Control simulation of a distillation column using SIMple® Control System on Altair Activate™

Introduction

SIMple® provides a powerful set of user-friendly, accurate and high-performance libraries for logical and physical modeling and simulation. Using the SIMple® Control Systems library, the user can design, study and simulate sophisticated control logic for entire processes in a fast and uncomplicated way. A control case of a distillation process is presented here.

Distillation columns are very common units found in several processes. Its purpose is to separate liquid mixtures based on the relative volatility of the components. In the case presented, taken from [1], the distillation column is used to separate ethanol from the water.

Model

The system considered is shown in Figure 1. The reflux flow (U1) was chosen by the authors of [1] to control the molar fraction of ethanol in the top product (Y1) while the reheated steam (U2) flow rate was chosen to control the composition of the product on the bottom (which is influenced by Y2, the temperature of the bottom plate). The locally linearized model for the system is as shown on [1]:

$$\begin{bmatrix} Y_1(s) \\ Y_2(s) \end{bmatrix} = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} \begin{bmatrix} U_1(s) \\ U_2(s) \end{bmatrix} \quad (1)$$

Where,

$$G_{11}(s) = \frac{0.66e^{-2.6s}}{6.7s + 1} \quad (2)$$

$$G_{12}(s) = \frac{-0.49e^{-s}}{9.06s + 1} \quad (3)$$

$$G_{21}(s) = \frac{-34.7e^{-9.2s}}{8.15s + 1} \quad (4)$$

$$G_{22}(s) = \frac{0.87(11.6s+1)e^{-s}}{(3.89s+1)(18.8s+1)} \quad (5)$$

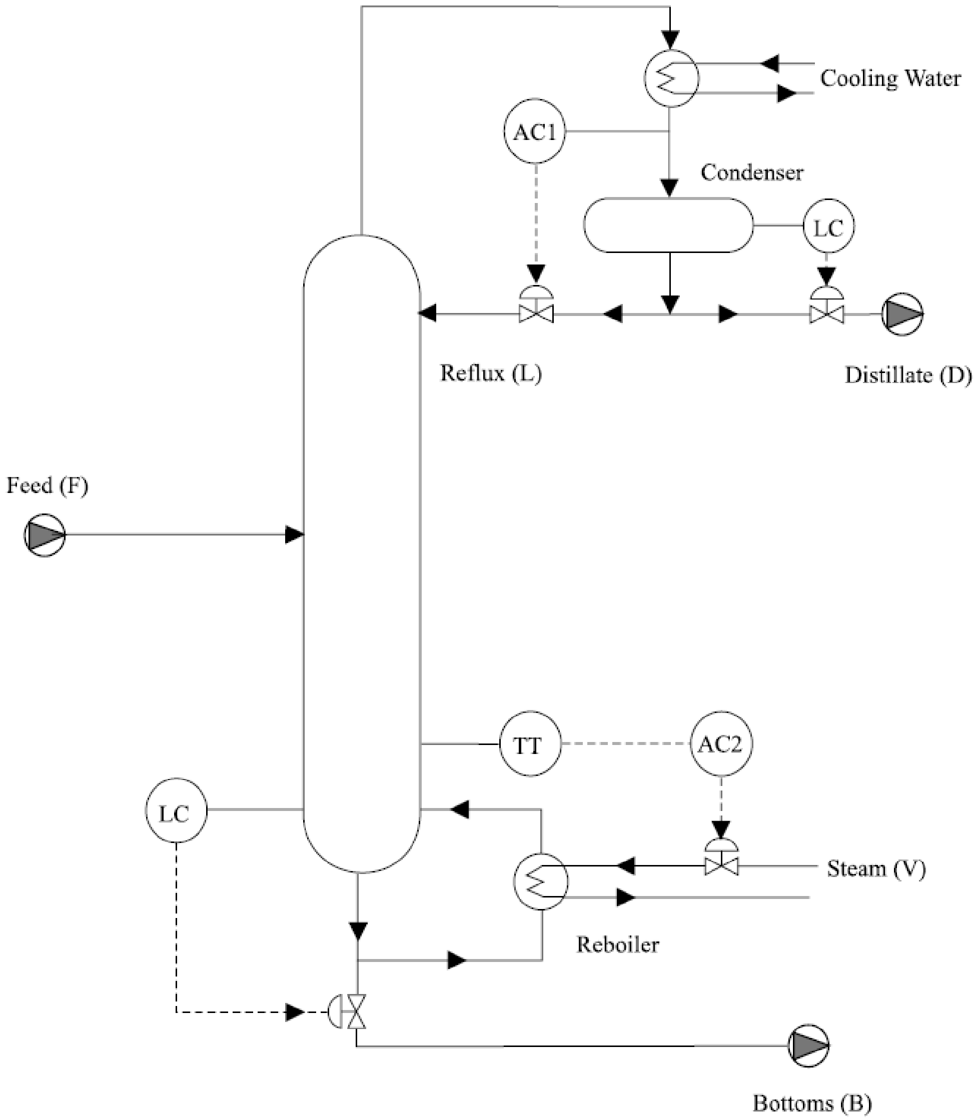

Figure 1 - Illustration of a water-ethanol distillation column from [1] .

As shown by [1], the transfer functions G12 and G21 indicate that there is interference of one process variable in the other, i.e. not only U1 affects Y1 (via transfer function G11) but also affects Y2 (via transfer function G21) and, similarly, U2 affects both Y2 (via transfer function G22) and Y1 (via transfer function G12). However, for the controller's design, the authors chose to implement two separate SISO systems without interference from one another to evaluate the results:

$$\begin{bmatrix} Y_1(s) \\ Y_2(s) \end{bmatrix} = \begin{bmatrix} G_{11}(s) & 0 \\ 0 & G_{22}(s) \end{bmatrix} \begin{bmatrix} U_1(s) \\ U_2(s) \end{bmatrix} \quad (6)$$

Considering two separate SISO processes and without interference from one another, the design of the controllers becomes more simplified. The resulting controllers are two Proportional-Integers (PI), whose transfer functions are given by:

$$C_1(s) = 1 + \frac{0.25}{s} \tag{7}$$

$$C_2(s) = 1 + \frac{0.15}{s} \tag{8}$$

Simulation

It's possible and easy to simulate the system shown in previous section extracted from [1] using blocks from SIMple® Control Systems on Altair Activate™ environment. The diagram shown in Figure 2 below was built using Activate™ native blocks to design the transfer functions systems and two PI controllers included in SIMple® Control Systems to design the control:

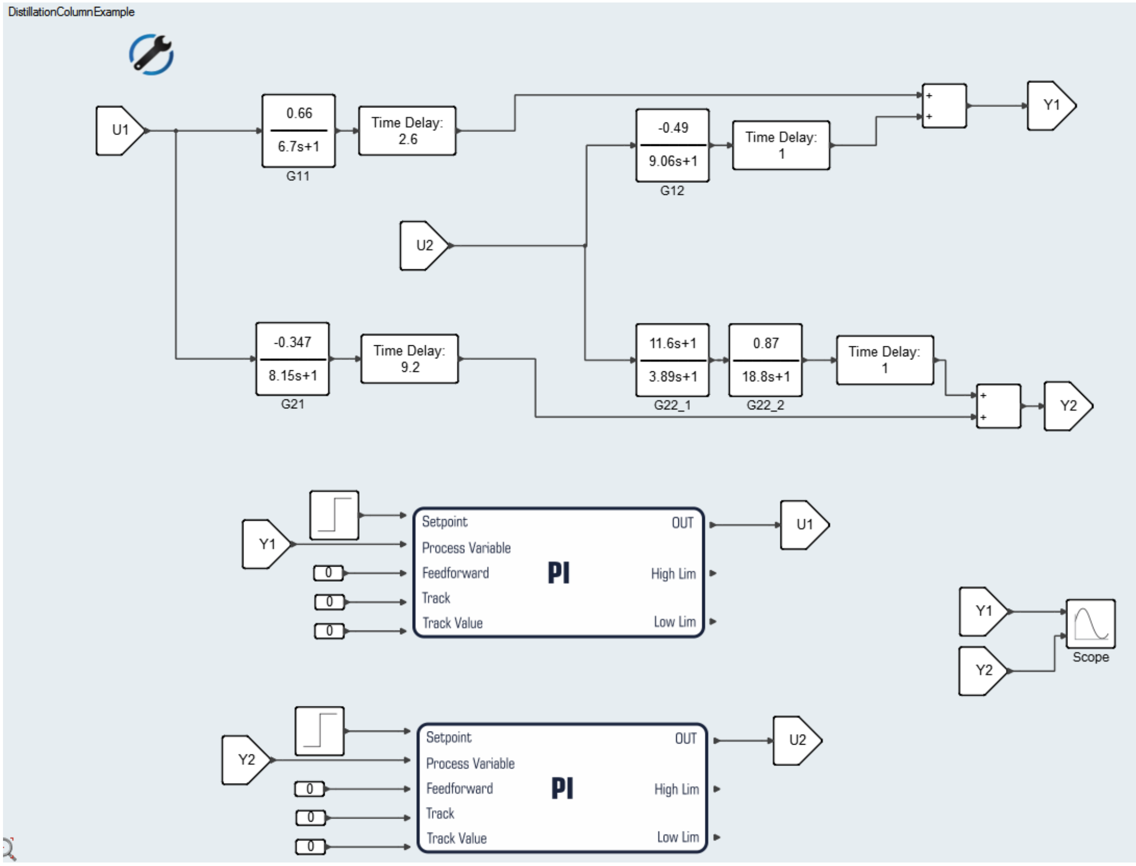

Figure 2 - Control diagram of the distillation column using the SIMple® Control Systems library.

For control of the plant, two PI control blocks of SIMple® Control Systems were used, which can be easily configured with the proper gains and parameters required for the simulation. This block provides additional configurations as an option for using the integrator's anti-windup function and option for output limitation, as can be seen in its parameter configuration window (Figure 3).

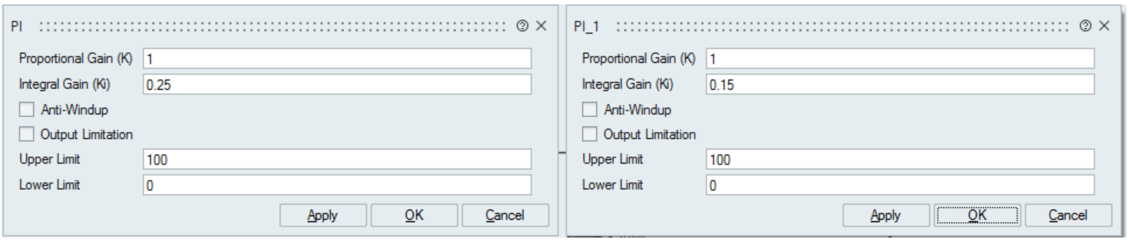

Figure 3 - Configuration windows of PI controller blocks parameters.

For the test, the reference for output Y1 is a step of amplitude 2 applied at t = 50 min and for output Y2 this is a unit step applied at t = 250 min. In other words, an amplitude increases 2 is expected in the ethanol molar fraction at the top of the distillation column at time t = 50 min, and a 1 degree increase in the base temperature of the distillation column at time t = 250 min.

Result and discussion

The graph with the values of the outputs Y1 (mole fraction of ethanol in the top product) and Y2 (bottom plate temperature) resulting from the simulation using SIMple® Control blocks on Activate™ can be seen in Figure 4, while results from [1] are in Figure 5.

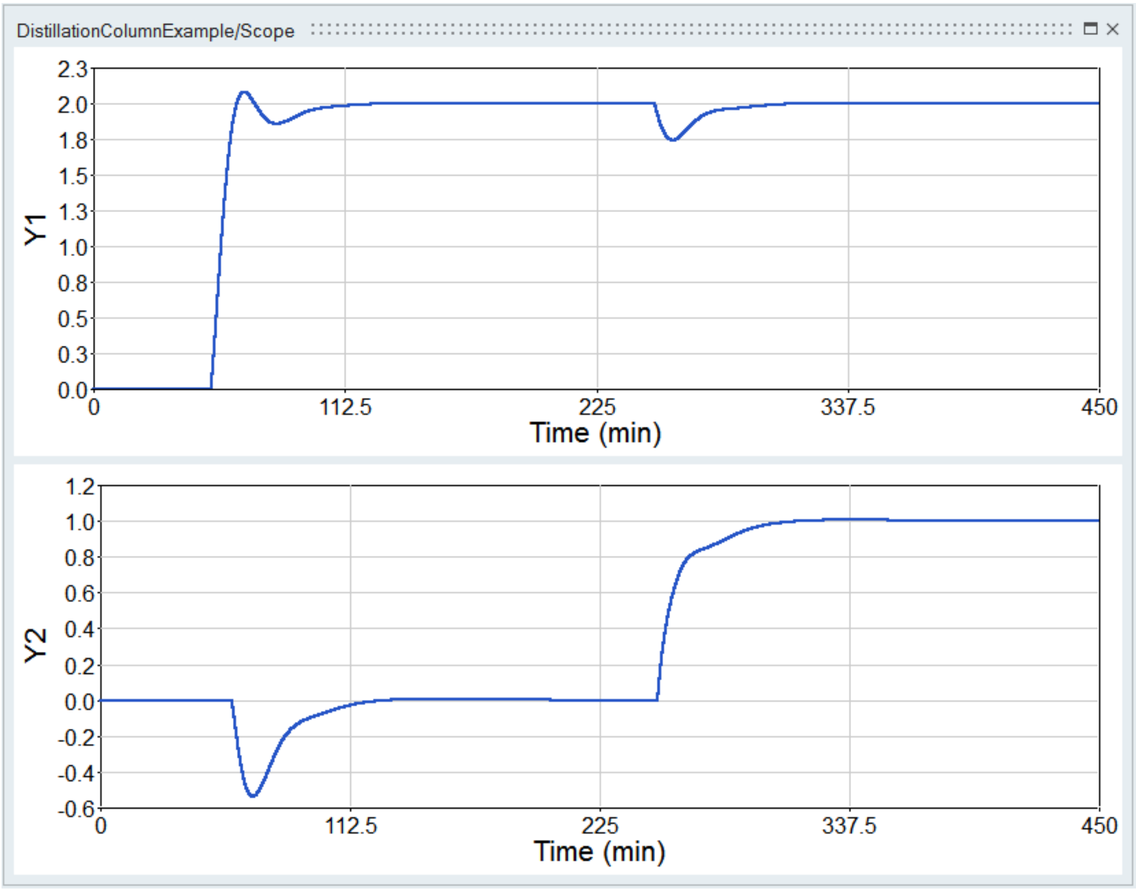

Figure 4 - Graphs of the outputs Y1 and Y2 resulting from the simulation.

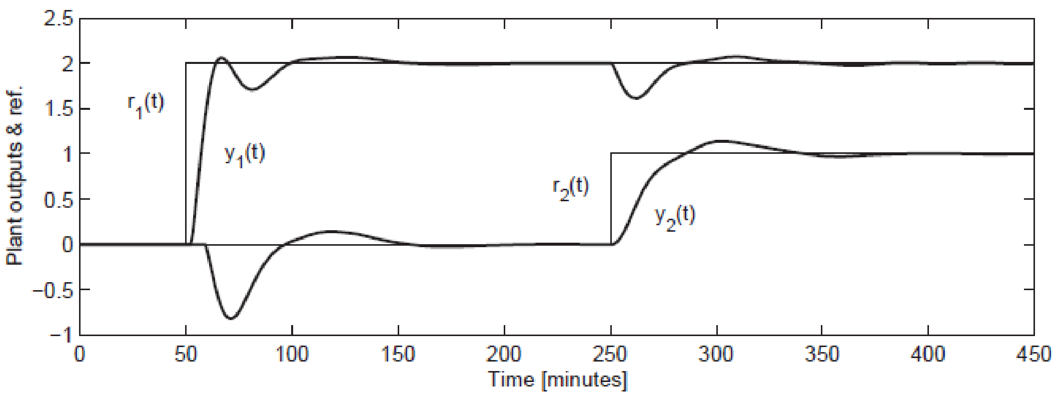

Figure 5 - Results from [1].

The authors in [1] state that results in Figure 4 show that the PI controller provides an acceptable performance for the problem. However, the figure also shows that a change in the reference r1 not only causes a change in Y1, but also induces a transient behavior in Y2. Similarly, the change of r2 causes a change in Y1. This is very common in practical applications. In this case the interactions are small and probably acceptable.

It is also possible to notice from comparison between Figure 4 and Figure 5 that the general behavior could be reproduced by the system built on Activate™ with SIMple® Control Systems blocks. Since the author's proportional and integral gains are not known, the case simulation had its gains estimated, what caused minor differences in overshoot behavior.

Conclusion

The work presented showed how the SIMple® Control Systems library can be easily used for modeling and control design for real applications. With only one block (the PI block), the controller from [1] could be reproduced with accuracy. The native block from the library still provides useful features as anti-windup limits protection, if the user desires. If not, the user needs to input only 2 parameters to set proportional and integral gains and perform a simple closed loop control. There are also inputs for feedforward (not used in this simulation) and track values, if the user wants to develop a master-slave control case.

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References

[1] G. C. Goodwin, S. F. Graebe e M. E. Salgado, Control System Design, Upper Saddle River: Prentice Hall, 2001, p. 170.