Constrained Steady-State Controllers – Exercise Problem

Objectives

- Gain experience in using constrained steady-state (CSS) controllers in achieving steady conditions.
- Learn how to add CSS controllers to an input model.
- Become familiar with the capability of CSS controllers and practical applications.
- Applying CSS data beyond steady-state.

Overview of Steps

1. Run Base Model and Collect Calculated Data.
2. Create CSS Controllers for Pump Flow
3. Create CSS Heat Controllers for Obtaining the Cold Leg Temperature
4. Create CSS Heat Controllers to Increase Secondary Side Pressure
5. Using Another CSS Controller Type to Increase Secondary Pressure
6. Create CSS Pressure Controller to Achieve Core Differential Pressure
7. Applying CSS Control Data

The input model used in this exercise is of the LOFT experimental facility that was operated by the Idaho National Laboratory during the 1970s and 1980s. LOFT was a PWR experimental facility powered by nuclear fuel rods. The facility contains two loops, with each loop containing two reactor coolant pumps. This input model is setup for steady-state operation. For this exercise it is desired to obtain target values for the pump flow, the cold leg fluid temperature, and the core differential pressure.

These target values are:

- Mass flow rate per pump – 245.0 kg/s
- Cold leg fluid temeprature – 552.8 K
- Core differential pressure – 0.1592 Mpa

These conditions will be achieved using the constrained steady-state option available in TRACE.

Step 1 Run Base Model and Collect Calculated Data.

The base model used for this exercise is set to run in a steady-state mode using a generalized steady-state calculation (STDYST = 1). The object in this step is to run the base model and collect calculated data in various locations of the facility.

1. Open the base model (CSS1.med) in the SNAP Model Editor. The base model, **CSS1.med**, is located in the Day2/Morning/Steady-State_Model_Options/Exercise folder. A Job Stream tab is located at the bottom of the 2D view window. In the Job Stream tab, and assure the following:

    a) submit name is titled "CSS-Test1",

    b) Code Application is pointing to the TRACE executable being used in this workshop (TRACE Base_Job),

    c) View in Job Status is turned on,

    d) Animation Model is pointing to "napcss-anim.med" located in the same folder as the CSS1.med file,

    e) Open Animation "Immediately",

    f) Data Sources should be pointing to trcxtv:Master,

    g) Interactive Step should be "on",

    h) Start Paues should be "on", and

    i) Demultiplexing Plot Files should be turned on.

2. Click on the lock icon  in the upper left-hand corner of the 2D view window and then click on the Submit button. This will submit the job to execution. The progress of the submitted job will appear in the Job Status window. After input processing, the job will pause and an animation window will appear in the Model Editor. The animation shows several time history plots of the calculation. Click the appropriate buttons to start the calculation running.

   At the end of the calculation, record the calculated values into the column labeled CSS-1 in the table located at the end of this exercise instruction.

Step 2 Create CSS Controllers for Pump Flow

From the base run, it is noted that the pump mass flow rates are high, the cold leg temperatures are low and the core differential pressure is low. During this step, four CSS controllers will be added to the model that will control the pump speed to yield the target pump mass flow rate of 245 kg/s.

1. In the model editor, save the CSS1.med file as CSS2.med.
2. Unlock the 2D view , then locate and click on the Model Options in the Navigation window. In the component navigation window, locate Steady State Mode and change it from a GSS Calculation to a CSS Calculation. This signals TRACE that we want to do a CSS calculation and the SS inputs need to be entered into the input model.
3. While in the component navigation window, locate Constrained Steady-State and expand  the input box.
4. Add four CSS controllers. Since we want these controllers to adjust the pump speed to obtain the target pump mass flow rate, these controllers need to be the Pump Controller Type. Verify the Type is correct for the four CSS controllers.
5. The adjusted component will be PUMP 4, PUMP 5, PUMP 104, and PUMP 105.

Make these selections in the Adjusted Component Box for each of the four CSS controllers.

6. The parameter that will be monitored will be the pump mass flow rate. Verify and change if necessary the Monitored Parameter input for each of the controllers. In addition, set the Liquid Massflow Setpoint to 245.0 kg/s. This is the target pump mass flow rate. What SNAP will do is apply that mass flow rate as an initial condition input for the liquid velocity at cell face 2 of the pump component input.

   (When finished with the CSS controller input data, verify the mass flow rate by observing the ascii input for the PUMP. This is done by right clicking on the PUMP component and selecting the view ascii option.)

7. The final thing left to input is the Maximum and Minimum Adjusted Values. We note from the PUMP input the rated pump speed is 369.66 rad/s. The maximum and minimum values should bound this value. For simplicity sake, input a maximum value of 500 and a minimum value of 200.

8. In the Job Stream tab at the bottom of the 2D view window, click on the Submit button and in the component navigation window change the name to "CSS-Test2". **Save the input model changes** by clicking on the save button in the top tool bar of the Model Editor. As in Step 1 above, lock the model and submit the job stream.

9. Record the calculated values in the table.

Points of Discussion: Although the CSS controllers honed in on the correct pump mass flow rate, the pump angular speed is a little different for each pump. What are some probable causes for the different pump speeds?

The CSS controllers slowed the pump speed to obtain the target mass flow rate. The other monitored parameters did not significantly change. Is this expected? If so, why, if not why.

Step 3 Create CSS Heat Controllers for Obtaining the Cold Leg Temperature

In this step, we will add some CSS controllers to bring the cold leg temperature to the target value of 552.8 K. There are several ways to accomplish this. As we recall in the discussion of the CSS controllers, a Type 4 controller (HTSTR) can be used to adjust the coolant temperature. There are several different way this can be accomplished with the CSS HTSTR controller. These include changing the BREAK pressure that is associated with the loop which the HTSTR resides in, using a multiplier on the inside or outside surface area, or both, using a multiplier on the inner or outer surface conductivity, or both, using a multiplier on the conduction at each radial node, or using a multiplier on the surface areas and conductivity. For purposes of demonstration, lets assume that a small change in the inside and outside surface area of the SG U-tube heat structures (HTSTR 901 [Loop 1] and HTSTR 921 [Loop 2]) will do the job.

1. In the model editor, save the CSS2.med file as CSS3.med.
2. Unlock the 2D view , then locate and click on the Model Options in the Navigation window. Locate Constrained Steady-State and expand the input box.
3. Add two more CSS controllers.
4. Since we want these controllers to adjust the surface area of the SG U-tube heat structures, the controller type must be set to Heat Controller.
5. The Adjusted Components will be the U-Tube heat structures (HTSTR 901 and HTSTR 921).
6. The Adjusted Parameter will be the inner and outer surface area of the U-Tube HTSTRs.
7. The Monitored Parameter is the fluid temperature in the outlet plenum of the SG U-Tubes, PIPE 2 and PIPE 102, cell 10. To activate this parameter in SNAP locate the Monitored Parameter in the CSS controller popup window and change "Control" to

"Cell Location". Expand the Monitored Parameter input and select PIPE 2 and PIPE 102, Cell 10.

8. Note that by selecting "Cell Location" two more pieces of information are needed for input; the Setpoint type and the Setpoint. Since we want the Heat Controller to adjust the surface areas to achieve a target cold leg temperature the Setpoint Type must be "Temp" and the Temperature Setpoint must be the target temperature of 552.8 K. What SNAP will do is use the input of 552.8 K as an initial condition liquid temperature in Cell 10 of PIPEs 2 and 102.

   (When finished with the CSS controller input data, verify the cold leg temperature input by observing the ascii input for the SG U-Tube hydro components [PIPEs 2 and 102]. This is done by right clicking on the PIPE component and selecting the view ascii option.)

9. The final thing left to input is the Maximum and Minimum Adjusted Values. Recall in the CSS controller discussion, the controllers should not significantly change the heat structure surface area and/or thermal conductivity. A rule of thumb was given as -10% to +2%. Thus the Maximum Adjusted Value should be 1.02 and the Minimum Adjusted Values should be 0.9.

10. In the Job Stream tab at the bottom of the 2D view window, click on the Submit button and in the component navigation window change the name to "CSS-Test3". **Save the input model changes.** As in Step 1 above, lock the model and submit the job stream.

11. Record the calculated values in the table.

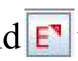
Points of Discussion: We observed that the change in the heat structure surface area had little effect on the cold leg temperature. It is still too low. By what other means could the cold leg temperature be affected?

One method of affecting the cold leg temperature is by increasing the steam generator secondary side saturation temperature. By increasing the secondary side pressure we are increasing the secondary side saturation temperature. The next step will proceed by using the Heat Controller to increase the steam generator secondary pressure.

Step 4 Create CSS Heat Controllers to Increase Secondary Side Pressure

In PWR models, the steam generator secondary side is modeled with several components to represent the various parts of the steam generator, including the steam line out to the turbine. The steam line is typically modeled with PIPEs and VALVEs, the PIPEs modeling the steam lines and the VALVEs modeling the turbine control and stop valves. The turbine is typically modeled with a BREAK component. In this model, the steam line and turbine control/stop valves are modeled with a VALVE component with six computational cells. The VALVE action occurs near the exit of the VALVE component at cell face 6. A BREAK component is attached to the outlet side of the VALVE component and represents the turbine.

In this step, we will add two CSS Heat Controllers to increase the steam generator secondary side pressure. By increasing the secondary side pressure, we increase the saturation temperature, thereby affecting the primary side cold leg temperature. One option of the CSS Heat Control is adjusting a BREAK pressure to achieve the target coolant temperature. Either an inner or an outer HTSTR surface BREAK pressure can be adjusted. What this means is if the inner surface BREAK pressure is selected, TRACE will search for a BREAK component in the hydraulic loop that is connected to the inner surface of the CSS selected heat structure. Likewise, if the outer surface of a HTSTR is selected, TRACE will look for a BREAK component in the hydraulic loop connected to the HTSTR to adjust the pressure. Note that TRACE will not allow more than one CSS Heat Controller to be connected to a HTSTR component. Since we want to adjust the secondary side pressure, we can choose any steam generator secondary side heat structure other than HTSTRs 901 and 921, since they are already used in Step 3 above.

1. In the model editor, save the CSS3.med file as CSS4.med.
2. Locate and click on the Model Options in the Navigation window. Locate Constrained Steady-State and expand the input box.
3. Add two more CSS controllers.
4. As in Step 3 above, we want to select the Heat Controller Type.
5. The Adjusted Components will be the steam generator boiler wall heat structures (HTSTR 903 and HTSTR 923).
6. The Adjusted Parameter for this step will be the "Outer Surface Pressure". Note that for these heat structures the "Inner Surface Pressure" could have been selected since both heat structures point to the secondary side hydrodynamic components.
7. As in Step 3 above, the Monitored Parameter is the fluid temperature in the outlet plenum of the SG U-Tubes, PIPE 2 and PIPE 102, cell 10. To activate this parameter in SNAP locate the Monitored Parameter in the CSS controller popup window and change "Control" to "Cell Location". Expand  the Monitored Parameter input and select  PIPE 2 and PIPE 102, Cell 10.
8. Note that by selecting "Cell Location" two more pieces of information are needed for input; the Setpoint type and the Setpoint. Since we want the Heat Controller to adjust the surface areas to achieve a target cold leg temperature the Setpoint Type must be "Temp" and the Temperature Setpoint must be the target temperature of 552.8 K. What SNAP will do is use the input of 552.8 K as an initial condition liquid temperature in Cell 10 of PIPEs 2 and 102.
9. The final thing left to input is the Maximum and Minimum Adjusted Values. For a Heat Controller type that adjusts a BREAK pressure, TRACE applies a multiplier to the BREAK pressure. The maximum and minimum range of this multiplier is determined by the input for the maximum and minimum adjusted values. For this case, let us select a maximum multiplier of 5.0 and a minimum multiplier of 0.01. Note that these inputs may need to be modified if the BREAK pressure maxes out and the target cold leg fluid temperature is not achieved.
10. In the Job Stream tab at the bottom of the 2D view window, click on the Submit

button and in the component navigation window change the name to "CSS-Test4". **Save the input model changes.** As in Step 1 above, lock the model and submit the job stream.

11. Record the calculated values in the table.

Points of Discussion: Using the CSS Heat Controller to change the BREAK pressure resulted in obtaining the desired cold leg temperature. The issue now at hand is with the BREAK component pressure. We see that the CSS Heat Controller increased the BREAK pressure from about 2.0 Mpa to about 5.0 Mpa. If the BREAK pressure was meant to remain at 2.0 Mpa to model the turbine inlet pressure, then using the CSS Heat Controller to modify the BREAK pressure is not the correct method of changing the secondary side pressure to achieve the cold leg temperature.

Under the constraints of the CSS controllers, what other method could be used to increase the steam generator secondary side pressure?

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One method of affecting the cold leg temperature is by increasing the steam generator secondary side saturation temperature. By increasing the secondary side pressure we are increasing the secondary side saturation temperature. The next step will proceed by using the Heat Controller to increase the pressure on the outer surface of the steam generator U-Tubes.

Step 5 Using Another CSS Controller Type to Increase Secondary Pressure

This step will modify the CSS controller applied in Step 4 to use a different Type to adjust the secondary side pressure in order to achieve the target cold leg temperature.

We note that the average steam generator dome pressure was about 5.825 MPa to achieve the cold leg temperature of 552.8 K. Another type to adjust the steam generator secondary side pressure is the CSS Valve Controller. One option for this controller is to adjust the valve face flow area to increase/decrease the upstream pressure. This method preserves the BREAK pressure and uses a multiplier to adjust the VALVE face area.

1. In the model editor, save the CSS4.med file as CSS5.med.
2. Locate and click on the Model Options in the Navigation window. Locate Constrained Steady-State and expand the input box.
3. The CSS controllers added in Step 4 above are 7 and 8. These controllers will be modified to use the VALVE controller.
4. Change the CSS controllers to Type "Valve Controller".
5. The Adjusted Components will be the steam line valves (VALVE 23 and VALVE 123).
6. Since we want to adjust the valve flow area to achieve a target upstream pressure, verify that the Monitored Parameter is set to "Upstream Pressure".
7. The Pressure Setpoint for which the VALVE flow area will be adjusted is the steam generator dome pressure obtained in Step 4 above (set pressure = 5.82 MPa).
8. The final thing left to input is the Maximum and Minimum Adjusted Values. Since the valve cannot open any more that an area fraction of 1.0 and close less than an area of 0.0, set these as the maximum and minimum values.
9. In the Job Stream tab at the bottom of the 2D view window, click on the Submit button and in the component navigation window change the name to "CSS-Test5". **Save the input model changes.** As in Step 1 above, lock the model and submit the job stream.
10. Record the calculated values in the table.

Points of Discussion: Applying the CSS controller to adjust the steam line valve area produced the desired secondary side pressure to achieve the cold leg fluid temperature. The BREAK pressure was preserved. Note the valve area was reduced by about half.

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The final thing to do is develop a CSS controller that will adjust the additive flow loss to achieve the target core differential pressure.

Step 6 Create CSS Pressure Controller to Achieve Core Differential Pressure

The CSS Pressure Controller Type adjusts the additive form loss at a specified cell face to achieve a target differential pressure. Implementation of this controller type is a little more involved than the other types. The required inputs to make this controller type work includes an initial condition velocity at the cell face where the additive flow loss is to be adjusted (a zero velocity will result in an input error). It also includes specifying the initial condition pressures in the component cells where the differential pressure is to be calculated that gives the target differential pressure. For this example problem, the core differential pressure is calculated between TEE 36, Cell 4 (vessel lower plenum inside) and TEE 83, Cell 1 (upper plenum and core bypass). The location where the additive flow loss will be adjusted is at cell face 5 of TEE 36 (core inlet flow plate). The following steps outline what is required to achieve a working CSS Pressure Controller.

1. In the model editor, save the CSS5.med file as CSS6.med.
2. Locate and click on the Model Options in the Navigation window. Locate Constrained Steady-State and expand the input box.
3. Add another CSS controller (should be a total of nine CSS controllers).
4. Change the CSS controller to Type "Pressure Controller".
5. The Adjusted Component is the lower plenum, TEE 36 and the adjusted cell edge is 5.

6. The Monitored Parameter is TEE 36, Cell 4 and the Adjusted parameter is TEE 83 Cell 1.

7. TRACE adjusts the additive flow loss coefficient at the specified location by using a multiplier on the user input K-Loss at that location. For this problem, the location where the additive flow loss is to be adjusted is in TEE 36, Cell Face 5. By examination of the input for TEE 36, it is shown that the user input for the K-Loss at Cell Face 5 is 0.0. The Minimum Adjusted Value input can not be any lower that 0.0. The Maximum Adjusted Value must be sufficiently large enough to accommodate the adjusted flow loss to achieve the target differential pressure. For this problem we will assume a maximum value of 3.0.

8. The target differential pressure is 0.1592 MPa. Obtain the initial condition pressure in TEE 36, Cell 4. The Cell 4 pressure is: ______________. Subtract the target differential pressure from the initial pressure in Cell 4: __________________. This pressure is the initial condition pressure that you will need to set in TEE 83, Cell 1.

9. The final thing left to input is a seeded velocity at the cell face where the additive flow loss is to be adjusted. For this case, the flow loss is adjusted at TEE 36, Cell Face 5. It is noted the initial condition liquid and vapor velocities at Cell Face 5 of TEE 36 are set to 0.0. Reset these initial conditions input to a seeded value of 2.0.

10. In the Job Stream tab at the bottom of the 2D view window, click on the Submit button and in the component navigation window change the name to "CSS-Test6". **Save the input model changes.** As in Step 1 above, lock the model and submit the job stream.

11. Record the calculated values in the table.

Points of Discussion: Applying the CSS controller to adjust the additive flow loss at the core inlet flow plate resulted in the desired core differential pressure. An examination of all of the monitored parameters show that using the CSS controllers yields steady-state conditions that meet all of the target conditions.

Step 7 Applying CSS Control Data

The steps above illustrate how using CSS controllers are very helpful in achieving target values during a steady-state calculation. Experience has shown that direct restarts from the end of a CSS calculation do not work. Therefore, the recommended method is to import the steady conditions from the end of a CSS calculation into the input file, then apply the adjusted CSS parameters to the input file. This step provides guidance for applying the CSS adjusted parameters into the input file.

For this example problem, the adjusted parameters from the CSS controllers were the pump angular speeds, the steam line valve flow area, the steam generator U-tube heat structure surface area, and the core inlet (core plate) additive flow loss factor. It was observed that adjusting the surface area of the steam generator U-Tube heat structures had an insignificant effect on the primary side cold leg temperature, therefore this adjusted parameter can be ignored.

This step will port the CSS adjusted parameters back into the base input file and the generalized steady-state calculation rerun to assure initial conditions are maintained with the adjusted parameters.

1. Open the base model (CSS1.med) in the SNAP Model Editor (the base model, **CSS1.med**, is located in the Day2/Morning/Steady-State_Model_Options/Exercise folder). In the Model Editor, save the file as CSS7.med.
2. Update the steam line valve component initial flow area fraction:
   a) Click on the Hydraulics Components View tab located at the bottom of the 2D view window and locate and click on the Loop 1 main steam line valve component (VALVE 23). In the component navigation window, locate the input for the "Initial Flow Area Fraction". The valve open area is 0.03758 m2. Using

this value and the value for the steam line 1 valve area calculated in Step 6 (refer to the SL-1 area recorded in the table under the column labeled CSS-6), calculate the valve area fraction and input this value for the "Initial Flow Area Fraction".

b) Do the same thing for the Loop 2 steam line valve component (VALVE 123).

c) Note that if the steady conditions at the end of the Step 6 calculation had been imported into the model, the initial flow area fraction would have been imported.

3. Update initial speed of the PUMP components:

a) Locate and click on PUMP 4 in Loop 1. Locate the "Initial Speed" input box (See Speed Values). Input the pump speed value recorded in the table below under the CSS-6 column. Enter the same value in the "Speed Scale Factor" box.

b) Repeat Step 3a for the other three PUMP components.

4. Update the input for the additive flow loss factor for TEE 36, Cell Face 5:

a) Note the values recorded for the additive form loss – wall-drag for the CSS-5 and CSS-6 calculations (wfl-36A05). This parameter includes the additive flow loss factor plus the wall-drag loss. Also note that the additive flow loss factor for TEE 36, Cell Face 5 is set to 0.0. Thus, the wall-drag loss is the value recorded for the CSS-5 calculation. Calculate the <u>additive flow loss factor</u> of the CSS-6 calculation for TEE 36 Cell Face 5. Keep in mind that the format for this factor is in terms of FRIC and the namelist variable IKFAC = 1 is for K-Loss.

b) Convert the additive flow loss factor from FRIC to K-Loss. The conversion is K-Loss = FRIC*L/Dh, where L is the length of Cell 4 of TEE 36 (0.28233 m) plus the length of Cell 1 of PIPE 37 (0.381 m) and the Dh is the hydraulic diameter for Cell Face 4 of TEE 36 (0.0122 m).

c) Enter the value of the adjusted additive flow loss factor for Cell Face 5, TEE 36 (calculated above) into the "Friction" input box.

5. In the Job Stream tab at the bottom of the 2D view window, click on the Submit button and in the component navigation window change the name to "CSS-Test7". **Save the input model changes.** As in Step 1 above, lock the model and submit the

job stream.

6. Record the calculated values in the table.

Points to Consider

- This example exercise demonstrates that using CSS controllers to obtain steady conditions can be done without manual iteration of parameters or complicated control systems.
- Running restart calculations from a CSS controlled calculation does not work, due to missing data adjusted during the calculation. Therefore, the adjusted parameters must be ported into the input file.

Parameter	Target	CSS-1	CSS-2	CSS-3	CSS-4	CSS-5	CSS-6	CSS-7
Pump Mass Flow Rate (kg/s)	245.0							
Loop 1A (mflow-4)								
Loop 1B (mflow-5)								
Loop 2A (mflow-104)								
Loop 2B (mflow-105)								
Pump Angular Velocity (rad/s)								
Loop 1A (omegan-4)								
Loop 1B (omegan-5)								
Loop 2A omegan-104)								
Loop 2B omegan-105)								
Cold Leg Temperature (K)	552.8							
Loop 1 (tln-2A10)								
Loop 2 (tln-102A10)								
SG Dome Pressure (MPa)								
SG 1 (cb-32)								
SG 2 (cb-33)								
Steam Line Valve Area (m^2)								
SL 1 (area-23)								
SL 2 (area-123)								
Core Differential Pressure (MPa)	0.1592							
Core DP (cb-14)								
Additive Form Loss-Wall-Drag								
wfl-36A05								