Megawatt Loss Accounting at Catawba Nuclear Station

By

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Introduction

Catawba Nuclear Station is a two unit, four loop Westinghouse pressurized water reactor plant located in York County, South Carolina. Both units are equipped with General Electric turbine/generators and induced draft cooling towers. Each unit is nominally rated at 1129 MWe net.

The thermal performance monitoring program at Catawba utilizes PEPSE and PMAX to account for generation losses due to equipment degradation, environmental factors, and unit configuration and to calculate specific loss values for each.

Definition of Reference State

Losses for each parameter are calculated by starting with a reference state, and sequentially applying actual operating conditions. To do this a starting point, or "reference state" must be defined. These values are constant and are independent of actual plant conditions. The choice of the reference state is somewhat arbitrary and can be adjusted to reflect the "ideal conditions" of the plant.

For Catawba, the reference conditions are:

1. Turbine Cycle Input Power - this is the sum of 100% reactor power (3411 MWt) plus the heat input from the reactor coolant pumps (~5 MWt per pump) for a total of 3431 MWt.

2. Generator Power Factor and Hydrogen Pressure - Although the original heat balances assumed a lagging power factor of 0.9, Catawba typically runs very close to unity, with lagging power factors as low as 0.93 during the summer. Thus, it was felt that a power factor of 1 was appropriate for the reference state. The reference hydrogen pressure is 89.7 psia, consistent with original heat balance.

3. Circulating water inlet temperature - The original heat balance assumed a condenser absolute backpressure of 2.5 inHg. Catawba is equipped with a triple pressure condenser and the pressures in each section are never the same. Thus, the reference state for the condenser is 65 °F circulating water temperature (lowest temperature allowed by procedure), 609,000 gpm circulating water flow (typical three pump flow rate), and a condenser cleanliness factor of 1.

4. Steam generator blowdown is assumed to be zero.

5. Steam pressure is assumed to be 975 psia. This figure is based on the heat balance figure. This pressure is adjusted for reactor power via a schedule based on design heat balances at 20%, 40%, 60%, 80%, 100% power, and valves wide open.

6. All feedwater heaters assume the heat balance values of terminal temperature difference (TTD) and drain cooler approach (DCA).

7. First and second stage reheaters use design values of TTD.

8. Complete cycle isolation, i.e., no heater drains dumping to the condenser.

9. All heater drain pumps operating.

For Catawba these assumptions produce a reference power of 1244.6 MWe for Unit 1 and 1251.3 MWe for Unit 2.

Calculation of Losses

Losses are calculated by sequentially changing reference conditions to actual. Actual plant data in imported to PEPSE from the plant computer via the OILS-PI adding to Microsoft Excel. The following losses are calculated in the course of normal performance monitoring.

1. Reactor power - the loss due to operating at less than 100% power is calculated by substituting the sum of the actual reactor power and reactor coolant pump power for the reference state of 3431 MWt in Special Option 4 in PEPSE. The difference between this value and the reference value is the reactor power loss. Example:

Generation at 3431 MWt	=	1244.6 MWe
Generation at 3425 MWt	=	- 1242.5 MWe
		2.1 MWe

2. Cycle Isolation - Piping that carries main steam that connect to the condenser. These include condenser steam dumps and steam line drains. Digital computer points monitor the position of these valves and open fixed flow splitters to divert flow to the condenser.

3. Predicted circulating water flow and predicted cooling tower outlet temperature. The predicted cooling tower outlet temperature is based on the measured wet bulb temperature (input to PEPSE via special input/output) calculated from the cooling tower vendor supplied performance curves that have been input to PEPSE as a schedule. The difference between this value and the value in step 2 is the loss due to environmental conditions.

Generation from previous step	=	1242.5 MWe
Generation at predicted flow and temperature	=	- 1238.2 MWe
		4.3 MWe

4. Actual circulating water flow and predicted cooling tower outlet temperature. The predicted cooling tower outlet temperature is based on the measured wet bulb temperature (input to PEPSE via special input/output) calculated from the cooling tower vendor supplied performance curves that have been input to PEPSE as a schedule. The difference between this value and the value in step 3 is the loss due to off normal circulating water pump operation.

Generation from previous step	=	1238.2 MWe
Generation at actual flow and temperature	=	- 1238.0 MWe
		0.2 MWe

5. Actual circulating water flow and actual cooling tower outlet temperature. The difference between this value and the value in step 4 is the loss due to off normal cooling tower operation.

Generation from previous step	=	1238.0 MWe
Generation at predicted flow and temperature	=	- 1235.8 MWe
		2.2 MWe

6. The condenser is then changed to performance mode and the actual condenser backpressures are input. The difference between this value and the value in step 5 is the loss due to condenser fouling.

Generation from previous step	=	1235.8 MWe
Generation at predicted flow and temperature	=	- 1227.4 MWe
		8.4 MWe

7. Actual steam generator blowdown flow. The actual blowdown flow is input to the PEPSE model via a performance mode steam generator. Blowdown enthalpy calculated as saturated liquid at the measured blowdown temperature. The difference between this value and the value in step 6 is the loss due to steam generator blowdown.

Generation from previous step	=	1227.4 MWe
Generation at measured blowdown flow	=	- 1225.3 MWe
		2.1 MWe

8. Actual main steam pressure - main steam and blowdown pressure is adjusted to actual values. The difference between this value and the value in step 7 is the loss due to steam pressure.

Generation from previous step	=	1225.3 MWe
Generation at actual main steam pressure	=	- 1227.0 MWe
		-1.7 MWe

9. Actual first and second stage reheater conditions - The TTDs of the first and second stage reheaters are adjusted to actual values. The difference between this value and the value in step 8 is the loss due to reheater performance.

Generation from previous step	=	1227.0 MWe
Generation at actual main steam pressure	=	- 1227.0 MWe
		0.0 Mwe

10. Splitters that direct flow to from moisture separator and reheater drains are then changed as necessary to based on digital inputs of valve position to determine the loss due to MSR drains being routed to the condenser.

Generation from previous step	=	1227.0 MWe
Generation at actual MSR heater drain alignment	=	- 1227.0 MWe
		0.0 MWe

11. Splitters that direct flow to from feedwater heater drains are then changed as necessary to based on digital inputs of valve position to determine the loss due to feedwater heater drains being routed to the condenser.

Generation from previous step	=	1227.0 MWe
Generation at actual Feedwater heater drain alignment	=	- 1227.0 MWe
		0.0 MWe

12. Splitters that direct flow to from high pressure heater drain pumps are then changed as necessary to based on digital inputs of valve position to determine the loss due to high pressure feedwater heater drains not being pumped forward.

Generation from previous step	=	1227.0 MWe
Generation at actual heater drain pump alignment	=	- 1227.0 MWe
		0.0 MWe

13. Actual feedwater heater inlet, outlet, and drain temperatures and heater shell pressures are entered to determine loss due to feedwater heater performance

Generation from previous step	=	1227.0 MWe
Generation at actual heater conditions	=	- 1228.5 MWe
		-1.5 MWe

14. Actual generator power factor and hydrogen pressure are entered to determine losses due a power factor other than unity and hydrogen pressure less than 75 psig.

Generation from previous step	=	1228.5 MWe
Generation at actual heater conditions	=	- 1226.6 MWe
		1.9 MWe

Details of Model Construction

Catawba is equipped with one double flow high pressure turbine, three double flow low pressure turbines exhausting to a three section multipressure condenser. There are seven stages of feedwater heaters with two heaters in each stage, with the exception of the two lowest pressure heaters. There are three each of these heaters and they are located in the condenser neck. Two stages of reheat are provided.

Low pressure heaters drains flow to the condenser. High pressure drains are pumped to the suction of the feedwater heaters.

High Pressure Turbine

The high pressure turbine is modeled as two turbine trains each with one end. This allows a single extraction line between the extraction point and each high pressure feedwater heater. This makes for more stable convergence when isolating feedwater heaters.

Moisture Separator and Reheaters

These are modeled in the performance mode with a schedule for pressure drop across the supply valves. Shell side pressure drops from the GE Thermal Kit are used. Moisture separator drains routed to high pressure heater drain tank, first stage reheater drains to the 'B' heater shell, and second stage reheater drains are routed to the 'A' heaters.

Low Pressure Turbine

The low pressure turbine is modeled as three trains with each stage having two ends. The three turbines provide extraction steam for two strings of 'D' and 'E' heaters. This arrangement of extraction supply and heaters makes it difficult to model the bypassing of the 'D' and 'E' heaters.

Feedwater Heaters

Feedwater heaters are modeled in the performance mode. Design mode information has been entered to allow modeling the effects of raising/lowering level, plugging tubes, changing tube material, etc.

Pumps

There are three sets of pumps in the secondary cycle. The low pressure hotwell pumps, the intermediate pressure condensate booster pumps, and the high pressure steam turbine driven feedwater pumps. Pump curves have been entered as schedules for all pumps, and pressure drops vs. flow have been input as schedules to model pump suction conditions.

Condensers

The three main condensers and the feedwater pump turbine condensers have been modeled in the HEI design mode. The cleanliness factor is set to one. A schedule is available that adjusts the cleanliness factor as a function of inlet temperature. This schedule is based on recent historical data.

Import of Plant Data

Plant data is imported to PEPSE via the OILS-PI interface with the operator aid computer. Data is brought into Microsoft Excel and then exported to PEPSE by use of OLE automation. Examples of OLE automation are installed on your computer when PEPSE is installed.

The following data imported into PEPSE:

1. Turbine cycle input power - the sum of reactor power and reactor coolant pump power.
2. Wet bulb temperature
3. Circulating water inlet temperature
4. Turbine exhaust hood temperatures for calculation of turbine exhaust pressure.
5. Feedwater heater inlet, outlet, and drain temperatures.
6. Feedwater heater shell pressures.
7. Steam generator blowdown flow and temperature.
8. Main steam pressure.
9. Position data for heater dump valves.
10. Service flags for pumps.
11. Generator power factor and hydrogen pressure
12. Reheater TTDs.

Calculation and Publishing of Results

A macro scheduling program is used to start Excel and run the OLE Automation macros unattended at 0600 and 1800 each day. Results are saved to a network drive and a link is provided on the site web page that is available for all to review. Each set of results is archived for historical purposes. A copy of the results sheet is shown in Figure 2.

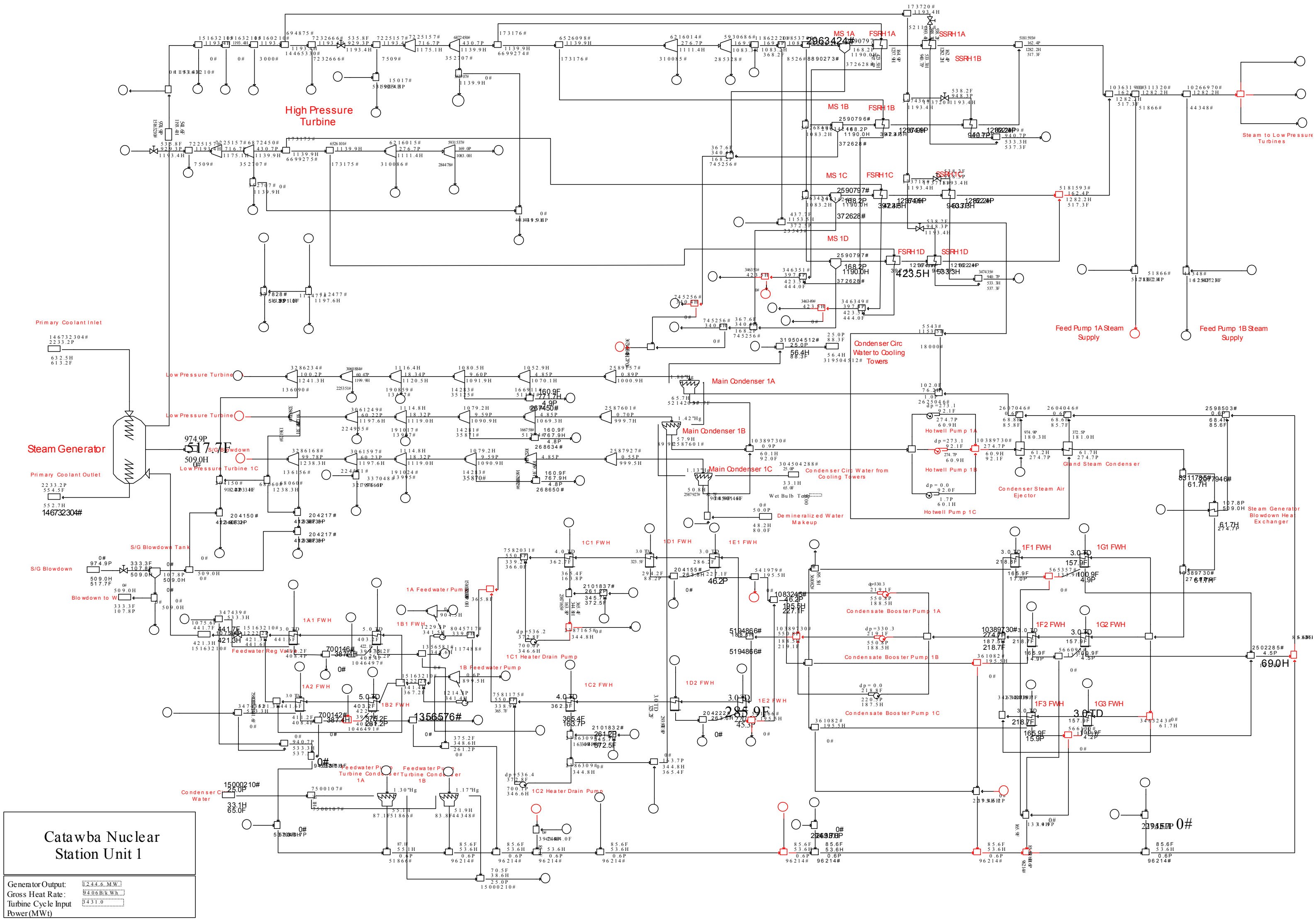

Figure 1 - PEPSE Model for Catawba Nuclear Station

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	UNIT 1	UNIT 2
ACTUAL UNIT OUTPUT	1221.2 MWe	1211.0 MWe
OUTPUT FROM THERMAL PERFORMANCE MODEL	1220.6 MWe	1211.6 MWe
ACTUAL OUPUT CORRECTED TO BASELINE CONDITIONS	1245.2 MWe	1250.8 MWe
ACCOUNTED FOR LOSSES (GAINS)		
Operation Alignments		
Blowdown	2.2 MWe	1.5 MWe
MSR Drains	0.0 MWe	0.0 MWe
C Heater Drain Pumps Out of Service	0.0 MWe	0.0 MWe
RC Temperature	6.8 MWe	7.9 MWe
Condenser Fouling	10.1 MWe	8.4 MWe
FWH Off-Design	(1.0) MWe	4.3 MWe
Opposite Unit Aux Steam Usage	0.0 MWe	0.0 MWe
Cooling Tower Inefficiency	3.0 MWe	2.9 MWe
S/G Pressure Loss	(1.4) MWe	2.7 MWe
Heater Drains	0.0 MWe	(0.0) MWe
RC Flow	0.3 MWe	0.0 MWe
MSR Performance	0.0 MWe	0.1 MWe
Cycle Isolation	0.0 MWe	0.0 MWe
Power Reductions		
Generator Power Factor	1.8 MWe	1.8 MWe
Power Level	2.3 MWe	10.0 MWe
UNACCOUNTED FOR LOSSES (GAINS)	(0.6) MWe	0.6 MWe
AUXILIARY LOAD	61.1 MWe	59.7 MWe
NET UNIT OUTPUT	1160.1 MWe	1151.3 MWe
GROSS HEAT RATE	9514.0 BTU/kwh	9532.1 BTU/kwh
NET HEAT RATE	10014.9 BTU/kwh	10026.2 BTU/kwh

Figure 2 - Output of PEPSE Calculations

PMAX Modeling

The Catawba PMAX model utilizes the same approach as the PEPSE method for calculating losses. Using PEPSE, bogey curves were developed to calculate the following losses:

1. Steam generator blowdown as a function of blowdown mass flow and turbine cycle input power.

2. Off design steam pressure as a function of actual steam pressure and turbine cycle input power.

3. Generator power factor as a function of actual power factor and turbine cycle input power.

Bogey curves of generator output as a function of average condenser absolute backpressure and turbine cycle input power were also generated using PEPSE. PMAX calculates an absolute backpressure for the following cases:

1. Case 1 - Nominal three circulating water pump flow, 65 °F circulating water temperature, and cleanliness factor of 1.

2. Case 2 - Nominal three circulating water pump flow, predicted circulating water temperature based on wet bulb temperature and temperature rise for three pumps, and a cleanliness factor of 1.

3. Case 3 - Actual circulating water pump flow, predicted circulating water temperature based on wet bulb temperature and actual temperature rise, and a cleanliness factor of 1.

4. Case 4 - Actual circulating water pump flow, actual circulating water, and a cleanliness factor of 1.

5. Case 5 - Actual condenser absolute backpressure.

The condenser absolute backpressures are then input to the bogey curves for output vs. turbine cycle input power and condenser absolute backpressures. The following losses are then calculated:

1. Loss due to wet bulb temperature = $Output_{Case\ 1}$ - $Output_{Case\ 2}$
2. Loss due to off normal circulating water flow = $Output_{Case\ 2}$ - $Output_{Case\ 3}$
3. Loss due to cooling tower inefficiency = $Output_{Case\ 3}$ - $Output_{Case\ 4}$
4. Loss due to condenser fouling = $Output_{Case\ 4}$ - $Output_{Case\ 5}$

Feedwater heater losses are determined using the PMAX/PEPSE link that calculates an output at actual turbine cycle input power with all feedwater heaters at design values of terminal temperature difference (TTD) and drain cooler approach (DCA).

For Moisture Separator and Reheater drains, digital points monitor valve positions of drain valves to the condenser and assign a predetermined (via PEPSE) loss for any drains that are routed to the condenser. The same approach is used for assigning losses to the high pressure heater drain pumps when one or both are out of service.

Usually, each unit supplies it own auxiliary steam needs and these are accounted for in the PEPSE and PMAX models. However, then one unit is offline, with condenser vacuum established and main feedwater pump(s) operating, a 6 MWe loss is assigned to the operating unit to account for auxiliary steam being sent from the operating unit to the offline unit. This value is based on plant experience as there is no instrumentation to measure this flow.

A screen shot of the main PMAX screen is shown in Figure 3.

The models also include comparisons of main feedwater and main steam flow rates and calculates the degree of venturi fouling. While the result of this calculation can't be used for an absolute value of fouling, it is useful for trending purposes. See Figure 4.

Conclusions

This approach allows Catawba to routinely predict unit output to within 2 MWe of actual. It has been extremely useful in pointing out small losses (1 - 2 MWe range) that would not be readily apparent to the control room operators. Publishing the results twice daily to the site web page has also raised the awareness of thermal performance issues among plant management, Operations, and Work Control.

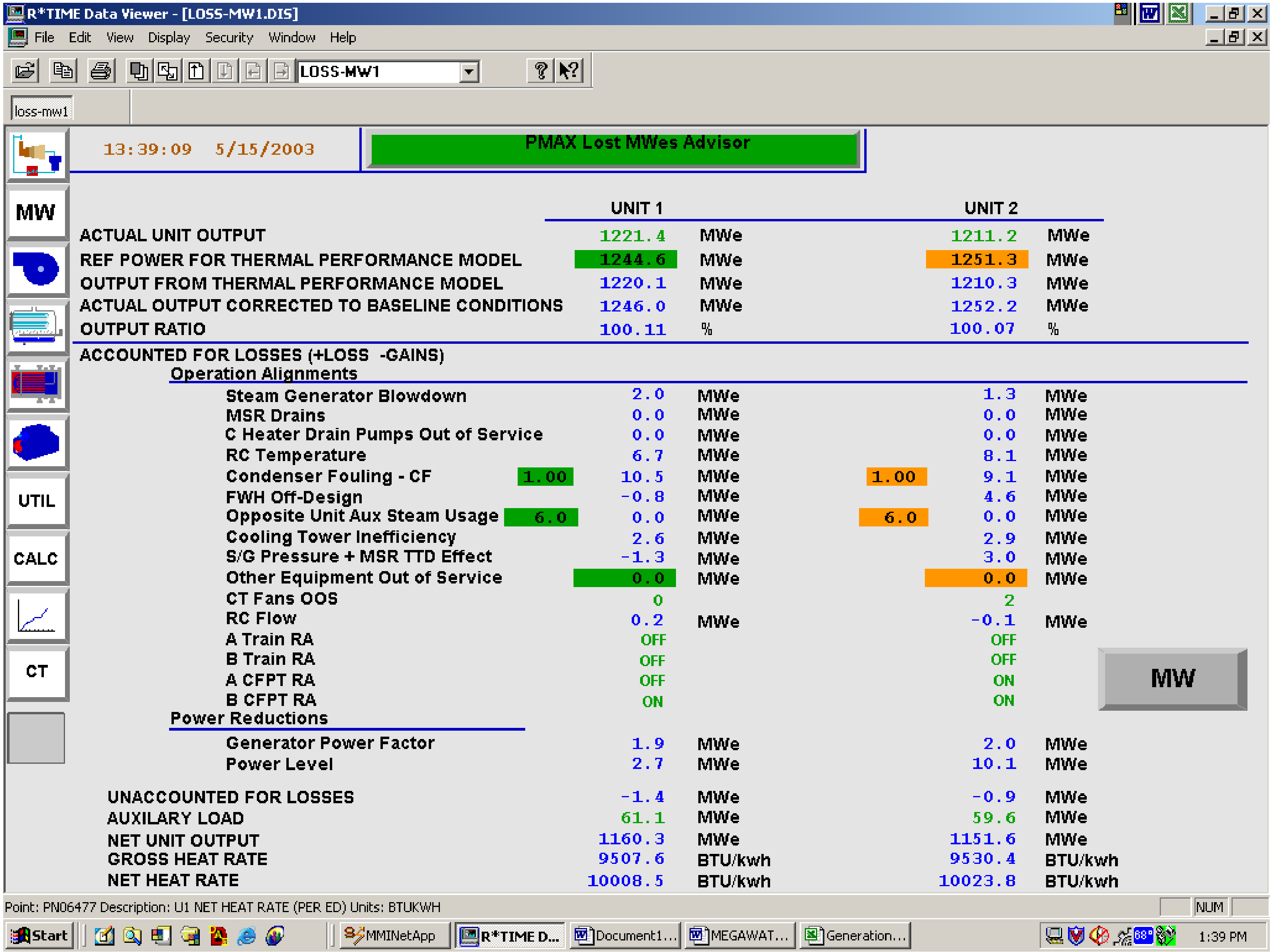

Figure 3 - Main PMAX Screen

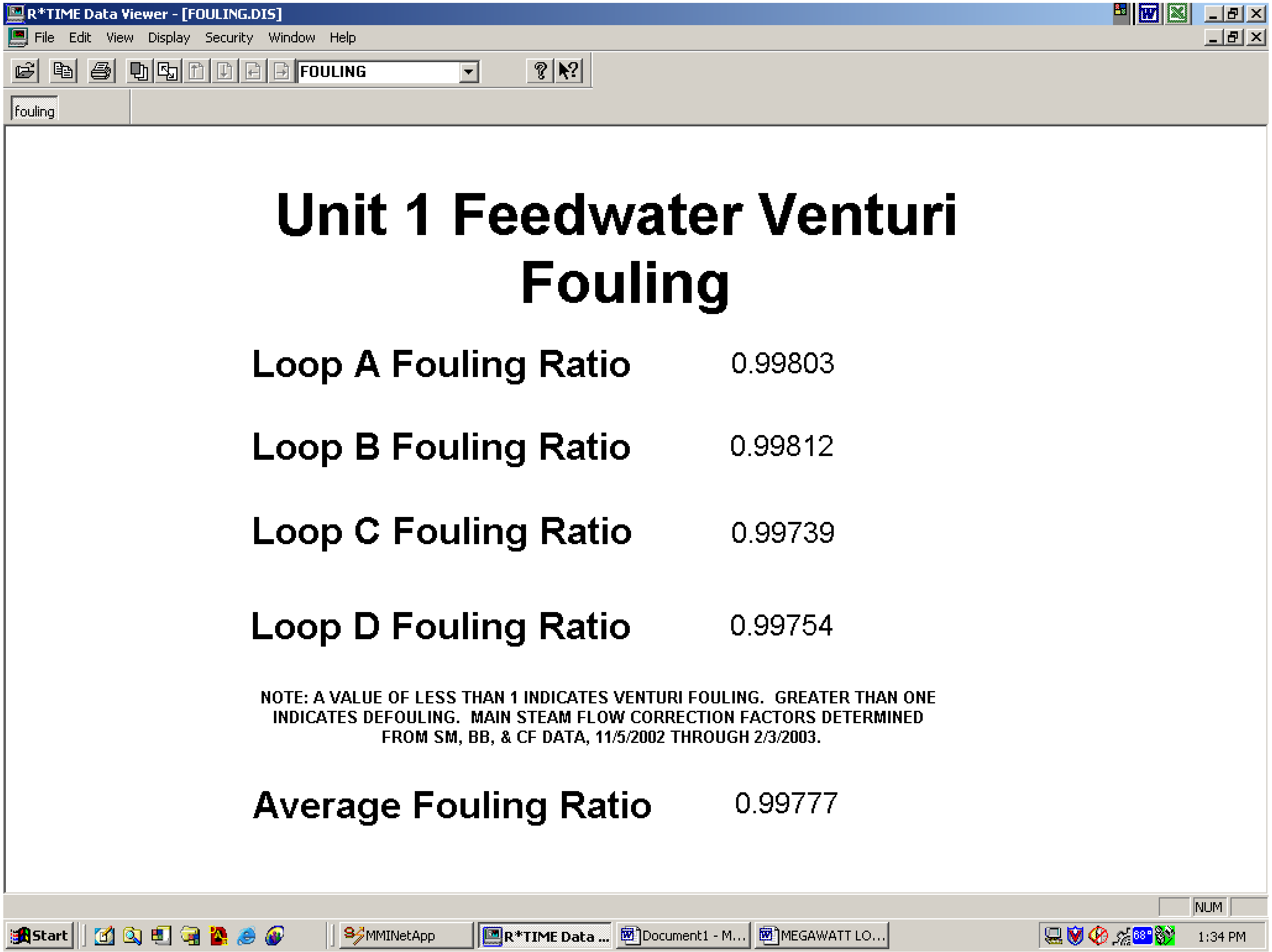

Figure 4 - Venturi Fouling Screen