HEAT BALANCE MODELS IMPROVE THERMAL PERFORMANCE MONITORING

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ABSTRACT

Computer heat balance (HB) models have been created for the Tennessee Valley Authority (TVA) Browns Ferry Nuclear (BFN) and Sequoyah Nuclear (SQN) Plants utilizing the SYNTHA II (1), a computer code developed by the Syntha Corporation of Greenwich, CT. At SQN, which has a pressurized water reactor (PWR) with a Westinghouse Electric (W) turbogenerator (TG), the vendor-supplied curves of pressure and enthalpy could not be used for HB modeling because the as-constructed configuration differs significantly from the vendor's HB. To circumvent this problem, the SYNTHA II code allows the user to employ the General Electric (GE) Procedure to model turbine performance. The resulting model was first compared with the WE HB to confirm the accuracy of the modeling of the turbine components. Then it was modified to reflect the as-constructed plant configuration. This paper describes the methods employed to create accurate HB models employing SYNTHA II and how the models are used to establish HB target values. A Quattro Pro (QP) data base of target values has been created for each plant by employing a computer program developed by TVA to extract the HB state point values of interest from the SYNTHA II output files and down-loading them into a QP spreadsheet. Using the excellent QP graphics capability, curves of target values have been generated to monitor thermal performance (TP). This paper describes how the HB models may be used to support plant operations.

INTRODUCTION

Increased competition among utilities and among the various forms of electrical generation has stimulated an increased interest in TP. A reduction in the gross heat rate (GHR) of your plant means that there are more kilowatt-hours (KWH) to sell with no increase in fuel cost. These savings go straight to the bottom line. TP monitoring is important, because most of the easy gains have been made. Now comes the hard part.

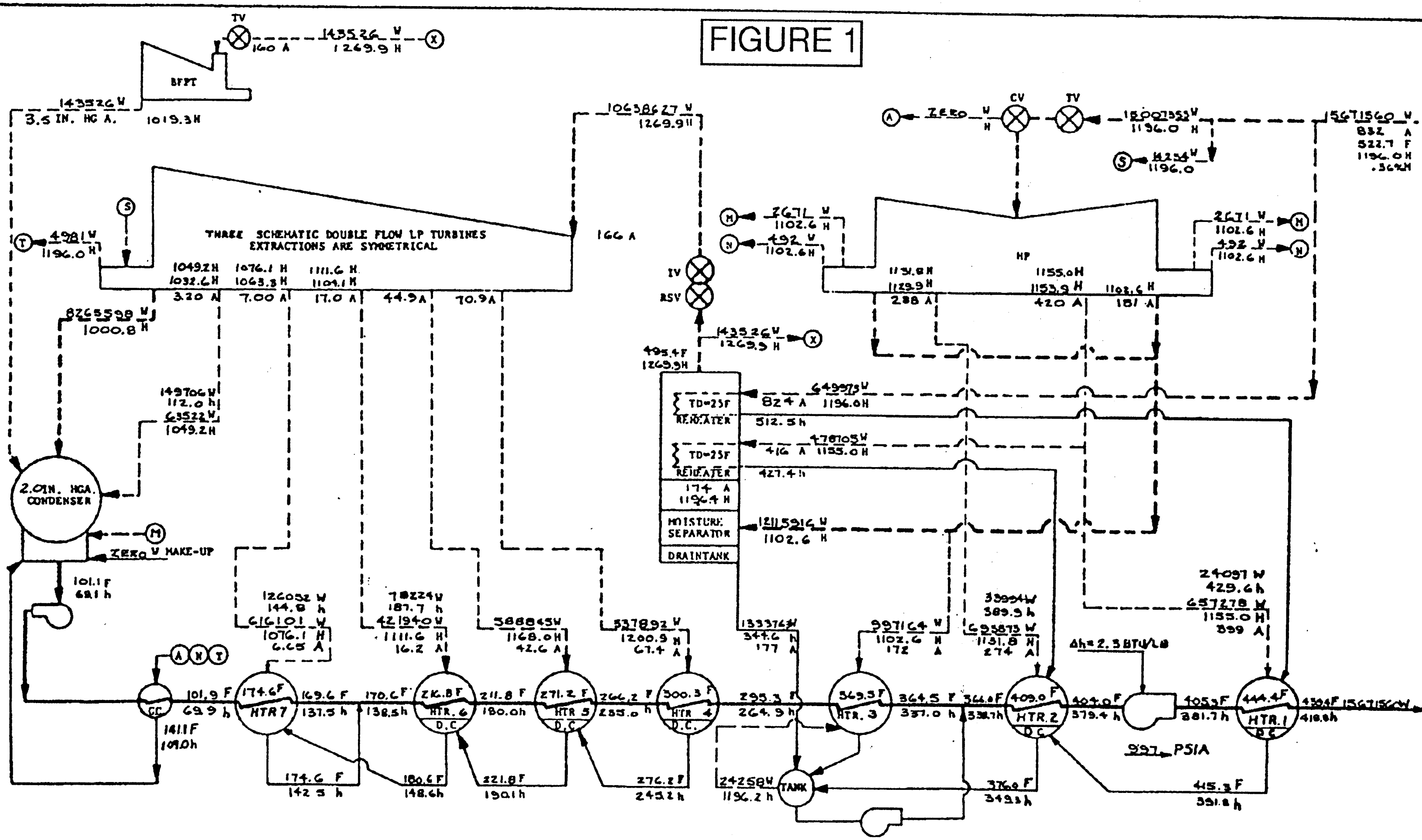
A rigorous HB model is an important element of an effective TP monitoring program. It provides highly accurate baseline target values and corrections for seasonal variations in back pressure (BP) and for unit load. HB models can provide trending information and can be invaluable in identifying and troubleshooting problems before they affect the bottom line. However, they have their limitations. They are steady-state, not transient models, and the rigorous models are not designed to support real-time operation or trending. Building a rigorous HB model requires that a considerable amount of TP data be pulled together by a person who understands thermodynamics, heat cycle equipment, and the required computer software.

DEVELOPING HB MODELS

Since the publication of the GE procedures (2) (3), it has been possible to model the performance of steam turbines in the as-constructed plant configuration. This is an important development because of the limitations of the HB's provided by the TG vendor. The vendor-supplied HB's are generally for a fixed main condenser (MC) BP and a fixed feedwater heater (FWH) terminal temperature difference (TTD) and drain cooler approach (DCA).

The first step in creating a HB model is to build a schematic diagram (SD). This is done by taking the familiar TG VWO HB diagram shown in Figure 1 and selecting from a menu of SYNTHA II components, then tying them together to produce the SD shown as Figure 2. Note that this SD includes turbines, FWHs, a MC, and various pipes, splitters, mixers,

FIGURE 1



NET HEAT RATE = 1567156O(1196.0 – 418.8) / 1232385 = 9883 BTU/KWHR	TEP = 1000.6 BTU/LB ELEP = 988.0 BTU/LB MECH. LOSS = 3694 KW ELECT. LOSS = 15336 KW 1.0 PF 75 H_2 BFP POWER = 10539 KW	NAME PLATE RATING 1183192 KW TURBINE-GENERATOR UNIT 832 PSIA 522.7 F 2.0 IN. HG A. 1356200 KVA 0.90 PF 24000 VOLTS 75 H_2	LESTER, PENNA ENGR. VEH/GP LCD-2795 DATE: 6/16/70 AB 959-0658 REV.

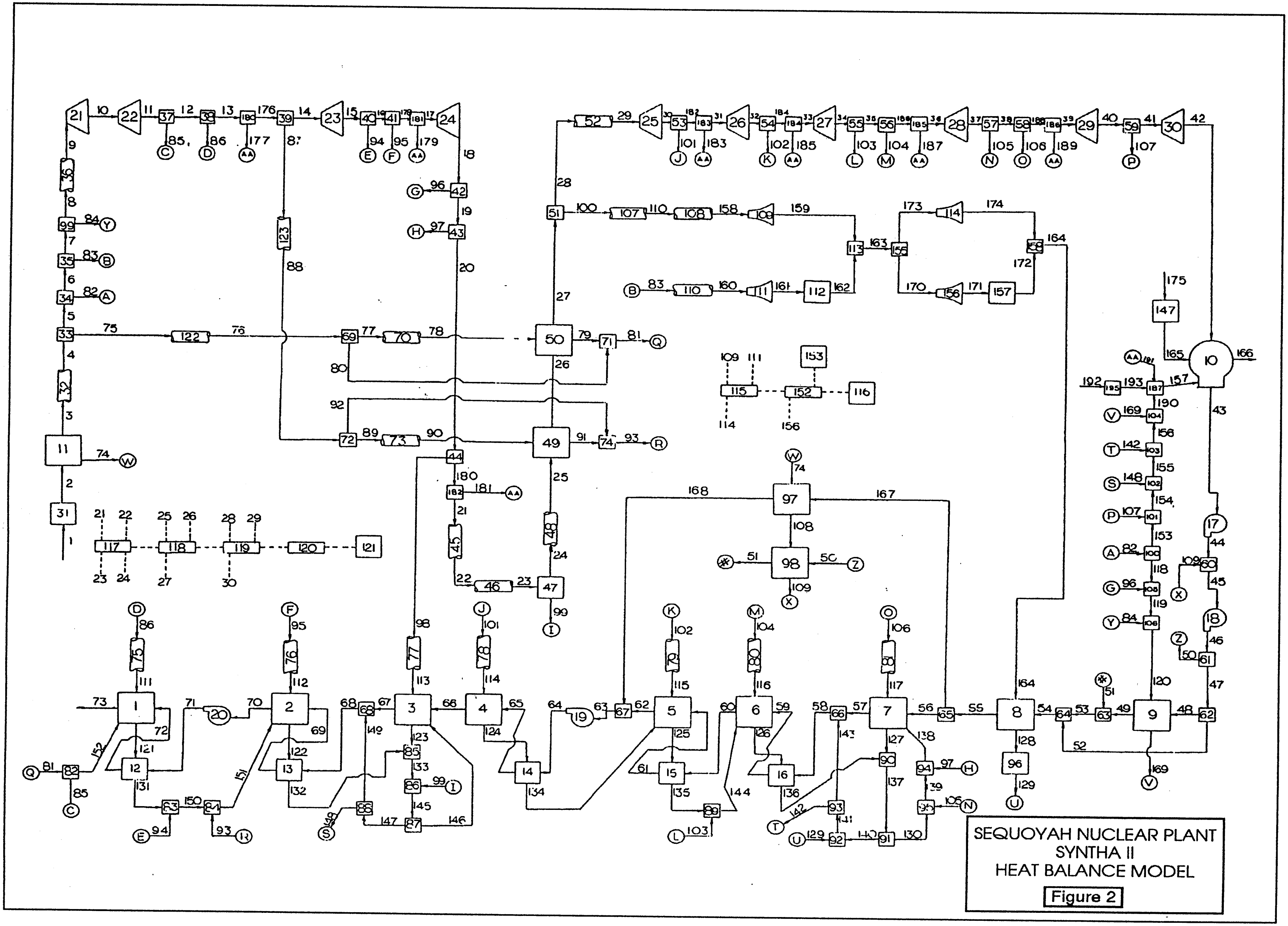
(1) CALCULATIONS ARE BASED ON NO RADIATION LOSSES TO HEATERS OR EXTRACTION PIPING LOCATED IN THE CONDENSER NECK.
(2) CALCULATIONS ARE BASED ON 1967 ASME STEAM TABLES.
(3) PRIMARY VALVE AND ABOVE HEAT RATES ARE CALCULATED ON LOCUS OF VALVE POINTS.

STEAM GENERATOR FLOW AT MAX. CALC. IS NOT GUARANTEED.

MAX. GUAR. STEAM GEN. FLOW=14925295 LB/HR MAX. CALC. STEAM GEN. FLOW=15671560 LB/HR

1232385 KW NET LOAD HEAT BALANCE
MAXIMUM CALCULATED @ 832 PSIA-NOT GUARANTEED

TC6F-44



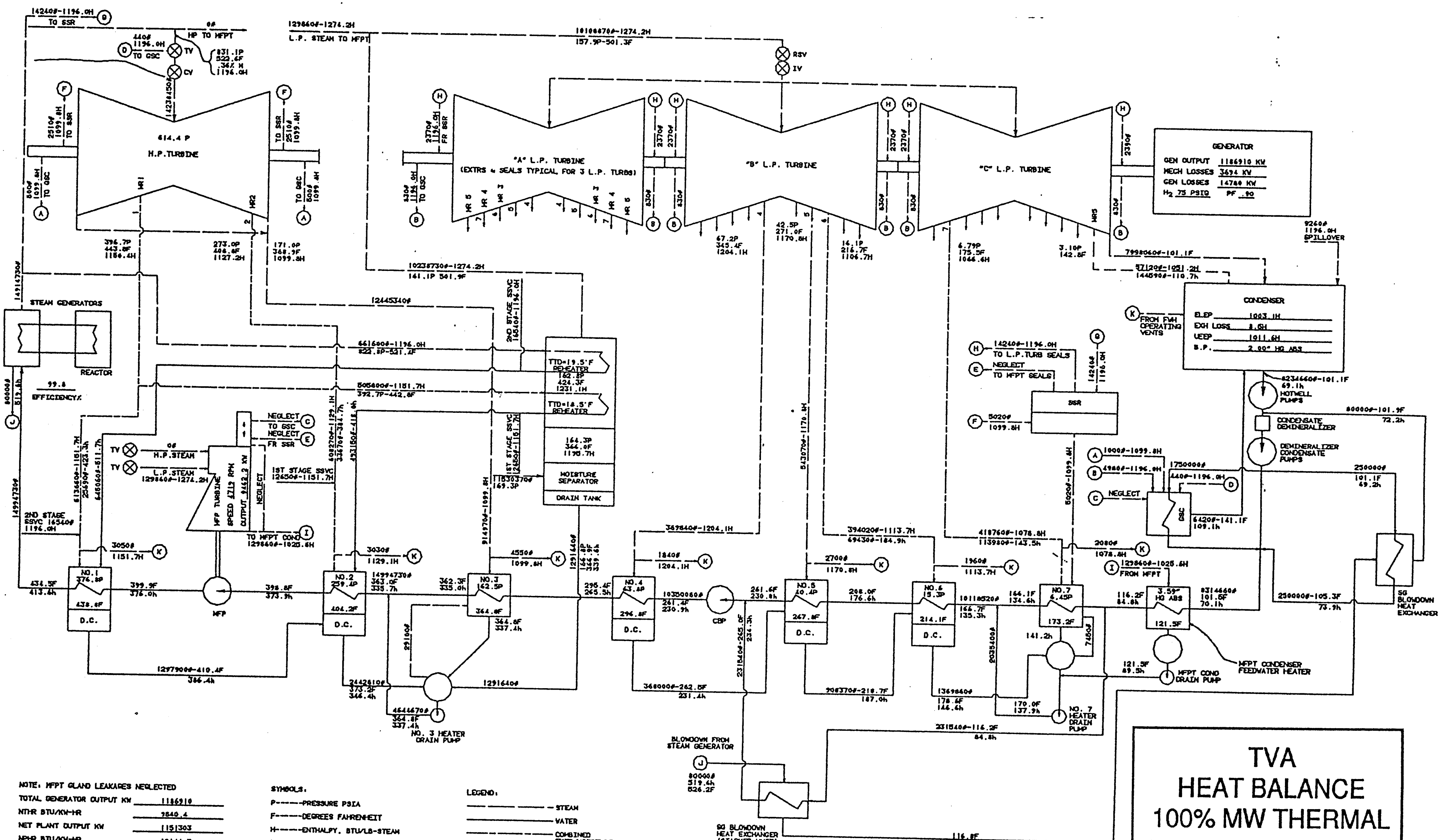
SEQUOYAH NUCLEAR PLANT
SYNTHA II
HEAT BALANCE MODEL

Figure 2

pumps, etc., as well as the nuclear steam supply shown as a heater. The high pressure (HP) and low pressure (LP) turbines are modeled as a series of turbines representing the impulse stage and each group of stages between extraction points. A SYNTHA II input file is created by collecting and entering the required performance information for each component. For components where input data varies based on a given relationship, a schedule is added to vary the input data based on the performance curve of the component.

In order to obtain the required flow factors (FF) and efficiency correction factors (ECF) for each turbine component, the TG VWO HB and turbine stage exit pressures and enthalpies are used in the SYNTHA II model to calculate the FFs and ECFs per the GE procedure. Then a design point HB model is created to match the configuration in the TG VWO HB including fixing the FWH TTDs and DCAs, the MC BP, etc. The TVA HB produces agreement with the TG VWO HB within a range of 0% to .05%.

The next step is to modify the SYNTHA II input file to model the off-design conditions which reflect the as-constructed plant configuration. A minimum set of performance data is required so that the program can rigorously calculate values such as FWH TTD and DCA and the MC BP from first principals. At SQN a number of design changes have resulted in a HB diagram that deviates significantly from the guaranteed conditions. These changes include a moisture separator reheater (MSR) upgrade, new FWHs, placing the main feedpump turbine condenser in the condensate system, and adding steam generator blowdown with heat exchangers in the condensate system. The as-constructed cycle for 100% megawatt thermal (MWT) power is shown in Figure 3. The result of each of these changes may be evaluated separately. The results presented in Table I show the effect of these and other indicated changes to the HB model.



NOTE: MFPT GLAND LEAKAGES NEGLECTED

TOTAL GENERATOR OUTPUT KW	1186910
NTHR BTU/KW-HR	9840.4
NET PLANT OUTPUT KW	1151303
NPHR BTU/KW-HR	10144.7
REACTOR OUTPUT MWT	3423

SYMBOLS:

P------PRESSURE PSIA
F------DEGREES FAHRENHEIT
H------ENTHALPY, BTU/LB-STEAM
h------ENTHALPY, BTU/LB-WATER
M------MOISTURE
#------FLOW, LBS/HR

LEGEND:

STEAM
WATER
COMBINED EXTR/MOISTURE
MOISTURE

TVA
HEAT BALANCE
100% MW THERMAL
FIGURE 3

Table I

	Gross Heat Rate (BTU/KWH)		Generator Output (KW)	
		(change)		(change)
Base Model	9,866.2		1,183,820	
MSR Retube	9,844.5	(-21.7)	1,186,421	(+2,601)
New FWHs	9,867.0	(+0.80)	1,183,723	(-97)
MFPTC in CS	9,848.2	(-18.0)	1,185,982	(+2,162)
SGB/HX in CS	9,873.1	(+6.90)	1,182,993	(-827)
FWH vents	9,872.4	(+6.20)	1,183,071	(-749)
Sum of Changes		-25.8		+3,090
Target Perf.	9,840.4		1,186,910	

ESTABLISHING TARGET VALUES

The authors acknowledge that TP engineers have mixed feelings about TP target values. There is a school of thought that the important thing is to trend performance to detect performance degradation. Although trending is certainly important, if only trending is performed without target values, the full potential of the plant may never be realized. For example, trending alone will not identify cycle isolation problems such as open startup vents or turbine problems that may have existed since initial startup. Therefore, realistic target values are highly desirable.

An accurate off-design HB model offers the potential to provide much more information than appears on a single HB diagram. With a simple program input file change, the SYNTHA II code allows the user to schedule changes to a single input parameter such that multiple HB runs may be made in batch mode. TVA used this feature to generate multiple HB runs for an array of condenser circulating water (CCW) temperatures. This parameter, which varies seasonally, significantly impacts a number of important parameters including MC BP and kilowatts electrical (KWE). Failure to accurately compensate for this effect can mask serious performance problems such as MC fouling or air in-leakage. To facilitate the management of the large volume of data associated with the SYNTHA II HB output, TVA developed a software product to extract the data of interest from the SYNTHA II output file on the main frame computer and transfer it to a QP spreadsheet file on a personal computer (PC). This approach enables the user to access the superior graphics capability of QP and to manipulate the data to calculate values of interest that may not be a direct output of SYNTHA II (e.g. BP in in. Hga.).

Figures 4 and 5 show target values for MC BP and gross KWE output as a function of CCW temperature and MC cleanliness factor (CF) at 100% MWT output for TVA's BFN Unit 3. Similar curves have also been developed for unit loads down to 75%. Figure 6 is an example of other graphs of target values that can be produced to aid in troubleshooting at fractional load operation. TVA has developed QP macros to double-interpolate HB data in QP spreadsheets to automatically return the desired target value for comparison with operating data.

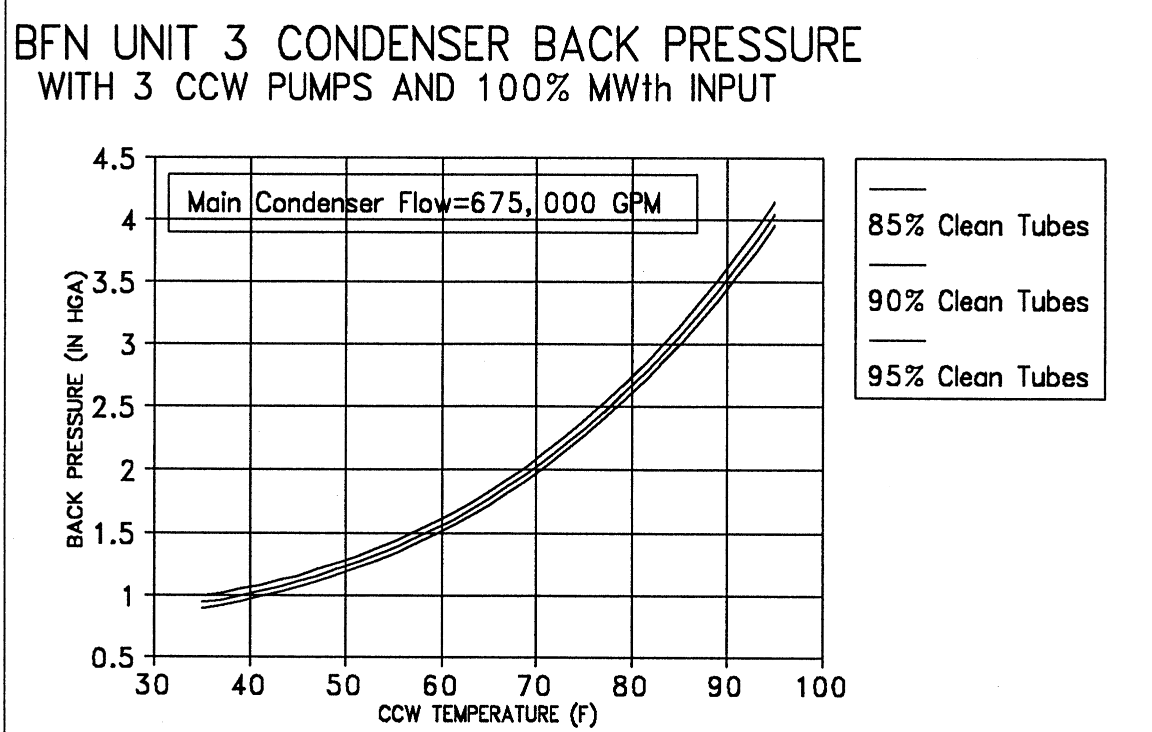


Figure 4

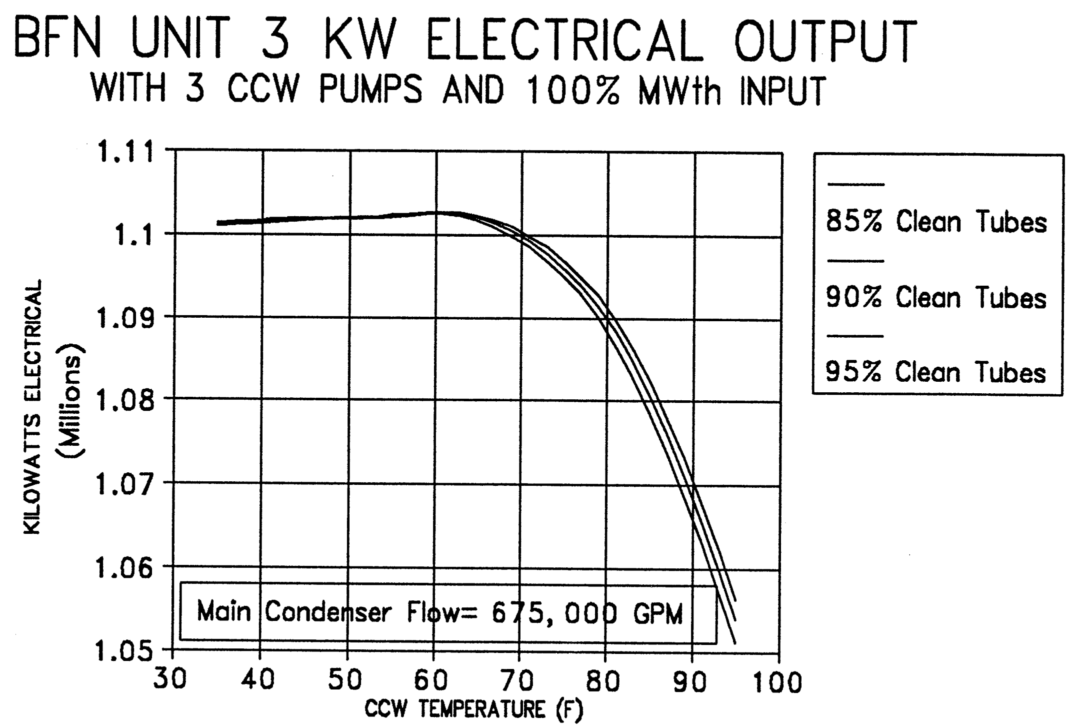


Figure 5

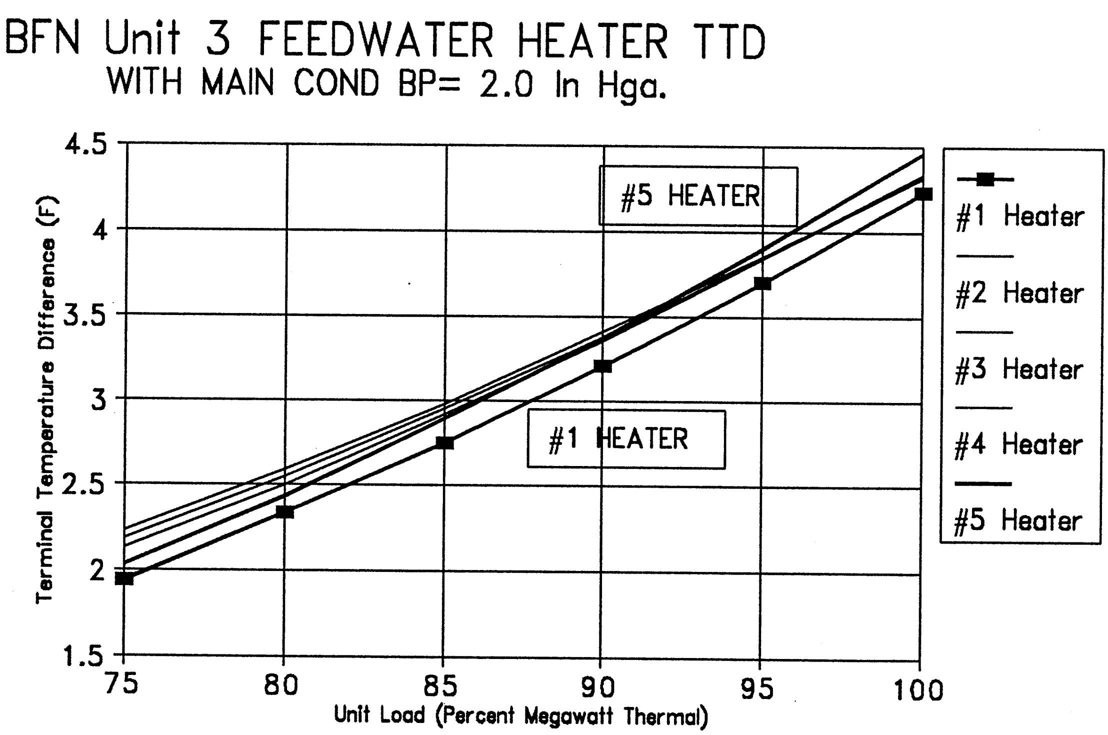


Figure 6

MONITORING PERFORMANCE

Figure 7 shows how target values are used to monitor the thermal performance of the MC at TVA's SQN Unit 1. By providing target values as a function of CCW temperature and MC CF, the TP engineer is alerted when the MC BP strays outside of expected values. Figure 8 shows the impact that poor MC performance can have on GHR. Corrective action may be as simple as checking the Amertap system or checking the head loss across the MC waterboxes for macrofouling.

TROUBLESHOOTING

Although the SYNTHA II HB models do not lend themselves to supporting day-to-day plant operation, they can be used to support troubleshooting activity if required. The TVA's BFN plant, which has a GE 1100 megawatt electrical (MWE) boiling water reactor (BWR) and GE TG, was returned to service in the summer of 1991 following a long outage during which the MC had been retubed with AL6XN tubes and the CCW pumps were rebuilt. At 50% MWT the plant reported a MC BP of 4 in. Hga. with a CCW temperature

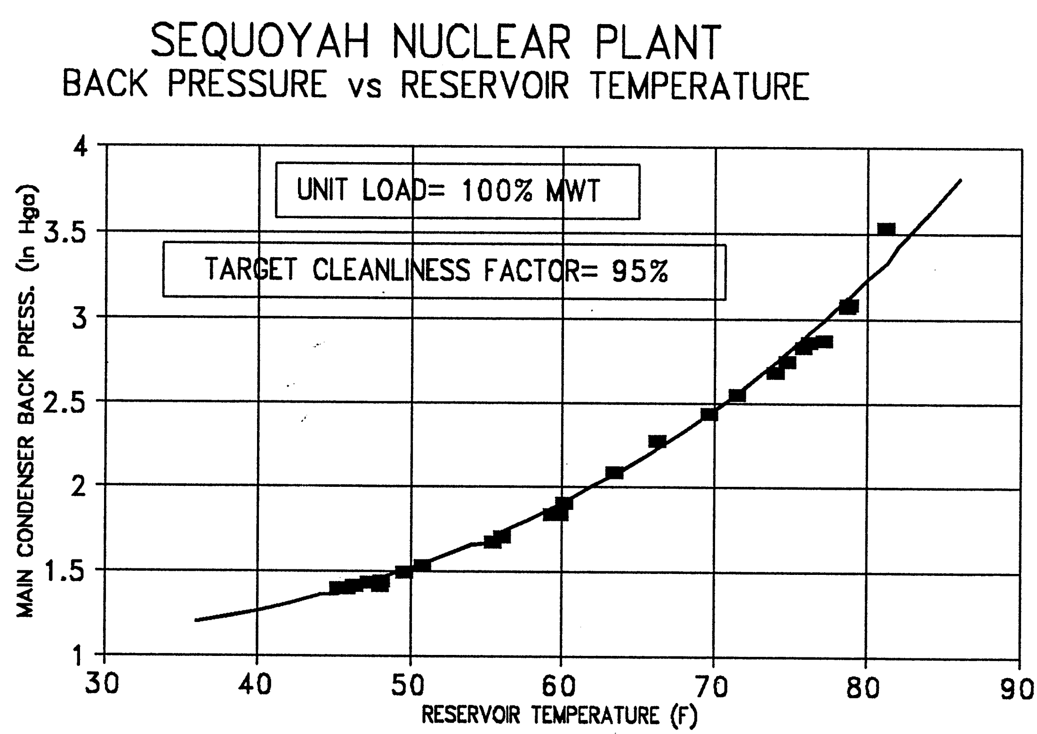


Figure 7

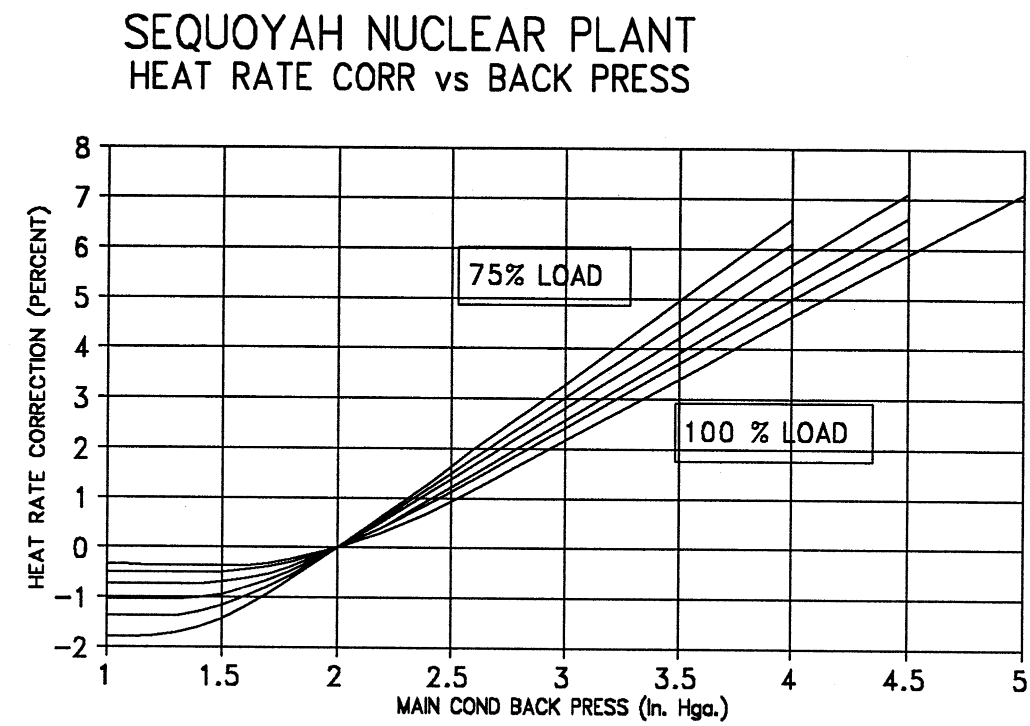


Figure 8

of 80°(F). We were concerned that the plant would exceed the 5 in Hga. BP limit set by GE before reaching full load. We determined based on the high head loss through the MC and the high CCW pump discharge pressure that approximately 20% of the MC tubes were plugged with macrofouling. Based on this information, we were able to back-calculate the MC CF and to estimate how high the BP would go as we took individual MC waterboxes out of service for cleaning. Over a period of ten days we were able to predict the MC BP within 1/10 in. Hg. using the Syntha II HB model even though the unit load, MC surface area, and CCW temperature and flow were constantly changing. The unit eventually achieved full power without exceeding the BP limit.

CONCLUSIONS

HB models using the rigorous off-design capabilities of computer codes such as SYNTHA II can accurately predict target values for important heat cycle parameters. For example, on January 24, 1992, with the BFN

Unit 2 operating at full load, the HB model was compared with operating data as shown in Table II for a MC BP of 1.4 in Hga.

Table II

	SYNTHA II	Measured
Generator Output (MWE)	1,113.3	1,111.9
Main Steam Pressure (psig)	950.3	937.8
First Stage Press. (psig)	673.7	675.0
Final Feedwater Temp. (F)	377.0	377.8
Final Feedwater Flow (lb/hr)	13,316,000	13,322,700

An HB model can be a powerful tool for establishing target values, monitor important performance parameters, and supporting plant operations if required. In an era of intense competition among sources of electrical generation, an effective thermal performance monitoring program is essential because potential problems must be identified and corrected before they affect the bottom line.

REFERENCES

(1) SYNTHA II User/Reference Manual Revision F, Syntha Corporation, Greenwich, CT.

(2) General Electric Company Publication GET-6020, "Predicting the Performance of 1800 RPM Large Steam Turbine-Generators Operating with Light Water-Cooled Reactors", by F. G. Bailey, J. A. Booth, K. C. Cotton, and E. H. Miller.

(3) General Electric Company Publication GER-2454A, "Predicting the Performance of Large Steam Turbine-Generators Operating with Saturated and Low Superheat Steam Conditions", by F. G. Bailey, K. C. Cotton, and R. C. Spencer.