Calculating Best Achievable Heat Rate Using Energy Balance Calculations

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Abstract

The Institute for Nuclear Power Operations' (INPO) revised thermal performance indicator (TPI) is defined as the best achievable heat rate (BAHR) divided by the average adjusted actual gross heat rate (AAHR). This indicator is used to monitor the nuclear industry's progress in achieving efficient thermal operation. However, determining the BAHR to be used in calculating the TPI can be a difficult task. The BAHR must represent performance of the as-built plant configuration without degraded components, referenced to 100% power. Although testing the plant is one option in determining BAHR, a large scale performance test, such as might be needed to calculate the BAHR, may not be justified on a cost basis. A thermal computer model, however, provides a mechanism to calculate the BAHR in a cost-effective manner.

In early 1995, Performance Engineering, Inc. developed a thermal computer model of the Monticello Nuclear Generating Plant to determine its BAHR. This model was developed

using the PEPSE[1] computer software package. PEPSE, a modular heat balance program, allows for the development of a model that simulates all the major plant components (pieces of hardware) either as originally designed, currently as-built, or in a proposed future configuration. Because of this, it may be used to calculate the plant performance (and hence the BAHR) using component specifications that are not degraded and that are operating under specified conditions such as circulating water inlet temperature.

This paper describes the development of the Monticello PEPSE computer model and the use of this model to calculate the BAHR.

Unit Description

The Monticello Nuclear Generating Plant has a boiling water reactor designed and built by General Electric (GE). Its turbine-generator set was also manufactured by GE. The turbine is a horizontal, tandem compound unit with one single-flow high pressure (HP) turbine, and two double-flow low pressure (LP) turbines. The original turbine vendor rating was 569 MWe at valves-wide-open (VWO).

Monticello has ten feedwater heaters in two strings of five heaters each - a total of four high pressure heaters and six low pressure heaters. All are closed heaters and have internal drain coolers except the two lowest pressure heaters, which have external drain coolers. The condenser is a two zone design with each zone operating at a different pressure.

The unit came on line in 1971.

Thermal Performance Indicator

The purpose of the INPO revised thermal performance indicator is to monitor the nuclear industry's progress in achieving and maintaining efficient thermal operation[2]. It is defined as the BAHR divided by the AAHR. The AAHR is determined from weekly heat rate calculations on the unit. BAHR is determined from historical operating data from the plant or may be calculated based on historical information, design information, re-design information, or a combination of these sources. It represents the best performance the unit can achieve at 100% power at a reference value of circulating water inlet temperature. Using the BAHR to calculate the thermal performance indicator reduces the uncertainty in using the design value of gross heat rate because it reflects a more realistic value of what the unit can achieve. Design heat rate is typically a guarantee value and may contain varying degrees of conservatism.

Calculating BAHR for Monticello

Unfortunately, no acceptance test was performed on Monticello during its initial start-up. Therefore, original or "new" cycle performance and individual component/hardware performance is difficult to determine.

To overcome the lack of initial data, a thermal computer model of Monticello was constructed using the PEPSE computer software package. This model appears in Figure 1. The PEPSE model was built based on the original turbine vendor heat balance diagrams and modified to reflect the as-built plant configuration.

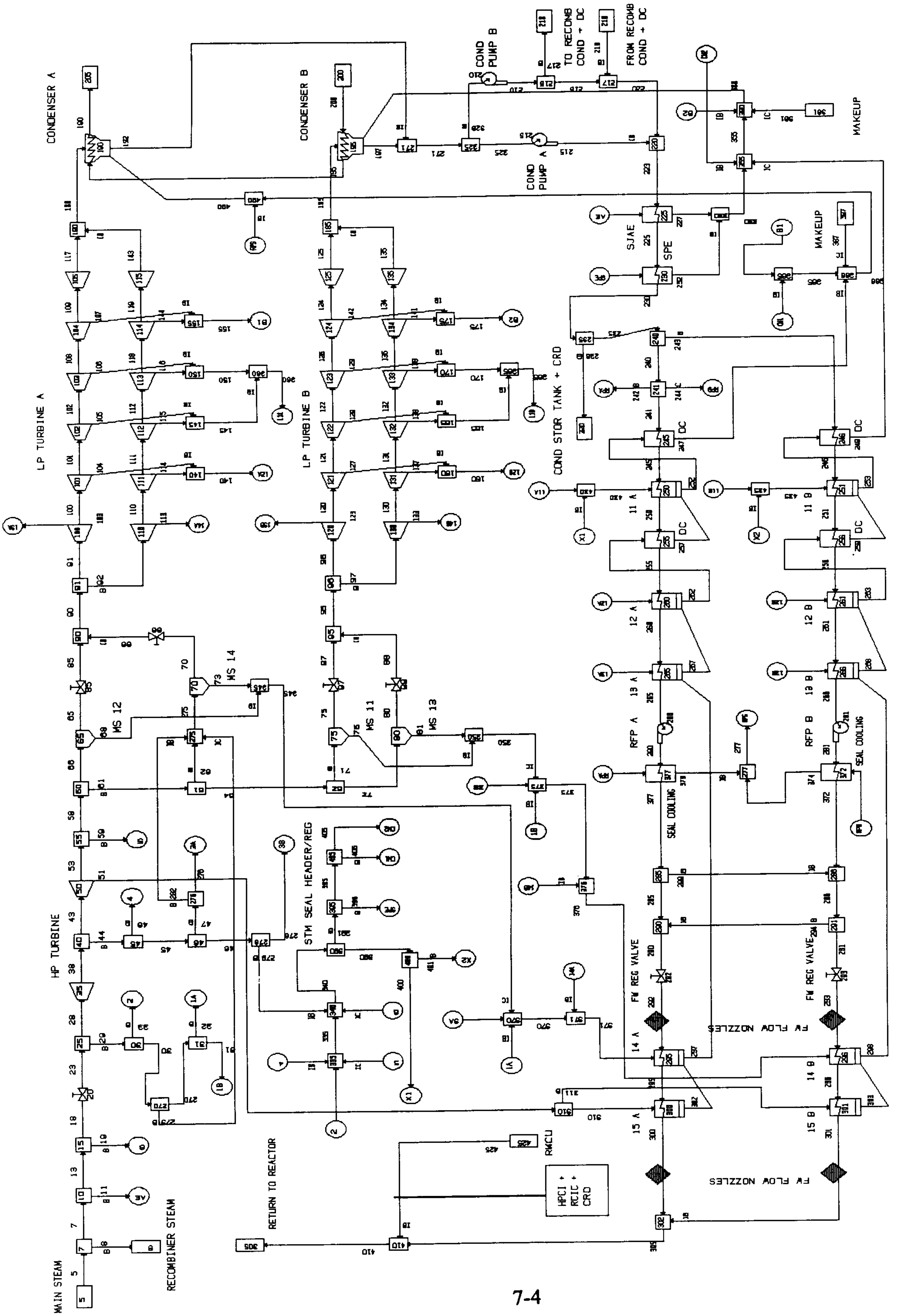
By using a thermal computer model such as PEPSE, predictions can be made as to the best achievable performance of the system. This is done by individually characterizing the components using information that describes their best operating condition, such as original design, new as-tested data, re-design data, monthly performance data, or engineering judgment as to the best achievable component performance. In addition, any boundary condition can be simulated, such as reactor thermal power to the turbine cycle, circulating water inlet temperature, and others. By doing this, a computer calculation can predict the best achievable heat rate under specified operating conditions and specified component performance. The key is to characterize the components as to their best achievable non-degraded performance.

For the Monticello model, several sources of data were used to describe the best performance of each component. Some start-up data (not acceptance test data) was used in combination with design data and data from re-designed components. For all cases, the start-up data was assumed to represent the best achievable performance unless the component had been re-designed, in which case the re-designed data was used. When no start-up data or re-design data was available, the original design information was used. This combination was determined to represent the best achievable performance of the components in the plant and thus represent the best achievable response or heat rate calculation.

Results

Figure 2 shows a graph of the BAHR for Monticello based on the results of several PEPSE cases. Figure 3 shows the generation based on circulating water inlet temperature for several other PEPSE cases.

Based on the results from the PEPSE study shown in Figure 2, the BAHR is 1.4% lower than the heat rate determined during a recent ASME PTC 6.1 test on the unit at the same power level. Monticello personnel suspected that they were indeed above the BAHR,



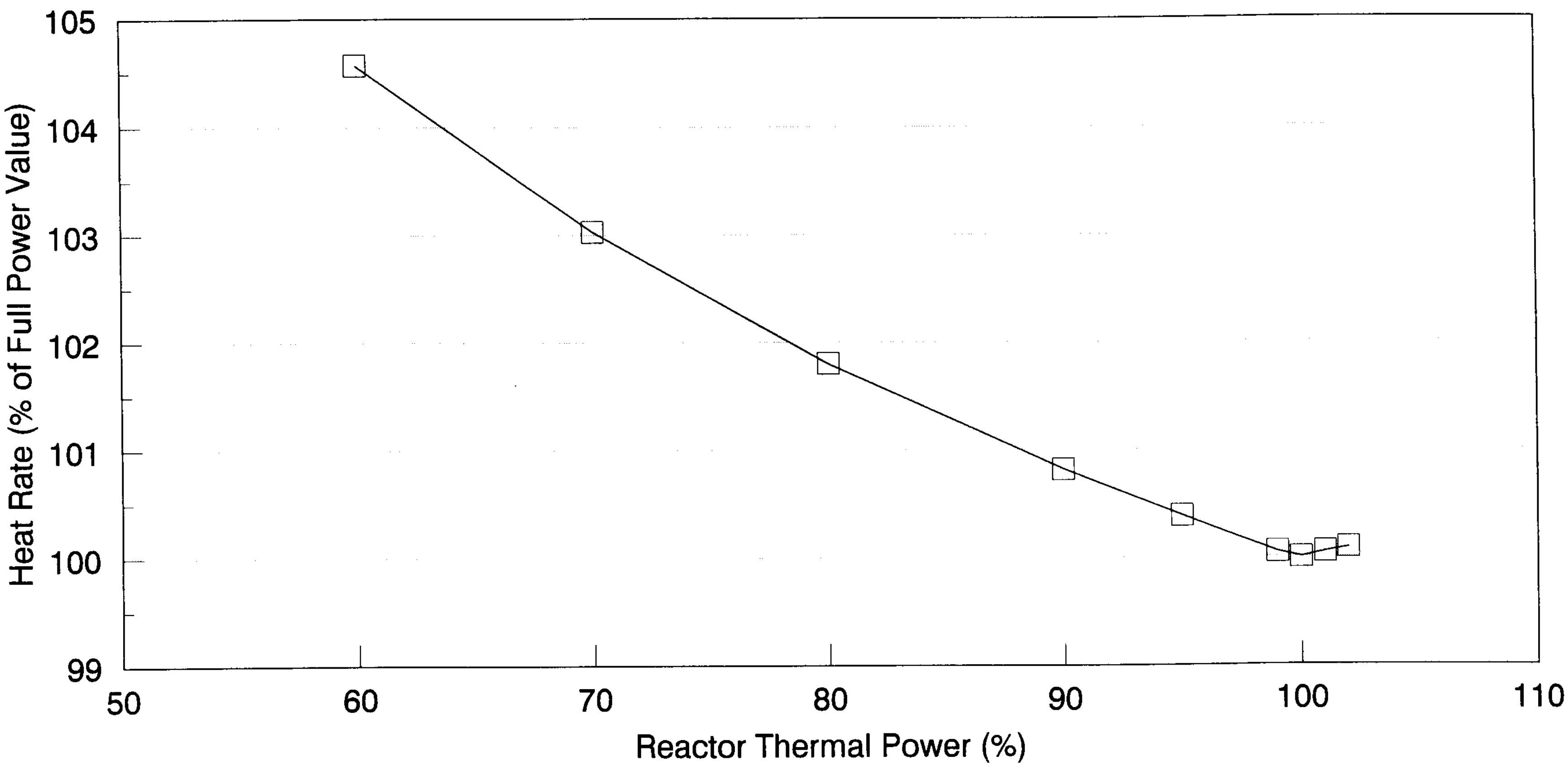
MONTICELLO NUCLEAR GENERATING PLANT - PEPSE MODEL

Figure 1

<u>Figure 2</u>

MONTICELLO NUCLEAR GENERATING PLANT

Heat Rate vs. Reactor Thermal Power

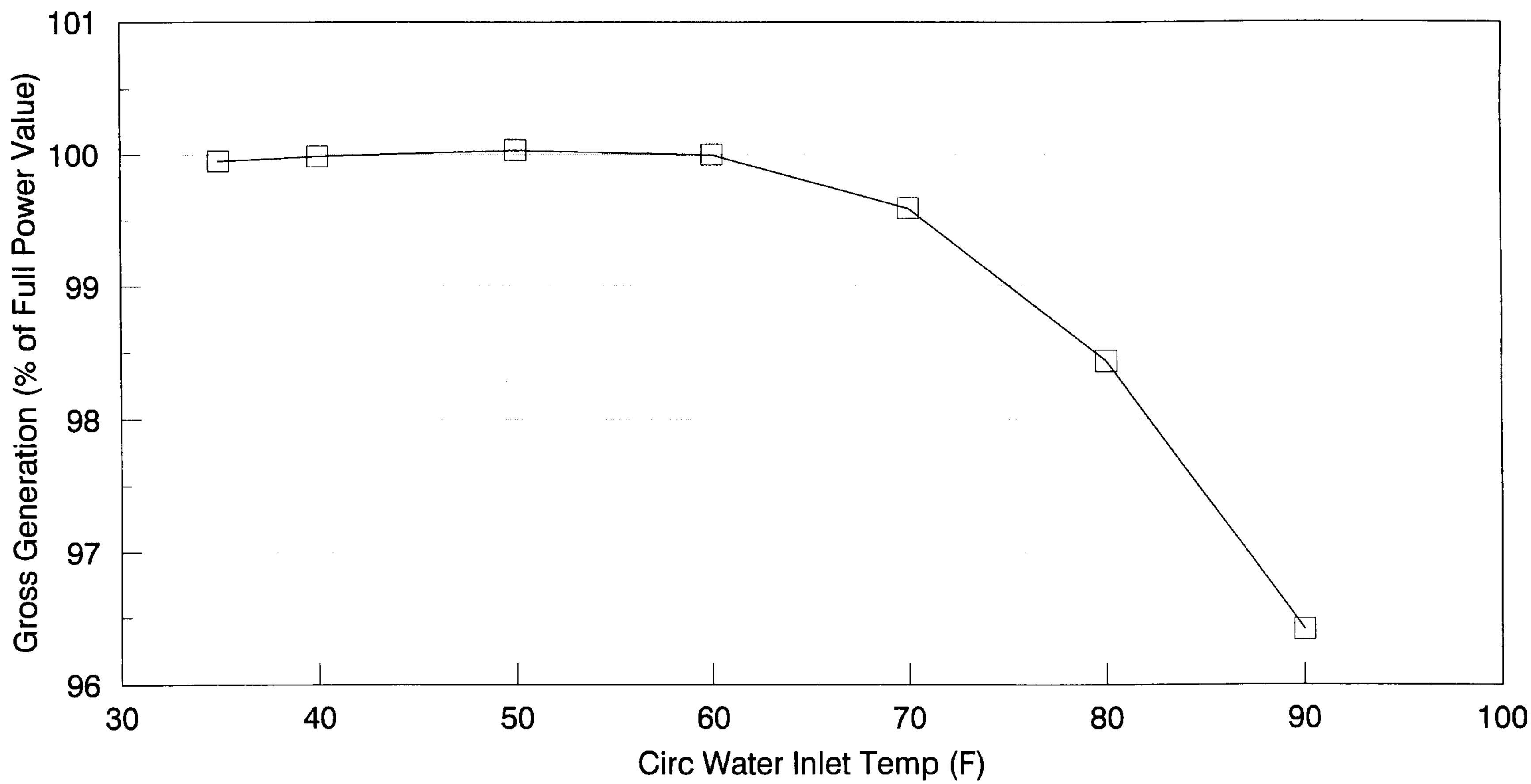


100% Power = 1670 MWt Reactor Thermal Power (RTP)
Circulating Water Inlet Temp = 60 F
Full Power Based on PEPSE-Calculated BAHR at 100% RTP

Figure 3

MONTICELLO NUCLEAR GENERATING PLANT

Generation vs Circ Water Inlet Temp



Results at 100% Reactor Thermal Power (RTP) = 1670 MWt

Full Power Based on PEPSE-Calculated Generation at 100% RTP and 60 F Circ Water however, they could not verify the heat rate increase until the PEPSE study was performed. These results indicate that one or more plant components are operating below their optimum performance.

Conclusions

Thermal simulation calculations such as PEPSE can be used to calculate BAHR because of their flexibility in allowing the characterization of the individual pieces of plant equipment. When there is a lack of acceptance test data, a computer simulation can be the best alternative to the calculation of BAHR. Monticello personnel will continue to use their PEPSE model to make future calculations of BAHR and study a variety of other issues related to thermal performance.

References

1. PEPSE Computer Software, Version 58, Halliburton-NUS Corporation, Idaho Falls, Idaho.

2. INPO 94-009, Performance Indicator Program - Utility Data Coordinator Reference Notebook, Appendix A - Revised Thermal Performance Indicator.

PEPSE is a registered trademark of NUS Corporation.