Turbine Last Stage Bucket & Diaphragm Upgrade Evaluation

Dale C. Karg, P.E.
William R. Toombs

Santee Cooper

TURBINE LAST STAGE BUCKET & DIAPHRAGM UPGRADE EVALUATION

Submitted to the PEPSE User's Group Meeting June 1994

Dale C. Karg, P. E. & William R. Toombs
Principal Engineers
Performance Services
Santee Cooper
Moncks Corner, SC

ABSTRACT

The Performance Services group at Santee Cooper (South Carolina Public Service Authority) conducted turbine performance tests before and after a seven week overhaul in the Fall of 1992 on our Cross Unit 2. The purpose of the program was to measure the change in turbine cycle performance associated with the turbine maintenance and to evaluate the heat rate impact of replacing the last stage L-O buckets and diaphragms on both low pressure turbines.

This paper presents the economic evaluation for the replacement and the associated testing program undertaken to evaluate the subsequent 1.5% (123 BTU/KWH) heat rate improvement and 1.8% (9,450 KW) output gain attributed solely to the last stage modification. The use of test procedures guided by ASME PTC 6[1] test procedures, test quality instrumentation, sound calibration methods and extensive use of PEPSE and it's special option six feature enabled good predictions and analysis of the performance improvement contribution of each turbine section. The evaluation included N2 packing leakage testing to allow correction of the intermediate pressure turbine efficiency. A steam path audit to more accurately determine the performance impact of other turbine maintenance was also completed during the outage.

INTRODUCTION

The Cross Unit 2 General Electric (GE) turbine generator is designed to produce a gross output of 520 megawatts, it is a high pressure tandem cross compound opposed four flow reheat turbine generator. The unit was placed in service in 1984. Prior to the planned outage, Santee Cooper's Production Maintenance group investigated the advantages of installing the GE upgraded 26 inch last stage bucket and diaphragm design. The modern GE design claims a more aerodynamic shape to reduce drag losses, reduced leakage rates, improved structural integrity and erosion resistance. The guaranteed heat rate improvement of 1% provided sufficient economic justification (a 3.2 year payback) to warrant the installation, with the additional suggested advantage of improved reliability.

Performance Services conducted a feasibility study to determine the requirements of a test program that would provide supporting data to verify the 1% performance improvement in heat rate. The testing program would require the performance contribution of the Low Pressure (LP) turbine, more specifically the last stage, to be evaluated in the pre and post outage tests. At the present time there exists no practical industry accepted method of directly measuring LP turbine efficiency due to the inability to measure the energy content of the wet steam leaving the LP turbine. The method utilized by Performance Services to calculate the LP turbine efficiency is to measure the High Pressure (HP) turbine efficiency, Intermediate Pressure (IP) turbine efficiency, feedwater heater performance, condenser performance and unit output. $PEPSE_2$ heat balance software is used to conduct an iterative approach to match the required LP output and efficiency contribution. PEPSE calculates the energy content in the LP exhaust steam by swinging the expansion line to solve for the required LP output and efficiency.

A review of similar test programs by other utilities was performed to estimate the test uncertainty associated with the measurement of change in heat rate attributed solely to the last stage modification. In order to further reduce the uncertainty we conducted a series of repeatable Valves Wide Open (VWO) performance tests. Cycle isolation and test procedures were in accordance with ASME PTC 6.1 version 1976. A steam path audit was also executed to estimate the effect of maintenance on the performance of the LP Turbine. The study concluded that with modifications to our existing routine turbine cycle heat rate testing program test uncertainty could be reduced to acceptable levels for the determination of the heat rate and output changes associated with the last stage upgrade.

PEPSE's Special Option 6 feature was used extensively to determine the performance contribution of each turbine section and cycle component and the change in that contribution between pre and post overhaul tests.

TURBINE OVERHAUL

The last stage upgrade was accomplished during a scheduled turbine maintenance overhaul with work planned for each turbine section. The planned work included replacement of several sections for improved reliability (upgrade packages for solid particle erosion protection) to the nozzle block and first reheat stage. The scope included installation of the upgraded last stage as well as cleaning, inspection and replacement of various packing to all turbine sections. The second and third stage diaphragms were also replaced due to peening of the trailing edges. A steam path audit was conducted to estimate the contribution of maintenance work in the remaining LP stages. Results of the audit were used to validate the test data.

TEST SET UP

Test data was collected by installing a dedicated data acquisition system with all points on the GE heat balance instrumented with precision instrumentation. All instruments were calibrated at the Santee Cooper Performance Services Temperature

& Pressure Laboratories. The laboratories maintain primary standards that are traceable to the National Institute of Standards & Technology (NIST). Each pressure transmitter was calibrated to within 0.25% accuracy using a certified pneumatic calibration system prior to testing.

The temperature instruments are calibrated against four "freeze point" (melting point) reference standards: water, indium, tin and zinc with respective melting points of 32.2, 313.9, 449.7 and 787.2 degrees F. Additional temperature corrections up to unit operating temperatures were accounted for by comparing individual RTD readings against the primary SPRT which had recently been calibrated by NIST. A calibration correction curve for each four wire resistance transmitting device (RTD) was determined from 32.2 to 1,000 degrees F and a second order equation for temperature correction applied for the testing program. Primary flow was measured with a condensate flow nozzle, calibrated at Alden Laboratories just prior to the pre outage testing.

TEST PROCEDURE

Santee Cooper's Performance Services group routinely conducts turbine cycle heat rate tests combined with N2 packing leakage tests using the Booth / Kautzman temperature variation test method on each of our nine pulverized coal fired generating plants. The tests are done on an annual basis and before and after a turbine overhaul. As discussed in the introduction, our test procedures were modified slightly to reduce uncertainty in the LP efficiency calculation since the modification would effect LP efficiency and output only.

Pre and post-overhaul testing adhered to identical test procedures and to the extent possible, the calibrated instrumentation was left in place to reduce the effect of introducing any additional uncertainty. Our test analysis indicated that sixteen repeatable tests of one hour duration both pre and post outage would be required to achieve the desired accuracy for the test comparison. Unit cycle isolation was guided by ASME PTC 6 - 1976 paragraph 3.09 through 3.17 and verified prior to each day of testing. In addition a steam path audit was conducted so that the effect on performance of any maintenance work conducted in sections other than the last stage could be estimated. The audit also documented the as found condition of the original LP last stage.

Tests were conducted at VOW conditions only and the unit was allowed to stabilize for several hours prior to data collection. Each test run consisted of one hour of data collected once every minute from the test data acquisition system with several runs collected each day of the program. Each data set was saved as a LOTUS spreadsheet with the averages, minimum and maximum values and standard deviations calculated. A review of the variations in inlet steam conditions, flow measurements and other key parameters to determine the steadiness of the each run was conducted. A LOTUS "print file" of the sixty minute average of each point was created and "imported" into another spread sheet that applied all the waterlegs and temperature corrections. This spreadsheet also created a PEPSE special option 6 test deck. The test deck file was then transferred as an ascii file to the mainframe for execution.

PEPSE SPECIAL OPTION 6 TEST DECK

PEPSE Special Option 6 was utilized to make the comparison of pre outage to post outage results. This option automates the analysis by allowing the submittal of the following in a single run submittal;

1. Benchmark case - in this case pre outage for comparison to post outage results.

2. Test case - computation of the test case (post outage test run results at test

boundary conditions, i.e. uncorrected for ASME PTC - 6 group 2 steam pressure and temperature conditions).

3. Correct to Standard case - computation of the test case corrected to standard conditions (post outage test run results at standard design boundary conditions, i.e. corrected for ASME PTC - 6 group 2 steam pressure and temperature conditions).

4. Performance Upgrades - PEPSE calculates the individual contribution of specified components to allow comparison of the performance contribution of each Benchmark component specified to be applied to the current test run performance refer to the following explanation.

The PEPSE Special Option 6 deck was set up to provide a test reduction and standard (corrected to group 2) output of the turbine section/stage efficiencies, detailed heater performance and standardized gross turbine cycle heat rate and generation. The upgrade feature of Special Option 6 was then set up to allow PEPSE to calculate the effect of the performance change to the HP, IP and LP sections, LP feedwater heaters and HP feedwater heaters. This allows the user to easily evaluate the change in the performance contribution of each one of the "upgraded sections" by comparing the calculated heat rate and output of the upgraded case to the previous case. For example in the HP upgrade case we force PEPSE to calculate the test post outage data with the pre outage HP efficiency. In our situation the HP efficiency improved from 84.3% to 86.7%. Comparison of the "Correct to Standard" (post outage results) to the "HP Upgrade" (post outage results with the pre outage 84.3% HP efficiency) indicated that the percent improvement in HP efficiency of 2.8% contributed 4,500 KW and improved gross heat rate by 35 BTU/KWH.

RESULTS & ECONOMIC ANALYSIS

The test results indicate that the upgraded last stage resulted in a 1.5% (123

BTU/KWH) heat rate improvement and a 1.8% (9,450 KW) increase in generator output. Based on the test results an economic analysis indicated that the project had a 2.1 year payback, this was 1.2 years better than the original project justification. The project cost was $2.75 M with an estimated annual savings of $1.28 M. The estimated annual fuel savings for the improved heat rate is $794,000 and an avoided annual capacity savings of $489,100.

CONCLUSION

Results of the Cross Unit 2 Last Stage upgrade evaluation show that a carefully designed and planned test program employing the following can be used to measure a small (1 percent) change in heat rate very accurately:

1. Accurate test grade instrumentation.
2. Statistical analysis.
3. Accurate accounting of turbine heat balance performance changes using PEPSE.
4. An accurate steam path audit.

Results of the test program were used of the Vendor's performance improvement claim and provided valuable decision support services to management for maintenance planning on a cost/benefit basis.

References:

1. ASME PTC 6 - 1976, The Performance Test Code For Steam Turbines, ASME - New York, NY, 1976

2. Minner, G. L. 1993, PEPSE Volume I, Haliburton NUS Corp., Idaho Falls, Idaho