Evaluation of the Adverse Impact of Replacing a Once Through Cooling System With a Closed Loop System

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Abstract

Accurate modeling of turbine cycles can be a valuable asset in assessing vendor claims and resolving contract disputes. This paper describes the practical application of a PEPSE model to successfully resolve a contract dispute worth over five million dollars. The subject of this paper is the application of a PEPSE model in the evaluation of the adverse impact of replacing a once through cooling system with a closed loop system employing a forced draft cooling tower.

Introduction

In 1985, two coal fired units at Santee Cooper's Jefferies Generating Station were converted form once-through cooling with river water to closed loop cooling as a result of the U.S. Army Corps of Engineers Cooper River Re-diversion Project. Jefferies Station Management requested that Santee Cooper's Performance Services Unit develop a model to determine the adverse impact on operating efficiency and capacity due to the re-design. A PEPSE turbine cycle model including an HEI condenser was used to predict the impact of the conversion from once-through cooling to closed loop cooling. A bi-variate function developed from model predictions was used to quantify the resulting adverse impact. The demonstrated accuracy of the model was instrumental in obtaining a favorable settlement in 1995 of a claim for compensation filed in 1993 for adverse impacts to station capacity and operating efficiency. This paper describes the practical application of a PEPSE turbine cycle model and an On-Line Performance Monitoring System in providing Management Decision Support services for contract evaluation.

Background

Santee Cooper's Jefferies generating station is located on the south-east end of Lake Moultrie in Pinopolis, South Carolina. The Jefferies hydro plant was completed in 1942 as a part of the original Santee Cooper Hydro Project. The facility consists of six generating bays with five units installed. Rated power generation capacity is 133 MW. The combined maximum discharge capacity for these units is approximately 27,500 cfs.

The Jefferies steam plant is located on the tailrace canal immediately downstream from the Jefferies hydro plant. The steam plant consists of four units. Units 1 and 2 were completed in 1953 and have a rated capacity of 50 MW each. These units are presently used as standby capacity. Units 3 and 4 were placed in commercial operation in 1969 and 1970 respectively. Units 3 and 4 are coal fired with a net capacity of 153 MW each and are used primarily in a base load mode of operation. Condenser water cooling for all four units was designed and built with an open loop (once through) cooling system utilizing river water from the tailrace canal. The Jefferies steam plant is required to operate in accordance with the 1970 Pollution Control Act of South Carolina. This Act generally limits the temperature rise in the tailrace canal to 5 degrees and the maximum temperature in the tailrace canal to 90 degrees. In the initial design considerations for the Cooper River Re-diversion Project, average flows from the Jefferies Hydro Plant were limited to 3000 cfs. At this flow rate, the Jefferies Steam Plant can be operated utilizing the existing open loop for only a limited number of hours each year. Alternate methods of condenser water cooling were studied in the design for the Cooper River Re-diversion Project. From this analysis, cooling towers were selected as the most desirable and cost-effective method for cooling and the design parameters for the cooling towers were selected. The contract for the design and construction of the cooling towers was awarded to Research Cottrell Inc. After the completion of construction in 1985, the cooling towers were not able to deliver the required cooling capacity. According to the agreement between Santee Cooper and the Corps, Santee Cooper was to be "kept whole" with respect to any impact to operating efficiency or capacity of units 3 and 4. Pursuant to that agreement, Jefferies Station Management initiated a plan to assess and document the impact and transmit this information to the Corps for reimbursement.

Approach

In order for Santee Cooper to be compensated for the adverse impact of closed-loop cooling, impacts on operating efficiency (heat rate) and capacity (output) needed to be determined and documented. To assess the impact, the station recorded cooling water inlet temperatures, steam flows and output for units 3 and 4 and the temperature in the tail-race canal. Unit operators manually tabulated instrument readings on an hourly basis.

Data collected by the unit operators revealed that there was a quantifyable and repeatable deficiency in cooling water temperature available from the closed-loop system versus the open-loop system. Figure 1 shows the water temperatures recorded for the cooling water inlet to the condenser for both units and the water temperature in the canal. Both condensers are supplied by a common cooling water return from the cooling tower. Inspection of figure 1 shows that the deficiency in available cooling water temperature occurs year-round.

Santee Cooper's Performance Services Unit was asked to develop a model of the turbine cycle that could accurately predict the adverse impact of closed-loop cooling operation. Two tools were developed to meet these needs, a model of the system and an algorithm to

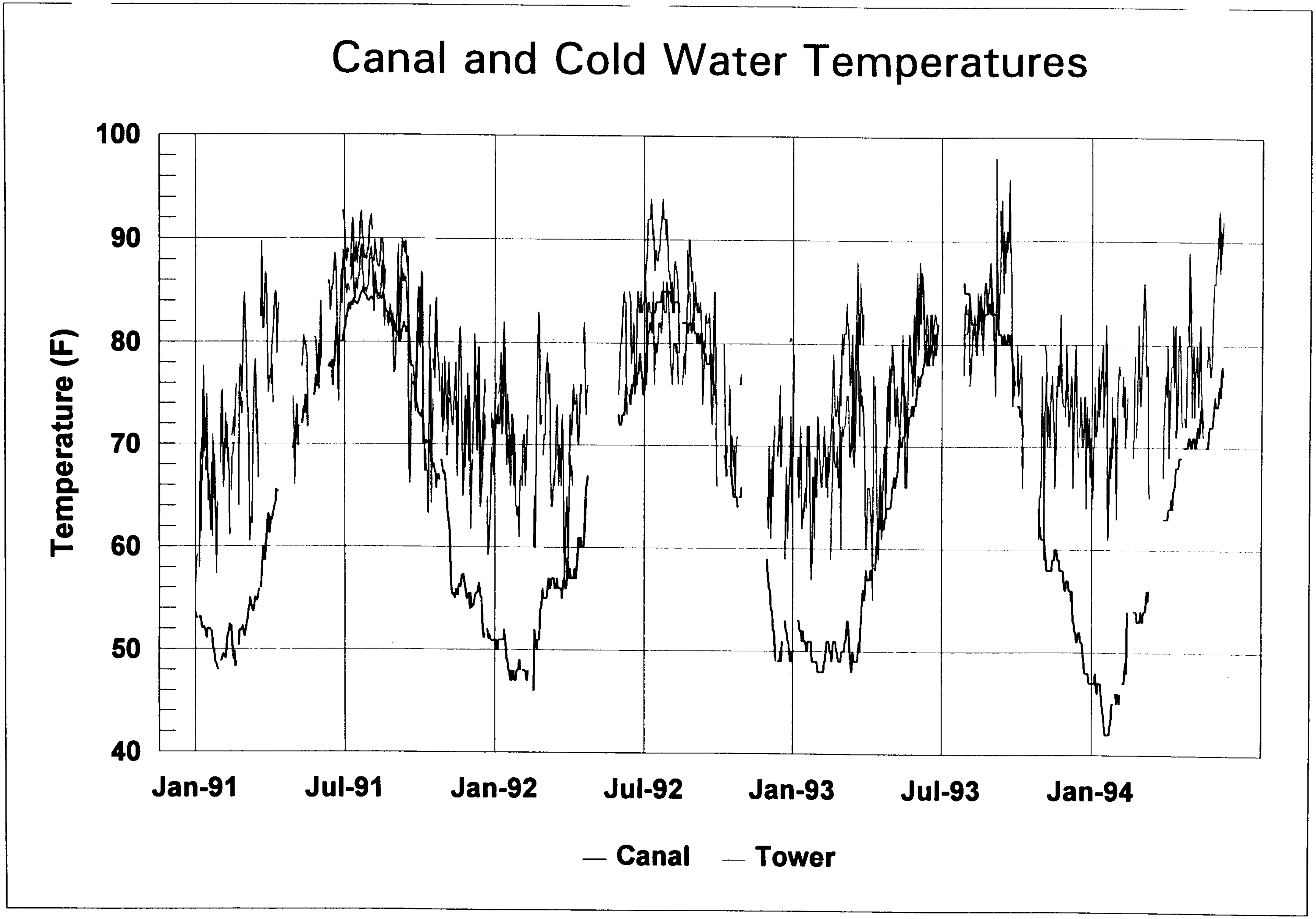
Canal and Cold Water Temperatures
Temperature (F)
100
90
80
70
60
50
40
Jan-91
Jul-91
Jan-92
Jul-92
Jan-93
Jul-93
Jan-94
Canal
Tower

figure 1

apply the results of the model to daily operating conditions. A PEPSE turbine cycle design model was developed using an HEI condenser to predict the amount of the impact. Adverse impact results were calculated over the operating range of the units and over a range of expected cooling water temperatures (tables 1 and 2). To apply these results, Performance Services engineers developed an algorithm from the PEPSE analysis to calculate the impact at any operating condition in the expected range. Instrument readings were then loaded into the software for processing each day to calculate the hourly adverse impact. Jefferies Station Management used this software to produce monthly adverse impact reports submitted to the Corps from 1985 to 1993. A sample page of a report is provided in figure 2.

Santee Cooper submitted two studies (May 1991 and June 1993) to the Corps concerning the adverse impact of closed-loop cooling. In November 1993, Santee Cooper filed a formal claim for the cost of the lost generation capacity and reduced operating efficiency due to closed-loop cooling of approximately $5.7 million for the 8.5 year period.

In September 1993, Santee Cooper began collecting data required to support the Adverse Impact Claim using the newly-installed Jefferies On-Line Performance Monitoring System (OLS). Test quality instrumentation was installed and recorded continuously at five-minute intervals.

In December 1993, the Engineering Division of the Charleston District Corps of Engineers and Santee Cooper began a technical review of the Santee Cooper claim. As a result of their review the Corps disputed two items in Santee Cooper's claim. Central to the review was the question of the accuracy of the PEPSE model developed to evaluate the impact of closed-loop cooling. In addition, the Corps questioned the accuracy of the data collected by unit operators using plant instrumentation.

table 1

Heat Rate Sensitivity Study - Results of PEPSE Analysis

Cold Water Temp		Steam Flow 1,200,000	1,100,000	1,000,000	900,000	800,000	700,000	600,000	500,000
C									
o	40	7735	7726	7717	7714	7732	7766	7809	7861
l	45	7732	7721	7712	7709	7727	7765	7814	7873
d	50	7727	7715	7704	7701	7720	7762	7816	7884
	55	7720	7707	7696	7691	7712	7758	7818	7895
W	60	7714	7700	7687	7682	7703	7753	7821	7909
a	65	7710	7694	7680	7675	7696	7751	7826	7926
t	70	7709	7692	7677	7671	7694	7754	7838	7951
e	75	7714	7697	7681	7675	7700	7766	7859	7987
r	80	7728	7710	7694	7688	7717	7790	7893	8039
	85	7751	7734	7719	7713	7750	7831	7945	8108
T	90	7786	7770	7757	7753	7799	7889	8016	8195
e	95	7834	7820	7809	7806	7865	7966	8104	8298
m	100	7893	7881	7874	7874	7946	8057	8205	8410
p									

table 2

Capacity Sensitivity Study - Results of PEPSE Analysis

Cold Water Temp		Steam Flow 1,200,000	1,100,000	1,000,000	900,000	800,000	700,000	600,000	500,000
C									
o	40	171.7	166.4	160.4	149.1	125.6	107.6	91.6	75.8
l	45	171.7	166.5	160.4	149.1	125.6	107.6	91.6	75.9
d	50	171.8	166.5	160.5	149.2	125.7	107.7	91.7	75.9
	55	171.9	166.6	160.5	149.2	125.7	107.7	91.7	75.9
W	60	171.9	166.6	160.6	149.3	125.8	107.7	91.7	75.9
a	65	171.9	166.6	160.6	149.3	125.8	107.8	91.7	75.8
t	70	172.0	166.7	160.6	149.3	125.8	107.7	91.6	75.6
e	75	172.0	166.7	160.6	149.3	125.6	107.5	91.3	75.2
r	80	171.8	166.5	160.4	149.0	125.3	107.1	90.8	74.7
	85	171.4	166.1	160.0	148.6	124.8	106.4	90.1	73.9
T	90	170.7	165.4	159.3	147.8	124.0	105.6	89.2	73.0
e	95	169.7	164.4	158.3	146.8	122.9	104.5	88.2	72.1
m	100	168.4	163.1	156.9	145.5	121.6	103.3	87.0	71.1
p									

Jefferies 3 Cooling Tower Impact

August 14, 1995

Time (hr)	Canal Temp (F)	Cold Water Inlet Temp. (F)	Steam Flow (lb/hr)	Condenser Pressure (in Hga)	Gross Output (MWh)	Lost Output (KWh)
100	83.5	90.6	732	2.5	96	1,120
200	83.3	89.7	954	2.7	126	830
300	83.3	89.2	905	2.6	120	780
400	83.2	88.9	715	2.4	99	850
500	83.2	88.7	761	2.4	104	790
600	83.9	89.4	1,012	2.8	136	790
700	83.4	88.7	723	2.4	97	780
800	83.5	88.5	716	2.4	97	750
900	83.7	92.0	1,217	3.3	163	1,070
1000	83.7	93.0	1,241	3.4	163	1,250
1100	83.9	93.8	1,232	3.5	162	1,410
1200	84.5	94.1	1,243	3.6	163	1,420
1300	84.8	94.1	1,268	3.6	166	1,380
1400	84.7	94.4	1,247	3.6	166	1,460
1500	85.1	94.2	1,256	3.6	168	1,370
1600	85.0	94.2	1,256	3.6	167	1,390
1700	85.4	93.7	1,240	3.5	167	1,240
1800	85.6	94.0	1,282	3.6	168	1,280
1900	85.1	94.3	1,281	3.6	169	1,380
2000	84.6	94.0	1,251	3.6	167	1,380
2100	84.3	93.3	1,252	3.5	16	1,250
2200	84.0	93.9	1,245	3.6	166	1,400
2300	84.0	93.3	1,250	3.5	166	1,290
2400	83.6	93.1	889	2.9	121	1,500
Total						**28,160**

figure 2

Model Accuracy

Based on the hourly data, model results indicated that the capacity of each unit was reduced by 3 or more MW when both units were operated concurrently at VWO conditions during the summer. Capacity losses were less during the remainder of the year. Figure 3 presents typical results for the period September 1993 to June 1994. In order to satisfy the Corps that the model, and therefore 8.5 years of calculated results, were indeed accurate, special tests were arranged for Jefferies 3 and 4. Testing was conducted to verify the models sensitivity to changes in cooling water temperature. The difference in the open-loop and closed loop cooling water temperature was simulated by a series of test runs conducted with both units at VWO conditions off-load control. Initial testing was conducted with all eight cells of the cooling tower in operation. This provided the baseline condition. Subsequent tests were conducted removing one cell of the cooling tower from operation, then two cells. These test runs provided elevated cooling water temperatures for comparison to the baseline condition. Results of the tests are shown in table 3.

Testing confirmed the capability of the PEPSE model to accurately predict the impact of the change to closed-loop cooling. Test results also indicated that adverse impacts predicted by the model were conservative. However, the Corps disputed these results on the basis of the difference in heat rate and output results from the test data and design model (table 3). To resolve this question, Performance Services engineers modified the design models to reflect as-tested turbine efficiecncies. This tuning was limited to turbine efficiencies due to time constraints but, as shown in table 3, was sufficiently accurate to satisfy the Corps that the models used in the analysis were indeed accurate and conservative.

Data Validity

Data collected by the Jefferies OLS from September 1993 to July 1994 was compared to plant data collected by the unit operators over the same period. Results of this comparison supported station data . Santee Cooper's OLS installations use NIST traceable instrumentation maintained by Santee Cooper's Performance Services Standards

Comparison of Test Data and Model Results

	Units	Test 1	Test 2	Test 3	Total Change
Test Data					
Circ. Water Temp.	(F)	92	95.7	98.8	6.8
Gross generation	(MW)	166.4	165.1	164.6	-1.8
Gross turbine Heat Rate	(Btu/kWh)	8290	8335	8376	86
Design PEPSE Model					
Circ. Water Temp.	(F)	92	95.7	98.8	6.8
Gross generation	(MW)	176.7	175.7	175.2	-1.6
Gross turbine Heat Rate	(Btu/kWh)	7830	7864	7900	70
Tuned PEPSE Model					
Circ. Water Temp.	(F)	92	95.7	98.8	6.8
Gross generation	(MW)	167.1	165.8	165.2	-2.0
Gross turbine Heat Rate	(Btu/kWh)	8304	8353	8401	97

table 3

and Calibration Laboratories. These laboratories are located at the corporate main office complex in Moncks Corner. Results showed that the test-grade instruementation and data acquisition system supported the data collected by the Jefferies Station unit operators. The closeness of the reslts is a direct reflection of the dilegence of Jefferies Station Operations Personnel who accurately collected this data each hour on a continuous basis processed it and provided monthly reports for ten years from 1985 to 1995.

Resolution

In December 1995, Santee Cooper and the Corps settled the adverse impact claim. The Corps paid Santee Cooper approximately $ 5.6 million for the adverse impact of closed-loop cooling for the 1985 - 1995 period and agreed to pay for future impacts according to the monthly statements submitted to the Corps by Santee Cooper. Monthly Adverse Impact Statements are prepared by Jefferies Station Management using an automated data processing/report preparation feature included in the Jefferies OLS.

Conclusions

Consistency of results provided by industry recognized computer tools (PEPSE) and straight-forward engineering analysis, in combination with accurate, repeatable data provide the basis for a powerful argument in contract negotiations. In this case, Santee Cooper submitted a claim for adverse impact due to lost revenue resulting from reduced turbine-generator output capacity and reduced operating efficiency due to the change from an open (once through river water) cooling system to a closed loop (cooling tower) cooling system. Here, the strongest arguments were made by:

- The reputation of PEPSE as an industry standard heat balance product
- Consistency and repeatability of 8.5 years of hand-scribed instrument readings recorded hourly.
- Validation of the PEPSE model by special performance tests.
- Validation of the hand scribed instrument readings by a state-of-the-art

data acquisition system and NIST traceable instruments.

Santee Cooper's success in resolving this contract dispute is directly attributable to the ability to accurately model the effects of changes in operating constraints on turbine cycle performance.