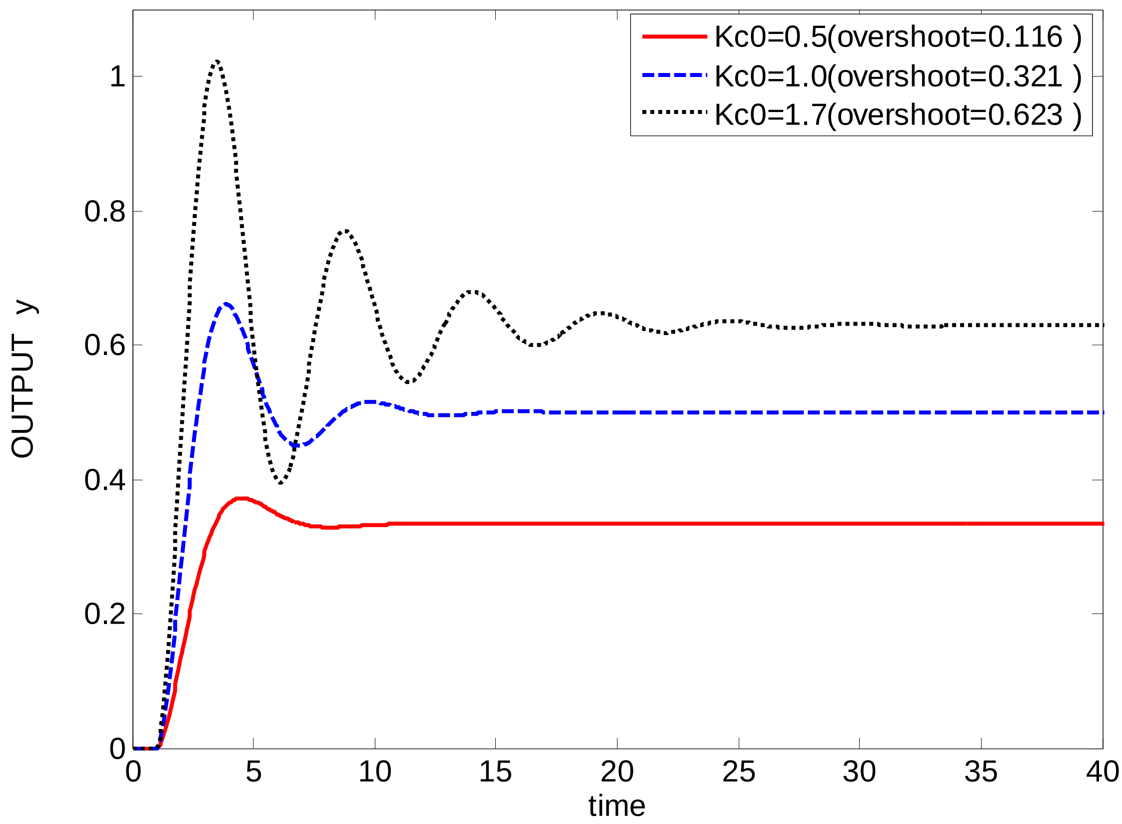
E6 $\frac{(0.17s+1)^2}{s(s+1)^2(0.028s+1)}$



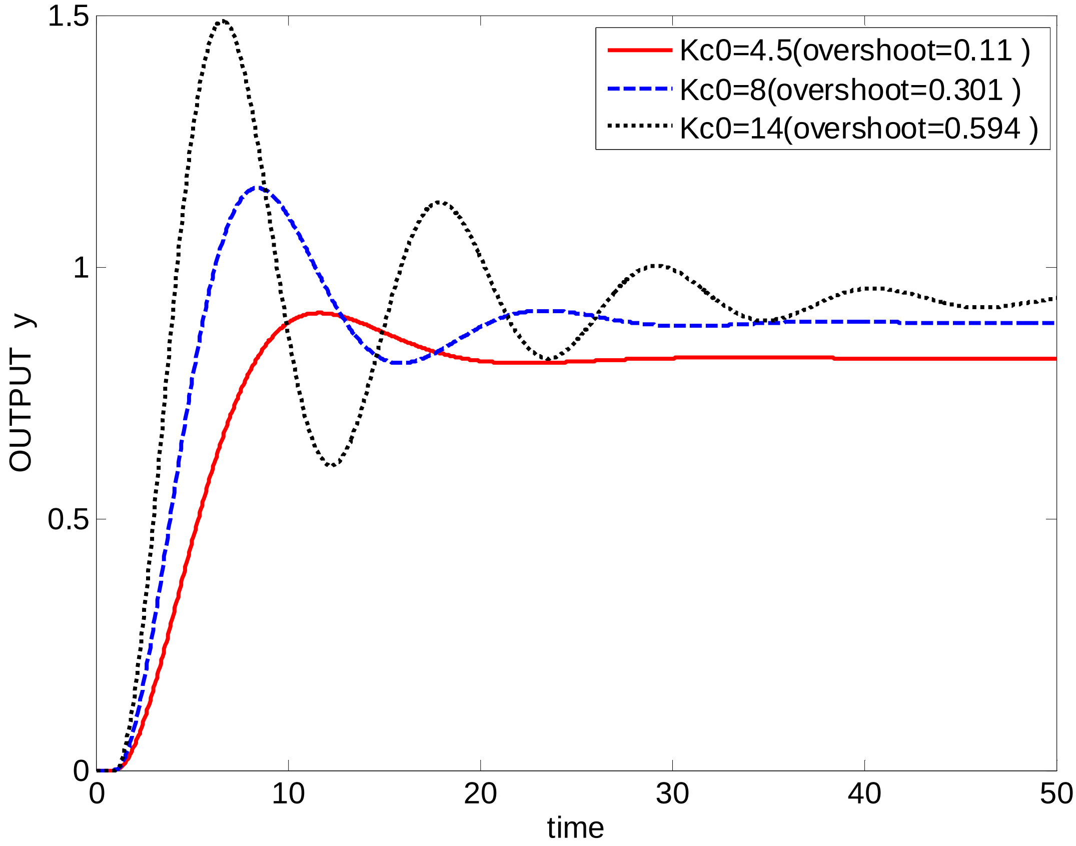
E7 $\dfrac{-2s+1}{(s+1)^3}$



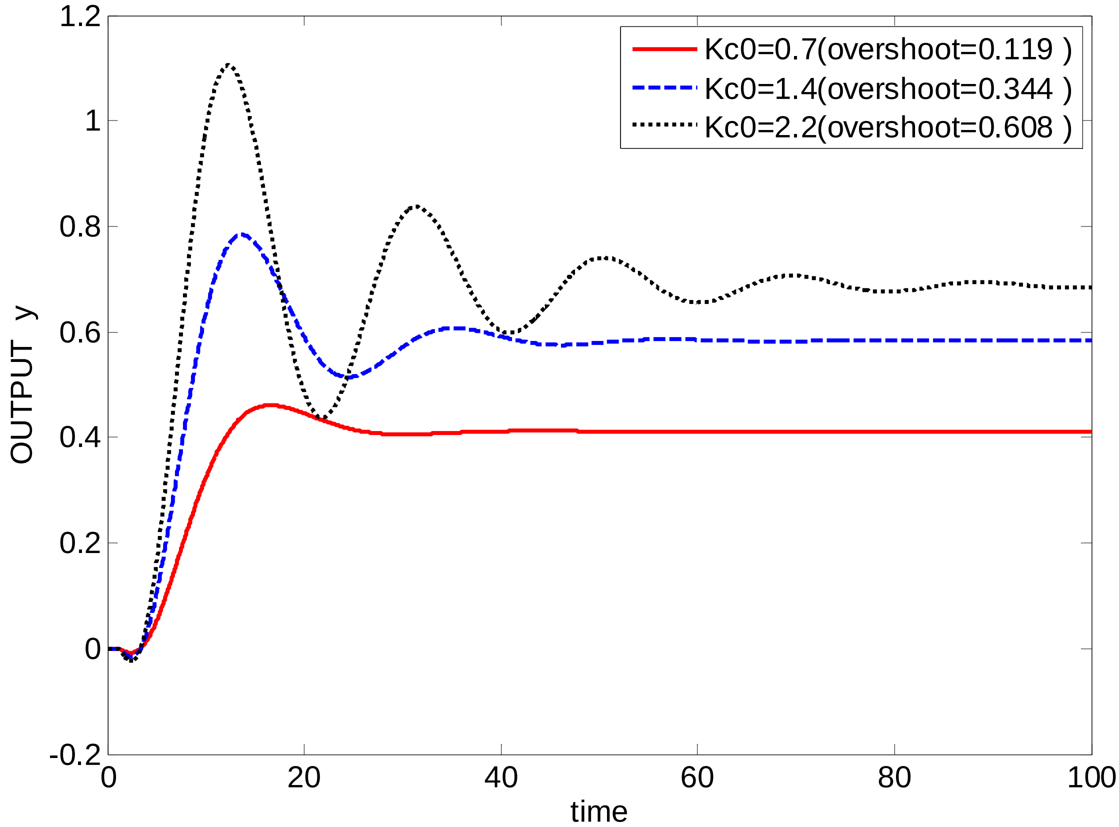
E8 $\frac{1}{s\left(s+1\right)^2}$



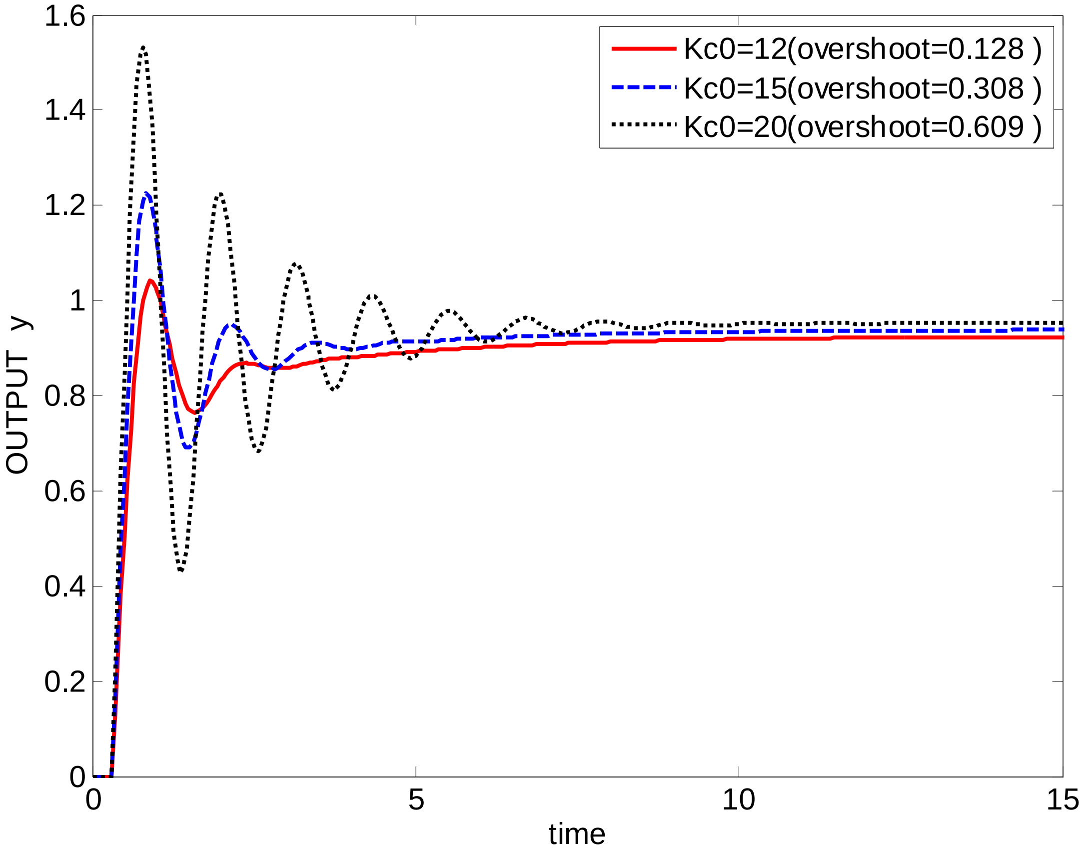
E9 $\frac{e^{-s}}{(s+1)^2}$



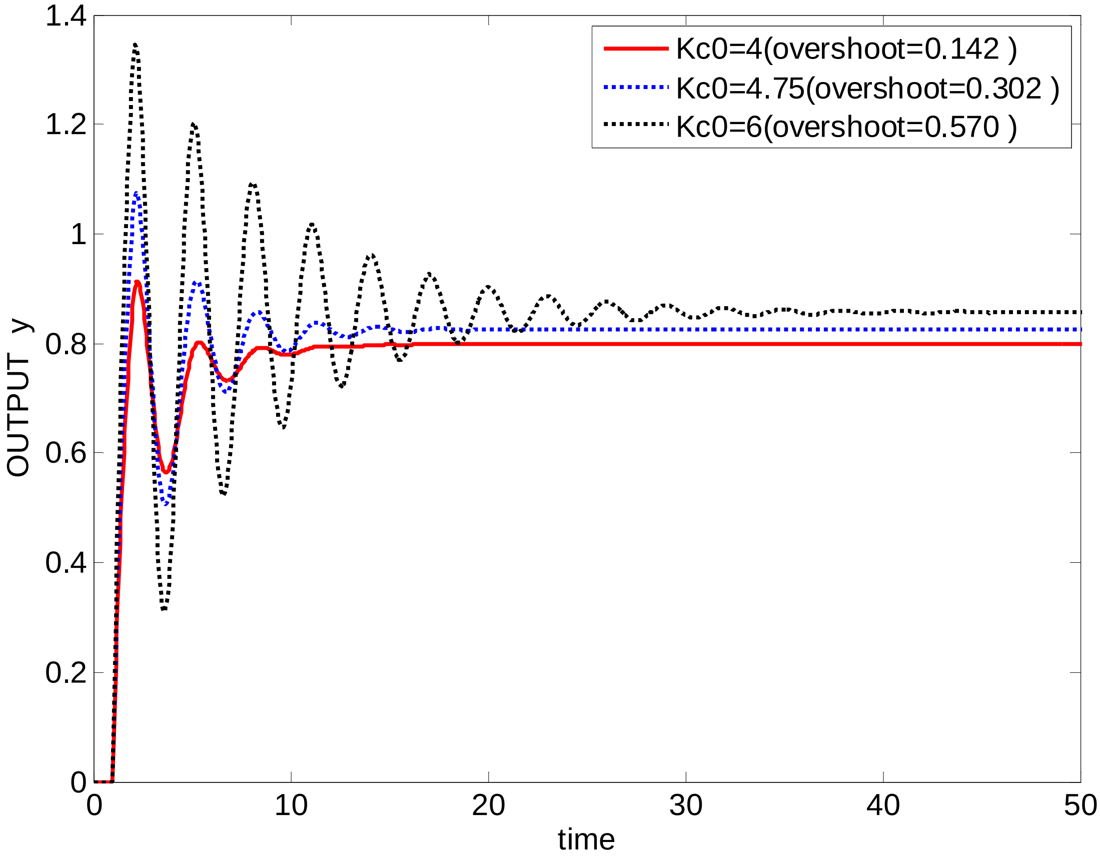
E10 $\frac{e^{-s}}{(20s+1)(2s+1)}$



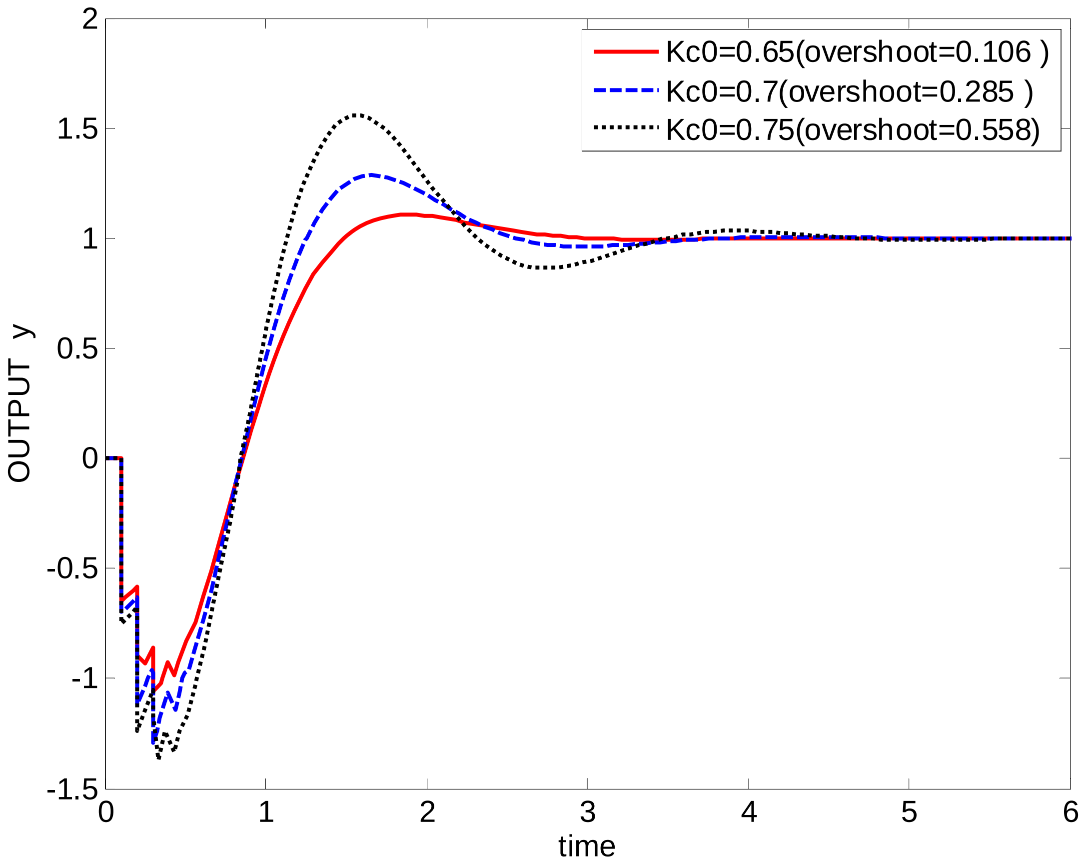
E11 $\dfrac{(-s+1)e^{-s}}{(6s+1)(2s+1)^2}$



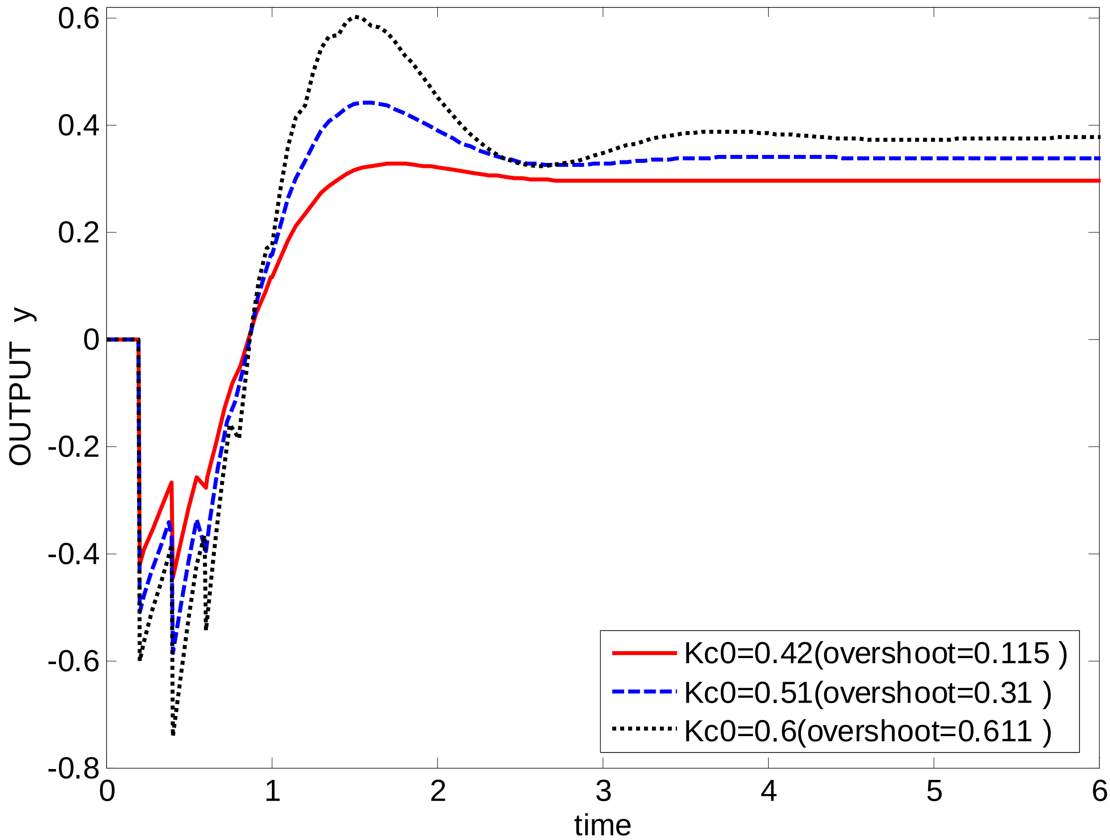
E12 $\frac{(6s+1)(3s+1)e^{-0.3s}}{(10s+1)(8s+1)(s+1)}$



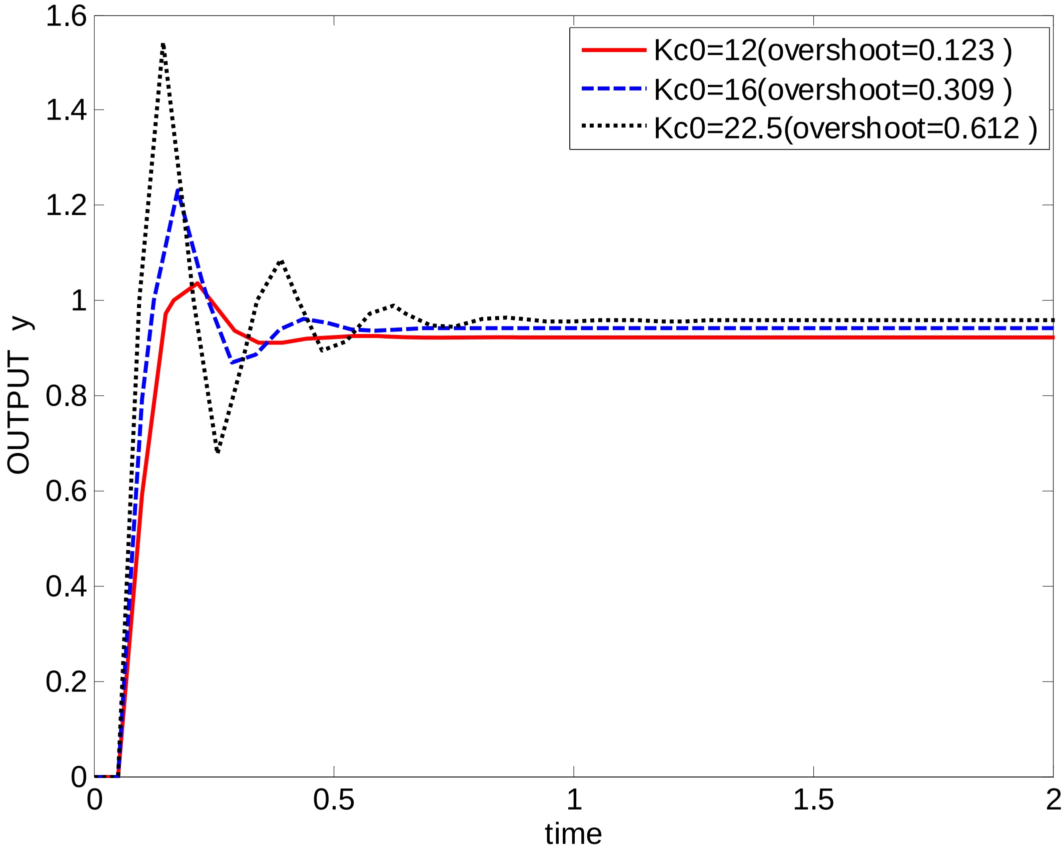
E13 $\frac{(2s+1)e^{-s}}{(10s+1)(0.5s+1)}$



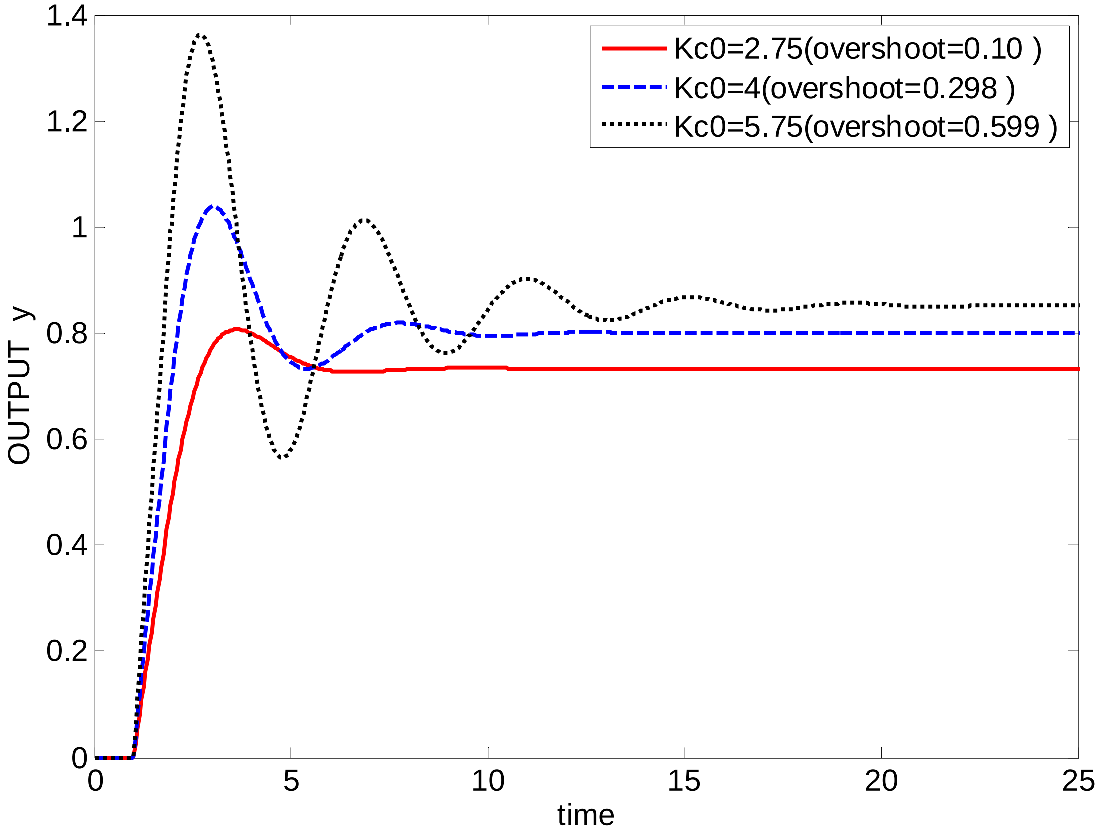
E14 (a) $\frac{(-s+1)e^{-0.1s}}{s}$



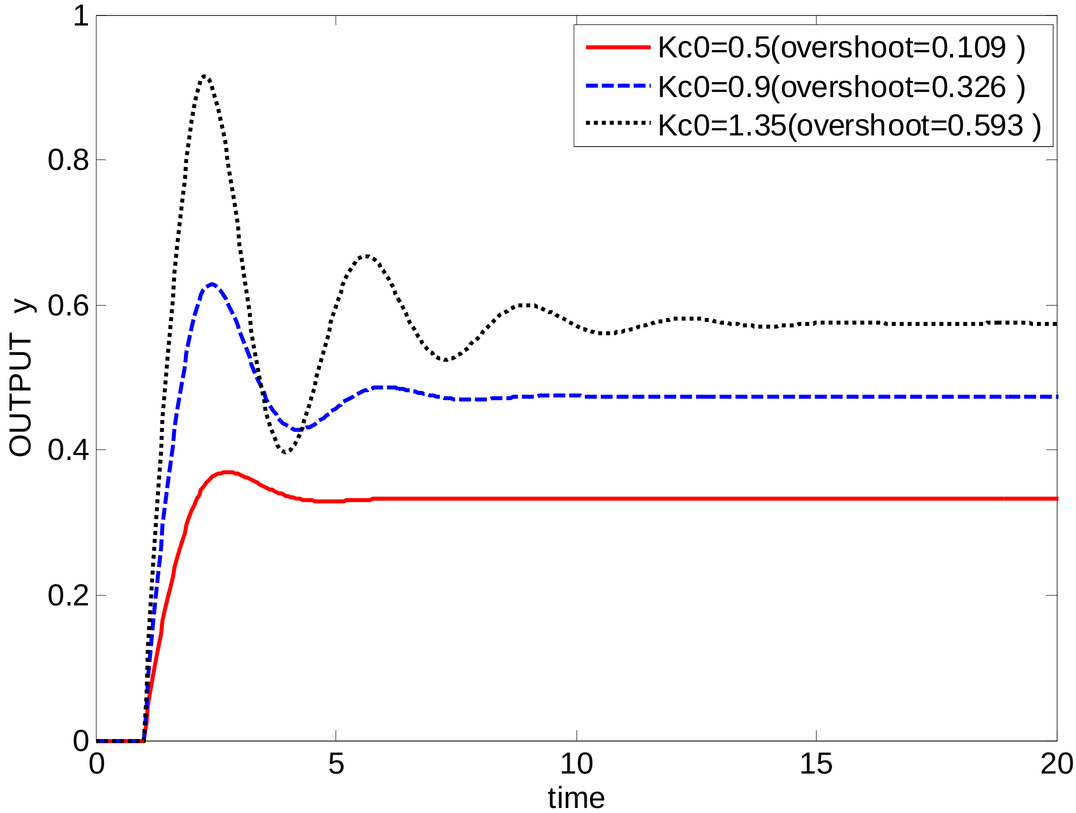
E15 (a) $\dfrac{(-s+1)e^{-0.2s}}{(s+1)}$



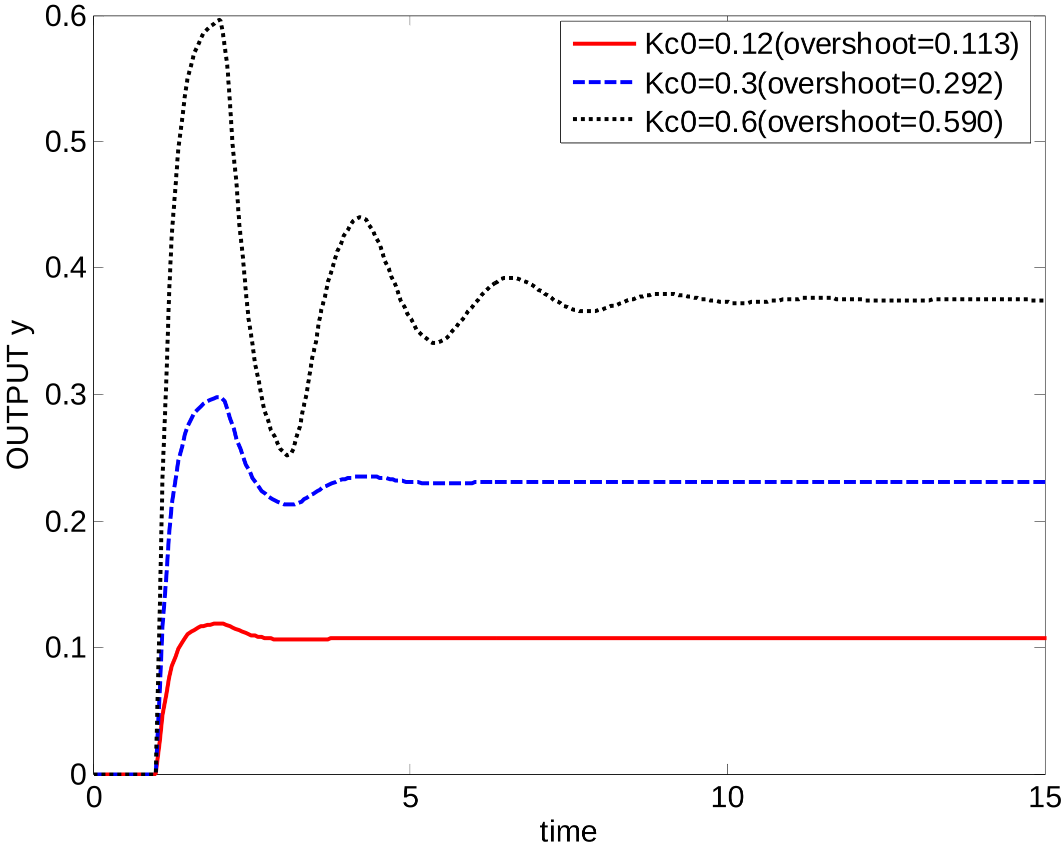
E16 (a) $\frac{e^{-0.05s}}{(s+1)}$



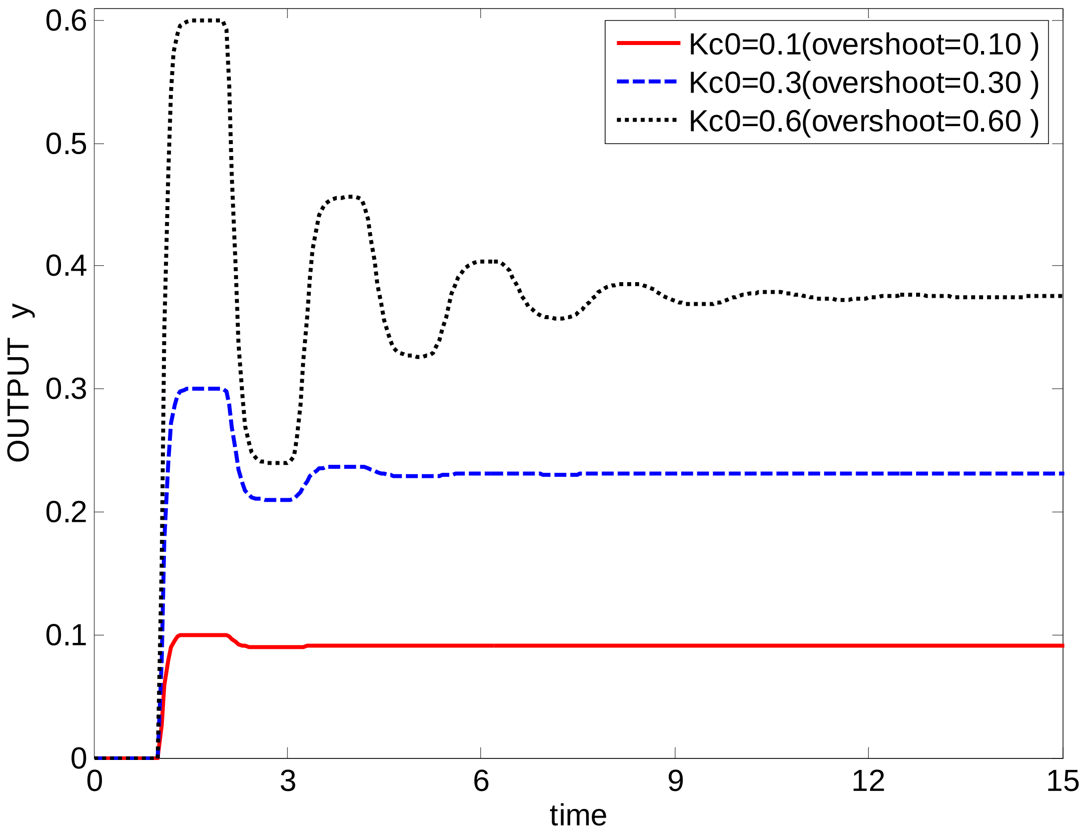
E17 $\frac{e^{-s}}{(5s+1)}$



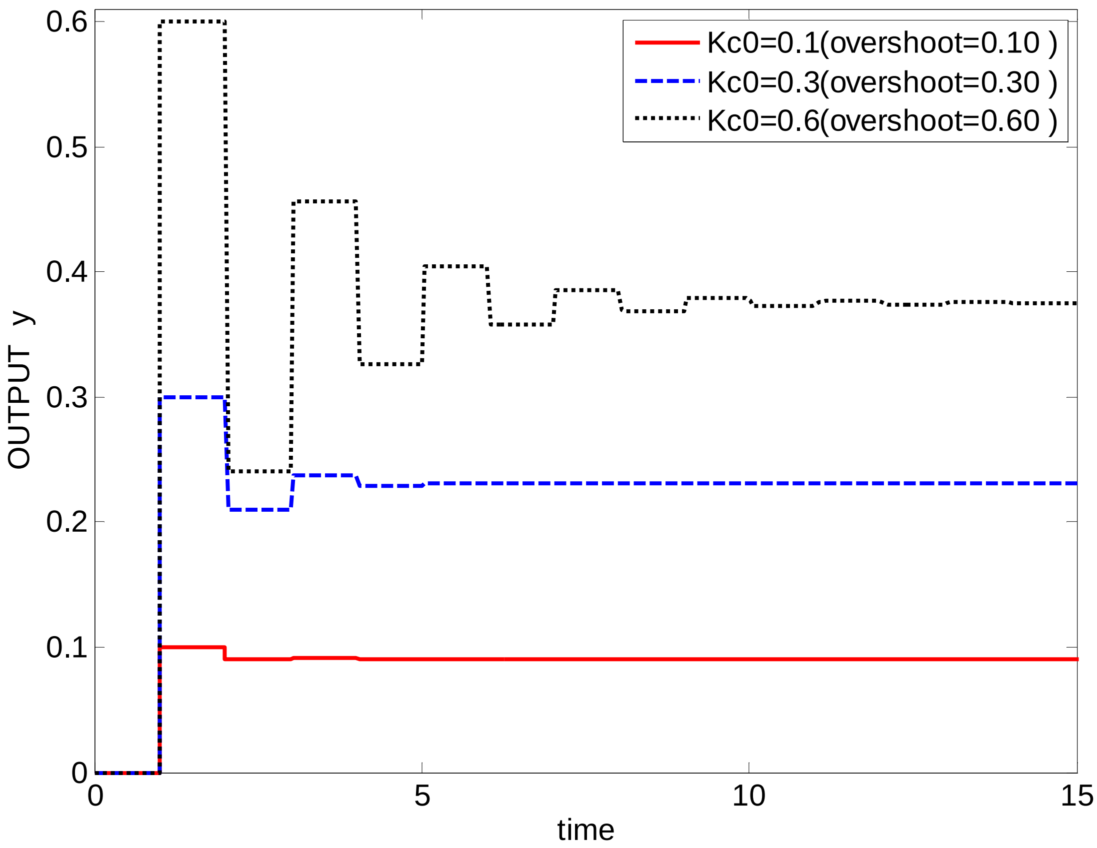
E18 $\frac{e^{-s}}{(s+1)}$



E19 $\frac{e^{-s}}{(0.2s+1)}$

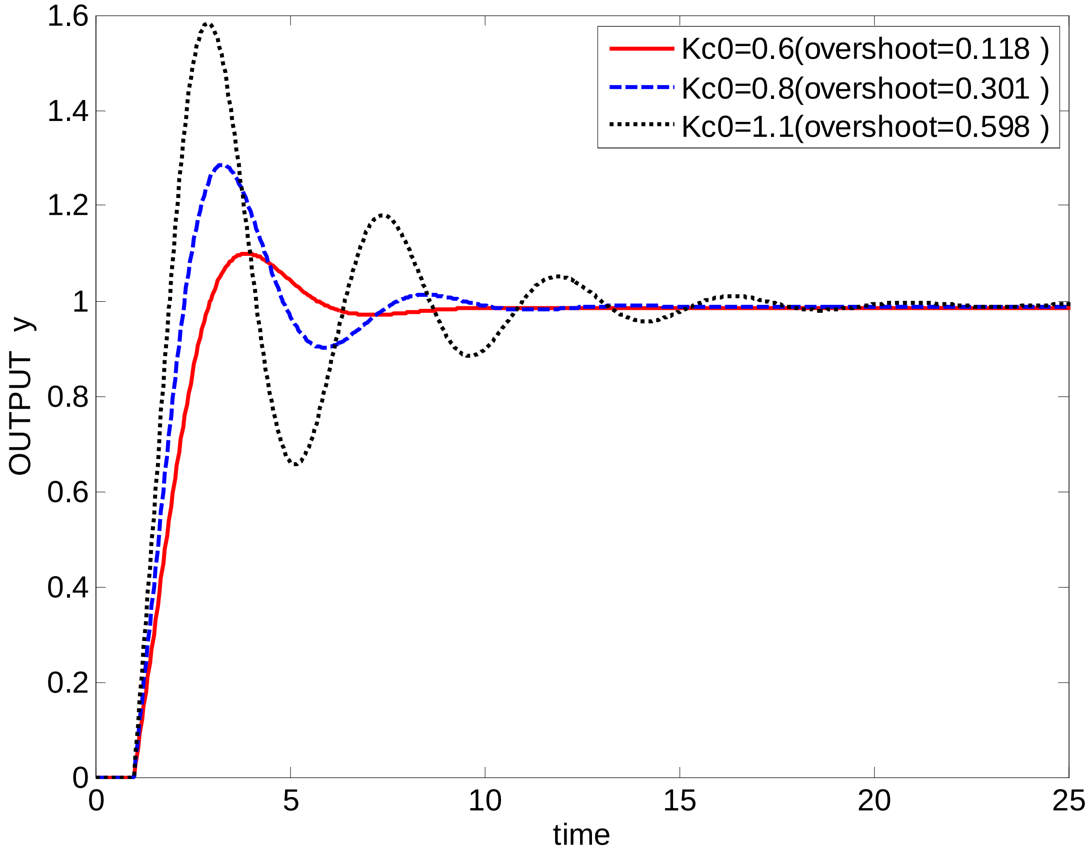


E20 $\frac{e^{-s}}{(0.05s+1)^2}$

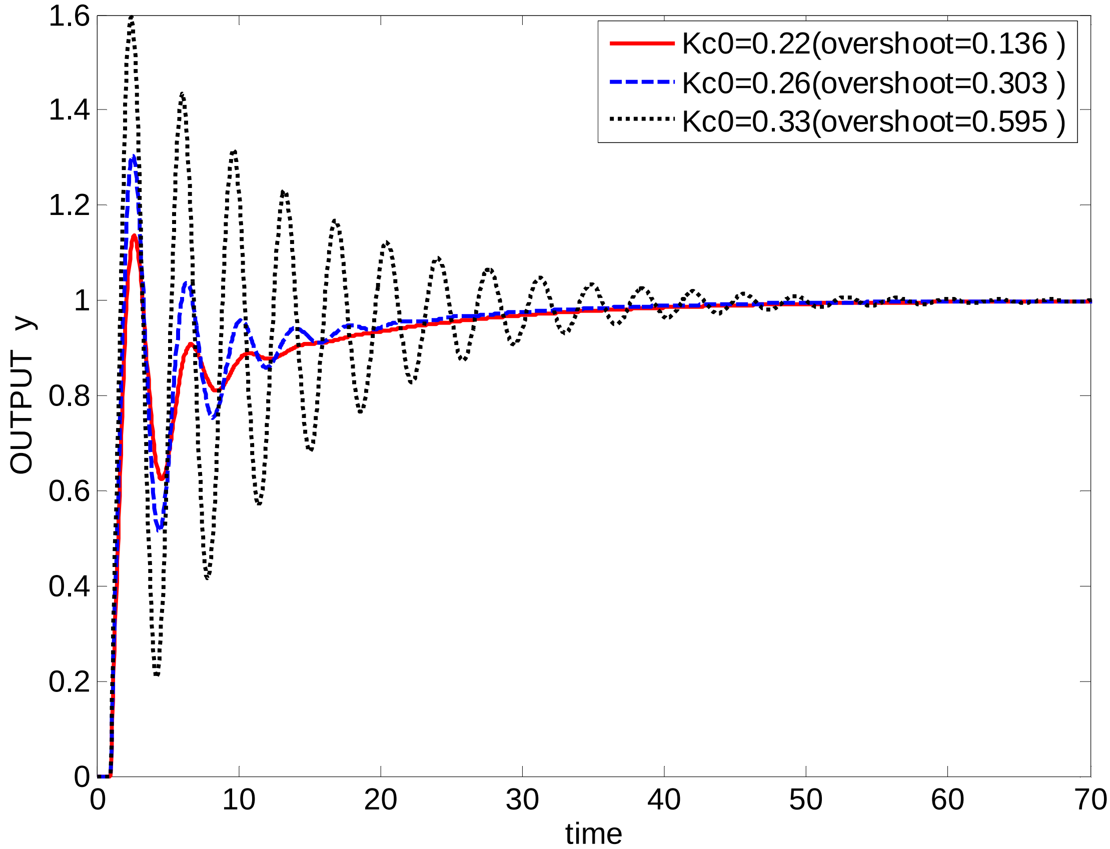


0.6
0.5
0.4
0.3
0.2
0.1
0
OUTPUT y
0
5
10
15
time
Kc0=0.1(overshoot=0.10)
Kc0=0.3(overshoot=0.30)
Kc0=0.6(overshoot=0.60)

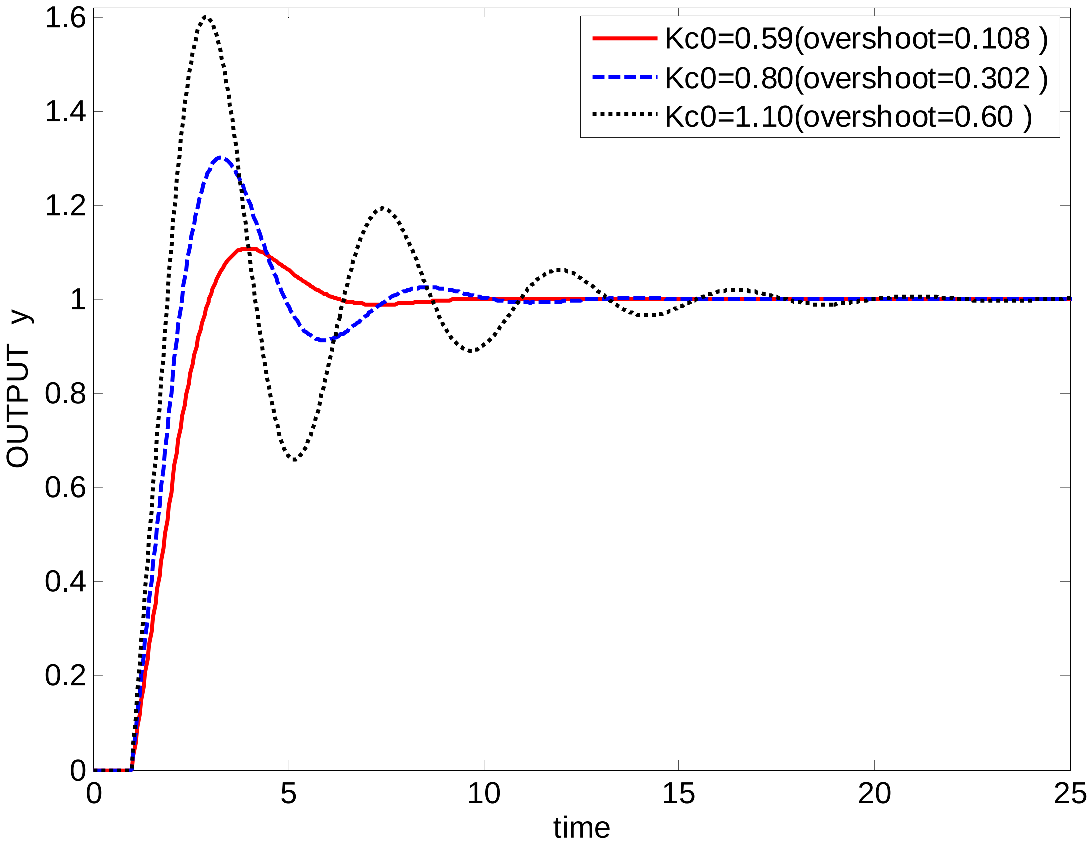
E21 e^{-s}



E22 $\frac{100e^{-s}}{100s+1}$

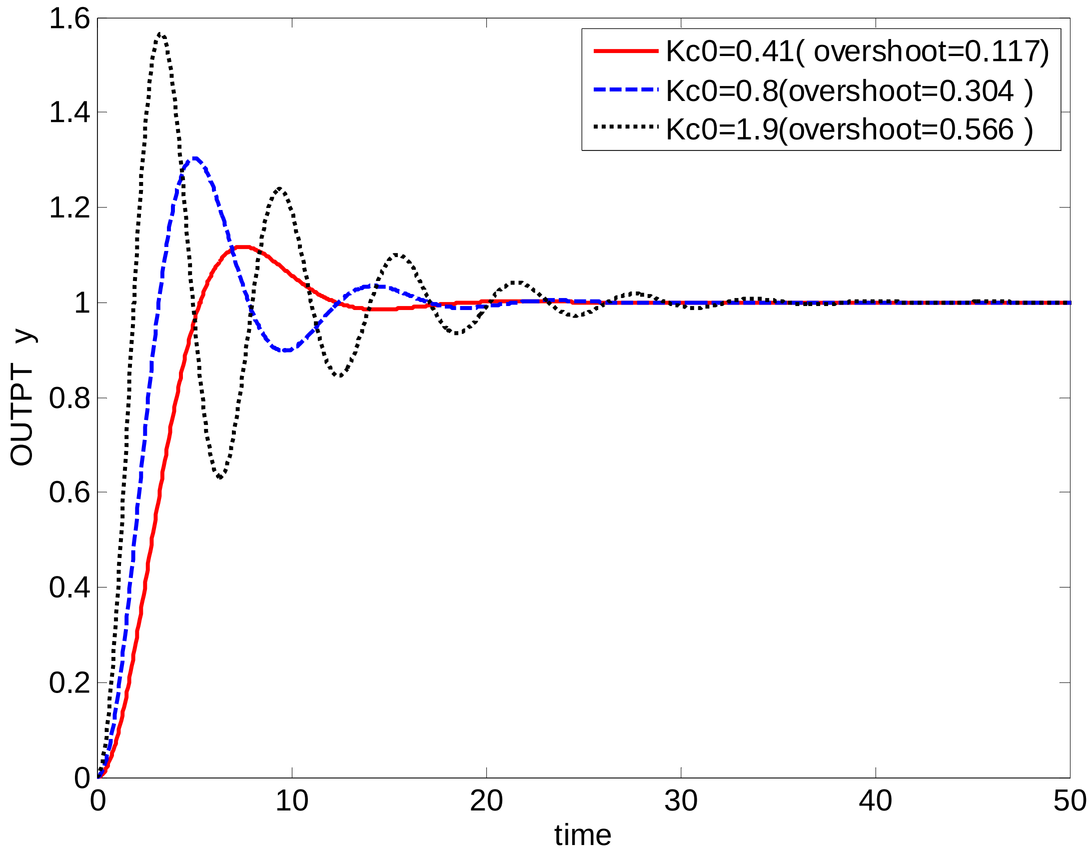


E23 $\frac{(10s+1)e^{-s}}{s(2s+1)}$

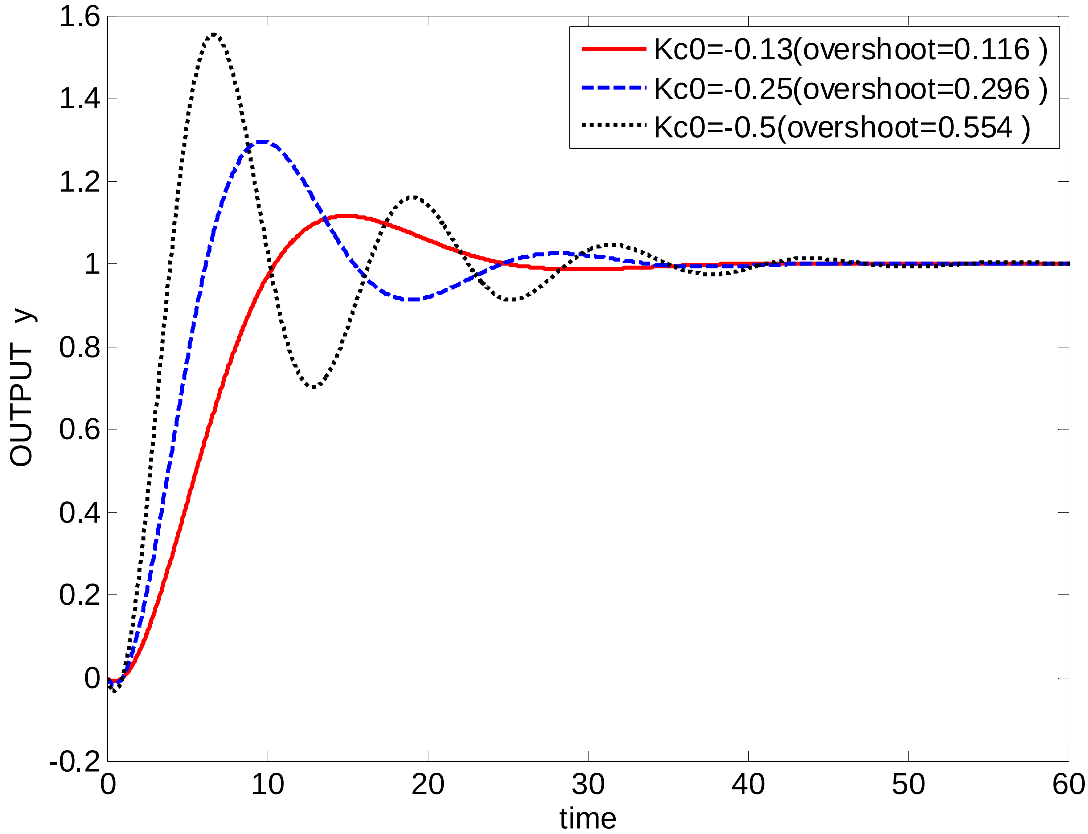


Kc0=0.59(overshoot=0.108)
Kc0=0.80(overshoot=0.302)
Kc0=1.10(overshoot=0.60)
OUTPUT y
time
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25

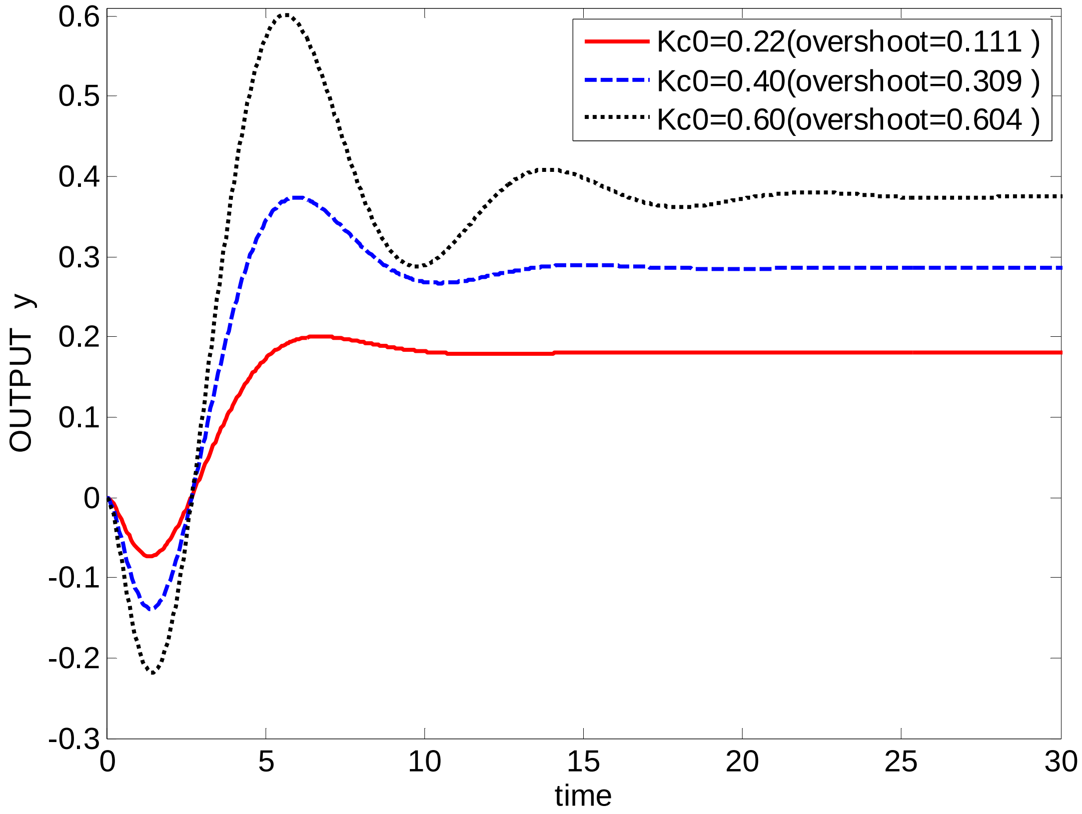
E24 $\frac{e^{-s}}{s}$



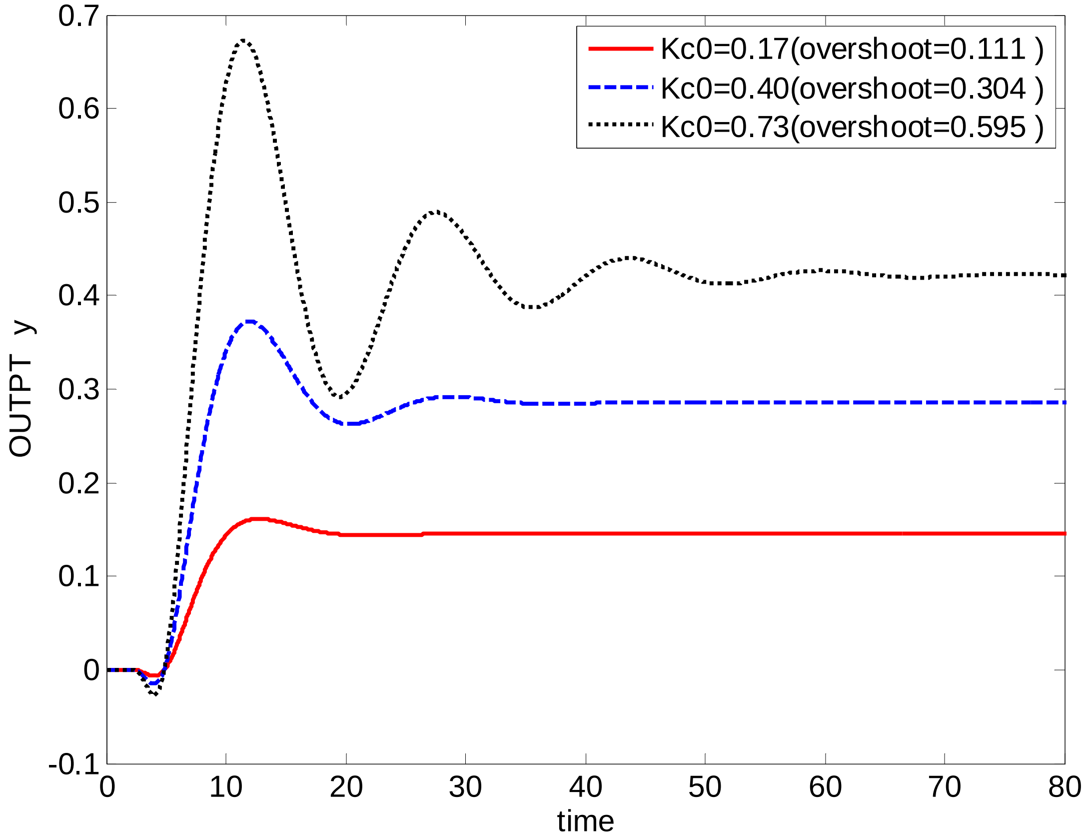
E25 $\dfrac{(s+6)^2}{s(s+1)^2(s+36)}$



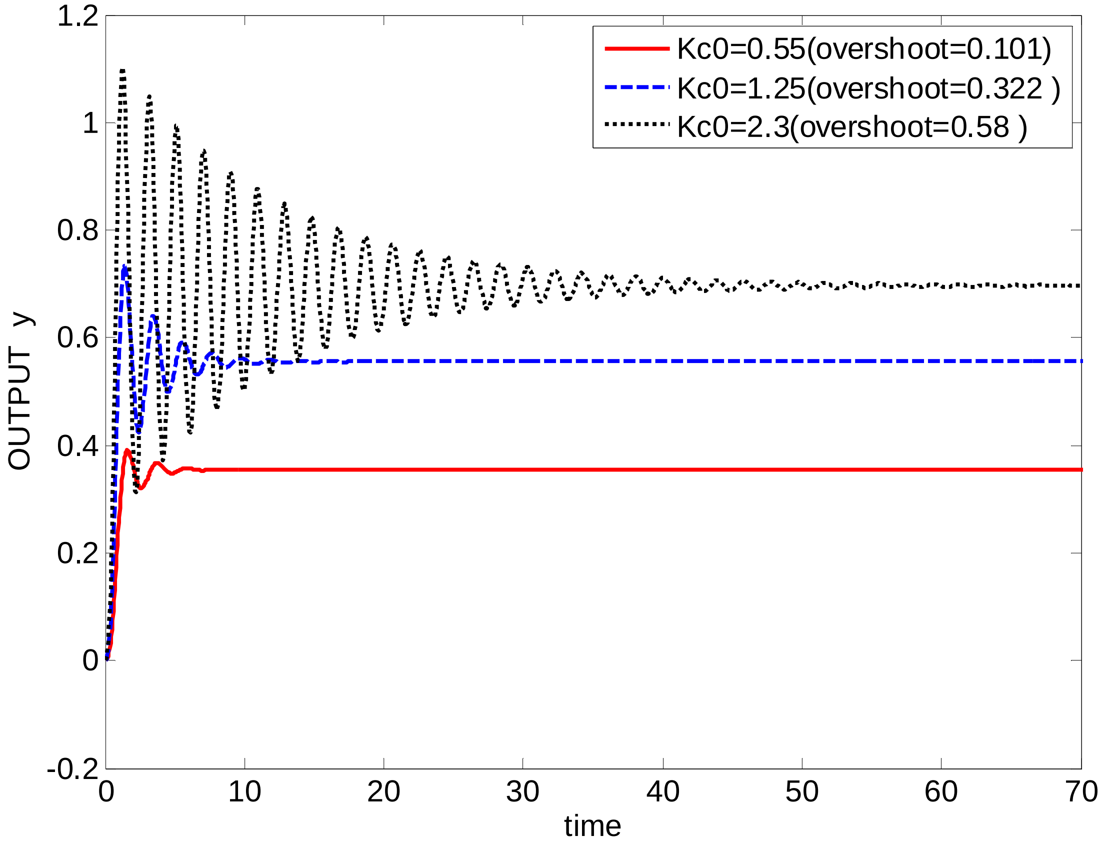
E26 $\dfrac{-1.6(-0.5s+1)}{s(3s+1)}$



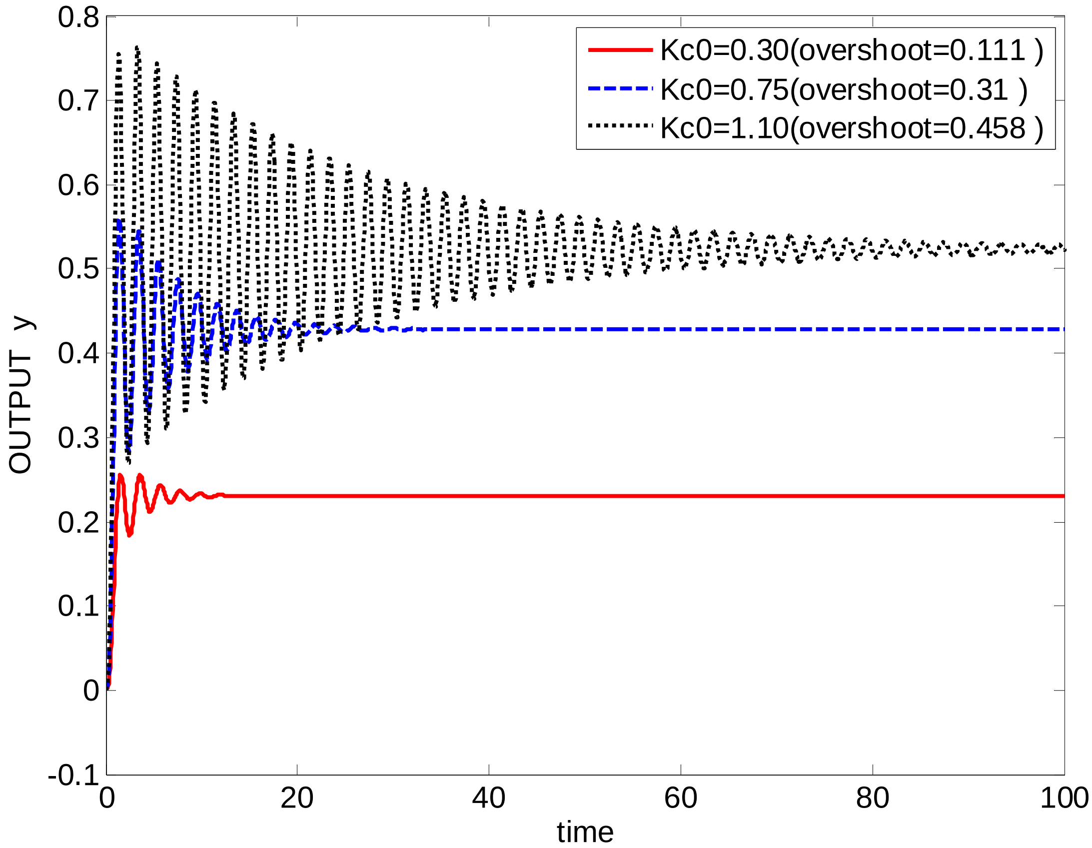
E28 $\dfrac{(-2s+1)}{(s+1)^3}$



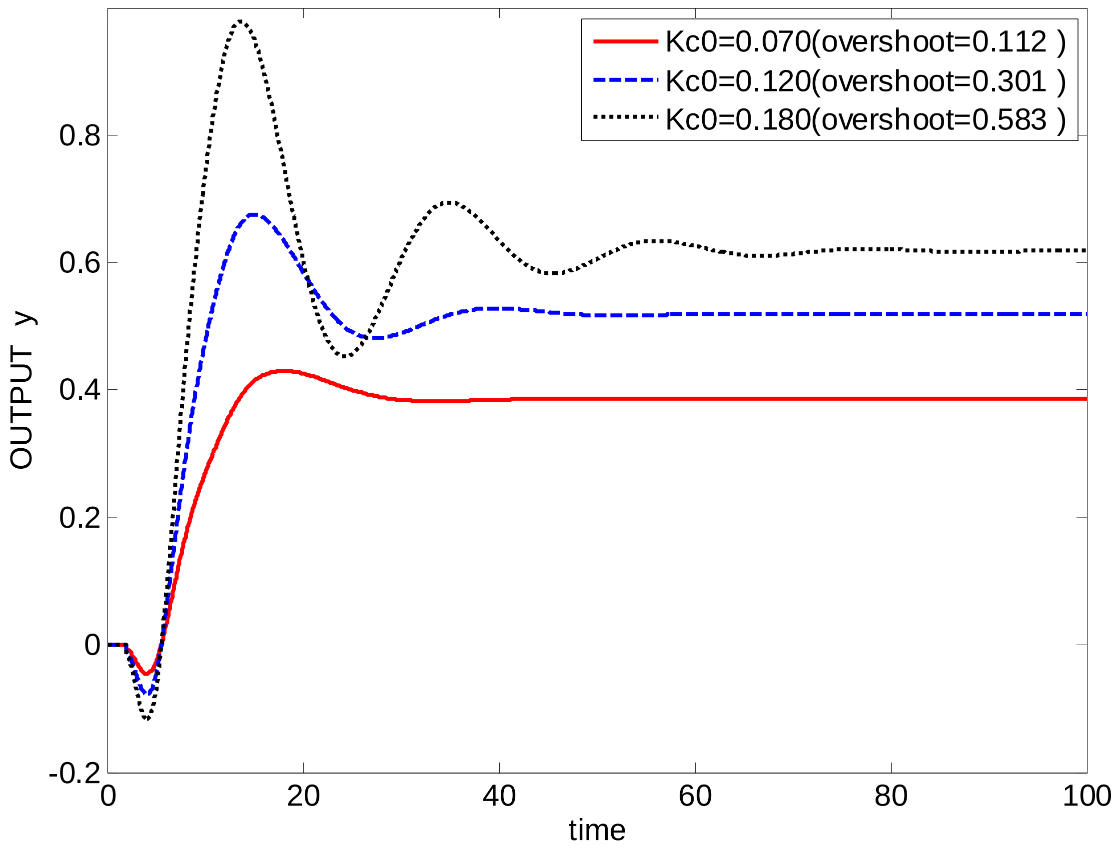
E29 $\dfrac{(-s+1)e^{-2s}}{(s+1)^5}$



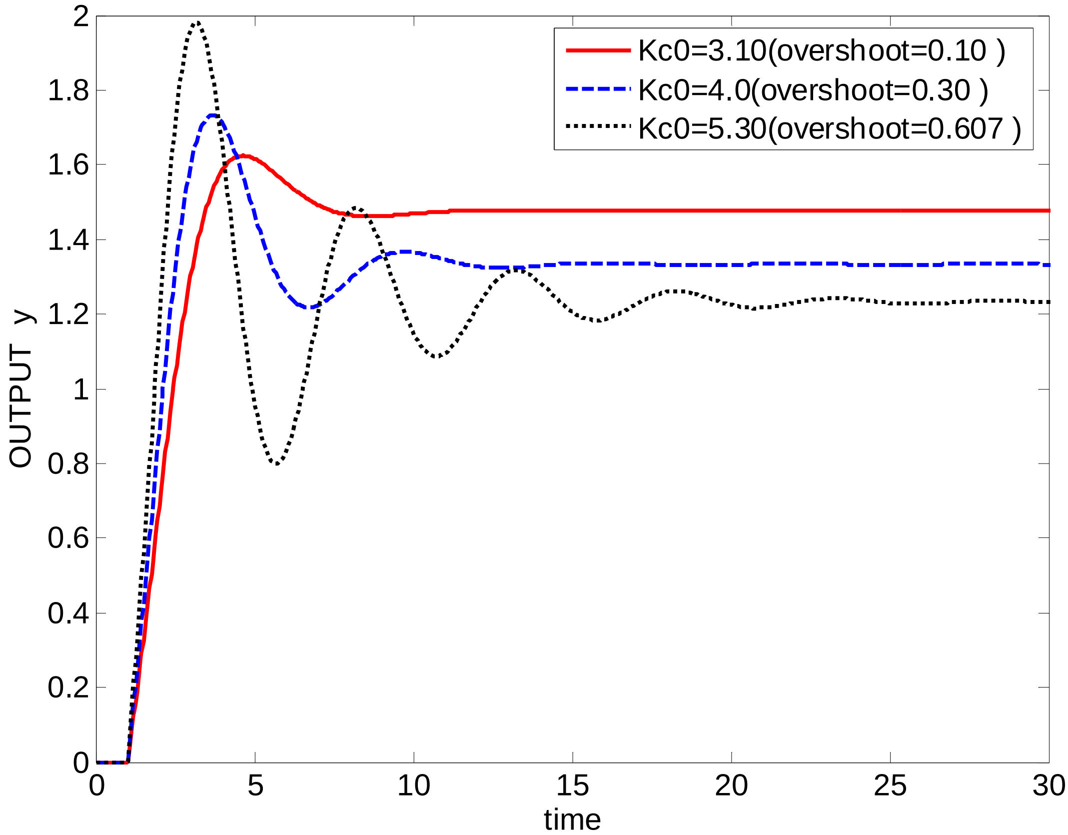
E30 $\frac{9}{(s+1)(s^2+2s+9)}$



E31 $\frac{9}{(s+1)(s^2+s+9)}$



E32 $\dfrac{\left(s^2+2s+9\right)\left(-2s+1\right)\left(s+1\right)e^{-2s}}{\left(s^2+0.5s+1\right)\left(5s+1\right)^2}$



E33 $\frac{e^{-s}}{(5s-1)}$

Section: 2,

Responses for PI-control for E1-E33.

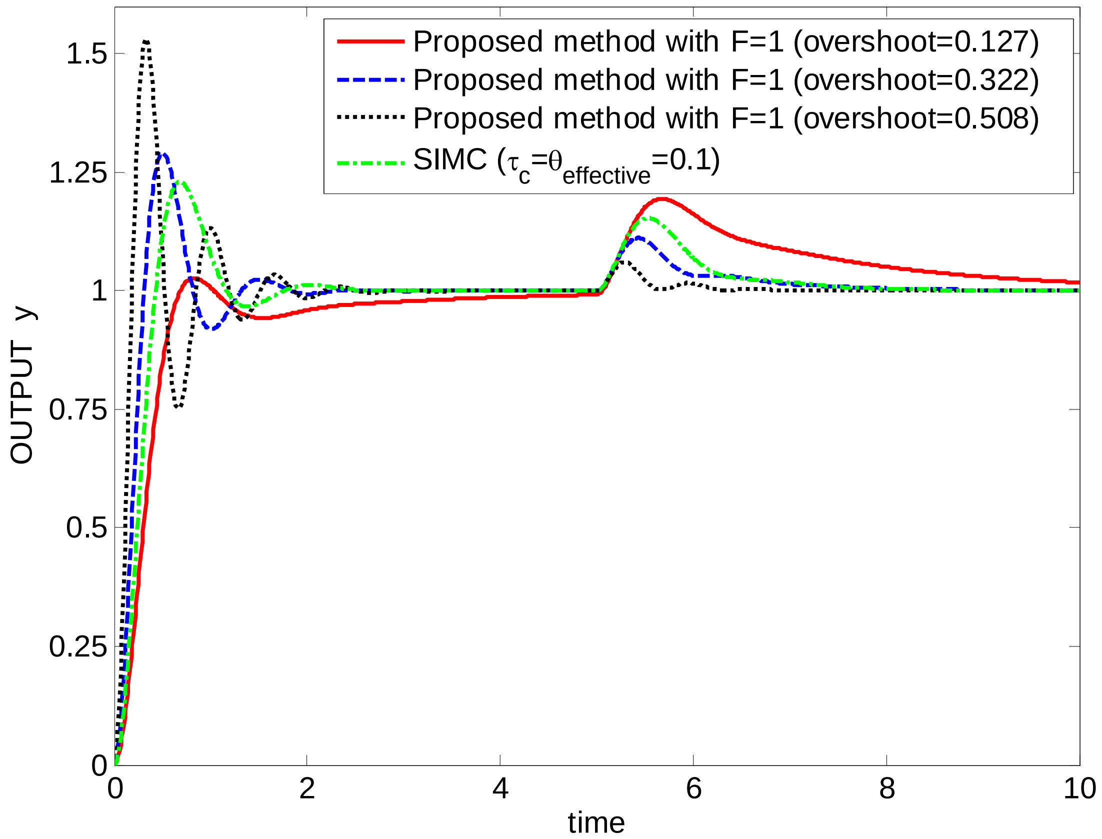


Fig.1. Responses for PI-control of process $\frac{1}{(s+1)(0.2s+1)}$ (E1), Setpoint change at t=0; load disturbance of magnitude 1 at t=5.

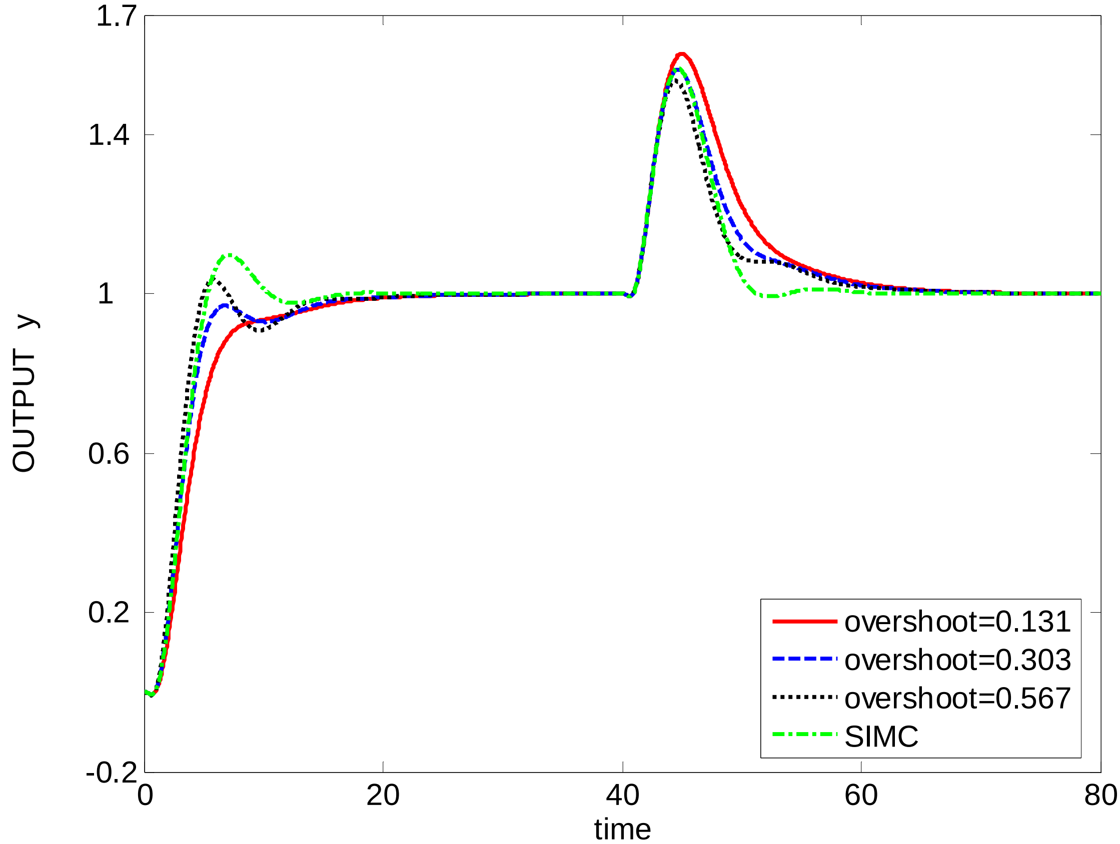


Fig.2. Responses for PI-control of process $\frac{(-0.3s+1)(0.08s+1)}{(2s+1)(s+1)(0.4s+1)(0.2s+1)(0.05s+1)^3}$ (E2), Setpoint change at t=0; load disturbance of magnitude 1 at t=40.

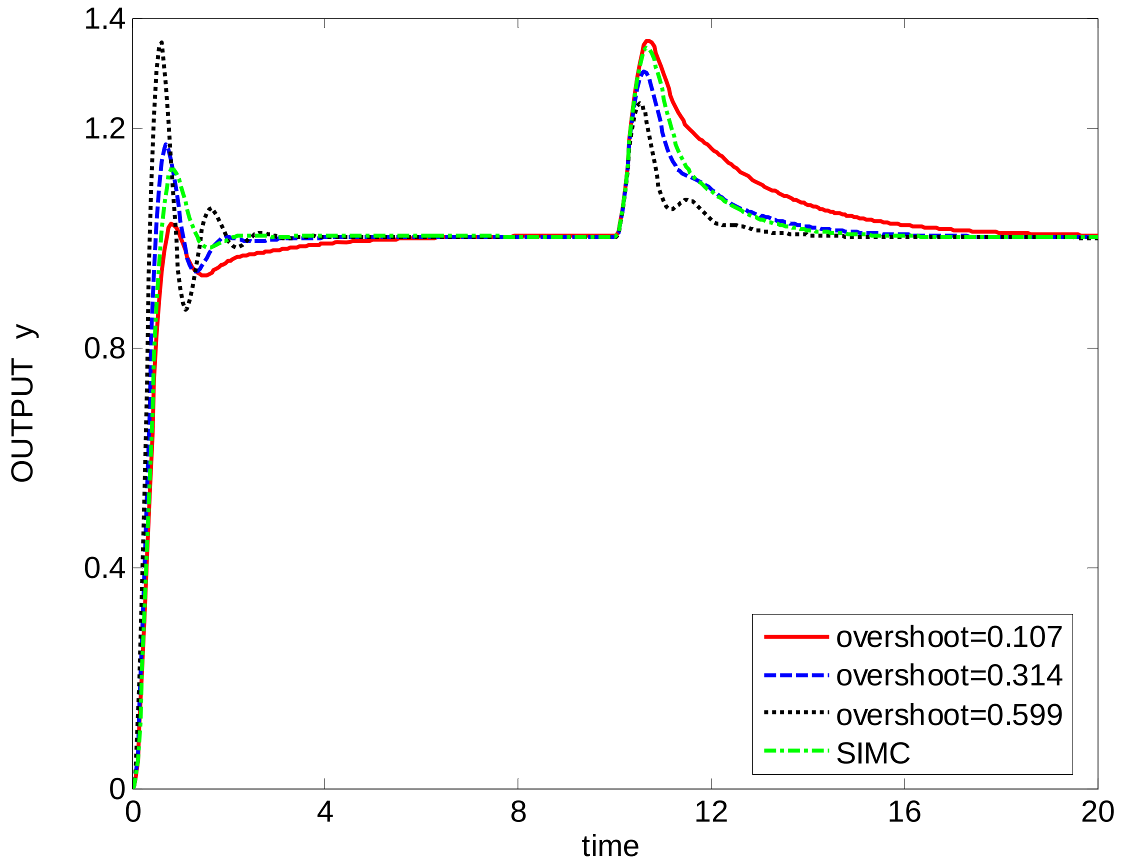


Fig.3. Responses for PI-control of process $\frac{2(15s+1)}{(20s+1)(s+1)(0.1s+1)^2}$ (E3), Setpoint change at t=0; load disturbance of magnitude 1 at t=10.

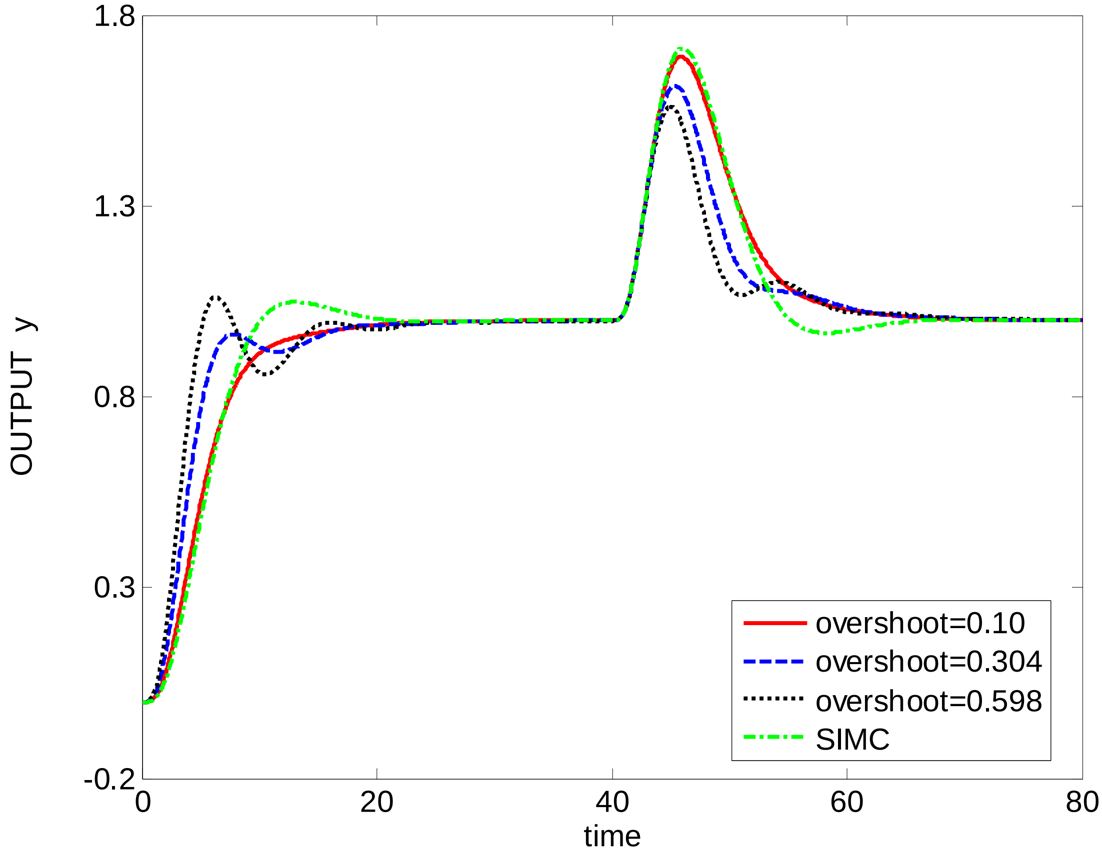


Fig.4. Responses for PI-control of process $\frac{1}{(s+1)^4}$ (E4), Setpoint change at t=0; load disturbance of magnitude 1 at t=40.

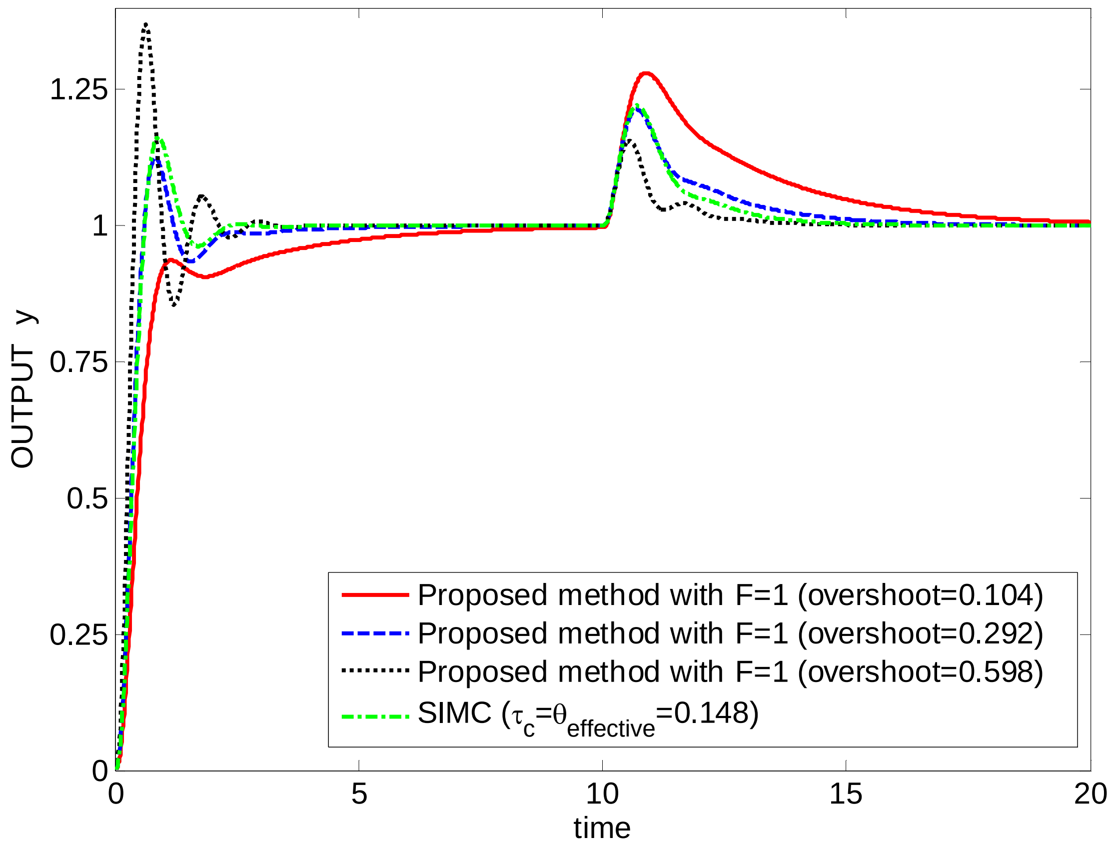


Fig.5. Responses for PI-control of process $\frac{1}{(s+1)(0.2s+1)(0.04s+1)(0.008s+1)}$ (E5), Setpoint change at t=0; load disturbance of magnitude 1 at t=10.

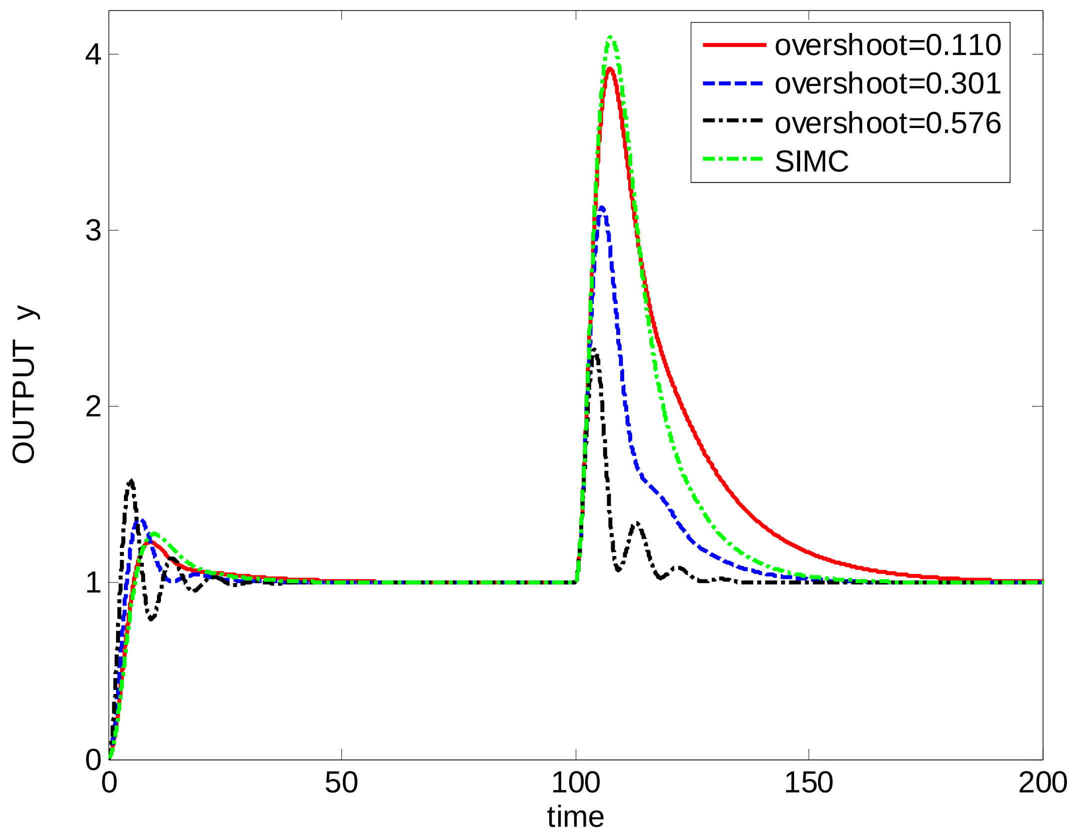


Fig.6. Responses for PI-control of process $\frac{(0.17s+1)^2}{s(s+1)^2(0.028s+1)}$ (E6), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

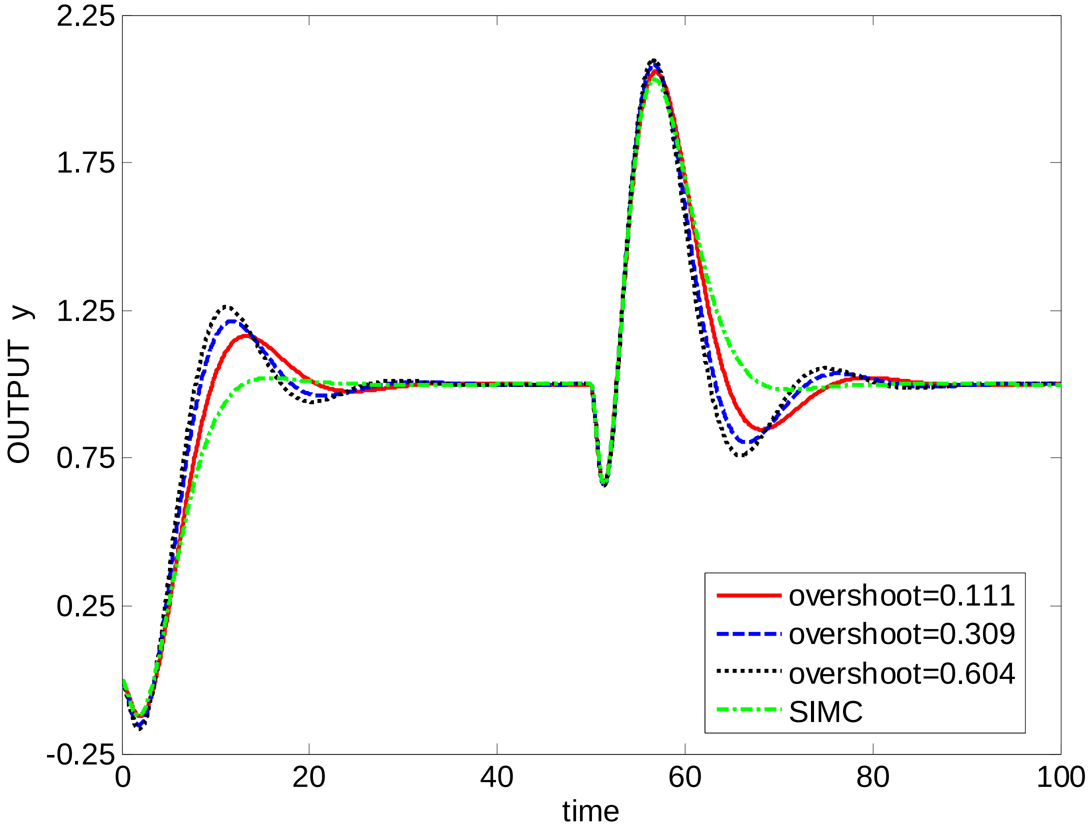


Fig.7. Responses for PI-control of process $\frac{-2s+1}{(s+1)^3}$ (E7), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

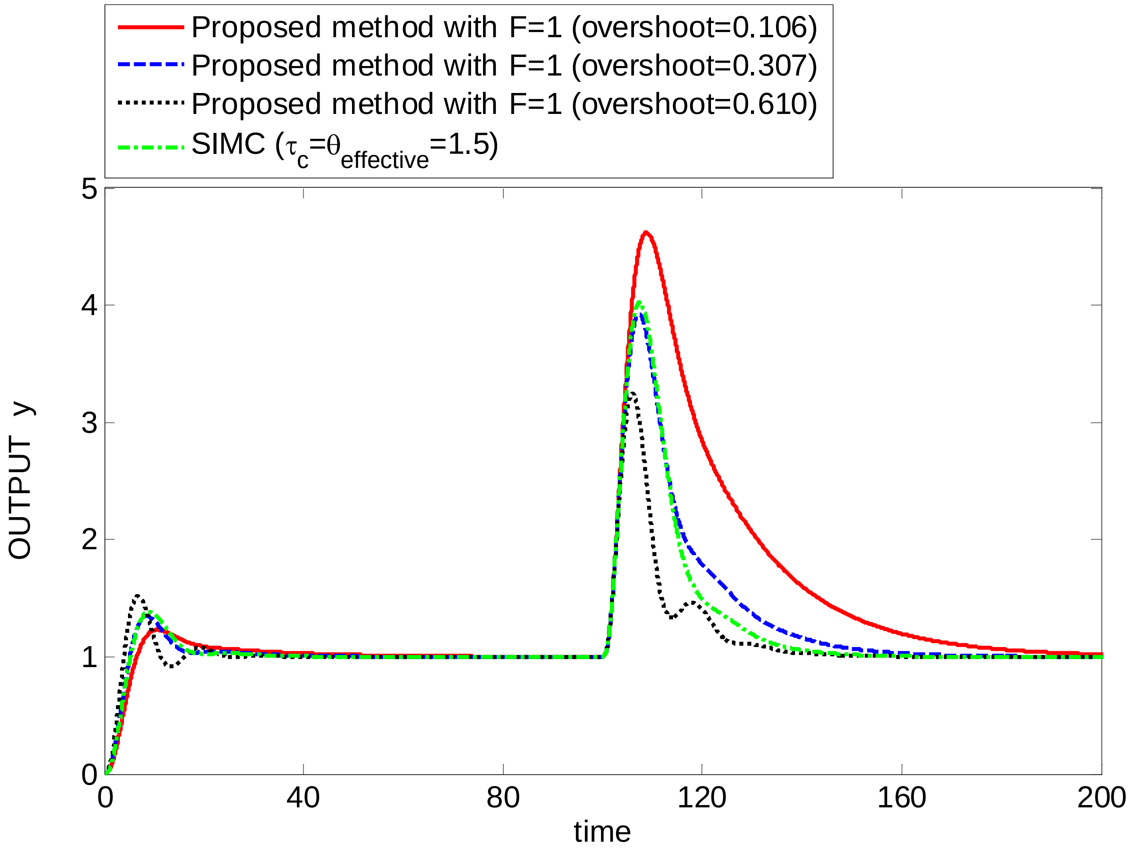


Fig.8. Responses for PI-control of third-order integrating process $\frac{1}{s(s+1)^2}$ (E8), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

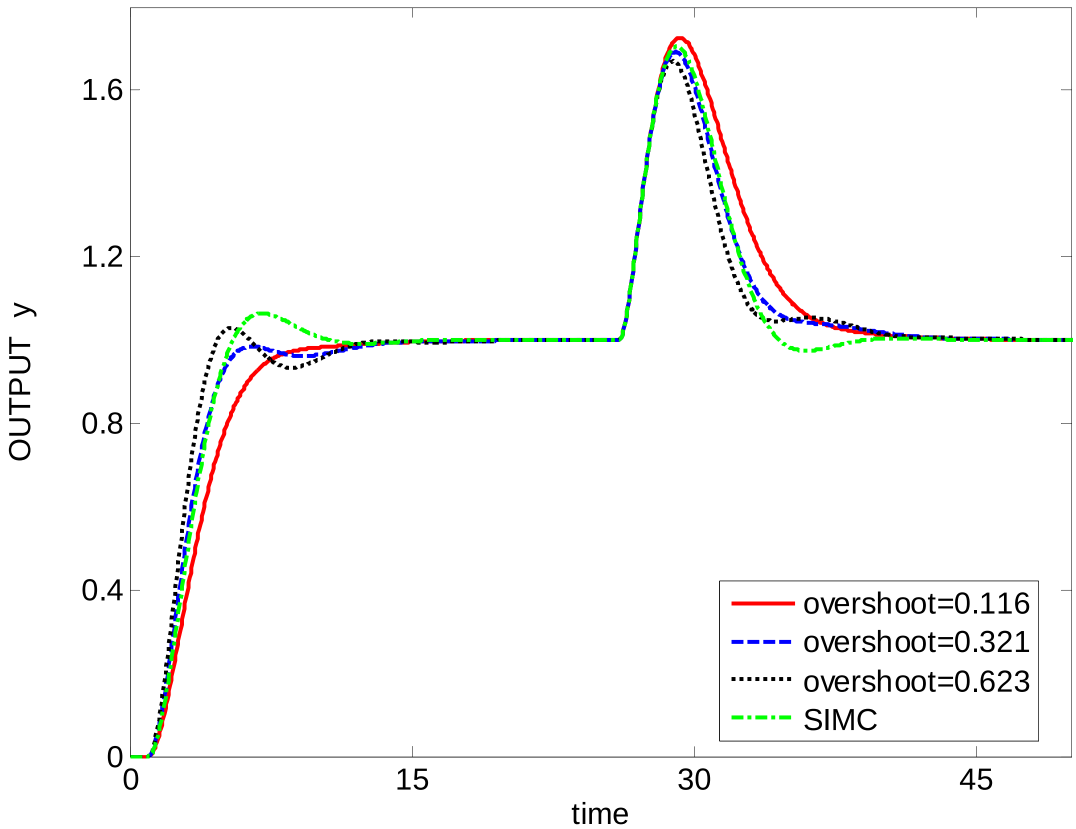


Fig.9. Responses for PI-control of process $\frac{e^{-s}}{(s+1)^2}$ (E9), Setpoint change at t=0; load disturbance of magnitude 1 at t=25.

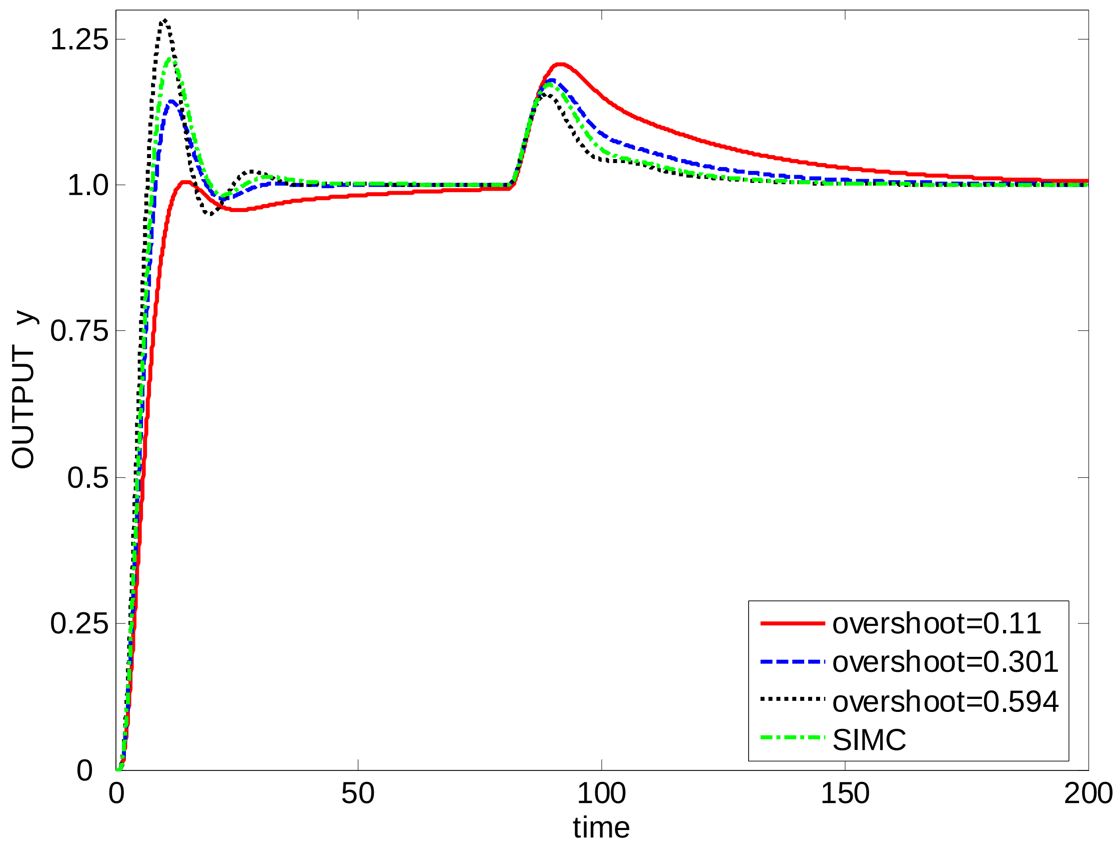


Fig.10. Responses for PI-control of process $\frac{e^{-s}}{(20s+1)(2s+1)}$ (E10), Setpoint change at t=0; load disturbance of magnitude 1 at t=80.

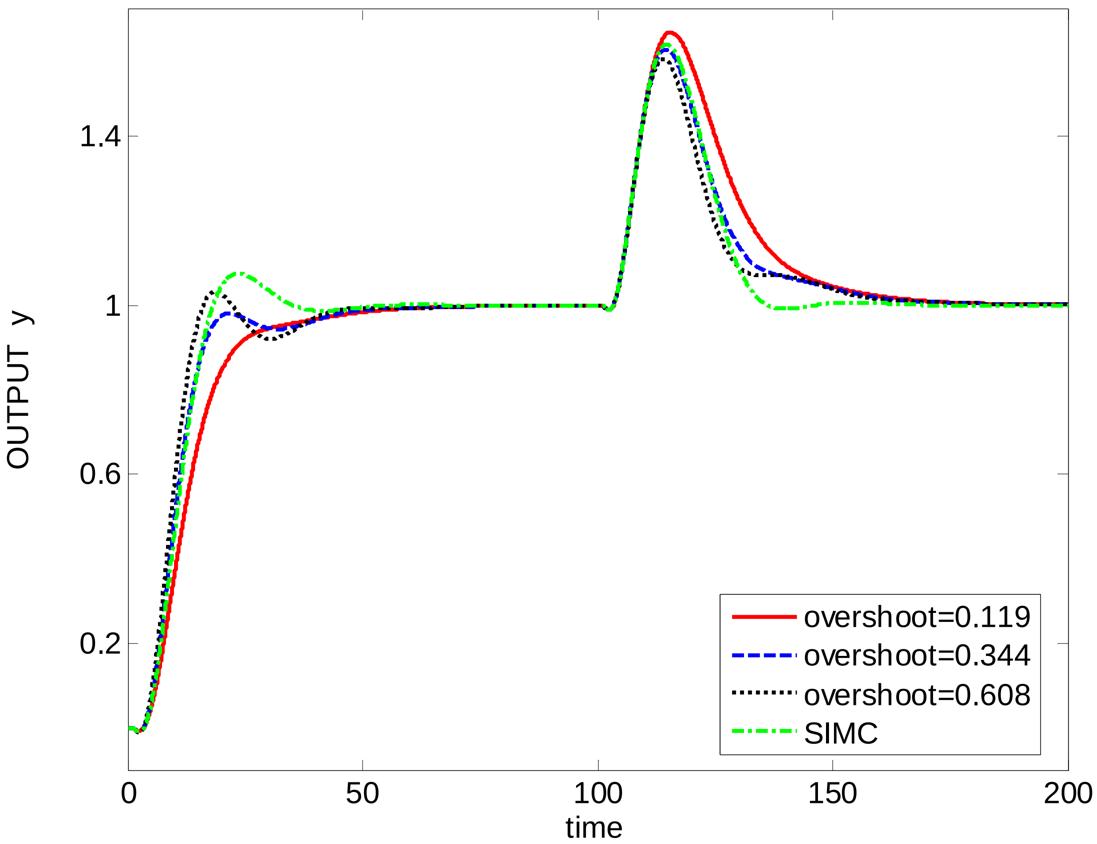


Fig.11. Responses for PI-control of process $\frac{(-s+1)e^{-s}}{(6s+1)(2s+1)^2}$ (E11), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

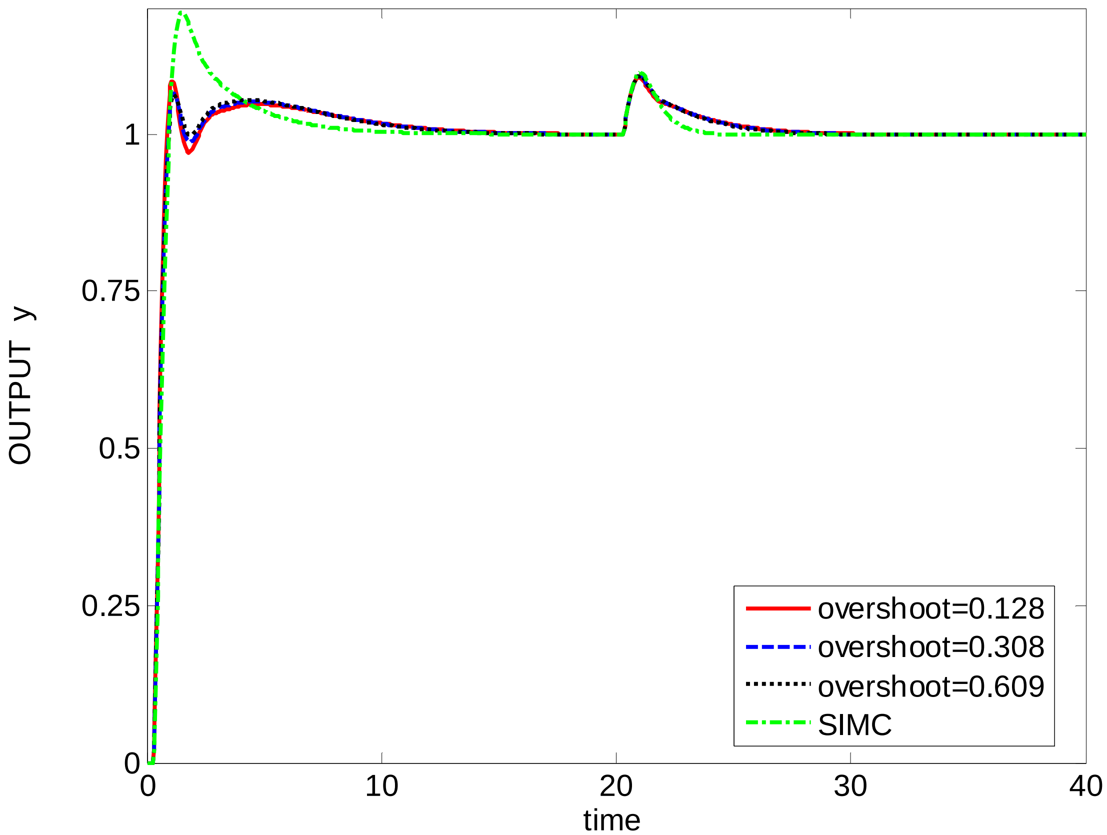


Fig.12. Responses for PI-control of process $\frac{(6s+1)(3s+1)e^{-0.3s}}{(10s+1)(8s+1)(s+1)}$ (E12), Setpoint change at t=0; load disturbance of magnitude 1 at t=20.

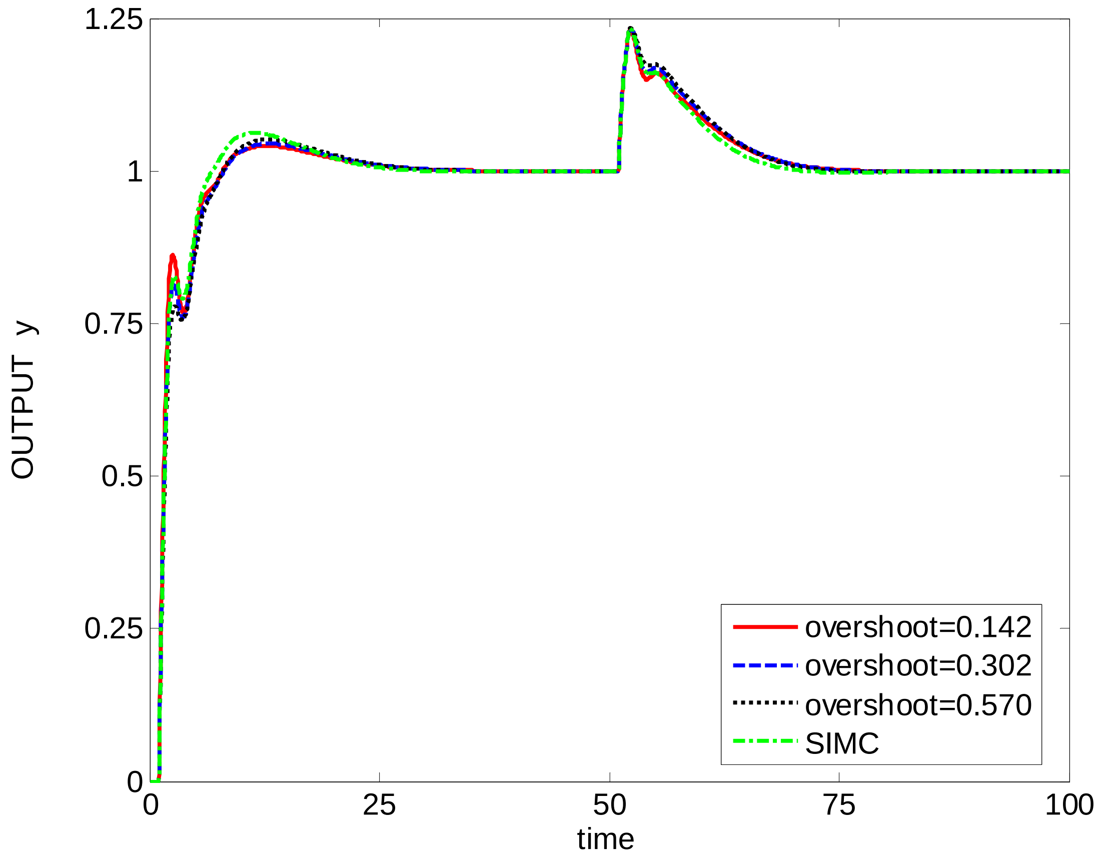


Fig.13. Responses for PI-control of process $\frac{(2s+1)e^{-s}}{(10s+1)(0.5s+1)}$ (E13), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

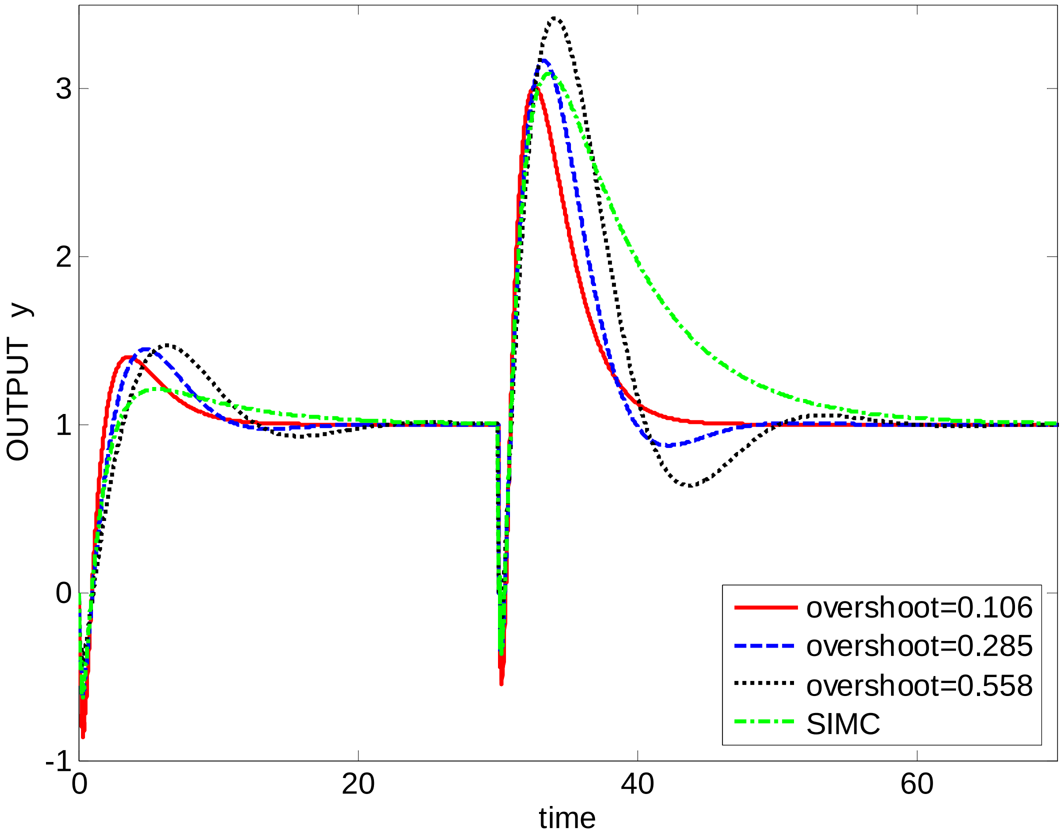


Fig.14 (a). Responses for PI-control of process $\frac{(-s+1)e^{-0.1s}}{s}$ (E14-a), Setpoint change at t=0; load disturbance of magnitude 1 at t=30.

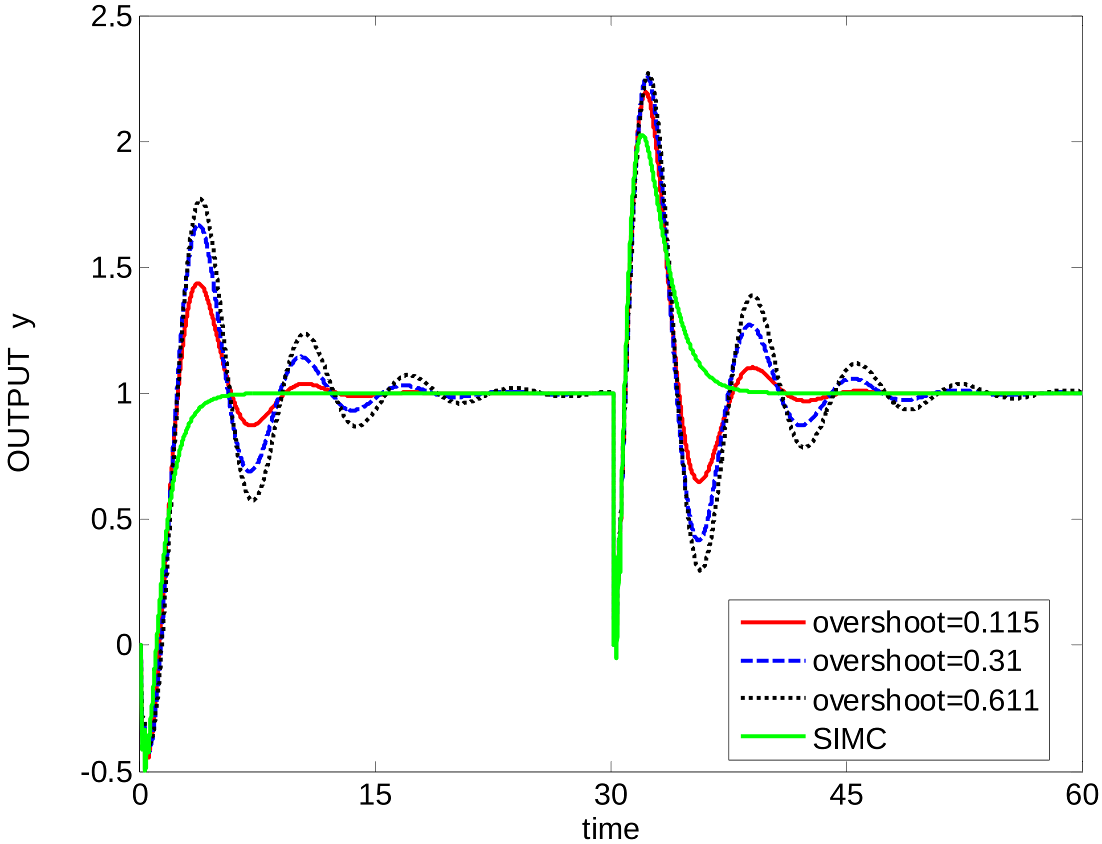


Fig.15 (a). Responses for PI-control of process $\frac{(-s+1)e^{-0.2s}}{(s+1)}$ (E15-a), Setpoint change at t=0; load disturbance of magnitude 1 at t=30.

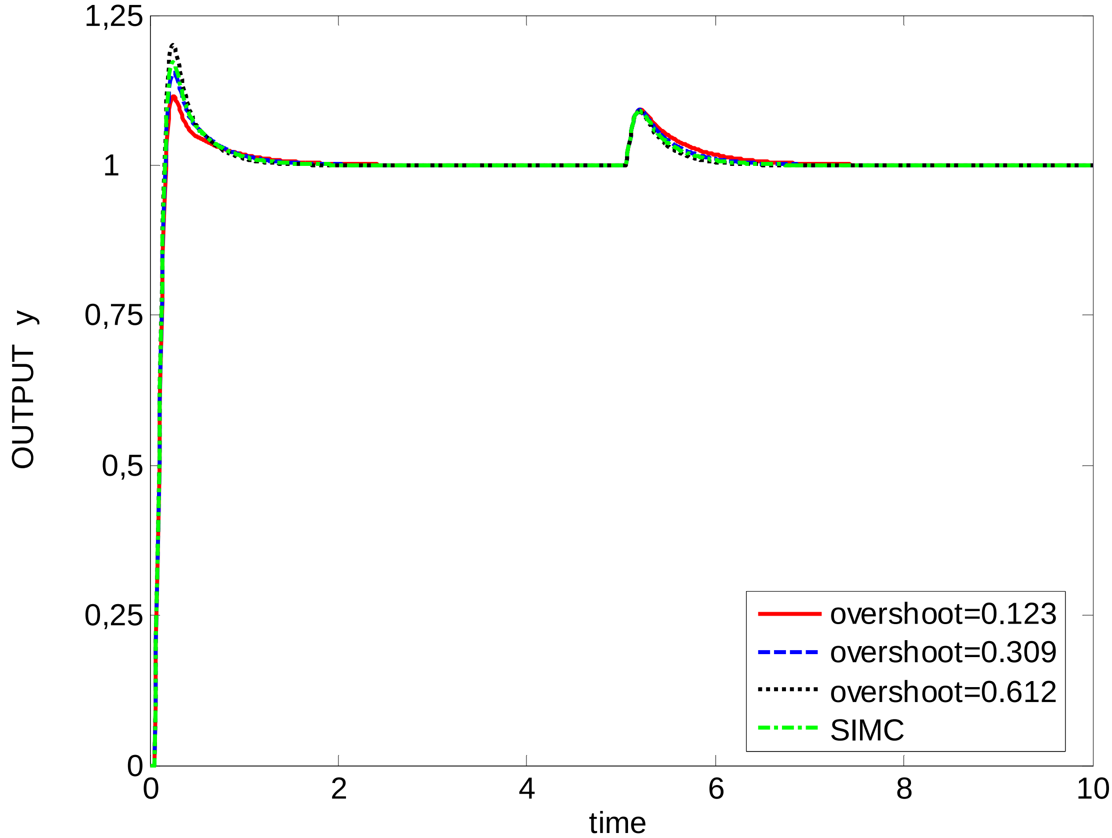


Fig.16 (a). Responses for PI-control of process $\frac{e^{-0.05s}}{(s+1)}$ (E16-a), Setpoint change at t=0; load disturbance of magnitude 1 at t=5.

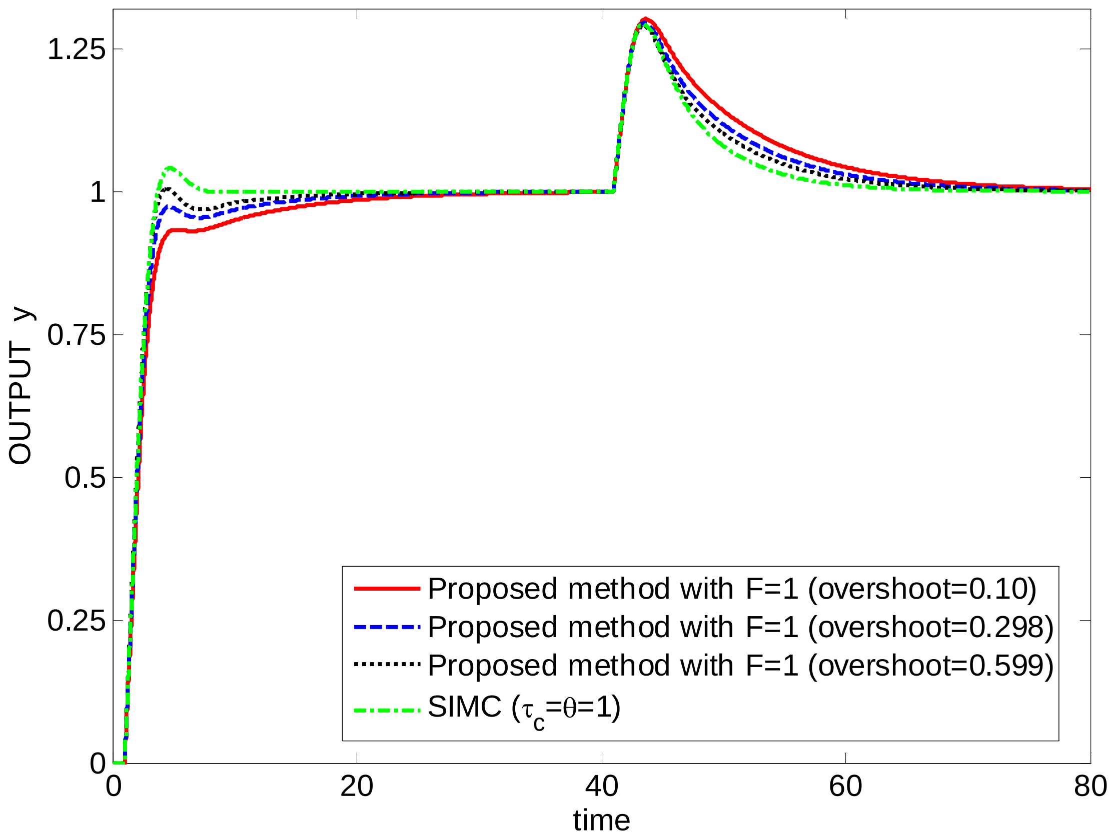


Fig.17. Responses for PI-control of process $\frac{e^{-s}}{(5s+1)}$ (E17), Setpoint change at t=0; load disturbance of magnitude 1 at t=40.

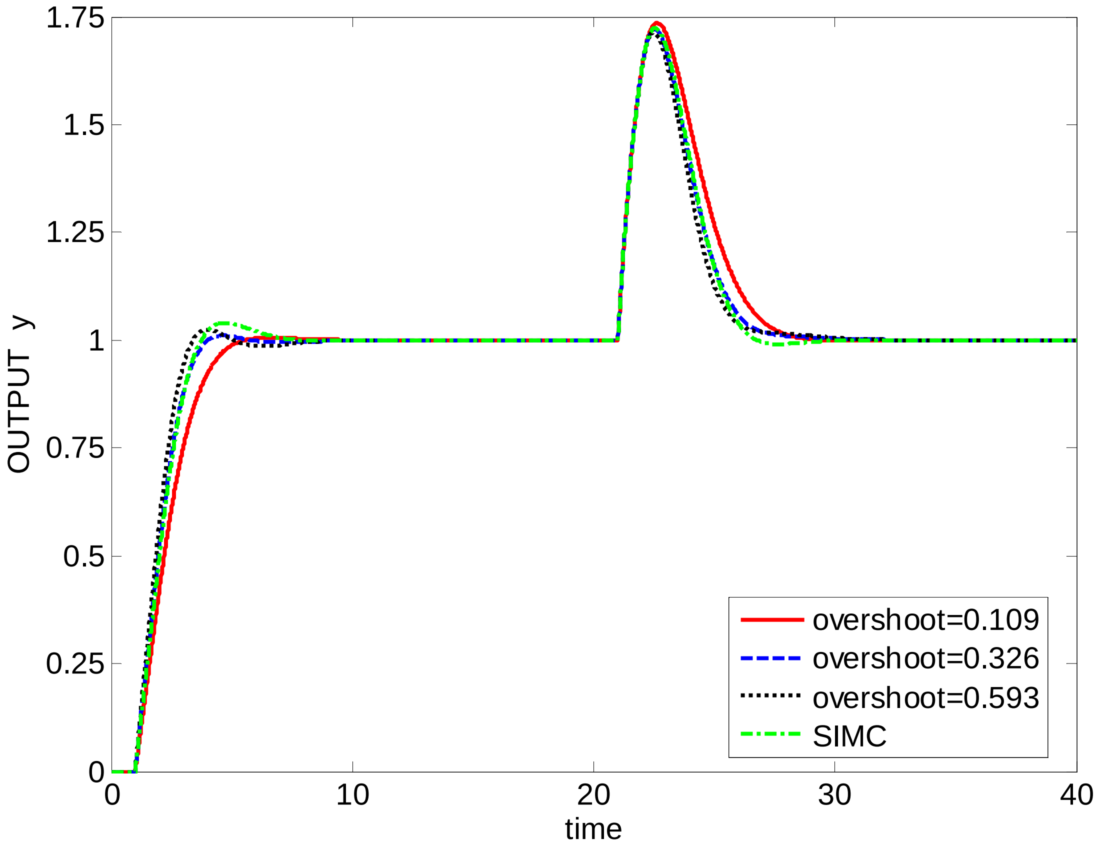


Fig.18. Responses for PI-control of process $\frac{e^{-s}}{(s+1)}$ (E18), Setpoint change at t=0; load disturbance of magnitude 1 at t=20.

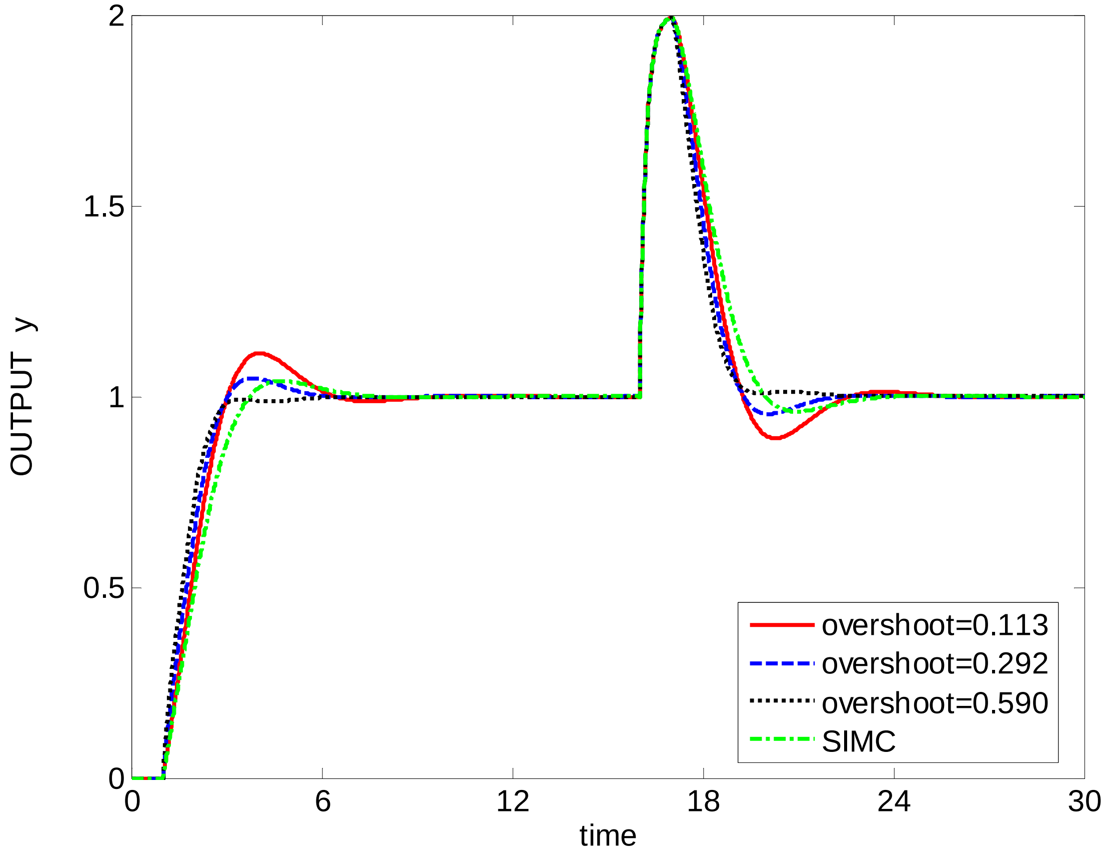


Fig.19. Responses for PI-control of process $\frac{e^{-s}}{(0.2s+1)}$ (E19), Setpoint change at t=0; load disturbance of magnitude 1 at t=15.

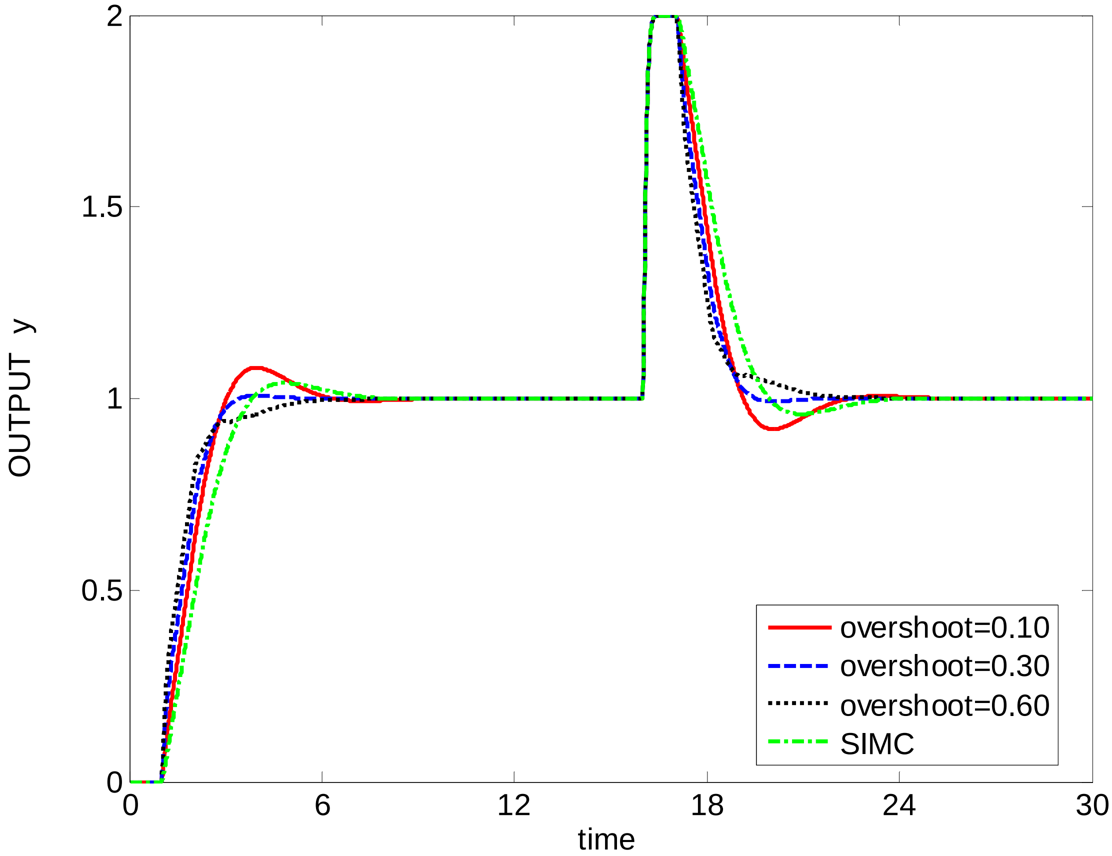


Fig.20. Responses for PI-control of process $\frac{e^{-s}}{(0.05s+1)^2}$ (E20), Setpoint change at t=0; load disturbance of magnitude 1 at t=15.

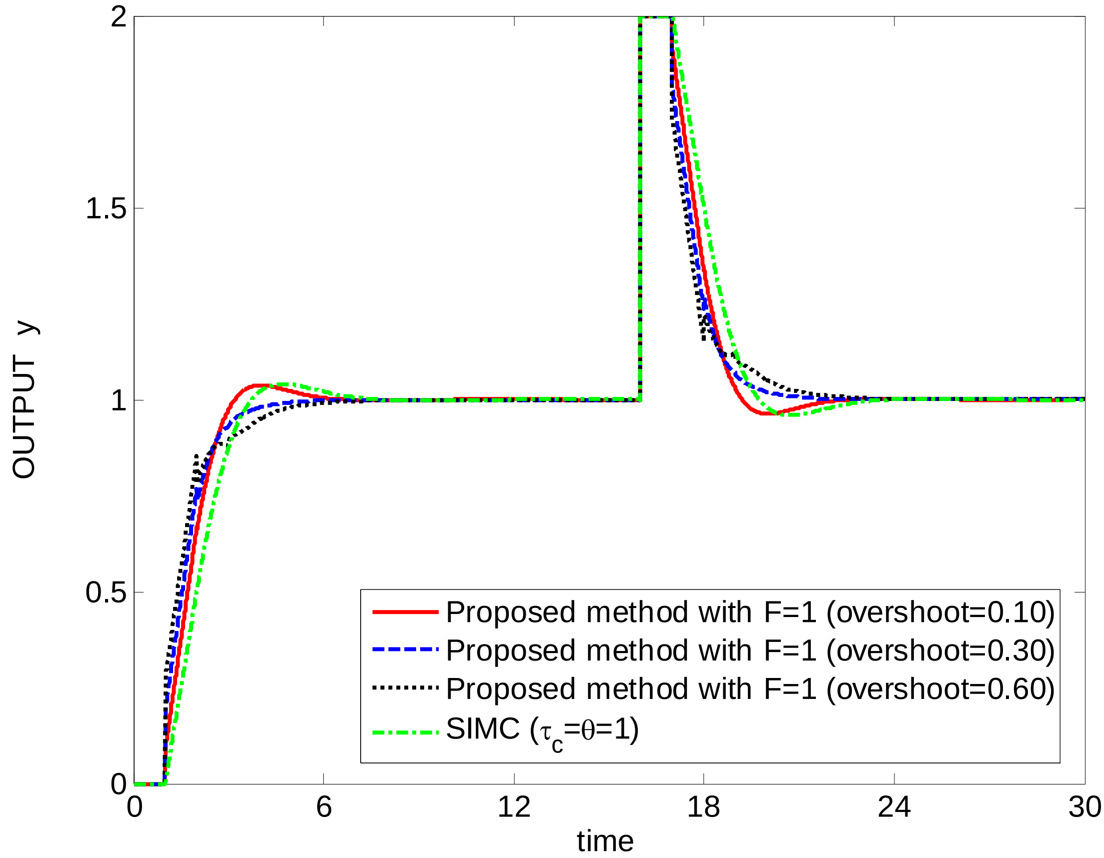


Fig.21. Responses for PI-control of process e^{-s} (E21), Setpoint change at t=0; load disturbance of magnitude 1 at t=15.

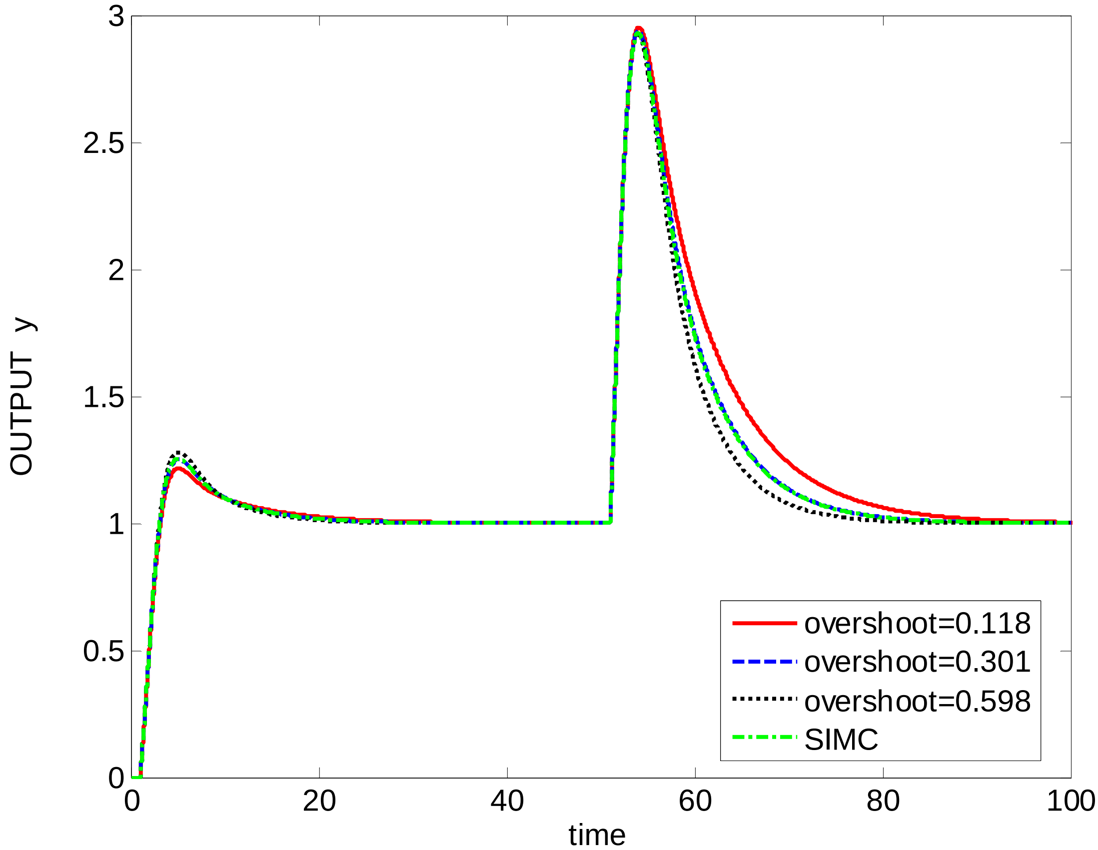


Fig.22. Responses for PI-control of process $\frac{100e^{-s}}{100s+1}$ (E22), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

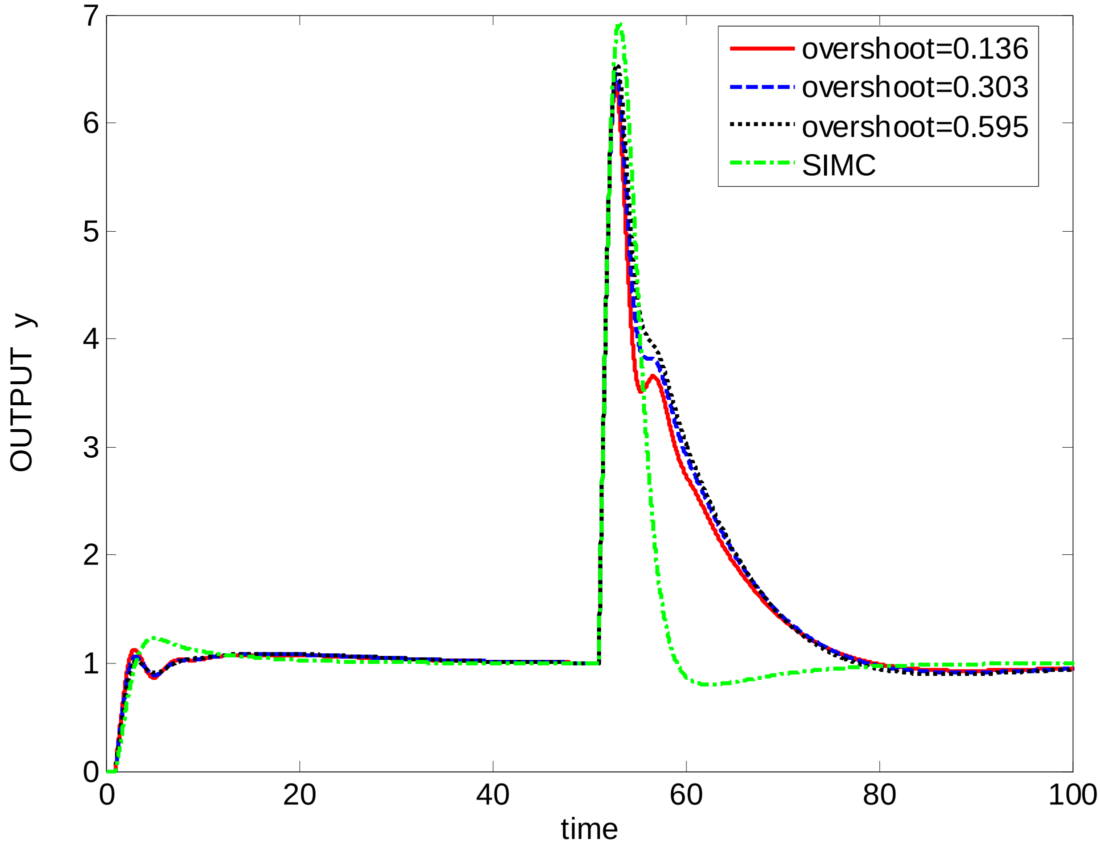


Fig.23. Responses for PI-control of process $\frac{\left(10s+1\right)e^{-s}}{s\left(2s+1\right)}$ (E23), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

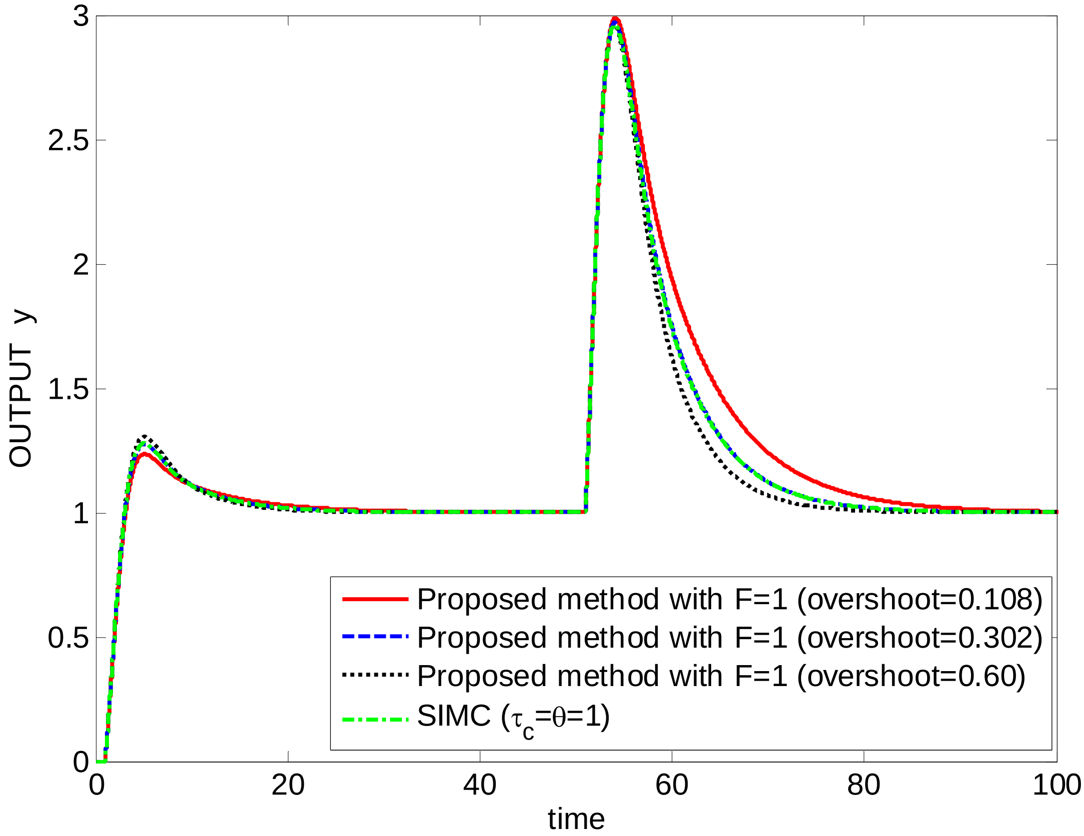


Fig.24. Responses for PI-control of process $\frac{e^{-s}}{s}$ (E24), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

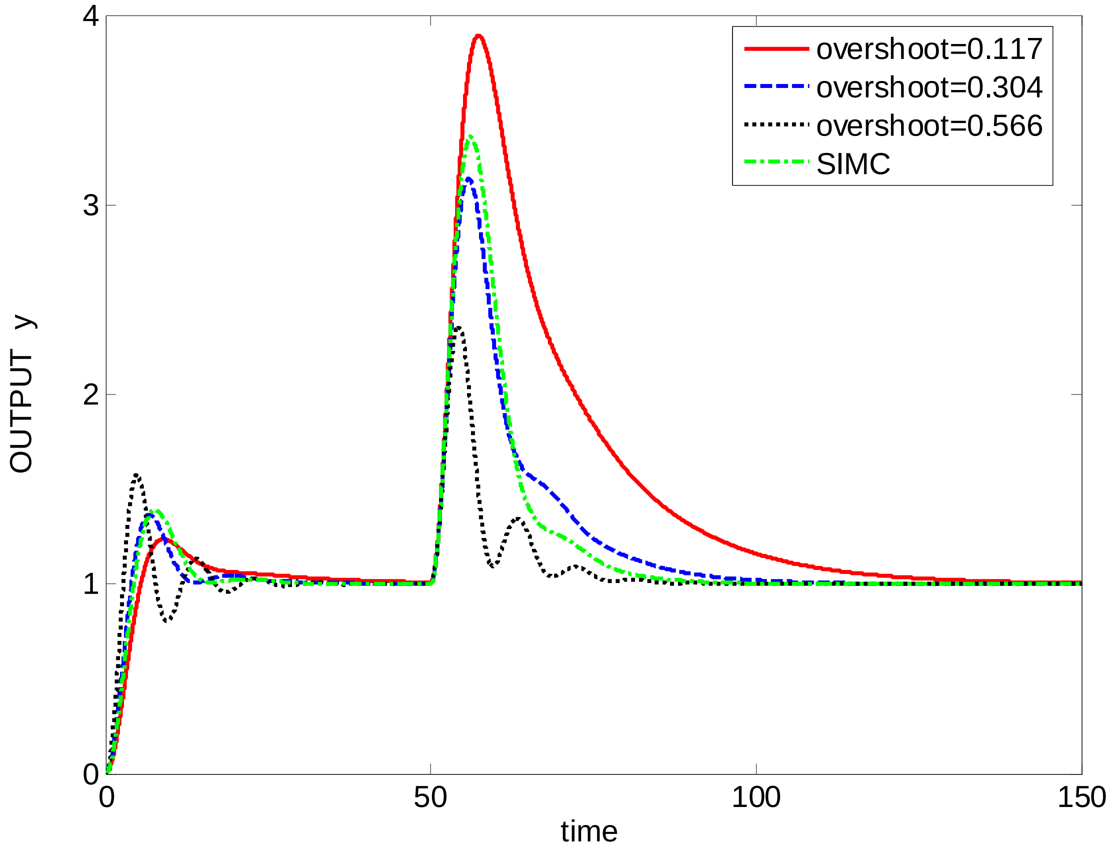


Fig.25. Responses for PI-control of process $\frac{(s+6)^2}{s(s+1)^2(s+36)}$ (E25), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

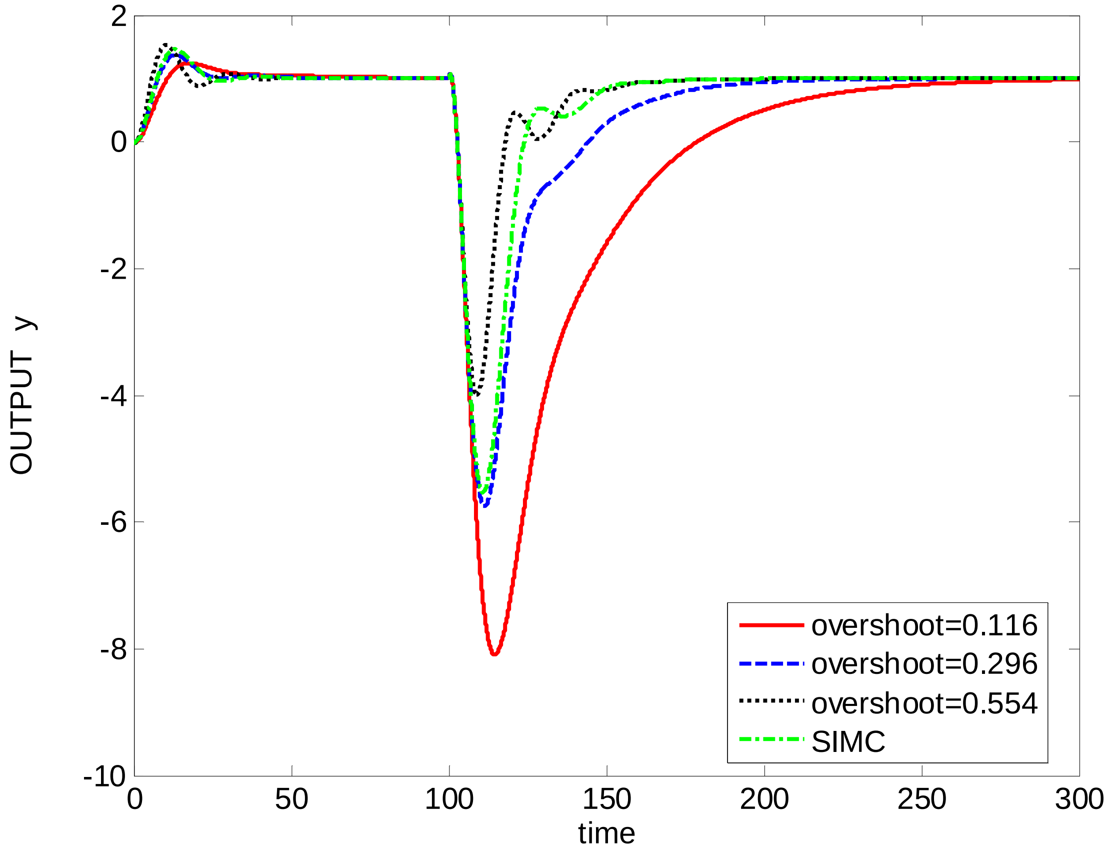


Fig.26. Responses for PI-control of process $\frac{-1.6\left(-0.5s+1\right)}{s\left(3s+1\right)}$ (E26), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

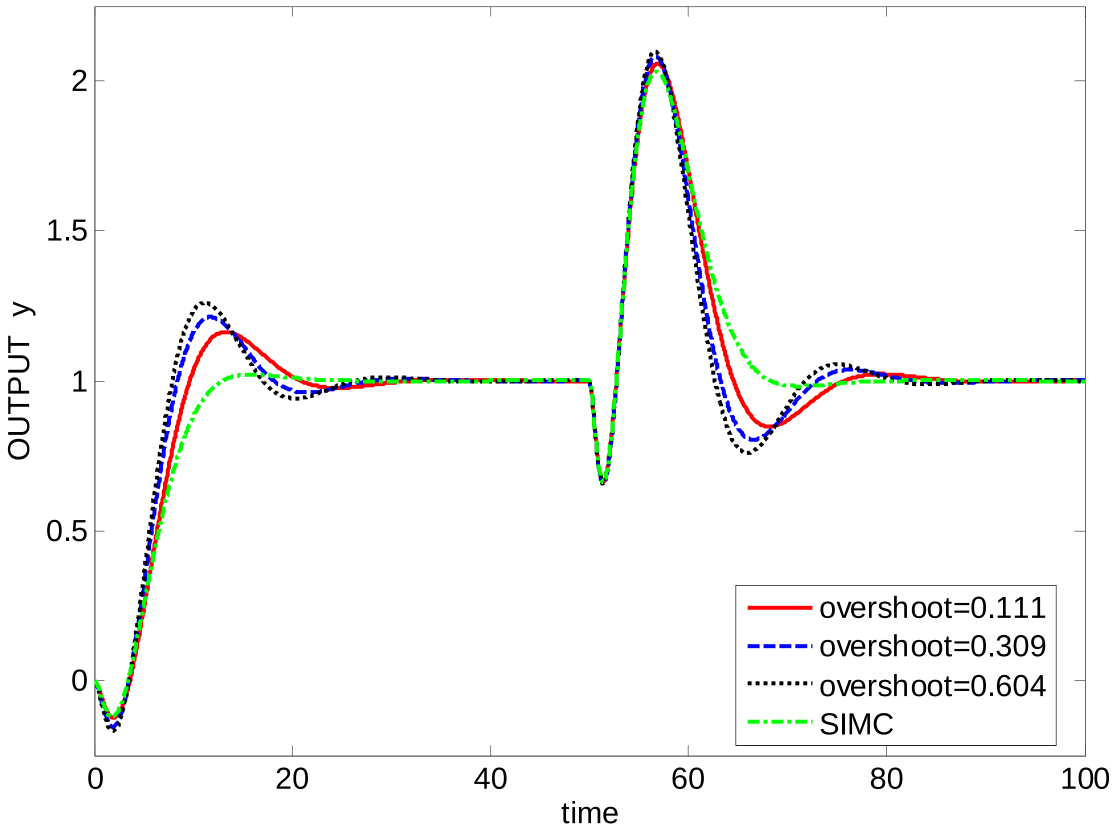


Fig.28. Responses for PI-control of process $\frac{(-2s+1)}{(s+1)^3}$ (E28), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

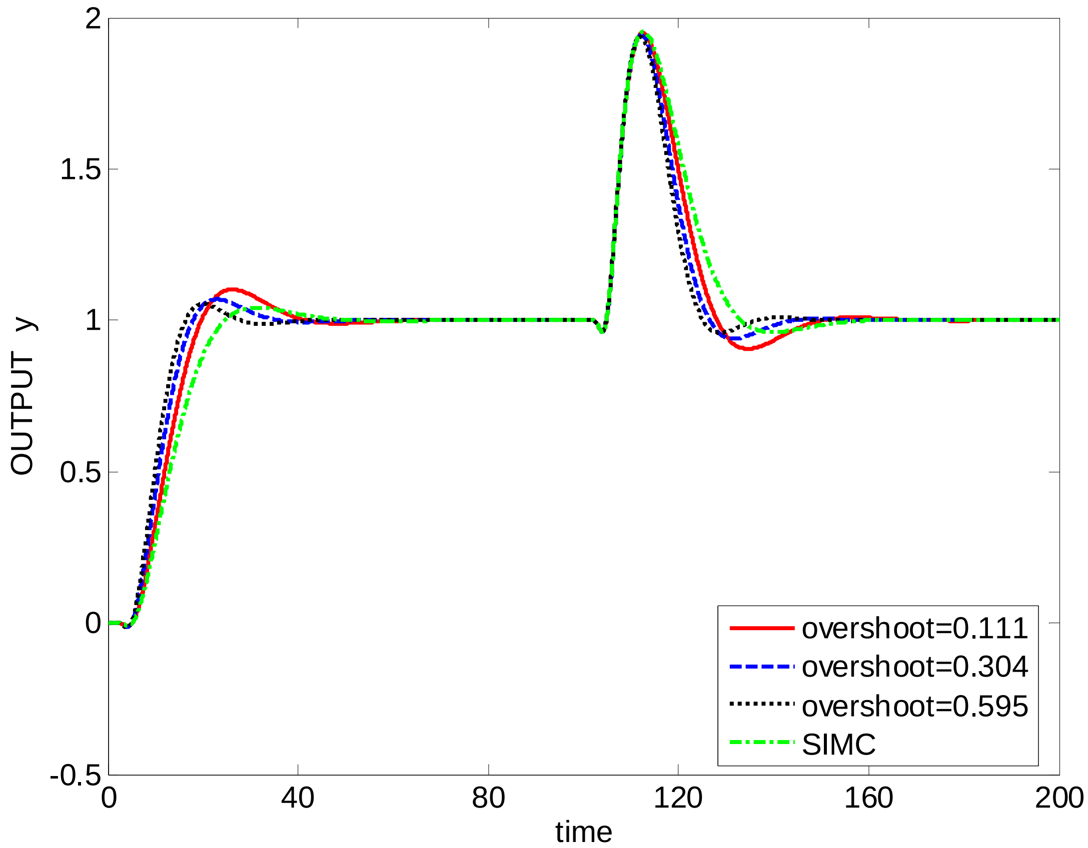


Fig.29. Responses for PI-control of process $\frac{(-s+1)e^{-2s}}{(s+1)^5}$ (E29), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

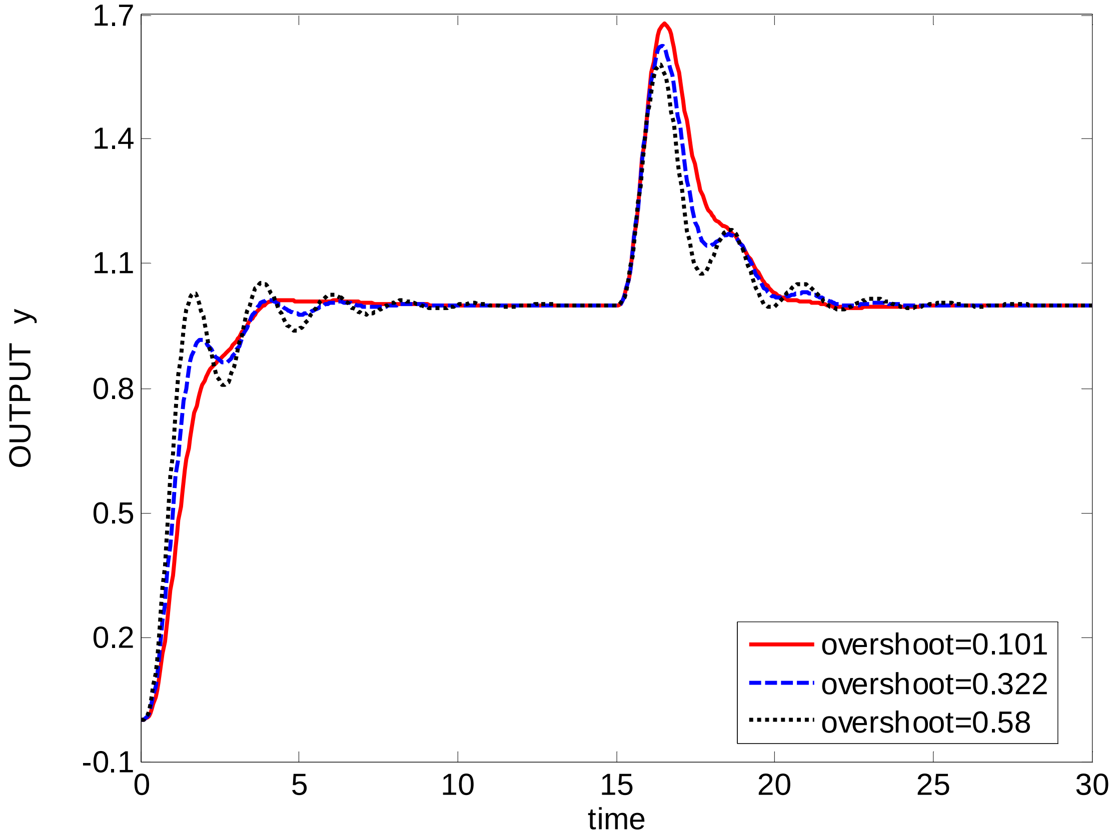


Fig.30. Responses for PI-control of process $\frac{9}{(s+1)(s^2+2s+9)}$ (E30), Setpoint change at t=0; load disturbance of magnitude 1 at t=15.

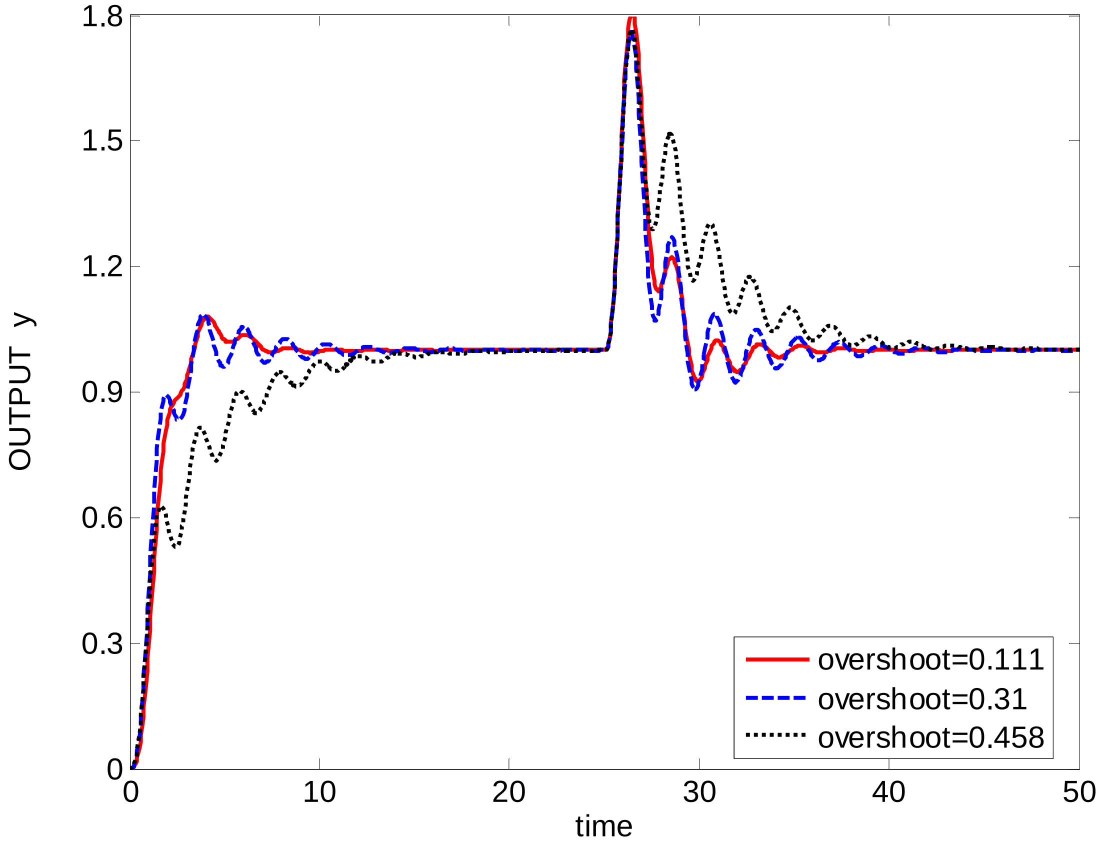


Fig.31. Responses for PI-control of process $\frac{9}{(s+1)(s^2+s+9)}$ (E31), Setpoint change at t=0; load disturbance of magnitude 1 at t=25.

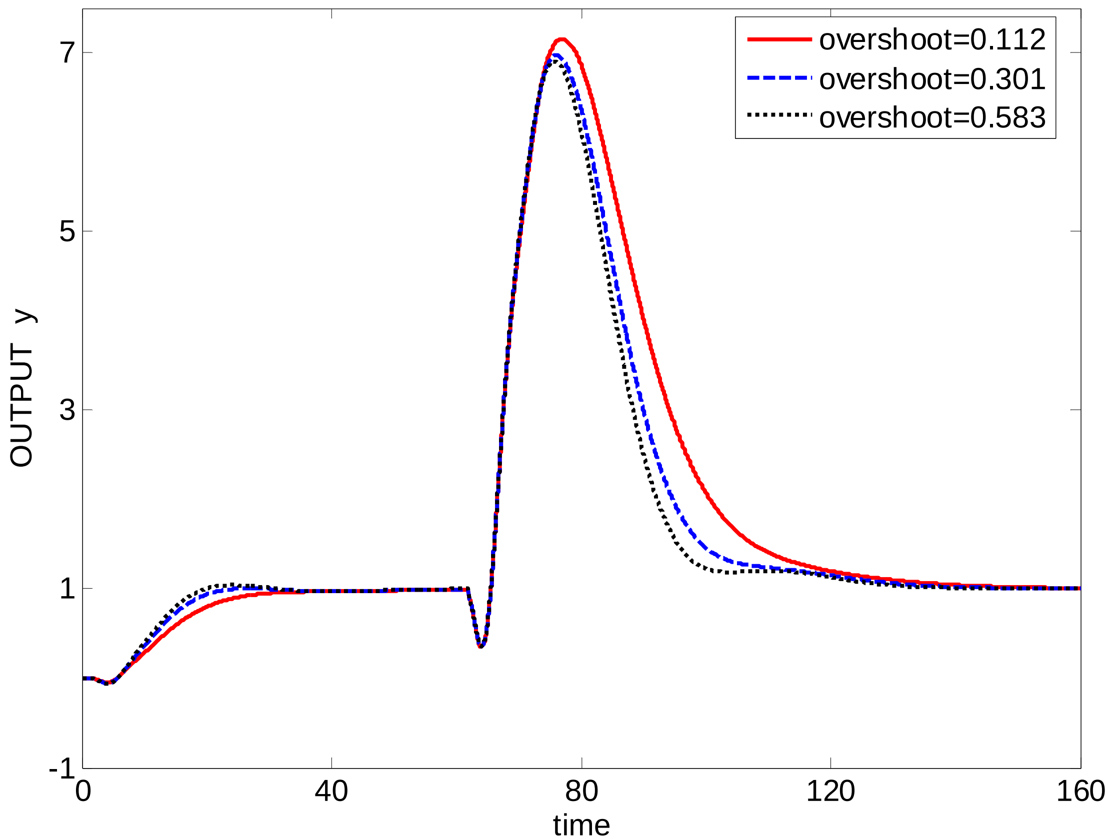


Fig.32. Responses for PI-control of process $\frac{(s^2+2s+9)(-2s+1)(s+1)e^{-2s}}{(s^2+0.5s+1)(5s+1)^2}$ (E32), Setpoint change at t=0; load disturbance of magnitude 1 at t=60.

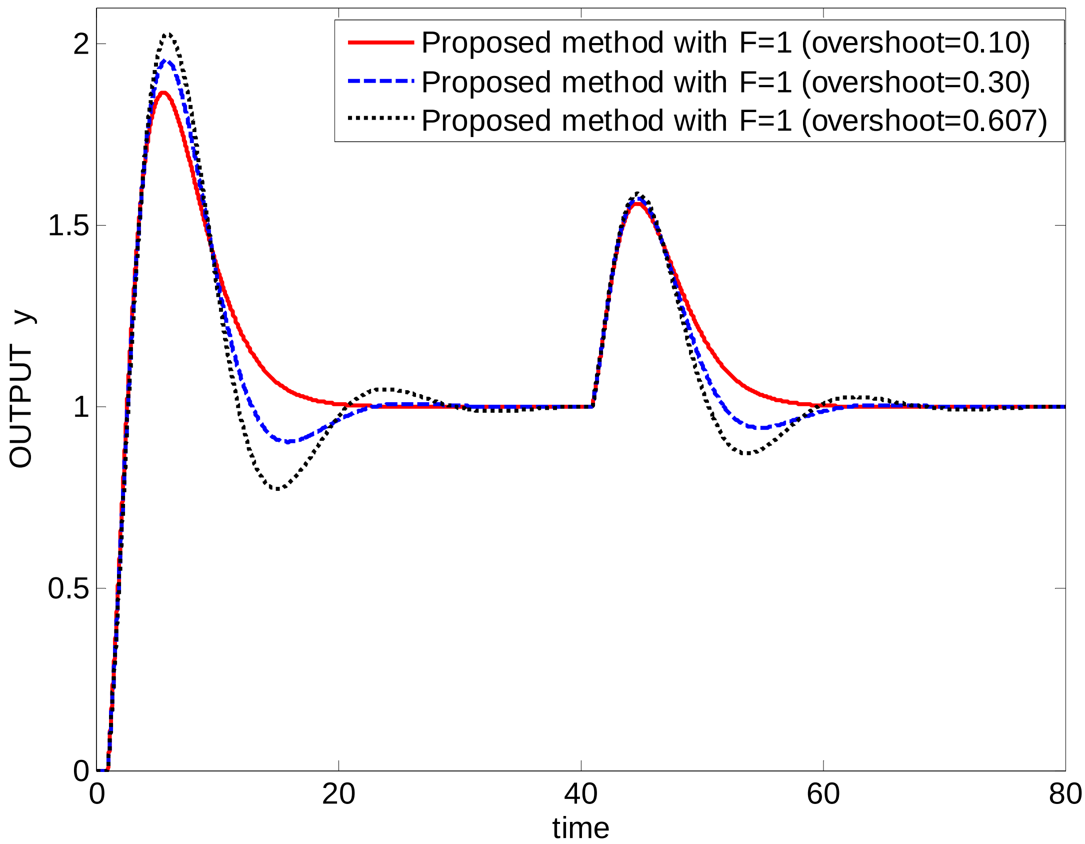


Fig.33. Responses for PI-control of first order **unstable process** $\frac{e^{-s}}{(5s-1)}$ (E33), Setpoint change at t=0; load disturbance of magnitude 1 at t=40.

<u>Section: 3,</u>

Comparison of proposed PI controller performance with Yuwana and Seborg (AIChE, 1982) for E1-E32.

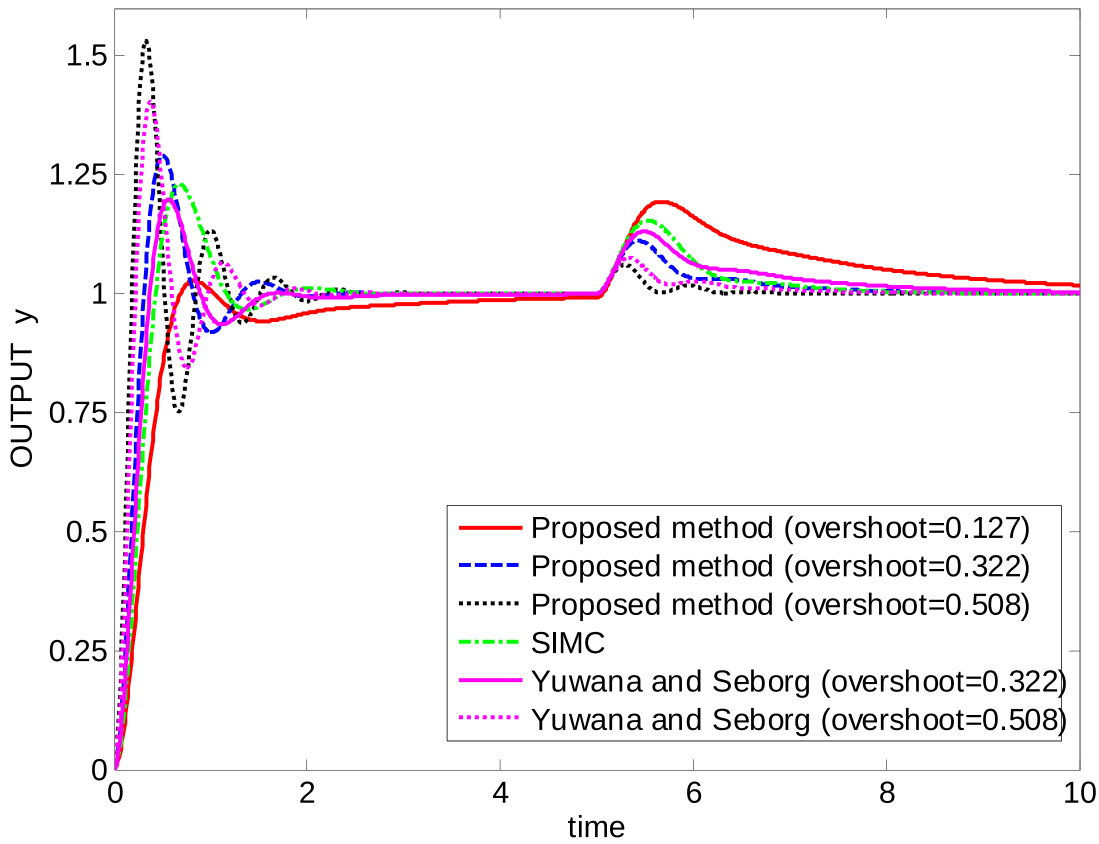


Fig.1. Responses for PI-control of process $\frac{1}{(s+1)(0.2s+1)}$ (E1), Setpoint change at t=0; load disturbance of magnitude 1 at t=5.

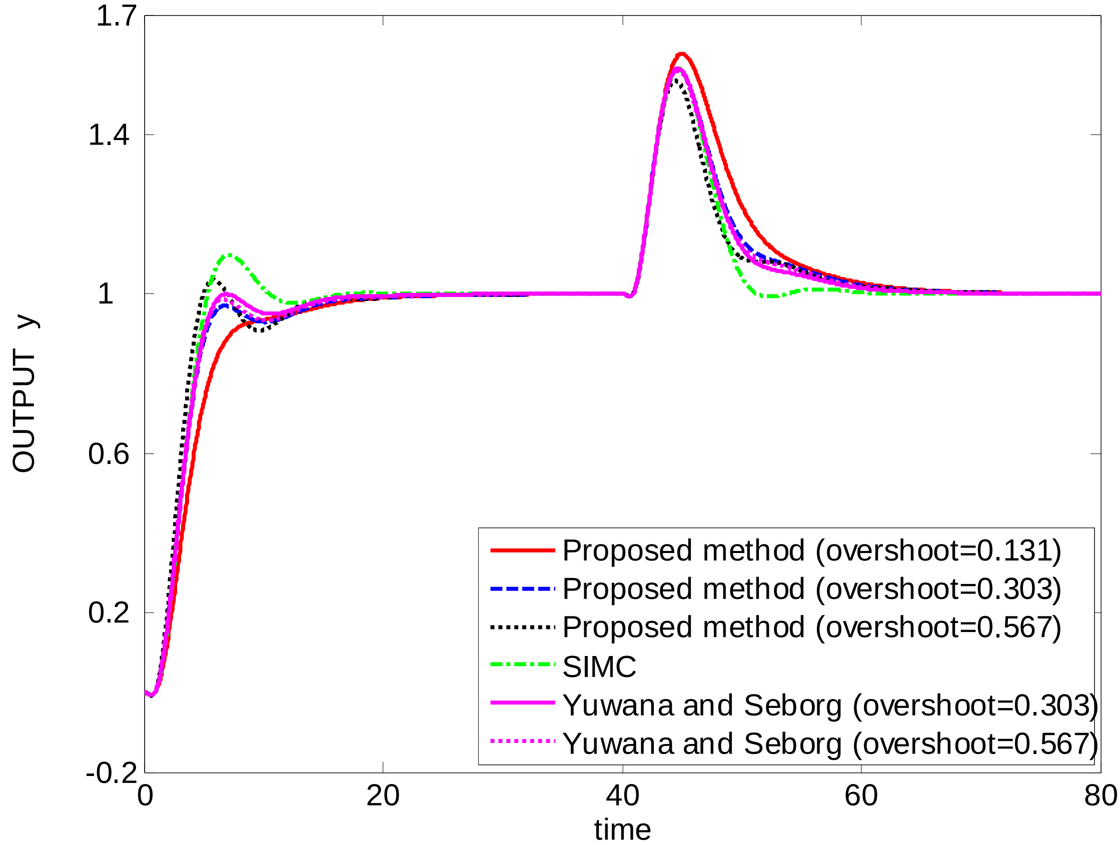


Fig.2. Responses for PI-control of process $\frac{(-0.3s+1)(0.08s+1)}{(2s+1)(s+1)(0.4s+1)(0.2s+1)(0.05s+1)^3}$ (E2), Setpoint change at t=0; load disturbance of magnitude 1 at t=40.

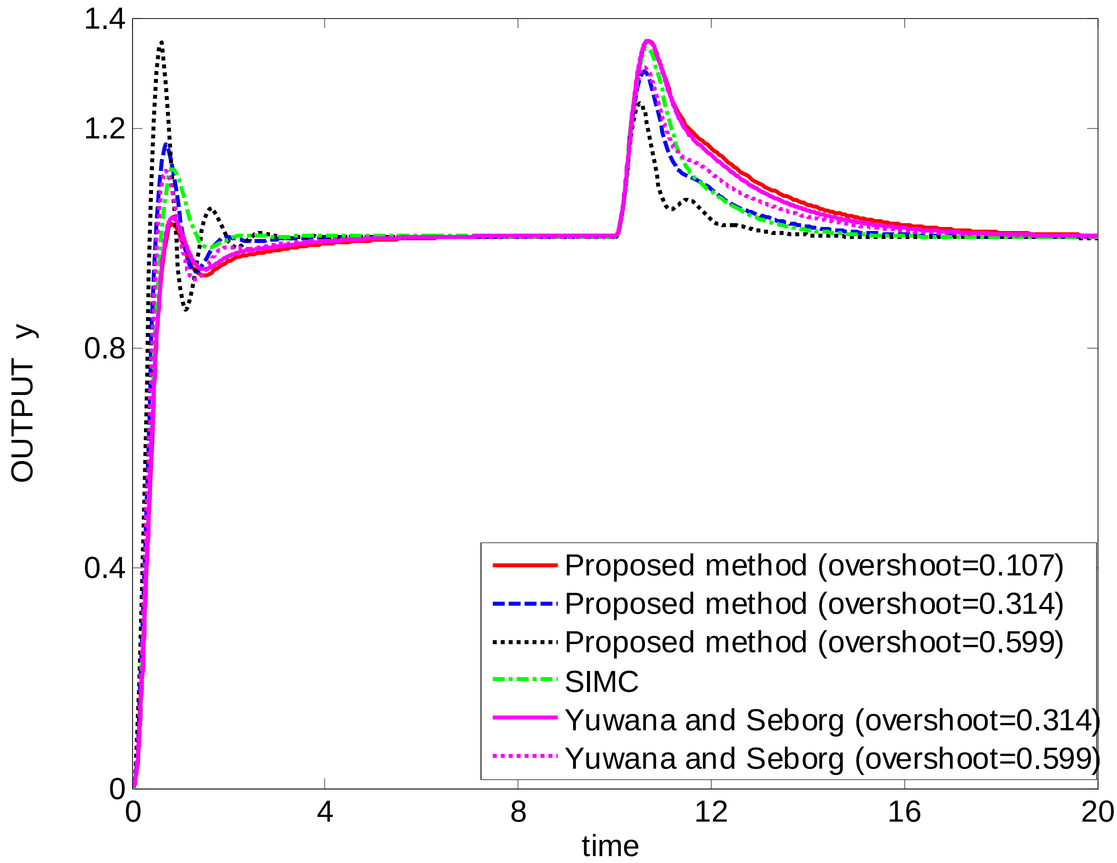


Fig.3. Responses for PI-control of process $\frac{2(15s+1)}{(20s+1)(s+1)(0.1s+1)^2}$ (E3), Setpoint change at t=0; load disturbance of magnitude 1 at t=10.

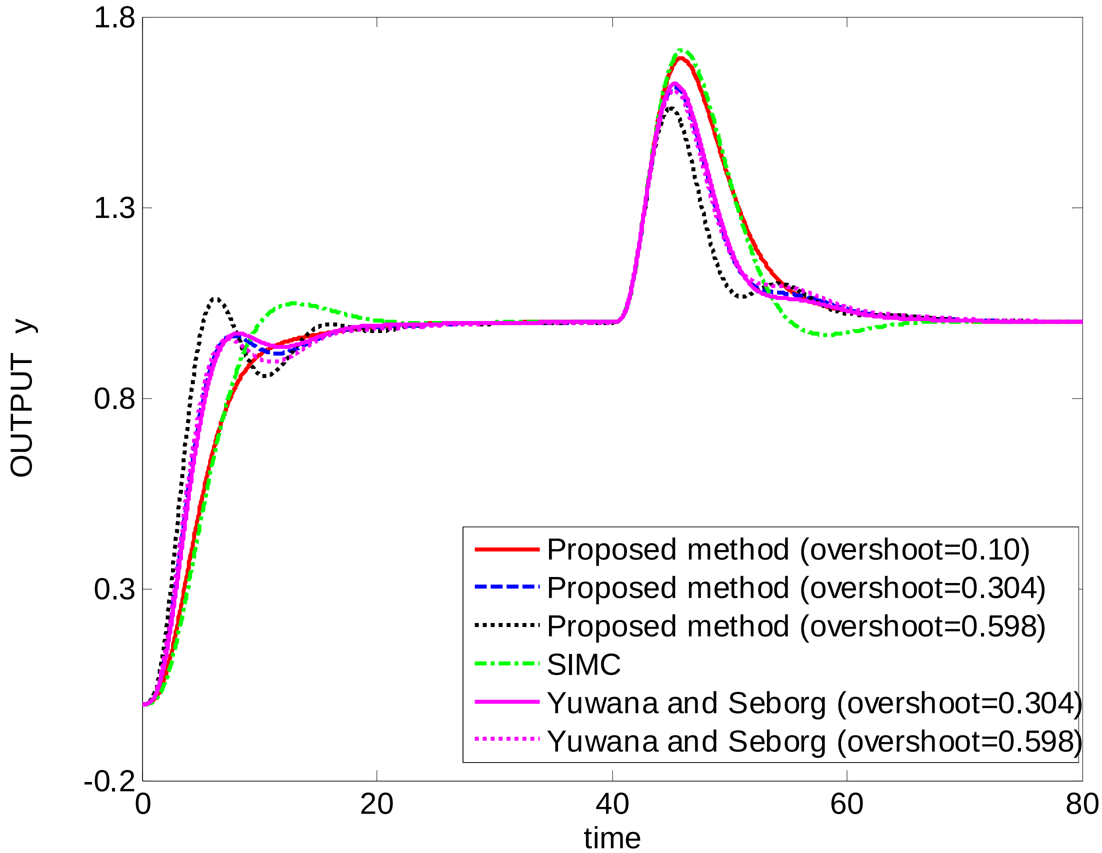


Fig.4. Responses for PI-control of process $\frac{1}{(s+1)^4}$ (E4), Setpoint change at t=0; load disturbance of magnitude 1 at t=40.

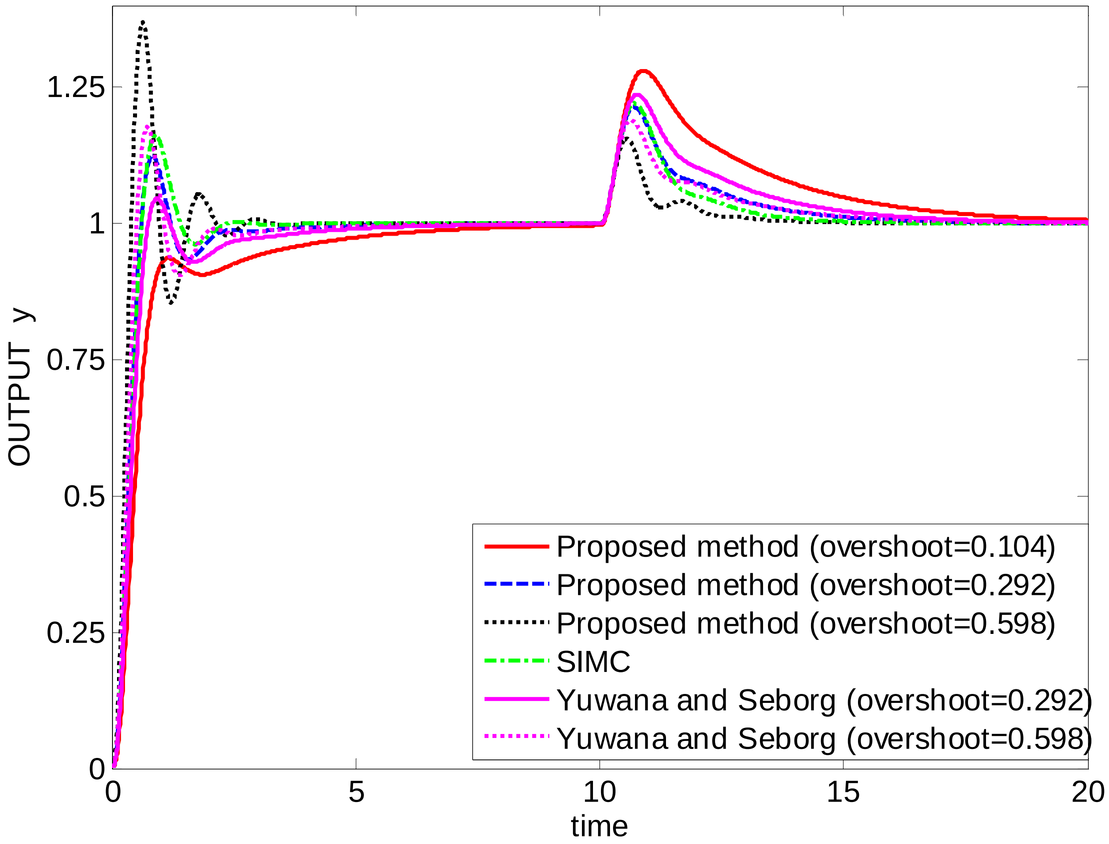


Fig.5. Responses for PI-control of process $\frac{1}{(s+1)(0.2s+1)(0.04s+1)(0.008s+1)}$ (E5), Setpoint change at t=0; load disturbance of magnitude 1 at t=10.

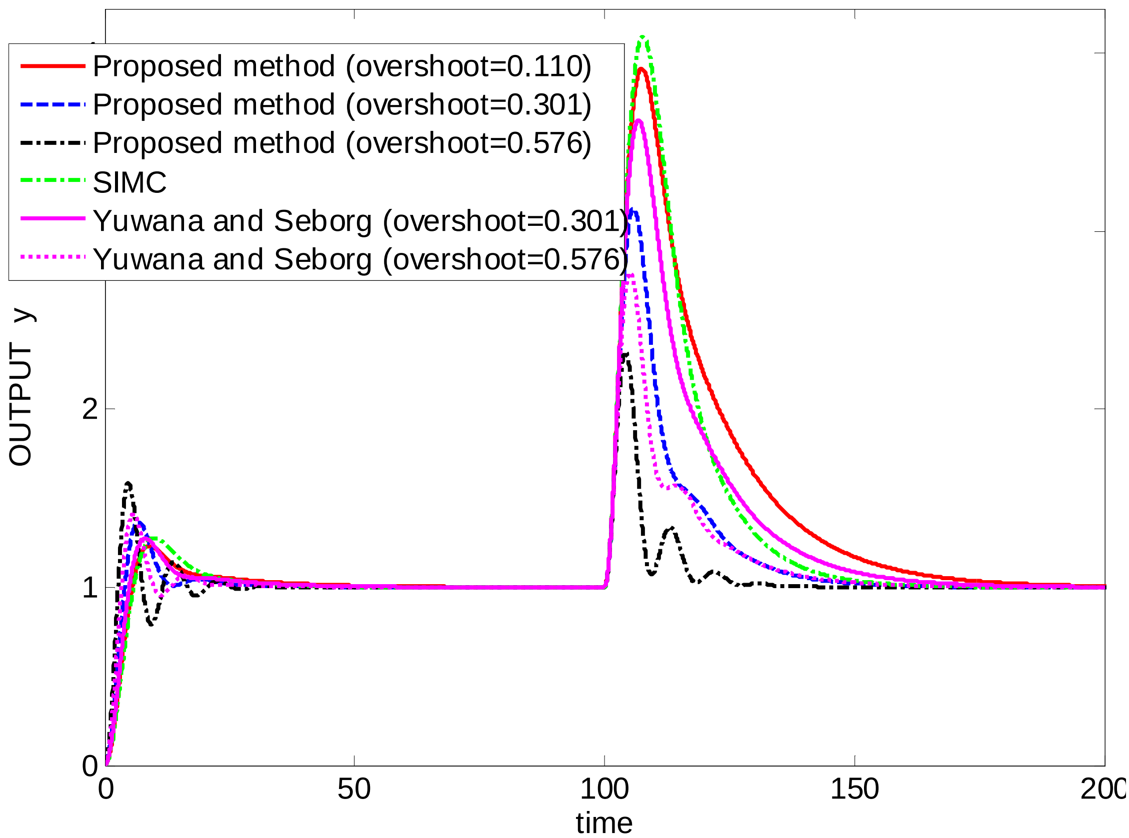


Fig.6. Responses for PI-control of process $\frac{(0.17s+1)^2}{s(s+1)^2(0.028s+1)}$ (E6), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

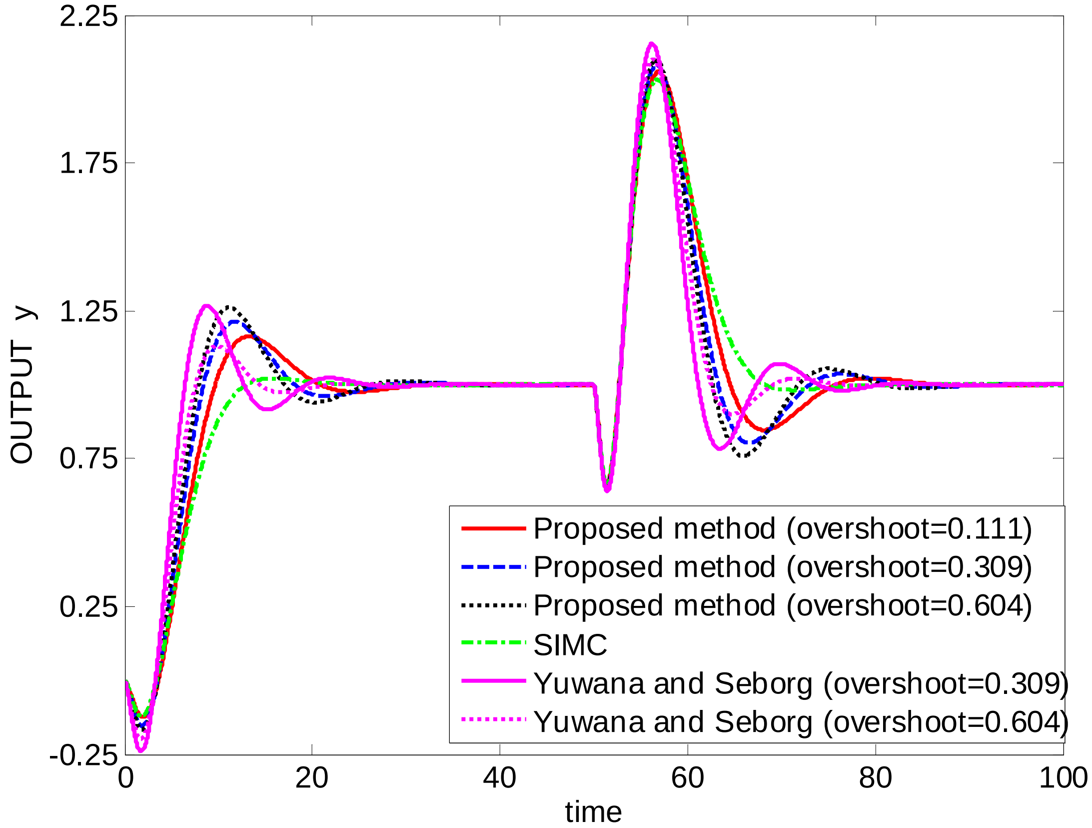


Fig.7. Responses for PI-control of process $\frac{-2s+1}{(s+1)^3}$ (E7), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

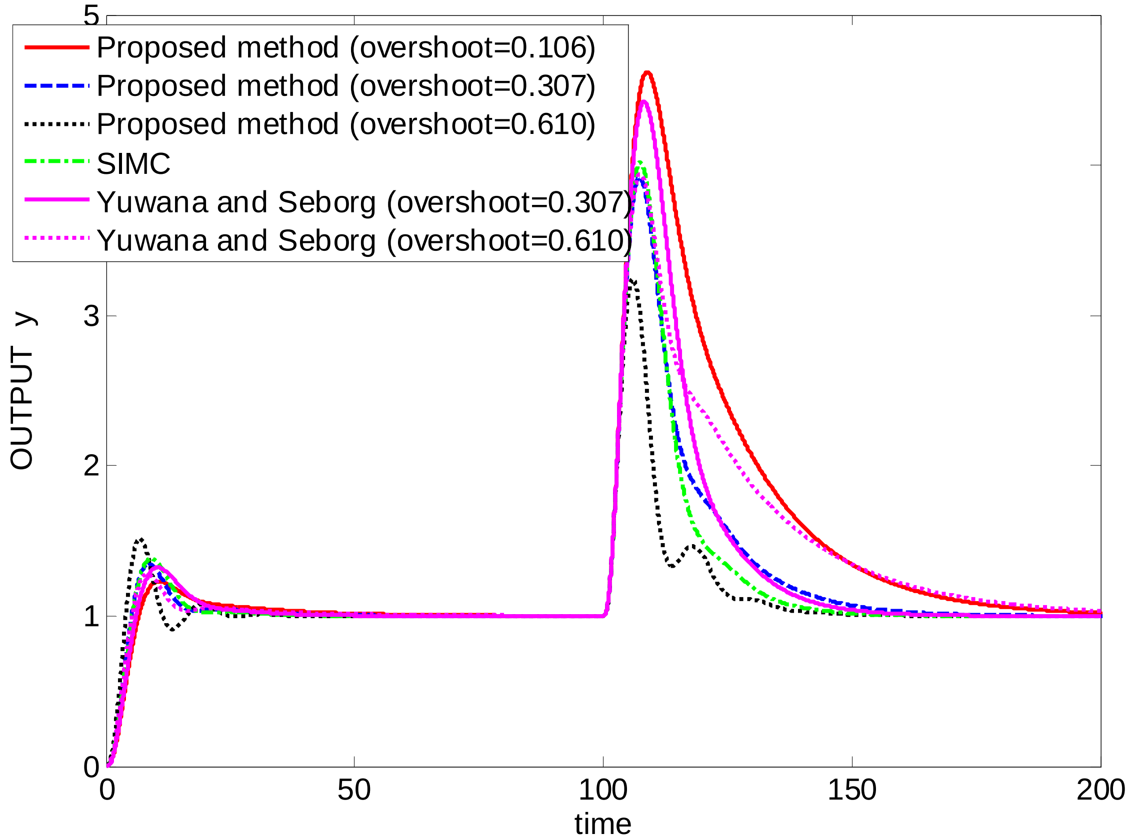


Fig.8. Responses for PI-control of third-order integrating process $\frac{1}{s(s+1)^2}$ (E8), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

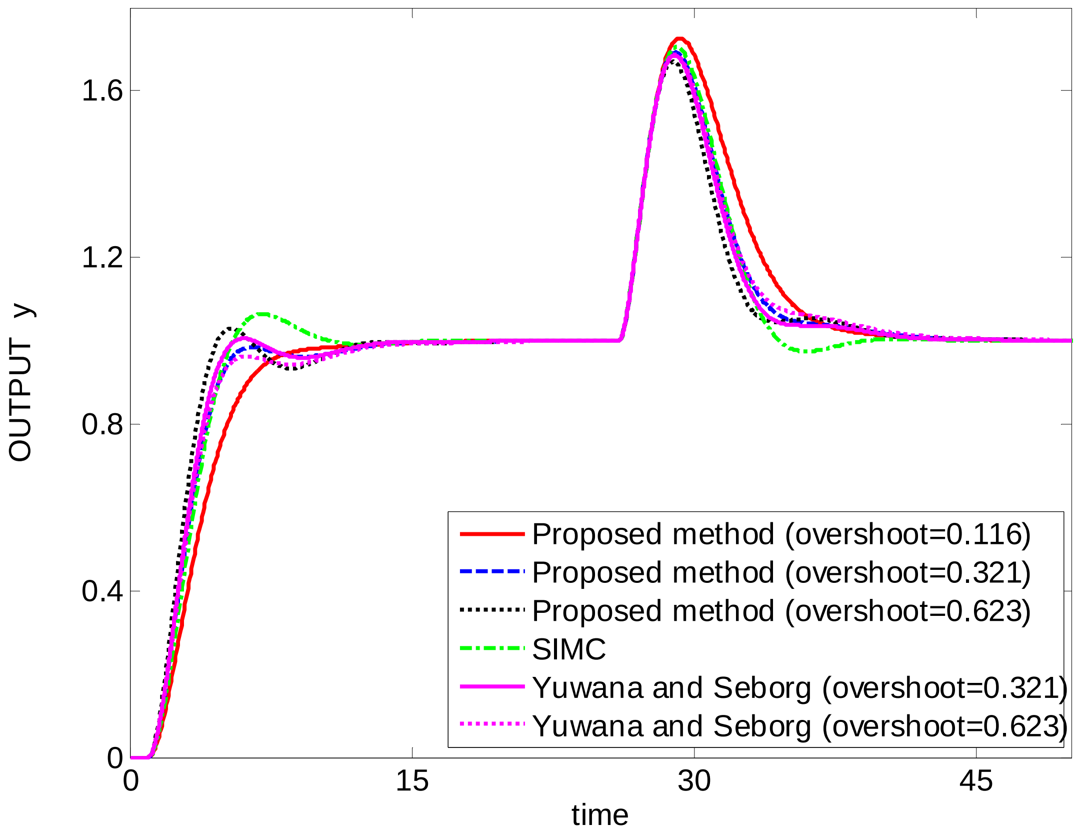


Fig.9. Responses for PI-control of process $\frac{e^{-s}}{(s+1)^2}$ (E9), Setpoint change at t=0; load disturbance of magnitude 1 at t=25.

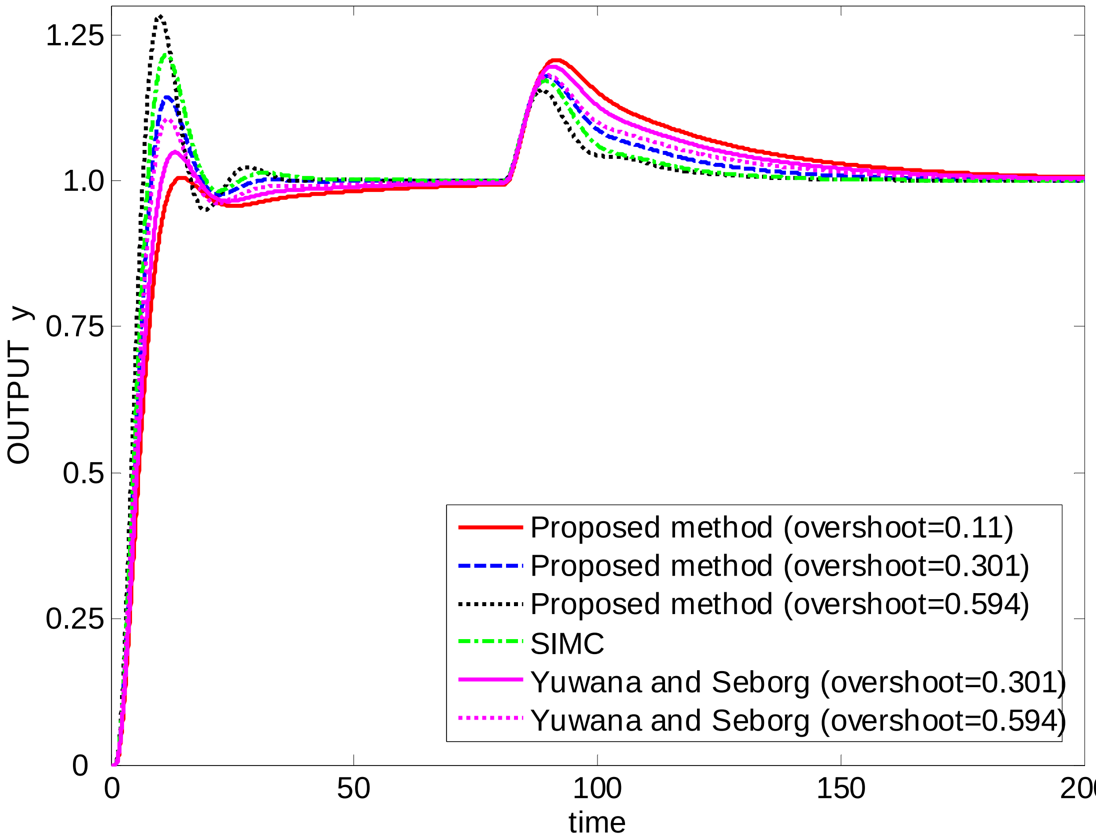


Fig.10. Responses for PI-control of process $\frac{e^{-s}}{(20s+1)(2s+1)}$ (E10), Setpoint change at t=0; load disturbance of magnitude 1 at t=80.

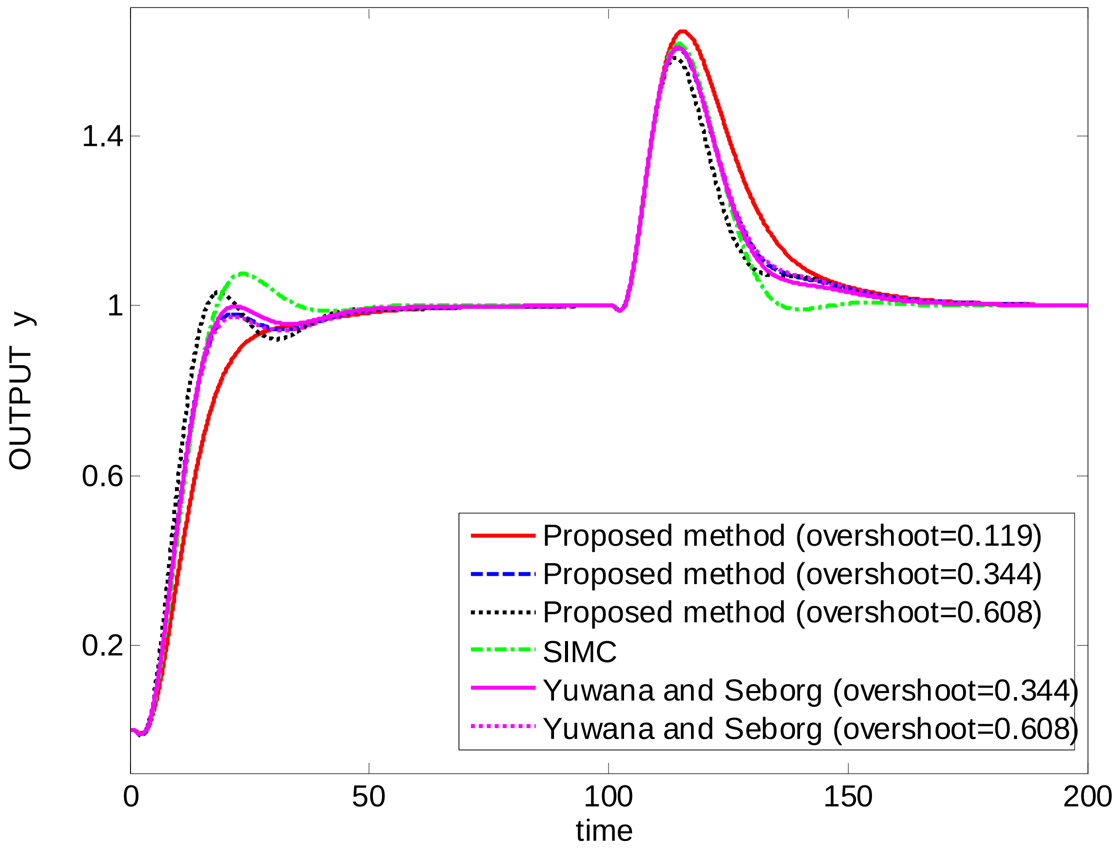


Fig.11. Responses for PI-control of process $\frac{(-s+1)e^{-s}}{(6s+1)(2s+1)^2}$ (E11), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

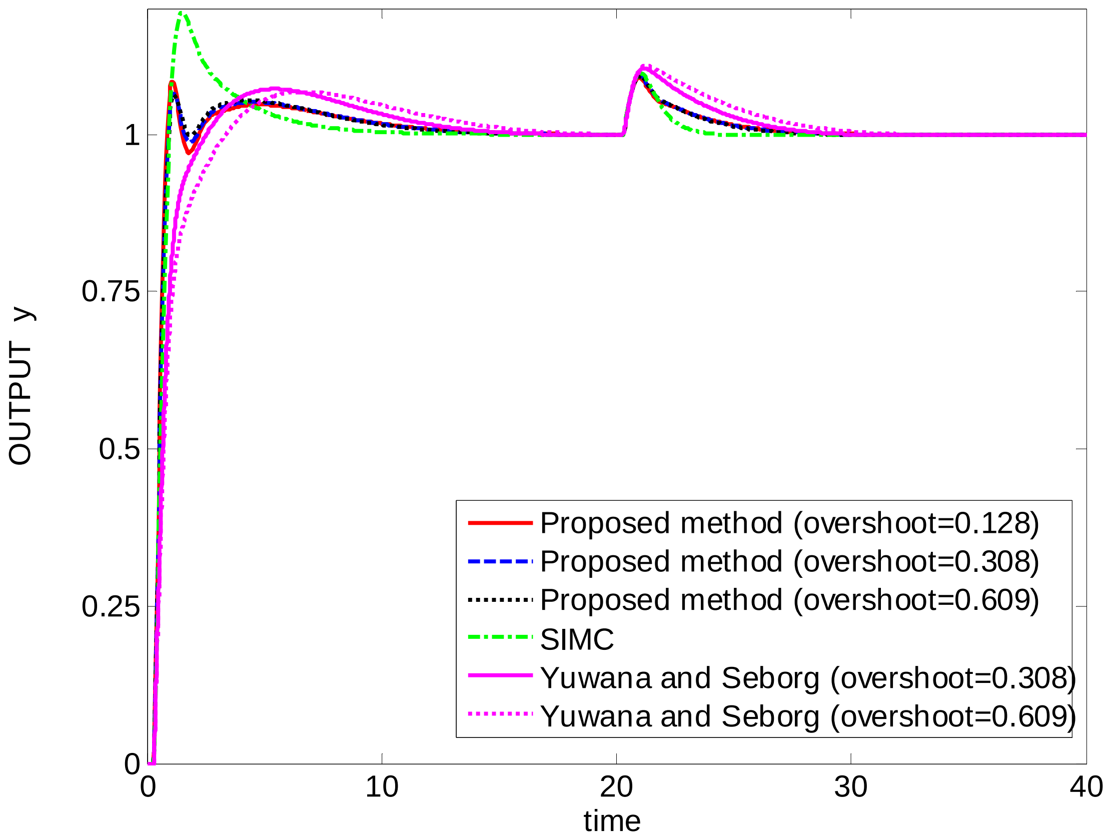


Fig.12. Responses for PI-control of process $\frac{(6s+1)(3s+1)e^{-0.3s}}{(10s+1)(8s+1)(s+1)}$ (E12), Setpoint change at t=0; load disturbance of magnitude 1 at t=20.

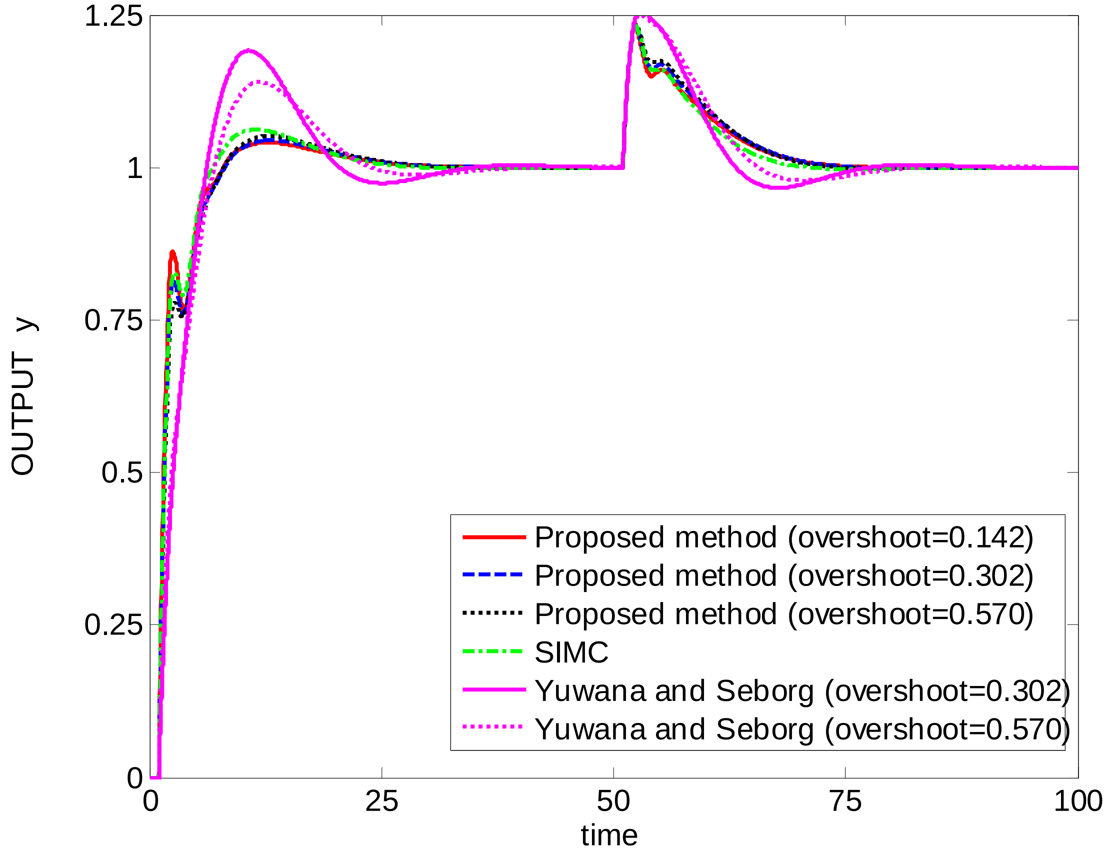


Fig.13. Responses for PI-control of process $\frac{(2s+1)e^{-s}}{(10s+1)(0.5s+1)}$ (E13), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

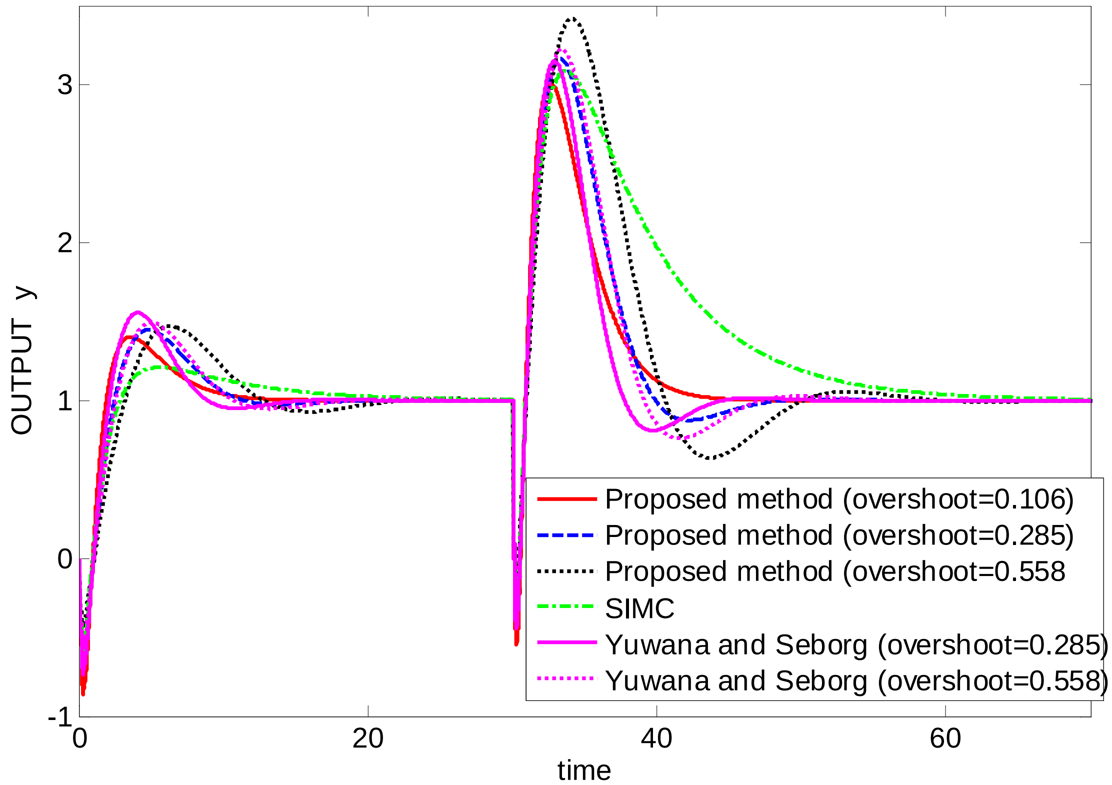


Fig.14 (a). Responses for PI-control of process $\frac{(-s+1)e^{-0.1s}}{s}$ (E14-a), Setpoint change at t=0; load disturbance of magnitude 1 at t=30.

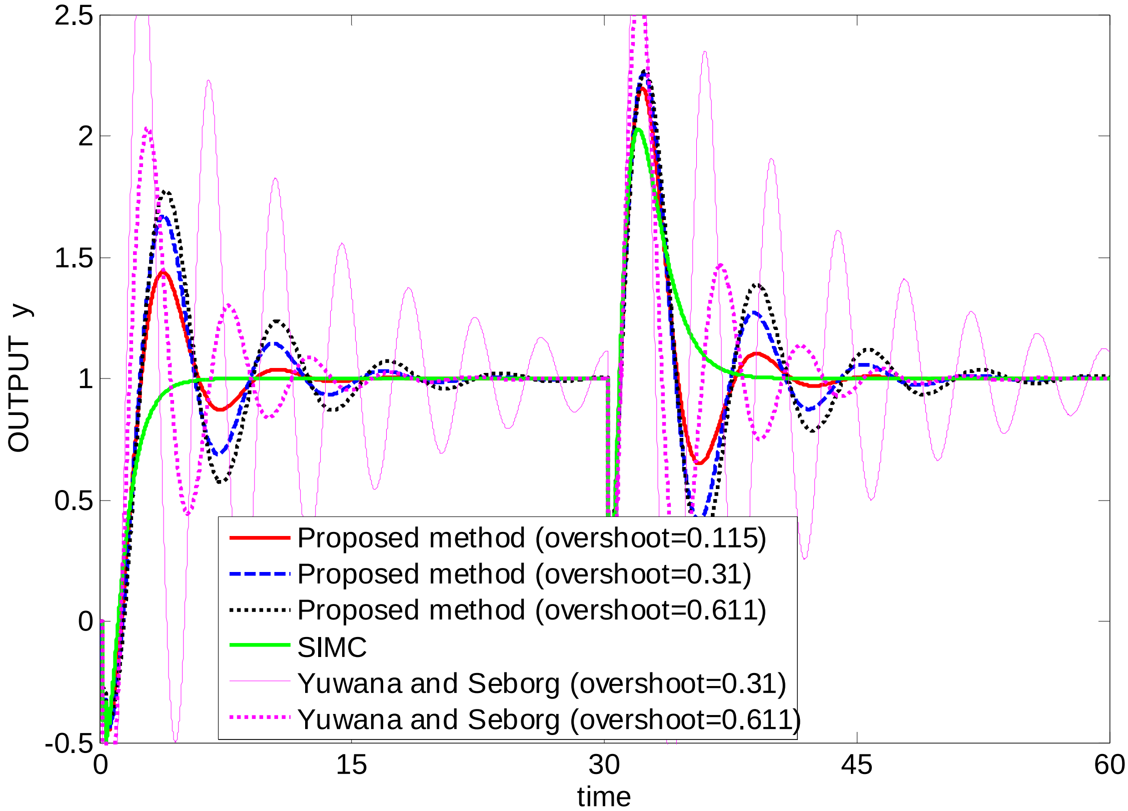


Fig.15 (a). Responses for PI-control of process $\frac{(-s+1)e^{-0.2s}}{(s+1)}$ (E15-a), Setpoint change at t=0; load disturbance of magnitude 1 at t=30.

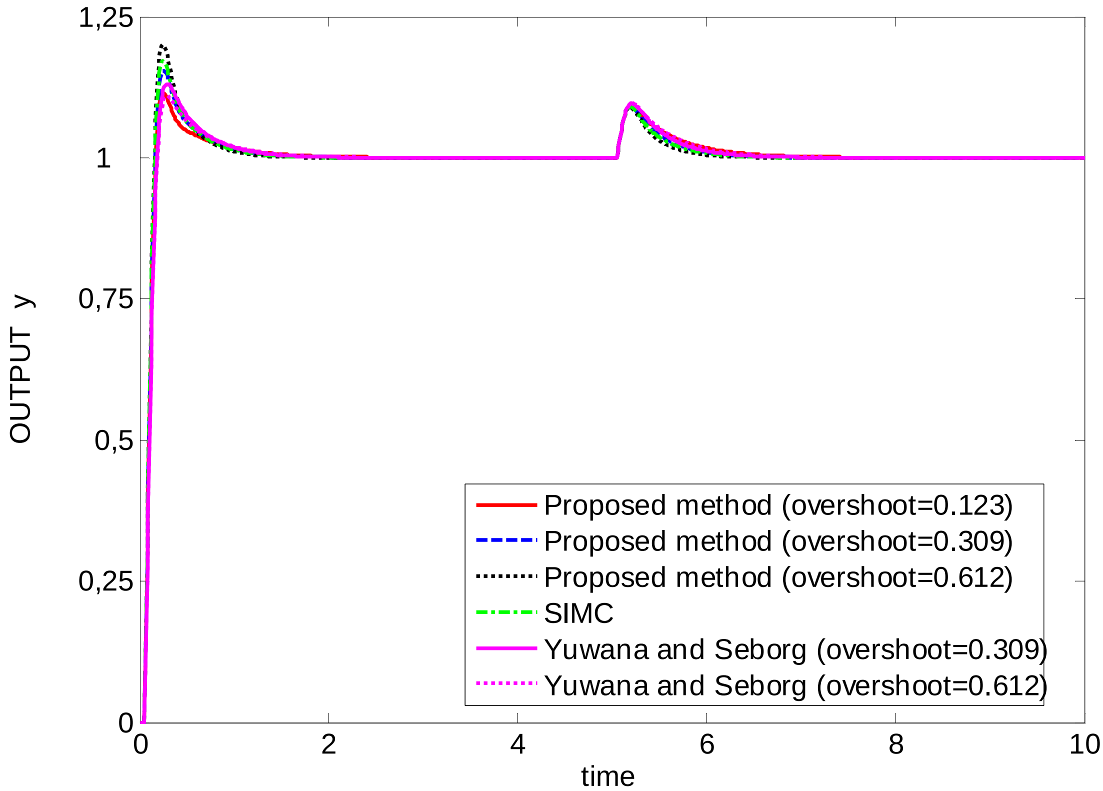


Fig.16 (a). Responses for PI-control of process $\frac{e^{-0.05s}}{(s+1)}$ (E16-a), Setpoint change at t=0; load disturbance of magnitude 1 at t=5.

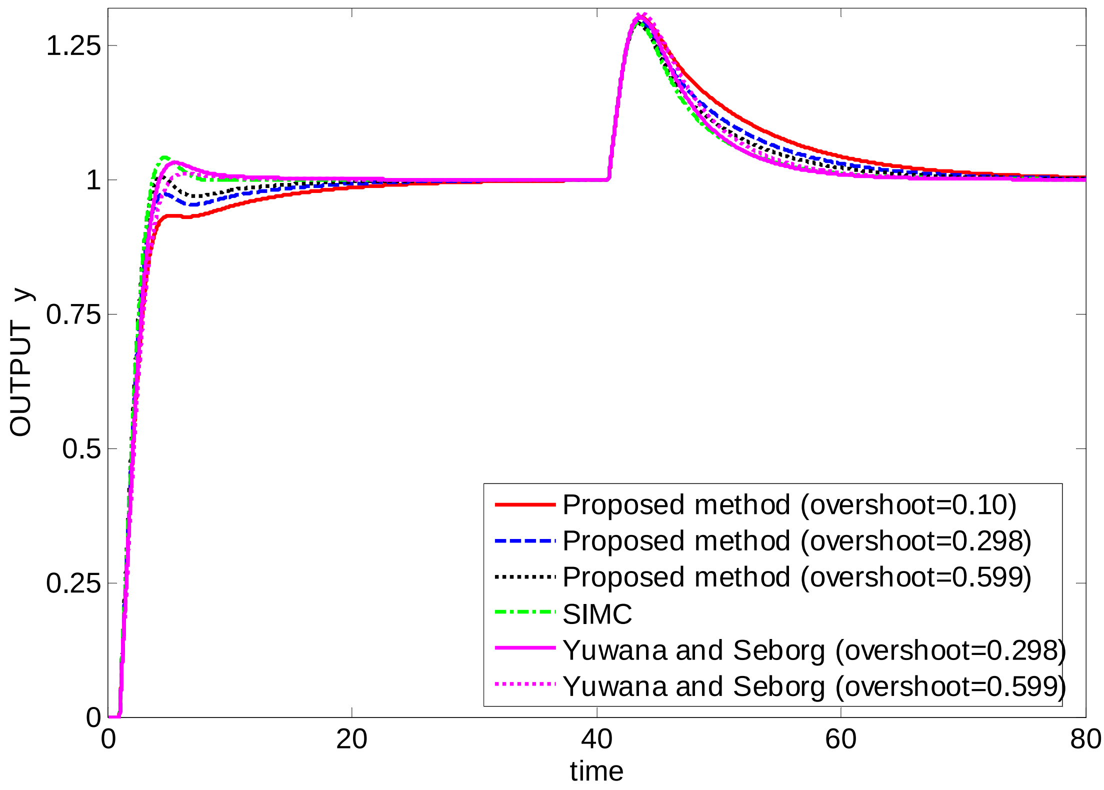


Fig.17. Responses for PI-control of process $\frac{e^{-s}}{(5s+1)}$ (E17), Setpoint change at t=0; load disturbance of magnitude 1 at t=40.

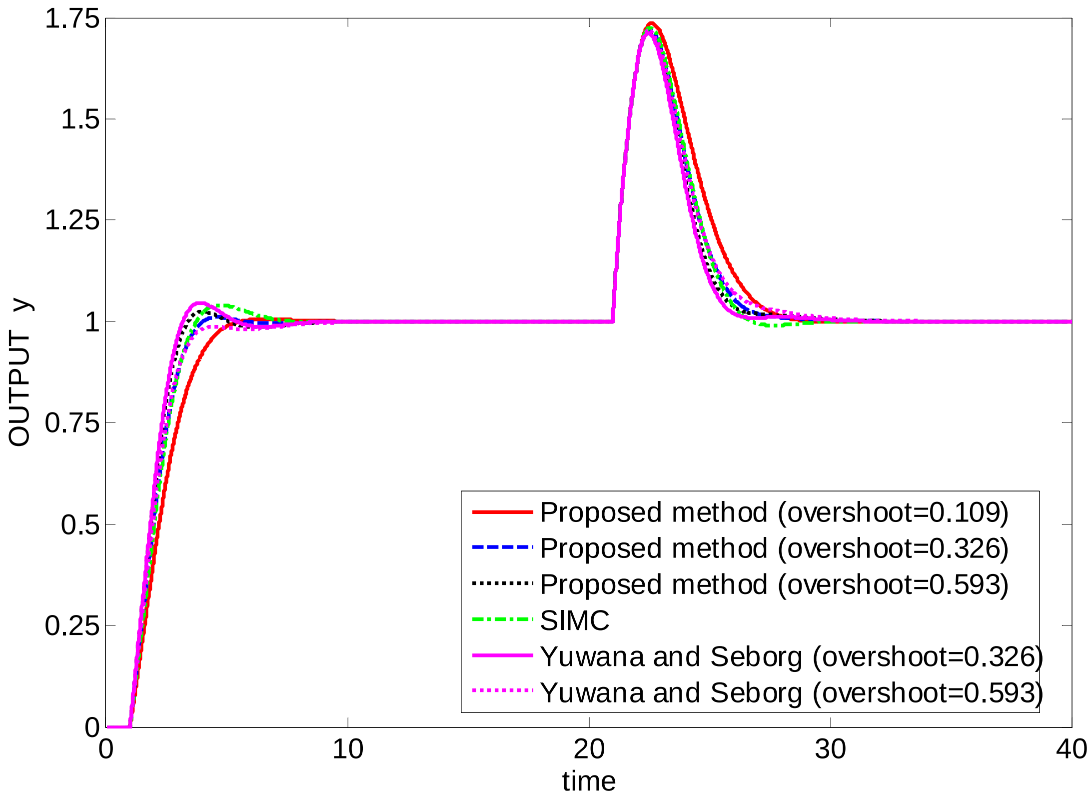


Fig.18. Responses for PI-control of process $\frac{e^{-s}}{(s+1)}$ (E18), Setpoint change at t=0; load disturbance of magnitude 1 at t=20.

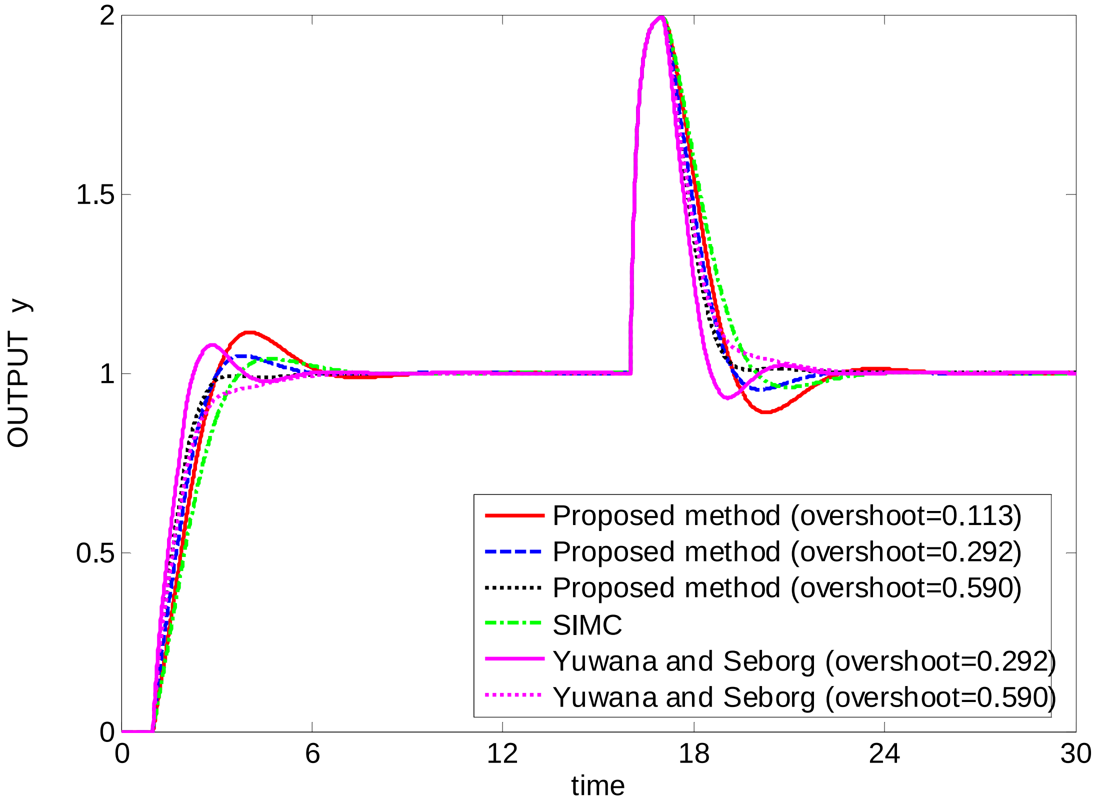


Fig.19. Responses for PI-control of process $\frac{e^{-s}}{(0.2s+1)}$ (E19), Setpoint change at t=0; load disturbance of magnitude 1 at t=15.

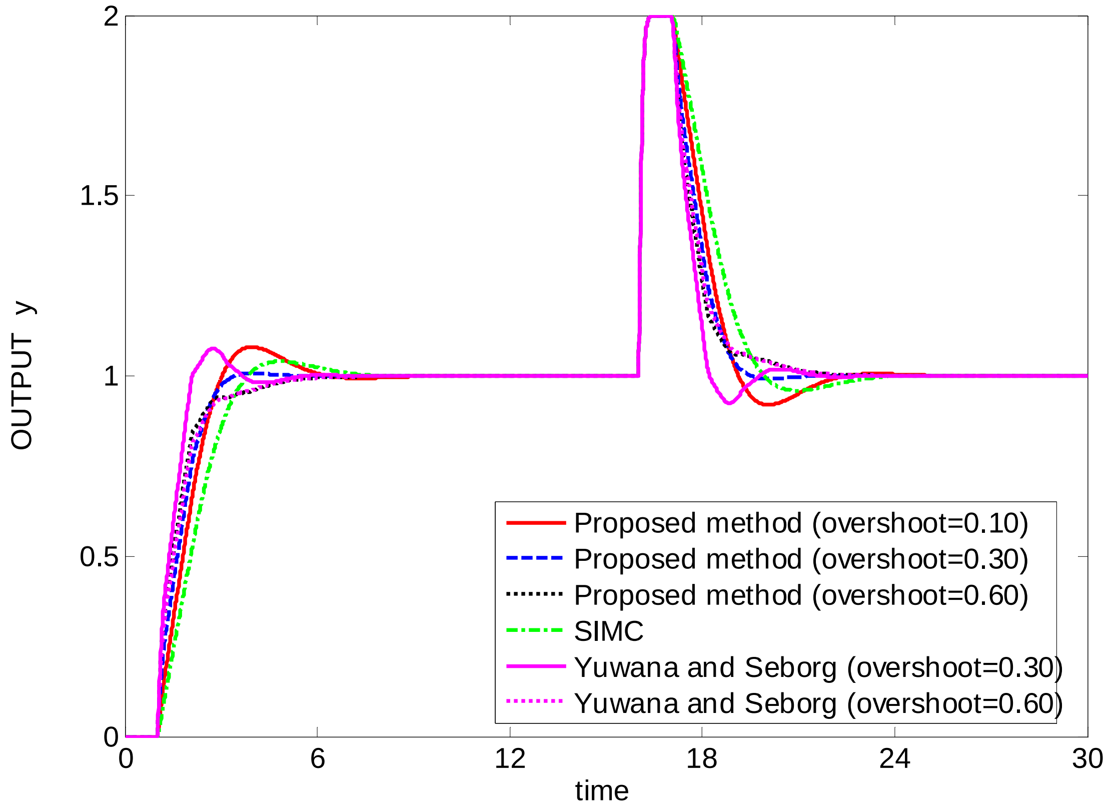


Fig.20. Responses for PI-control of process $\frac{e^{-s}}{(0.05s+1)^2}$ (E20), Setpoint change at t=0; load disturbance of magnitude 1 at t=15.

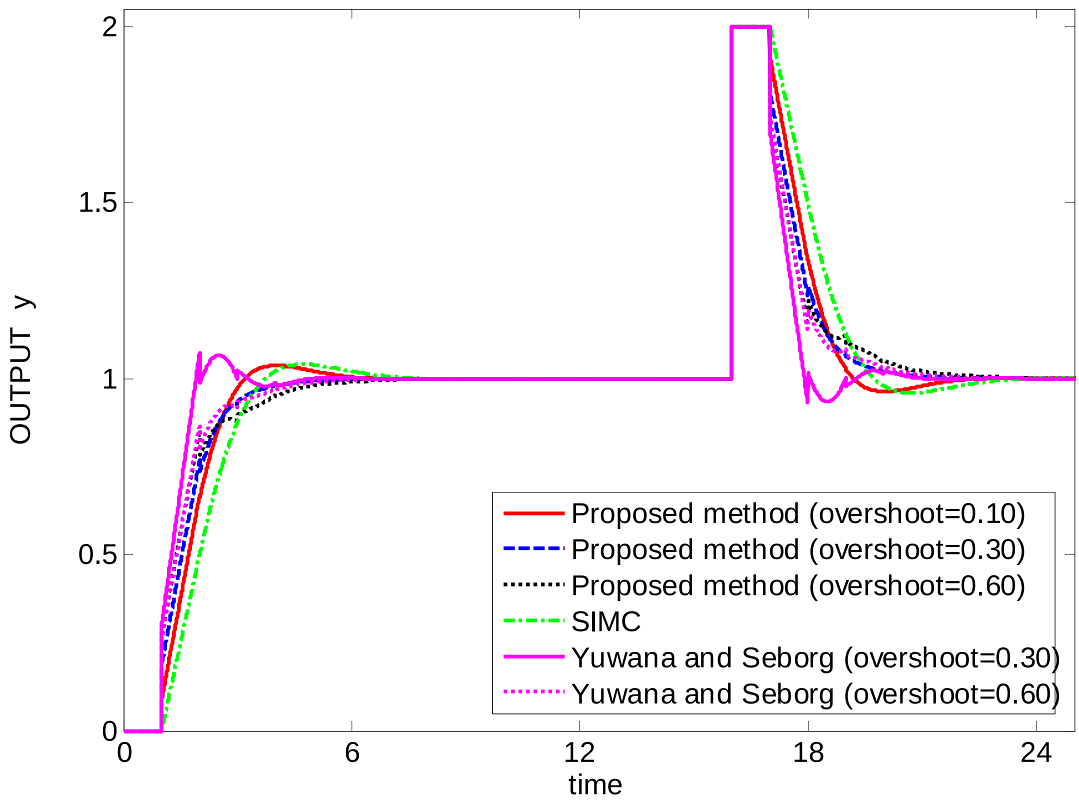


Fig.21. Responses for PI-control of process e^{-s} (E21), Setpoint change at t=0; load disturbance of magnitude 1 at t=15.

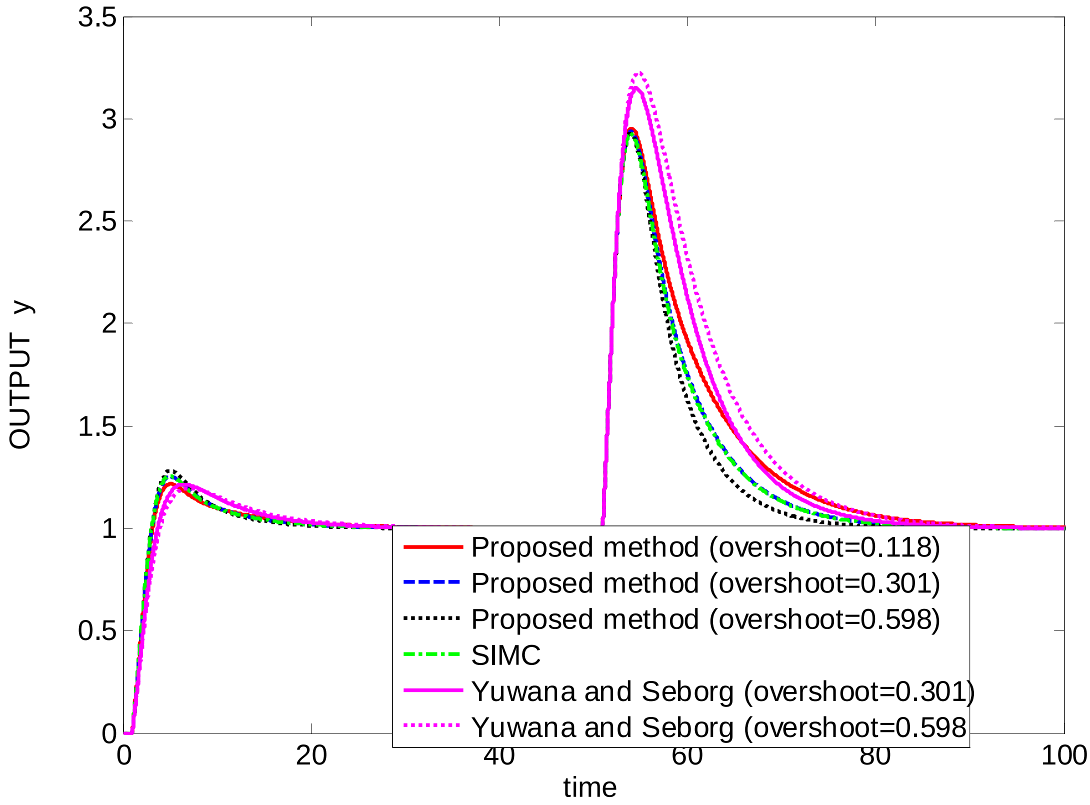


Fig.22. Responses for PI-control of process $\frac{100e^{-s}}{100s+1}$ (E22), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

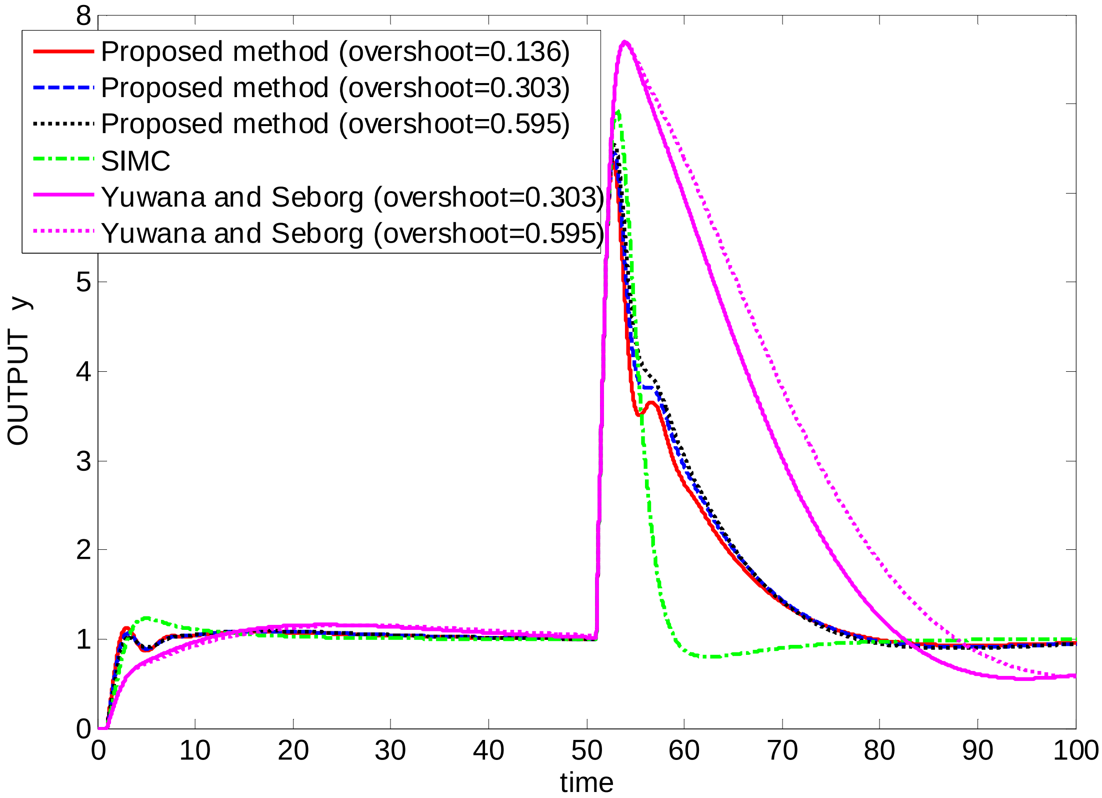


Fig.23. Responses for PI-control of process $\frac{(10s+1)e^{-s}}{s(2s+1)}$ (E23), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

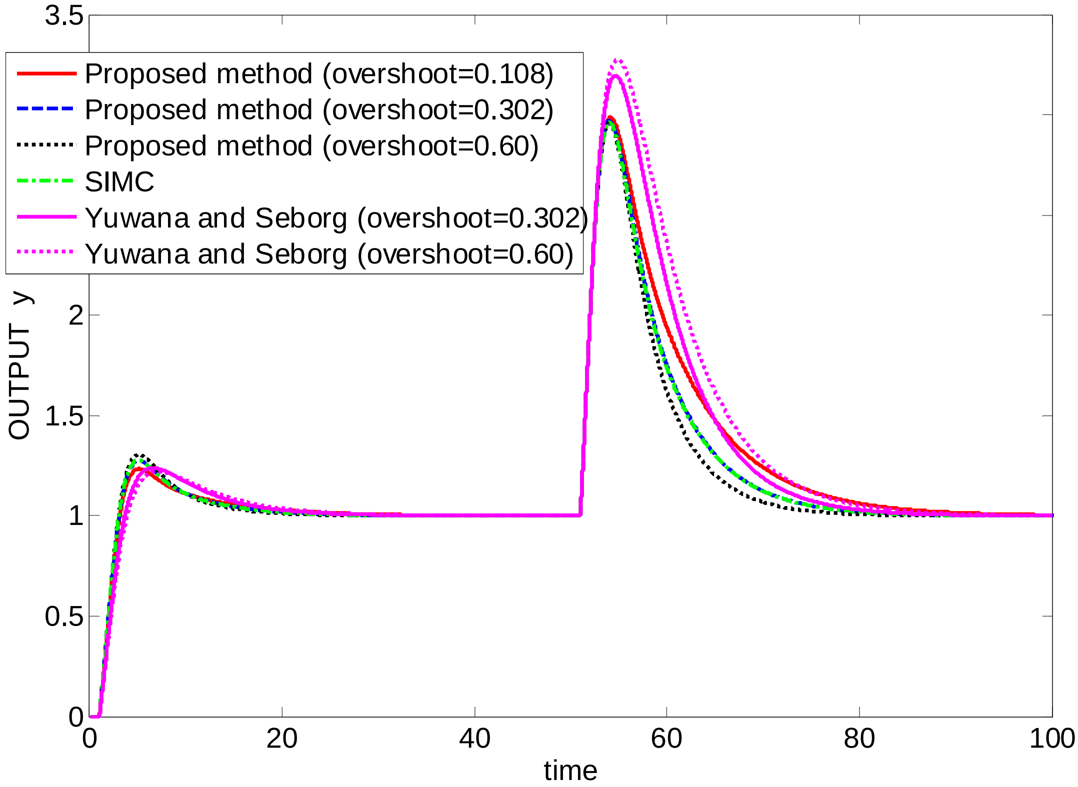


Fig.24. Responses for PI-control of process $\frac{e^{-s}}{s}$ (E24), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

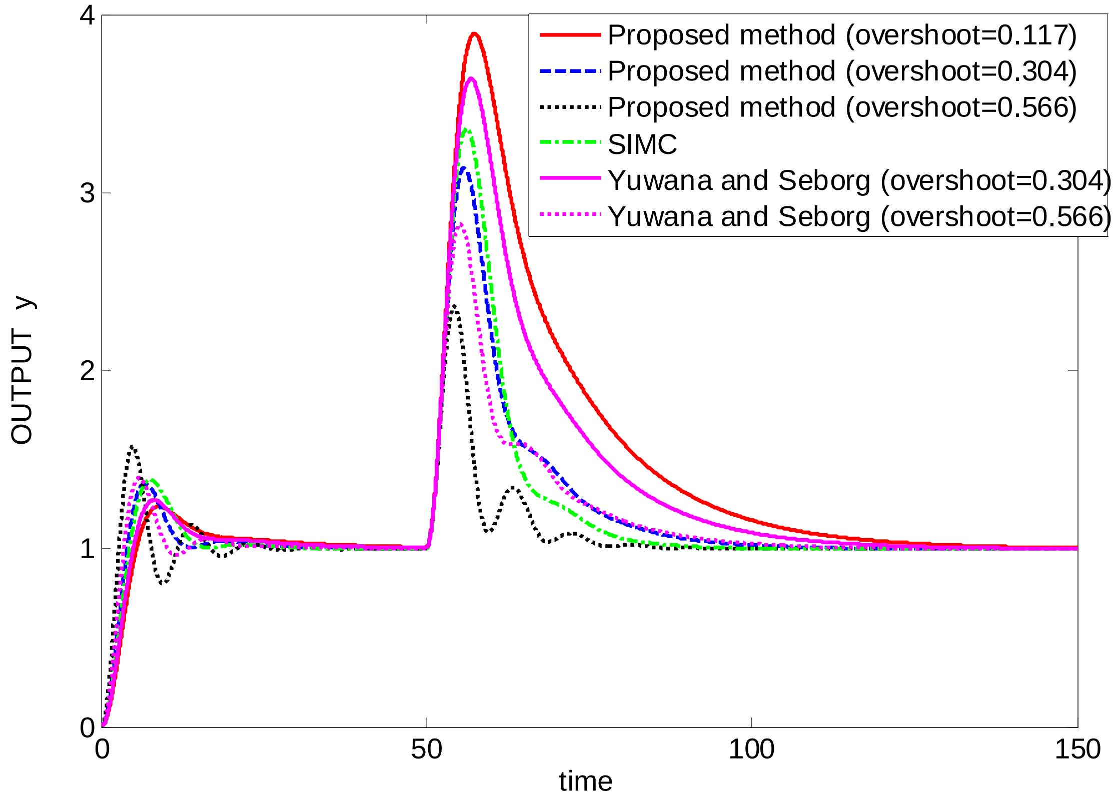


Fig.25. Responses for PI-control of process $\frac{(s+6)^2}{s(s+1)^2(s+36)}$ (E25), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

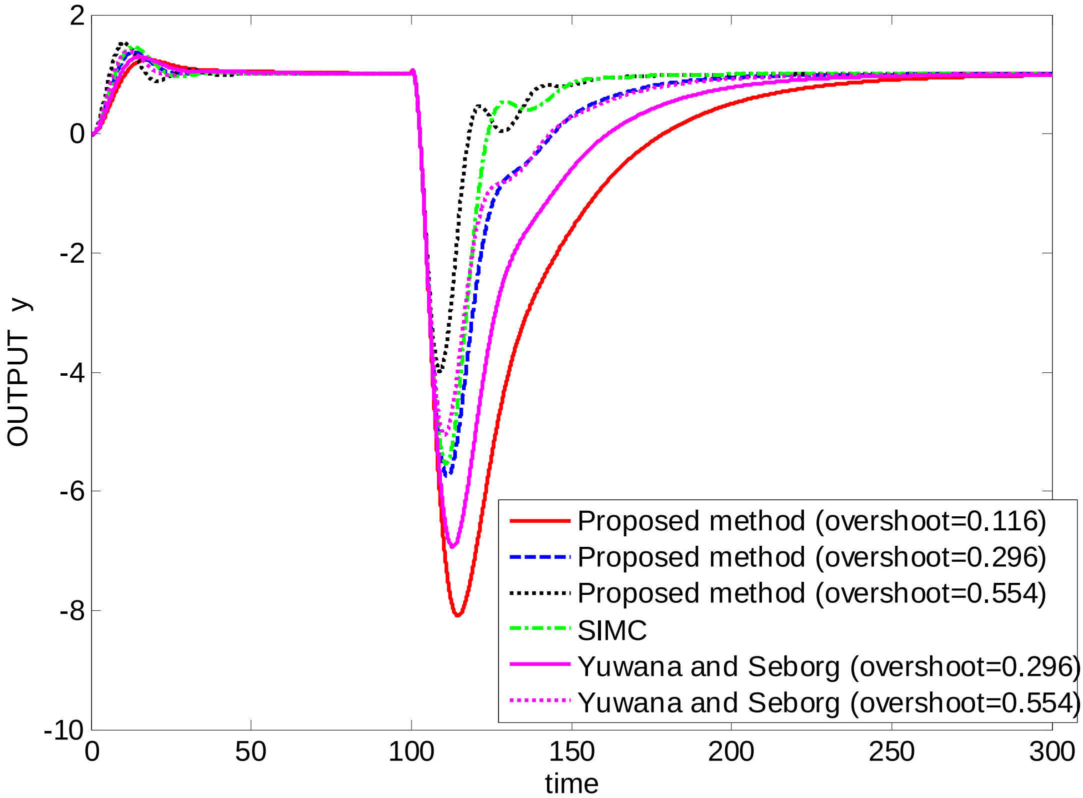


Fig.26. Responses for PI-control of process $\frac{-1.6(-0.5s+1)}{s(3s+1)}$ (E26), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

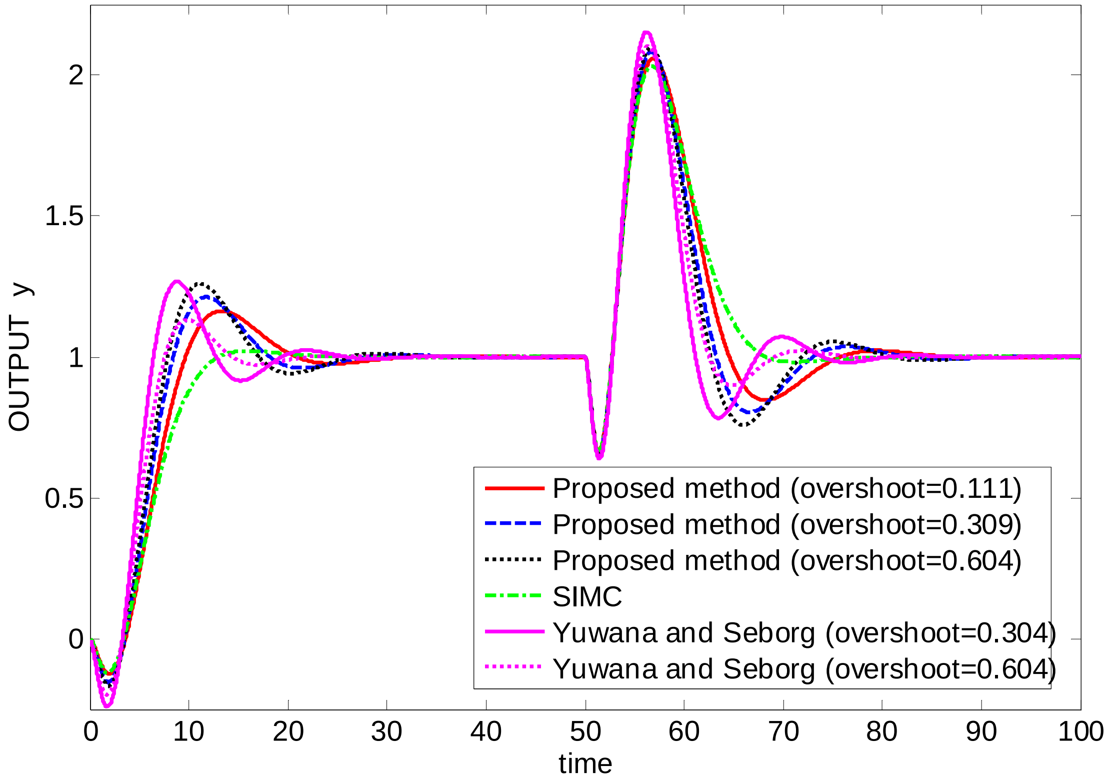


Fig.28. Responses for PI-control of process $\frac{(-2s+1)}{(s+1)^3}$ (E28), Setpoint change at t=0; load disturbance of magnitude 1 at t=50.

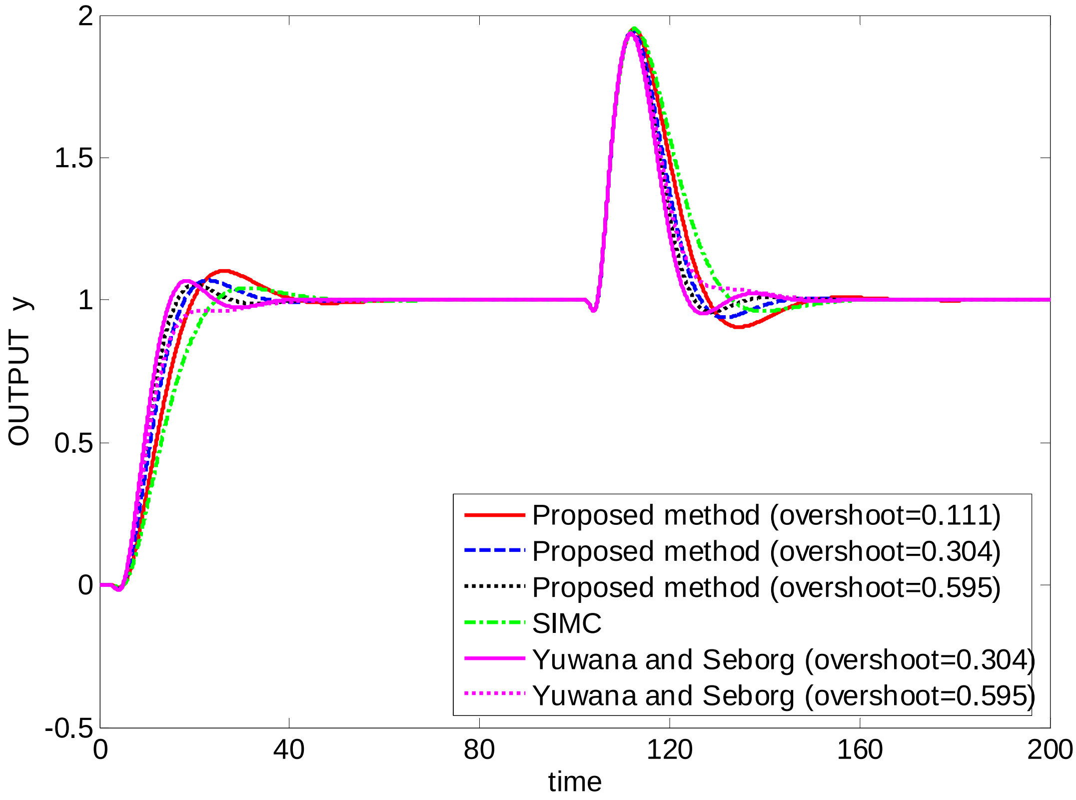


Fig.29. Responses for PI-control of process $\frac{(-s+1)e^{-2s}}{(s+1)^5}$ (E29), Setpoint change at t=0; load disturbance of magnitude 1 at t=100.

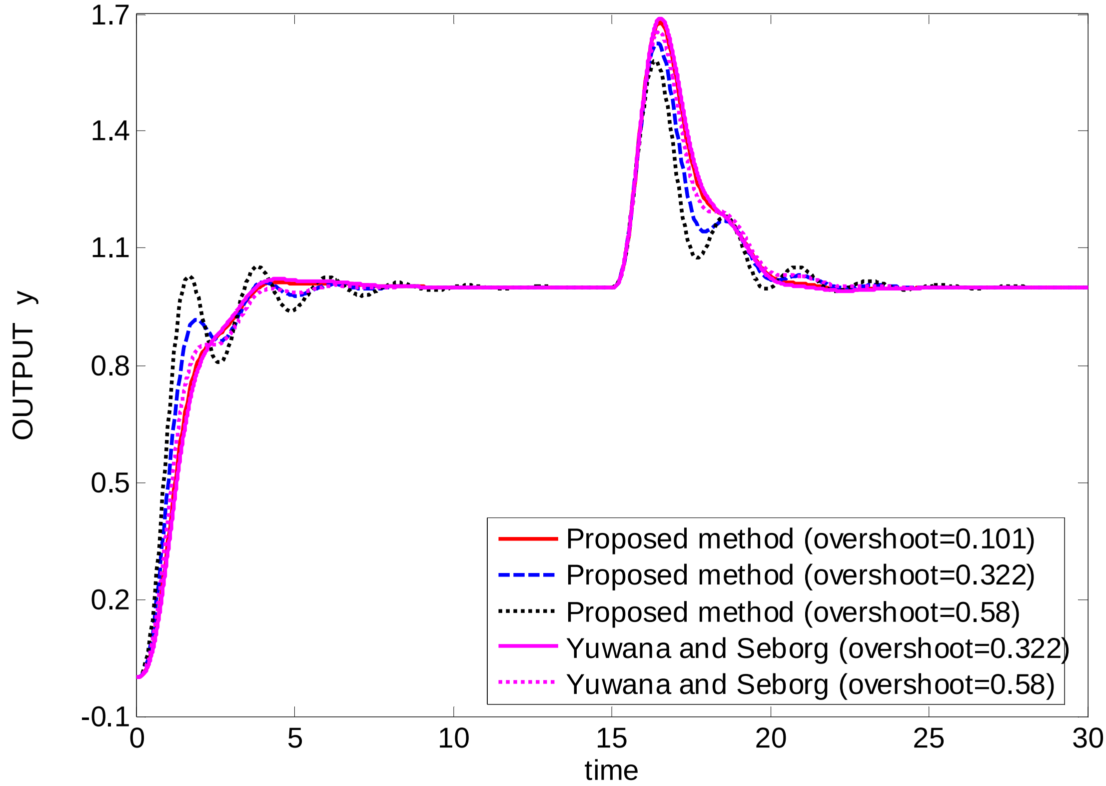


Fig.30. Responses for PI-control of process $\frac{9}{(s+1)(s^2+2s+9)}$ (E30), Setpoint change at t=0; load disturbance of magnitude 1 at t=15.

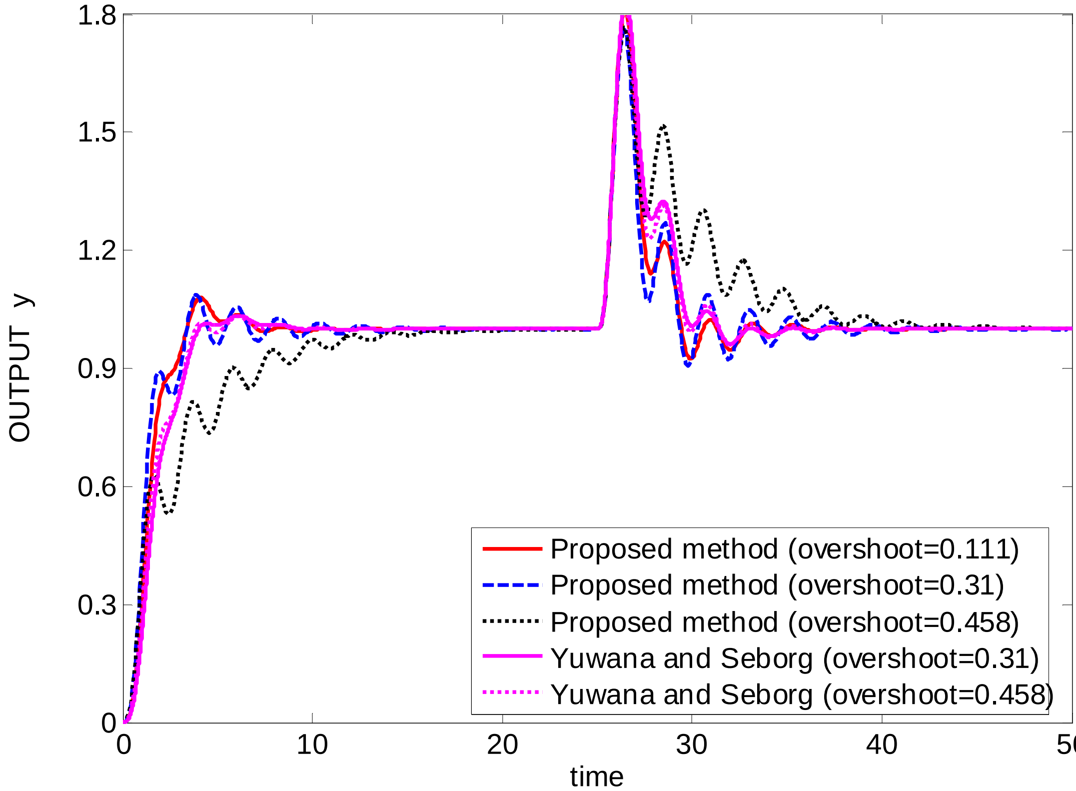


Fig.31. Responses for PI-control of process $\frac{9}{(s+1)(s^2+s+9)}$ (E31), Setpoint change at t=0; load disturbance of magnitude 1 at t=25.

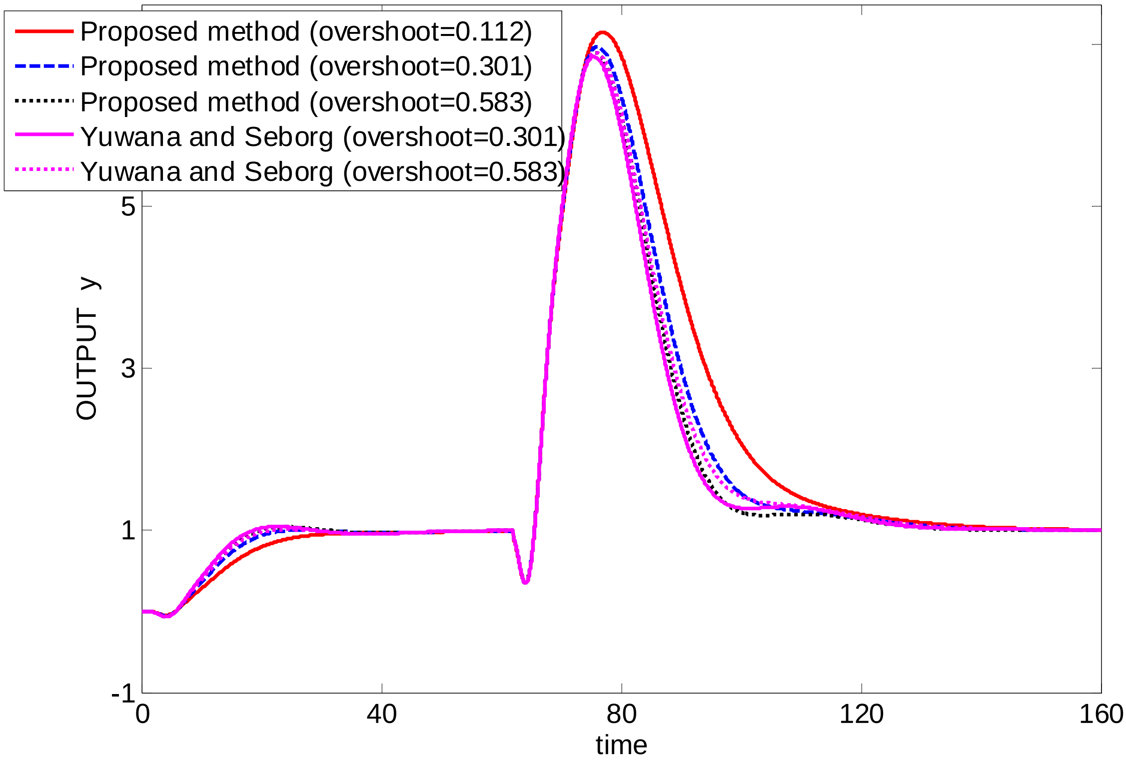


Fig.32. Responses for PI-control of process $\frac{(s^2+2s+9)(-2s+1)(s+1)e^{-2s}}{(s^2+0.5s+1)(5s+1)^2}$ (E32), Setpoint change at t=0; load disturbance of magnitude 1 at t=60.

Section:4,

Table 1: Parameters identification and SIMC PI setting: Yuwana and Seborg (AIChE, 1982) E1-E32

Case	Process model	P-control setpoint experiment		Resulting PI-controller					
		K_{c0}	overshoot	k	τ	θ	K_c	τ_I	M_s
E1	$\frac{1}{(s+1)(0.2s+1)}$	15.0	0.322	1.0	2.4398	0.1652	7.3851	1.3215	1.57
		40.0	0.508	0.9996	3.5087	0.115	15.2552	0.9204	2.09
E2	$\frac{(-0.3s+1)(0.08s+1)}{(2s+1)(s+1)(0.4s+1)(0.2s+1)(0.05s+1)^3}$	1.50	0.303	1.0	3.2415	1.7922	0.9043	3.2415	1.57
		2.50	0.567	1.0	3.4932	1.8442	0.947	3.4932	1.58
E3	$\frac{2(15s+1)}{(20s+1)(s+1)(0.1s+1)^2}$	5.0	0.314	2.0002	1.8074	0.1973	2.29	1.5783	1.48
		9.50	0.599	2	2.4275	0.2035	2.9822	1.628	1.65
E4	$\frac{1}{(s+1)^4}$	1.25	0.304	1.0002	3.2112	2.2319	0.7192	3.2112	1.54
		2.50	0.598	1.0001	3.8499	2.2997	0.837	3.8499	1.59
E5	$\frac{1}{(s+1)(0.2s+1)(0.04s+1)(0.008s+1)}$	6.50	0.292	0.9968	1.7356	0.253	3.4415	1.7356	1.47
		15.0	0.598	1.0086	2.1688	0.2118	5.0767	1.6942	1.72
E6	$\frac{(0.17s+1)^2}{s(s+1)^2(0.028s+1)}$	0.80	0.301	-	-	-	0.3814	15.9466	1.56
		2.0	0.576	-	-	-	0.6485	13.1372	1.97
E7	$\frac{-2s+1}{(s+1)^3}$	0.40	0.309	0.9999	2.0443	2.2607	0.4522	2.0443	2.56
		0.60	0.604	1.0	1.9504	2.6031	0.3746	1.9504	2.12
E8	$\frac{1}{s(s+1)^2}$	0.58	0.307	-	-	-	0.2778	13.7229	1.61
		1.15	0.610	-	-	-	0.3692	24.559	1.70
E9	$\frac{e^{-s}}{(s+1)^2}$	1.0	0.321	1.0	2.0223	1.5676	0.645	2.0223	1.63
		1.70	0.623	0.9999	2.1732	1.7076	0.6364	2.1732	1.59
E10	$\frac{e^{-s}}{(20s+1)(2s+1)}$	8.0	0.301	1.0001	27.3844	3.2615	4.1976	26.0922	1.48
		14.0	0.594	1.0011	30.4956	3.1011	4.9117	24.8086	1.59

Case	Process model	P-control setpoint experiment		Resulting PI-controller					
		K_{c0}	overshoot	k	τ	θ	K_c	τ_I	M_s
E11	$\frac{(-s+1)e^{-s}}{(6s+1)(2s+1)^2}$	1.40	0.344	0.9999	9.0124	5.6718	0.7946	9.0124	1.59
		2.20	0.608	1.0	9.6612	5.963	0.8101	9.6612	1.58
E12	$\frac{(6s+1)(3s+1)e^{-0.3s}}{(10s+1)(8s+1)(s+1)}$	15.0	0.308	1.0	3.3086	0.2655	6.2299	2.1244	1.42
		20.0	0.609	1.0004	3.8292	0.3292	5.8144	2.6332	1.38
E13	$\frac{(2s+1)e^{-s}}{(10s+1)(0.5s+1)}$	4.75	0.302	0.9994	1.9769	0.7589	1.3033	1.9769	1.27
		6.0	0.570	0.9988	2.7259	0.8907	1.532	2.7259	1.31
E14	$\frac{-s+1}{s}$	No oscillation with P-controller, proposed method does not apply							
E14(a)	$\frac{(-s+1)e^{-0.1s}}{s}$	0.70	0.285	-	-	-	0.4918	3.3218	2.32
		0.75	0.558	-	-	-	0.4216	3.644	2.01
E15	$\frac{-s+1}{(s+1)}$	No oscillation with P-controller, proposed method does not apply							
E15(a)	$\frac{(-s+1)e^{-0.2s}}{(s+1)}$	0.60	0.31	0.9998	0.6443	0.4705	0.6849	0.6443	18.95
		0.67	0.611	1.0	0.5958	0.5481	0.5435	0.5958	5.93
E16	$\frac{1}{(s+1)}$	No oscillation with P-controller, proposed method does not apply							
E16(a)	$\frac{e^{-0.05s}}{(s+1)}$	16.0	0.309	1.0004	0.972	0.0545	8.9179	0.4358	1.55
		22.50	0.612	0.9989	1.093	0.061	8.9623	0.4884	1.54
E17	$\frac{e^{-s}}{(5s+1)}$	4.0	0.298	1.0	4.7117	1.0427	2.2594	4.7117	1.52
		5.75	0.599	1.0004	4.8857	1.152	2.1197	4.8857	1.48
E18	$\frac{e^{-s}}{(s+1)}$	0.90	0.326	1.0001	1.1513	0.9287	0.6198	1.1513	1.69
		1.35	0.593	1.0001	1.2117	1.0573	0.5729	1.2117	1.59
E19	$\frac{e^{-s}}{(0.2s+1)}$	0.30	0.292	1.0002	0.4874	0.7338	0.332	0.4874	1.88
		0.60	0.590	1.0	0.5083	0.9264	0.2744	0.5083	1.60

Case	Process model	P-control setpoint experiment		Resulting PI-controller					
		K_{c0}	overshoot	k	τ	θ	K_c	τ_I	M_s
E20	$\frac{e^{-s}}{(0.05s+1)^2}$	0.30	0.30	1.0002	0.4156	0.6982	0.2976	0.4156	1.88
		0.60	0.60	1.0	0.4428	0.8789	0.2519	0.4428	1.61
E21	e^{-s}	0.30	0.30	1.0002	0.3842	0.6454	0.2976	0.3842	1.87
		0.60	0.60	1.0	0.4113	0.8164	0.2519	0.4113	1.60
E22	$\frac{100e^{-s}}{100s+1}$	0 .80	0.301	100.376	90.0121	1.0833	0.4139	8.666	1.53
		1.10	0.598	100.101	92.8611	1.1785	0.3936	9.428	1.49
E23	$\frac{(10s+1)e^{-s}}{s(2s+1)}$	0.26	0.303	-	-	-	0.0767	6.4671	1.32
		0.33	0.595	-	-	-	0.0792	8.0188	1.33
E24	$\frac{e^{-s}}{s}$	0.80	0.302	-	-	-	0.4116	8.6757	1.54
		1.10	0.60	-	-	-	0.3917	9.436	1.50
E25	$\frac{(s+6)^2}{s(s+1)^2(s+36)}$	0.80	0.304	-	-	-	0.3797	16.1036	1.56
		1.90	0.566	-	-	-	0.6231	13.3796	1.93
E26	$\frac{-1.6(-0.5s+1)}{s(3s+1)}$	-0.25	0.296	-	-	-	-0.1279	30.5254	1.59
		-0.50	0.554	-	-	-	-0.1838	25.5285	1.87
E27	$\frac{e^{-s}}{s^2}$	Not possible to stabilize with PI controller							
E28	$\frac{(-2s+1)}{(s+1)^3}$	0.40	0.309	0.9999	2.0438	2.2602	0.4522	2.0438	2.57
		0.60	0.604	1.0	1.9475	2.5994	0.3746	1.9475	2.12

Case	Process model	P-control setpoint experiment		Resulting PI-controller					
		K_{c0}	overshoot	k	τ	θ	K_c	τ_I	M_s
E29	$\frac{(-s+1)e^{-2s}}{(s+1)^5}$	0.40	0.304	0.9999	3.6354	4.7321	0.3841	3.6354	1.83
		0.73	0.595	0.9997	3.85	5.6722	0.3395	3.85	1.63
E30	$\frac{9}{(s+1)(s^2+2s+9)}$	1.25	0.322	1.0002	0.5885	0.708	0.4156	0.5885	1.38
		2.30	0.58	1.0001	0.8391	0.6967	0.6021	0.8391	1.53
E31	$\frac{9}{(s+1)(s^2+s+9)}$	0.75	0.31	1.0001	0.315	0.8542	0.1844	0.315	1.39
		1.10	0.458	1.0	0.4325	0.8063	0.2682	0.4325	1.53
E32	$\frac{(s^2+2s+9)(-2s+1)(s+1)e^{-2s}}{(s^2+0.5s+1)(5s+1)^2}$	0.12	0.301	8.9989	9.2217	5.7674	0.0888	9.2217	1.75
		0.18	0.583	8.9992	9.1887	6.2233	0.082	9.1887	1.67

Section: 5,

Table 2, the correlation has been further tested on the 33 processes from Table 1 for $\Delta y_\infty = 0.895(\Delta y_p + \Delta y_u)/2 \approx 0.45(\Delta y_p + \Delta y_u)$ and result is listed for different overshoot for E1-E33.

Case	overshoot	b from Eq. (10)	Case	overshoot	b from Eq. (10)	Case	overshoot	b from Eq. (10)
E1	0.127	0.7915	E13	0.142	0.6648	E22	0.118	0.9315
	0.322	0.9348		0.302	0.7115		0.301	0.9843
	0.508	0.9871		0.570	0.7452		0.598	1.008
E2	0.131	0.437	E14	Proposed method does not apply		E23	0.136	0.7918
	0.303	0.5967					0.303	0.8181
	0.567	0.7215					0.595	0.811
E3	0.107	0.776	E14 (a)	0.106	0.9451	E24	0.108	0.9435
	0.314	0.8825		0.285	1.0109		0.302	0.9968
	0.599	0.926		0.558	1.09		0.60	1.017
E4	0.10	0.3132	E15	Proposed method does not apply		E25	0.117	0.9461
	0.304	0.5496					0.304	0.9905
	0.598	0.7052					0.566	0.9893
E5	0.104	0.7062	E15 (a)	0.115	0.2798	E26	0.116	0.9462
	0.292	0.8594		0.31	0.3447		0.296	0.9944
	0.598	0.9384		0.611	0.4159		0.554	1.0153
E6	0.110	0.9437	E16	Proposed method does not apply		E27	Not possible to stabilized with PI controller	
	0.301	0.9901						
	0.576	0.9877						
E7	0.111	0.1706	E16 (a)	0.123	0.8762	E28	0.111	0.1706
	0.309	0.2884		0.309	0.9453		0.309	0.2884
	0.604	0.4001		0.612	0.9987		0.604	0.4001
E8	0.106	0.9423	E17	0.10	0.6899	E29	0.111	0.1373
	0.307	0.9923		0.298	0.7971		0.304	0.2858
	0.610	0.99		0.599	0.8672		0.595	0.4341
E9	0.116	0.3154	E18	0.109	0.3148	E30	0.101	0.3197
	0.321	0.4997		0.326	0.4755		0.322	0.5211
	0.623	0.6375		0.593	0.5906		0.58	0.6364
E10	0.11	0.7723	E19	0.113	0.1013	E31	0.111	0.198
	0.301	0.8842		0.292	0.2299		0.31	0.3796
	0.594	0.9418		0.590	0.3818		0.458	0.465
E11	0.119	0.39	E20	0.10	0.0855	E32	0.112	0.3654
	0.344	0.5842		0.30	0.2295		0.301	0.5207
	0.608	0.6944		0.60	0.378		0.583	0.644
E12	0.128	0.8123	E21	0.10	0.0855	E33	0.10	1.3887
	0.308	0.8626		0.30	0.2295		0.30	1.3279
	0.609	0.8825		0.60	0.378		0.607	1.2511

THE END