

Modelling and Analysis of the Simple Water Heater System

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Abstract

Modelling is nothing but converting physical information in to mathematical form. Mathematical model plays vital role for identification and analysis of the system. In this paper simple water heater system was taken as test bench. Considering system parameters mathematical model of first order with time delayed was derived. Model was simulated in the simulation tool MATLAB and systems response has been studied by changing various parameters like static gain, time constant, delay time and noise, for applied step input. Response of the simulated system was analysed and compare with the actual real time system parameters.

Keywords: Modelling, Analysis, MATLAB, Water heater system.

1. Introduction

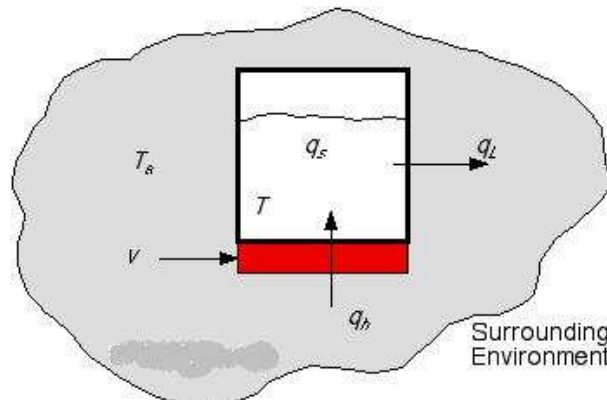
Modelling and analysis play fundamental roles in the field of automatic control, since it is not possible to perform a control system design without having a model describing the dynamics of the process to be controlled. Mathematical models are key elements in the field of automatic control. They are required for simulation as well as design in a typical control system development. Models cannot represent every aspect of reality and hence assumptions must be made in order to use them for control purposes [1]. The basic aim here is to have simulation analysis of system parameters considering simple water heater system using tool MATLAB and comparison with real time parameters.

The idea to change properties of the system and immediately being able to see the effects of the changes is very powerful both for learning and for designing. Effect of the system response can be observed straight forward in the graph and further information can be derived for the system behavior for both analysis and contro purpose[2].

The paper is organized as follows. In Section 2, the dynamic model of simple water heater system is presented, Simulation and analysis is presented in Section 3, and a few real time comparison s are given in Section 4. The paper ends with references.

2. Modelling of simple water heater system[3]

Consider a mathematical model (differential equation) for the simple water heater system which describes its dynamics. The different signals and components needed to derive a mathematical model for the thermal system are shown in Figureure 1.



Figureure 1. Thermal system

Where, V = Voltage applied to the heater (input), T = Temperature of water, (output), T_a = Ambient temperature, Q_h = Energy supplied by heater, Q_s = Energy stored by liquid, Q_L = Energy lost to the surrounding environment by conduction. The differential equation is obtained by applying heat balance equation. Energy supplied by the heater (Q_h) = Energy stored by water (Q_s) + Energy lost to the surrounding environment by conduction (Q_L) i.e. $Q_h = Q_s + Q_L$.

$$k \cdot V = C \cdot (dT/dt) + (T - T_a)/R \quad (1)$$

Where, k is a constant provided by the heater manufacturer, C is a thermal capacitance of the liquid, R is the thermal resistance of the tank wall (heat conduction) and t is the time. Equation (1) is the differential equation that describes the dynamics of the thermal system. Taking Laplace transform at both the side of equation (1) and rearranging in the transfer function form.

$$k \cdot V(s) = C \cdot s \cdot T(s) + 1/R \cdot T(s) \quad (2)$$

$$T(s)/V(s) = k/(C \cdot s + 1/R) \quad (3)$$

Equation (3) is a First order system with the time constant $C \cdot R$. $k \cdot R$ can be treated as system static gain. if we add more complexity in the system by adding time delay in the system and substituting system parameters, its transfer function is derived, which is shown in following Figure 2. at the MATLAB command window.

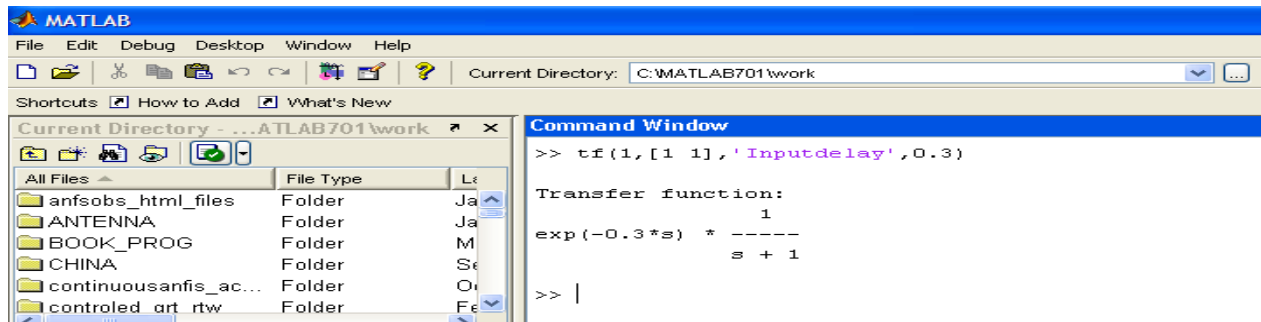


Figure 2. MATLAB Command window.

3. Simulation and Analysis

Consider Open loop system having the system parameters as under. Input applied is step function having unity amplitude. System gain =1, Time constant =1, and Time delay = 1, the system dynamic behaviors for the above conditions are shown in the following Figure.3.

3.1. Response open loop system

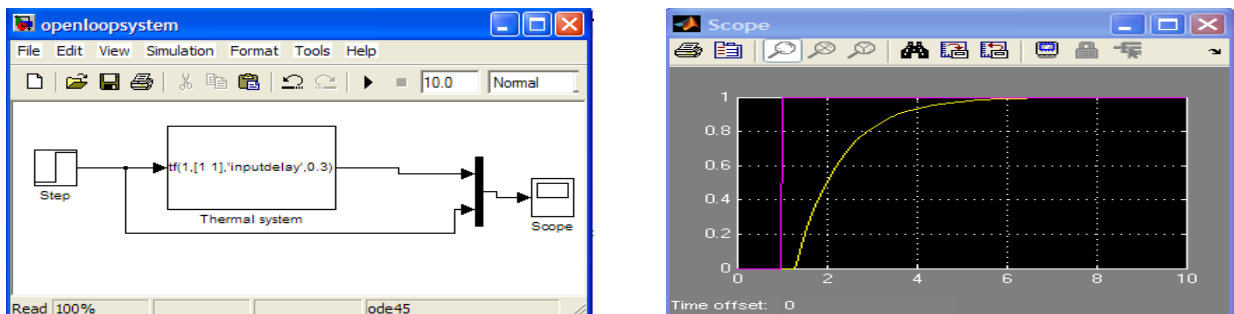


Figure 3 Step response of system.

Signal with color MAGENTA is applied step input and response of the system is YELLOW. As shown in the graph Figure.3. step input is applied at 1 s and time delay is 0.3 s, so response will start at 1.3s and it stabilized at amplitude 1 because system static gain is unity and step input is having final value '1'. If there is change in static gain to '2' without changing other parameters in the system, the response will be stabilized at amplitude '2' instead of

'1' on the contrary by changing final value of the step input to '2' and considering same transfer function without changing system gain system will have same response as shown in the graph Figure.3.

3.2. Change in static gain of the system.

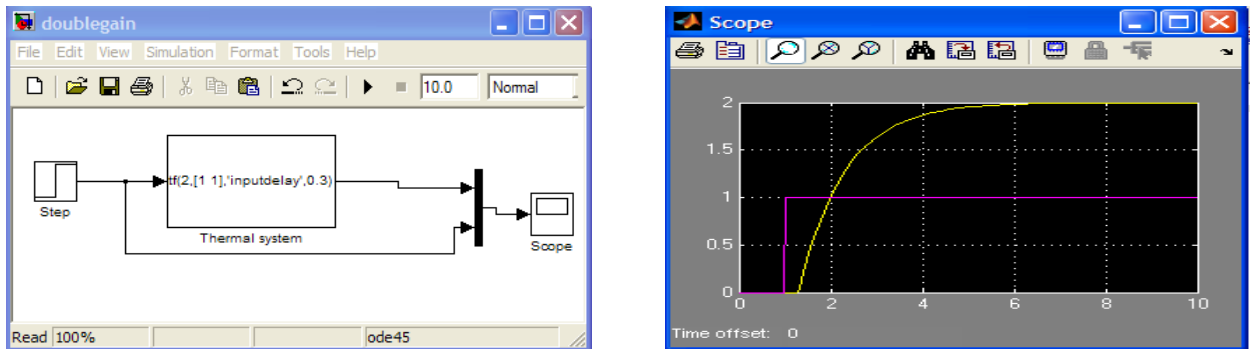


Figure.3 Change in static gain.

3.3. Change in Delay time.

Changing delay of the system from 0.3s to 0.6s keeping rest of the parameters unchanged. The system response shows that system having higher time delay takes more time to change parameters though; both the responses reached the final value at the same time approximately 7s shown in Figure.4.

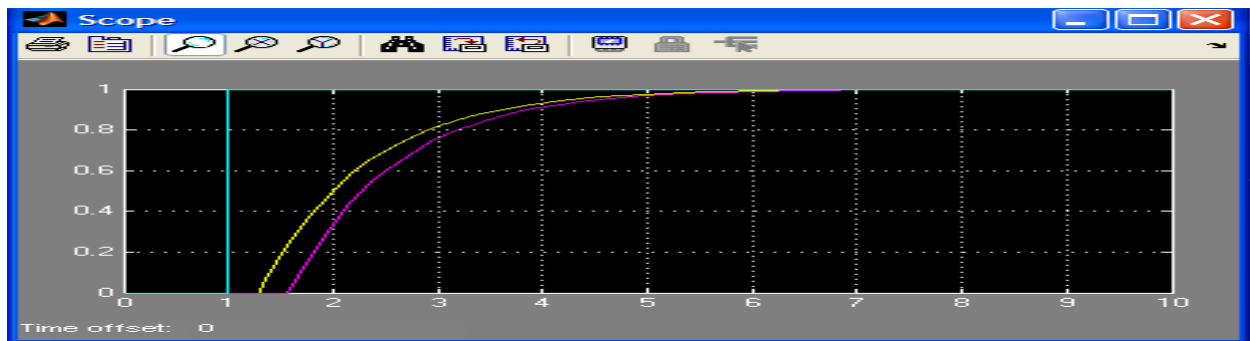


Figure.4 Change in delay time of system.

3.4. Change in Time constant

Changing system time constant from 1s to 2s keeping rest of the parameters unchanged. The system response shows that system having higher time constant takes more time to reach final value i.e 7s and 13s respectively Figure.5.

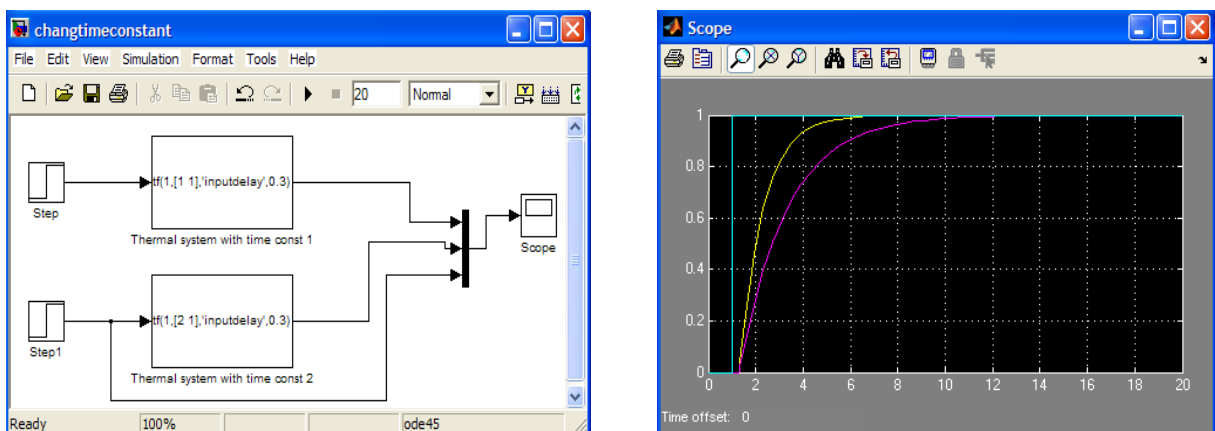


Figure.5 Step response with change in time constant of system.

3.5. Adding white Noise

Adding white Gaussian noise having amplitude 0.001, sample time 0.1s keeping rest of the parameters unchanged. Effect on the signal can be easily observed in the signal marked with YELLOW color.

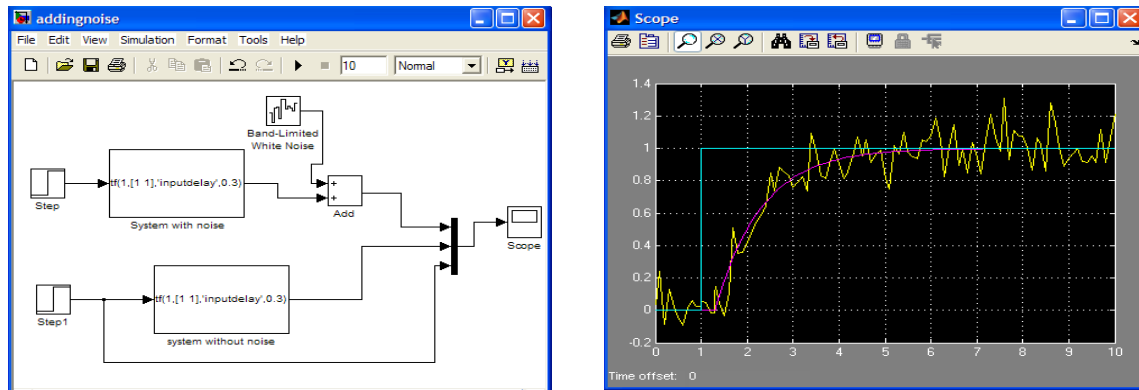


Figure.6 Step response with white noise.

4. Conclusion

Various conditions for the first order system have been observed and can be taken as reference with the response of real time system. The various conditions can be correlated as under.

1. Response of the open loop system can be used to study the behavior of the plant. Various methods like Reaction curve and relay feedback can be used to find PID parameters.
2. Static gain of the system can be easily correlated with proportional gain of the PID controller.
3. Time delay can be correlated with the sensor position, location of the sensor in the system decides the time delay in the system. Tip of the sensor in directly contact with the actual process gives fast response compared to placing far away from the actual process.
4. Effect of the noise can be correlated with the chattering of the contactor and switching of the other devices in the system.

Analysis carried out using tool MATLAB can be useful to compare the results of the real time system where temperature is being controlled with simple heater system. It can be useful to derive control strategy for the system.

References

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