MATLAB MODULE 5

Time Response Characteristics and LTI Viewer

LTI Viewer

The LTI (**L**inear **T**ime **I**nvariant) Viewer is an interactive graphical user interface (GUI) for analyzing the time and frequency responses of linear systems and comparing such systems. In particular, some of the graphs the **LTI Viewer** can create are step and impulse responses, Bode, Nyquist, Nichols, pole-zero plots, and responses with arbitrary inputs. In addition, the values of critical measurements on these plots can be displayed with a click of the mouse. Table 5.1 shows the critical measurements that are available for each plot.

Table 5.1

-	Peak time or Peak frequency	Settling time	Rise time	Steady state value	Gain/phase margins; zero dB/1800 frequencies	Pole-zero value
Step		✓	✓	✓	-	-
Impulse	✓	✓	-	-	-	-
Bode	✓	-	-	-	✓	-
Nyquist	✓	-	-	-	✓	-
Nichols	✓	-	-	-	✓	-
Pole-zero	-	-	-	-	-	✓

Here we provide steps you may follow to use the **LTI Viewer** to plot time and frequency responses.

1. **Access the LTI Viewer**: The **LTI Viewer** window, shown in Fig. M5.1, can be accessed by typing **ltiview** in the MATLAB Command Window or by executing

this command in an M-file.

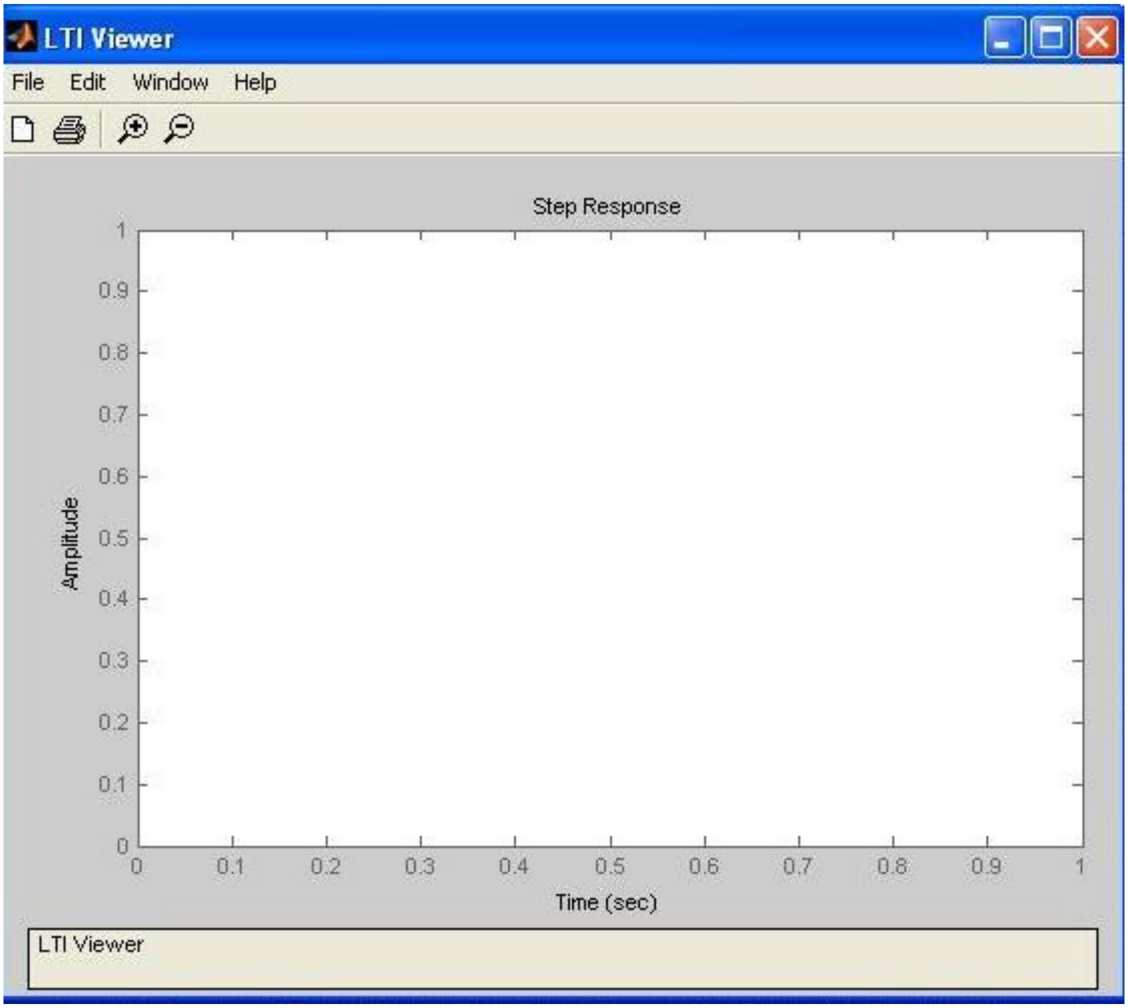

Fig. M5.1 *LTI Viewer Window*

2. **Create LTI transfer functions**: Create LTI transfer functions for which you want to obtain responses. The transfer functions can be created in an M-file or in the MATLAB Command Window. Run the M-file or MATLAB Command Window statements to place the transfer function in the MATLAB workspace. All LTI objects in the MATLAB workspace can be exported to the **LTI Viewer**.

The following MATLAB commands create the transfer function $G(s) = \dfrac{1}{s+1}$.

```
>> s = tf('s');
```

```
>> G = 1/(s+1);
```

3. **Select LTI transfer functions for the LTI Viewer:** Choose **Import…** under the **File** menu in the **LTI Viewer** window and select all LTI objects whose responses you wish to display in the **LTI Viewer** sometime during your current session. Selecting **G** results in Fig. M5.3.

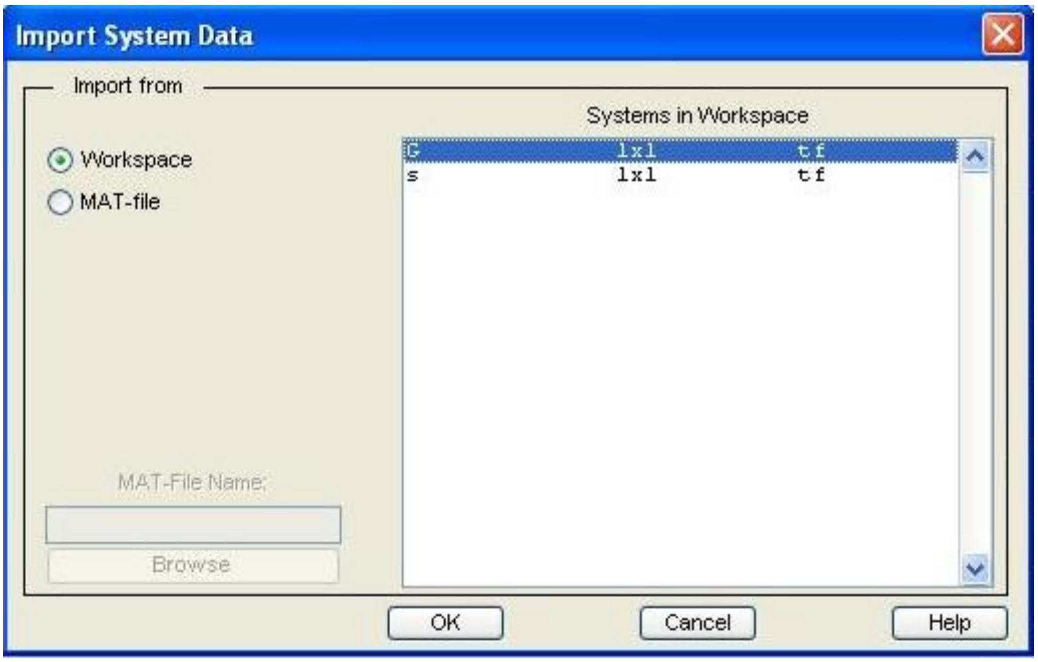

Fig. M5.2 *Import System Data Window*

4. **Select the LTI objects for the next response plot:** Right-click anywhere in the **LTI Viewer** plot area to produce a pop-up menu. Under **Systems**, select or deselect the objects whose plots you want or do not want to show in the **LTI Viewer**. More than one LTI transfer function may be selected.

5. **Select the plot type:** Right-click anywhere in the **LTI Viewer** plot area to produce a pop-up menu. Under **Plot Types**, select the type of plot you want to show in the **LTI Viewer** (Fig. M5.3).

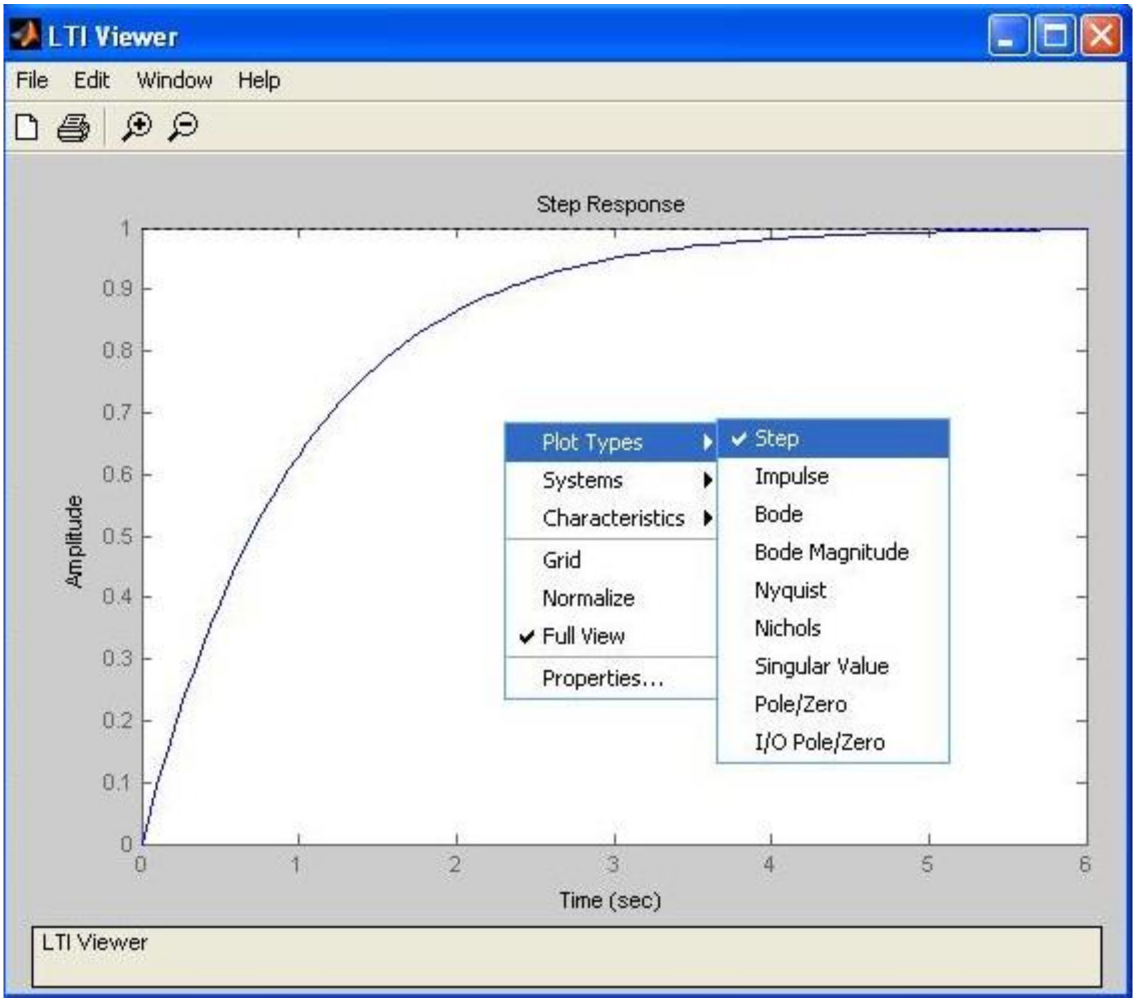

Fig. M5.3

Example M5.1

Take a typical underdamped second-order transfer function and import it to the LTI viewer window.

6. **Select the characteristics:** Right-click anywhere in the LTI Viewer plot area to produce a pop-up menu. Under **Characteristics**, select the characteristics of the plot you want displayed. More than one characteristic may be selected. For each characteristic selected, a point will be placed on the plot at the appropriate location.

The characteristics menu and the submenu are displayed in Fig. M5.4 obtained by importing a typical second-order transfer function.

Note the difference in the definition of rise time employed in the LTI Viewer with respect to the one used in the text.

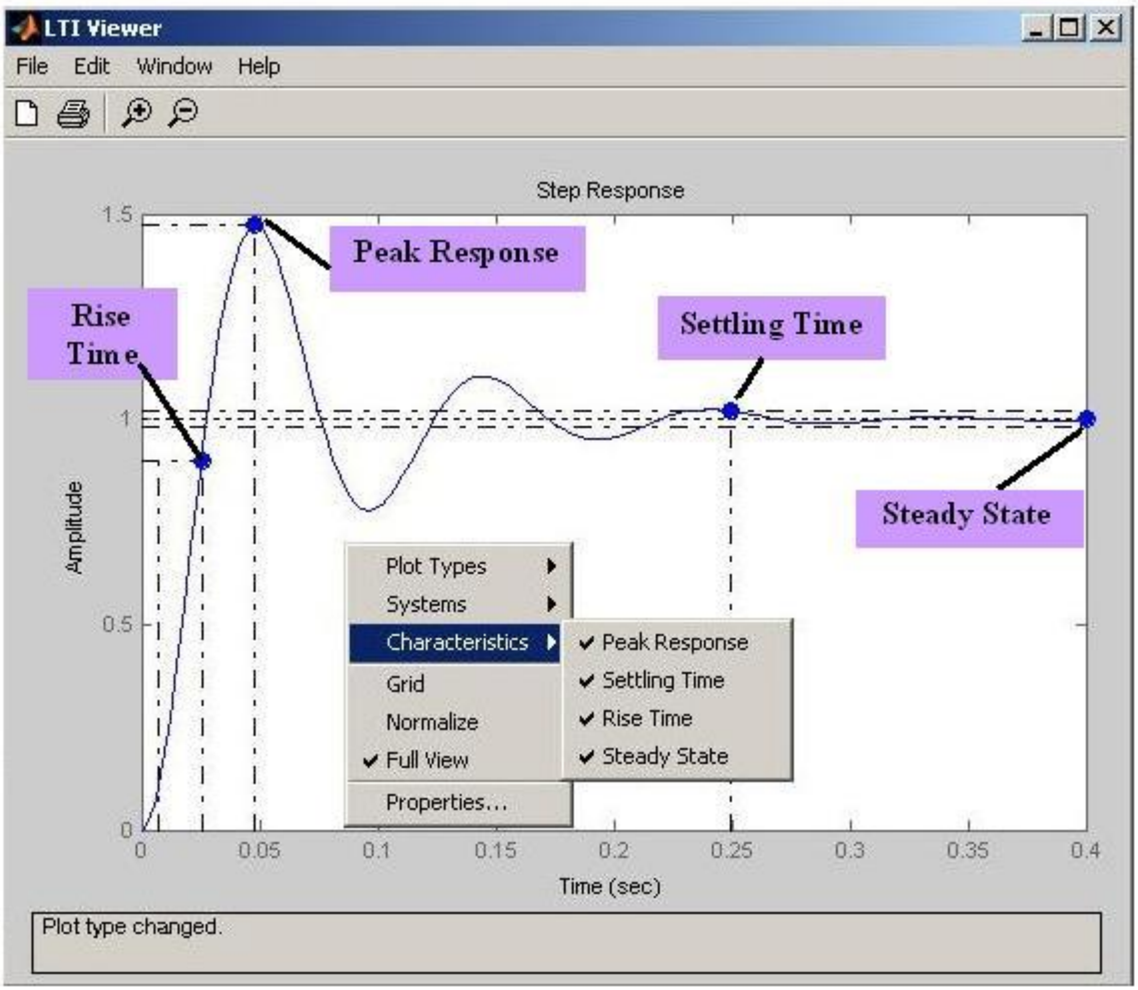

Fig. M5.4 *LTI Viewer with step response plot and characteristics*

7. **Interact with the plot:**

   - **Zoom In (Zoom Out):** Select the **Zoom In (Zoom Out)** button (with the + (−) sign) on the tool bar. Hold the mouse button down and drag a rectangle on the plot over the area you want to enlarge (deluge), and release the mouse button.

- **Original View:** Select **Reset to Original View** in the menu popped up by right-click to return to original view of your plot after zooming.

- **Grid:** Select **Grid** in the right-click menu to on or off the grid. The right click menu will not work if any zoom button on the tool bar is selected.

- **Normalize:** Select **Normalize** in the right-click menu to normalize all curves in view.

- **Characteristics:** Read the values of the characteristics by placing the mouse on the characteristics point on the plot. Left-click the mouse to keep the values displayed (Fig. M5.5).

- **Properties:** Select **Properties** in the right-click menu or double-click anywhere (except the curve) on the graph sheet to change the appearance of the graph. You can change the title, axes labels, x and y limits, font sizes and styles, colors, and response characteristics definitions.

- **Coordinates and curve:** Left-click the mouse at any point on the plot to read the system identification and the coordinates (Fig. M5.5, shown by square block).

- **Add text and graphics:** Under the **File** menu, choose **Print to Figure**. An additional figure with toolbar will open (Fig. M5.6).The toolbar of this figure has additional tools for adding text, arrows, lines, legends, and to rotate the figure.

- **Additional plot-edit capabilities:** The **Edit** menu of the **LTI Viewer** and the figures created by selecting **Print to Figure**, offer a wide variety of controls over the plot presentation.

8. **Viewer preferences:** Choose **Viewer Preferences…** in the **Edit** menu. **LTI Viewer Preferences** window (Fig. M5.7) will open. This allows users to set parameters such as units (**Units**), style of labels (**Style**), response characteristics definitions (**Characteristics**), and also provide a control over the time and frequency vector generation (**Parameters**).

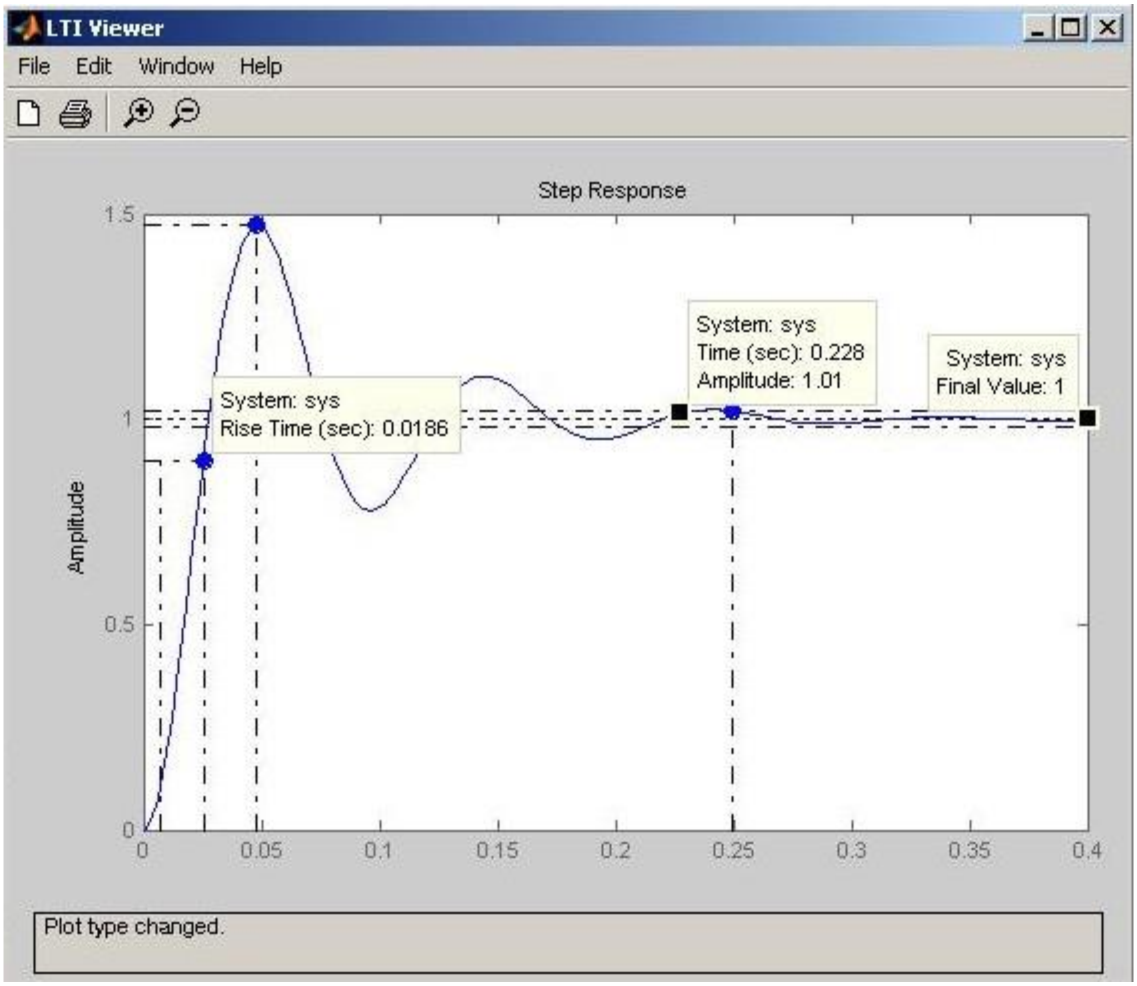

Fig. M5.5 *Coordinate values in step response curve*

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Time Response Characteristics and LTI Viewer

Time Response Characteristics in MATLAB window

Example M5.1

Consider the position control system shown in Fig. M5.8.

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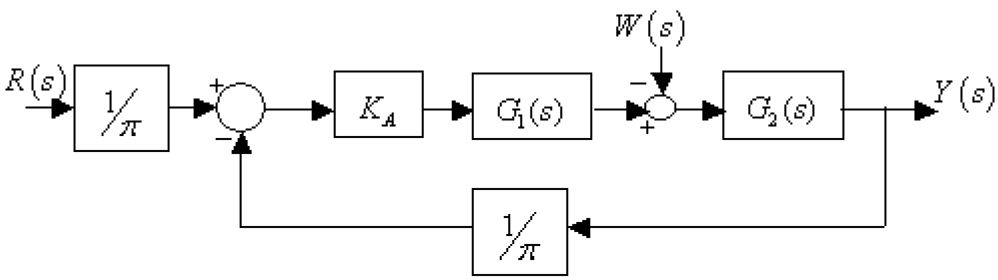

Fig. M5.8

(transfer function of motor, gears, and load)

$G_1(s) = \dfrac{100}{s+100}$ (transfer function of power amplifier)

K_A = preamplifier gain

$1/\pi =$ sensitivity of input and output potentiometers

Time response characteristics of the system are generated by the following MATLAB script.

```
s = tf('s');

G1 = 100/(s+100);

G2 = 0.2083/(s*(s+1.71));

K = 1000;

G = series(K*G1,G2);

H = 1/pi;

M = series(feedback(G,H),H);
```

```
ltiview(M);
```

MATLAB response is shown in Fig. M5.9.

In the following we compare the time response characteristics of this system with the one obtained by replacing the power amplifier with a transfer function of unity (Fig. M5.10).

```
s = tf('s');

G1 = 1;

G2 = 0.2083/(s*(s+1.71));

K = 1000;

G = series(K*G1,G2);

H = 1/pi;

M1 = series(feedback(G,H),H);

ltiview(M1);
```

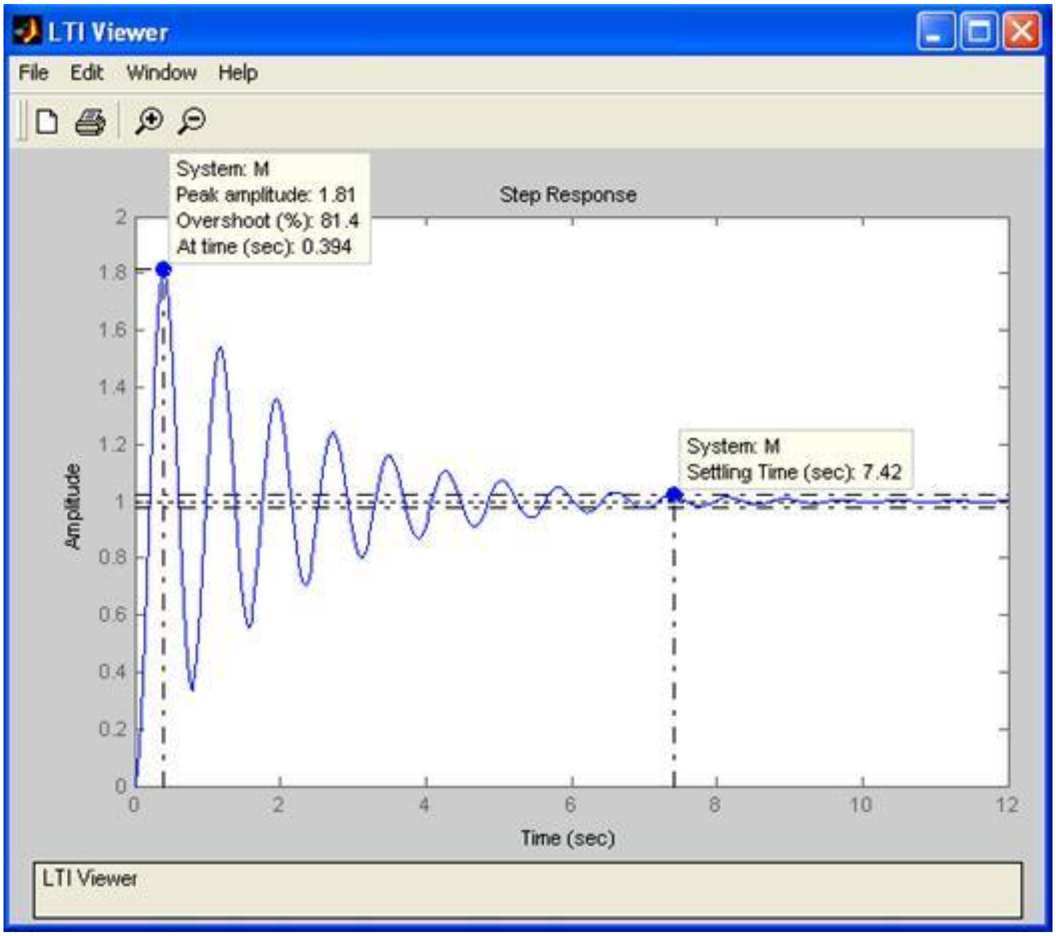
LTI Viewer
File Edit Window Help
System: M
Peak amplitude: 1.81
Overshoot (%): 81.4
At time (sec): 0.394
Step Response
System: M
Settling Time (sec): 7.42
Amplitude
Time (sec)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
2
4
6
8
10
12
LTI Viewer

Fig. M5.9

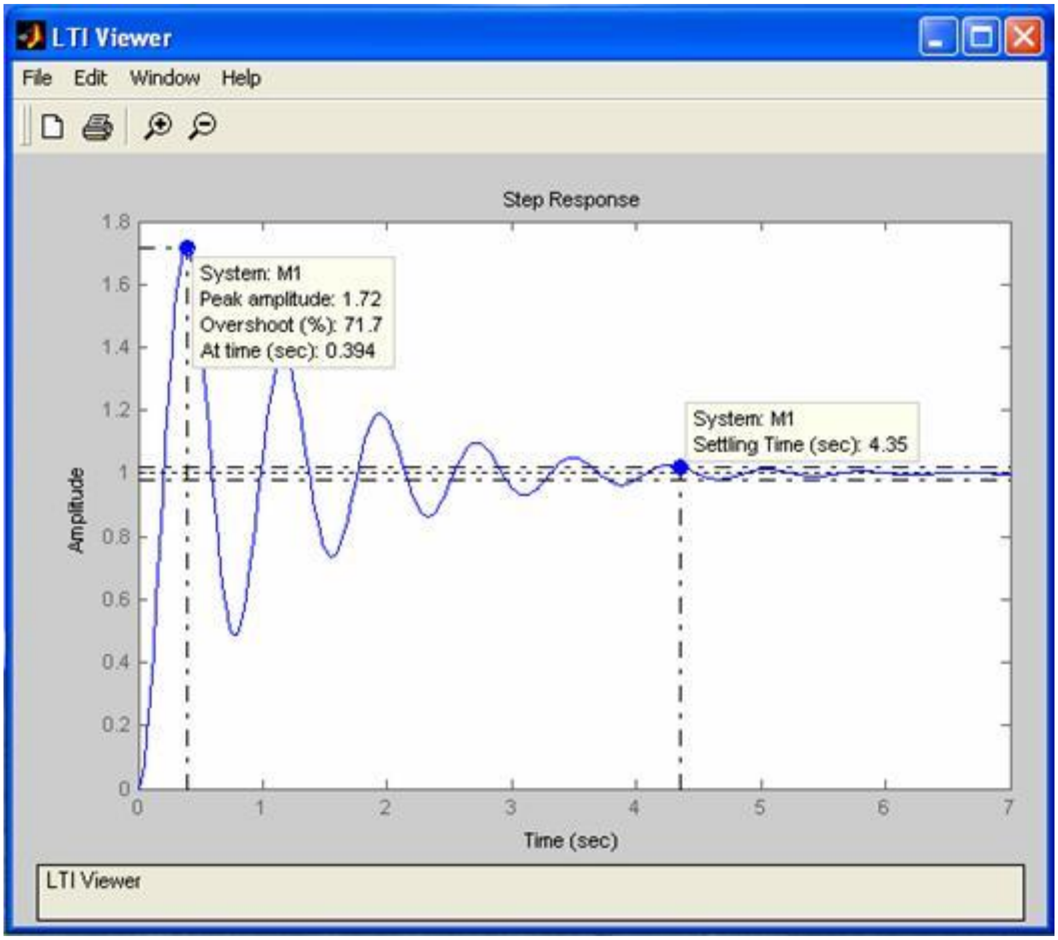

Fig. M5.10

The second-order approximation seems to be quite reasonable.

The two responses in Figs M5.9 and M5.10 can be obtained in a single plot using the command **ltiview(M,M1)**. Alternatively, choose **Import...** under the **File**menu in the **LTI Viewer** window and select **M.**

Example M5.2

Consider a unity feedback system shown in Fig. M5.11.

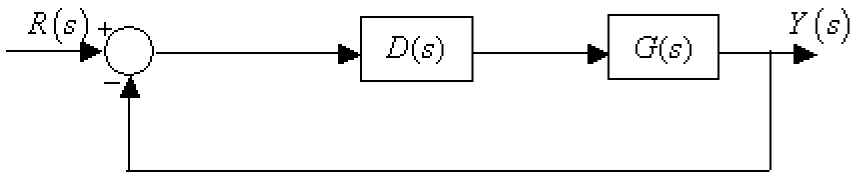

Fig. M5.11

$$G(s) = \frac{59.292}{s^2 + 6.9779s + 15.1239} \text{(plant transfer function)}$$

$$D(s) = \left(K_P + \frac{K_I}{s} + K_D s \right) \text{(controller transfer function)}$$

We will consider the following three controllers:

*D*1(*s*) = 3; *D*2(*s*)=3+(15/ *s*); and *D*3(*s*)=(3+(15/ *s*)+0.3 *s*)

The following MATLAB code generates the step responses shown in Fig. M5.12.

```
s = tf('s');

G = 59.292/(s^2+6.9779*s+15.12);

D1 = 3;

D2 = 3 + 15/s;

D3 = 3 + 15/s +0.3*s;

M1 = feedback(D1*G,1);

M2 = feedback(D2*G,1);

M3 = feedback(D3*G,1);

step(M1);

hold;

step(M2);
```

```
step(M3);
```

We need not access LTI viewer to find out the time response characteristics of the closed-loop system. The `step` command in MATLAB has this feature inbuilt in it as is seen in Fig. M5.12.

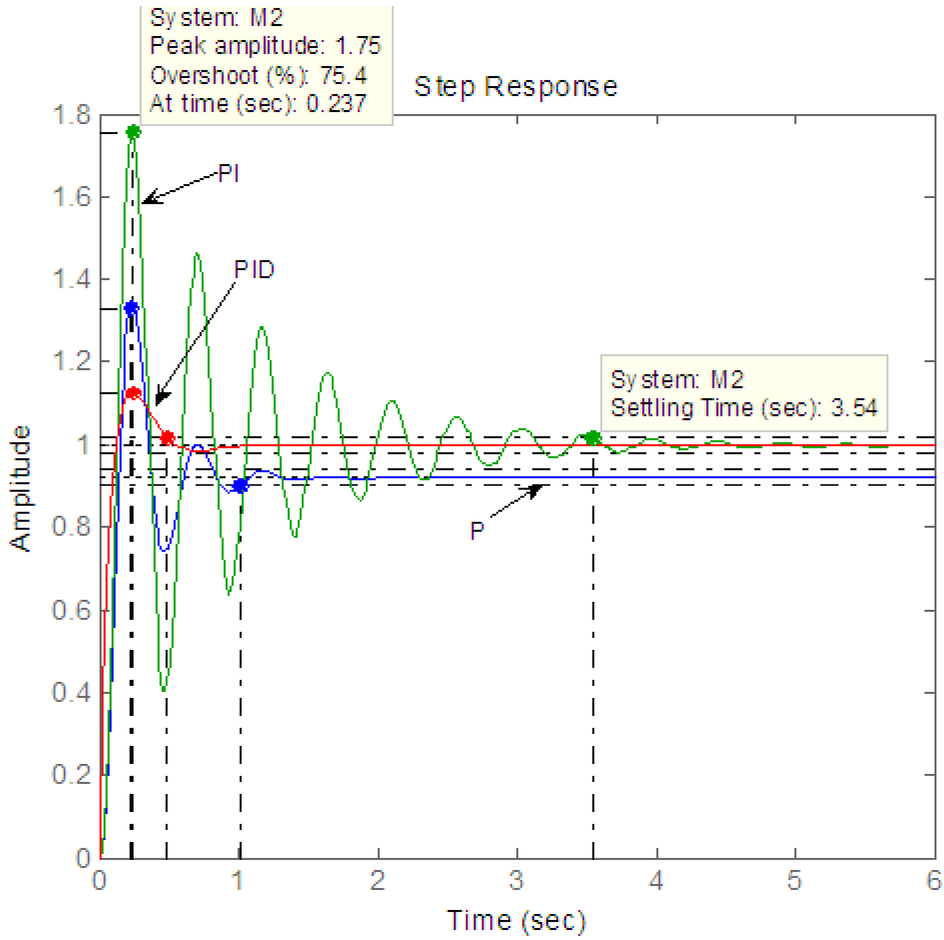

Fig. M5.12

Note that adding the integral term increases the oscillatory behaviour but eliminates the steady-state error, and that adding the derivative term reduces the oscillations, while maintaining zero steady-state error.

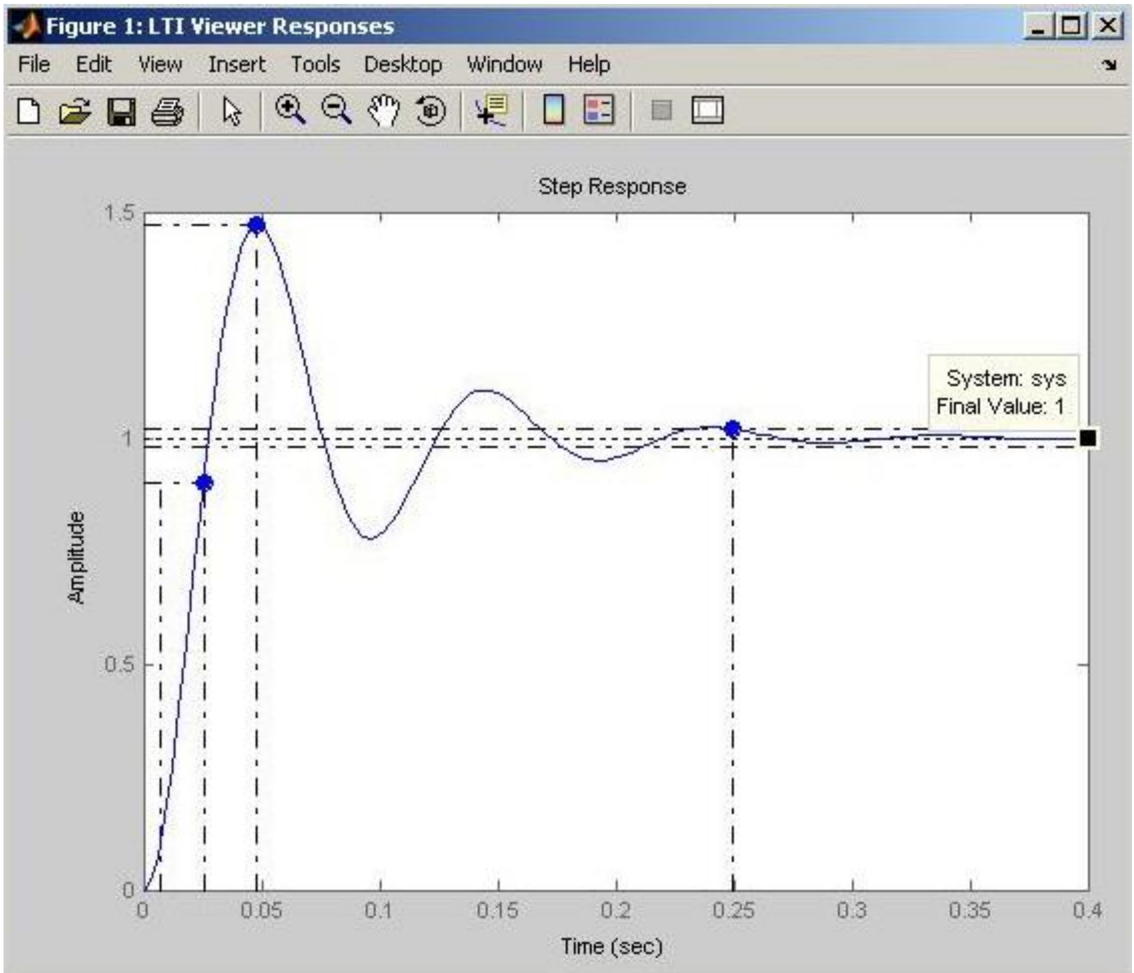

Fig. M5.6 *LTI response with text and graphics editor toolbar*

Fig. M5.7 *LTI Viewer Preferences window*

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Time Response Characteristics in SIMULINK window

Example M5.3

Consider a unity feedback, PID controlled system with following parameters:

Plant transfer function: $G(s) = \dfrac{3}{3.1s+1}$

PID controller transfer function: $D(s) = 3.37\left(1+\dfrac{1}{1.2s}+0.06s\right)$

Reference input: $R(s) = \dfrac{30}{s}$

A Simulink block diagram is shown in Fig. M5.13.

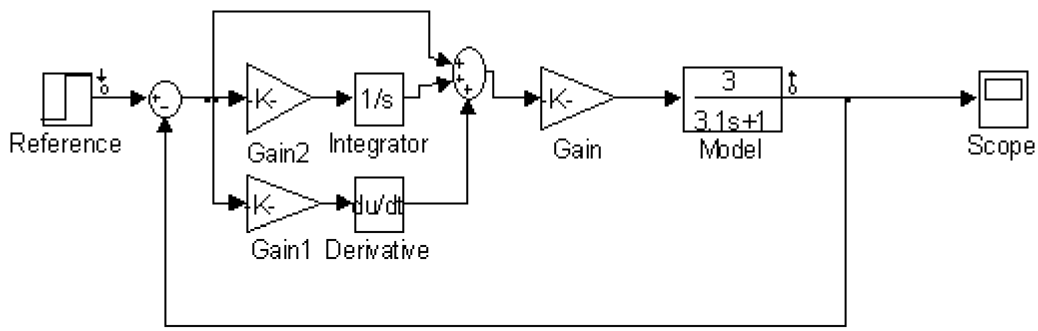

Fig. M5.13 [(download)]

The Simulink model inputs a step of 30 to the system.

Time response characteristics of the model developed in Simulink can be obtained by invoking the LTI Viewer directly from the Simulink. LTI Viewer for Simulink can be invoked by following **Tools -- Control Design -- Linear Analysis** as shown in Fig. M5.14.

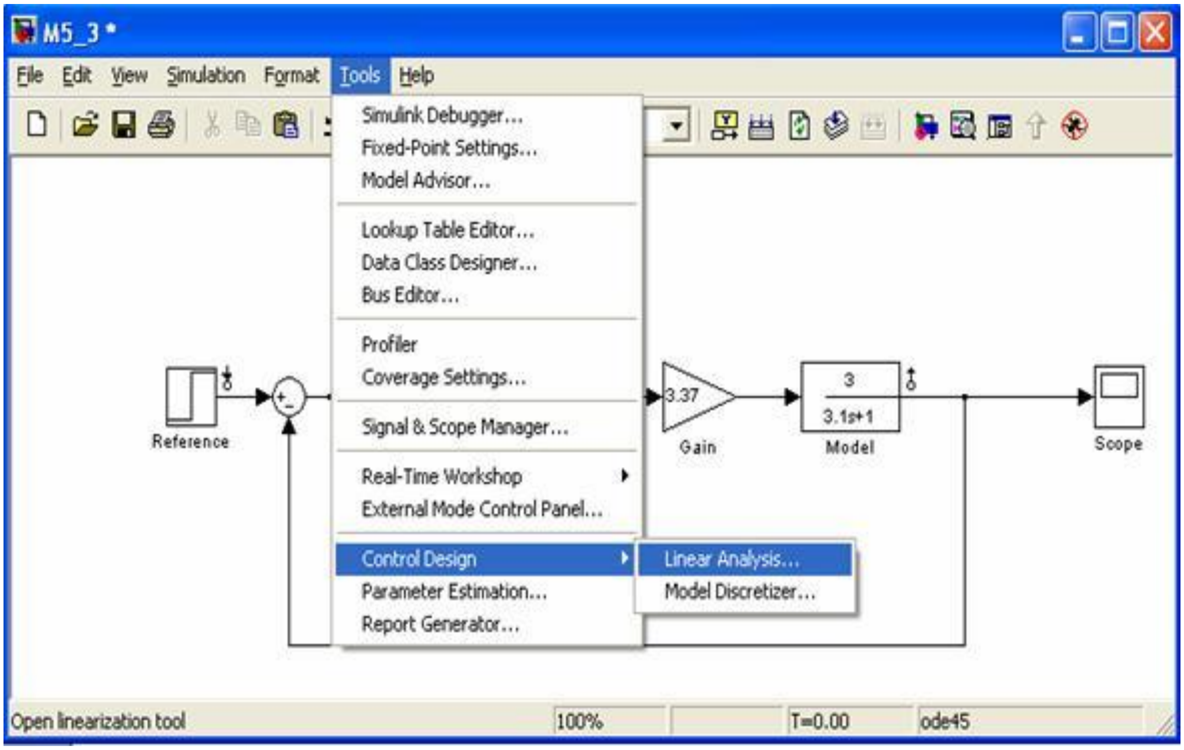

Fig. M5.14

This opens **Control and Estimation Tools Manager** shown in Fig. M5.15.

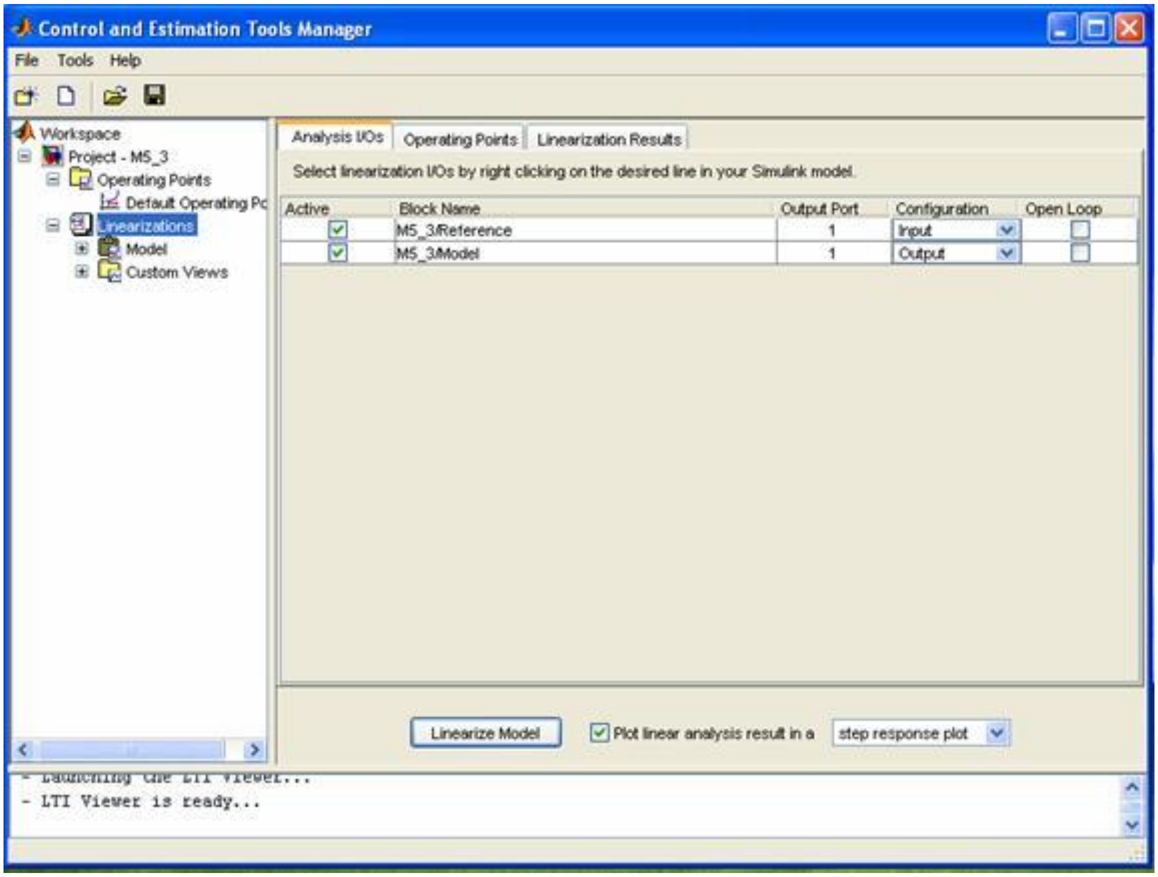

Fig. M5.15

Select linearization input-output points by right clicking on the desired line and selecting **Linearization Points** in your Simulink model. Fig. M5.16 explains the selection of input point. Similarly output point has been selected. Once input-output linearization points appear in the **Control and Estimation Tools Manager**window, click on the **Linearize Model** at the bottom of the window (Fig. M.5.15). The type of response can be selected from the drop down menu just near the**Linearize Model** button. Other linear analysis plots available are: Bode, Impulse, Nyquist, Nichols, Bode magnitude plot, and pole-zero map.

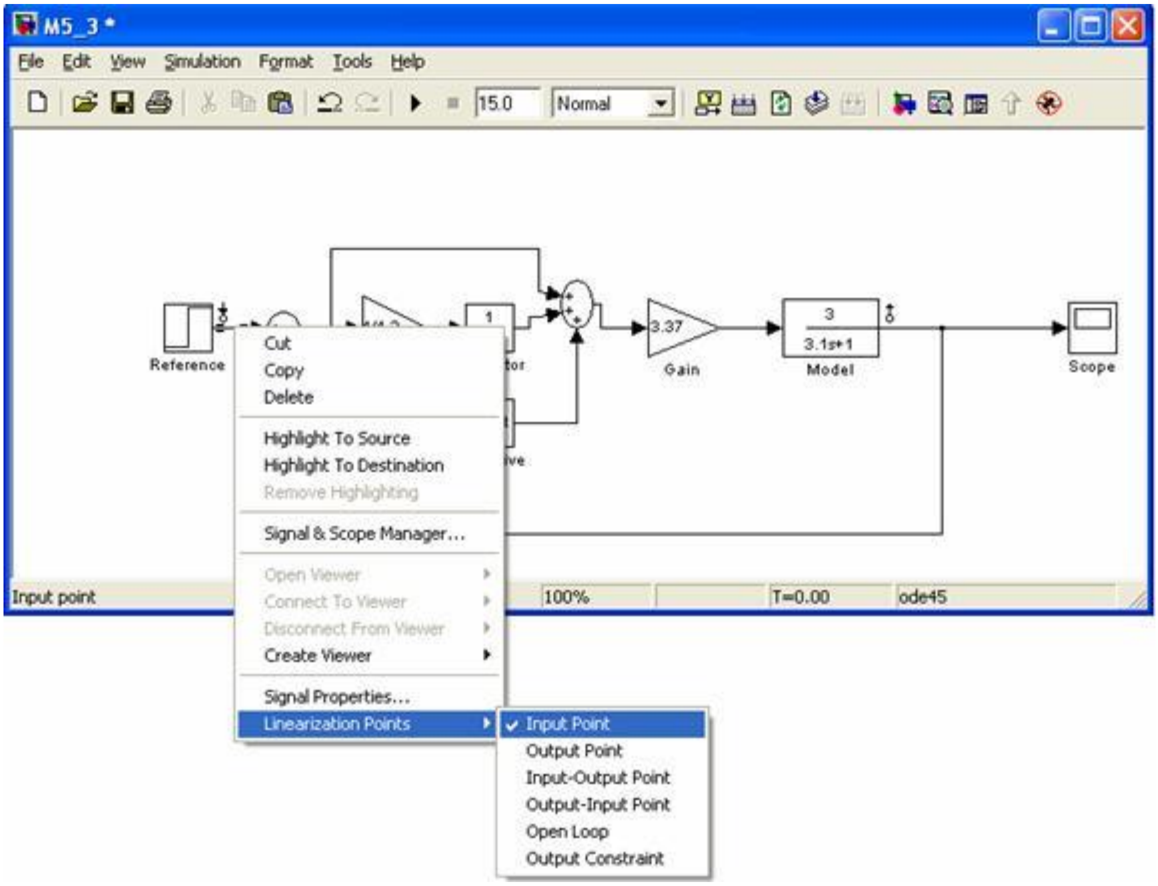

Fig. M5.16

The step response with the characteristics is shown in Fig. M5.17.

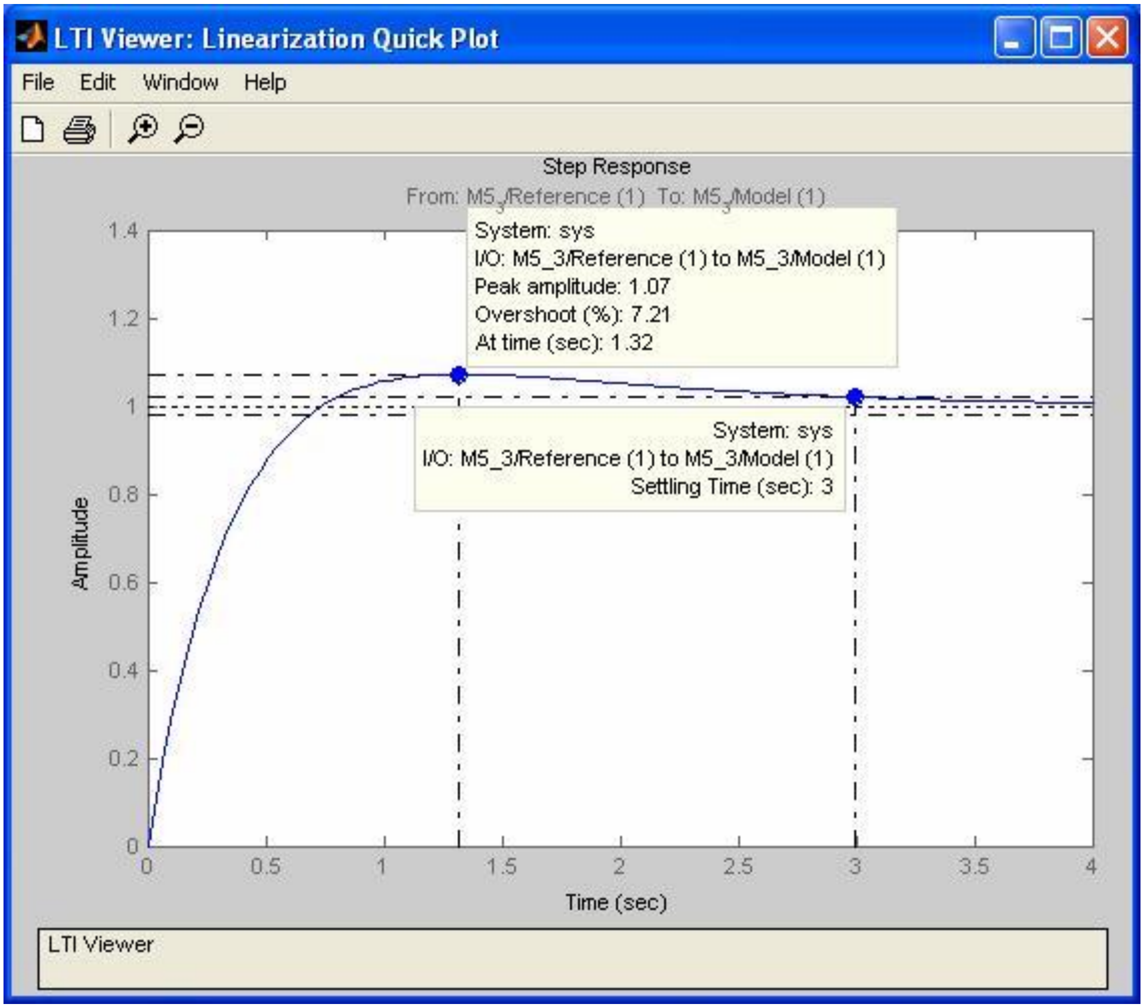

Fig. M5.17

Example M5.4

Consider a unity feedback, PI controlled system with following parameters:

Plant transfer function: $G(s) = \dfrac{8.55}{0.55s+1}$

Plant deat-time: τ_D = 0.15 minutes

PI controller transfer function: $D(s) = 0.09 + \dfrac{0.95}{s}$

Actuator saturation characteristic: Unit slope; maximum control signal =1.7.

Reference input: $R(s) = \frac{10}{s}$

A Simulink block diagram is shown in Fig. M5.18. PID controller block is available in **Additional Linear** block set in **Simulink Extras** block library. The parameters of PID controller block have been set as : P = 0.09, I = 0.95, and D = 0.

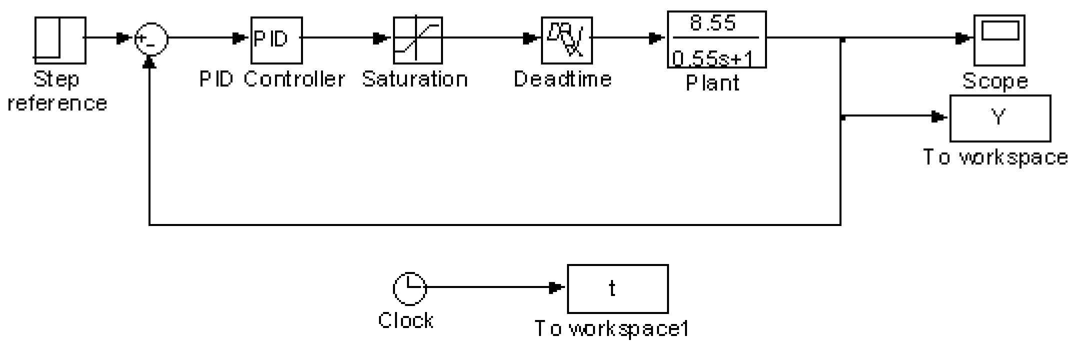

Fig. M5.18 (download)

We can invoke LTI Viewer to determine the time response characteristics of the system of Fig. M5.18. However, LTI Viewer will linearize the system and then plot the characteristics. An alternative is to transfer the output response data to workspace using **To Workspace** block and then generate the time response using the **plot** command. A MATLAB code can then be written to determine the required characteristics. The following code gives settling time, peak overshoot, and peak time for the output response data of Fig. M5.18.

```
time = t.signals.values;

y = Y.signals.values;

plot(time,y);

title('Step response');

xlabel('Time (min)');
```

```
ylabel('Output');
ymax = max(y);
step_size = 10;
peak_overshoot = ((ymax-step_size)/step_size)*100
index_peak = find(y == ymax);
peak_time = time(index_peak)
s = length(time);
while((y(s)>=0.95*step_size) & (y(s)<=1.05*step_size))
s = s-1;
end

settling_time = time(s)
```

The MATLAB responds with Fig. M5.19 and the following characteristics.

```
peak_overshoot =
39.0058
peak_time =
1.9339
settling_time =
5.9739
```

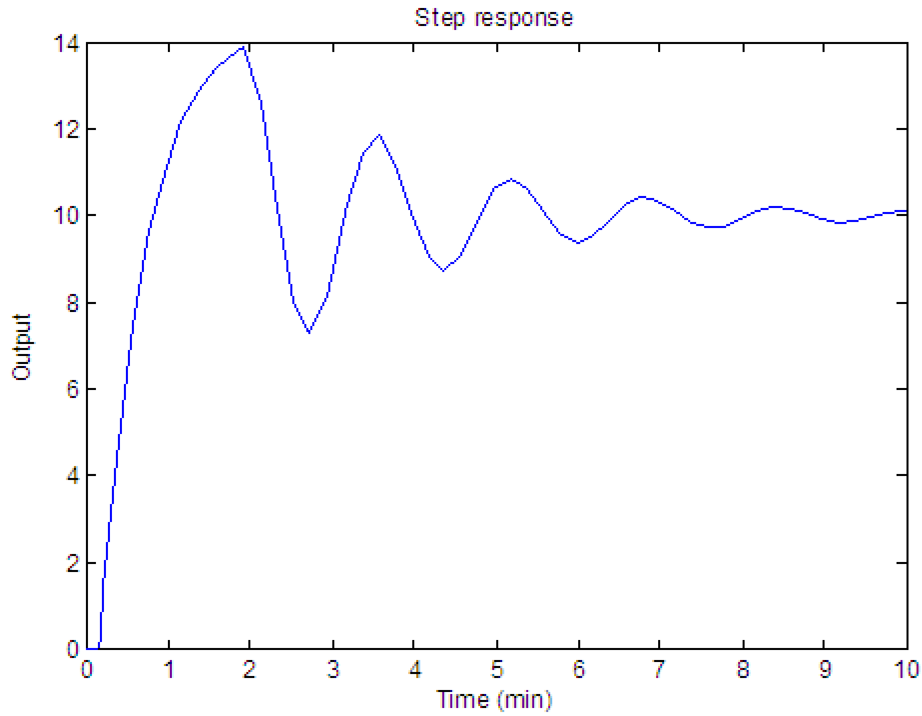

Fig. M5.19