SECTION 1

Modeling Techniques for Increased Accuracy

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Modeling Techniques for Increased Accuracy

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The PEPSE model for the Catawba Units have been refined over the years to more accurately represent how the plant operates. These improvements have usually been in response to questions posed by Operations prior to executing certain evolutions that affect unit output. Some were developed to diagnose unusual behavior. Some were developed in planning of unit uprates.

Use of Type 1 Streams

By its nature, PEPSE is first and foremost a mass and energy balance modeling tool. Default stream settings do not take into the realities of pressure drop in piping systems. Type 1 streams allow the user to input piping information much like a flow modeling program to determine pressure drops. However, when splitters are encountered, PEPSE will determine the flow through the splitter based on the type of splitter, not hydraulics. If the splitter says to put a million pounds per hour through a 1 inch pipe, PEPSE will attempt to do it. In the real world, the flow will distribute in parallel lines according to the hydraulic resistance in the piping. This is encountered in turbine cycles as parallel trains of feedwater heaters and associated bypass piping.

To model this in PEPSE, controls may be used to adjust the flow in a splitter to get an equal pressure drop in parallel lines. This is illustrated below:

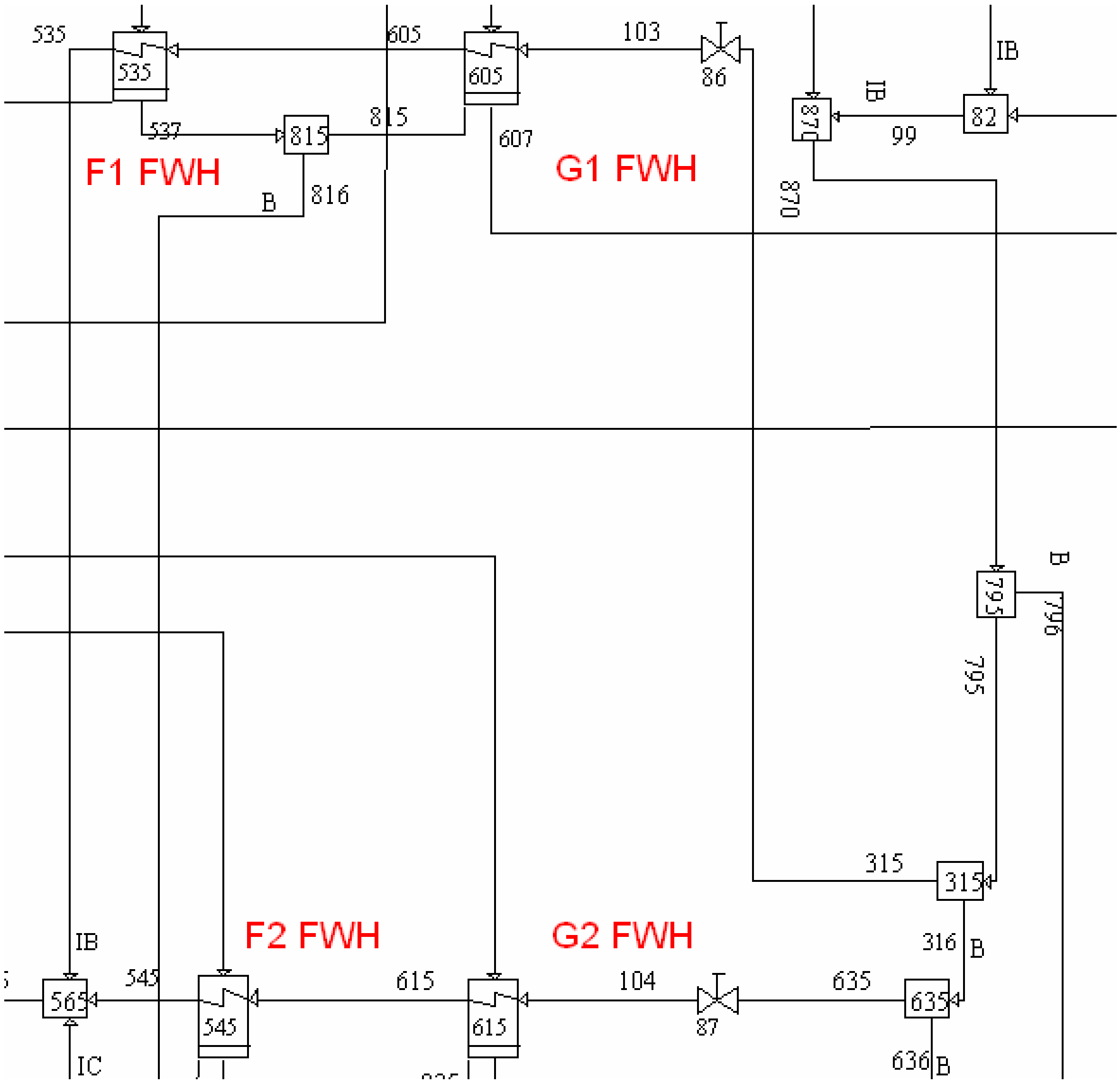

Figure 1 – Parallel Trains of Feedwater Heaters

Shown above are three parallel trains of low pressure feedwater heaters. Assuming one third of the flow goes through each feedwater gives the following results:

Heater	Flow
G1/F1	3,487,429
G2/F2	3,487,429
G3/F3	3,487,429

Table 1 – Condensate Flow Through Parallel Trains of Feedwater Heaters

To more accurately represent the split of flow between the three parallel trains, two controls are used. One will adjust the split in splitter 315 such that the pressure at the end of streams 535 and

545 are equal. The second control will adjust the split of splitter 635 such that the pressure at the end of streams 545 and 555 are equal. The control is illustrated below.

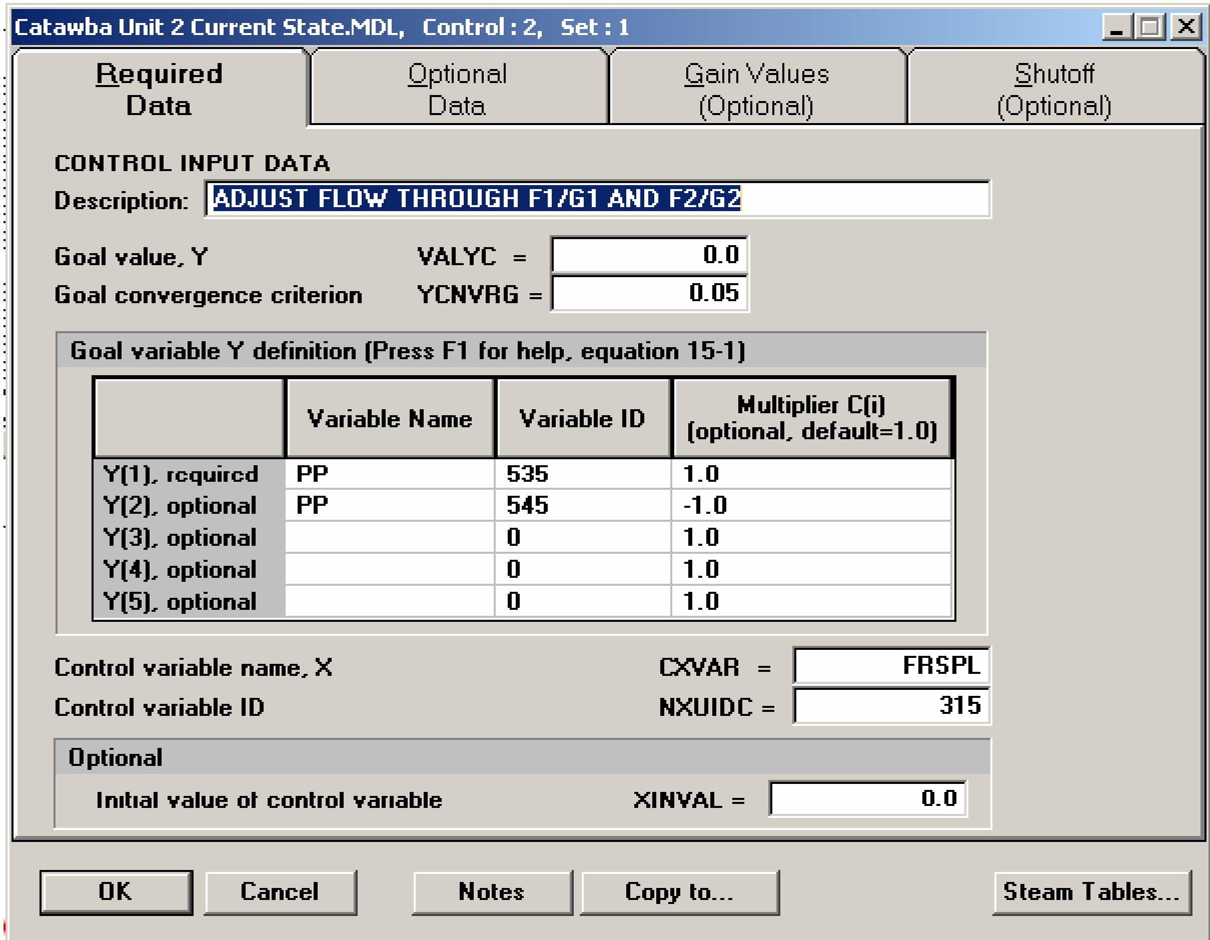

Figure 2 – Control to Balance Flow Through Feedwater Heaters

After the control is activated, the flow split becomes

Heater	Flow
G1/F1	3,846,808
G2/F2	3,608,805
G3/F3	3,006,786

Table 1 – Condensate Flow Through Parallel Trains of Feedwater Heaters, Flow Balanced with Control

As seen here, the flow is not evenly distributed between the feedwater heaters. The pressure results are shown below.

Component Output – REFERENCE CASE

COMP	STREAM /PORT	FLU ID	MASS FLOW (lbm/hr)	TEMP (F)	PRESS (psia)	QUALITY (R HUM) (-)	ENTH (B/lb)	ENTROPY (B/lb-F)	SPEC. VOLUME (ft3/lbm)
565/M3WA	545/IA	0	3608805.	217.4	236.58	-0.2227	186.1	0.31999	0.0167
	535/IB	0	3846808.	217.0	236.64	-0.2232	185.7	0.31934	0.0167
	555/IC	0	3006786.	218.5	235.90	-0.2210	187.2	0.32153	0.0167
	565/U	0	10462400.	217.6	236.58	-0.2225	186.3	0.32019	0.0167

Figure 3 – Pressure at Point Where Feedwater Heater Condensate Flow Mixes

Variable Speed Feedwater Pumps

Catawba is equipped with two turbine driven variable speed feedwater pumps. The difference between the feedwater header pressure and main steam pressure is controlled as a function of reactor power. The purpose of this is to maintain the feedwater regulating valves in the optimum control position throughout the load range of the unit.

Expressed mathematically, the relationship is:

$$DP(TP) = if\ (TP \le 50\%, DP = 140{,}140 + 80(TP - 50\%))$$

Where TP = Thermal power in % full power.

This relationship is input as a schedule. Thus, the feedwater pumps speed up or slow down as power changes. To model this in PEPSE, the pump affinity laws are used. The pump performance curve at a reference speed is input as a schedule. The output of the schedule is an operational variable. This variable is multiplied by a second operational variable to obtain the PHEAD variable for the pump. The control varies the second operational variable to force the DP between the feedwater header and main steam to match the programmed value for the given power level. This second operational variable is the ratio of the actual head to the head at the reference speed. The relationship between head and pump rotational speed is:

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

Where H_1 = Actual head
H_2 = Head at reference speed
N_1 = Actual pump speed
N_2 = Reference speed

Solving for the actual speed yields:

$$N_1 = N_2\sqrt{\left(\frac{H_1}{H_2}\right)}$$

This calculation is done as an operation.

Dual Steam Supplies to Turbine Driven Feedwater Pumps

As stated above, Catawba is equipped with two turbine driven feedwater pumps per unit. Data from the pump and turbine manufacturers for pump and turbine efficiency are input to PEPSE as schedules. The normal steam supply is the outlet of the second stage reheaters. Demand splitters are in this line (splitters 116 and 725). The second source is main steam. Fixed flow splitters (splitters 820 and 925), with a flow of 0 lb/hr are in the main steam line. The two supplies are mixed to form a single steam supply to each pump (mixers 16 and 18). Using the OLE automation feature, these splitters can be changed back and forth as demand or fixed flow splitters

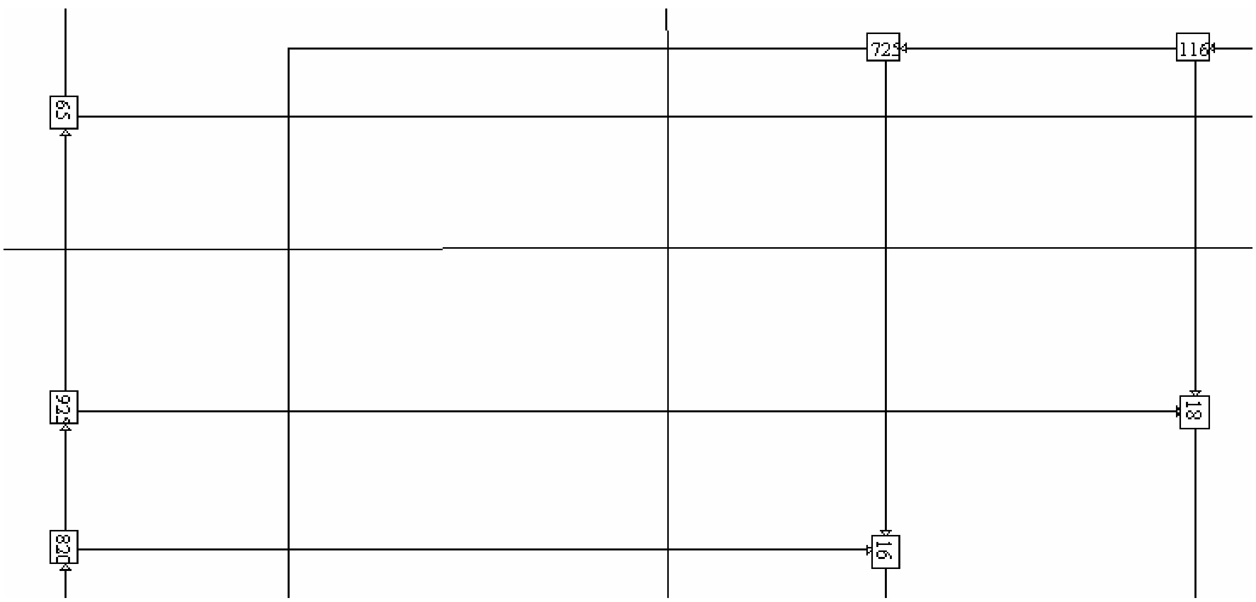

Figure 4 – Steam Supply Arrangement to Feedwater Pump Turbines

"Advanced" Performance Mode Steam Generators

In evaluating various uprate scenarios, it was necessary to have an accurate estimation of the steam pressure at the uprate conditions. Rather than try to model all four steam generators as design mode steam generators a method was developed that used performance mode steam generators with steam pressures modeled in a schedule as a function of reactor power. The heat transferred from the reactor coolant to the steam generators is described by several equations. On the primary side,

$$Power = m_{Reactor\_Coolant}\left(h_{hot\_leg} - h_{cold\_leg}\right)$$

Where $m_{Reactor\ Coolant}$ = mass flow of reactor coolant
$h_{hot\ leg}$ = enthalpy of hot leg
$h_{cold\ leg}$ = enthalpy of cold leg

The heat transfer equation,

$$Power = UA \frac{(T_{hot} - T_{cold})}{\ln\left(\dfrac{T_{hot} - T_{steam}}{T_{cold} - T_{steam}}\right)}$$

Where U = Overall heat transfer coefficient of the steam generator
A = Heat transfer area of the steam generator
T_{hot} = Hot leg temperature
T_{cold} = Cold leg temperature

Using plant data of power, reactor coolant flow, reactor coolant temperatures, and steam pressure, the product UA can be determined over a range of power levels. From these data, an equation correlating UA to thermal power level can be determined. This correlation is valid only for the current configuration. Any changes to tube plugging or fouling will change it.

The average reactor coolant temperature is a programmed function of reactor power. Thus, we now have three equations and three unknowns to solve at any particular reactor power.

(1) $$Power = m_{Reactor\_Coolant}\left(h(T_{hot}) - h(T_{cold})\right)$$

(2) $$Power = UA(Power)\frac{(T_{hot} - T_{cold})}{\ln\left(\dfrac{T_{hot} - T_{steam}}{T_{cold} - T_{steam}}\right)}$$

(3) $$\frac{T_{hot} - T_{cold}}{2} + \Delta T_{avg} = f(Power)$$

Where the ΔT_{avg} term accounts for deviations in T_{avg} from the programmed value. Reactor coolant enthalpies use the ASME steam table functions to calculate enthalpy as a function of pressue and temperature. Since the recirculating steam generators in use at Catawba produce saturated steam, steam temperature is expressed as an ASME steam table function that calculates saturation temperature as a function of pressure.

Solving this system of equations at various power levels and various deviations in T_{avg} allows a schedule to be developed that predicts steam pressure at a given power level and ΔT_{avg}. The schedule for steam pressure as a function of power (in MWt) is shown below.

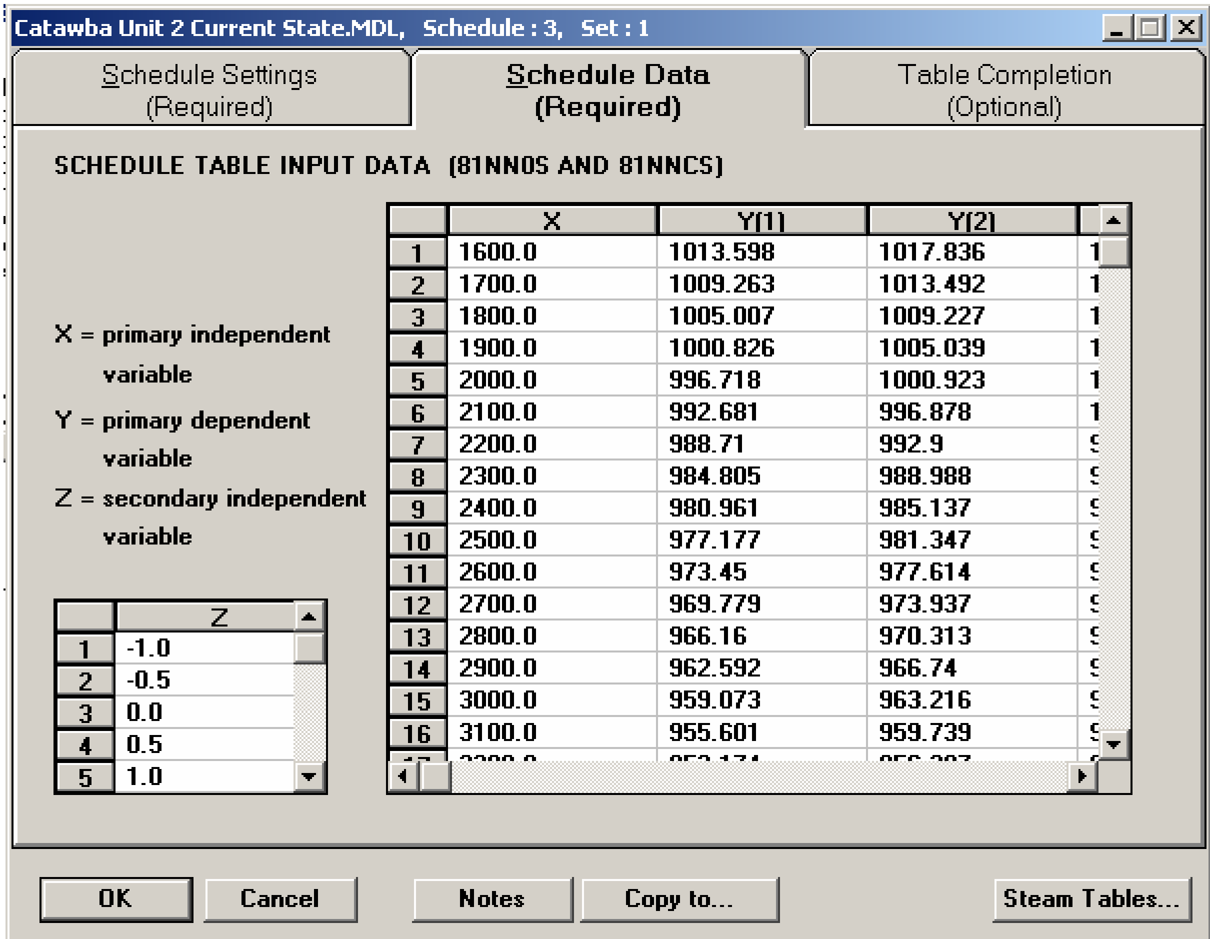

Figure 5 – Schedule of Steam Pressure vs Thermal Power

The X column is thermal power in megawatts. The Y columns are steam pressure in psia. The Z column is ΔT_{avg}.

The reactor coolant average temperature program is also input as a schedule and calculates the required average reactor coolant temperature as a function of the turbine cycle input power. This operational variable is used as a goal variable in a control that varies T_{hot} to produce the required T_{avg} for the given power level and reactor coolant flow. A schematic of the steam generator in the PEPSE model is shown below:

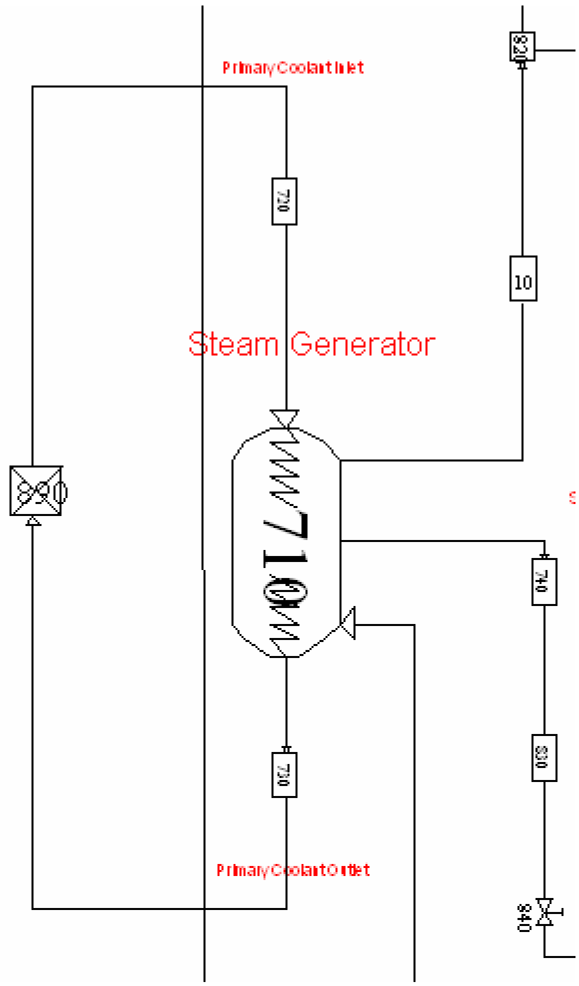

Figure 6 – Steam Generator and Reactor Component in PEPSE

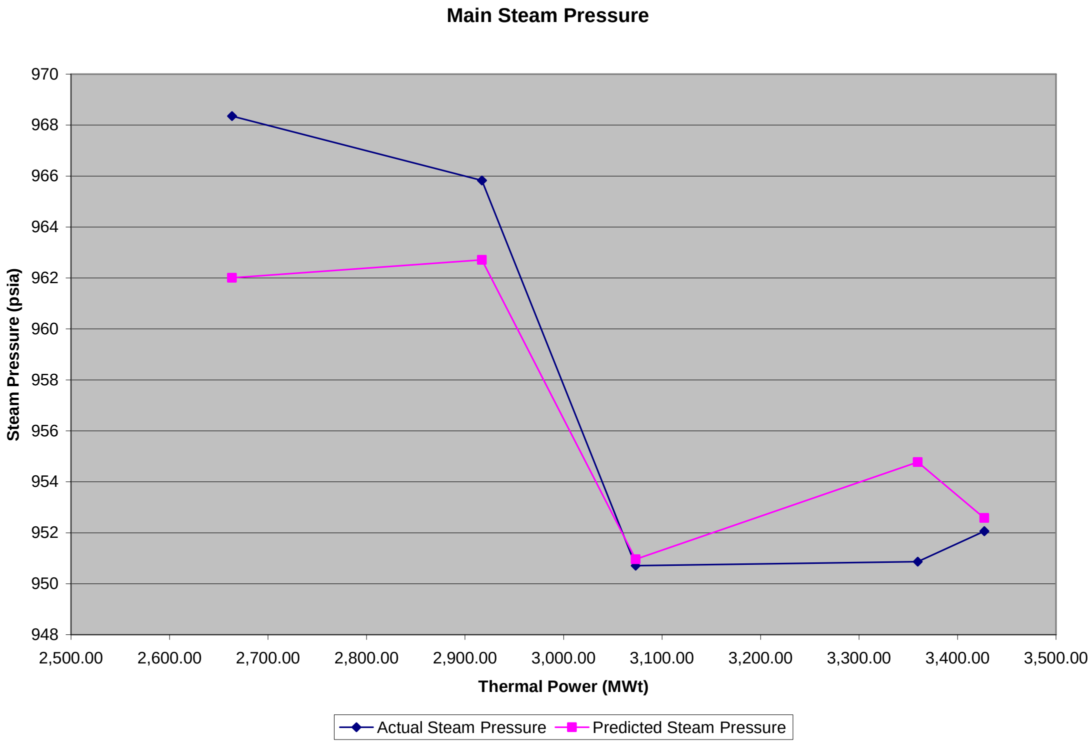

Figure 7 – Actual vs. Predicted Steam Pressure

Design Mode Cooling Towers

Each Catawba is equipped with three induced draft cooling towers. Each cooling tower can be bypassed by sending the inlet directly to the basin. The configuration in PEPSE is shown in Figure 8. The cooling towers can be switched between design and performance modes. This feature has been especially useful in determining condenser performance in various uprate scenarios. One of the cooling towers is modeled with a bypass to determine the effects of cooling tower bypass. This was added when Operations requested the generation loss of bypassing a cooling tower to clean the upper basin screens during the summer. Doing so would have resulted in a turbine trip on high backpressure.

The design mode uses the cooling tower performance curves (supplied by the cooling tower manufacturer) and the wet bulb temperature to determine outlet temperature. Air flow, humidity, and outlet air temperature are also required inputs. Makeup due to evaporation and blowdown is also determined.

Figure 9, shows predicted cooling tower outlet temperatures compared with actual. The model does not account for conditions that degrade performance such as wind and plume recirculation.

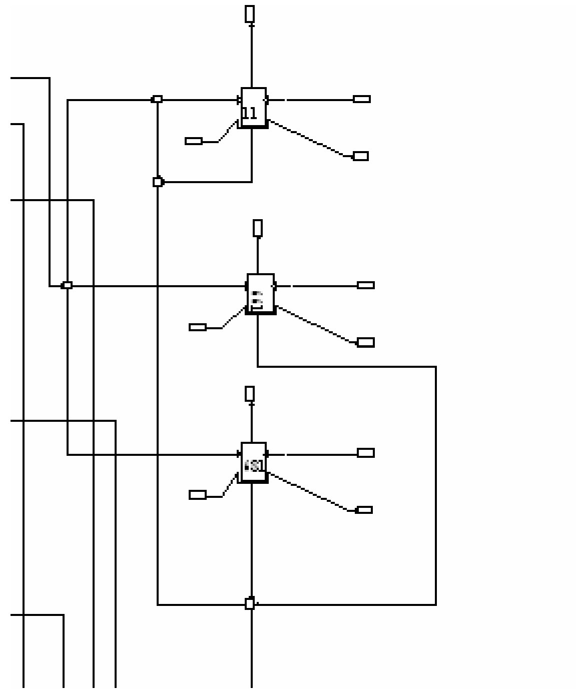

Figure 8 – Cooling Towers

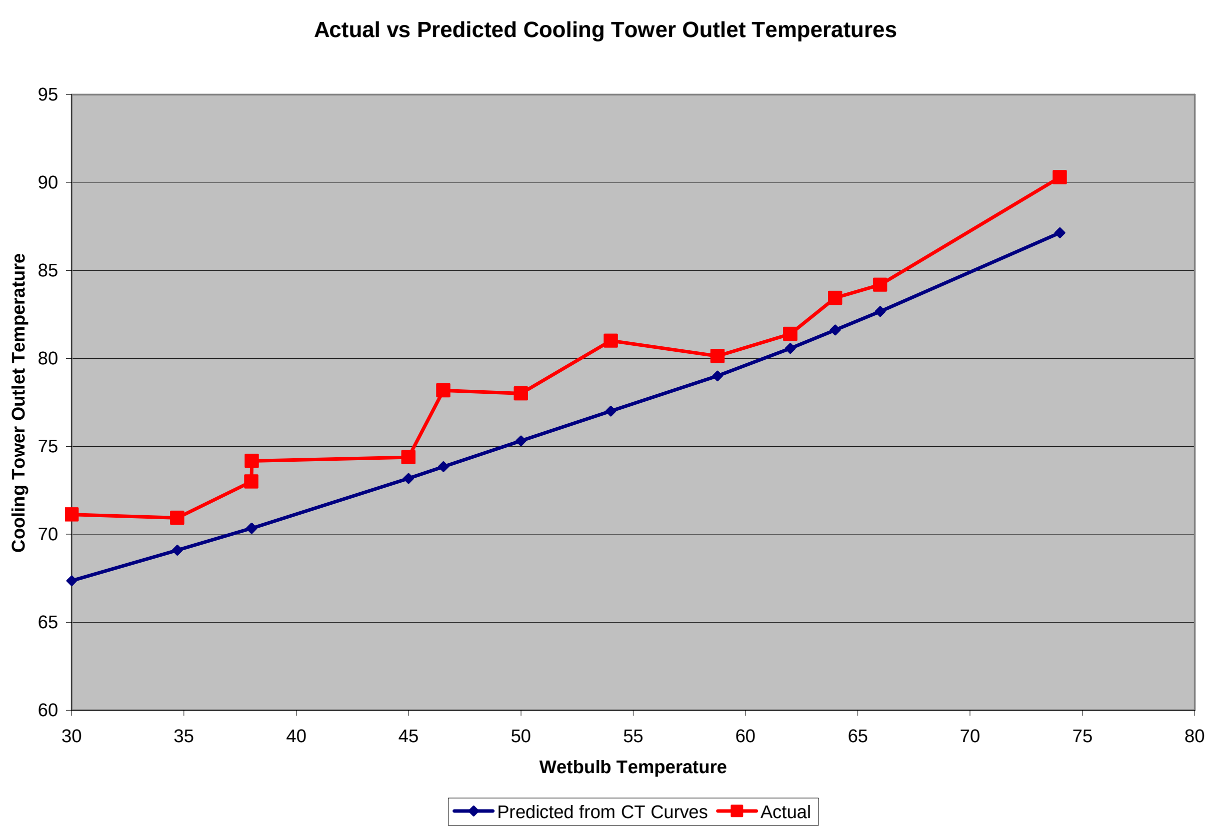

Figure 9 – Actual Cooling Tower Outlet Temperature vs. Predicted

Design Mode Condenser with Variable Condenser Cleanliness

Data taken over several years have demonstrated that the condenser cleanliness factor is a very repeatable function of circulating water inlet temperature. The operation (or lack of operation) of the condenser tube cleaning system has no effect on this relationship

Each low pressure turbine is equipped with its own condenser. The circulating water flows in series from one condenser to the next. The PEPSE configuration is shown below.

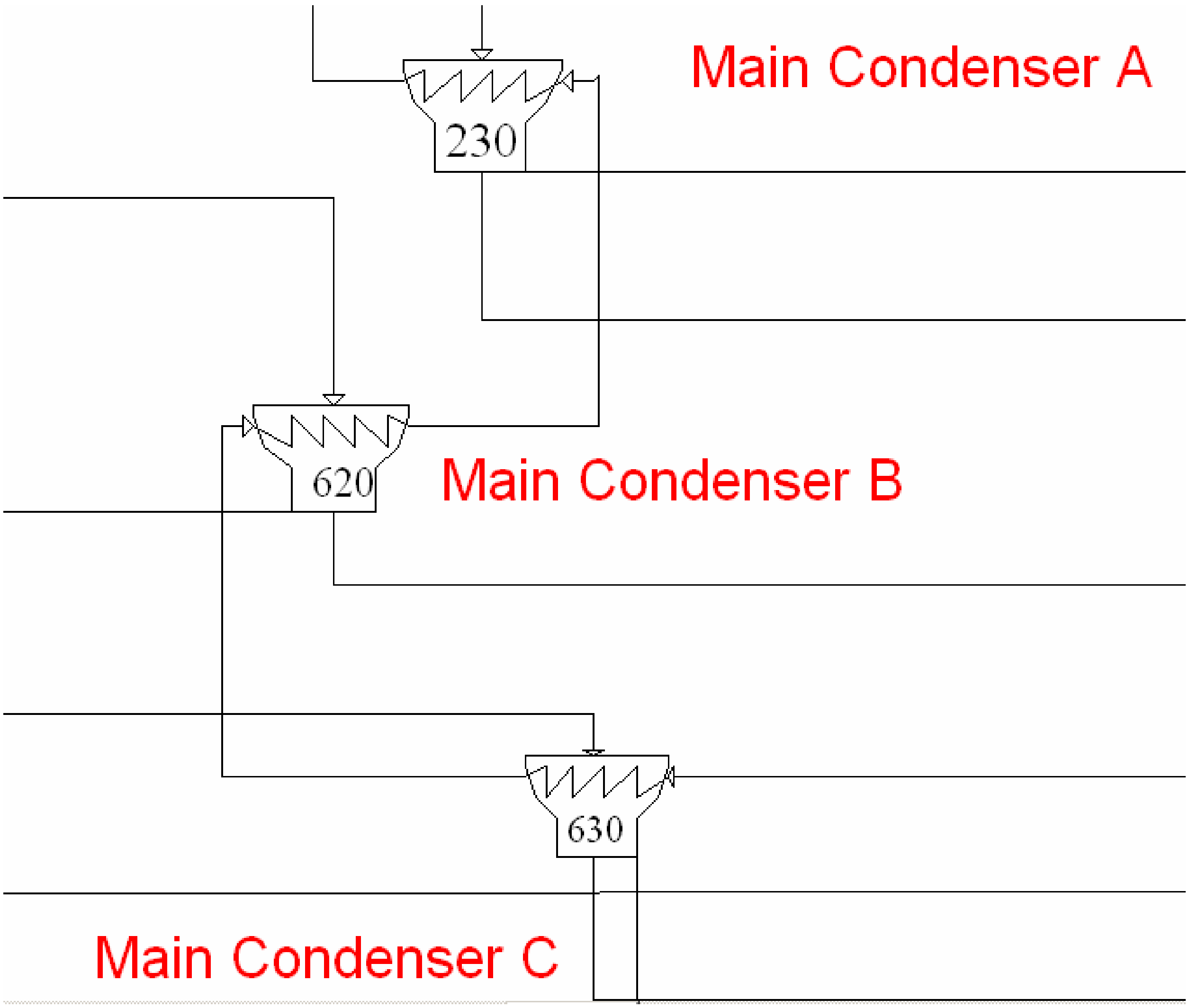

Figure 10 – Condensers in PEPSE

The condenser cleanliness factors from plant data were curve fit to a linear equation and input to a schedule as a function of the circulating water temperature. Graphs showing actual condenser pressure and expected pressure are shown in figures 11 through 13.

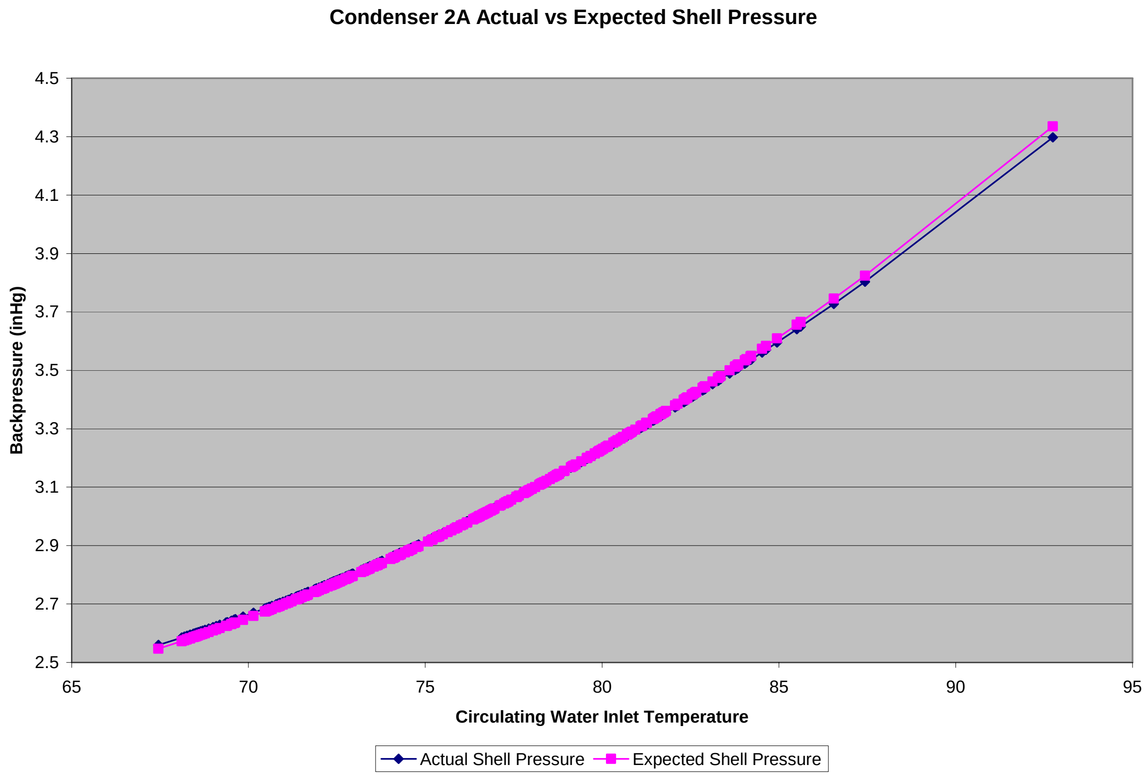

Figure 11 – Condenser 2A

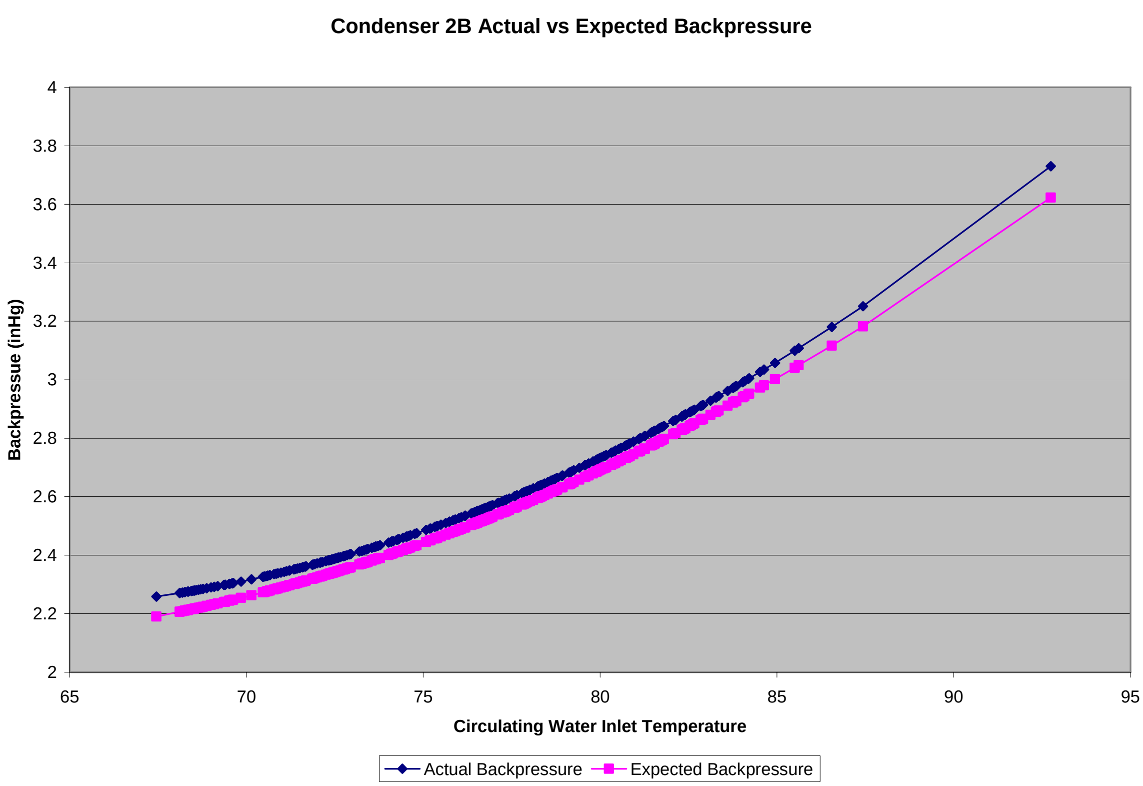

Figure 12 – Condenser 2B

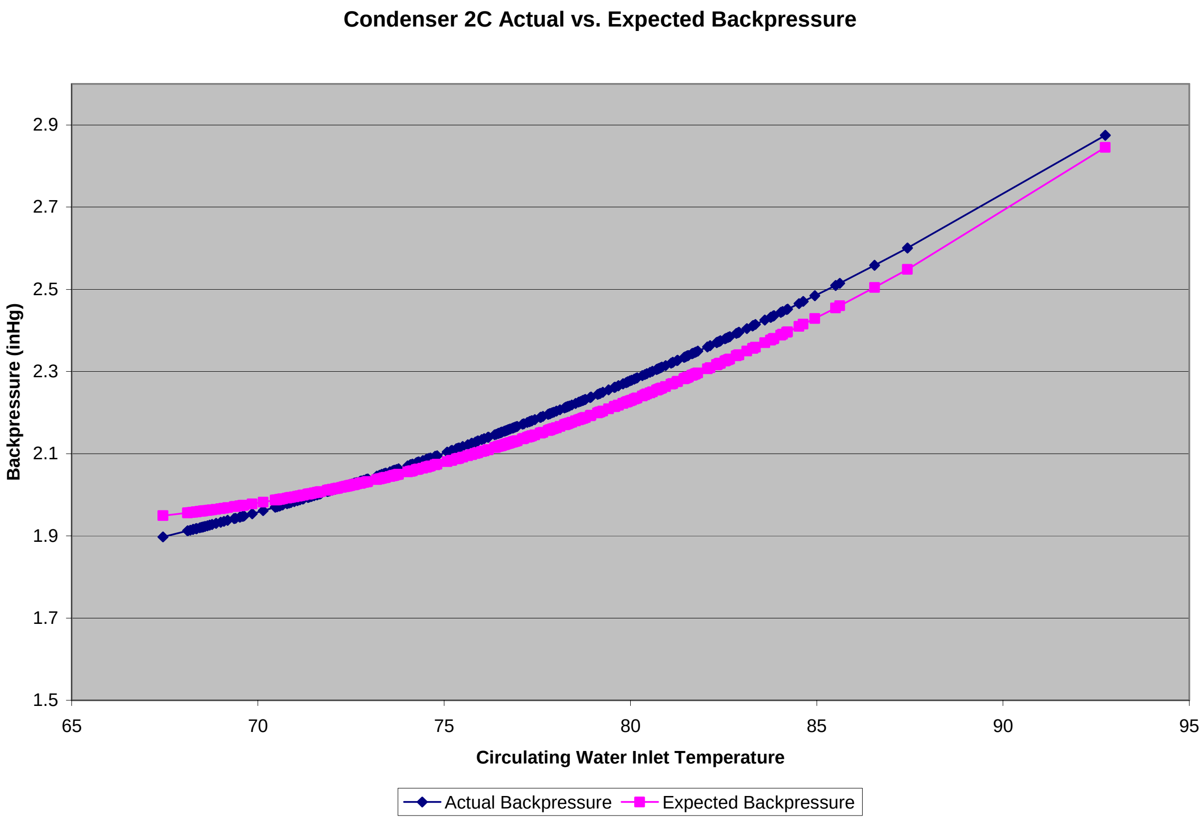

Figure 13 – Condenser 2C