Steam Generator Modeling Considerations

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Objective

- Discuss and illustrate issues affecting development of acceptable TRACE steam generator models

Outline

- Principal parameters influencing SG behavior
- Discussion of SG model balancing methods
- SG model rebalancing exercise

Steam Generator Balancing

- Balancing the steam generator system
  - Adjusts steam generator controls to achieve targets
  - Obtain satisfactory agreement of key parameters between TRACE-calculated and target values
  - Represents a significant part of the effort needed to develop a new plant model or revise an existing plant model
- SG system is often balanced separately from plant model
  - Highly recommended approach
  - SG system is integrated into the model when acceptable performance is obtained
- Rebalancing of existing SG models is frequently needed
  - TRACE code revisions since the SG model was last used
  - Revisions in the target SG conditions (power plant uprate, etc.)

Steam Generator Balancing

- What are the key system parameters that we need to target?
  - Are there different concerns for steady-state or transients?
- What are the “knobs” that we can safely adjust without significantly affecting the system or accuracy of the results?

Important Parameters for Steady-State

- Primary System
  - Hot leg fluid temperature
  - Cold leg fluid temperature
  - Coolant loop flow rate
  - Power removed from the primary coolant system
- Secondary System
  - Main feedwater liquid temperature
  - Main feedwater/main steam flow rate
  - SG Pressure
    - Determines SG tube secondary side heat sink temperature
    - Significantly influences SG tube heat transfer rate
    - Significantly influences SG power

Important Parameters for Transients

- Secondary side liquid mass
  - Why is this important for transients?
- Downcomer level
  - Why is this important?
- Recirculation ratio
  - Mass flow rate from separator into downcomer divided by main feedwater/main steam flow rate.
  - Why is this important?

Successful Balancing = Compromise

- Most, but (usually) not all parameter values match desired conditions
- Code and plant models are limited in ability to predict complex flow in the SG boiler region
  - Code limited to 1-D modeling
  - Swirling axial and cross-flows in the tube bundle
  - Local effects near tube support plates are difficult to model

Successful Balancing = Compromise

- Inconsistencies and uncertainties in steady-state desired conditions
  - Basis for desired loop mass flow rate is typically not clear
  - Generally small uncertainties
    - Primary system pressures
    - Primary system temperatures
    - SG power
  - Generally moderate uncertainties
    - Secondary system pressure
    - Downcomer level
    - Main feedwater temperature
    - Main feedwater flow rate
    - Steam flow rate
  - Generally large uncertainties
    - Secondary system mass
    - Recirculation Ratio

Parameters to Compromise

- Based on principal application of plant system model
- What are "must-get-rights" for:
  - LOCA?
  - Station blackout?
  - Main steam line break?
  - Steam generator tube rupture?
- Since the acceptable compromises are somewhat use-dependent, might need more than one model to address all applications

Rebalancing Exercise

- Start with SG-1.med file in the SteamGeneratorExercise folder.
- Run model as-is, and note resulting values for the important SG parameters
- After the completion of each TRACE calculation, we will discuss the results
  - While some of you may be able to complete the exercise without further discussion, part of the objective is to outline a thought process for steam generator rebalancing
- The rest of the exercise re-balances the SG model to new target conditions
  - Similar changes to what would be needed for a power uprate

Run 1 Discussion

- How do your results compare to the targets?
  - Hot leg temp is too low
  - Cold leg temp is too high
  - Hot leg flow rate, feedwater temperature, steam flow rate and SG power are too low
  - Secondary pressure, recirculation ratio and secondary mass are too high
  - Controllers have achieved desired downcomer level and desired average loop temperature (CB 203 specifies 576.0 K, which is not the desired target, but it reaches the 576.0 K value)
- Some of these are boundary conditions and can be easily fixed
- Other parameters result from conditions in the steam generator and maybe more difficult to achieve

Setup Run 2

- What do you propose that we change to meet the targets better, and why?
  - FILL 1 hot leg boundary conditions should be set to desired values
  - Steam dome pressure is too high
    - Lower steam pressure boundary condition in BREAK 555 by difference in steam dome pressure and target
    - This has the effect of increasing the steam demand
  - Set the target average loop temperature in Control block 203 on the “Controls” Tab
  - Set the main feedwater temperature in FILL 21 to the new desired target value
- Return to the Exercise instructions for details

Run 2 Discussion

- How do your results compare to the targets?
  - Hot leg temp and flow are good
  - Cold leg and average loop temperatures are good
  - Downcomer level and steam pressure are good
  - Recirculation ratio and secondary mass are both high
  - Steam flow rate is high
  - SG power is high

Recirculation Ratio

- Mass flow of water returning to downcomer from the separators is greater than the feedwater mass flow
- With inadequate circulation, heat transfer surfaces can be blanketed with steam (reducing heat transfer)
- Recirculation pre-heats the incoming feedwater, which minimizes thermal stresses on the tube sheet and U-tubes
- What factors affect the recirculation ratio?
  - Weight difference between downcomer water and the riser steam/water mixture
  - Head loss from water flow through structures
  - Change in rate of heat transfer
  - Change in steam generator pressure

Recirculation Ratio

- Increases in power increase the rate of heat transfer and produce more steam
- What happens to recirculation ratio?
  - Density and weight of steam/water is reduced, increasing the driving head
  - Losses increase faster
  - Recirculation rate increases with power increases at low power levels (<50%), remains the same at higher power
- Steam generator pressure change (increase in steam demand) is similar to an increase in power

Setup Run 3

- What do you propose that we change to meet the targets better, and why?
  - Reduce flow area fraction in the connection between the bottom downcomer and boiler
    - These fractions/losses are generally not well understood within steam generators
  - Reduce the flow area fraction in the connection between the boiler and separator
    - These fractions/losses are generally not well understood within steam generators
- (Continued next slide)

Setup Run 3

- What do you propose that we change to meet the targets better, and why?
  - Reduce the flow area fraction in the connection between the boiler and separator
    - These fractions/losses are generally not well understood within steam generators
  - Adjust reactor power (Primary temperature and/or flow rate)
    - This is a high power case, so we would not expect a change to recirculation ratio
    - Would probably miss power targets
    - May be acceptable if running a secondary-specific transient, since primary conditions are less important
  - Adjust downcomer level
    - Change the secondary system mass
    - If scenario is primary-system based, this might be acceptable
- Return to the Exercise instructions for details

Run 3 Discussion

- How do your results compare to the targets?
  - Recirculation ratio is good, secondary mass is reduced
  - SG power is still too high
  - Steam flow rate still high
  - Other parameters relatively unchanged
- SG power is perhaps most important parameter, since all SGs have to remove the core power

Setup Run 4

- What do you propose that we change to meet the SG power target better, and why?
  - Increase the average loop temperature
    - Will result in a smaller hot leg-to-cold leg differential temperature, which equates to a lower primary system power
    - Reduced primary system power should reduce steam generator power
- Return to the Exercise instructions for details

Run 4 Discussion

- How do your results compare to the targets?
  - Average loop temperature increased to new setpoint
  - SG power is lower, but still too high
  - Steam flow rate lower, but still high
  - Slight increase in cold leg temperature
  - Slight increase in steam dome pressure and secondary system mass

Setup Run 5

- What do you propose that we change to meet the SG power target better, and why?
  - Increase the average loop temperature even more
    - Our experience shows that this is a good “knob”
- Return to the Exercise instructions for details

Run 5 Discussion

- How do your results compare to the targets?
  - Average loop temperature increased to new setpoint
  - SG power is only slightly to high
  - Steam flow rate good
  - Cold leg temperature too high
  - Steam dome pressure too high
  - Secondary system mass high
- Do you think that the compromises are acceptable? Under what conditions?
  - Dependent upon conditions, they could be acceptable
  - Many parameters are close to desired values (including SG power)
  - Average loop temperature is 0.8 K too high, so cold leg temp and steam dome pressure are also high
  - Model limitations and/or inconsistencies in the set of target values could be the reason we have to compromise

Setup Run 6

- Examining our target parameters, which values do you anticipate are less certain?
  - Hot leg flow rate
  - SG Tube Heat transfer area
  - Steam generator losses
  - Steam generator level
  - Recirculation ratio
  - Others?
- We will attempt to correct some of the targets by adjusting the hot leg flow rate in the next run
- Return to the Exercise instructions for details

Run 6 Discussion

- How do your results compare to the targets?
  - Except for loop flow rate, all important calculated parameters are close
  - If 5% change in loop flow rate matches uncertainty of that value, then these results could be acceptable

Setup Run 7

- Recall that the steam generator tube heat transfer area is also a source of uncertainty in the model
- We will attempt to correct some of the targets by adjusting the SG Tube heat transfer area in the next run
  - TRACE variable RDX represents the number of SG tubes modeled
  - Reducing the multiplier effectively reduces the SG tube heat transfer area while not affecting the hydrodynamics portion of the model
- Return to the Exercise instructions for details

Run 7 Discussion

- How do your results compare to the targets?
  - SG power is still too high (~39 MW)
  - Little change from SG-3 Results
    - This run is the same, except for heat transfer area
  - Why didn't the reduction in area reduce the SG power?
    - Automatic steam outlet valve control adjusts the valve to keep the same loop average temperature
    - With the same loop average temperature, the hot leg-to-cold leg differential temperature and SG power stay the same
    - Recall that the SG-2 run changed the steam sink pressure in BREAK 555 – should that have worked?

Setup Run 8

- VALVE 550 is under automatic control to achieve a target primary average temperature
- Removing the controller and setting VALVE 550 manually will allow adjustment of the SG power level by changing SG thermal/hydraulic conditions
- What impacts in the SG conditions would you expect from reducing the flow area of VALVE 550?
  - Increase steam dome pressure
  - Raise secondary system temperature
  - Reduce primary-to-secondary system differential temperature
  - Reduce SG tube heat flux
- Return to the Exercise instructions for details

Run 8 Discussion

- How do your results compare to the targets?
  - Cold leg, average loop temperatures a little high
  - SG power and steam flow rate a little low
  - Steam dome pressure a little high
  - Depending on application, this agreement might be sufficient
    - SG power and steam flow are pretty well calculated
    - Average loop temperature 0.9 K high cold leg temperature 1.8 K high