Section 7B

PMAX Model Tuning of the Watts Bar Multi-pressure Condenser

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Abstract

In the spring of this year, TVAN completed the implementation phase of our PMAX project which was undertaken to standardize our Thermal Performance Monitoring tools and techniques for the three sites (Browns Ferry, Sequoyah, and Watts Bar). The Browns Ferry and Sequoyah models were relatively well behaved with acceptably small unaccounted megawatt terms from the initial date of model implementation. However, the Watts Bar model consistently exhibited a wide ranging unaccounted loss term. Extensive investigation revealed that this variation was related to the condenser performance and its megawatt effect calculations. This paper describes the various steps taken to resolve this problem, including validation of the megawatt deviation bogey curves for multi-pressure, once through condensers.

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Introduction

Following deployment of the Watts Bar PMAX model, Scientech provided the customary onsite training for the TVAN thermal performance staff and performed support services to tune the model to the plant performance. At the culmination of this work, the unaccounted megawatt loss term exhibited a relatively wide variation on the order of ± 10 megawatts. This was not expected and not consistent with variations on the order of ± 3 megawatts for the Browns Ferry and Sequoyah models.

The Watts Bar condenser and cooling system differs from the other TVA units, which utilize once through raw water cooling from the Tennessee River and three parallel, single pressure condenser zones for the three LP turbines. Watts Bar utilizes a natural draft cooling tower and essentially, closed loop cooling (a modification adds cold supplemental cooling water to the tower basin during warm weather). To maximize the efficiency of the tower, the Watts Bar condenser is a 110 foot longitudinal, once through, multi-pressure condenser. This design configuration results in a diurnal condenser cooling water (CCW) variation which follows the ambient air temperature and ranges as much as 10 degrees each day.

Inspection of PMAX trend data indicated that the magnitude of the unaccounted megawatt term varied with the CCW inlet temperature. Since the megawatt effect of varying CCW temperature is one of the accounted terms, the unaccounted variation didn't make sense. The following questions were posed:

- How is the unaccounted value determined?
- What parameters actually vary with CCW temperature?
- Why does condenser cleanliness also vary more than expected?
- What measured parameters effect condenser calculations and how can they be validated and/or made more reliable?
- How were the initial bogey curves developed and are they correct?

This paper addresses these questions and applies new methods for modeling condensers in a PMAX model. It also offers a different technique for the development of PMAX bogey curves for condenser megawatt deviations. This alternate technique validated the original curves.

Problem

The wide and continuous variation in the unaccounted megawatt term masked other potential problems, making it difficult to trust the accounting system. Figure 1 shows the trends of the unaccounted term, the gross generation, and the average CCW inlet temperature.

Figure 1 – Trend of Unaccounted, Gross Generation and CCW Inlet Temperature Based on Original Watts Bar PMAX Model and Bogey Curves

Two observations are important in Figure 1. First, it is obvious that the unaccounted term has a wide daily variation on the order of ± 10 megawatts and follows the CCW inlet temperature swings. Second, the gross generation term also presents a fairly noisy signal trend.

Unaccounted Megawatt Term

The unaccounted megawatt term in the Watts Bar model is determined by subtracting the baseline or design output from the actual output corrected for accounted MW deviations:

$$\text{Unaccounted} = \text{Gross Generation} - \sum \text{Accounted Deviations} - \text{Baseline}$$

Since the Baseline value is a constant (manual input) in the above equation, the only way that the Unaccounted term could vary with CCW temperature is if the ∑ Accounted Deviations, which includes CCW temperature, do not match the actual change in Gross Generation as the CCW temperature changes. In others words, the CCW temperature MW effect does not match the effect that the plant actually experiences. In addition, if the CCW temperature MW effect is off, it is likely that the cleanliness factor MW effect is also misrepresented since both these parameters are associated with the condenser and use the same MW effect curves.

Figure 2 shows the Watts Bar instantaneous (15 second) accounting display with typical values.

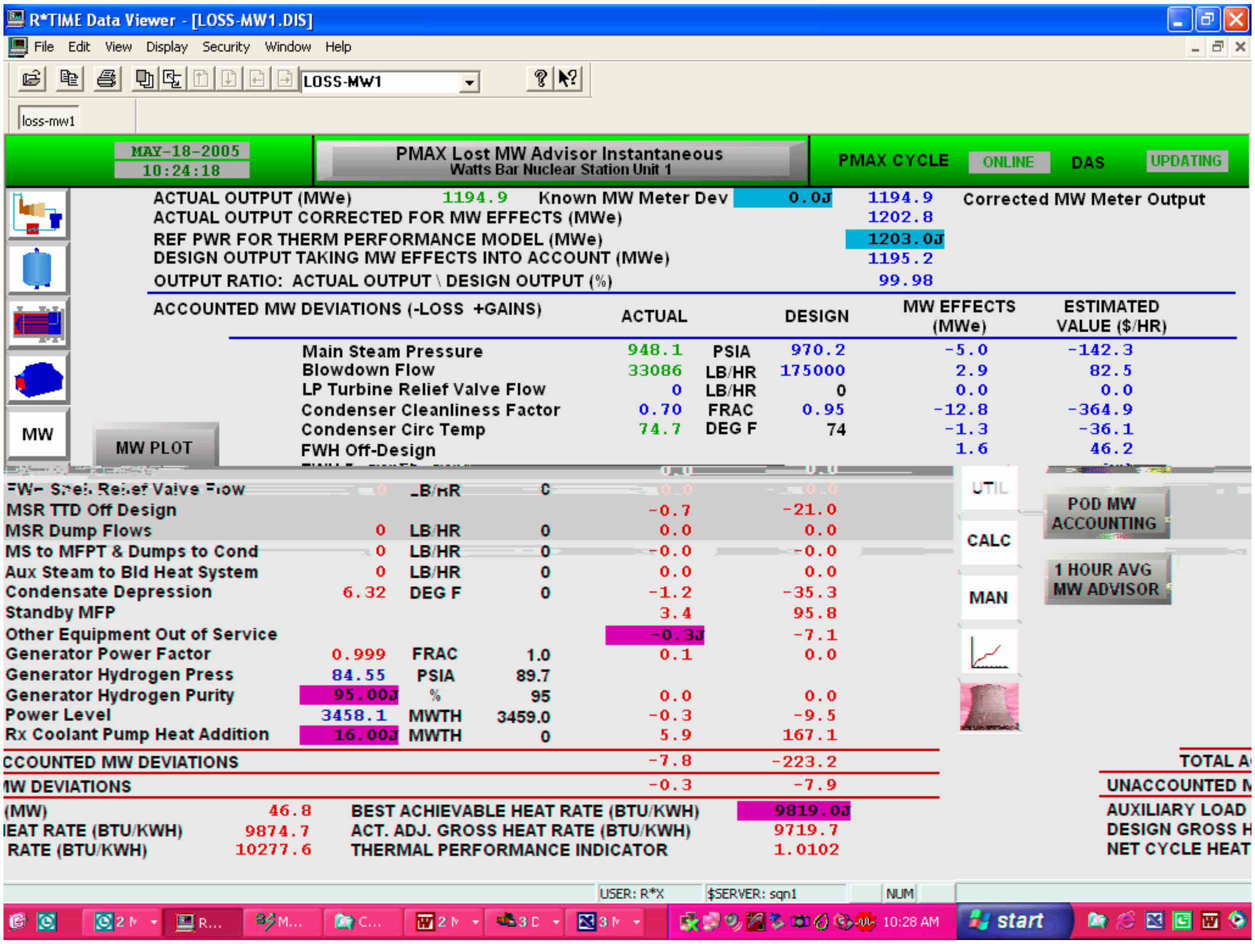

Figure 2 –Watts Bar PMAX Lost Megawatt Adviser (Megawatt Accounting)

CCW Temperature Sensitive Terms

Review of the terms presented in Figure 2 highlighted that only four of the parameters are direct or indirect functions of the CCW inlet temperature. From the top of the accounting sheet and moving down the list, gross generation obviously varies with backpressure which is dictated by the CCW temperature. Second, the condenser cleanliness factor calculated from the HEI method incorporates the HEI temperature correction factor, making it a function of the CCW inlet temperature. Third, there is the CCW temperature effect itself. Finally, the condensate depression term is a function of CCW inlet temperature.

The variation of gross generation with CCW inlet temperature was previously shown in Figure 1. Figure 3 shows the trends for the cleanliness factor, the cleanliness factor megawatt deviation, and the CCW temperature. The original model calculated the CCW flow rate from measured inlet and outlet temperatures. However, plant experience at the Sequoyah and Browns Ferry units indicated that the outlet temperature measurements may not be reliable due to thermal streaming effects. Using the measured temperature rise and turbine exhaust heat duty to calculate the flow rate yields varying CCW flow rates. To minimize this flow variance, the model was changed to utilize a constant volumetric CCW pump flow rate based on the number of pumps in service and assuming 100% design flow conditions. A manual input was then added to specify the CCW pump performance factor, which in this case is currently set at 97.2%. Finally, the outlet CCW temperatures were calculated using this flow rate, the heat duty, and the circ water inlet temperature. This change took effect on April 25th as indicated in Figure 3 below. This did seem to help stabilize the condenser calculations; however, the MW effect accounting did not receive much benefit.

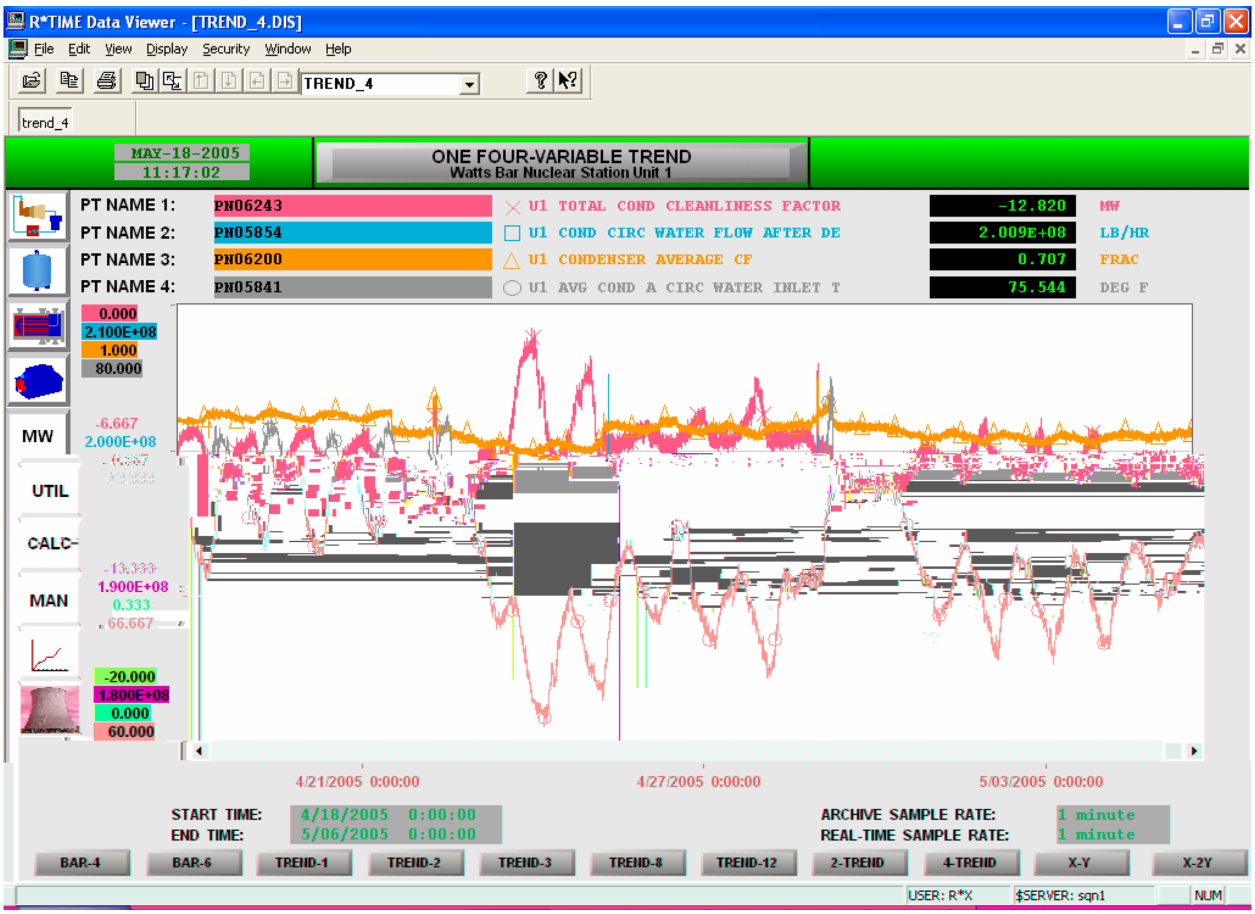

Figure 3 –Watts Bar Condenser Cleanliness Factor Trends

The megawatt deviation directly caused by the variation in CCW temperature is derived from the PMAX HEI condenser calculation module and the condenser bogey curves as a function of thermal power and condenser backpressure. The backpressure is first predicted at the current heat duty, CCW flow, design baseline CCW temperature (74 °F for Watts Bar), and 95% cleanliness. At this backpressure and the actual thermal power, the bogey curve is interpolated to give the associated megawatt deviation. Next, the backpressure at the current CCW temperature, heat duty, CCW flow, and 95% cleanliness is determined and this backpressure and the actual thermal power is used to obtain the associated megawatt deviation. The difference between these two deviations is the MW effect due to the CCW temperature variation from baseline. So it is actually the slope between a target back pressure and an actual backpressure in the curves illustrated in Figures 6 and 7 that yields the MW effect. The direct relationship between CCW temperature and its MW effect is shown in Figure 4.

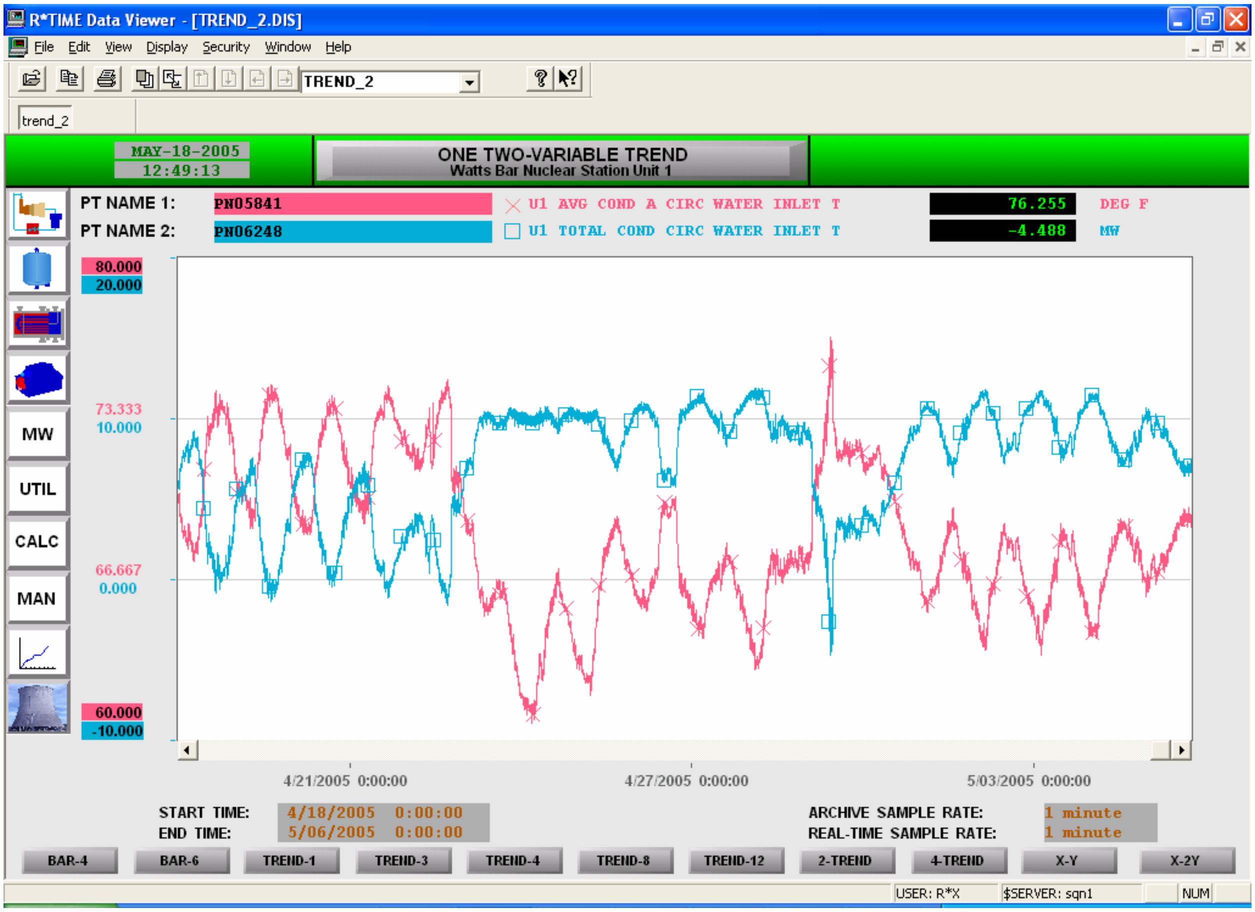

Figure 4 –Watts Bar Condenser Cooling Water Temperature Trends

At Watts Bar, it was always observed that the calculated back pressure derived from the LP turbine hood temperature was always higher than the measured condenser back pressure. Assuming this difference as a pressure drop and adding this pressure drop to the predicted backpressures used to determine MW effects for cleanliness and CCW inlet temperature yielded very stable MW accounting. Yet, using the measured shell pressures for condenser performance also yielded very realistic cleanliness values. Considering this pressure drop yields the actual backpressures that the turbine exhaust would experience. This is important because the backpressure MW effect curves were constructed based on turbine exhaust pressure. This also helps in the MW accounting because at low backpressures the MW deviation curve is less linear and the slope approaches zero as shown in Figures 6 and 7. Taking the pressure drop into account can help push the MW effect out into the steeper portion of the curve. Even though this helped to stabilize the sensitivity to CCW temperature at lower backpressures, it did not remedy the problem over the temperature range.

Condensate depression was ruled out as a cause of the unaccounted megawatt variability based on the relatively stable and small contribution that this parameter represented. This is clearly shown in Figure 5.

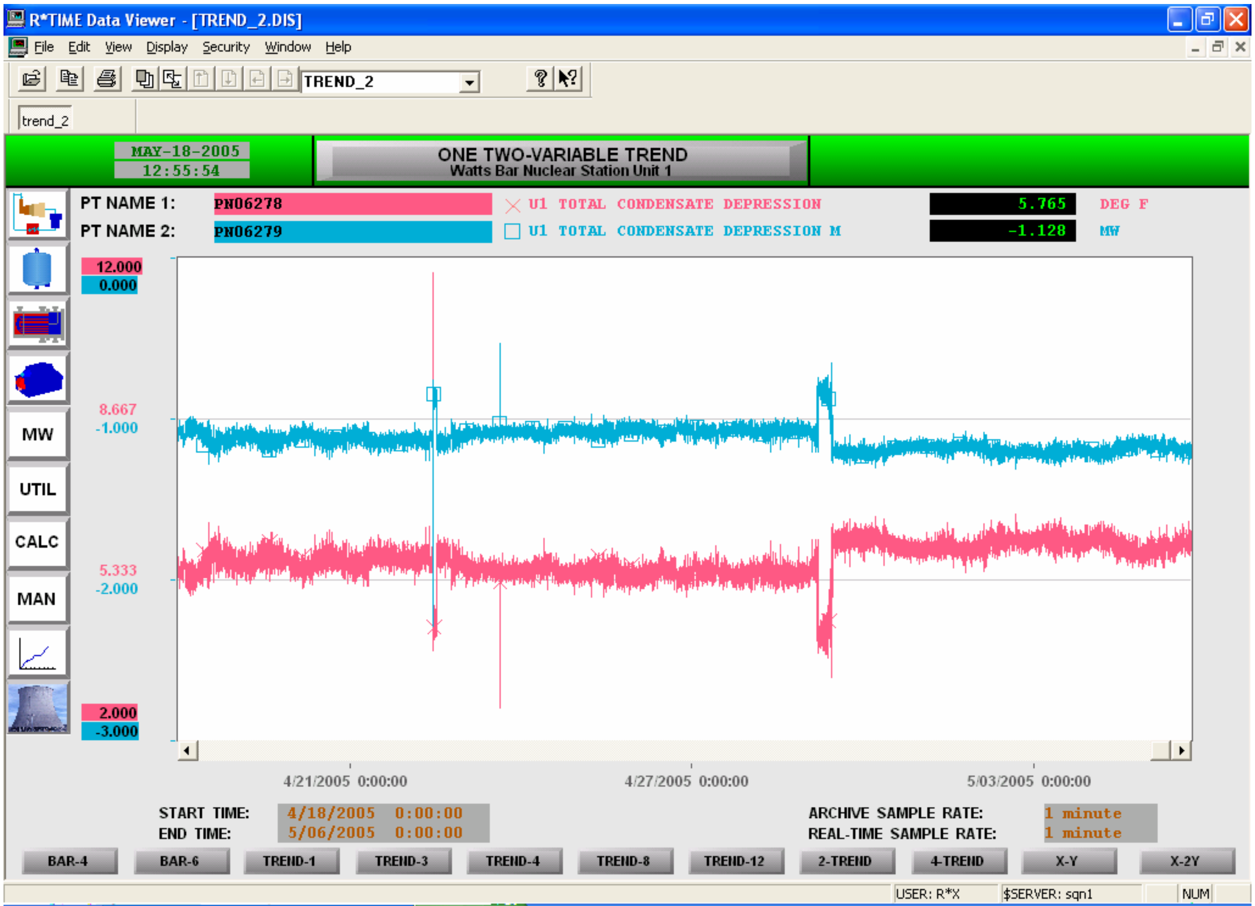

Figure 5 –Watts Bar Condensate Depression Trends

Review of these trends led to the following conclusions:

1. Averaging the Gross Generation value over a longer time period (5 minutes instead of 15 seconds) would smooth out one of the dominant terms in the Unaccounted equation.
2. Using CCW flow values entered into the PMAX model instead of calculating flow and then calculating the CCW outlet temperature produces better condenser performance results.
3. Considering a pressure drop from the turbine exhaust to the condenser shell is a realistic approach to analyzing the condenser MW effects.
4. Differences between the megawatt deviations in the original condenser bogey curves and the actual megawatt deviation indicated by the megawatt meter (Gross Generation) term are the primary cause of the apparent sensitivity of the Unaccounted term to CCW temperature.
5. Validation of the existing condenser bogey curves is necessary to ensure that they have the correct slope consistent with the actual unit performance data.

Original Condenser Bogey Curves

Watts Bar utilizes three identical LP turbines that exhaust to three different backpressure conditions. At the design conditions (CCW flow of 412,800 gpm, inlet temperature of 74 °F, and cleanliness of 95%), the backpressures predicted by PEPSE are 1.75, 2.48, and 3.46 in. Hga. The original bogey curves were developed from a series of PEPSE runs or case studies using the Watts Bar PEPSE model tuned by Scientech to the plant operational data. Power levels of 75, 80, 90, 100, and 110% MWt were analyzed for each condenser zone. Using performance mode condenser components, the respective condenser zone backpressure was varied over a bounding range (i.e., 0.5 to 5 in. Hga for Condenser A) holding the other two zones constant at 1.5 in. Hga, and the resulting gross generation values were compiled. The megawatt difference between the respective values and the baseline (74 °F which yields 1.75 in. Hga for Condenser A) value was then calculated to develop the bogey curves. The resulting curves for the 100% power condition are shown in Figure 6, and the bogey curves entered in the PMAX model are shown in Figure 7. The bogey curves were constructed using less data because in version 11 PMAX there was a limitation to the amount of data that could be entered into a bi-variant curve.

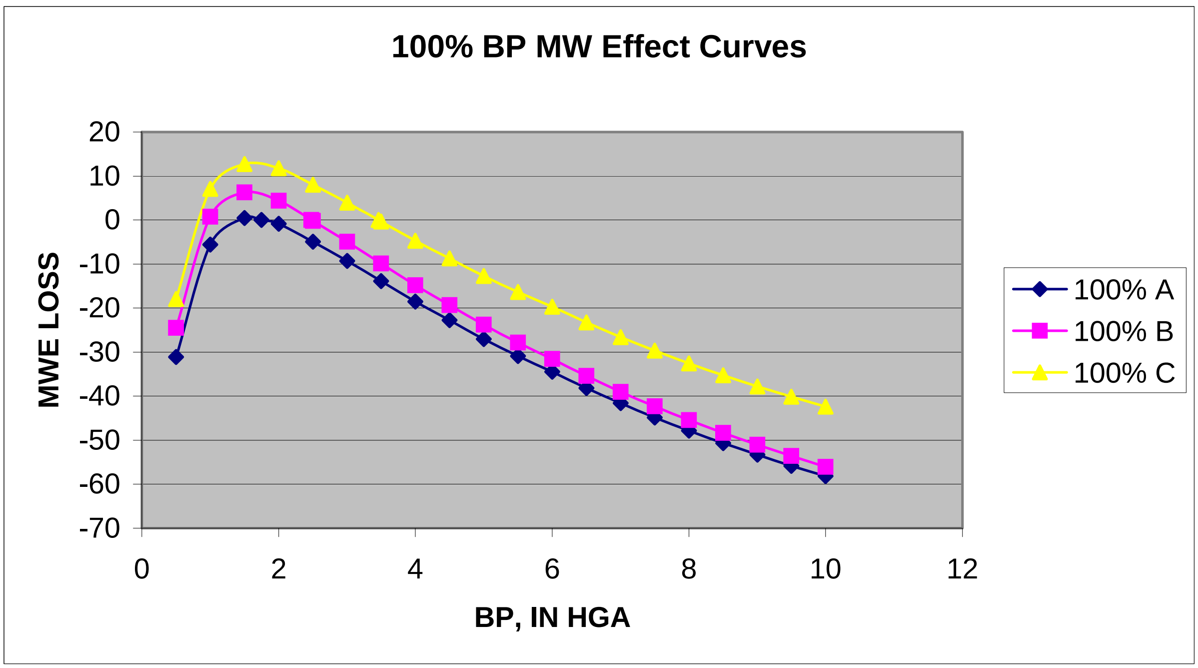

Figure 6 –Watts Bar Original Condenser Curves for 100% Power

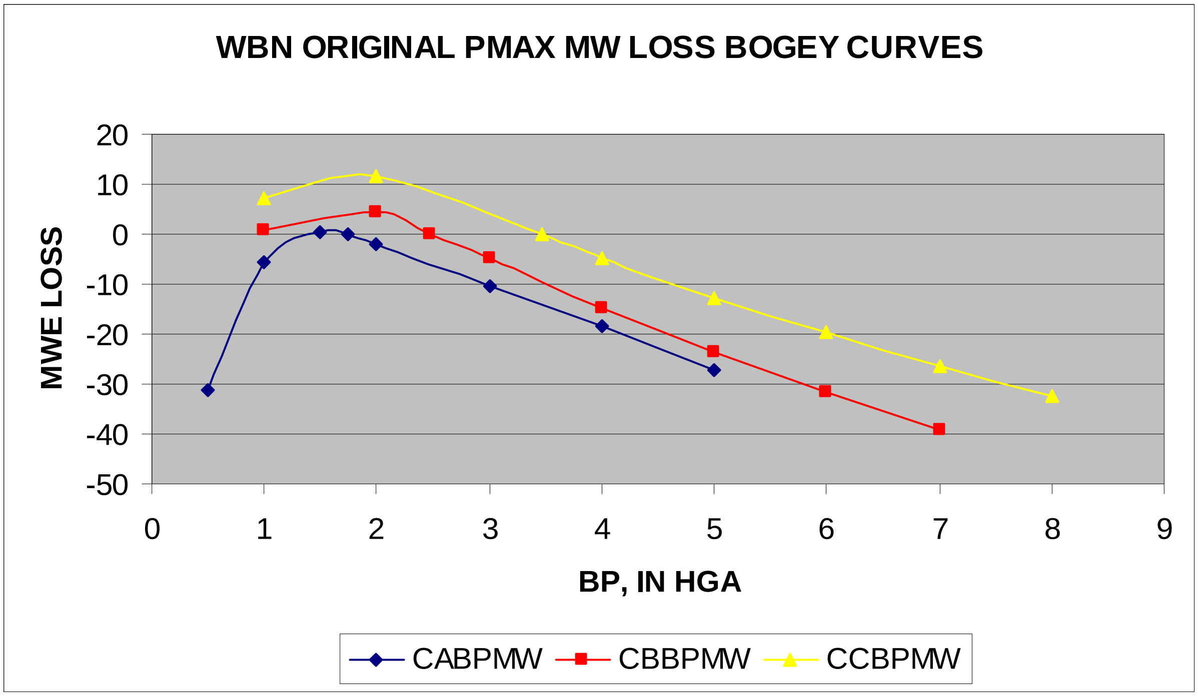

Figure 7 –Watts Bar Original Condenser Bogey Curves for 100% Power

Validation of Bogey Curves

It is well known that turbine efficiency is reduced with increasing backpressure. Therefore the three Watts Bar LP turbines contribute proportionately less power with increasing backpressure. The effect is small and limited to the last three stages of each turbine. However, it seemed that the original bogey curve development may not have captured the real way the cycle responds as all three condenser zones, sharing once through cooling water, react together.

To test this theory, a new set of PEPSE cases were run. Instead of manually specifying the condenser backpressure, all three condensers were set to the HEI simplified design mode solution with cleanliness fixed at 95% and CCW flow rate at 412,800 gpm (100% design). In this mode the CCW inlet temperature was varied over the range from 50 °F to 86 °F, bounding historical plant data. Again, all five thermal power levels were analyzed. A macro was written in Excel to import the PEPSE case results at each power level into Excel worksheets. To apportion the megawatt deviation to the three condenser zones/LPs, the wheel power terms from PEPSE for each of the LP stages were also imported into the spreadsheet. From this data, the fractional deviation of wheel power from baseline for each LP was calculated. It was then assumed that each LP contributed this fraction of the overall generator megawatt deviation from the baseline generation. The PEPSE results for the 100% power case are shown in Figure 8 including the resulting fractional megawatt deviations for each LP.

WBN PMAX PEPSE STUDY RESULTS FOR VARYING CCW TEMPERATURE IN HEI DESIGN MODE

ASSUMED 100% MWT AND CONSTANT CF=0.95 AND CCW FLOW = 412800 GPM

TCCW	MWE	BP A	BP B	BP C	DELTA MWE	LP A DELTA	LP B DELTA	LP C DELTA	CASE
50	1223	0.91	1.26	1.75	11.5	-7.83206	5.372665	13.9594	1
55	1226.1	1.04	1.44	2.02	14.6	-3.69563	5.531229	12.7644	2
60	1227.2	1.19	1.66	2.33	15.7	0.350361	5.223714	10.12593	3
65	1223.5	1.36	1.92	2.68	12	0.443448	4.375735	7.180816	4
70	1217.6	1.56	2.21	3.09	6.1	0.425106	2.283618	3.391276	5
74	1211.5	1.75	2.48	3.46	0	0	0	0	6
80	1200.4	2.08	2.95	4.09	-11.1	-1.4085	-3.96124	-5.73026	7
86	1185.8	2.48	3.49	4.83	-25.7	-4.7066	-8.92506	-12.0683	8

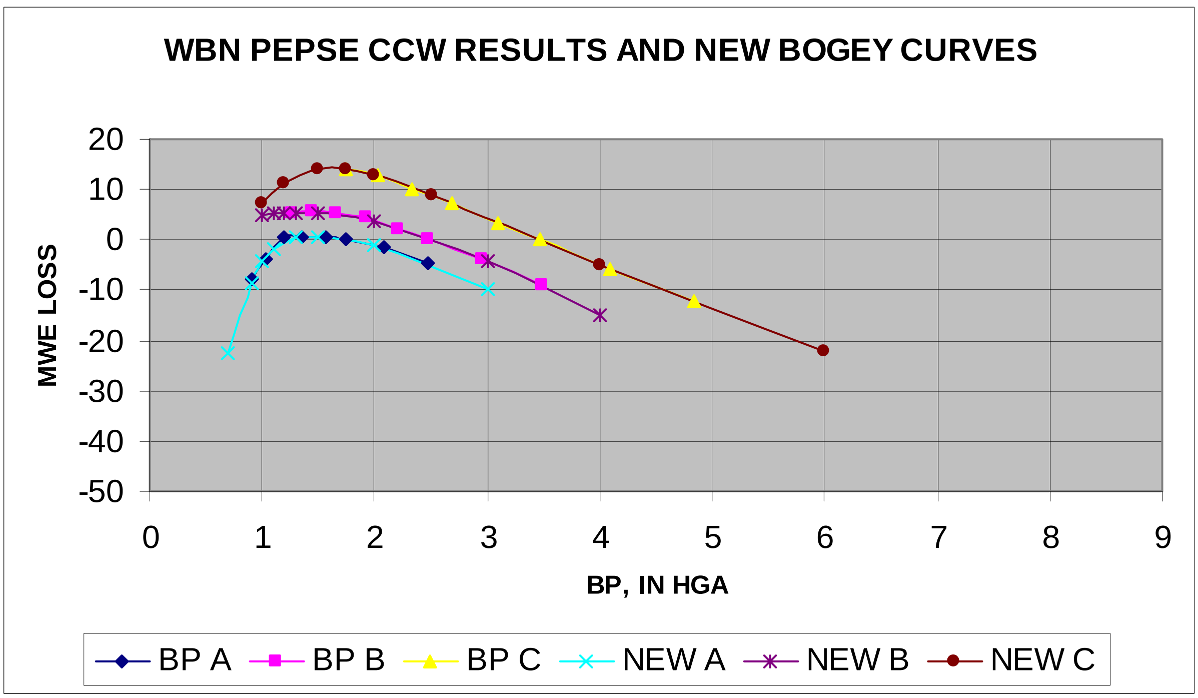

Figure 8 –New CCW Temperature Study Results for 100% Power

Comparison of Figures 7 and 8 reveal no significant difference in the relationship of the curves. The most notable differences are in the low pressure ends of the "B" and "C" condenser curves. These changes are evident in Figure 9, which shows an overlay of the old and new curves for the 100% power condition. Figure 8 also demonstrates the close fit of the new bogey curves to the PEPSE predicted data on which they are based.

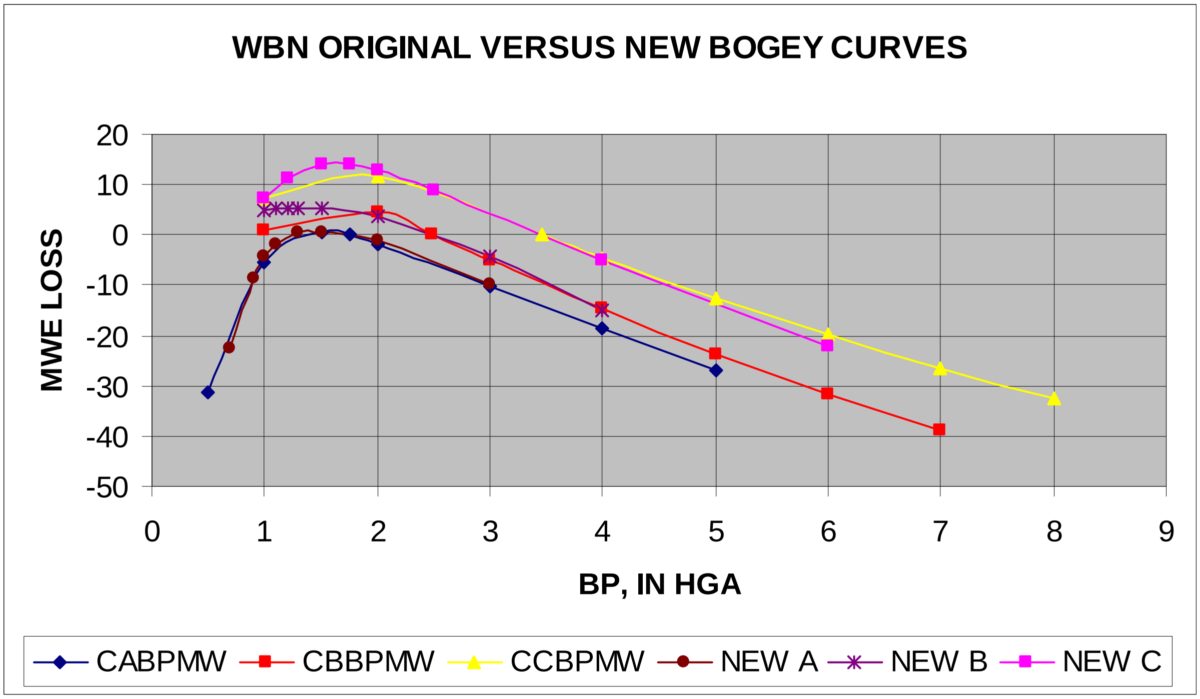

Figure 9 –WBN Original Versus New Bogey Curves for 100% Power

The conclusion of this exercise was that the original backpressure MW curves were as accurate a MW prediction as the PEPSE model could produce. This was validated by comparing the results of two independent methods. At this point in the study, it was assumed that the curve characteristic was correct, but that the slope was not steep enough. It was assumed that something in the plant had deviated from the original plant design that the PEPSE model was built on. So a final technique imposed on the model was to scale the original curves to match the actual plant variation of power with CCW temperature. The selected scale factor alleviated this problem. The results of this model have been very satisfying with low unaccounted MW effects as well as stable and reasonable condenser performance and MW effects. A trend of the latest unaccounted MW effect, cleanliness MW effect, CCW temperature MW effect, and CCW inlet temperature can be seen in Figure 10.

This approach is a good one since PMAX is a performance monitor that relies on the validity of the baseline data to determine future performance deviations. Tuning the condenser performance predictions to correlate with the plant data through a range of CCW temperatures can be done using a scale factor as demonstrated here. As long as this tuning is based on un-degraded plant performance or test data, then any future deviations can correctly be attributed to potential plant problems and not model correlation uncertainties.

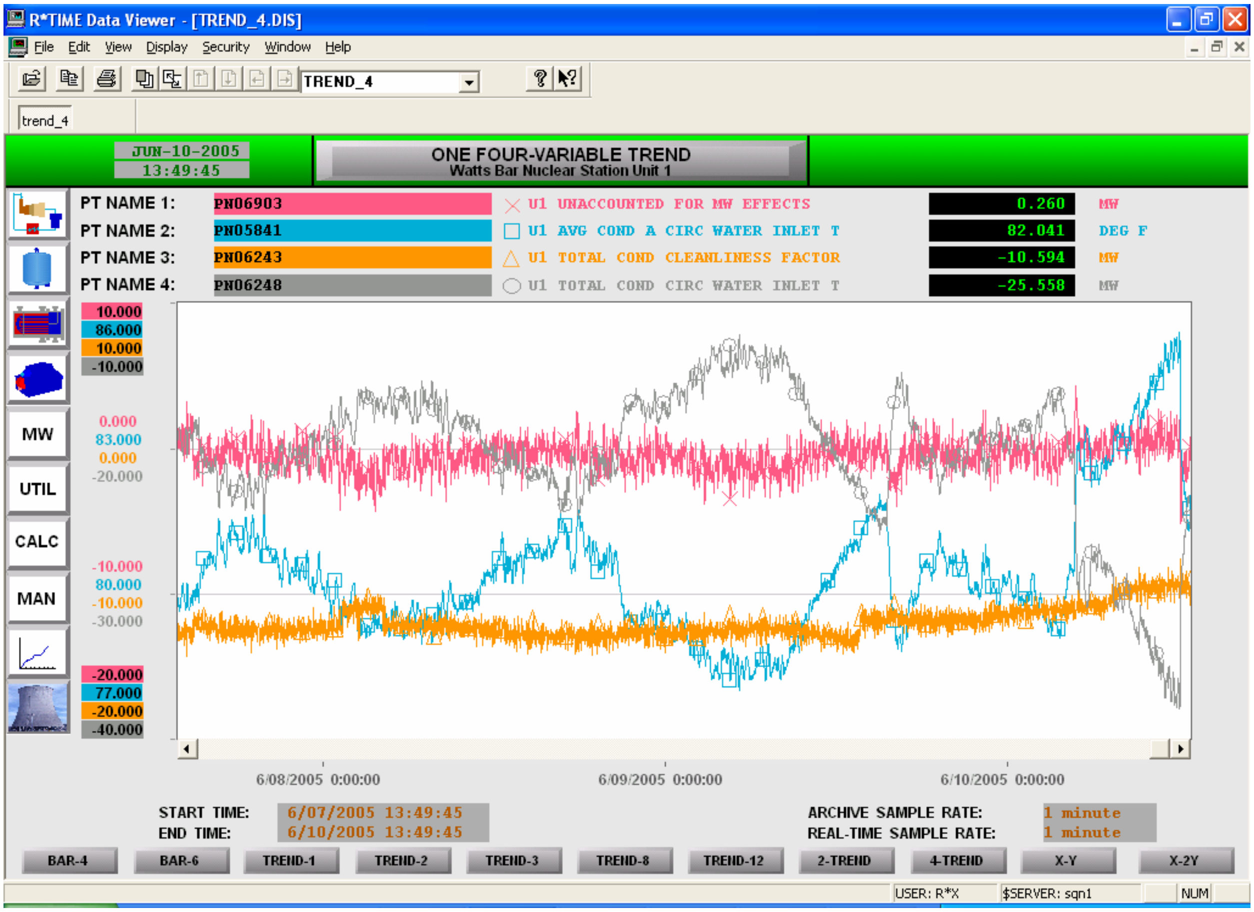

Figure 10 –Trend of Unaccounted, CCW Temperature, and Cleanliness MW Effects Versus CCW Average Inlet Temperature

Conclusions

Based on the results of this analysis, the following conclusions are drawn:

1. Understanding how the MW accounting is performed and what parameters go into the calculations is imperative to successful model tuning. In turn, getting the model properly tuned is imperative for concluding that accounting deviations represent real plant problems. At Watts Bar, it was determined that accounting problems were a result of condenser calculations that didn't correlate with the actual condenser performance. To remedy this problem several modeling techniques were employed.

2. Rapidly changing and widely varying megawatt meter data directly influences similar behavior in the unaccounted megawatt term. It may be necessary to average some instrument outputs to eliminate this type of "masking" data.

3. Obtaining a valid mixed outlet temperature for the condenser cooling water is imperative if a person is to rely on the temperature rise to determine condenser performance. Moreover using a set CCW flow in GPM can help to accomplish this by allowing the calculation of the outlet temperature to be performed.

4. Assuming a pressure drop between the LP turbine exhaust and the condenser shell is more realistic to the plant and yields better condenser performance modeling as well as better MW accounting results.
5. The original technique using performance mode condensers in PEPSE and varying the pressures yields the correct BP MW deviation curves for PMAX as long as the PEPSE model exactly matches the plant. In the case of Watts Bar, the plant somehow has deviated from the original design that the PEPSE model was built on. To remedy this, the curve behavior was assumed to be correct, and the curves were scaled to increase their slope and match the plant. Once this match has been made, any future deviations will alert users to potential plant problems.