Evaluating Generation Considering All Plant Losses and Efficiencies

Duane H. Morris, P.E.
Tennessee Valley Authority

James W. Brower
Scientech
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Abstract

In June 2007, TVA restarted Unit 1 at the Browns Ferry Nuclear Plant (BFNP) after the unit had sat idle for more than 20 years. Prior to restart, the unit's steam path was modified to take advantage of a 20% extended power uprate (EPU). However, because of delays in licensing approval for EPU, the unit has been operated at only 105% of the original licensed thermal power (OLTP). Based on the expected performance at 105% power, the unit has seemingly under produced electrical generation. This paper discusses the methods used to evaluate the generation anomaly for the unit. This evaluation included using thermal performance software to calculate plant performance parameters and efficiencies in order to validate the generation and try to identify the sources of the lost generation. The conclusion of this study was that turbine efficiency and throttle loss were the main culprits to lost generation.

Introduction

In June 2007, TVA restarted Unit 1 at the Browns Ferry Nuclear Plant (BFNP) after the unit had sat idle for more than 20 years. Prior to restart, the unit's steam path was modified to take advantage of a 20% extended power uprate (EPU). However, because of delays in licensing approval for EPU, the unit has been operated at only 105% of the original licensed thermal power (OLTP). Based on the expected performance at 105% power, the unit has seemingly under produced electrical generation.

A few theories for this under production were discussed, but no evidence could support them. One theory was that the feedwater flowrate was reading a flow that was higher than reality. Another was that since the HP turbine was sized for 120% of the OLTP flow rate and was only operating at 105%, it was less efficient. Yet another theory was that excessive throttling of the throttle valves was causing the loss of generation. In addition to these theories, any other possible plant losses had to be examined and/or determined.

This paper discusses the methods used to evaluate the generation anomaly for BFNP Unit 1. This evaluation included using plant data and thermal performance software to calculate plant performance parameters including turbine efficiencies and entering this information into heat balance software in order to validate the generation and try to identify the sources of the lost generation. Through this process, the theories discussed above were tested for validity.

The conclusion of this study was that BFNP Unit 1 does not perform at its design turbine efficiencies nor does its throttle valve behave as heat balances indicate. These factors cause the generation to be lower than expected. There is some room for possible additional losses including additional HP turbine efficiency loss, feedwater flow measurement error, and others (i.e. valve leaks, instrument error, etc.). However, as will be shown, most of the generation anomaly can be attributed to turbine inefficiencies and throttling losses.

Problem

Based on a comparison of actual plant data and the cycle computer model, BFNP Unit 1 has been generating approximately 14 MWe less than the predicted electrical output since restart in June 2007. The upgraded steam path was optimized in support of a 20% EPU; however, because of delays in licensing approval for EPU, the unit currently operates at only 105% OLTP. TVA initially thought that the MWe difference could all be attributed to excessive turbine flow margin either designed in by the vendor or as a result of lax manufacturing tolerances; and since the unit was expected to only operate at the lower thermal power level for a short period of time, a minimal effort was made to resolve the difference. Further delays in achieving EPU operation has, however, compelled TVA to make a full accounting of the discrepancy.

Background Information

BFNP Unit 1 was first put into commercial operation in 1973. The unit is an 1800-RPM tandem-compound design consisting of a double-flow HP section with six (6) stages and a six-flow LP section with eight (8) stages and 43inch last stage buckets. The turbine is a non-reheat N1 code type and is supplied with saturated steam from a boiling water reactor (BWR). The turbine generator was originally rated for a turbine cycle thermal power of 3298 MWt, and was originally designed with 5% flow margin. In 2007, the unit was restarted with anticipation of a 20% EPU; therefore the unit was equipped with a new steam path. The unit currently operates with four (4) control valves in single (full arc) admission mode.

Since there was no guarantee language associated with the steam path replacement, management decided that precision testing of the turbine would not be performed following restart. As a result of that decision, test point taps were not installed to aid in the verification of parameters such as the turbine first stage bowl pressure. No vendor heat balances were prepared for the new steam path at 105% OLTP.

The Unit 1 steam path modifications also resulted in an apparent loss of approximately 24 MWe when compared with BFNP Unit 2 and Unit 3's generation. Both Units 2 and 3 are similarly operated at 105% OLTP; however, their HP turbines were optimized for the uprate conditions.

After more than two years of delays in obtaining EPU approval, TVA started exploring steam path modifications to reclaim all or some portion of the accumulative loss of 38 MWe. The turbine vendor performed an evaluation of the existing steam turbine. The analysis showed that the existing unit had approximately 22% flow margin at 105% OLTP. This high level of margin resulted in significant performance losses due to control valve throttling. Several options were evaluated and the best option, when considering performance and flow capacity predictability, was to replace the first four (4) HP stages, including both diaphragms and buckets. The performance of the HP turbine section was primarily affected by the steam path design and throttling loss. In the case of BFNP Unit 1, the proposed changes to the HP steam path would result in an efficiency penalty due to the re-designed stages, which would no longer be optimum with the retained stages. However, the recovery in throttling loss due to a smaller flow capacity was greater and the vendor predicted a net expected output gain of 27.5 MWe.

Evaluation Procedure

To evaluate the generation at BFNP Unit 1, on-line and predictive, heat balance thermal performance software was employed. The on-line monitoring software supplied a historian of real-time plant performance data that could be entered into the predictive software to determine if the generation was justified.

Available performance data points were collected using the displays from the on-line thermal performance system. Some of these displays are illustrated in Figures 1 through 4. All the displays and calculations used from this system can be seen in Appendix A. Data was then retrieved from this system's historian. Data for 3/24/2010 from 15:00:00 to 16:00:00 was retrieved into Excel and averaged. This hour of data was used simply because the condenser shells were operating at an average backpressure around 2 inhgA. The averaged values were then plugged into the predictive, heat balance model. The averaged data used is shown in Table 1.

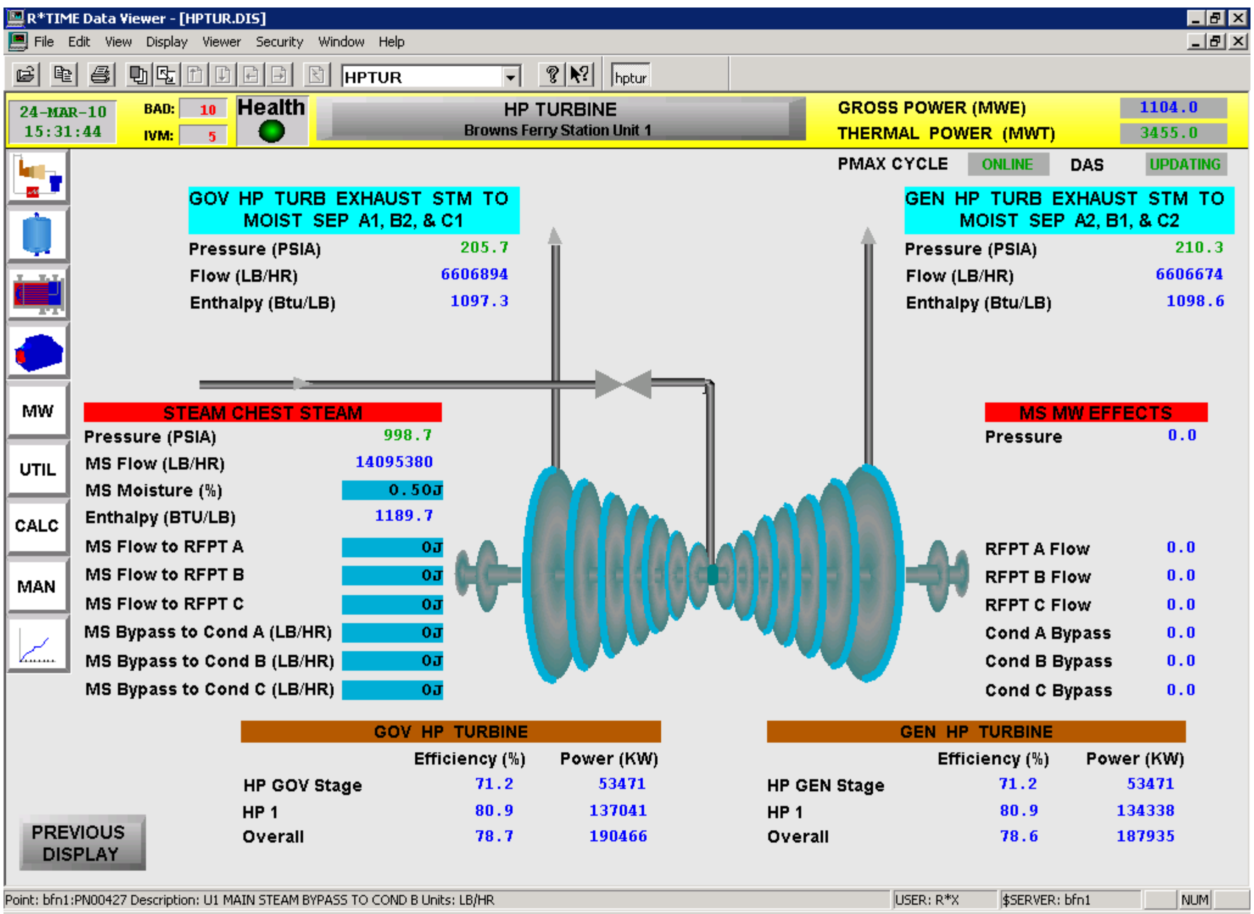


Figure 1: On-line Performance System - HP Turbine Display

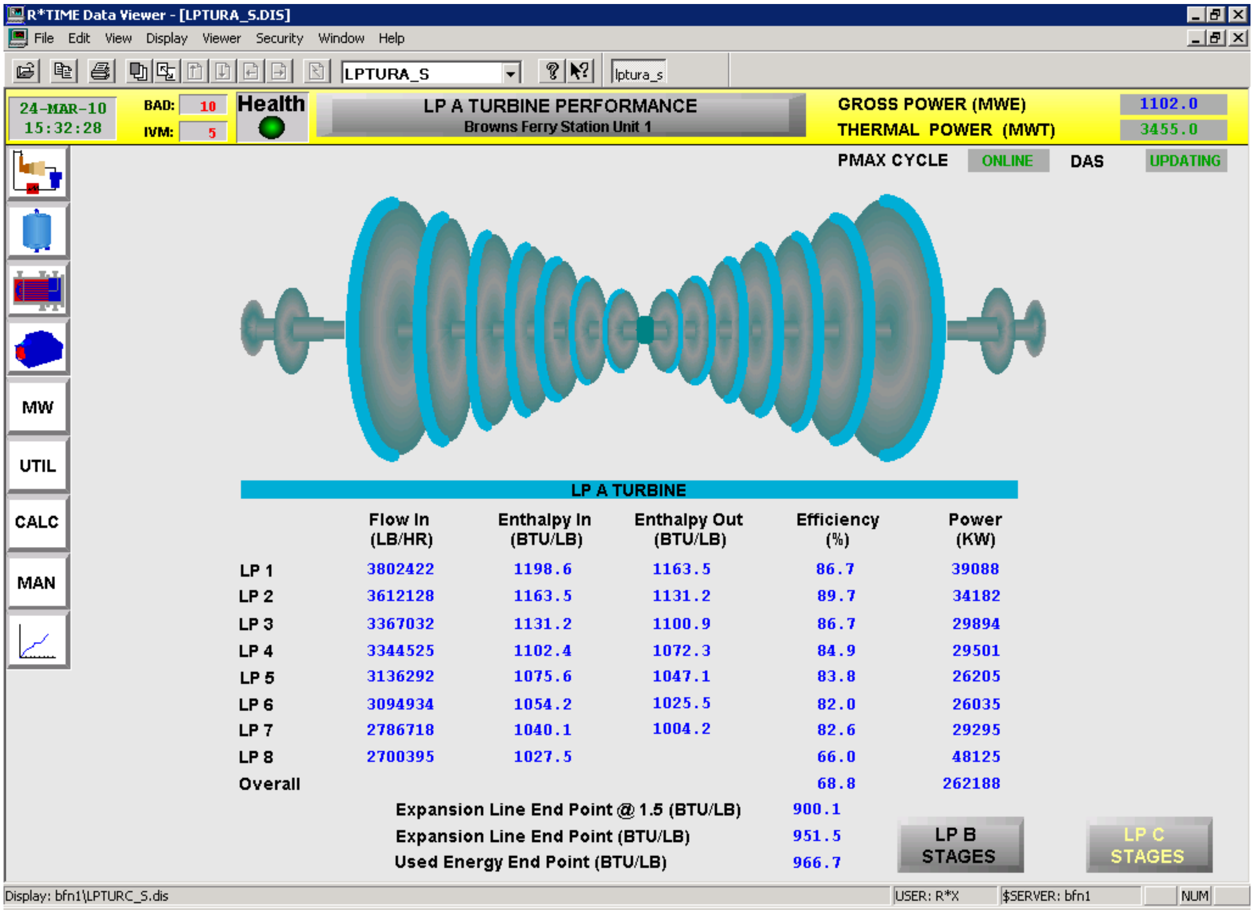


Figure 2: On-line Performance System - LP Turbine Display

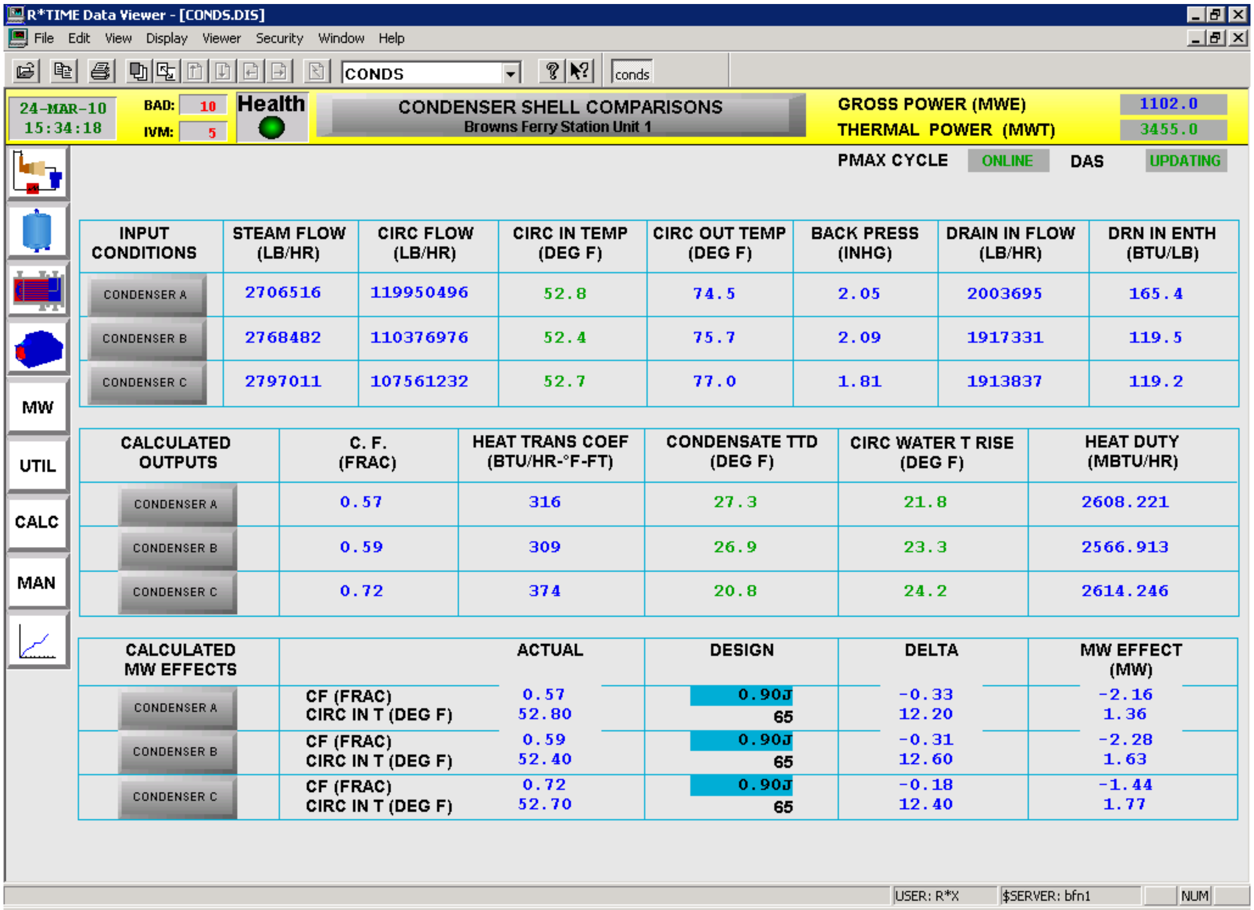


Figure 3: On-line Performance System - Condenser Display

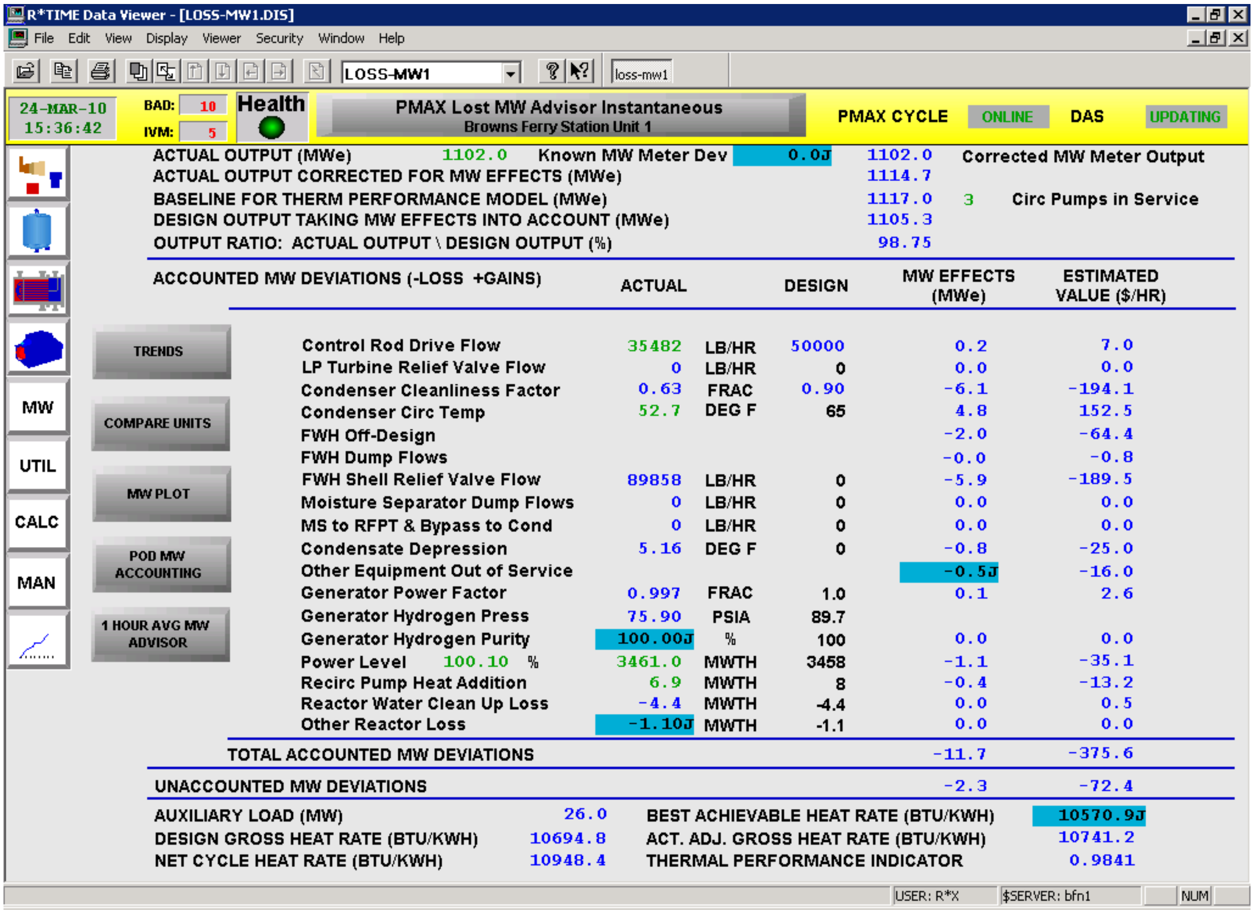


Figure 4: On-line Performance System - MW Effect Advisor

Table 1: 1 Hour Average of Plant performance Data

PARAMETER DESCRIPTION	MEASURED VALUE	CALCULATED VALUE	ADDITIONAL CALCULATION
U1 REACTOR POWER; NSSS CALCULATED	3455.966116	3457.399282	
U1 RECIRC PUMP POWER INPUT TO REACTOR	6.895523806		
U1 RWCU THERMAL LOSS	-4.362358125		Throttle Valve
U1 OTHER REACTOR LOSS	-1.099999905		Outlet Press
U1 MN STM EQUALIZING HEADER PRESS	998.3720823		704.5
U1 MAIN STEAM ENTHALPY	1189.74296		With New Throttle
U1 CONTROL ROD DRIVE FLOW	35446.19787		Valve Press Drop
U1 HP TURBINE GOV SIDE Stage Efficiency (GS)	71.25490508	71.22745214	85.1
U1 HP TURBINE GEN SIDE Stage Efficiency (GS)	71.1999992		
U1 HP TURBINE GOV SIDE Stage Efficiency stage 1	80.94473016	80.94170417	82.2
U1 HP TURBINE GEN SIDE Stage Efficiency stage 1	80.93867818		
U1 LP TURBINE A Stage Efficiency stage 1	86.74489731		
U1 LP TURBINE A Stage Efficiency stage 2	89.69011751		
U1 LP TURBINE A Stage Efficiency stage 3	86.65978979		

PARAMETER DESCRIPTION	MEASURED VALUE	CALCULATED VALUE	ADDITIONAL CALCULATION
U1 LP TURBINE A Stage Efficiency stage 4	84.86715073		
U1 LP TURBINE A Stage Efficiency stage 5	83.79521429		
U1 LP TURBINE A Stage Efficiency stage 6	82.03683822		
U1 LP TURBINE A Stage Efficiency stage 7	82.65007895		
U1 LP TURBINE A Stage Efficiency stage 8	65.91261216		
U1 LP TURBINE B Stage Efficiency stage 1	86.74571828		
U1 LP TURBINE B Stage Efficiency stage 2	89.69061755		
U1 LP TURBINE B Stage Efficiency stage 3	86.65986533		
U1 LP TURBINE B Stage Efficiency stage 4	84.82538792		
U1 LP TURBINE B Stage Efficiency stage 5	84.02503867		
U1 LP TURBINE B Stage Efficiency stage 6	82.3197987		
U1 LP TURBINE B Stage Efficiency stage 7	82.52579336		
U1 LP TURBINE B Stage Efficiency stage 8	64.99202591		
U1 LP TURBINE C Stage Efficiency stage 1	86.74571828		
U1 LP TURBINE C Stage Efficiency stage 2	89.69061755		
U1 LP TURBINE C Stage Efficiency stage 3	86.65986533		
U1 LP TURBINE C Stage Efficiency stage 4	84.8487041		
U1 LP TURBINE C Stage Efficiency stage 5	83.92969325		
U1 LP TURBINE C Stage Efficiency stage 6	82.23426294		
U1 LP TURBINE C Stage Efficiency stage 7	82.53939144		
U1 LP TURBINE C Stage Efficiency stage 8	60.44799029		
U1 FIRST STAGE PRESSURE GEN END	597.5862897	597.9130659	
U1 FIRST STAGE PRESSURE GOV END	598.2398421		
U1 GEN HP TURB EXHAUST PRESSURE	210.2206301	207.9521092	
U1 GOV HP TURB EXHAUST PRESSURE	205.6835882		
U1 LPA-1 EXTRACTION PRESSURE	126.7612918		
U1 LPA-2 EXTRACTION PRESSURE	79.97620955		
U1 LPA-3 EXTRACTION PRESSURE	49.93350783		
U1 LPA-4 EXTRACTION PRESSURE	30.21294072		
U1 LPA-5 EXTRACTION PRESSURE	18.20261639		
U1 LPA-6 EXTRACTION PRESSURE	10.54869896		
U1 LPA-7 EXTRACTION PRESSURE	5.196851777		
U1 LPB-1 EXTRACTION PRESSURE	126.7612918		
U1 LPB-2 EXTRACTION PRESSURE	79.97620955		
U1 LPB-3 EXTRACTION PRESSURE	49.93350783		
U1 LPB-4 EXTRACTION PRESSURE	32.28268645		
U1 LPB-5 EXTRACTION PRESSURE	19.44959228		
U1 LPB-6 EXTRACTION PRESSURE	10.08034706		
U1 LPB-7 EXTRACTION PRESSURE	4.966116905		

PARAMETER DESCRIPTION	MEASURED VALUE	CALCULATED VALUE	ADDITIONAL CALCULATION
U1 LPC-1 EXTRACTION PRESSURE	126.7612918		
U1 LPC-2 EXTRACTION PRESSURE	79.97620955		
U1 LPC-3 EXTRACTION PRESSURE	49.93350783		
U1 LPC-4 EXTRACTION PRESSURE	31.40603869		
U1 LPC-5 EXTRACTION PRESSURE	18.92142924		
U1 LPC-6 EXTRACTION PRESSURE	10.08034706		
U1 LPC-7 EXTRACTION PRESSURE	4.966116905		
U1 FWH A2 SHELL RELIEF VALVE FLW	70000		
U1 FWH C1 SHELL RELIEF VALVE FLW	19858		
U1 FWH A1 TTD	4.5838533		
U1 FWH A1 DCA	9.082290399		
U1 FWH B1 TTD	5.043056801		
U1 FWH B1 DCA	11.99836406		
U1 FWH C1 TTD	6.836347736		
U1 FWH C1 DCA	12.79059939		
U1 FWH A2 TTD	5.242781842		
U1 FWH A2 DCA	9.942733014		
U1 FWH B2 TTD	5.322023486		
U1 FWH B2 DCA	10.75793057		
U1 FWH C2 TTD	5.521011102		
U1 FWH C2 DCA	10.0953039		
U1 FWH A3 TTD	8.33517306		
U1 FWH A3 DCA	9.511474609		
U1 FWH B3 TTD	9.760298932		
U1 FWH B3 DCA	8.980218106		
U1 FWH C3 TTD	9.84737809		
U1 FWH C3 DCA	8.840547655		
U1 FWH A4 TTD	11.20881728		
U1 FWH A4 DCA	8.905022293		
U1 FWH B4 TTD	9.159110147		
U1 FWH B4 DCA	10.74906396		
U1 FWH C4 TTD	9.073017558		
U1 FWH C4 DCA	11.40698893		
U1 FWH A5 TTD	5.387792869		
U1 FWH A5 DCA	12.35092788		
U1 FWH B5 TTD	5.327023866		
U1 FWH B5 DCA	13.95628407		
U1 FWH C5 TTD	5.822652348		
U1 FWH C5 DCA	9.606557627		

PARAMETER DESCRIPTION	MEASURED VALUE	CALCULATED VALUE	ADDITIONAL CALCULATION
U1 CONDENSER A BACK PRESSURE	2.040279248		
U1 CONDENSER B BACK PRESSURE	2.081790721		
U1 CONDENSER C BACK PRESSURE	1.805001915		
U1 REACTOR FEED PUMP A EFFICIENCY	91.41999817		
U1 REACTOR FEED PUMP B EFFICIENCY	91.41999817		
U1 REACTOR FEED PUMP C EFFICIENCY	91.41999817		
U1 RFP A HEAD	1992.770468		
U1 RFP B HEAD	1981.627229		
U1 RFP C HEAD	1994.017898		
U1 AVERAGE HOTWELL TEMP	95.40683659		
U1 MAIN GENERATOR POWER (FILTERED)	1103.016393		
U1 UNACCOUNTED FOR MW EFFECTS	-3.09472256		
U1 RFP A DISCHARGE PRESSURE	1122.930552		
U1 RFP B DISCHARGE PRESSURE	1117.992848		
U1 RFP C DISCHARGE PRESSURE	1122.977547		
U1 FINAL FEED WATER TEMPERATURE	379.4208364		
U1 THROTTLE STEAM SUPPLY PRESSURE	998.3556889		
U1 HTR A1 SHELL STEAM PRESSURE	203.3536377		
U1 HTR B1 SHELL STEAM PRESSURE	204.7766969		
U1 HTR C1 SHELL STEAM PRESSURE	205.6574617		
U1 HTR A2 SHELL STEAM PRESSURE	117.2835994		
U1 HTR B2 SHELL STEAM PRESSURE	117.3936547		
U1 HTR C2 SHELL STEAM PRESSURE	118.9423986		
U1 HTR A3 SHELL STEAM PRESSURE	75.33102917		
U1 HTR B3 SHELL STEAM PRESSURE	76.3114664		
U1 HTR C3 SHELL STEAM PRESSURE	75.77704133		
U1 HTR A4 SHELL STEAM PRESSURE	29.67540766		
U1 HTR B4 SHELL STEAM PRESSURE	29.6998887		
U1 HTR C4 SHELL STEAM PRESSURE	28.89660976		
U1 HTR A5 SHELL STEAM PRESSURE	8.999998093		
U1 HTR B5 SHELL STEAM PRESSURE	8.999998093		
U1 HTR C5 SHELL STEAM PRESSURE	8.999998093		
U1 LP TURB A EXTR PRESS TO HTR5-GEN	9.108195227		
U1 LP TURB A EXTR PRESS TO HTR5-GOV	8.999998093		Moisture Separator Inlet Pressure
U1 LP TURB A EXTR PRESS TO HTR5-GEN	12.59016237		
U1 LP TURB INLET PRESSURE	207.1312326	1.544698746	208.6759313
U1 RFPT STEAM FLOW FROM MS B1	104380.3197	210202.1639	70067.38798
U1 RFPT STEAM FLOW FROM MS C1	105821.8443		

Nine case studies were completed in the predictive, heat balance software. The first case demonstrated the unit with design components and 2.0 inhgA of condenser back pressure at 105% OLTP and design main steam conditions. The second case demonstrated design components with the plant's actual thermal power (accounting for recirc pump heat addition, RWCU, and reactor losses), main steam pressure, condenser back pressure and sub-cooling, and control rod drive (CRD) flow. The third case imported the boundary conditions from case 2 but also included all the other performance parameters except turbine efficiencies. These parameters included feedwater heater terminal temperature difference (TTD) and drain cooler approach (DCA) temperatures, turbine stage pressures, and pump efficiencies and discharge pressures. Two known feedwater heater relief valve leaks, FWH A2, 70,000 lb/hr & FWH C1, 19,858 lb/hr, as well as 0.5% heater shell operating vent flows were also included in case 3. Finally, the fourth case ran everything from case 3 but also included LP turbine efficiencies.

The following 5 cases were set up to study the HP turbine. The fifth case study included everything from the previous case with the addition of a throttle valve pressure drop based on the saturation pressure which was determined from local temperature indication after the throttle valve. The HP bowl pressure was figured to be 704.5 psia. This new throttle valve pressure drop changed the HP governing stage efficiencies. These changes are shown in Table 2.

Table 2: HP Turbine Corrected Efficiencies

HP TURBINE STAGE	MEASURED VALUE	AVERAGE	NEW @ 704.5 PSIA
U1 HP TURBINE GOV SIDE Stage Efficiency (GS)	89.6536255	88.16176605	85.1
U1 HP TURBINE GEN SIDE Stage Efficiency (GS)	86.6699066		
U1 HP TURBINE GOV SIDE Stage Efficiency stage 1	84.8618164	84.32396698	82.2
U1 HP TURBINE GEN SIDE Stage Efficiency stage 1	83.7861176		

The sixth case included the new bowl pressure (704.5 psia) and the actual HP turbine efficiencies adjusted for it. The seventh case further degraded the HP turbine to match generation. In the eighth case, performance data predicted for the modified HP turbine and its design throttle valve pressure loss was inserted into the model. Finally, in the ninth case, the new turbine was run with a corrected new throttle valve pressure loss based on the percent error experienced in case 5.

These case studies showed how the different plant conditions were affecting the generation. The generation results for the nine case studies are shown in Table 3. Case 6 would ideally match the actual plant output of 1103.016 MWe, however, it is 1107.888 MWe, which is 4.872 MWe higher than actual. This difference could be considered reasonable, although a little on the high side given instrument error. In fact, the HP exhaust pressure instrument that was used reads about 11 psia lower than design, which is worth about 3 MWe. It is also very possible that there are some other unknown losses or a slight feed flow problem. Yet, another alternative will be discussed later.

Table 3: Predictive, Heat Balance Case Study Results

CASE	DESCRIPTION	GENERATION (MW)
1	BASE MODEL	1130.935
2	3/24/2010 ACTUAL PLANT DATA BOUNDARY CONDITIONS	1130.786
3	ALL ACTUAL CONDITIONS W/O TURBINE EFFICIENCIES	1133.428
4	LP TURBINE EFFICIENCIES INCLUDED	1120.019
5	ACTUAL THROTTLE VALVE OUTLET PRESSURE INCLUDED	1111.576
6	HP TURBINE EFFICIENCIES INCLUDED	1107.888
7	HP TURBINE DEGRADED TO MATCH GENERATION	1103.024
8	NEW HP TURBINE & THROTTLING CONDITIONS INCLUDED	1157.679
9	NEW HP TURBINE WITH 4.15% THROTTLED PRESS DIFF	1150.361

In case 1 with all 100% design conditions and a back pressure of 2 inhgA, the output was 1130.935 MWe. When considering actual plant boundary conditions in case 2 (main steam pressure, condenser back pressure and sub-cooling, and Control Rod Drive (CRD) flow), only 0.149 MWe was lost. When considering all other actual performance parameters besides turbine efficiencies (case 3), we actually gained 2.642 MWe. This gain was attributed to an 11 psia lower HP turbine exhaust pressure compared to design.

The main contributors to lost generation were turbine efficiencies and throttling losses. In case 4, the LP turbine efficiencies were incorporated to give a loss of 13.409 MWe. This is a 1.15% loss in generation. In the next five cases, the HP turbine was examined.

In case 5, actual throttle valve pressure drop was considered. This pressure drop was calculated based on the saturation pressure which was determined from a local temperature indication downstream of the control valves. This reduced the HP turbine inlet pressure from about 738.93 psia (pressure drop curve based on heat balances) to 704.5 psia. This was a pressure difference of 4.15% and was worth 8.443 MWe. Next, in case 6 the actual HP turbine efficiencies were entered for an additional loss of 3.688 MWe. These efficiencies came from the on-line thermal performance system and are calculated based on the design expansion line. The design expansion line is shaped from the vendor heat balances and is the best available representation of expected steam expansion through the turbine.

In case 7 the HP turbine was further degraded until the generation was matched. This illustrated what the efficiencies would be if all of the loss was due to throttle pressure drop and poor HP turbine efficiencies caused by the steam expansion not following the design expansion line. Table 4 shows the efficiency differences between case 3 and case 6; and case 3 and case 7.

Table 4: Turbine Efficiency Comparison

TURBINE STAGE	CASE 3 C3	CASE 6 C6	DELTA C3 - C6	CASE 3 C3	CASE 7 C7	DELTA C3 - C7	DELTA C6 - C7
HP GOV EFFICIENCY	87.87%	85.10%	2.77%	87.87%	84.41%	3.46%	0.69%
HP 1ST STAGE EFFICIENCY	84.06%	82.20%	1.86%	84.06%	80.30%	3.75%	1.90%
LPA 1ST STAGE EFFICIENCY	92.75%	86.75%	6.00%	92.75%	86.75%	6.00%	0.00%
LPA 2ND STAGE EFFICIENCY	89.49%	89.69%	-0.20%	89.49%	89.69%	-0.20%	0.00%
LPA 3RD STAGE EFFICIENCY	87.06%	86.66%	0.40%	87.06%	86.66%	0.40%	0.00%
LPA 4TH STAGE EFFICIENCY	84.93%	84.87%	0.06%	84.93%	84.87%	0.06%	0.00%
LPA 5TH STAGE EFFICIENCY	83.34%	83.80%	-0.46%	83.34%	83.80%	-0.46%	0.00%
LPA 6TH STAGE EFFICIENCY	82.21%	82.04%	0.18%	82.21%	82.04%	0.18%	0.00%
LPA 7TH STAGE EFFICIENCY	82.75%	82.65%	0.10%	82.75%	82.65%	0.10%	0.00%
LPA 8TH STAGE EFFICIENCY	68.01%	65.91%	2.09%	68.01%	65.91%	2.09%	0.00%
LPB 1ST STAGE EFFICIENCY	92.75%	86.74%	6.00%	92.75%	86.74%	6.00%	0.00%
LPB 2ND STAGE EFFICIENCY	89.49%	89.69%	-0.20%	89.49%	89.69%	-0.20%	0.00%
LPB 3RD STAGE EFFICIENCY	87.06%	86.66%	0.40%	87.06%	86.66%	0.40%	0.00%
LPB 4TH STAGE EFFICIENCY	85.02%	84.83%	0.19%	85.02%	84.83%	0.19%	0.00%
LPB 5TH STAGE EFFICIENCY	83.52%	84.02%	-0.50%	83.52%	84.02%	-0.50%	0.00%
LPB 6TH STAGE EFFICIENCY	82.21%	82.32%	-0.11%	82.21%	82.32%	-0.11%	0.00%
LPB 7TH STAGE EFFICIENCY	82.64%	82.53%	0.12%	82.64%	82.53%	0.12%	0.00%
LPB 8TH STAGE EFFICIENCY	67.18%	64.99%	2.19%	67.18%	64.99%	2.19%	0.00%
LPC 1ST STAGE EFFICIENCY	92.75%	86.74%	6.00%	92.75%	86.74%	6.00%	0.00%
LPC 2ND STAGE EFFICIENCY	89.49%	89.69%	-0.20%	89.49%	89.69%	-0.20%	0.00%
LPC 3RD STAGE EFFICIENCY	87.06%	86.66%	0.40%	87.06%	86.66%	0.40%	0.00%
LPC 4TH STAGE EFFICIENCY	84.98%	84.85%	0.13%	84.98%	84.85%	0.13%	0.00%
LPC 5TH STAGE EFFICIENCY	83.45%	83.93%	-0.48%	83.45%	83.93%	-0.48%	0.00%
LPC 6TH STAGE EFFICIENCY	82.20%	82.23%	-0.04%	82.20%	82.23%	-0.04%	0.00%
LPC 7TH STAGE EFFICIENCY	82.67%	82.54%	0.13%	82.67%	82.54%	0.13%	0.00%
LPC 8TH STAGE EFFICIENCY	63.24%	60.45%	2.79%	63.24%	60.45%	2.79%	0.00%

Finally, generation returns were studied for inserting the proposed modified HP turbine into the model. These turbine modifications are planned for implementation in the fall of 2010. At that point, plant data will again be examined to determine the actual MWe gain (i.e., pre and post test are to be conducted).

In case 8, the turbine and throttle valve tuned data from the new turbine heat balances were applied to the model along with the plant conditions from case 4. This resulted in a generation of 1157.679 MWe. This was mostly a result of a lower pressure drop across the throttle valve. In case 4 the throttled pressure was 738.9 psia, and in this case, it was 917.3 psia. In fact, the efficiencies of this new turbine are very similar to the design efficiencies of the current turbine as shown in Table 5.

Table 5: HP Turbine Efficiency Comparison

	CASE 4 C4	CASE 8 C8	DELTA C4 - C8
HP GOV EFFICIENCY	86.72%	86.76%	-0.04%
HP 1ST STAGE EFFICIENCY	83.20%	82.73%	0.47%

Finally in case 9, the 4.15% throttle valve pressure difference from case 5 was used with the modified HP turbine. This study showed how the generation would be impacted if the new design misses the throttle valve outlet pressure by the same percentage that the original did. The result was a turbine inlet pressure reduction from 917.28 psia to 879.216 psia and an output of 1150.348 MWe. This output is 7.318 MWe less than what the design would produce. These results show how important this pressure can be to generation. A pressure indication after the throttle valve is going to be added during the turbine replacement, so a better analysis of throttle effects can then be performed.

From the last two studies, it was shown that generation could increase 47.332 MWe to 54.663 MWe if the new turbine allows the plant to operate similar to the vendor's heat balances. This also assumes that the 4.872 MWe unaccounted loss is due to the HP turbine. However, if this loss is due to some other problem (leaks, feedwater flow, etc.), these gains would only be 42.460 MWe to 49.791 MWe.

Conclusion

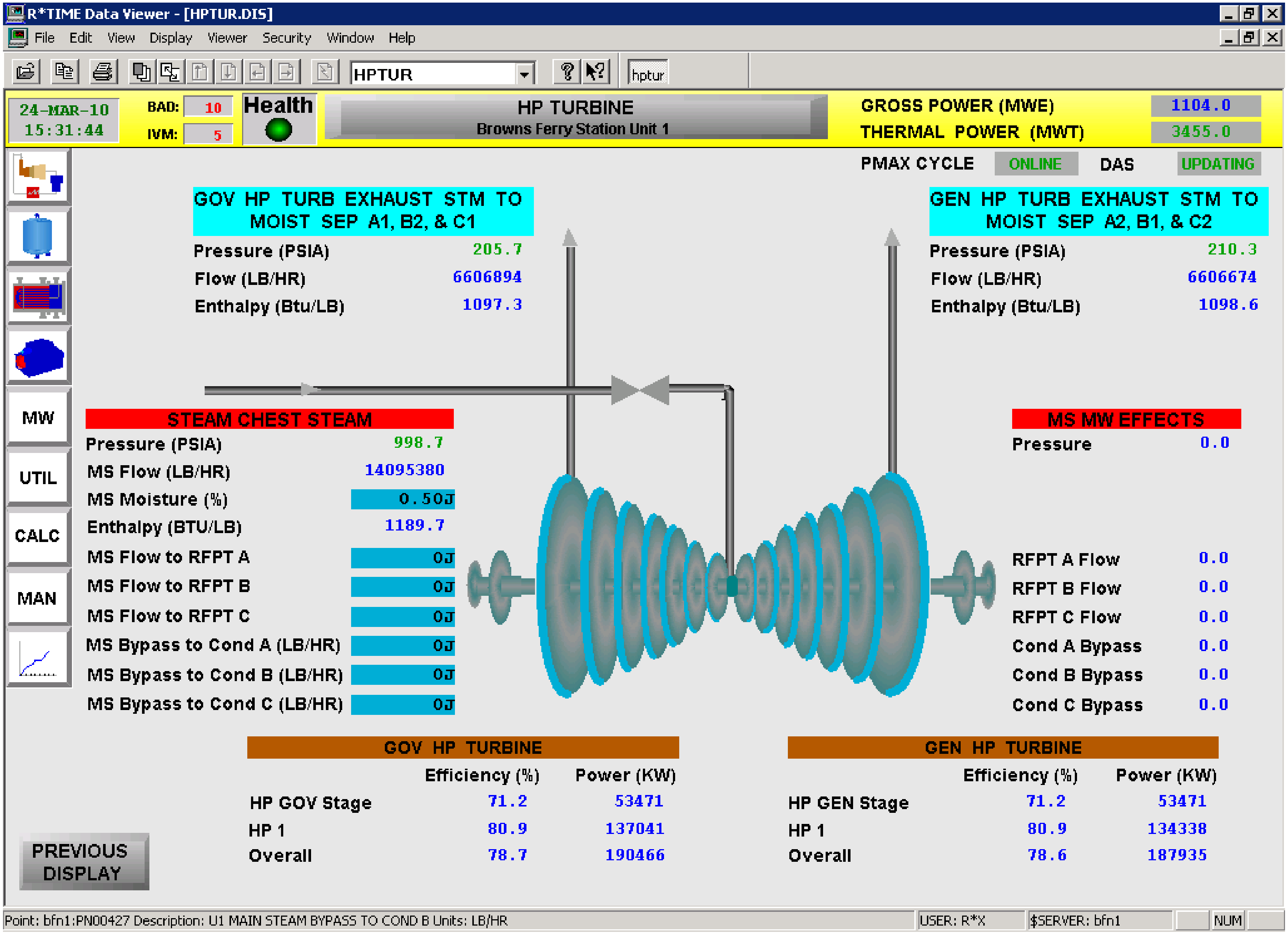
This study has shown that BFNP Unit 1 does not perform at its design turbine efficiencies or at its design throttle valve pressure drop, and that these issues cause the generation to pale in comparison to Units 2 & 3. During this study the measured generation was almost matched considering actual plant conditions. The unaccounted losses could be due to instrument error, other losses such as valve leaks, and/or a feedwater flow problem. It could also be a result of the HP turbine steam not expanding as the design expansion line predicts. It was shown that efficiencies based on design expansion lines can account for 3.688 MWe of HP turbine loss and 13.409 MWe of LP turbine loss totaling 17.097 MWe. The other large contributor was the throttled pressure which was worth 8.443 MWe bringing the total to 25.54 MWe. This would correct the actual output to 1128.556 MWe, which is close to the 1133.428 MWe expected. This would bring generation in line with Units 2 & 3; however, it is still almost 5 MWe short.

This 5 MWe could be the result of several issues. Plant instrument errors, other unknown losses, feedwater flow error, or the HP turbine not behaving as designed could make-up the 5 MWe. If the steam expansion through the HP turbine is the culprit then the total loss to HP turbine efficiency is brought up to 8.56 MWe.

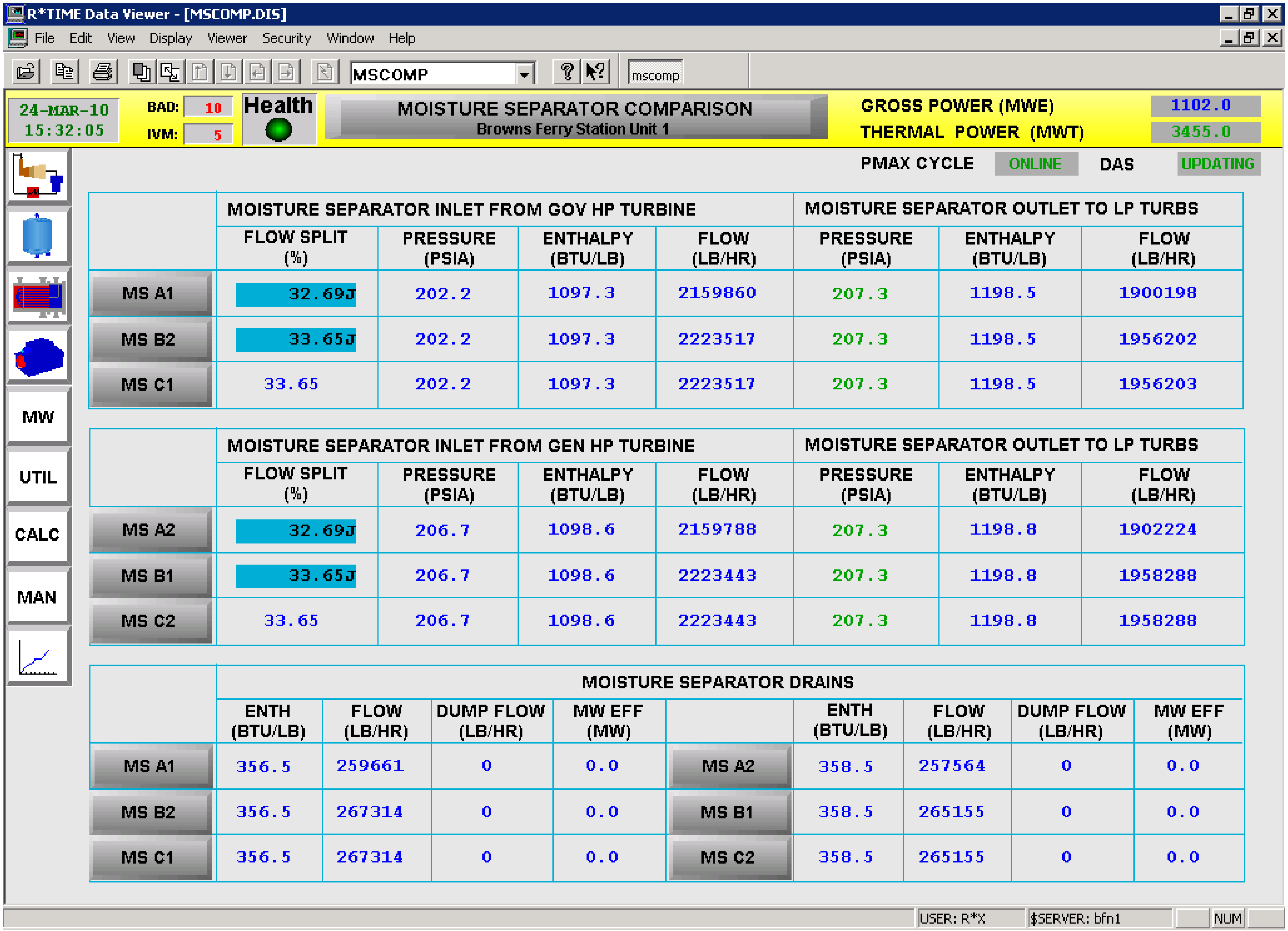
HP turbine efficiency and throttling have been suspects in loss generation since it was replaced and turbine flowrates have been at 105% OLTP instead of the 120% OLTP as the turbine was designed. As stated above, the HP turbine is going to be modified for 105% OLTP conditions in the fall of 2010 in an attempt to reclaim all or some portion of the losses. The throttle valves are expected to be opened to 54% (similar to Units 2 & 3) from the current 47%. After this occurs, we will have another data point to consider for this study, but some additional analyses were performed based on this upcoming replacement's heat balances.

These analyses showed that if the throttle valve and HP turbine behave as indicated by the new heat balances, around 50 MWe of generation could be regained. This number takes into account the 1.15% loss attributed to the LP turbines as well as all other known and about 5 MWe of unknown losses during the data acquisition period on 3/24/2010. The turbine vendor is suggesting a 27.5 MWe gain, so it will be interesting to see just what generation is obtained.

APPENDIX A



R*TIME Data Viewer - [HPTUR.DIS]
File Edit View Display Viewer Security Window Help
HPTUR
hptur
24-MAR-10
15:31:44
BAD: 10
IVM: 5
Health
HP TURBINE
Browns Ferry Station Unit 1
GROSS POWER (MWE) 1104.0
THERMAL POWER (MWT) 3455.0
PMAX CYCLE ONLINE
DAS UPDATING
GOV HP TURB EXHAUST STM TO MOIST SEP A1, B2, & C1
Pressure (PSIA) 205.7
Flow (LB/HR) 6606894
Enthalpy (Btu/LB) 1097.3
GEN HP TURB EXHAUST STM TO MOIST SEP A2, B1, & C2
Pressure (PSIA) 210.3
Flow (LB/HR) 6606674
Enthalpy (Btu/LB) 1098.6
STEAM CHEST STEAM
Pressure (PSIA) 998.7
MS Flow (LB/HR) 14095380
MS Moisture (%) 0.50J
Enthalpy (BTU/LB) 1189.7
MS Flow to RFPT A 0J
MS Flow to RFPT B 0J
MS Flow to RFPT C 0J
MS Bypass to Cond A (LB/HR) 0J
MS Bypass to Cond B (LB/HR) 0J
MS Bypass to Cond C (LB/HR) 0J
MS MW EFFECTS
Pressure 0.0
RFPT A Flow 0.0
RFPT B Flow 0.0
RFPT C Flow 0.0
Cond A Bypass 0.0
Cond B Bypass 0.0
Cond C Bypass 0.0
MW
UTIL
CALC
MAN
GOV HP TURBINE
Efficiency (%) Power (KW)
HP GOV Stage 71.2 53471
HP 1 80.9 137041
Overall 78.7 190466
GEN HP TURBINE
Efficiency (%) Power (KW)
HP GEN Stage 71.2 53471
HP 1 80.9 134338
Overall 78.6 187935
PREVIOUS DISPLAY
Point: bfn1:PN00427 Description: U1 MAIN STEAM BYPASS TO COND B Units: LB/HR
USER: R*X
$SERVER: bfn1
NUM


R*TIME Data Viewer - [MSCOMP.DIS]

File Edit View Display Viewer Security Window Help

MSCOMP

24-MAR-10 15:32:05

BAD: 10

IVM: 5

Health

MOISTURE SEPARATOR COMPARISON
Browns Ferry Station Unit 1

GROSS POWER (MWE) 1102.0

THERMAL POWER (MWT) 3455.0

PMAX CYCLE ONLINE DAS UPDATING

	MOISTURE SEPARATOR INLET FROM GOV HP TURBINE				MOISTURE SEPARATOR OUTLET TO LP TURBS		
	FLOW SPLIT (%)	PRESSURE (PSIA)	ENTHALPY (BTU/LB)	FLOW (LB/HR)	PRESSURE (PSIA)	ENTHALPY (BTU/LB)	FLOW (LB/HR)
MS A1	32.69J	202.2	1097.3	2159860	207.3	1198.5	1900198
MS B2	33.65J	202.2	1097.3	2223517	207.3	1198.5	1956202
MS C1	33.65	202.2	1097.3	2223517	207.3	1198.5	1956203

	MOISTURE SEPARATOR INLET FROM GEN HP TURBINE				MOISTURE SEPARATOR OUTLET TO LP TURBS		
	FLOW SPLIT (%)	PRESSURE (PSIA)	ENTHALPY (BTU/LB)	FLOW (LB/HR)	PRESSURE (PSIA)	ENTHALPY (BTU/LB)	FLOW (LB/HR)
MS A2	32.69J	206.7	1098.6	2159788	207.3	1198.8	1902224
MS B1	33.65J	206.7	1098.6	2223443	207.3	1198.8	1958288
MS C2	33.65	206.7	1098.6	2223443	207.3	1198.8	1958288

	MOISTURE SEPARATOR DRAINS								
	ENTH (BTU/LB)	FLOW (LB/HR)	DUMP FLOW (LB/HR)	MW EFF (MW)		ENTH (BTU/LB)	FLOW (LB/HR)	DUMP FLOW (LB/HR)	MW EFF (MW)
MS A1	356.5	259661	0	0.0	MS A2	358.5	257564	0	0.0
MS B2	356.5	267314	0	0.0	MS B1	358.5	265155	0	0.0
MS C1	356.5	267314	0	0.0	MS C2	358.5	265155	0	0.0

MW

UTIL

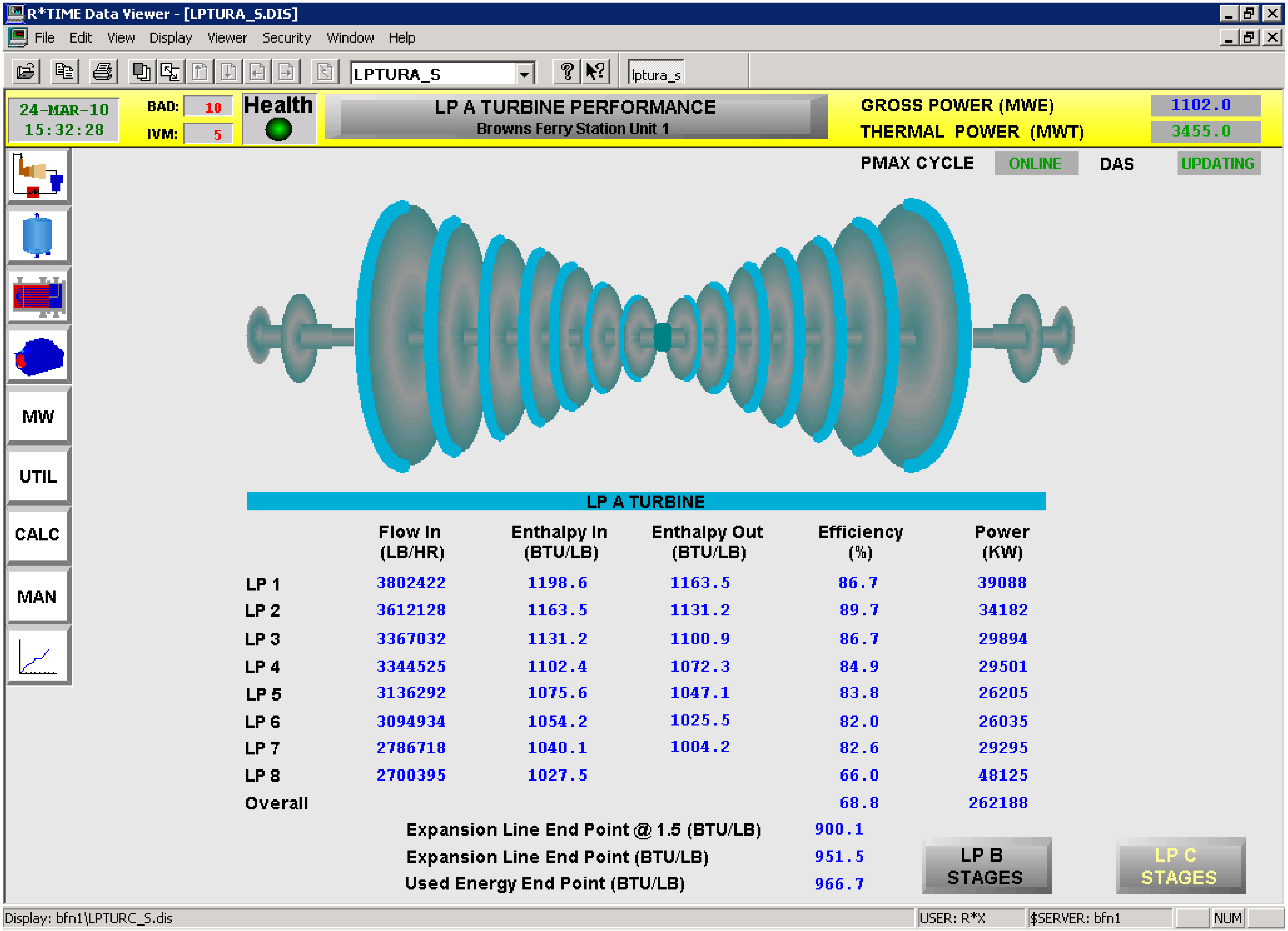
CALC

MAN

USER: R*X $SERVER: bfn1 NUM

Evaluating Generation Considering All Plant Losses and Efficiencies

APPENDIX A



APPENDIX A

R*TIME Data Viewer - [LPTURB_S.DIS]

File Edit View Display Viewer Security Window Help

LPTURB_S lpturb_s

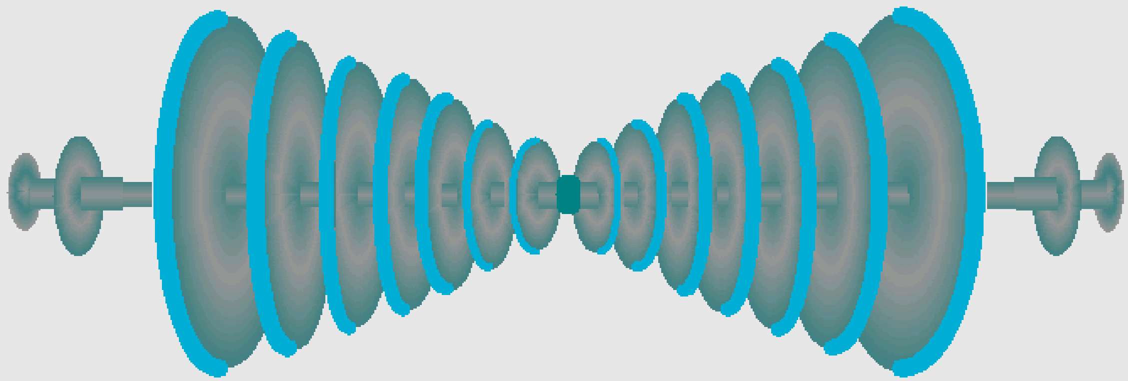
24-MAR-10 15:32:41 BAD: 10 IVM: 5 Health

LP B TURBINE PERFORMANCE
Browns Ferry Station Unit 1

GROSS POWER (MWE) 1102.0
THERMAL POWER (MWT) 3455.0

PMAX CYCLE ONLINE DAS UPDATING

MW
UTIL
CALC
MAN



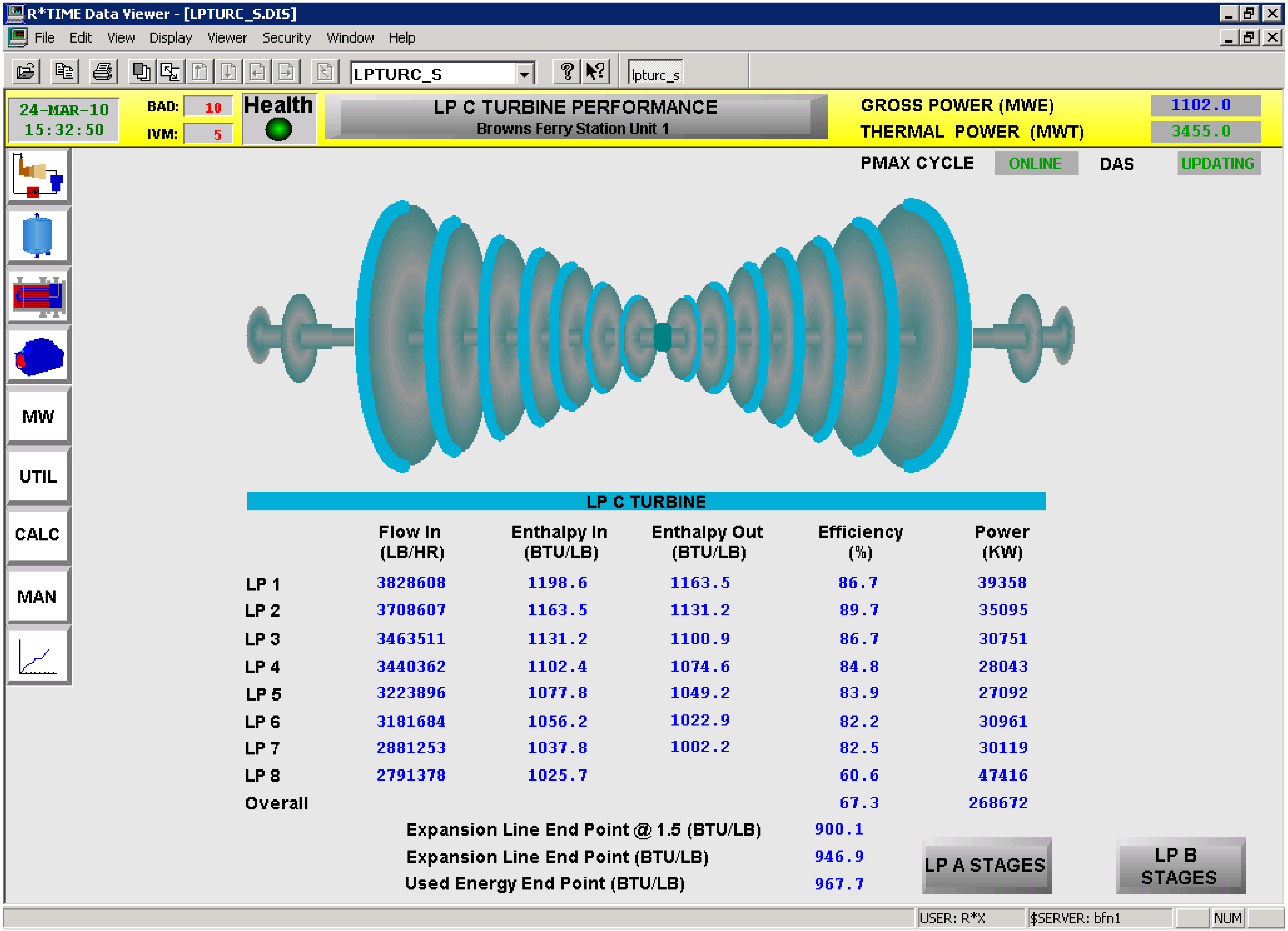
LP B TURBINE

	Flow In (LB/HR)	Enthalpy In (BTU/LB)	Enthalpy Out (BTU/LB)	Efficiency (%)	Power (KW)
LP 1	3828607	1198.6	1163.5	86.7	39358
LP 2	3708606	1163.5	1131.2	89.7	35095
LP 3	3463510	1131.2	1100.9	86.7	30751
LP 4	3440361	1102.4	1076.2	84.8	26422
LP 5	3223163	1079.4	1050.6	84.0	27192
LP 6	3181169	1057.6	1022.8	82.3	32368
LP 7	2852081	1037.6	1001.9	82.5	29801
LP 8	2763062	1025.5		65.0	46589
Overall				68.6	267310

Expansion Line End Point @ 1.5 (BTU/LB) 900.1
Expansion Line End Point (BTU/LB) 952.4
Used Energy End Point (BTU/LB) 967.9

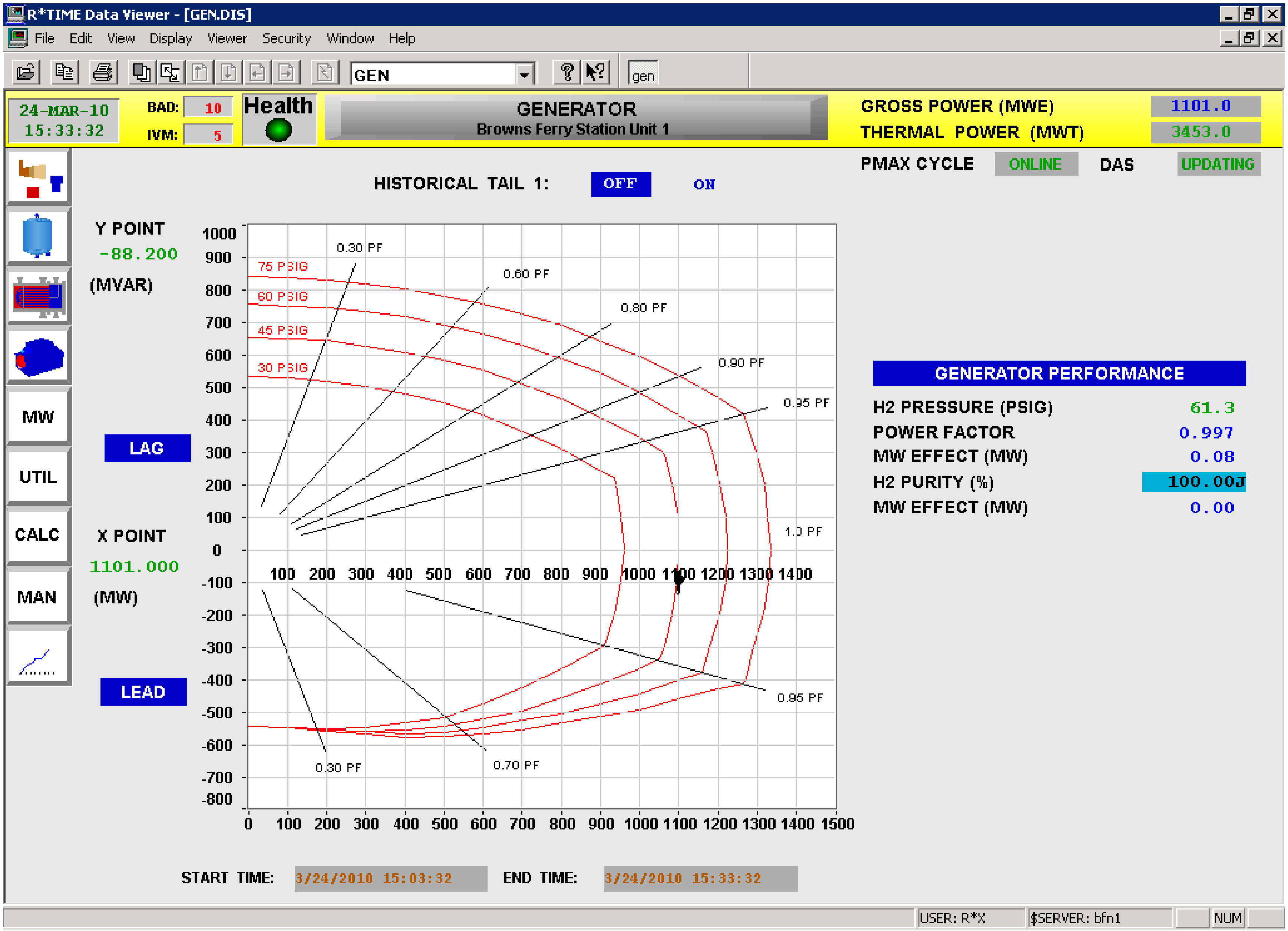
LP A STAGES LP C STAGES

Point: bfn1:PN03930 Description: U1 LP TURBINE B Stage Work stage 6 Units: KW USER: R*X $SERVER: bfn1 NUM



	Flow In (LB/HR)	Enthalpy In (BTU/LB)	Enthalpy Out (BTU/LB)	Efficiency (%)	Power (KW)
LP 1	3828608	1198.6	1163.5	86.7	39358
LP 2	3708607	1163.5	1131.2	89.7	35095
LP 3	3463511	1131.2	1100.9	86.7	30751
LP 4	3440362	1102.4	1074.6	84.8	28043
LP 5	3223896	1077.8	1049.2	83.9	27092
LP 6	3181684	1056.2	1022.9	82.2	30961
LP 7	2881253	1037.8	1002.2	82.5	30119
LP 8	2791378	1025.7		60.6	47416
Overall				67.3	268672

Expansion Line End Point @ 1.5 (BTU/LB)	900.1
Expansion Line End Point (BTU/LB)	946.9
Used Energy End Point (BTU/LB)	967.7


R*TIME Data Viewer - [GEN.DIS]
File Edit View Display Viewer Security Window Help
GEN
gen
24-MAR-10
15:33:32
BAD: 10
IVM: 5
Health
GENERATOR
Browns Ferry Station Unit 1
GROSS POWER (MWE) 1101.0
THERMAL POWER (MWT) 3453.0
PMAX CYCLE ONLINE
DAS UPDATING
HISTORICAL TAIL 1: OFF ON
Y POINT
-88.200
(MVAR)
LAG
X POINT
1101.000
(MW)
LEAD
MW
UTIL
CALC
MAN
75 PSIG
60 PSIG
45 PSIG
30 PSIG
0.30 PF
0.60 PF
0.80 PF
0.90 PF
0.95 PF
1.0 PF
0.95 PF
0.70 PF
0.30 PF
GENERATOR PERFORMANCE
H2 PRESSURE (PSIG) 61.3
POWER FACTOR 0.997
MW EFFECT (MW) 0.08
H2 PURITY (%) 100.00J
MW EFFECT (MW) 0.00
START TIME: 3/24/2010 15:03:32
END TIME: 3/24/2010 15:33:32
USER: R*X
$SERVER: bfn1
NUM

R*TIME Data Viewer - [CONDS.DIS]

File Edit View Display Viewer Security Window Help

CONDS conds

24-MAR-10 15:34:18 BAD: 10 IVM: 5 Health

CONDENSER SHELL COMPARISONS
Browns Ferry Station Unit 1

GROSS POWER (MWE) 1102.0
THERMAL POWER (MWT) 3455.0

PMAX CYCLE ONLINE DAS UPDATING

MW UTIL CALC MAN

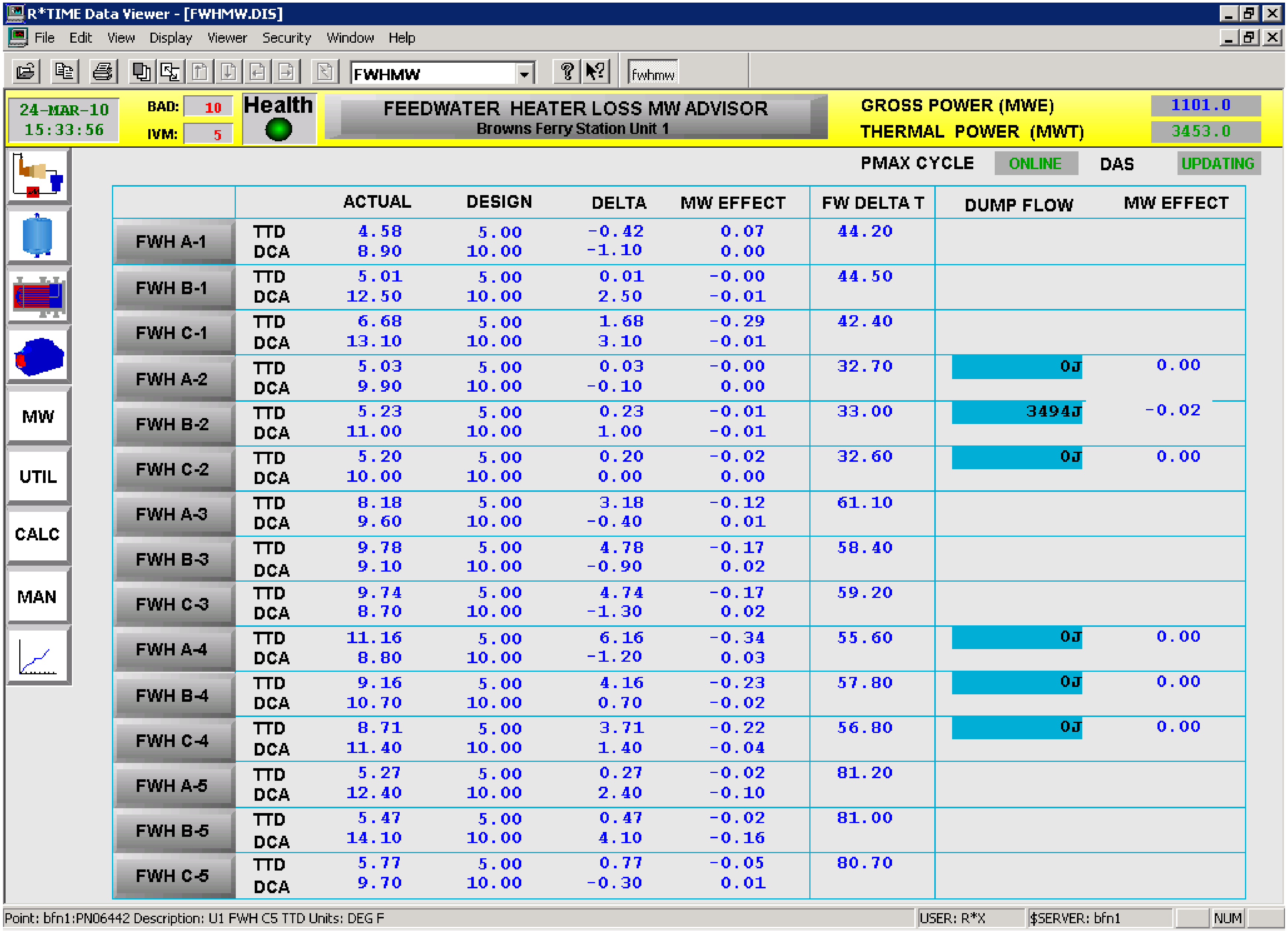
INPUT CONDITIONS	STEAM FLOW (LB/HR)	CIRC FLOW (LB/HR)	CIRC IN TEMP (DEG F)	CIRC OUT TEMP (DEG F)	BACK PRESS (INHG)	DRAIN IN FLOW (LB/HR)	DRN IN ENTH (BTU/LB)
CONDENSER A	2706516	119950496	52.8	74.5	2.05	2003695	165.4
CONDENSER B	2768482	110376976	52.4	75.7	2.09	1917331	119.5
CONDENSER C	2797011	107561232	52.7	77.0	1.81	1913837	119.2

CALCULATED OUTPUTS	C. F. (FRAC)	HEAT TRANS COEF (BTU/HR-°F-FT)	CONDENSATE TTD (DEG F)	CIRC WATER T RISE (DEG F)	HEAT DUTY (MBTU/HR)
CONDENSER A	0.57	316	27.3	21.8	2608.221
CONDENSER B	0.59	309	26.9	23.3	2566.913
CONDENSER C	0.72	374	20.8	24.2	2614.246

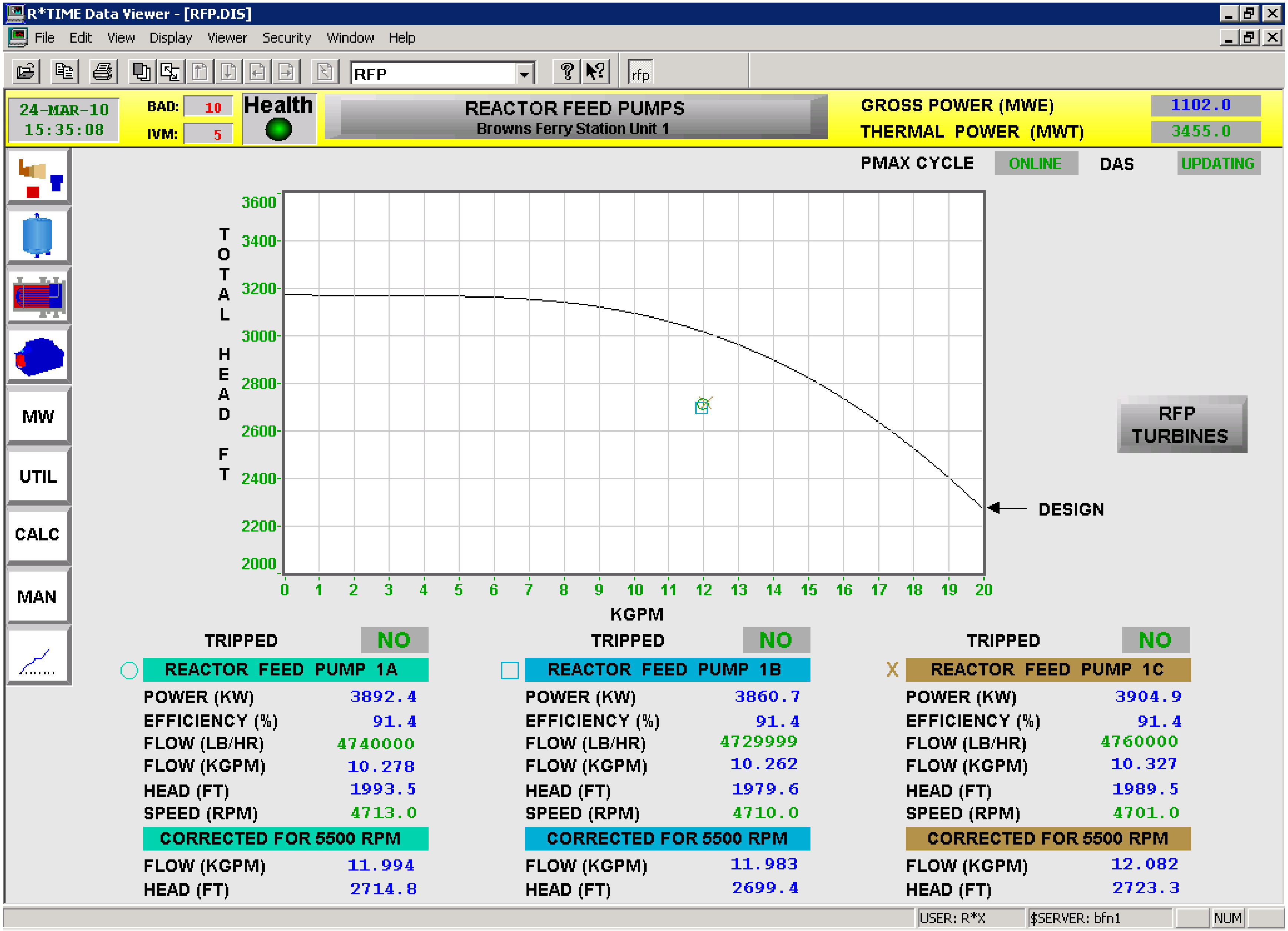
CALCULATED MW EFFECTS		ACTUAL	DESIGN	DELTA	MW EFFECT (MW)
CONDENSER A	CF (FRAC)	0.57	0.90J	-0.33	-2.16
	CIRC IN T (DEG F)	52.80	65	12.20	1.36
CONDENSER B	CF (FRAC)	0.59	0.90J	-0.31	-2.28
	CIRC IN T (DEG F)	52.40	65	12.60	1.63
CONDENSER C	CF (FRAC)	0.72	0.90J	-0.18	-1.44
	CIRC IN T (DEG F)	52.70	65	12.40	1.77

USER: R*X $SERVER: bfn1 NUM

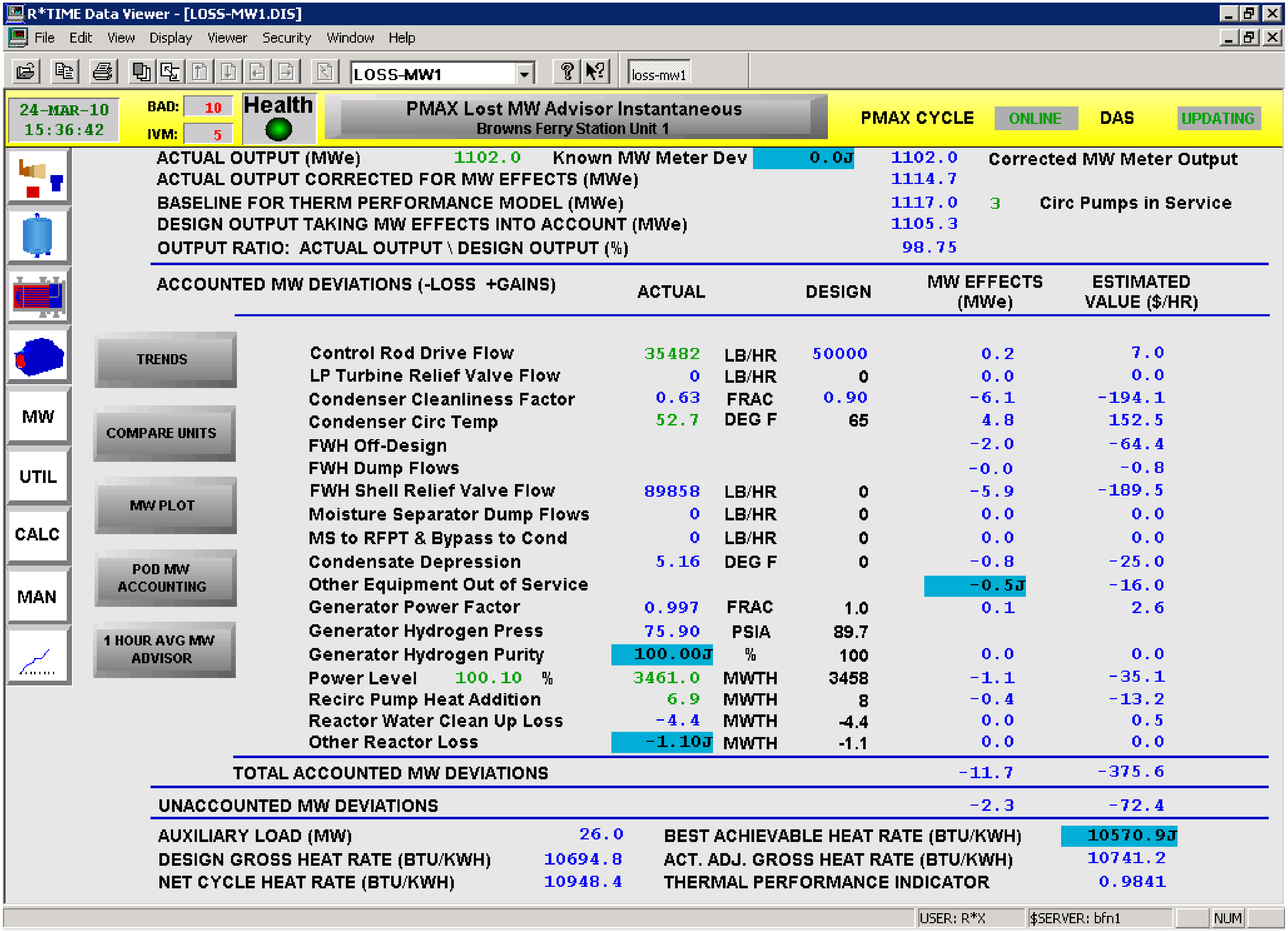
APPENDIX A



		ACTUAL	DESIGN	DELTA	MW EFFECT	FW DELTA T	DUMP FLOW	MW EFFECT
FWH A-1	TTD	4.58	5.00	-0.42	0.07	44.20		
	DCA	8.90	10.00	-1.10	0.00			
FWH B-1	TTD	5.01	5.00	0.01	-0.00	44.50		
	DCA	12.50	10.00	2.50	-0.01			
FWH C-1	TTD	6.68	5.00	1.68	-0.29	42.40		
	DCA	13.10	10.00	3.10	-0.01			
FWH A-2	TTD	5.03	5.00	0.03	-0.00	32.70	0J	0.00
	DCA	9.90	10.00	-0.10	0.00			
FWH B-2	TTD	5.23	5.00	0.23	-0.01	33.00	3494J	-0.02
	DCA	11.00	10.00	1.00	-0.01			
FWH C-2	TTD	5.20	5.00	0.20	-0.02	32.60	0J	0.00
	DCA	10.00	10.00	0.00	0.00			
FWH A-3	TTD	8.18	5.00	3.18	-0.12	61.10		
	DCA	9.60	10.00	-0.40	0.01			
FWH B-3	TTD	9.78	5.00	4.78	-0.17	58.40		
	DCA	9.10	10.00	-0.90	0.02			
FWH C-3	TTD	9.74	5.00	4.74	-0.17	59.20		
	DCA	8.70	10.00	-1.30	0.02			
FWH A-4	TTD	11.16	5.00	6.16	-0.34	55.60	0J	0.00
	DCA	8.80	10.00	-1.20	0.03			
FWH B-4	TTD	9.16	5.00	4.16	-0.23	57.80	0J	0.00
	DCA	10.70	10.00	0.70	-0.02			
FWH C-4	TTD	8.71	5.00	3.71	-0.22	56.80	0J	0.00
	DCA	11.40	10.00	1.40	-0.04			
FWH A-5	TTD	5.27	5.00	0.27	-0.02	81.20		
	DCA	12.40	10.00	2.40	-0.10			
FWH B-5	TTD	5.47	5.00	0.47	-0.02	81.00		
	DCA	14.10	10.00	4.10	-0.16			
FWH C-5	TTD	5.77	5.00	0.77	-0.05	80.70		
	DCA	9.70	10.00	-0.30	0.01			


R*TIME Data Viewer - [RFP.DIS]
File Edit View Display Viewer Security Window Help
RFP
rfp
24-MAR-10
15:35:08
BAD: 10
IVM: 5
Health
REACTOR FEED PUMPS
Browns Ferry Station Unit 1
GROSS POWER (MWE) 1102.0
THERMAL POWER (MWT) 3455.0
PMAX CYCLE ONLINE
DAS UPDATING
MW
UTIL
CALC
MAN
TOTAL HEAD FT
3600
3400
3200
3000
2800
2600
2400
2200
2000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
KGPM
DESIGN
RFP TURBINES
TRIPPED NO
REACTOR FEED PUMP 1A
POWER (KW) 3892.4
EFFICIENCY (%) 91.4
FLOW (LB/HR) 4740000
FLOW (KGPM) 10.278
HEAD (FT) 1993.5
SPEED (RPM) 4713.0
CORRECTED FOR 5500 RPM
FLOW (KGPM) 11.994
HEAD (FT) 2714.8
TRIPPED NO
REACTOR FEED PUMP 1B
POWER (KW) 3860.7
EFFICIENCY (%) 91.4
FLOW (LB/HR) 4729999
FLOW (KGPM) 10.262
HEAD (FT) 1979.6
SPEED (RPM) 4710.0
CORRECTED FOR 5500 RPM
FLOW (KGPM) 11.983
HEAD (FT) 2699.4
TRIPPED NO
X REACTOR FEED PUMP 1C
POWER (KW) 3904.9
EFFICIENCY (%) 91.4
FLOW (LB/HR) 4760000
FLOW (KGPM) 10.327
HEAD (FT) 1989.5
SPEED (RPM) 4701.0
CORRECTED FOR 5500 RPM
FLOW (KGPM) 12.082
HEAD (FT) 2723.3
USER: R*X
$SERVER: bfn1
NUM

APPENDIX A



R*TIME Data Viewer - [LOSS-MW1.DIS]

File Edit View Display Viewer Security Window Help

LOSS-MW1 loss-mw1

24-MAR-10 15:36:42 BAD: 10 IVM: 5 Health

PMAX Lost MW Advisor Instantaneous
Browns Ferry Station Unit 1

PMAX CYCLE ONLINE DAS UPDATING

ACTUAL OUTPUT (MWe)	1102.0	Known MW Meter Dev 0.0J	1102.0 Corrected MW Meter Output
ACTUAL OUTPUT CORRECTED FOR MW EFFECTS (MWe)			1114.7
BASELINE FOR THERM PERFORMANCE MODEL (MWe)			1117.0 3 Circ Pumps in Service
DESIGN OUTPUT TAKING MW EFFECTS INTO ACCOUNT (MWe)			1105.3
OUTPUT RATIO: ACTUAL OUTPUT \ DESIGN OUTPUT (%)			98.75

ACCOUNTED MW DEVIATIONS (-LOSS +GAINS)	ACTUAL		DESIGN	MW EFFECTS (MWe)	ESTIMATED VALUE ($/HR)
Control Rod Drive Flow	35482	LB/HR	50000	0.2	7.0
LP Turbine Relief Valve Flow	0	LB/HR	0	0.0	0.0
Condenser Cleanliness Factor	0.63	FRAC	0.90	-6.1	-194.1
Condenser Circ Temp	52.7	DEG F	65	4.8	152.5
FWH Off-Design				-2.0	-64.4
FWH Dump Flows				-0.0	-0.8
FWH Shell Relief Valve Flow	89858	LB/HR	0	-5.9	-189.5
Moisture Separator Dump Flows	0	LB/HR	0	0.0	0.0
MS to RFPT & Bypass to Cond	0	LB/HR	0	0.0	0.0
Condensate Depression	5.16	DEG F	0	-0.8	-25.0
Other Equipment Out of Service				-0.5J	-16.0
Generator Power Factor	0.997	FRAC	1.0	0.1	2.6
Generator Hydrogen Press	75.90	PSIA	89.7		
Generator Hydrogen Purity	100.00J	%	100	0.0	0.0
Power Level 100.10 %	3461.0	MWTH	3458	-1.1	-35.1
Recirc Pump Heat Addition	6.9	MWTH	8	-0.4	-13.2
Reactor Water Clean Up Loss	-4.4	MWTH	-4.4	0.0	0.5
Other Reactor Loss	-1.10J	MWTH	-1.1	0.0	0.0
TOTAL ACCOUNTED MW DEVIATIONS				-11.7	-375.6
UNACCOUNTED MW DEVIATIONS				-2.3	-72.4

AUXILIARY LOAD (MW)	26.0	BEST ACHIEVABLE HEAT RATE (BTU/KWH)	10570.9J
DESIGN GROSS HEAT RATE (BTU/KWH)	10694.8	ACT. ADJ. GROSS HEAT RATE (BTU/KWH)	10741.2
NET CYCLE HEAT RATE (BTU/KWH)	10948.4	THERMAL PERFORMANCE INDICATOR	0.9841

TRENDS COMPARE UNITS MW PLOT POD MW ACCOUNTING 1 HOUR AVG MW ADVISOR

MW UTIL CALC MAN

USER: R*X $SERVER: bfn1 NUM