BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

Project Report

Course No : EEE 318 **Section :** A

Course Title : Control System I Laboratory

Project Title: Analysis of the control system described in the publication titled “Variable-gain control for respiratory systems”

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Contents

Task 1: Determination the transfer function of the respiratory system shown in Fig. 3 3

Task 2: Determination the overall transfer function of the system shown in Fig. 4 4

Task 3: Sketch the root locus of in Figure 4 for 0<ki<∞ of the integral controller C(s) 5

Task 4: Reproducing Fig.7 results and discussion on the necessity of both feedback and feed-forward control 7

Task 5: Preference amongst pure integral, PI and lag controller.......... **Error! Bookmark not defined.**

Task 6: Designing a linear controller to meet the requirements in page-166 (column 1 & 2) .... **Error! Bookmark not defined.**

Task 7: Reproduce the results shown in Fig. 14 for linear and variable gain controllers. What are the pros & cons of non linear control over linear control? .... **Error! Bookmark not defined.**

Task 8: Discuss the performance of both linear and non linear control systems in presence of uncertainties such as different lung parameters, pressure drop etc. .... **Error! Bookmark not defined.**

Task 1: Determination the transfer function of the respiratory system shown in Fig. 3

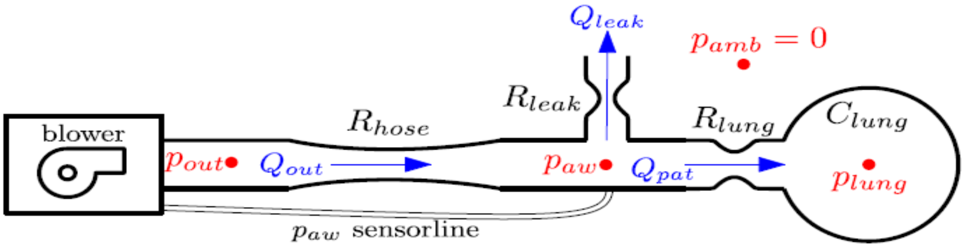


Fig. 3. Schematic of a respiratory system showing the different pressures (red), flows (blue), and resistances and compliance (black).

The respiratory system has the following transfer function:

H(*s*)=*C*$_h$(*sI*−*A*$_h$)$^{-1}$*B*$_h$+*D*$_h$..(1)

The parameters are defined as below:

$$A_h = -\frac{\frac{1}{R_{\text{hose}}} + \frac{1}{R_{\text{leak}}}}{R_{\text{lung}} C_{\text{lung}} \left(\frac{1}{R_{\text{lung}}} + \frac{1}{R_{\text{hose}}} + \frac{1}{R_{\text{leak}}} \right)}$$

$$B_h = \frac{\frac{1}{R_{\text{hose}}}}{R_{\text{lung}} C_{\text{lung}} \left(\frac{1}{R_{\text{lung}}} + \frac{1}{R_{\text{hose}}} + \frac{1}{R_{\text{leak}}} \right)}$$

$$C_h = \left[\frac{\frac{1}{R_{\text{lung}}}}{\frac{1}{R_{\text{lung}}} + \frac{1}{R_{\text{hose}}} + \frac{1}{R_{\text{leak}}}} - \frac{\frac{1}{R_{\text{hose}}} + \frac{1}{R_{\text{leak}}}}{R_{\text{lung}} \left(\frac{1}{R_{\text{lung}}} + \frac{1}{R_{\text{hose}}} + \frac{1}{R_{\text{leak}}} \right)} \right]^T$$

$$D_h = \left[\frac{\frac{1}{R_{\text{hose}}}}{\frac{1}{R_{\text{lung}}} + \frac{1}{R_{\text{hose}}} + \frac{1}{R_{\text{leak}}}} \quad \frac{\frac{1}{R_{\text{hose}}}}{R_{\text{lung}} \left(\frac{1}{R_{\text{lung}}} + \frac{1}{R_{\text{hose}}} + \frac{1}{R_{\text{leak}}} \right)} \right]^T$$

$$B(s) = \frac{p_{\text{out}}(s)}{p_{\text{control}}(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

And from the table:

TABLE I
PARAMETERS SETTINGS USED FOR SIMULATIONS

Variable	Value	Unit
R_{lung}	$\frac{5}{1000}$	$\frac{mbar}{\frac{mL}{s}}$
C_{lung}	20	$\frac{mL}{mbar}$
R_{leak}	$\frac{60}{1000}$	$\frac{mbar}{\frac{mL}{s}}$
R_{hose}	$\frac{4.5}{1000}$	$\frac{mbar}{\frac{mL}{s}}$
ω_n	$2\pi 30$	$\frac{rad}{s}$

Using these values:

A_h= -5.4430, B_h= 5.0633

$C_h = \begin{bmatrix} 0.4557 \\ -108.8608 \end{bmatrix}, D_h = \begin{bmatrix} 0.5063 \\ 101.2658 \end{bmatrix}$

Hence, from (1), transfer function of respiratory system:

$$\mathbf{H(s)} = \begin{bmatrix} \dfrac{0.5063s+5.063s}{s+5.443} \\ \dfrac{101.3s}{s+5.443} \end{bmatrix}$$

Where, $H_1(s) = \frac{0.5063s+5.063}{s+5.443}$, and $H_2(s) = \frac{101.3s}{s+5.443}$

We can also calculate the transfer function of blower:

$$\mathbf{B(s)} = \frac{3.553\times10^4}{s^2+377s+3.553\times10^4}$$

Task 2: Determination the overall transfer function of the system shown in Fig. 4

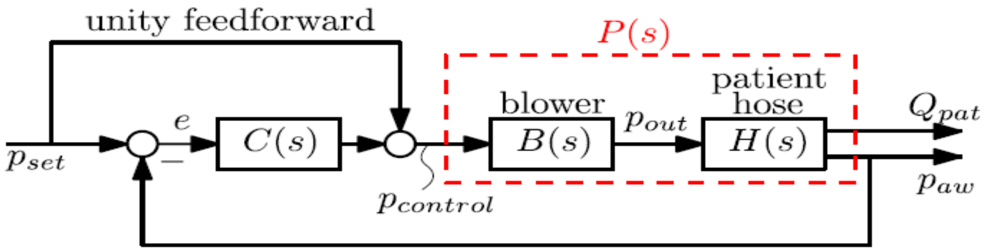
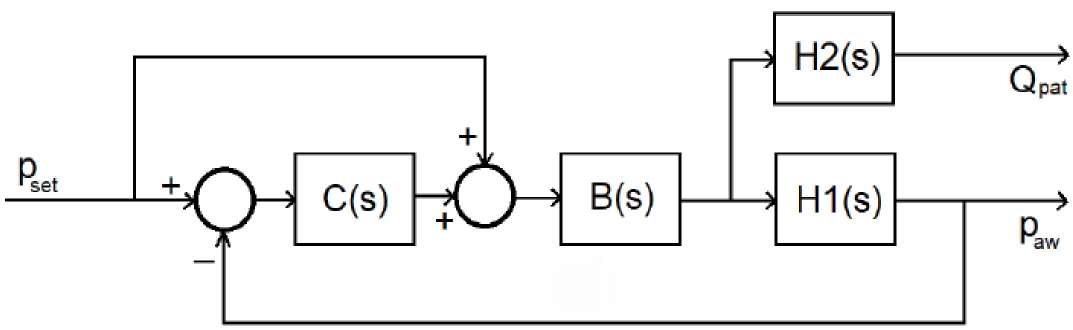


Fig. 4. Closed-loop control scheme with a linear controller $C(s)$.

Redrawing the flow diagram, we get:



We use Mason's rule to determine the transfer functions. Again, there is a integral controller, hence, **C(s)=** $\frac{1}{s}$

Again, let, P1(s)= B(s)H1(s) and P2(s)= B(s)H2(s)

After calculation, P1(s)= $\frac{1.799\times10^4 s+1.799\times10^5}{s^3+382.4s^2+3.758\times10^4 s+1.934\times10^5}$

And, P2(s)= $\frac{3.598\times10^6 s}{s^3+382.4s^2+3.758\times10^4 s+1.934\times10^5}$

1. Here, $T_{aw}(s)= \frac{Paw(s)}{Pset(s)}$

Finally we find, $T_{aw}(s)= \frac{[1+C(s)]P1(s)}{1+C(s)P1(s)}$

So, $\mathbf{T_{aw}(s)=} \frac{1.799\times10^4 s^2+1.979\times10^5 s+1.799\times10^5}{s^4+382.4s^3+3.758\times10^4 s^2+2.114\times10^5 s+1.799\times10^5}$

2. 1. Here, $T_{pat}(s)= \frac{Qpat(s)}{Pset(s)}$

Finally we find, $T_{aw}(s)= \frac{[1+C(s)]P2(s)}{1+C(s)P1(s)}$

So, $\mathbf{T_{pat}(s)=} \frac{3.598\times10^6 s^2+3.598\times10^6 s}{s^4+382.4s^3+3.758\times10^4 s^2+2.114\times10^5 s+1.799\times10^5}$

Task 3: Sketch the root locus of in Figure 4 for 0<��<∞ of the integral controller C(s)

We found the transfer functions for $T_{aw}(s)$ and $T_{pat}(s)$ in the previous task. Since the denominator for the two transfer functions are the same, the root locus will be same. $T_{aw}(s)$ and $T_{pat}(s)$ are represented by T1(s) and T2(s) respectively. The root locus is shown below using **rlocus()** function in MATLAB:

```
clc;
clear all;
close all;
% arbitrary variables taken from table 1
R_lung = 5/1000;
C_lung = 20;
R_leak = 60/1000;
R_hose = 4.5/1000;
W = 2*pi*30;
zeta = 1;
```

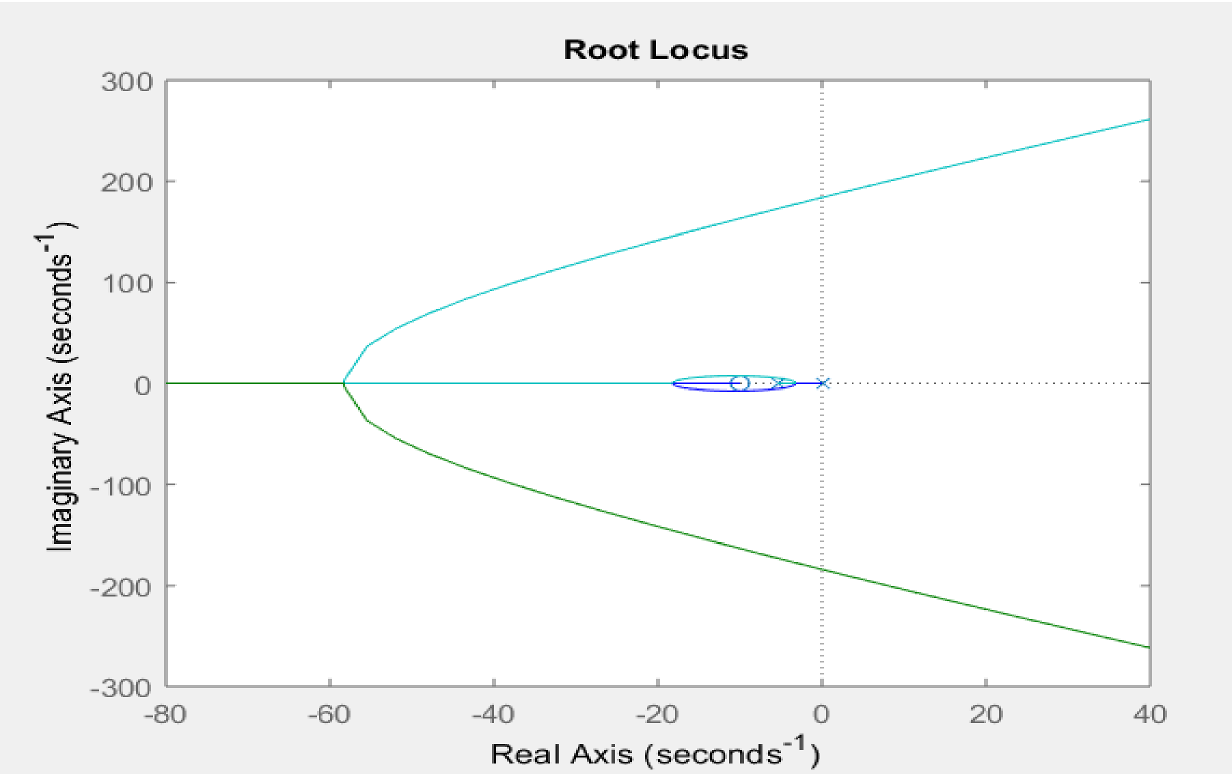
```
% variables from equations 9
A_h = (-1)*((1/R_hose)+(1/R_leak))/(R_lung*C_lung*(1/R_lung + 1/R_hose +
1/R_leak));
B_h = (1/R_hose)/(R_lung*C_lung*(1/R_lung + 1/R_hose + 1/R_leak));
C_h = transpose([(1/R_lung)/(1/R_lung + 1/R_hose + 1/R_leak) , (-1/R_hose -
1/R_leak)/(R_lung*(1/R_lung + 1/R_hose + 1/R_leak))]);
D_h = transpose([(1/R_hose)/(1/R_lung + 1/R_hose +
1/R_leak),(1/R_hose)/(R_lung*(1/R_lung + 1/R_hose + 1/R_leak))]);

%Patient hose transfer function
s=tf('s');
H = C_h*((s*eye(1)-A_h)^-1)*B_h + D_h

B= (W^2)/(s^2+2*zeta*W*s+W^2)
P = B*H
C = 1/s;

T1 = minreal((P(1)+P(1)*C)/(1+P(1)*C))
T2 = minreal((P(2)+P(2)*C)/(1+P(1)*C))

rlocus(P(1)/s,0:0.01:1000)
sgrid(1,0)
axis([-80 40 -300 300])
```



Task 4: Reproducing Fig.7 results and discussion on the necessity of both feedback and feed-forward control

The expected results are (according to the paper),

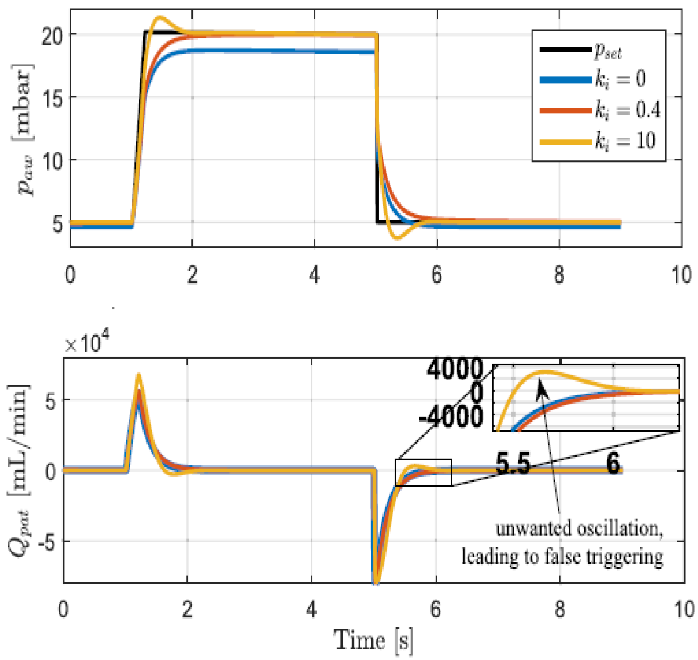


Figure: Simulation result of the closed-loop system using no controller, a low-gain controller (*ki* = 0.4), and a high-gain controller (*ki* = 10).

We have used SIMULINK to design the system.

The observations from the above two figures are:

1. The input $P_{set}(s)$ starts from 5 mbar and is limited to 20 mbar.
2. The input $P_{set}(s)$ is not exactly a pulse with infinite slopes.
3. The upward slope has finite (very high) magnitude but the downward slope is of infinite value.

We used ramp and step functions to generate our required $P_{set}(s)$. To simplify the problem and mitigate some transient errors, we kept $P_{set}(s)$ between 0-15 instead of 5-20 mbar. The finally chosen $P_{set}(s)$ is:

$$\mathbf{64.865[r(t-1)-r(t-1.23125)]-15u(t-5)} \leftrightarrow \frac{64.865}{s^2}[e^{-s}-e^{-1.23125s}]-\frac{15e^{-5s}}{s}$$

For each value of (0,0.4,10), a separate block diagram is made. As zero gain is not feasible in real application, we used very small value 0.0001 instead of 0.

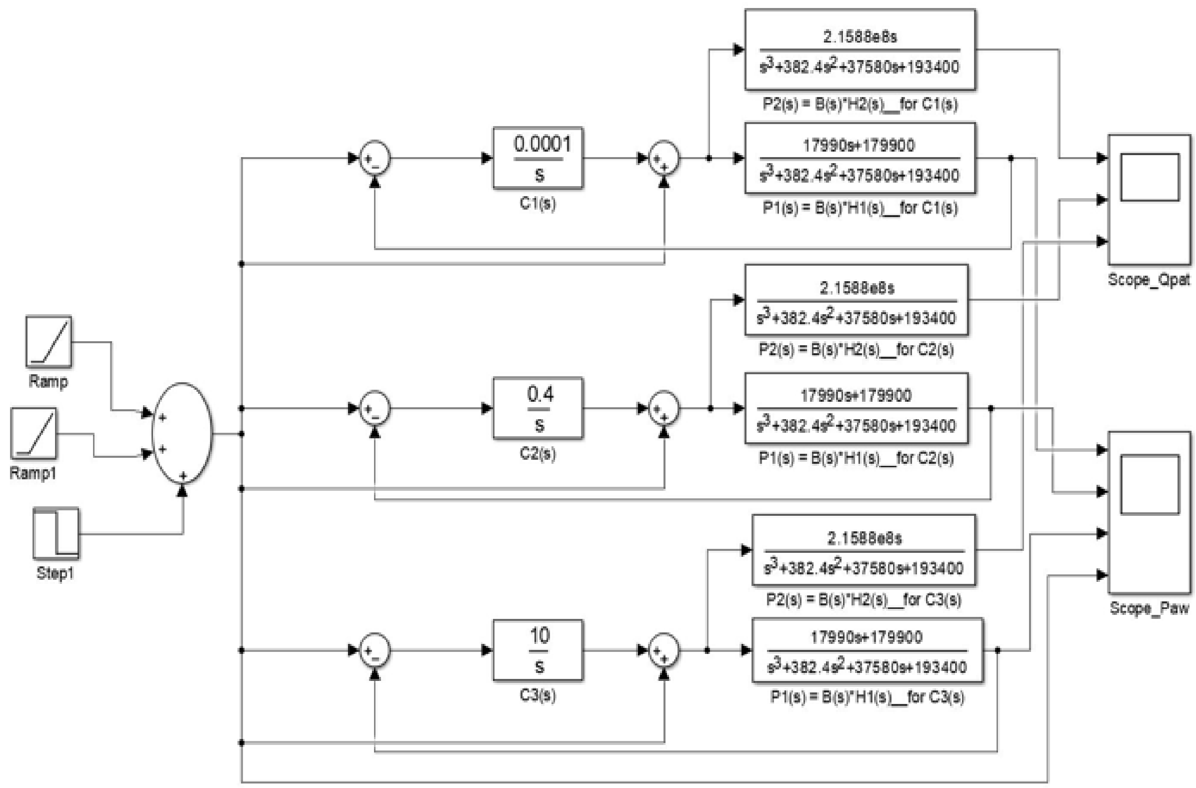
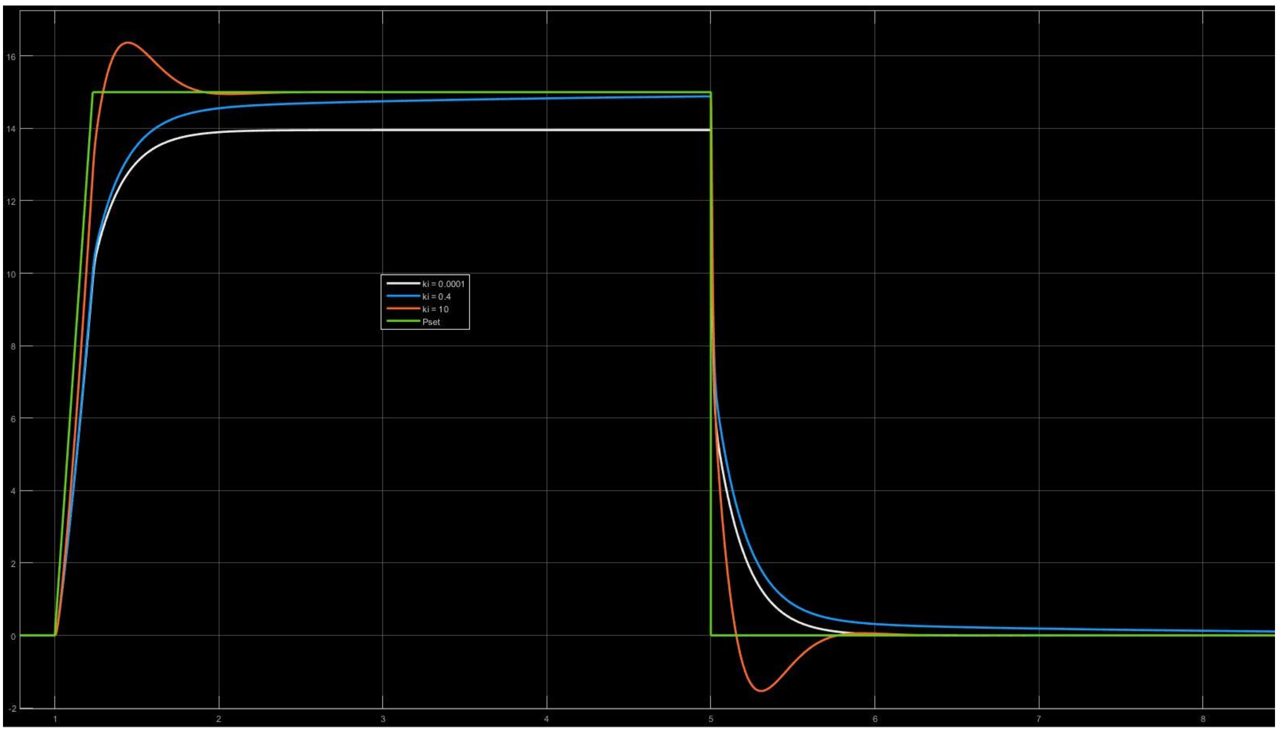
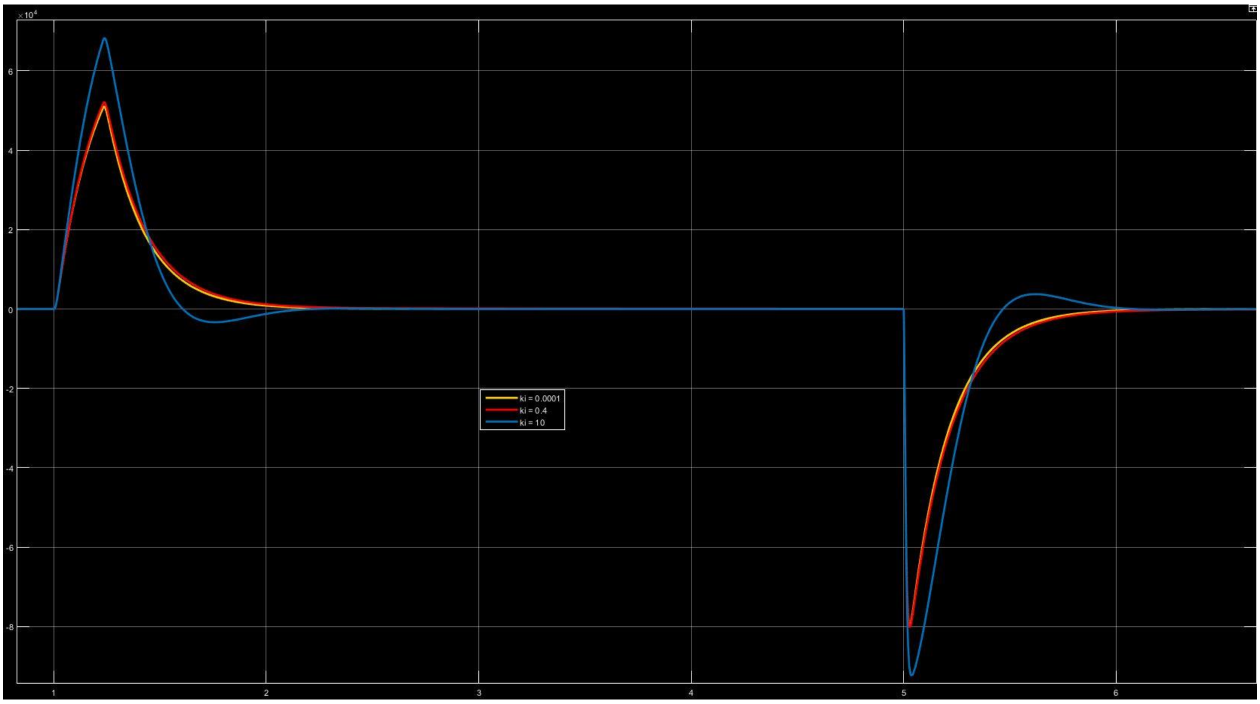


Figure: SIMULINK diagram for the given systems

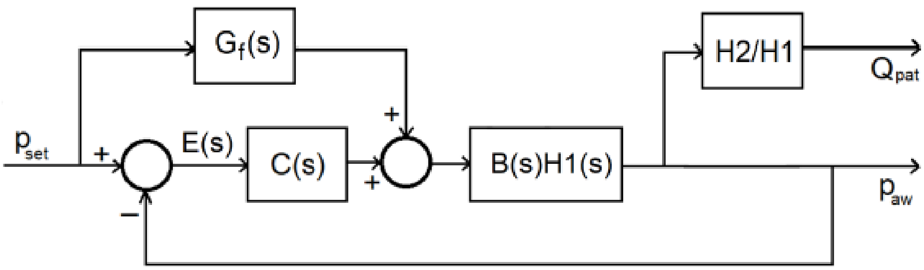
Output for Scope_Paw:



Output for Scope_Qpat:



Necessity of both feed-forward and feedback systems:



From Task 2, we found:

$T_{aw}(s) = \frac{Paw(s)}{Pset(s)} = \frac{[1+C(s)]P1(s)}{1+C(s)P1(s)}$

Here, we used a feed-forward system with gain G_f. Hence, the modified system:

$T_{aw}(s) = \frac{Paw(s)}{Pset(s)} = \frac{[Gf(s)+C(s)]P1(s)}{1+C(s)P1(s)}$

Hence, $e(s) = Pset(s) - Paw(s) = Pset(s)\left[1 - \frac{(Gf(s)+C(s))P1(s)}{1+C(s)P1(s)}\right]$

So, $e(s) = Pset(s)\left[\frac{1-Gf(s)P1(s)}{1+C(s)P1(s)}\right]$……………………………………………………..(2)

For a steady state errorless system,

e(∝)= $\lim_{s\to\infty} sE(s)$ =0

e(∝)=$\lim_{s\to\infty} sPset(s)\frac{1-\mathrm{Gf(s)P1(s)}}{1+\mathrm{C(s)P1(s)}}$ =0 so,$[1-\mathrm{Gf(s)P1(s)}]\lim_{s\to\infty}\frac{sPset(s)}{1+\mathrm{C(s)P1(s)}}$=0

The plant provides a non-zero error. Hence, the required condition:

$[1-\mathrm{Gf(0)P1(0)}]$= 0 so, **Gf(0)=** $\boldsymbol{\frac{1}{P1(0)}}$

Now, **P_1(0)= B(0)H_1(0)**

$$B(0)=\left.\frac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}\right|_{s=0}=1$$

And, H_1(0)= $\frac{179900}{193400}$= 0.9302

Therefore, **Gf(0)=** $\boldsymbol{\frac{1}{0.9302}=1.075}$

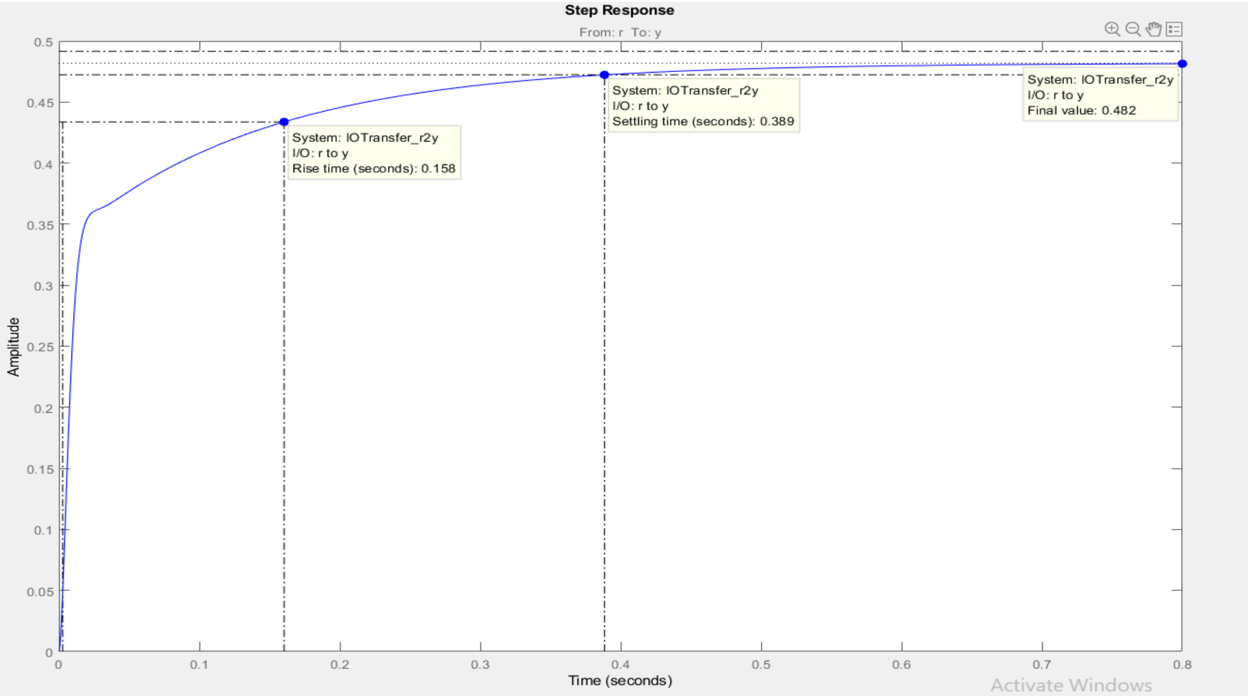
In this paper, Gf(0)= 1, which is very near to our new calculated gain. So the feed forward system is very much acceptable.

Therefore, a feed-forward system reduces steady state error if set properly.

The feedback introduces an error value between the input and output to the system which can control the response of the system. The system's response moves faster or slower based on the plant and controller, but the error makes the output follow the input set value. Without the feedback, the output may go out of bounds or become unstable as it cannot get any information or correction based on how it is performing.

Task 5: Preference amongst pure integral, PI and lag controller

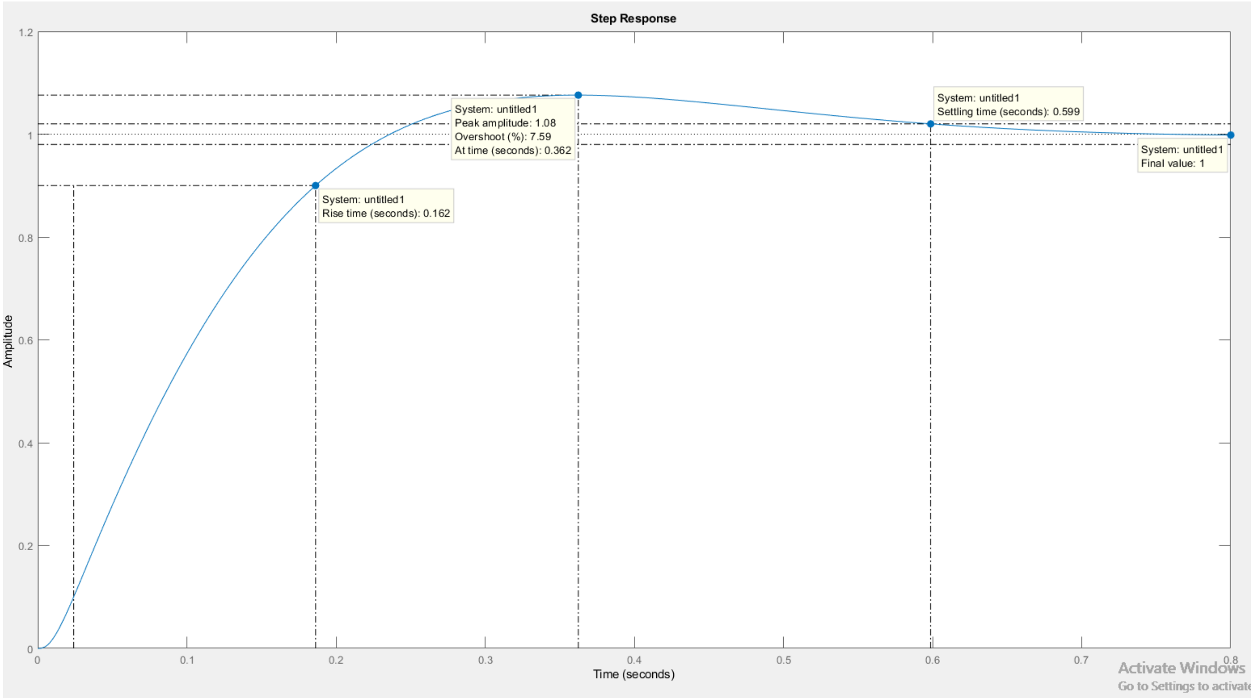
Step response characteristics for no controller



High steady state error can be observed.

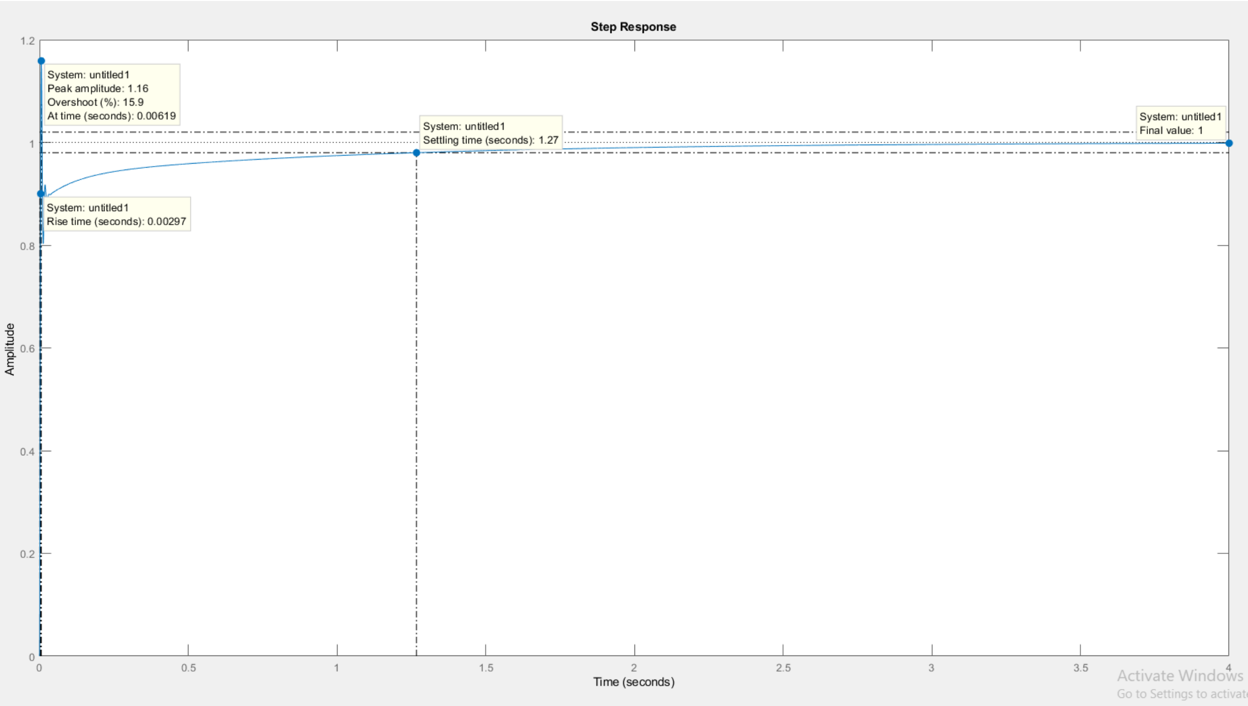
Now, the performance of a Pure integral controller was evaluated. Taking controller 14/s

the following step response was determined



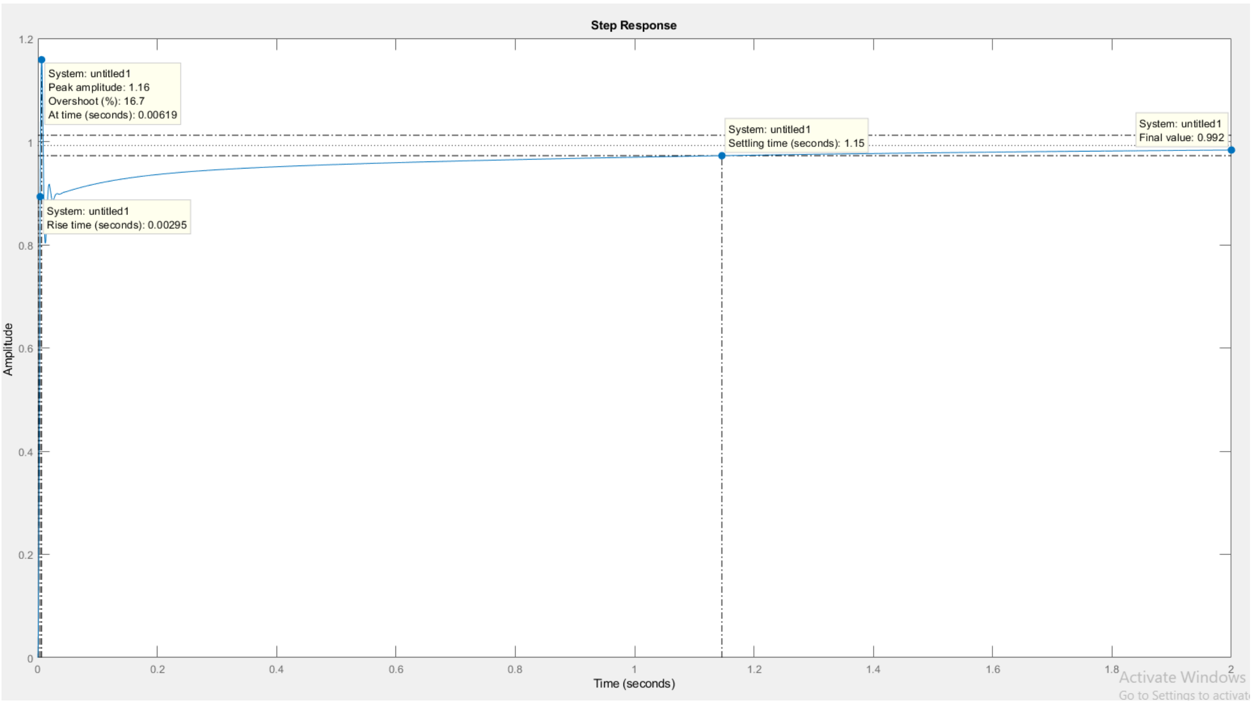
Here, it can be observed that the percentage overshoot has decreased a lot and the rise time and steady state error is optimum.

For further comparison, a PI controller 14(s+1)/s was implemented and the following step response was obtained



Here, it can be seen that, although the rise time has reduced a lot, the overshoot has increased and the settling time has increased.

Finally, for comparison. a lag controller 14(s+1)/(s+0.1) was implemented and the step response was visualized



Here, it can be seen that the overshoot percentage and rise time both exceed the optimum range.

Among all the controllers, the Pure Integral controller performs better for the given conditions.

Task 6: Designing a linear controller to meet the requirements in page-166 (column 1 & 2)

We need to find the boundary of the linear controller gain in order to meet the specifications.

For type-0 system:

The steady state error= $\frac{1}{1+\lim_{s\to 0} G(s)} = \frac{1}{1+KP1(0)} = \frac{1}{1+0.9302K}$

From the paper:

The goal of the pressure controller is to achieve sufficiently fast pressure buildup and accurate tracking of the desired pressure profile *P*set while simultaneously not introducing the oscillations in the flow signal, which may result in false triggers of the inhalation cycle. Quantitatively, these specifications can be formulated as follows,

1) The rise time from 10% to 90% of a pressure set point should be approximately 200 ms.

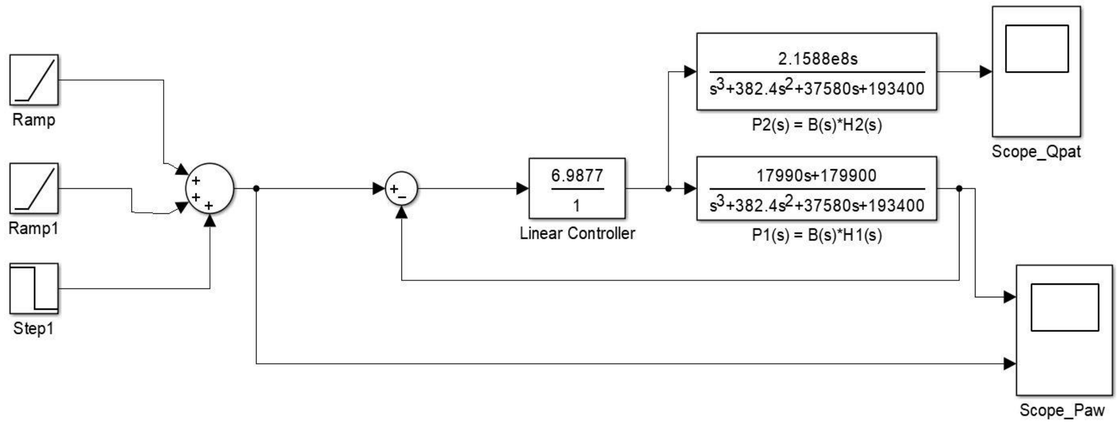
2) The pressure at the end of an inspiration, the so-called plateau pressure, should be within a pressure band of ±2 mbar of the pressure set point.

3) The overshoot in the flow during an expiration should be below the triggering value set by the clinician, and a typical value is 2 L/min.

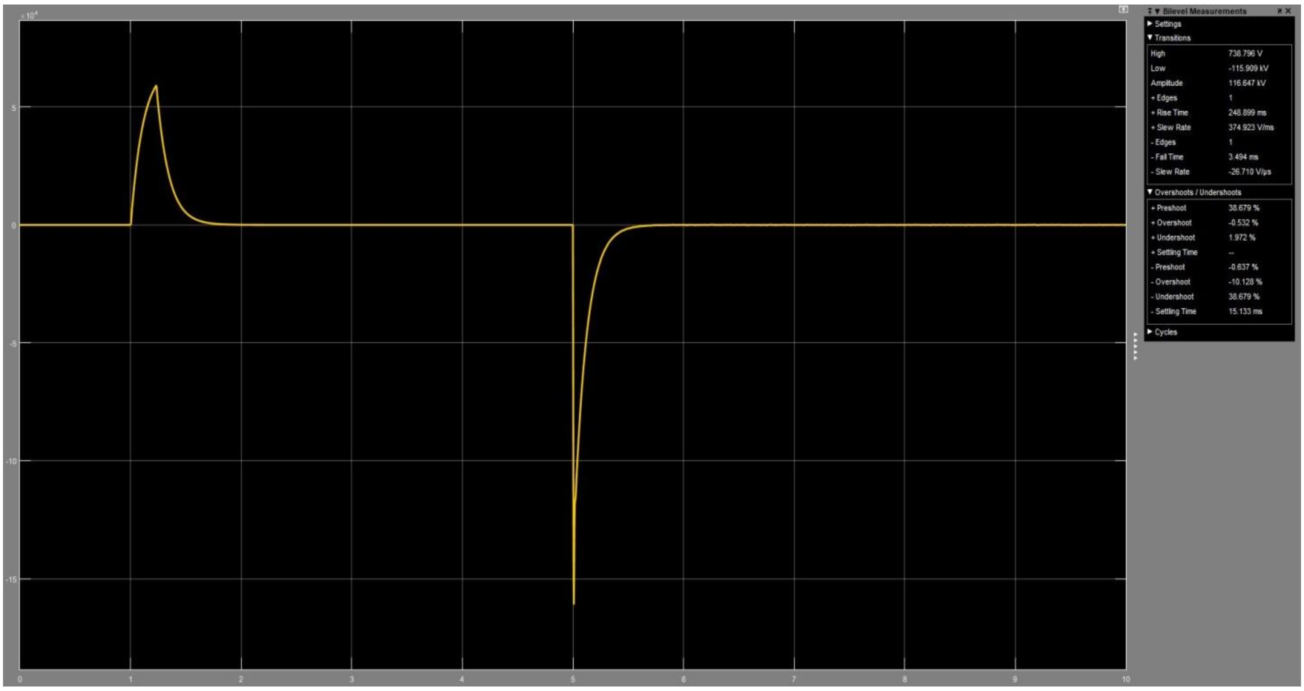
Hence, the pressure has to be 15$\pm$2 mvar. We used the settling value =15-2= 13 mbar.

Hence, the steady state error= $\frac{1}{1+0.9302K}$= $\frac{2}{15}$

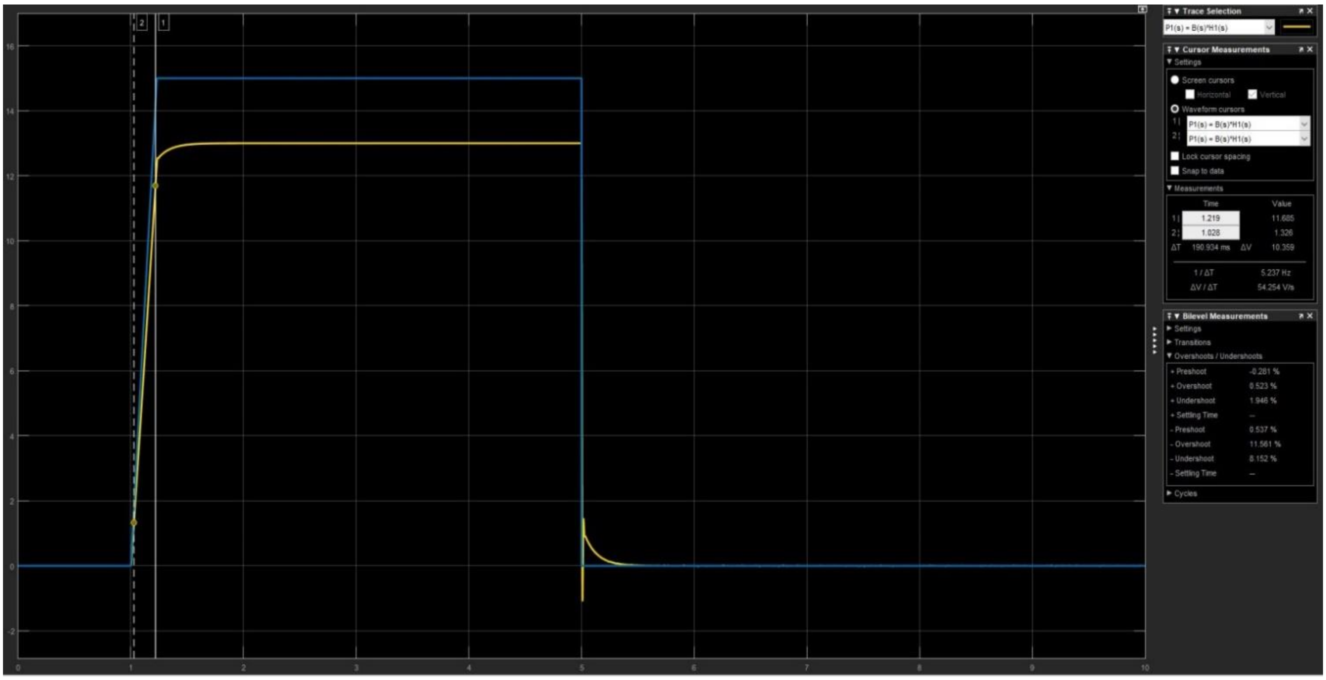
Solving, **K= 6.9877**



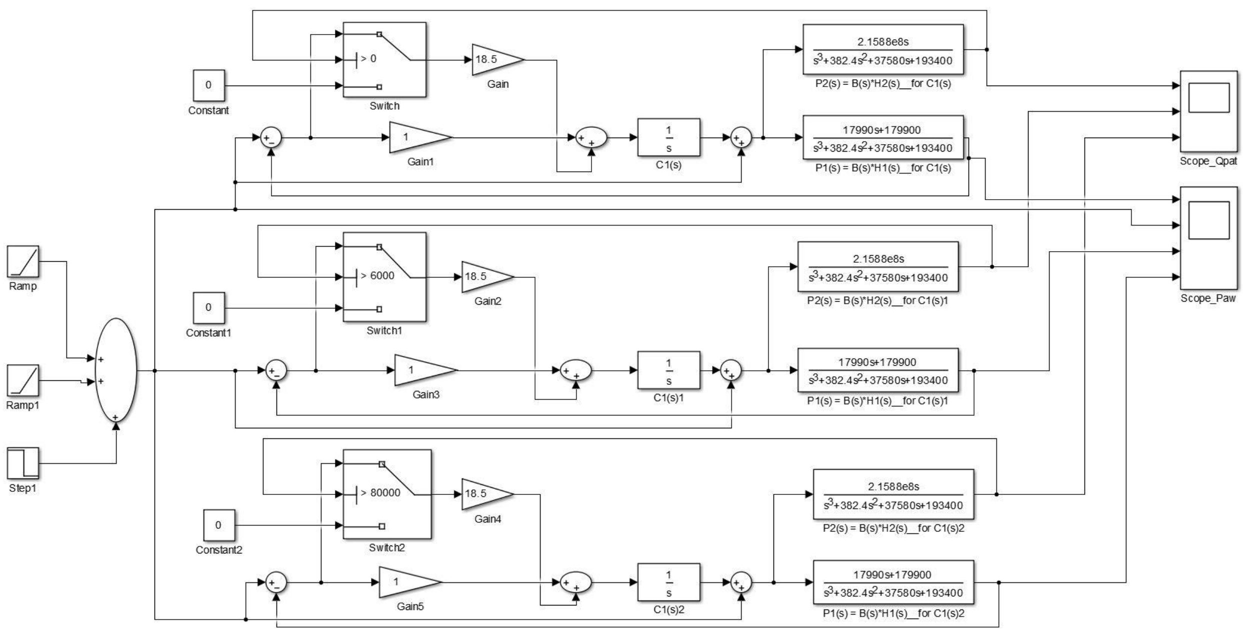
Output at Scope_Qpat:



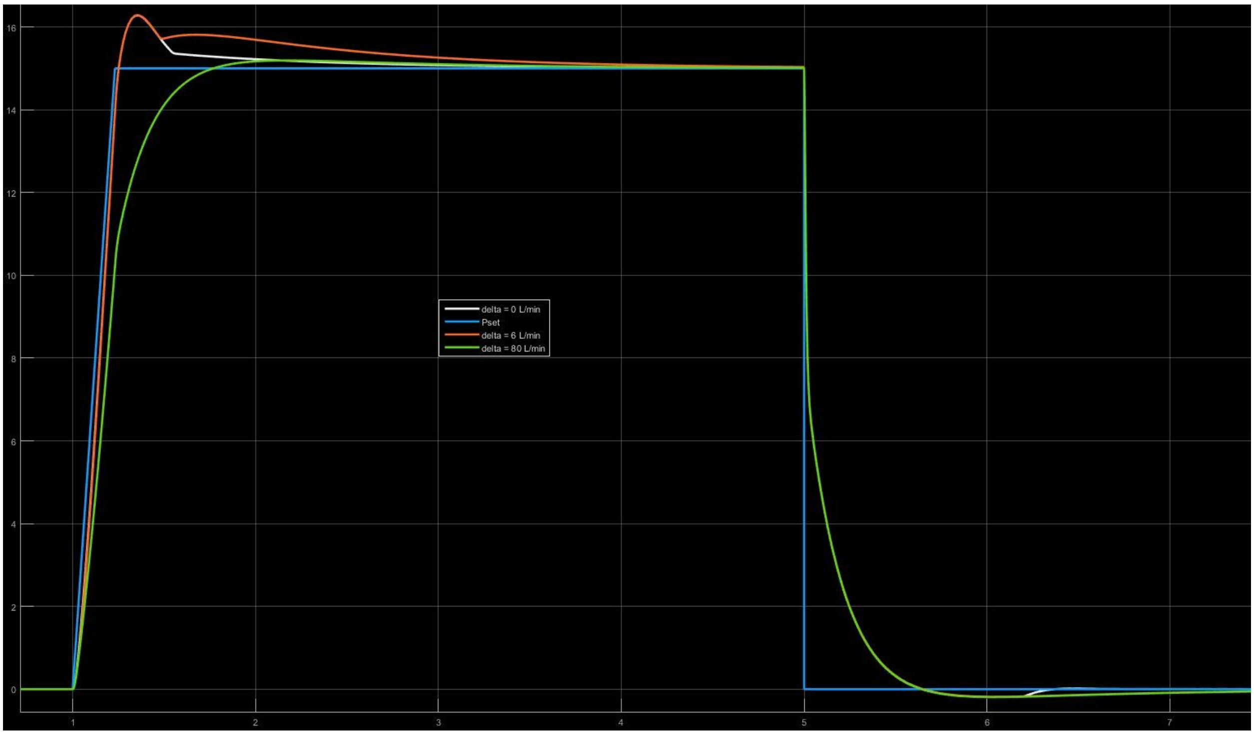
Output at Scope_Paw:



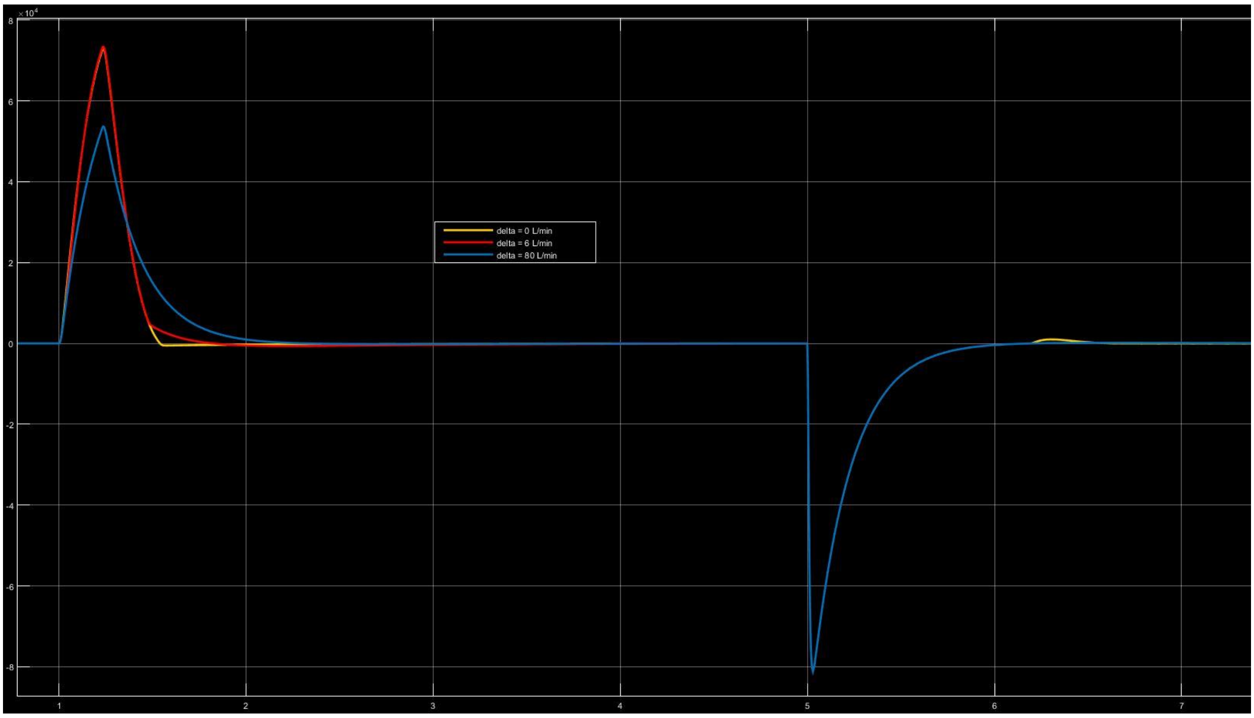
Task 7: Reproduce the results shown in Fig. 14 for linear and variable gain controllers. What are the pros & cons of non linear control over linear control?



Output at Scope_Paw:



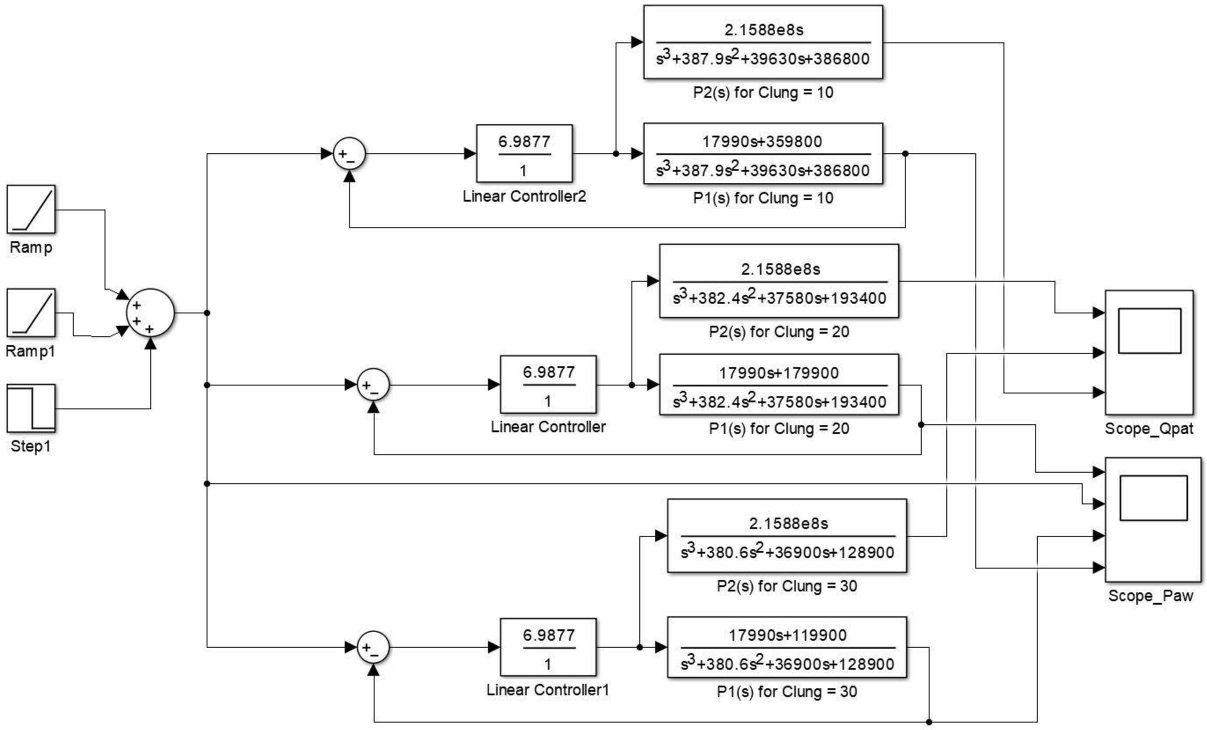
Output at Scope_Qpat:



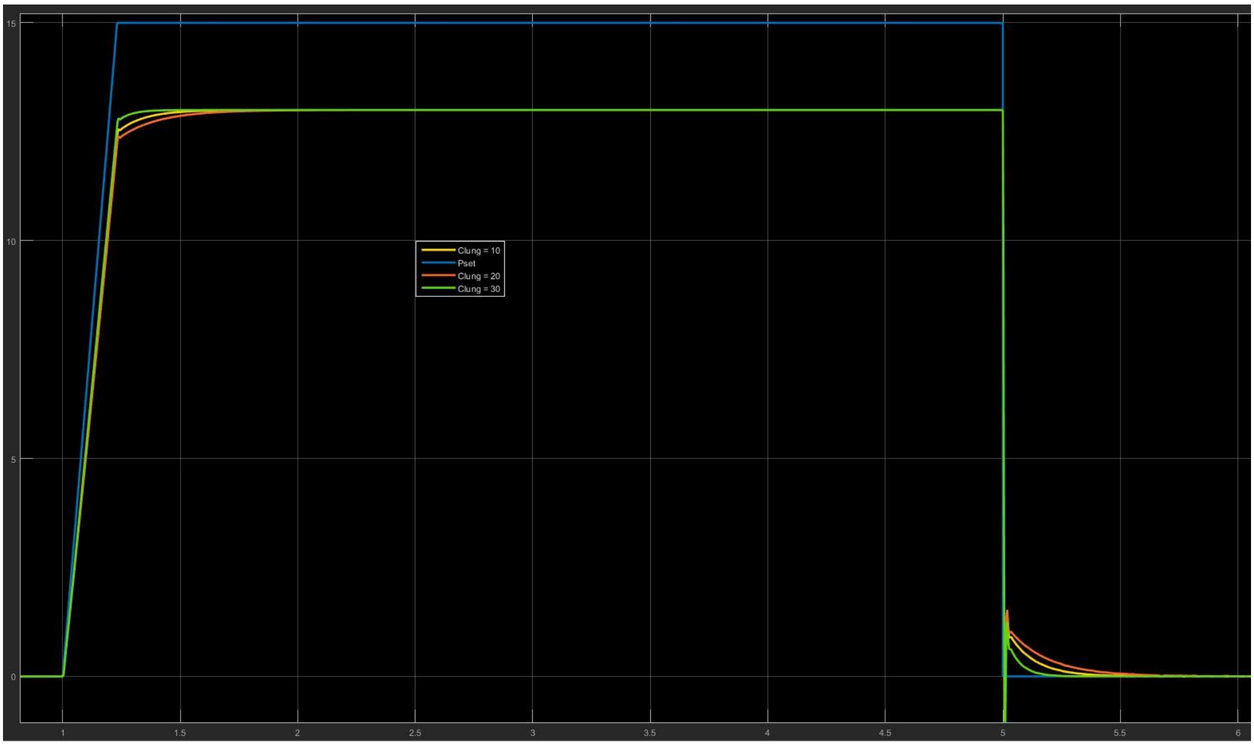
Even if the plant is linear, a nonlinear controller can often have attractive features such as simpler implementation, faster speed, more accuracy, or reduced control energy, which justify the more difficult design procedure.

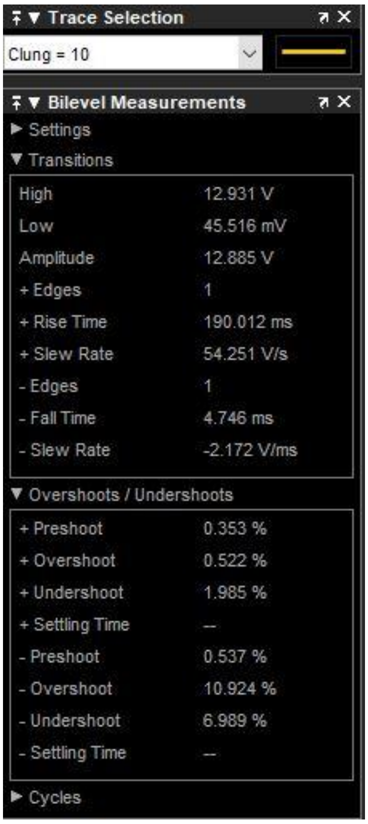
Task 8: Discuss the performance of both linear and non linear control systems in presence of uncertainties such as different lung parameters, pressure drop etc.

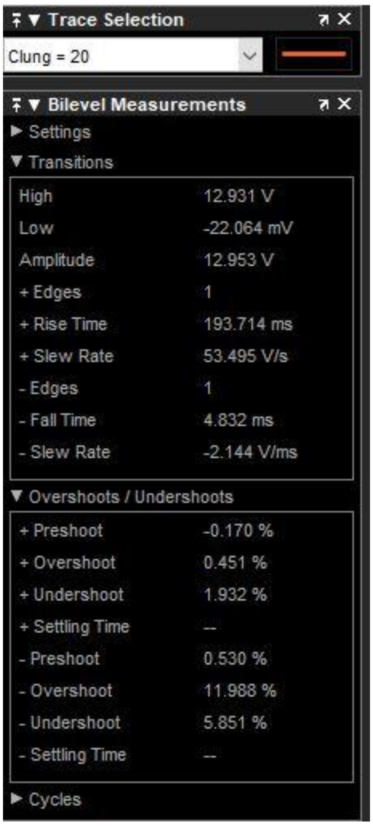
(i) Variation of C_{lung} in Linear Control System :

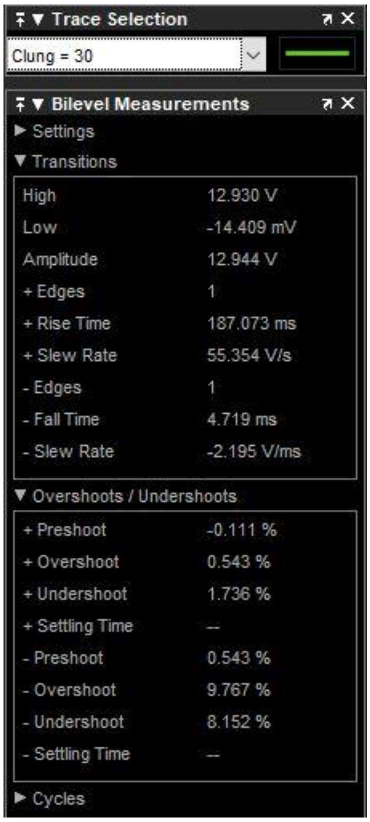


Output at Scope_Paw:

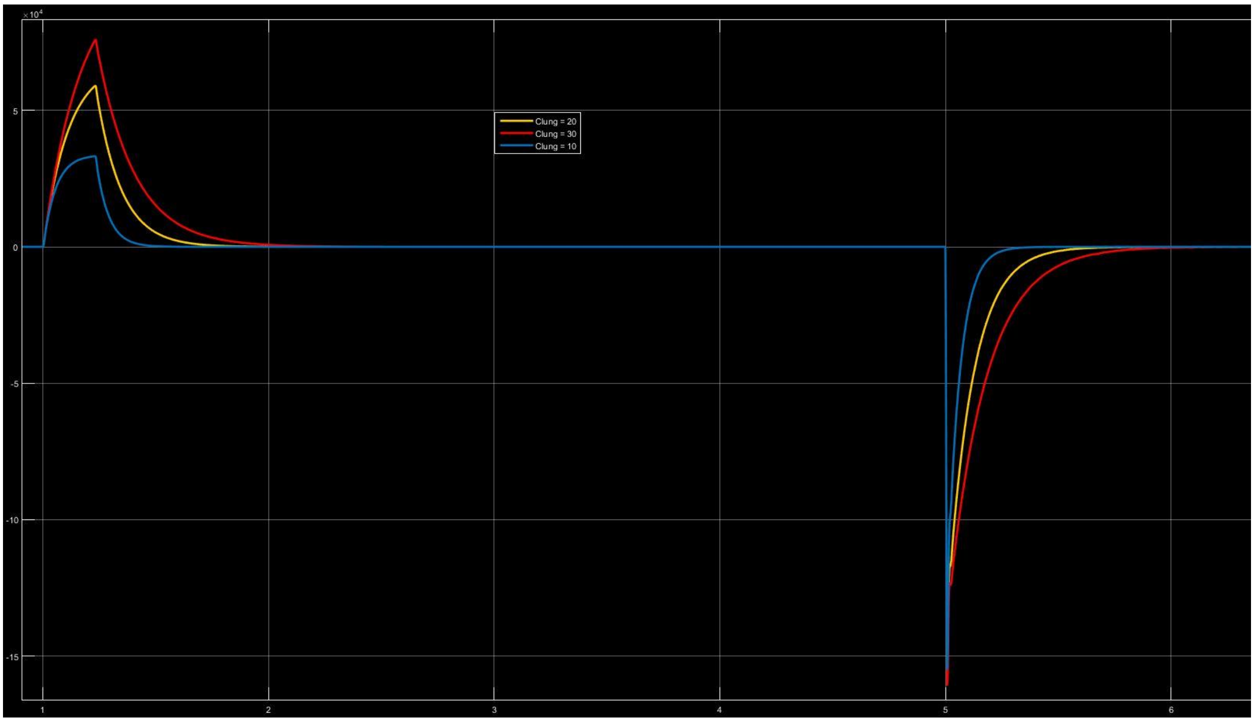


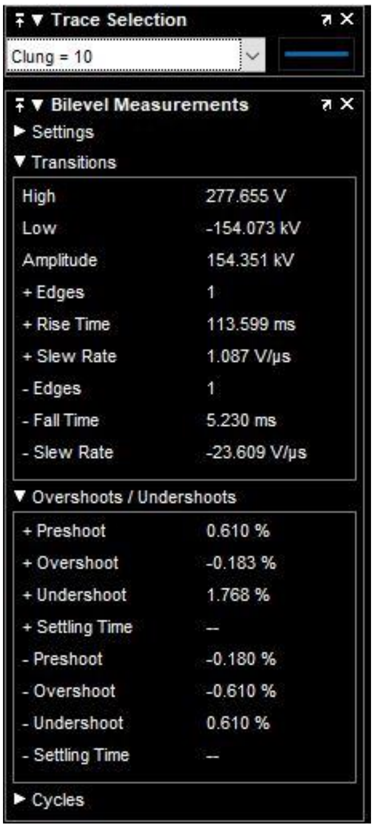


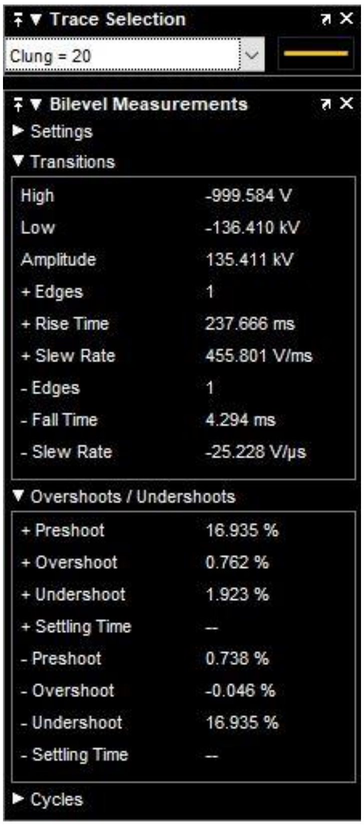


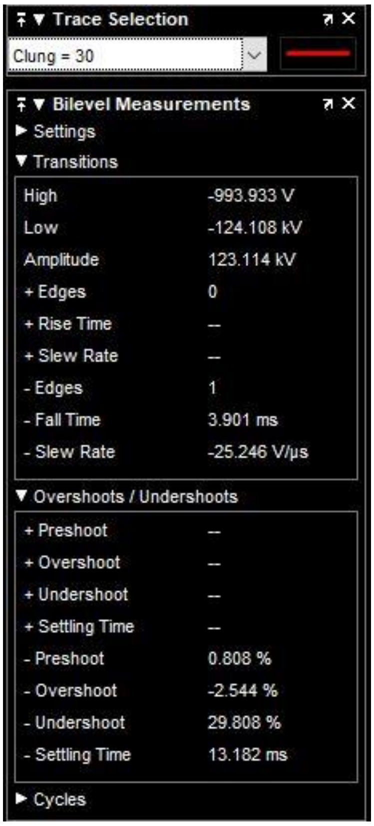


Output at Scope_Qpat:

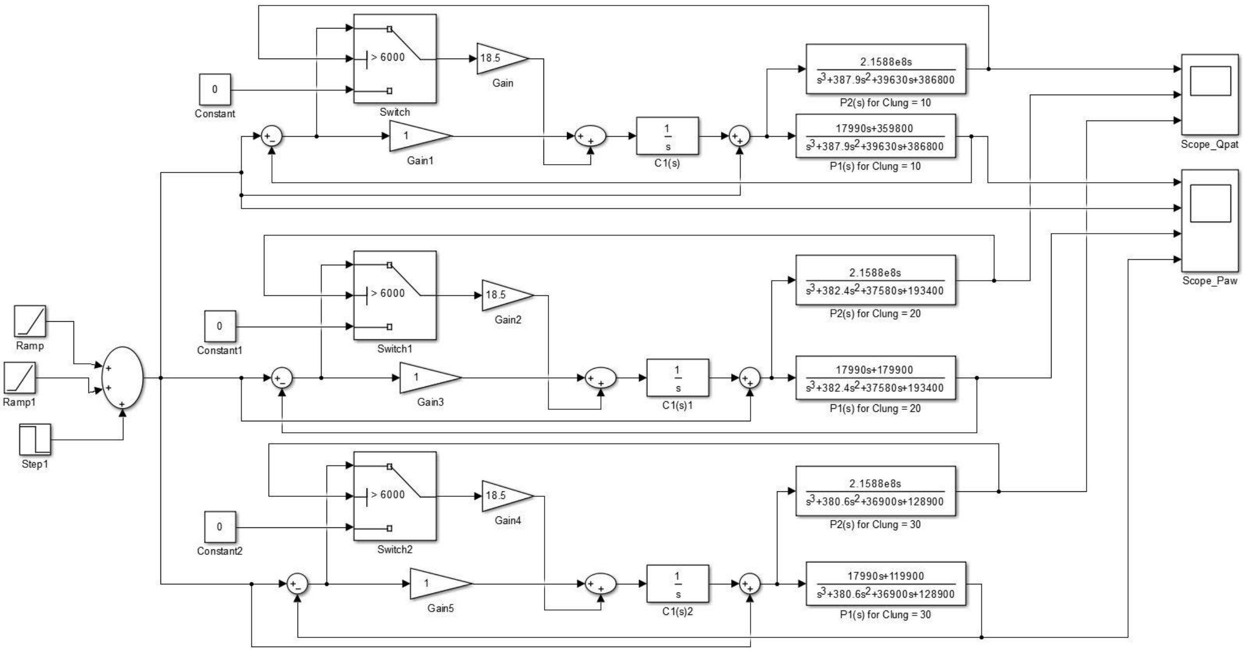




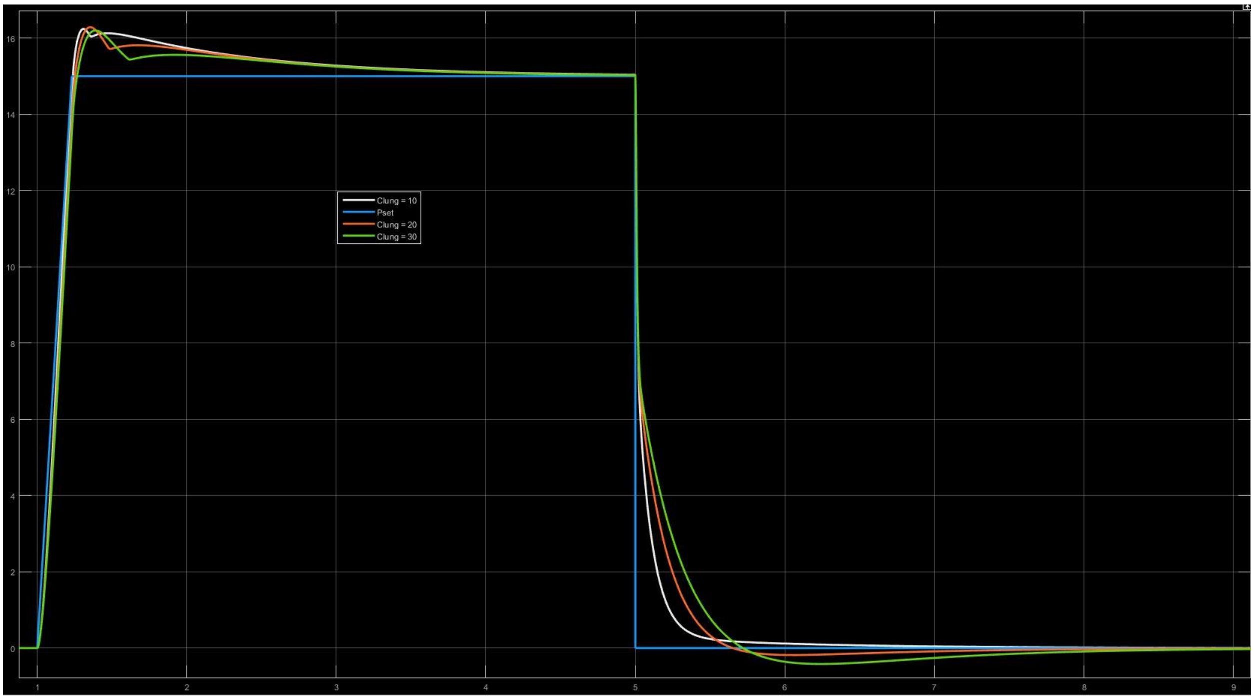


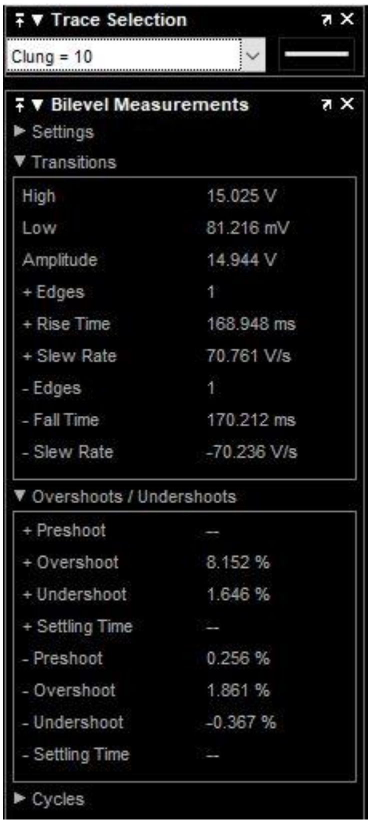


(ii) Variation of C_{lung} in Non-Linear Control System :



Output at Scope_Paw:





Trace Selection: Clung = 10

Bilevel Measurements

▶ Settings

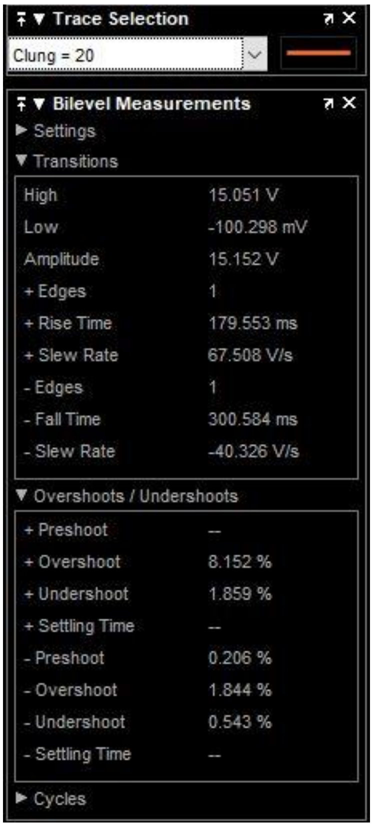
▼ Transitions

High	15.025 V
Low	81.216 mV
Amplitude	14.944 V
+ Edges	1
+ Rise Time	168.948 ms
+ Slew Rate	70.761 V/s
- Edges	1
- Fall Time	170.212 ms
- Slew Rate	-70.236 V/s

▼ Overshoots / Undershoots

+ Preshoot	--
+ Overshoot	8.152 %
+ Undershoot	1.646 %
+ Settling Time	--
- Preshoot	0.256 %
- Overshoot	1.861 %
- Undershoot	-0.367 %
- Settling Time	--

▶ Cycles



Trace Selection: Clung = 20

Bilevel Measurements

▶ Settings

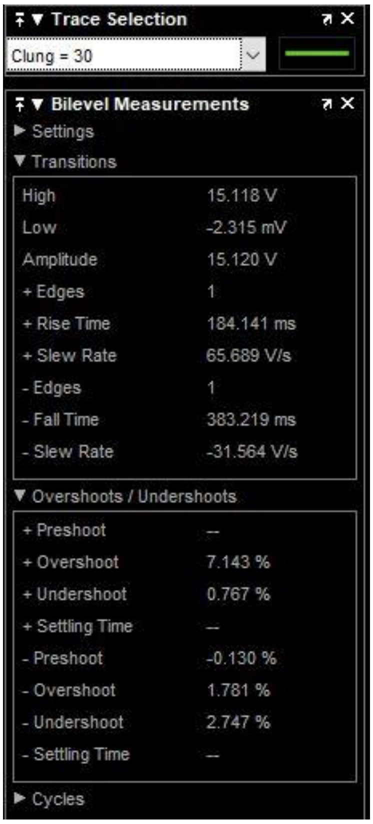
▼ Transitions

High	15.051 V
Low	-100.298 mV
Amplitude	15.152 V
+ Edges	1
+ Rise Time	179.553 ms
+ Slew Rate	67.508 V/s
- Edges	1
- Fall Time	300.584 ms
- Slew Rate	-40.326 V/s

▼ Overshoots / Undershoots

+ Preshoot	--
+ Overshoot	8.152 %
+ Undershoot	1.859 %
+ Settling Time	--
- Preshoot	0.206 %
- Overshoot	1.844 %
- Undershoot	0.543 %
- Settling Time	--

▶ Cycles



Trace Selection: Clung = 30

Bilevel Measurements

▶ Settings

▼ Transitions

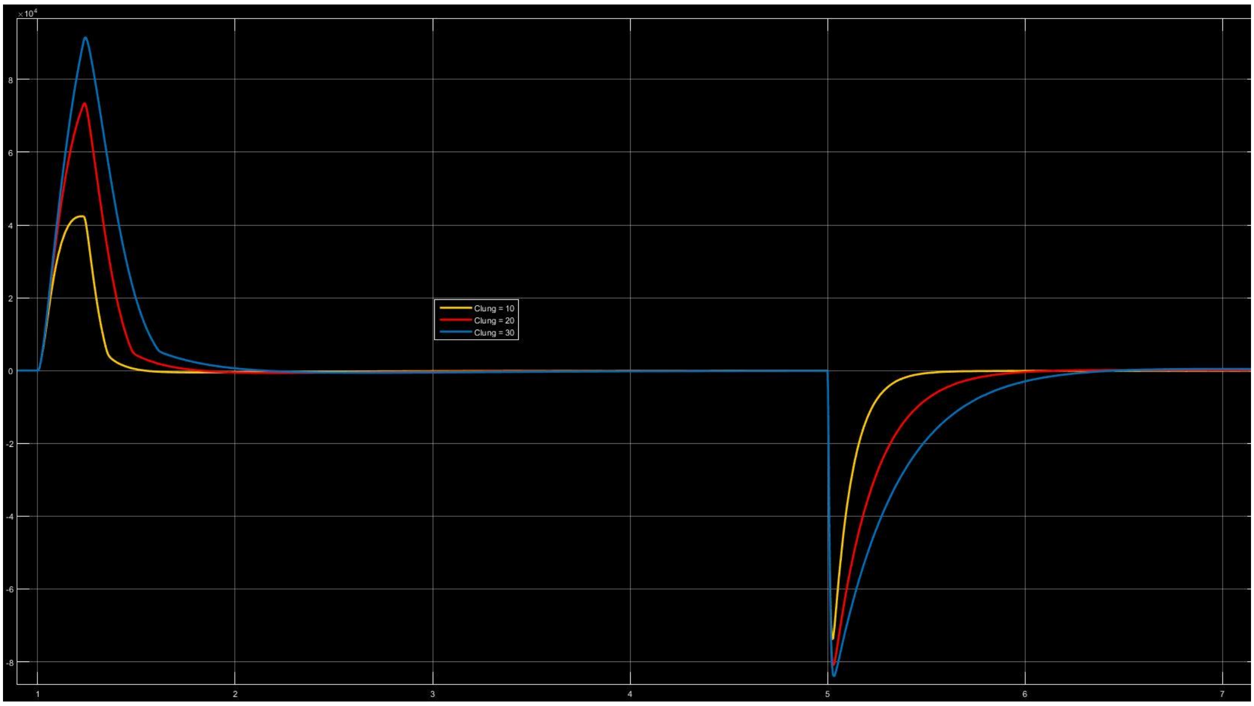
High	15.118 V
Low	-2.315 mV
Amplitude	15.120 V
+ Edges	1
+ Rise Time	184.141 ms
+ Slew Rate	65.689 V/s
- Edges	1
- Fall Time	383.219 ms
- Slew Rate	-31.564 V/s

▼ Overshoots / Undershoots

+ Preshoot	--
+ Overshoot	7.143 %
+ Undershoot	0.767 %
+ Settling Time	--
- Preshoot	-0.130 %
- Overshoot	1.781 %
- Undershoot	2.747 %
- Settling Time	--

▶ Cycles

Output at Scope_Qpat:



Trace Selection

Clung = 10

Bilevel Measurements

▶ Settings

▼ Transitions

High	-31.048 V
Low	-73.254 kV
Amplitude	73.223 kV
+ Edges	1
+ Rise Time	214.426 ms
+ Slew Rate	273.187 V/ms
- Edges	1
- Fall Time	13.115 ms
- Slew Rate	-4.467 V/μs

▼ Overshoots / Undershoots

+ Preshoot	0.794 %
+ Overshoot	-0.066 %
+ Undershoot	1.701 %
+ Settling Time	--
- Preshoot	0.010 %
- Overshoot	-0.351 %
- Undershoot	0.351 %
- Settling Time	--

▶ Cycles

Trace Selection

Clung = 20

Bilevel Measurements

▶ Settings

▼ Transitions

High	64.790 V
Low	-6.115 kV
Amplitude	6.179 kV
+ Edges	1
+ Rise Time	389.241 ms
+ Slew Rate	12.701 V/ms
- Edges	1
- Fall Time	1.893 ms
- Slew Rate	-2.611 V/μs

▼ Overshoots / Undershoots

+ Preshoot	1212.500 %
+ Overshoot	1.258 %
+ Undershoot	1.996 %
+ Settling Time	--
- Preshoot	-1.778 %
- Overshoot	-176.720 %
- Undershoot	447.961 %
- Settling Time	--

▶ Cycles

Trace Selection

Clung = 30

Bilevel Measurements

▶ Settings

▼ Transitions

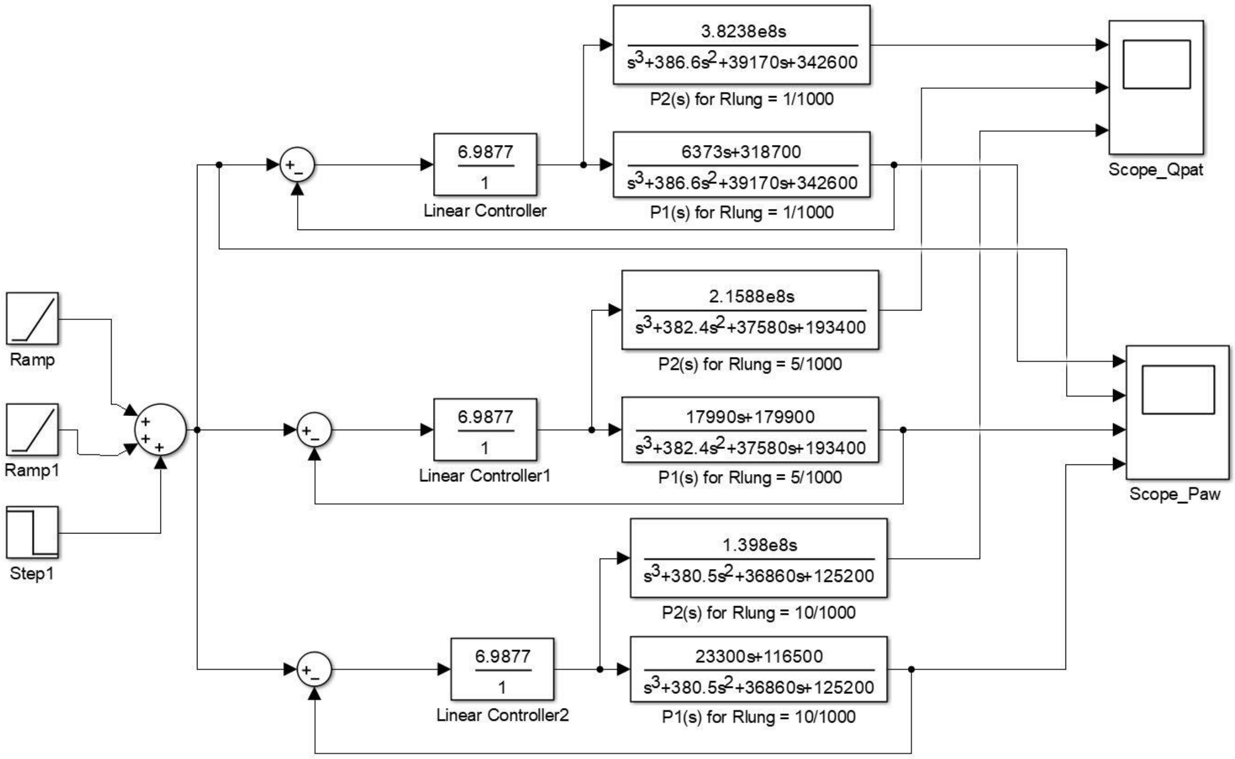
High	6.377 kV
Low	-647.080 V
Amplitude	7.024 kV
+ Edges	0
+ Rise Time	--
+ Slew Rate	--
- Edges	1
- Fall Time	513.707 ms
- Slew Rate	-10.939 V/ms

▼ Overshoots / Undershoots

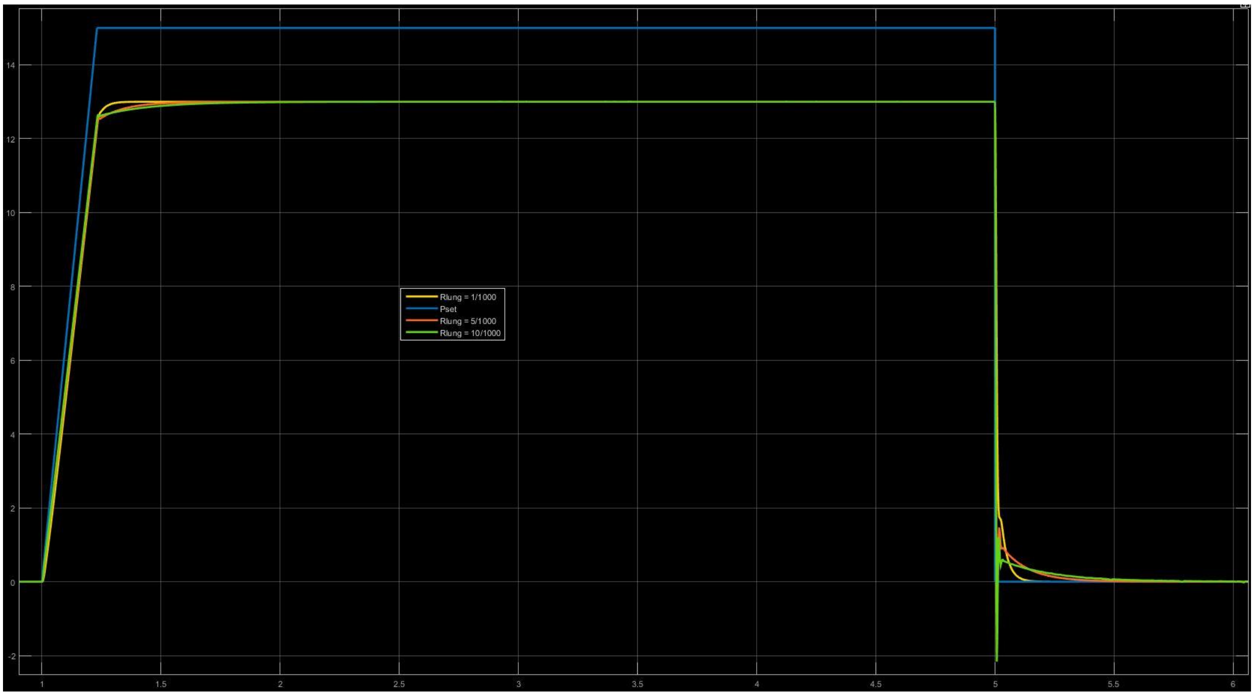
+ Preshoot	--
+ Overshoot	--
+ Undershoot	--
+ Settling Time	--
- Preshoot	1212.500 %
- Overshoot	6.132 %
- Undershoot	-0.704 %
- Settling Time	--

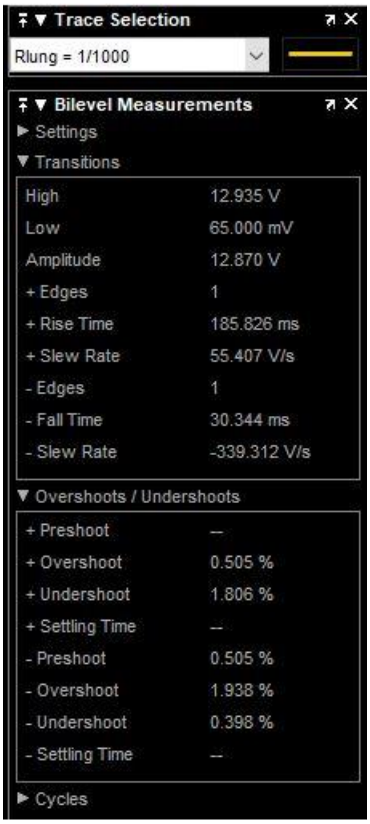
▶ Cycles

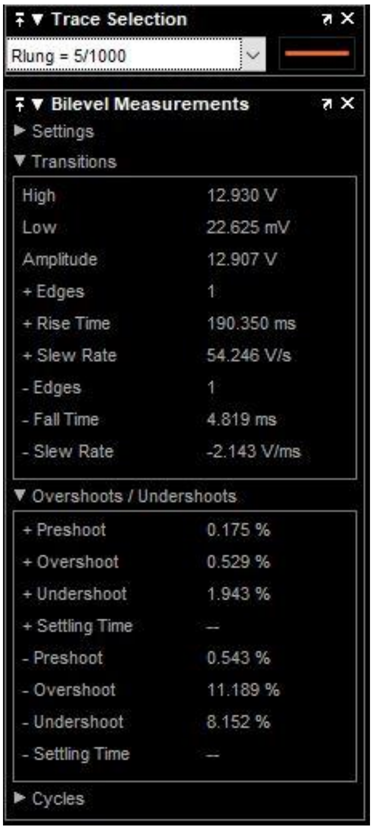
(iii) Variation of R_{lung} in Linear Control System:

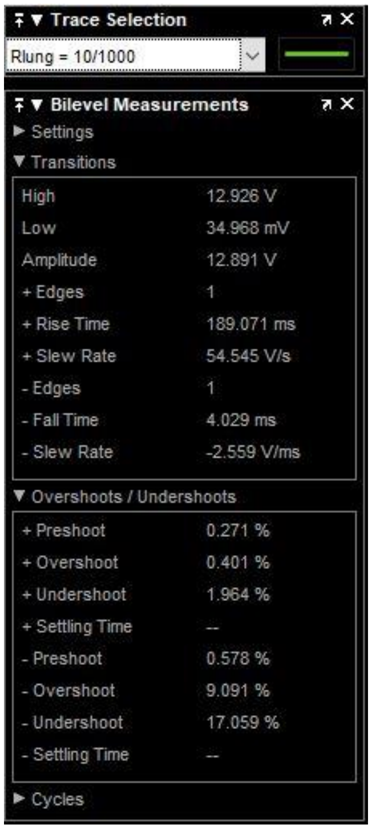


Output at Scope_Paw:

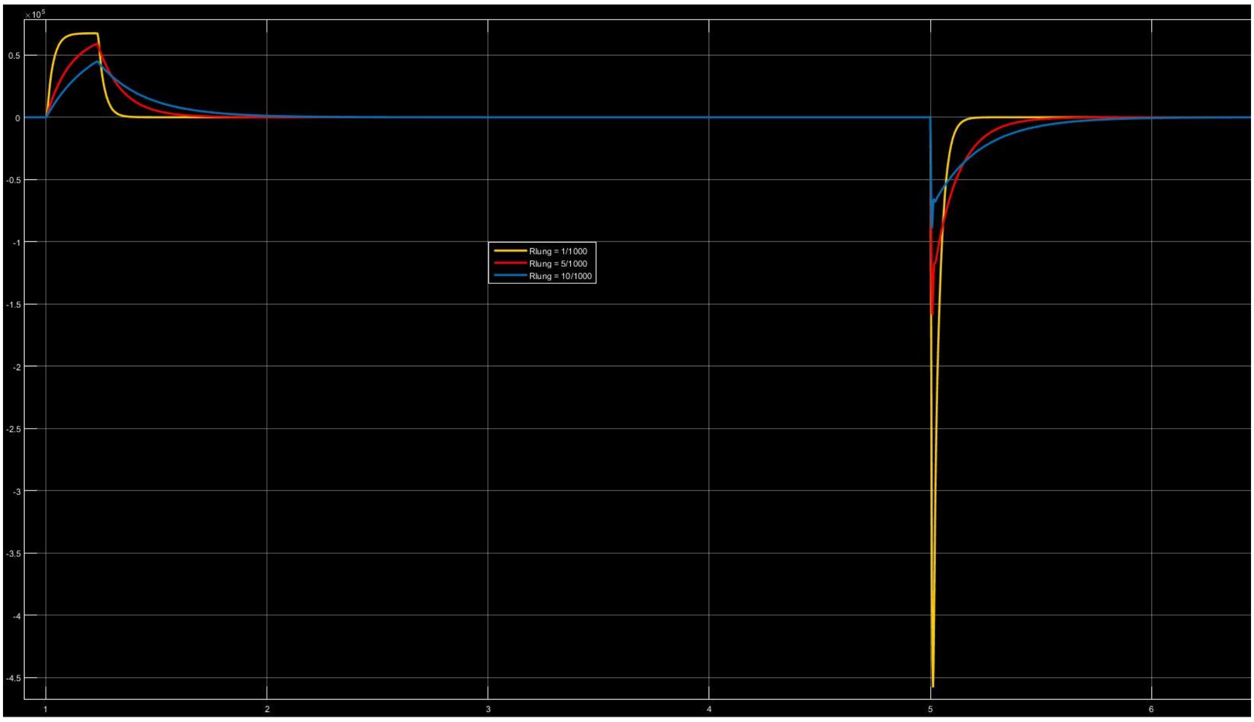


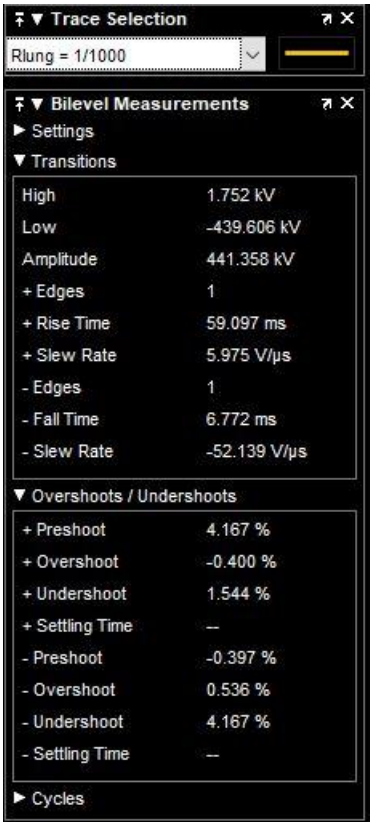






Output at Scope_Qpat:



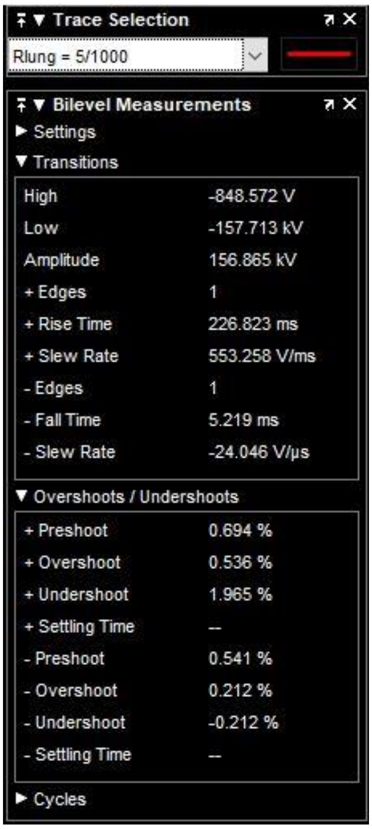


Trace Selection: Rlung = 1/1000

Bilevel Measurements

Transitions	
High	1.752 kV
Low	-439.606 kV
Amplitude	441.358 kV
+ Edges	1
+ Rise Time	59.097 ms
+ Slew Rate	5.975 V/µs
- Edges	1
- Fall Time	6.772 ms
- Slew Rate	-52.139 V/µs

Overshoots / Undershoots	
+ Preshoot	4.167 %
+ Overshoot	-0.400 %
+ Undershoot	1.544 %
+ Settling Time	--
- Preshoot	-0.397 %
- Overshoot	0.536 %
- Undershoot	4.167 %
- Settling Time	--

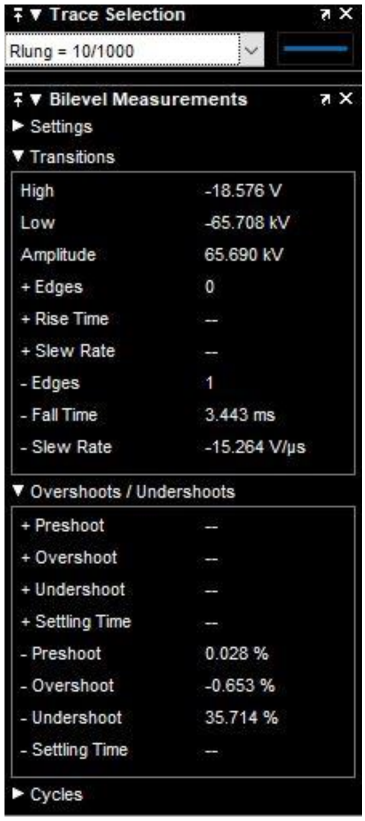


Trace Selection: Rlung = 5/1000

Bilevel Measurements

Transitions	
High	-848.572 V
Low	-157.713 kV
Amplitude	156.865 kV
+ Edges	1
+ Rise Time	226.823 ms
+ Slew Rate	553.258 V/ms
- Edges	1
- Fall Time	5.219 ms
- Slew Rate	-24.046 V/µs

Overshoots / Undershoots	
+ Preshoot	0.694 %
+ Overshoot	0.536 %
+ Undershoot	1.965 %
+ Settling Time	--
- Preshoot	0.541 %
- Overshoot	0.212 %
- Undershoot	-0.212 %
- Settling Time	--



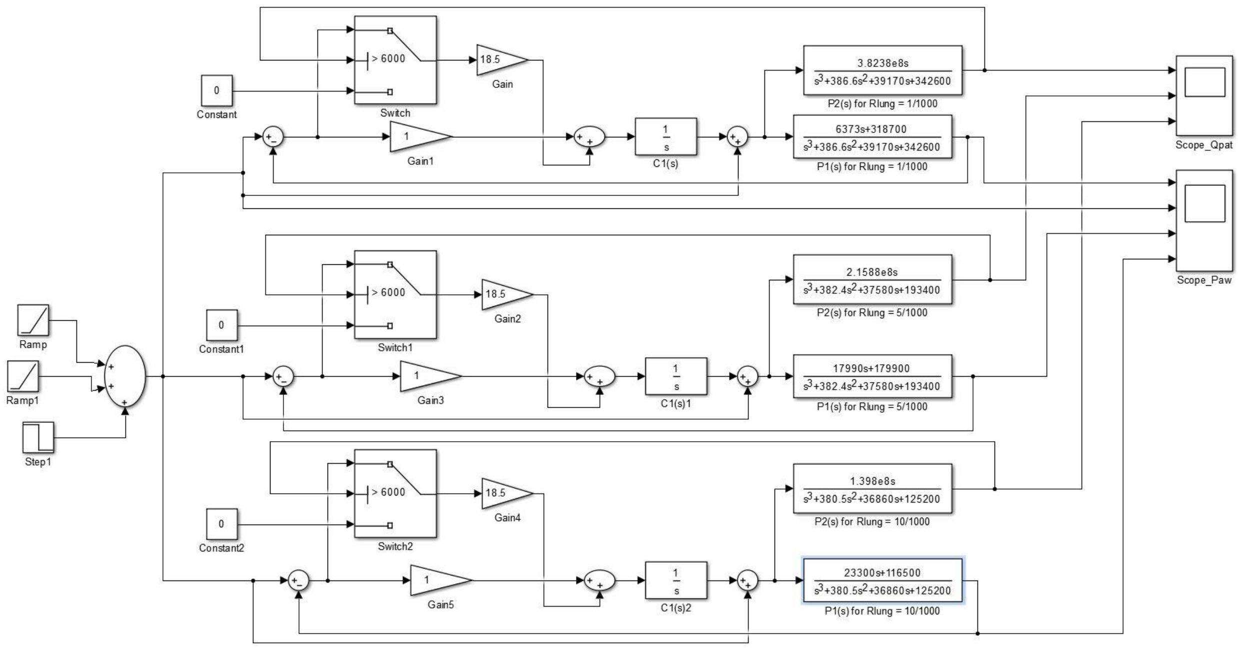
Trace Selection: Rlung = 10/1000

Bilevel Measurements

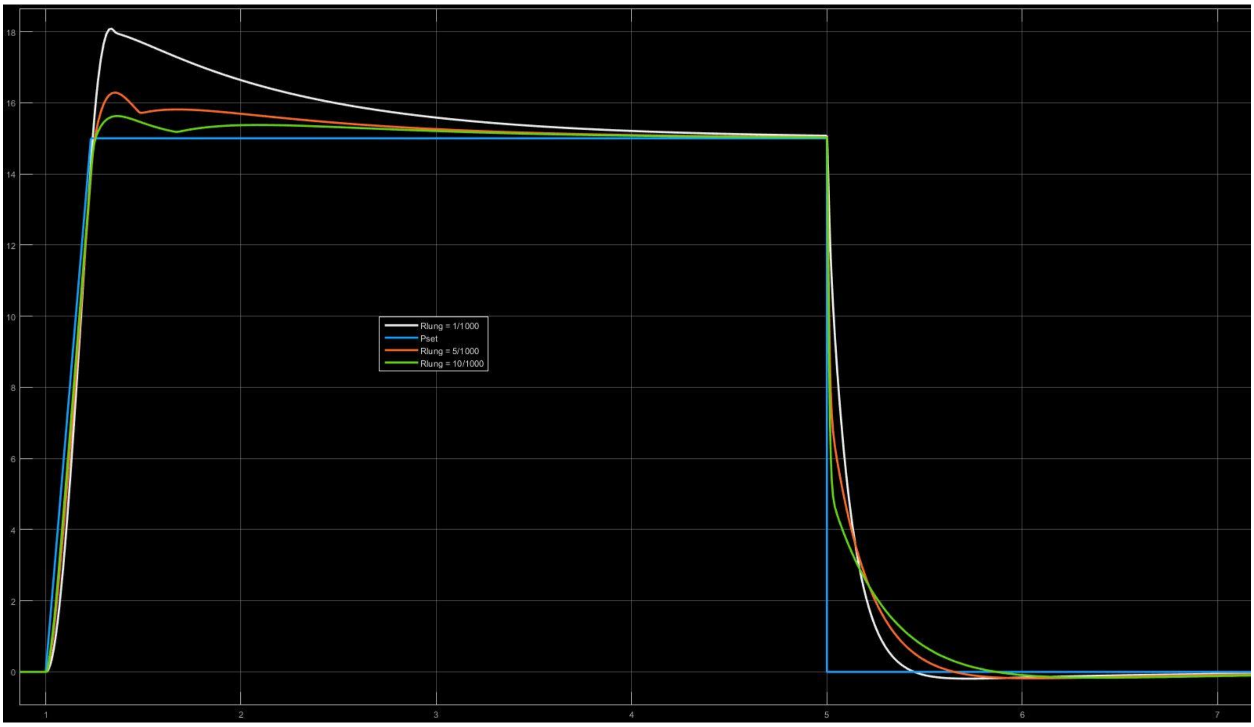
Transitions	
High	-18.576 V
Low	-65.708 kV
Amplitude	65.690 kV
+ Edges	0
+ Rise Time	--
+ Slew Rate	--
- Edges	1
- Fall Time	3.443 ms
- Slew Rate	-15.264 V/µs

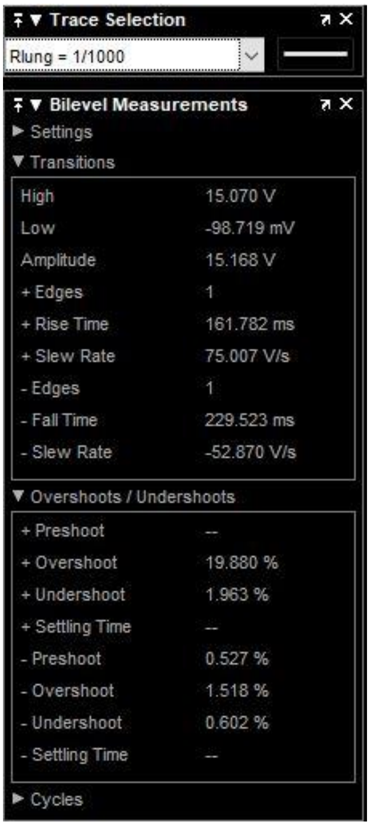
Overshoots / Undershoots	
+ Preshoot	--
+ Overshoot	--
+ Undershoot	--
+ Settling Time	--
- Preshoot	0.028 %
- Overshoot	-0.653 %
- Undershoot	35.714 %
- Settling Time	--

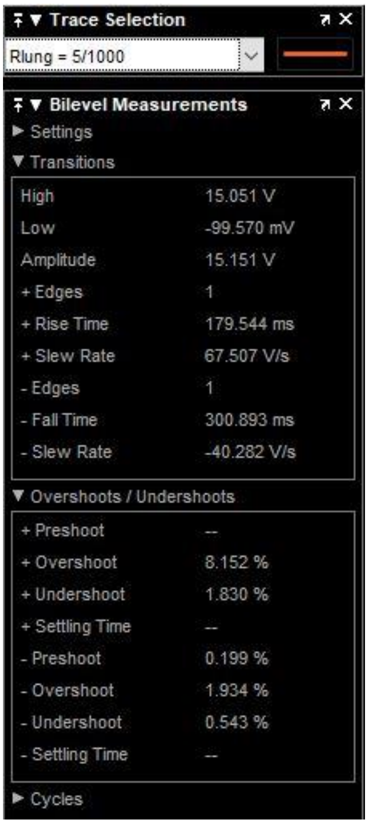
(iv) Variation of R_{lung} in Non-Linear Control System :

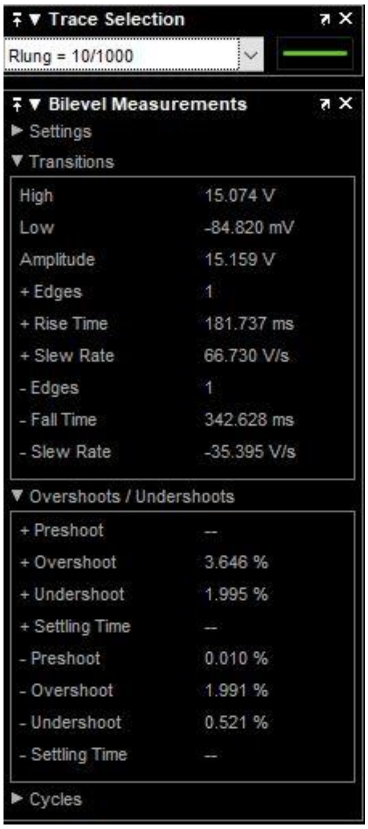


Output at Scope_Paw:

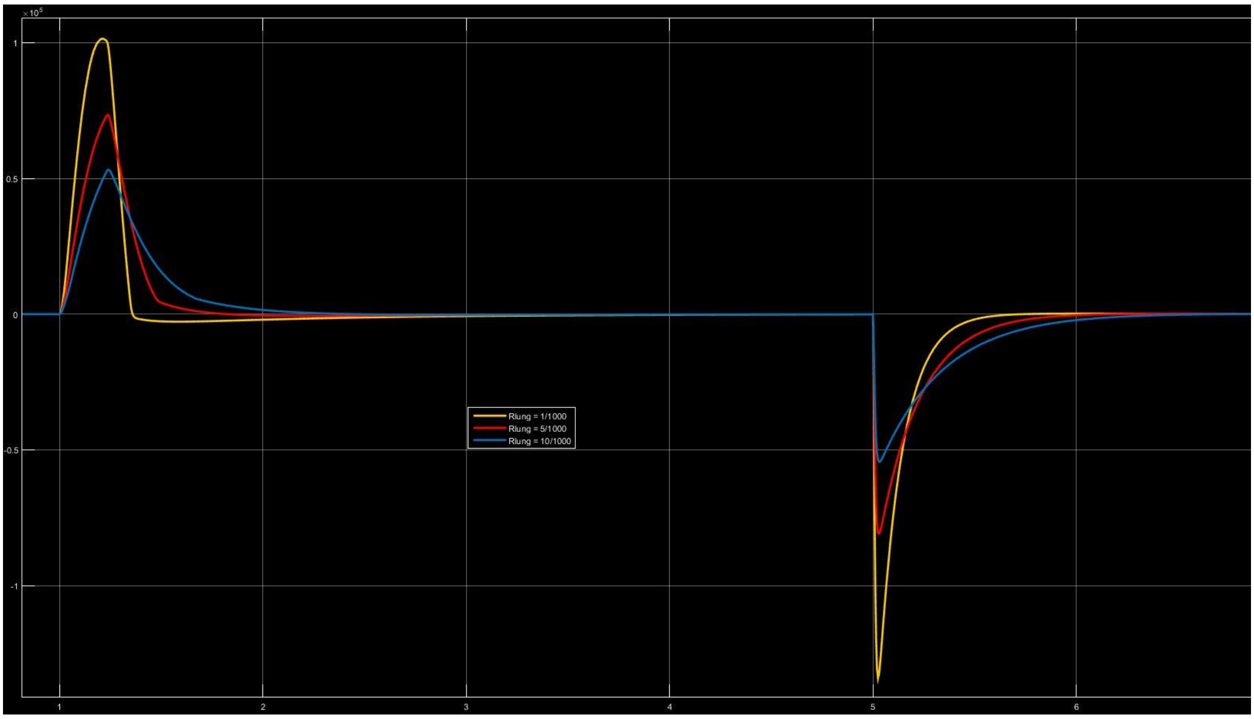


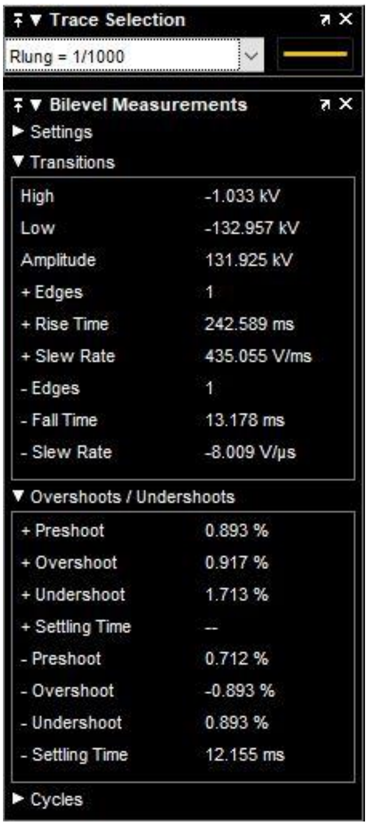


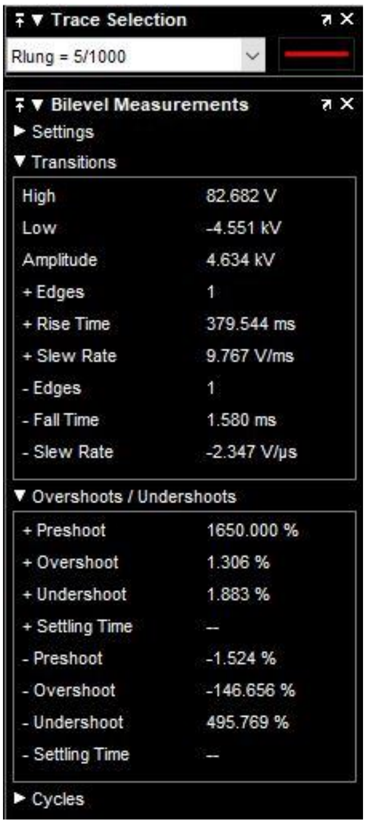


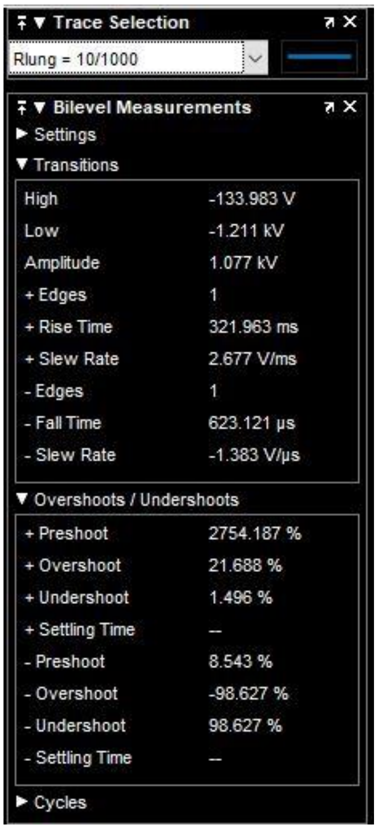


Output at Scope_Qpat:

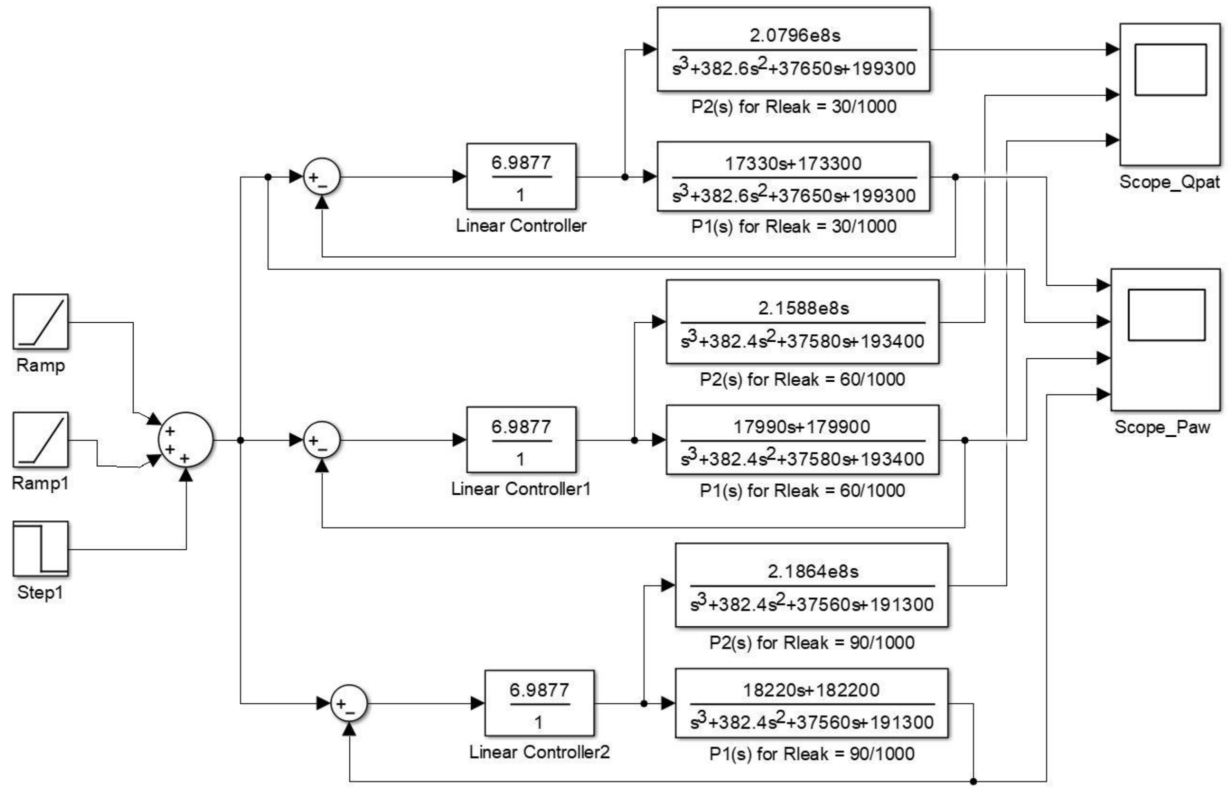




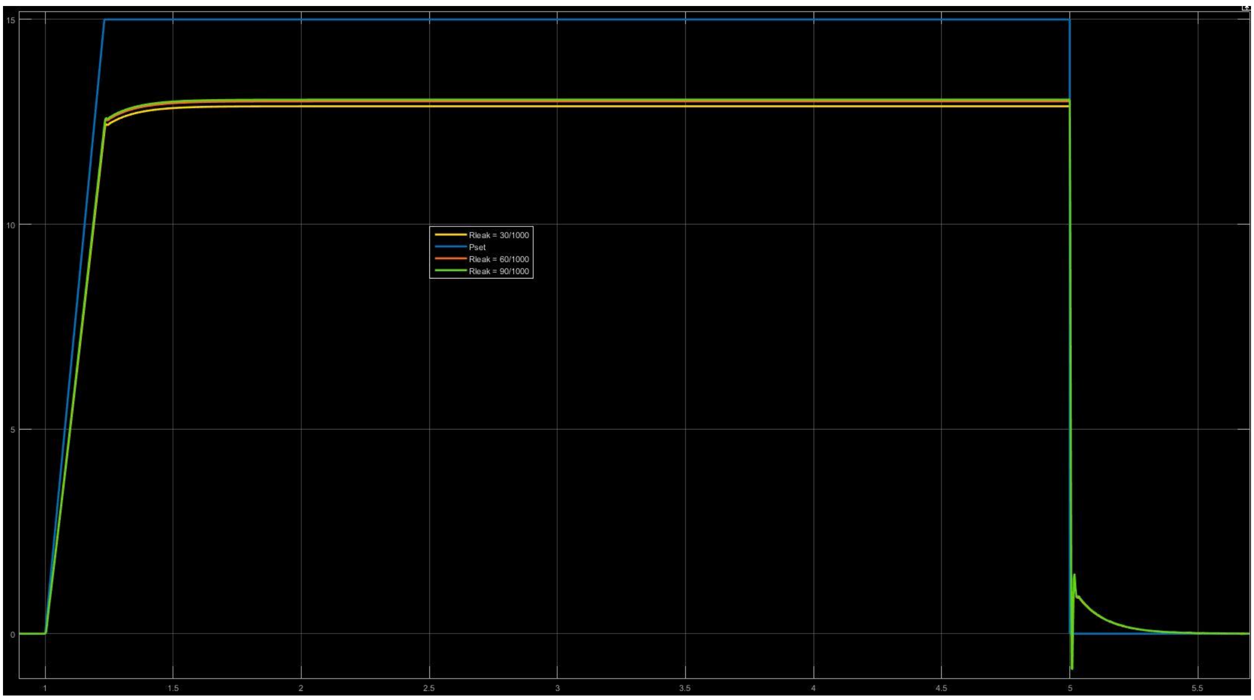


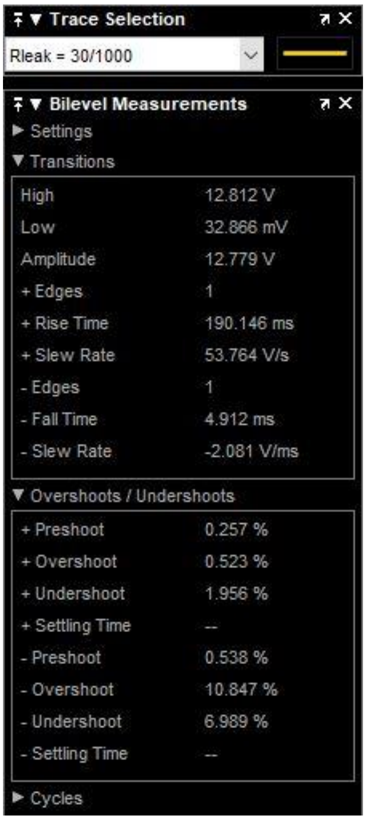


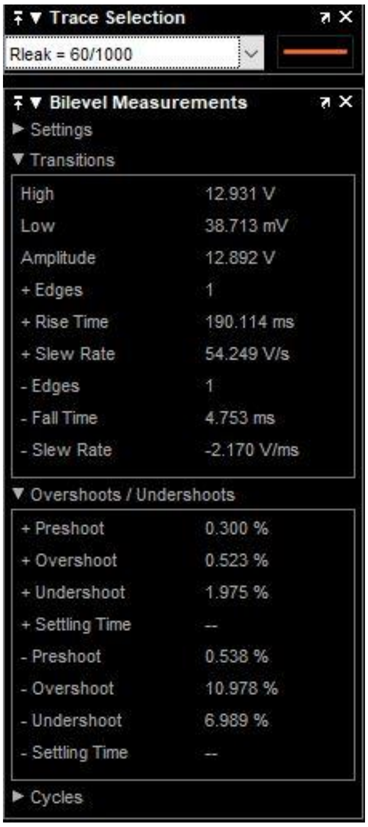
(v) Variation of R_{leak} in Linear Control System :

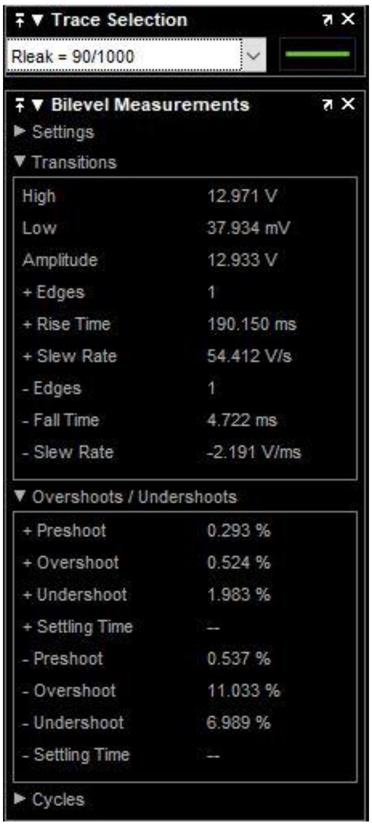


Output at Scope_Paw:

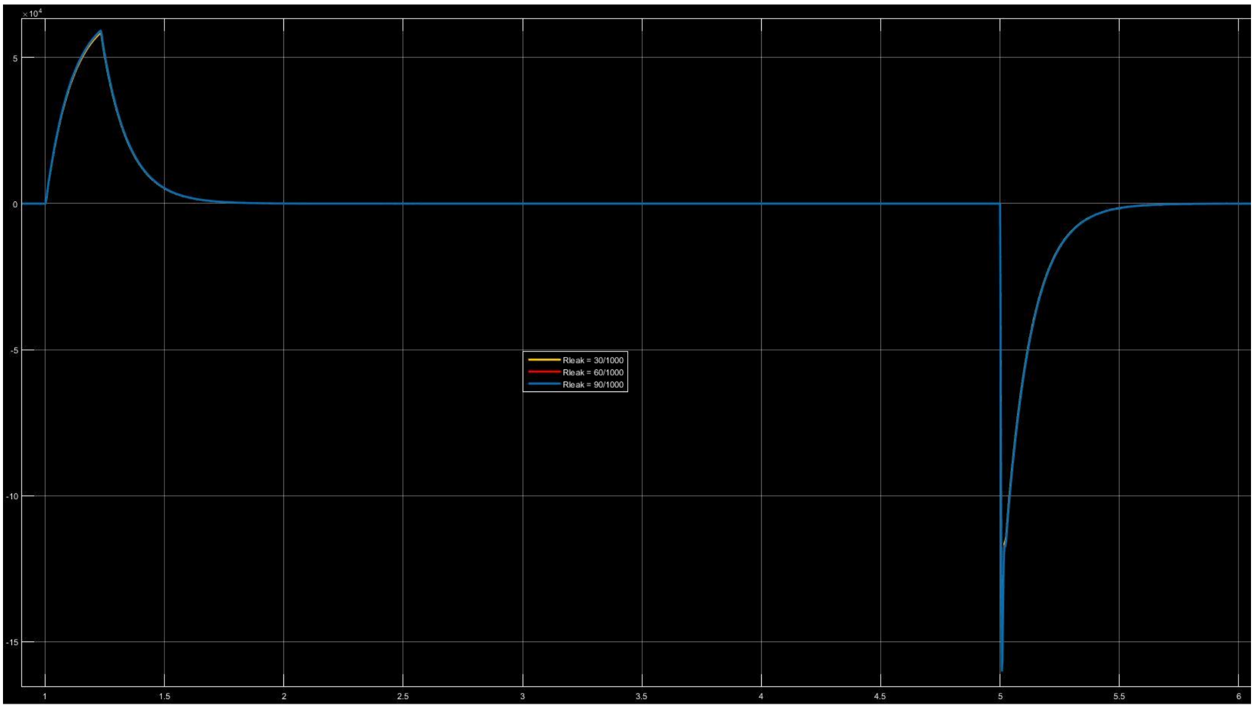


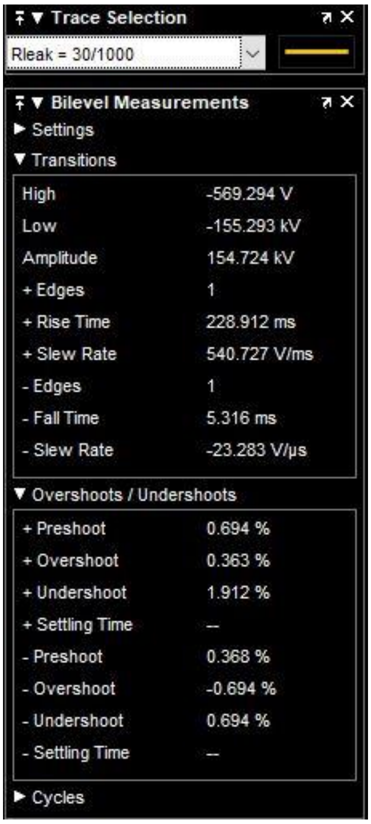






Output at Scope_Qpat:





Trace Selection

Rleak = 30/1000

Bilevel Measurements

▶ Settings

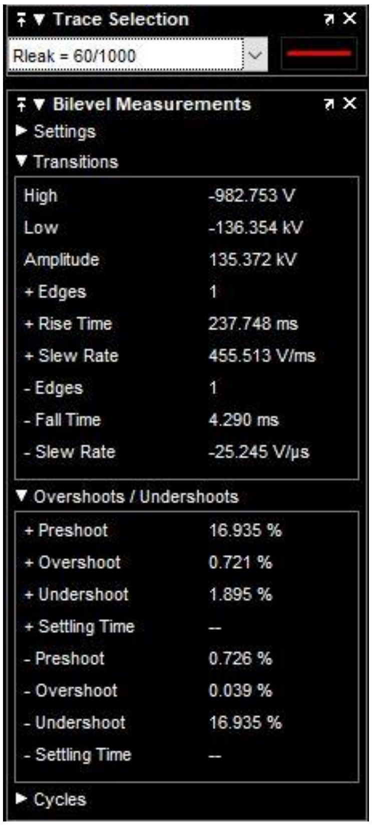
▼ Transitions

High	-569.294 V
Low	-155.293 kV
Amplitude	154.724 kV
+ Edges	1
+ Rise Time	228.912 ms
+ Slew Rate	540.727 V/ms
- Edges	1
- Fall Time	5.316 ms
- Slew Rate	-23.283 V/μs

▼ Overshoots / Undershoots

+ Preshoot	0.694 %
+ Overshoot	0.363 %
+ Undershoot	1.912 %
+ Settling Time	--
- Preshoot	0.368 %
- Overshoot	-0.694 %
- Undershoot	0.694 %
- Settling Time	--

▶ Cycles



Trace Selection

Rleak = 60/1000

Bilevel Measurements

▶ Settings

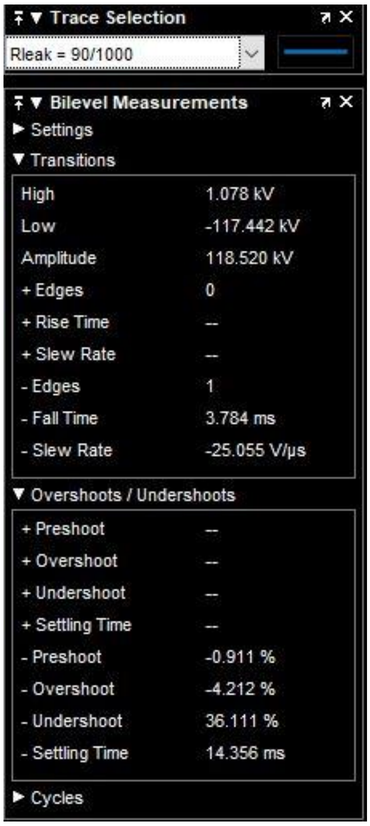
▼ Transitions

High	-982.753 V
Low	-136.354 kV
Amplitude	135.372 kV
+ Edges	1
+ Rise Time	237.748 ms
+ Slew Rate	455.513 V/ms
- Edges	1
- Fall Time	4.290 ms
- Slew Rate	-25.245 V/μs

▼ Overshoots / Undershoots

+ Preshoot	16.935 %
+ Overshoot	0.721 %
+ Undershoot	1.895 %
+ Settling Time	--
- Preshoot	0.726 %
- Overshoot	0.039 %
- Undershoot	16.935 %
- Settling Time	--

▶ Cycles



Trace Selection

Rleak = 90/1000

Bilevel Measurements

▶ Settings

▼ Transitions

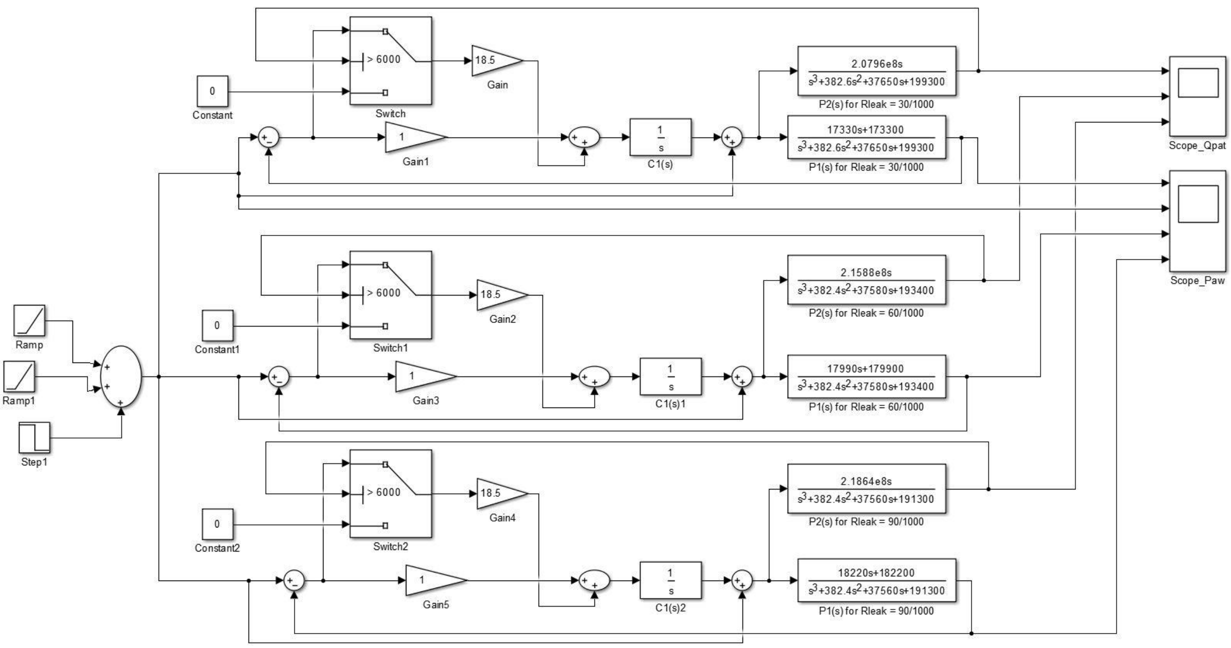
High	1.078 kV
Low	-117.442 kV
Amplitude	118.520 kV
+ Edges	0
+ Rise Time	--
+ Slew Rate	--
- Edges	1
- Fall Time	3.784 ms
- Slew Rate	-25.055 V/μs

▼ Overshoots / Undershoots

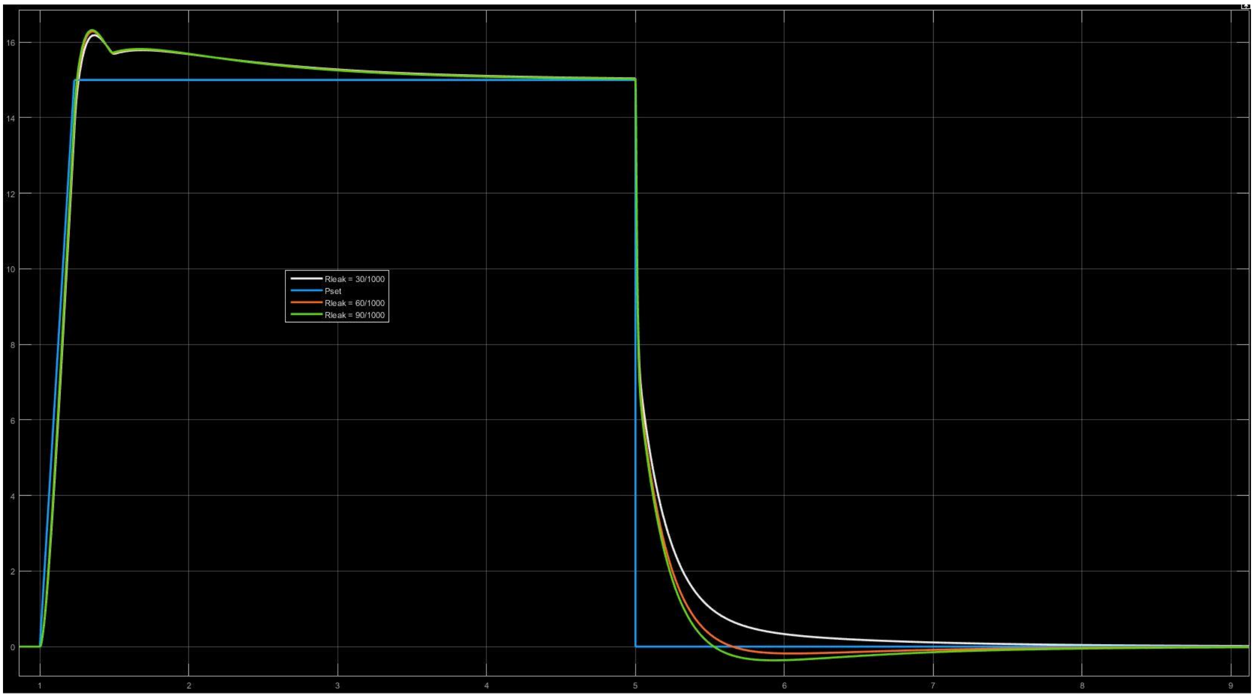
+ Preshoot	--
+ Overshoot	--
+ Undershoot	--
+ Settling Time	--
- Preshoot	-0.911 %
- Overshoot	-4.212 %
- Undershoot	36.111 %
- Settling Time	14.356 ms

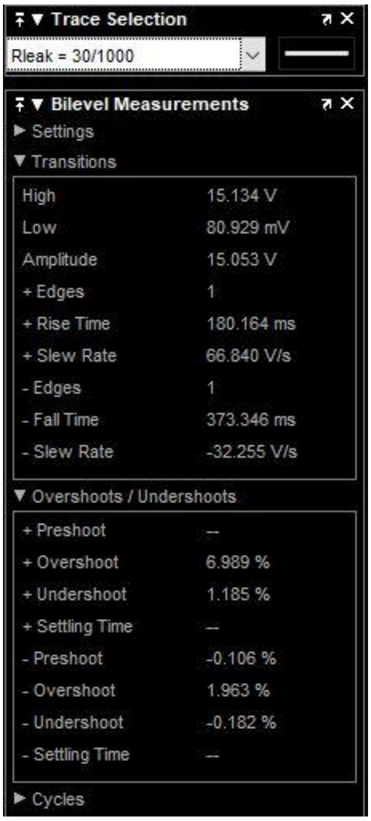
▶ Cycles

(vi) Variation of R_{leak} in Non-Linear Control System :



Output at Scope_Paw:





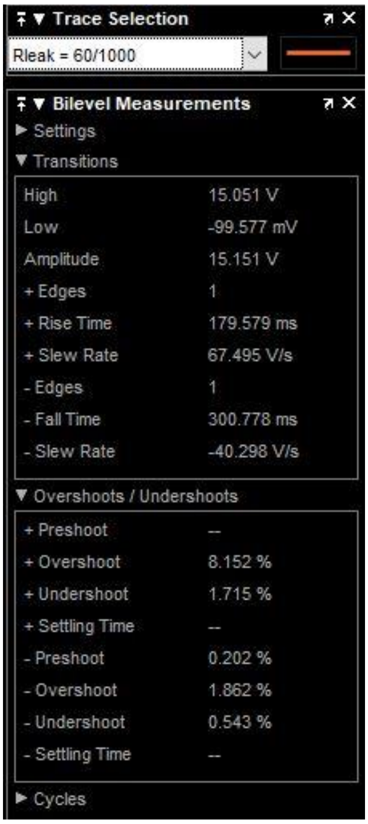
Trace Selection: Rleak = 30/1000

Bilevel Measurements

Transitions	
High	15.134 V
Low	80.929 mV
Amplitude	15.053 V
+ Edges	1
+ Rise Time	180.164 ms
+ Slew Rate	66.840 V/s
- Edges	1
- Fall Time	373.346 ms
- Slew Rate	-32.255 V/s

Overshoots / Undershoots	
+ Preshoot	--
+ Overshoot	6.989 %
+ Undershoot	1.185 %
+ Settling Time	--
- Preshoot	-0.106 %
- Overshoot	1.963 %
- Undershoot	-0.182 %
- Settling Time	--

▶ Settings
▶ Cycles



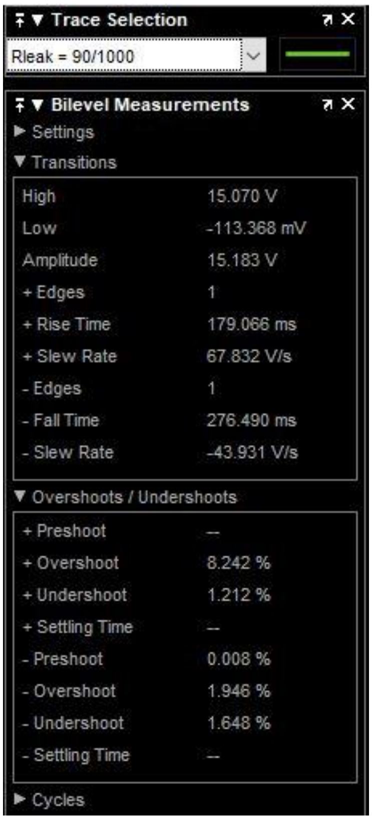
Trace Selection: Rleak = 60/1000

Bilevel Measurements

Transitions	
High	15.051 V
Low	-99.577 mV
Amplitude	15.151 V
+ Edges	1
+ Rise Time	179.579 ms
+ Slew Rate	67.495 V/s
- Edges	1
- Fall Time	300.778 ms
- Slew Rate	-40.298 V/s

Overshoots / Undershoots	
+ Preshoot	--
+ Overshoot	8.152 %
+ Undershoot	1.715 %
+ Settling Time	--
- Preshoot	0.202 %
- Overshoot	1.862 %
- Undershoot	0.543 %
- Settling Time	--

▶ Settings
▶ Cycles



Trace Selection: Rleak = 90/1000

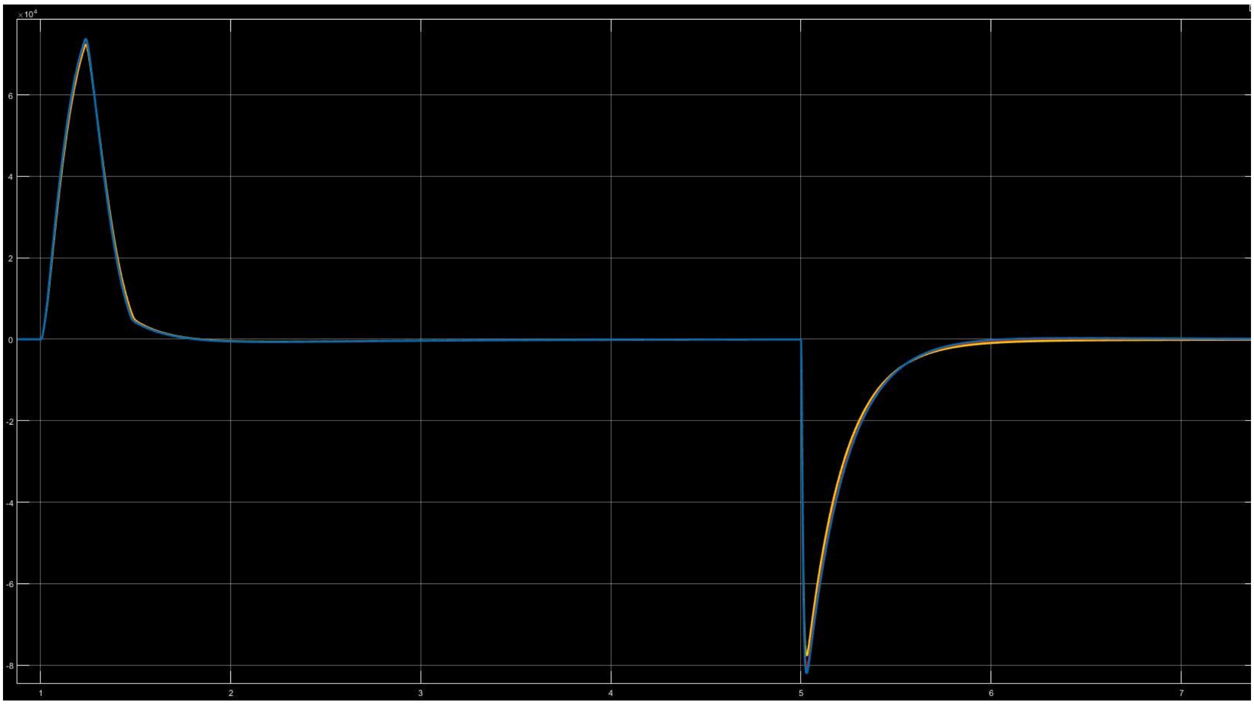
Bilevel Measurements

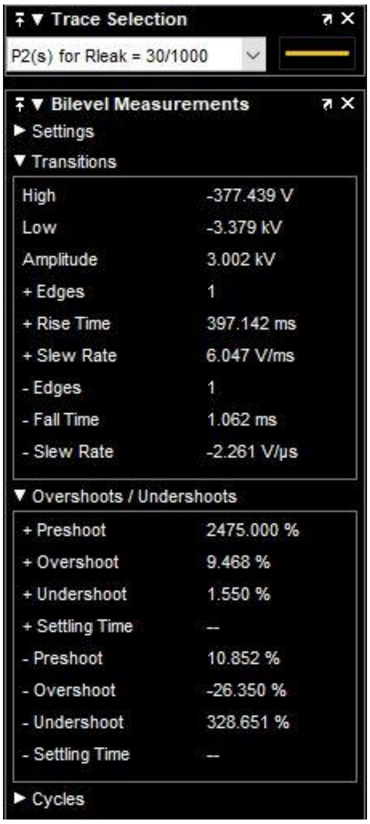
Transitions	
High	15.070 V
Low	-113.368 mV
Amplitude	15.183 V
+ Edges	1
+ Rise Time	179.066 ms
+ Slew Rate	67.832 V/s
- Edges	1
- Fall Time	276.490 ms
- Slew Rate	-43.931 V/s

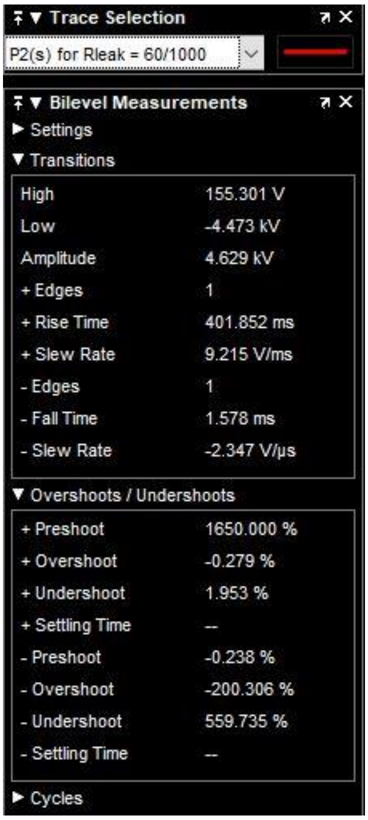
Overshoots / Undershoots	
+ Preshoot	--
+ Overshoot	8.242 %
+ Undershoot	1.212 %
+ Settling Time	--
- Preshoot	0.008 %
- Overshoot	1.946 %
- Undershoot	1.648 %
- Settling Time	--

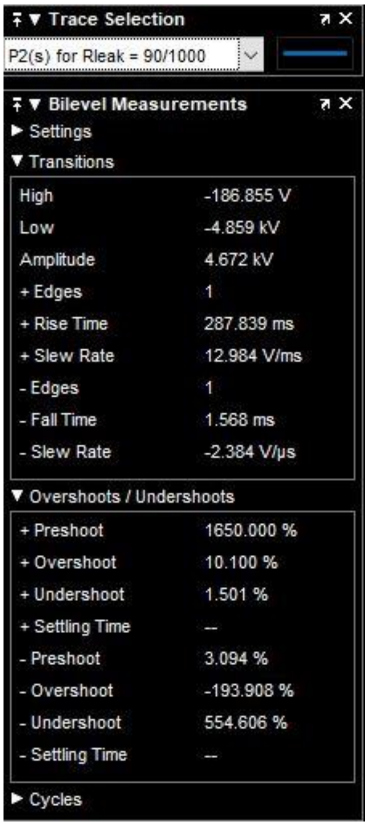
▶ Settings
▶ Cycles

Output at Scope_Qpat:

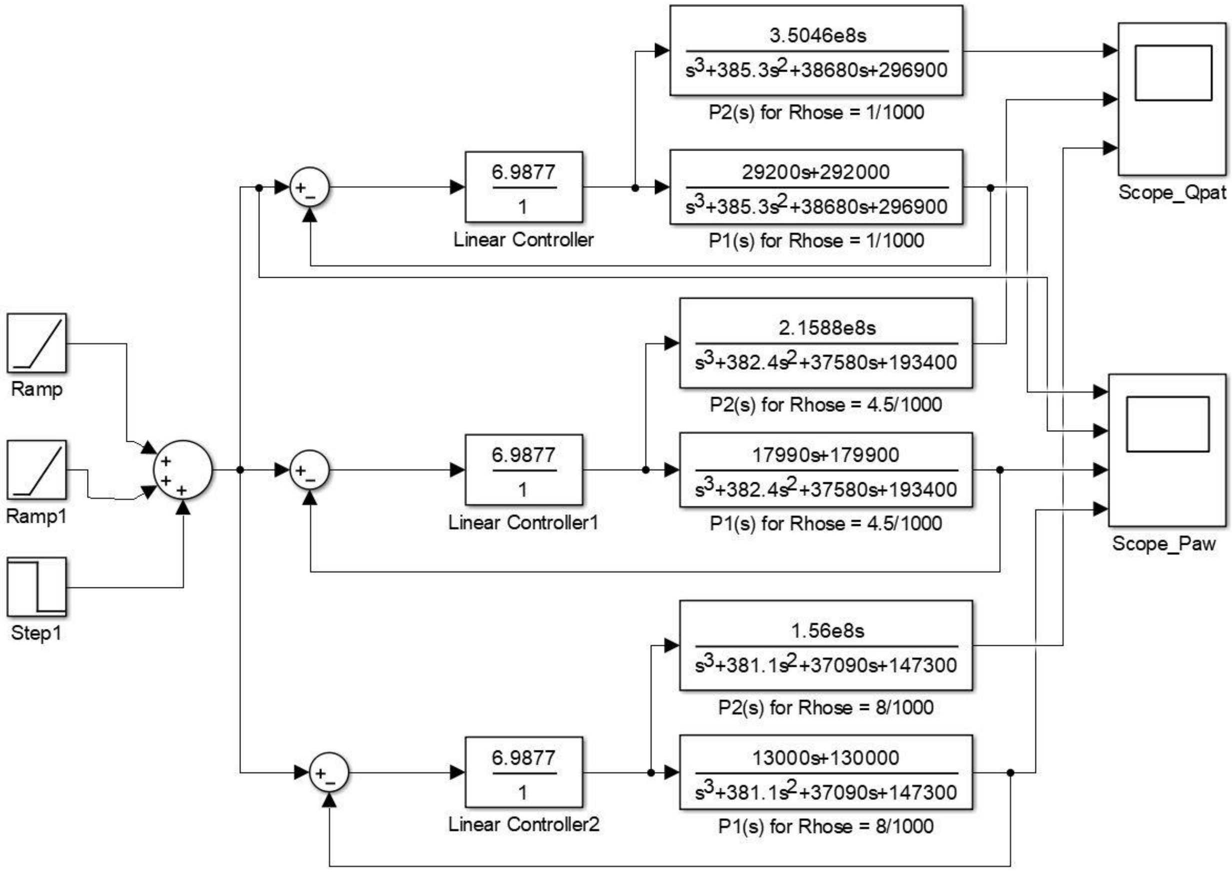




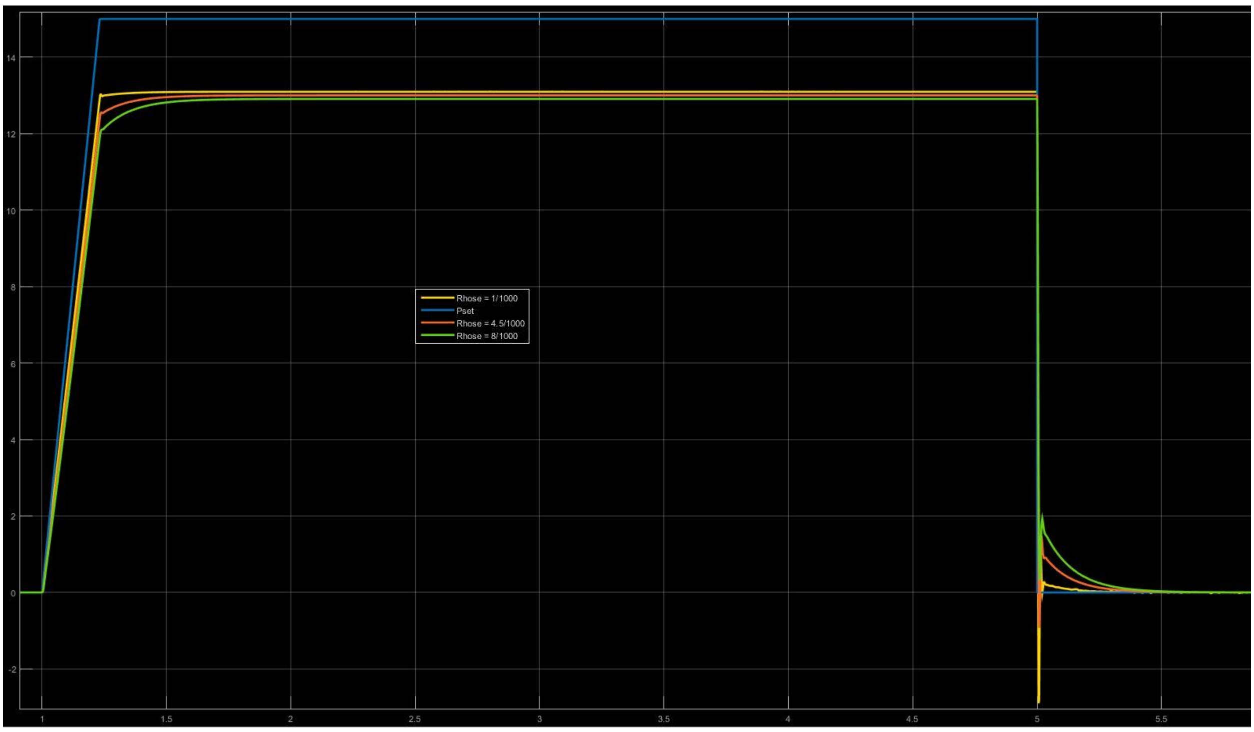


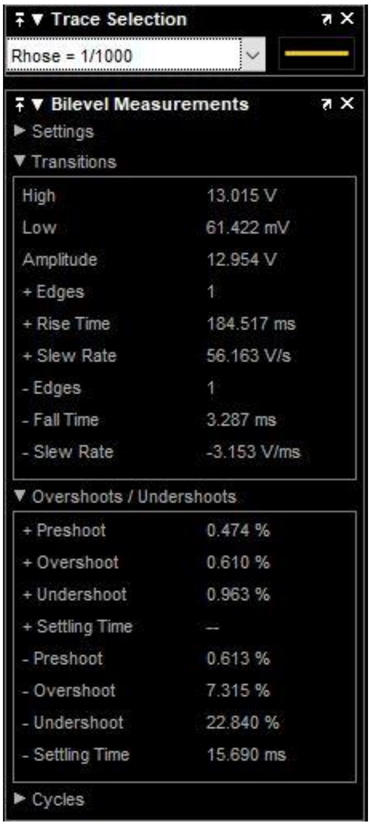


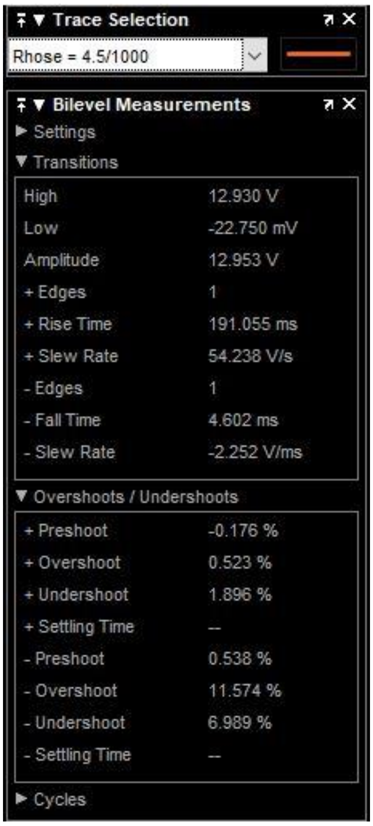
(vii) Variation of R_{hose} in Linear Control System :

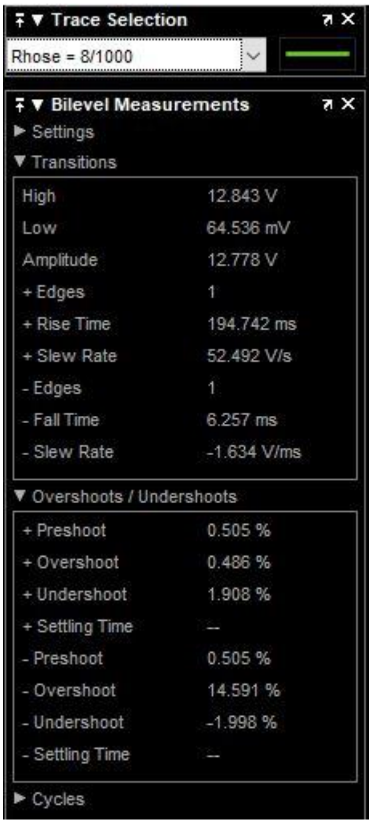


Output at Scope_Paw:

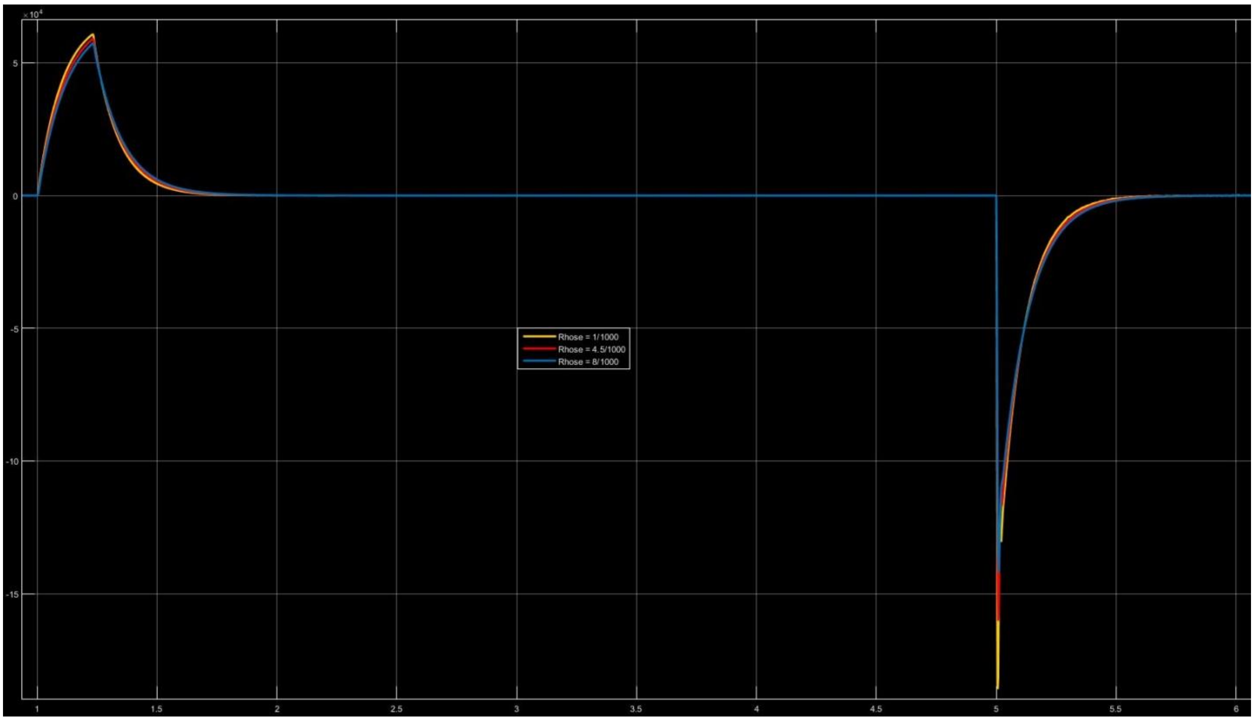


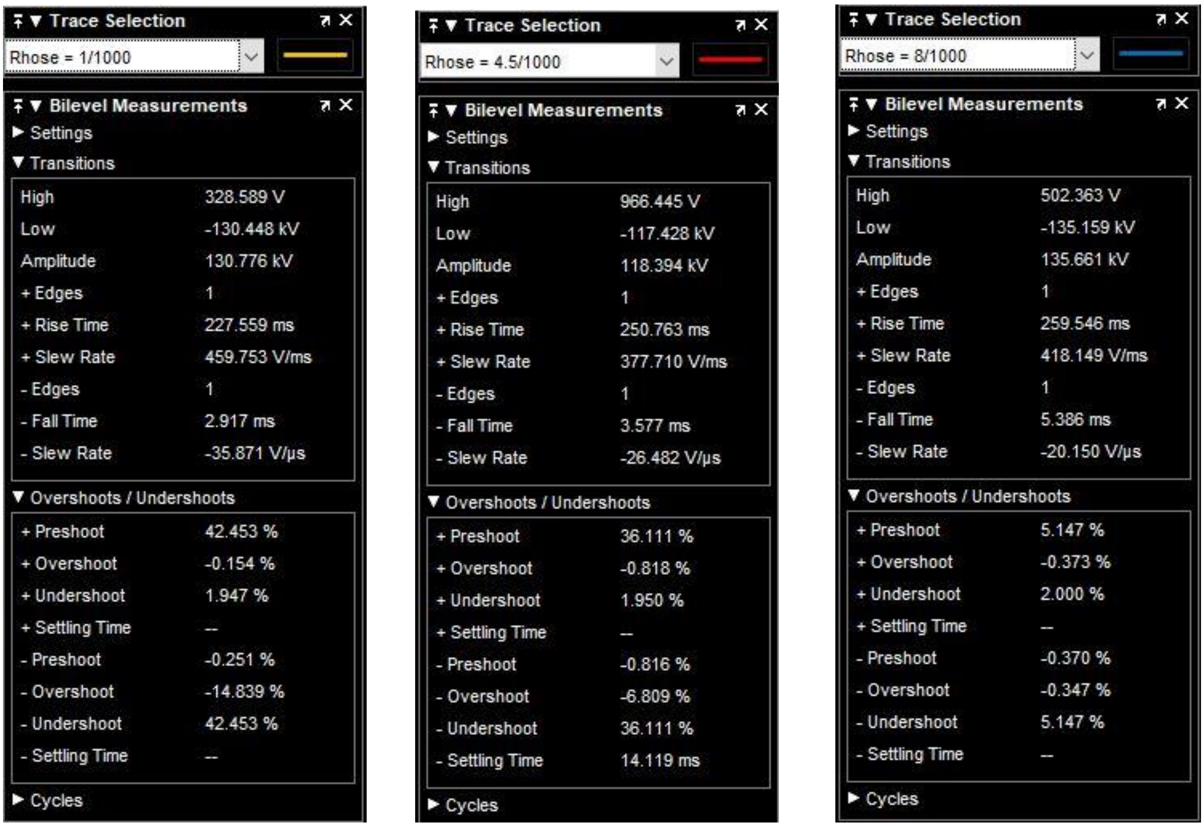




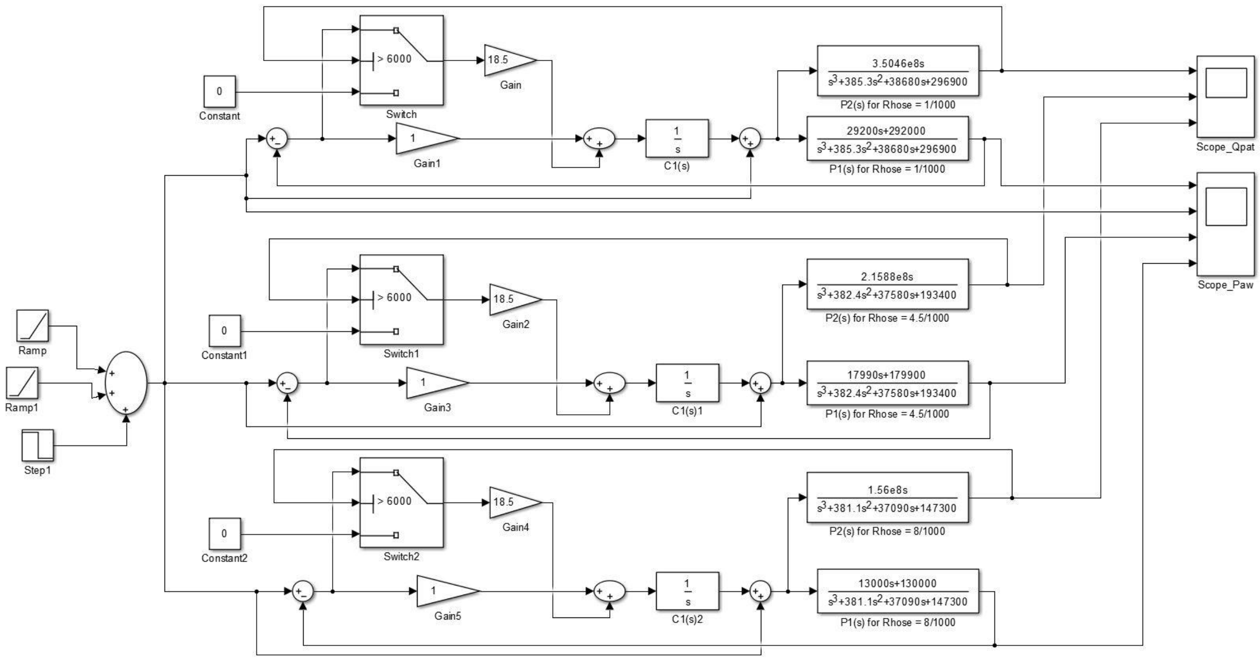


Output at Scope_Qpat:

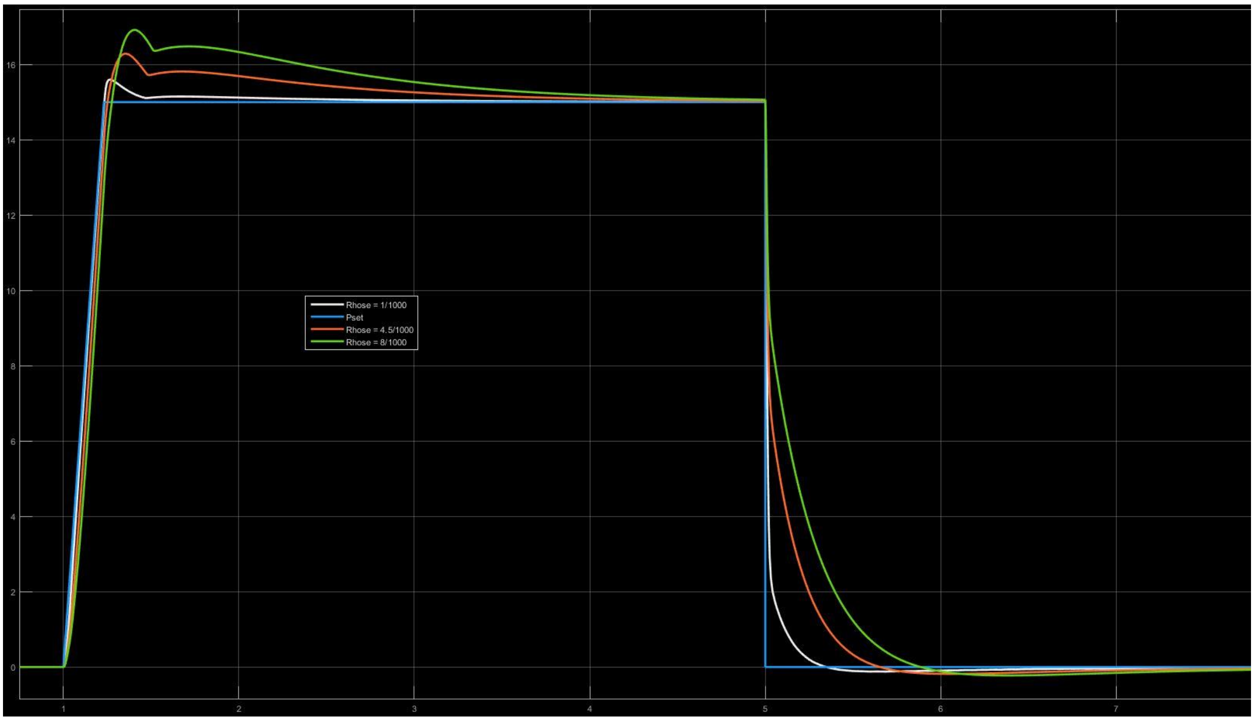


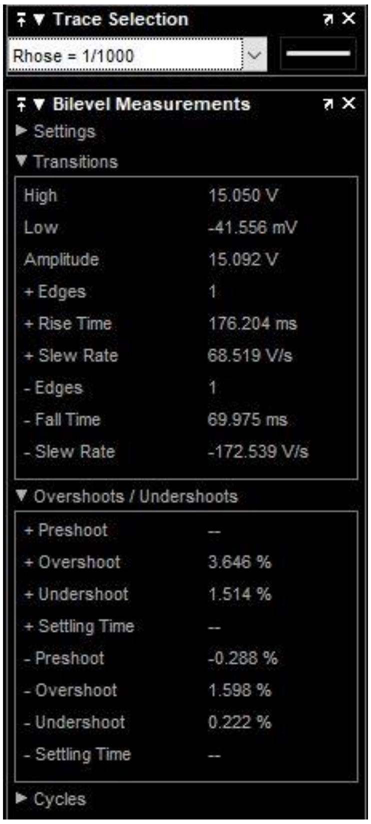


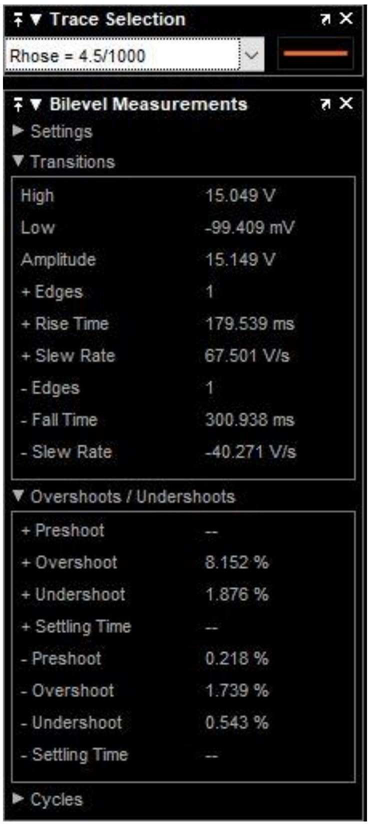
(viii) Variation of R_{hose} in Non-Linear Control System :

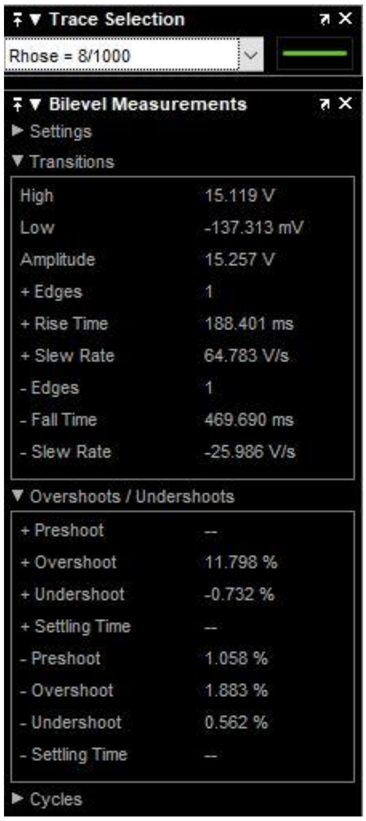


Output at Scope_Paw:

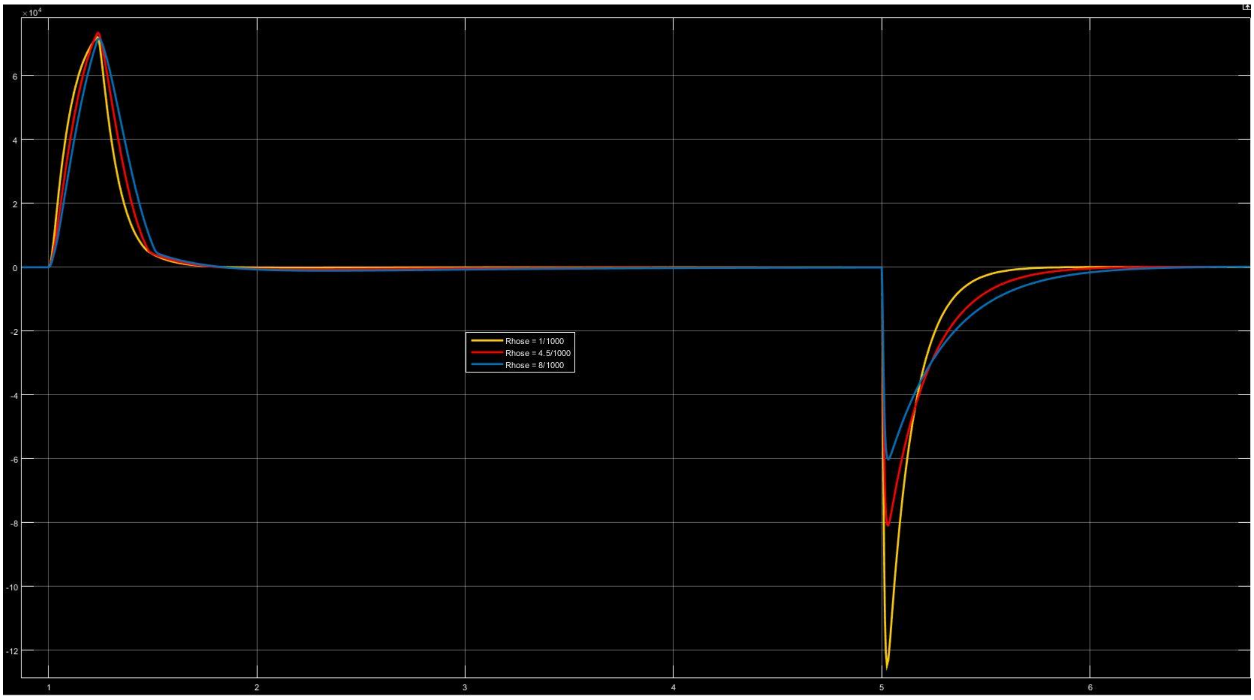








Output at Scope_Qpat:



Trace Selection: Rhose = 1/1000

Bilevel Measurements

▶ Settings

▼ Transitions

High	248.297 V
Low	-123.748 kV
Amplitude	123.996 kV
+ Edges	1
+ Rise Time	270.291 ms
+ Slew Rate	366.999 V/ms
- Edges	1
- Fall Time	13.560 ms
- Slew Rate	-7.315 V/µs

▼ Overshoots / Undershoots

+ Preshoot	0.794 %
+ Overshoot	-0.130 %
+ Undershoot	1.821 %
+ Settling Time	--
- Preshoot	-0.207 %
- Overshoot	-0.794 %
- Undershoot	0.794 %
- Settling Time	12.774 ms

▶ Cycles

Trace Selection: Rhose = 4.5/1000

Bilevel Measurements

▶ Settings

▼ Transitions

High	83.451 V
Low	-4.550 kV
Amplitude	4.633 kV
+ Edges	1
+ Rise Time	379.694 ms
+ Slew Rate	9.763 V/ms
- Edges	1
- Fall Time	1.577 ms
- Slew Rate	-2.350 V/µs

▼ Overshoots / Undershoots

+ Preshoot	1650.000 %
+ Overshoot	1.292 %
+ Undershoot	1.940 %
+ Settling Time	--
- Preshoot	-1.737 %
- Overshoot	-144.163 %
- Undershoot	493.205 %
- Settling Time	--

▶ Cycles

Trace Selection: Rhose = 8/1000

Bilevel Measurements

▶ Settings

▼ Transitions

High	4.976 kV
Low	-300.474 V
Amplitude	5.276 kV
+ Edges	0
+ Rise Time	--
+ Slew Rate	--
- Edges	1
- Fall Time	287.290 ms
- Slew Rate	-14.692 V/ms

▼ Overshoots / Undershoots

+ Preshoot	--
+ Overshoot	--
+ Undershoot	--
+ Settling Time	--
- Preshoot	1262.500 %
- Overshoot	1.196 %
- Undershoot	15.075 %
- Settling Time	--

▶ Cycles