The Tennessee Eastman Project

Creation of an S-Function to Model the TE Process

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I. What We Accomplished

Our main accomplishment is the implementation of a working S-function that models the TE process. We went through the following steps to achieve our goal:

- Gained an understanding of the S-function block in Simulink
- Stepped manually through the 'tefunc' program to understand how it worked
- Set-up a Simulink model to run the 'tefunc' & 'teinit' programs
- Wrote an S-function to use the 'tefunc' and 'teinit' programs so that they correctly model the TE problem in Simulink.
- Implemented internal controllers with the following parameters to stabilize the process in the absence of disturbances:

Internal Controller	Proportional Gain	Integral Time Constant (min.)
A Feed Flow	100	1
D Feed Flow	0.0172	1
E Feed Flow	0.008	0.05
A/C Feed Flow	6.5573	1
Purge Flow	118	1
Separator Underflow	0.8	0.5
Stripper Underflow	1.2	0.5
Stripper Steam Flow	0.206	3
Reactor Cooling Water Temp	-5	3
Separator Cooling Water Temp	-3	1

Table 1. Internal Controllers and their parameters

- Updated the user interface with external controllers using the following parameters to stabilize the reactor, stripper, and separator levels in the presence of a disturbance:

External Controller	Proportional Gain	Integral Time Constant (min)
Reactor Level	300	60
Separator Level	-0.301	60
Stripper Level	-0.1789	60

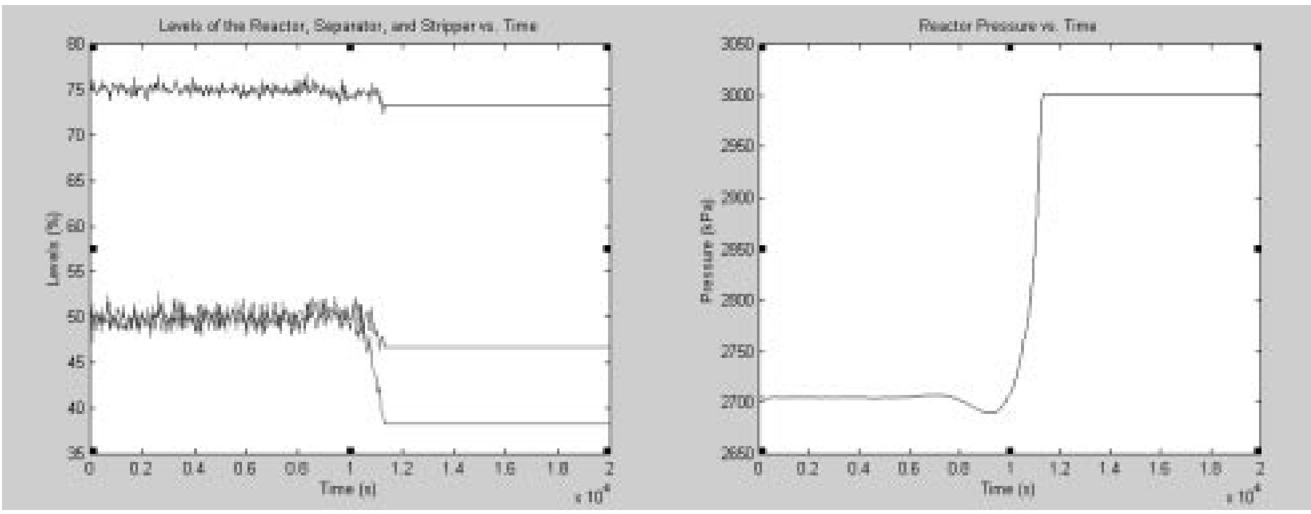
Table 2. External Controllers and their parameters

- Tests were run to examine the behavior of all Simulink models under different operating conditions.

II. Test Results

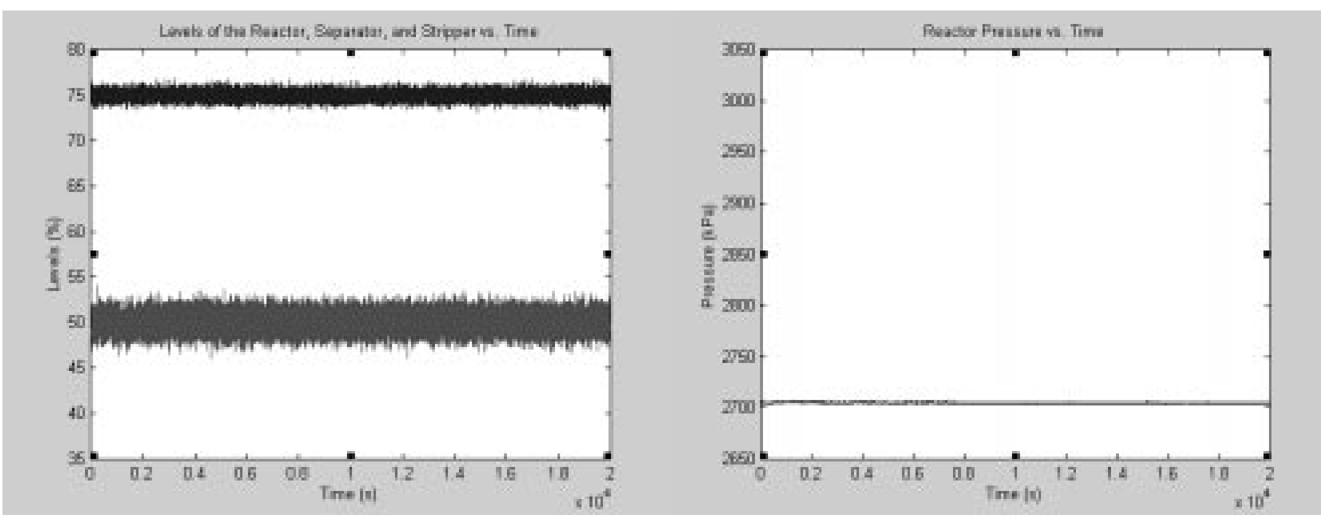
Four variables that were closely monitored: the levels of the reactor, the separator and the stripper, and the reactor pressure. It was found that when no controllers (external or internal) existed, the process ran out of control as seen in Figure 1 below:

Figure 1: The TE Process without Controllers



When the internal controllers were added, the process exhibited a steady state as seen below in Figure 2:

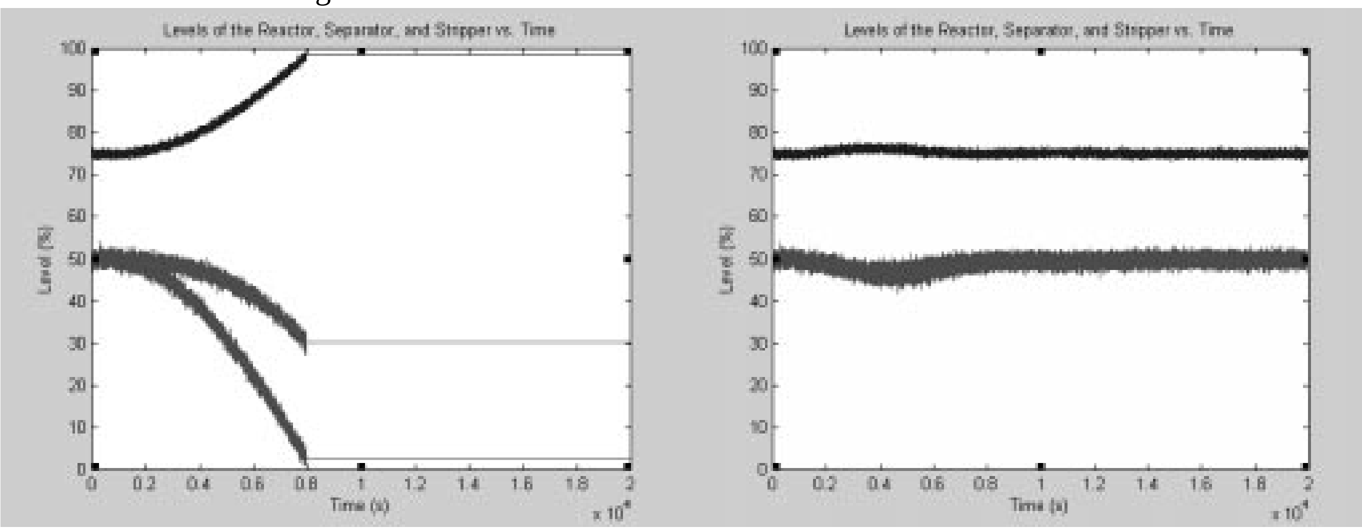
Figure 2: The TE Process with Internal Controllers



After implementing the external controllers, the performance of the model without external controllers and the one with external controllers in the presence of a disturbance was tested. The A Feed loss disturbance (Disturbance #6, see Appendix) was stepped from 0 to a value of 10 at 500 seconds; this disturbance was inputted to Simulink models Two4_new (without external controllers) and Two5 (with external controllers) (see Appendix for Simulink Diagrams).

The model without external controllers was clearly out of control as the levels deviated from their steady state values and no corrective action was observed. The model with external level controllers, however, kept the levels near their steady state values at all times. A comparison of these simulations is shown in Figure 3.

Figure 3: The TE Process in the Presence of an A Feed Loss



Without External Controllers   With External Controllers

For the model with external level controllers, however, the reactor pressure did not remain at steady state since there was no controller assigned to this variable. Thus, although the levels are clearly in control, other variables in the TE plant are still sensitive to disturbances. The graph of reactor pressure versus time is shown in Figure 4.

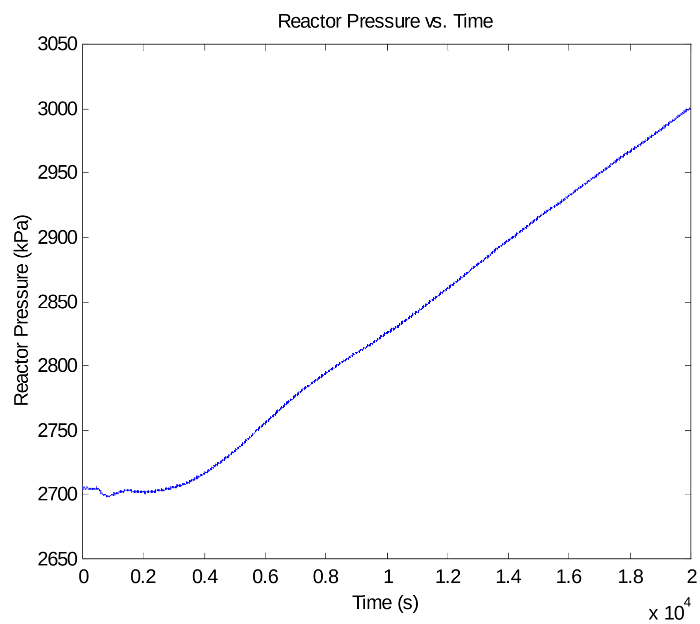


Figure 4: Reactor Pressure vs. Time for Two5.mdl

III. Issues Resolved

We consider the following issues to be resolved:

1. The creation of a working S-Function that models that TE process.
2. The stabilization of the TE Process under normal operating conditions using internal controllers.
3. The stabilization of the reactor, separator, and stripper levels in the presence of a disturbance using external controllers. Please note that the reactor pressure, among other variables, is not necessarily stable in the presence of a prolonged disturbance.

IV. Appendix

A. S-Functions

We have appended two S-Function programs:

1. sfnc3.m – the TE Plant with no internal controllers
2. sfnc5.m – the TE Plant with internal controllers for the manipulated variables

Both functions initialize the TE plant using the MEX file TEINIT and then step the plant through time by calling TEFUNC.

Both programs require a step size T_samp plus 32 inputs. In order to specify T_samp, one must open the S-Function Simulink block and enter the value under "S-Function parameters."

For sfnc3.m, the first 12 values of the additional 32 inputs correspond to the actual values of the manipulated variables. These inputs specify the xmv array used by TEFUNC. All values except for the agitator speed are listed as percentages:

Input Number	Manipulated Variable	Base Case Values
1	D Feed Flow Valve	63.053
2	E Feed Flow Valve	53.980
3	A Feed Flow Valve	24.644
4	A/C Feed Flow Valve	61.302
5	Compressor Recycle Valve	22.210
6	Purge Valve	40.064
7	Separator Liquid Underflow Valve	38.100
8	Stripper Liquid Underflow Valve	46.534
9	Stripper Steam Valve	47.446
10	Reactor Cooling Water Valve	41.106
11	Condenser Cooling Water Valve	18.144
12	Agitator Speed	50.000 rpm

The last 20 input variables correspond to the disturbances entering the process. Under normal conditions, these variables are set to zero. These disturbances must be specified in a vector named "disturb" in the Matlab workspace. Curiously, the vector "disturb" must have a length of 21 in order for the process to work. For an unknown reason, the "From Workspace" box in the Simulink model transfers only variables 2 to 21 into the model. We usually declared this array using the Matlab command:

```
disturb=zeros(1,21)
```

The descriptions corresponding to these variables are listed on the next page.

Disturbance Number	Type	Description
1	Step	A/C Feed Ratio
2	Step	B composition
3	Step	D Feed temperature
4	Step	Reactor Cooling Water Inlet Temperature
5	Step	Condenser Cooling Water Inlet Temperature
6	Step	A Feed loss
7	Step	C Header Pressure loss
8	Random Variation	A, B, C Feed composition
9	Random Variation	D Feed Temperature
10	Random Variation	C Feed Temperature
11	Random Variation	Reactor Cooling Water Inlet Temperature
12	Random Variation	Condenser Cooling Water Inlet Temperature
13	Slow Drift	Reaction Kinetics
14	Sticking	Reactor Cooling Water Valve
15	Sticking	Condenser Cooling Water Valve
16	Unknown	Unknown
17	Unknown	Unknown
18	Unknown	Unknown
19	Unknown	Unknown
20	Unknown	Unknown

Regarding the Matlab vector, disturb(2) = Disturbance #1 (A/C Feed Ratio).

For sfnc5.m, the first 12 values of the additional 32 inputs correspond to the setpoints for the manipulated variables. Please note that these are setpoint values and <u>not</u> the actual values of the manipulated variables.

Input Number	Manipulated Variable	Setpoint for Base Case
1	D Feed Flow	3664 kg/h
2	E Feed Flow	4509.3 kg/h
3	A Feed Flow	0.25052 kscmh
4	A/C Feed Flow	9.3477 kscmh
5	Compressor Recycle Setpoint	22.210 %
6	Purge Flow	0.33172 kscmh
7	Separator Liquid Underflow	25.160 m^3/h
8	Stripper Liquid Underflow	22.949 m^3/h
9	Stripper Steam Flow	230.31 kg/h
10	Reactor Cooling Water Temperature	94.599 °C
11	Condenser Cooling Water Temperature	77.297 °C
12	Agitator Speed	50 rpm

B. Simulink Diagrams

We have appended three Simulink Diagrams:

1. Two4.mdl – uses sfnc3.m and contains neither internal nor external controllers
2. Two4_new.mdl – uses sfnc5.m and contains internal but no external controllers
3. Two5.mdl – uses sfnc5.m and contains both internal and external controllers

We recommend that a T_samp of 1 second be used for all of these Simulink models.

The inputs for Two4.mdl are the actual values for the manipulated variables. These are given in the table above detailing the inputs to sfnc3.m.

The inputs for Two4_new.mdl are the setpoints for the manipulated variables. These setpoints are given in the table above detailing the inputs to sfnc5.m.

The majority of the inputs for Two5.mdl are identical to those for Two4_new.mdl; however, Two5.mdl also contains external controllers. These controllers adjust the setpoints of the manipulated variables based on measurements of the reactor level, the separator level, and the stripper level in order to control these same variables. The following external PI controllers have been added:

Manipulated Variable	**Measured and Controlled Variable**	**Setpoint of Measured Variable (%)**
Setpoint of E Feed	Reactor Level	75
Setpoint of Separator Underflow	Separator Level	50
Setpoint of Stripper Underflow	Stripper Level	50

Thus, the outputs of these PI controllers take the place of the constant blocks for E Feed Setpoint, Separator Underflow Setpoint, and Stripper Underflow Setpoint inputs.

The PI controllers used in the Simulink Blocks were programmed by Babu Joseph.