Modeling & Testing Low Pressure Turbine Replacements at DCPP[1]

Summary

Diablo Canyon Power Plant (DCPP), a dual unit nuclear plant rated at 1165MWe/hr each, replaced the Low Pressure Turbines (LPT's) on both of the units. A small part of the LPT warranty was improved efficiency measured by increased electrical generation of 35MWe/hr on each unit. Since the ratings of the units were 1165 MWe/hr when new, an upper end value of 1200 MWe/hr would be theoretically possible, but not probable as these units are 20+ years old and have been operated with capacity factors upwards of 90%. Unit 1 pre LPT replacement warranty test actual output was 1154.2 MWe/hr and the corrected output was 1156.5MWe/hr. Unit 2 pre LPT replacement warranty test actual output was 1143.8MWe/hr and the corrected output was 1146.9MWe/hr.

Post LPT replacement for Unit 1 LPT indicated 1191.8 MWe/hr uncorrected and 1202.5 MWe/hr corrected. Unit 2 LPT replacement indicated 1201MWe/hr uncorrected and a corrected output of 1202MWe/hr. The LP turbines on both units met the output improvement portion of the warranty.

Introduction

Diablo Canyon Power Plant unit specific PEPSE models were developed utilizing Valves Wide Open (VWO), Westinghouse original turbines and moisture separator reheaters, and OEM supplied feedwater heaters. Prior to operating, the condenser tubes were changed from admiralty brass to titanium, and the moisture separator reheaters were changed from two pass to four pass. Minor changes to the PEPSE model needed to be incorporated as a result of this which the heat balance diagram did not reflect. Full PTC – 6 testing was performed at initial start ups for the unit and good baseline data was obtained. Over the operating history, all feedwater heaters were replaced which included a tube material change from copper nickel to stainless steel, moisture separator reheaters tube bundles were changed from copper nickel to stainless steel and optimized hour glass shaped bundles were incorporated. In addition a blow down recovery system was installed. PEPSE models for each unit were modified to properly represent the plant changes as they occurred. Next the LPT's were replaced. Again the PEPSE program was modified to represent replaced Low Pressure Turbines while using the original vendors High Pressure Turbines (HPT), modified steam plant and reduced steam pressure that the units are currently forced to operate at preserving the life of the steam generators until they are replaced.

Detailed Discussion

PEPSE models of DCPP have existed for many years as the PEPSE license was issued in about 1983. In the 20+ years DCPP has owned and used PEPSE, albeit the mainframe version was difficult to use, many models of the power plant were built. Along in about the mid 90's, well after PEPSE ran on desktop computers and had a decent graphical users interface, detailed PEPSE diagrams began to

[1] Slide 1 PowerPoint

be built. Three reasons drove this. One is that DCPP's management was never pleased with simple one line diagrams not representing the reactor in the drawing. Secondly, the identical components were behaving differently as the equipment aged requiring different modeling techniques. And three, the identical units are not "identical in some steam pipe routing, and HP turbine first stage blades. Additionally, tubes in a feed water heaters became plugged, seal and shaft damage to a main feed water pump turbine occurred requiring it to draw a significant amount more steam to run properly, etc. Thus the need for additional details in a good model for each unit became apparent.

With a Westinghouse plant, Westinghouse turbines, data was relatively easy to gather and build detailed PEPSE models[2]. The Westinghouse LPT's were 44" Last Stage Blades (LSB). One of these detailed PEPSE models became the Heat Balance Diagram (HBD) layout utilized by Alstom and supplied to DCPP[3]. Once the HBD's were received from Alstom, the existing PEPSE models were changed to reflect the Alstom Low pressure rotors. This required changing extraction stage turbine group pressures, enthalpy, group efficiencies, moisture removal and the exhaust area went from127.4ft² to 178.36ft² per end. Also, if the modeler uses the Moisture Removal Effectiveness (MRE) curve supplied with the thermal kit, nothing makes sense in the resulting PEPSE runs. The Bogie diagrams do not use the MRE curve, and when programmed in via a schedule, each extraction stage results did not agree with the HBD. That initially was perplexing because obviously PEPSE was programmed wrong via Mr. Minner. Now how could that be? Maybe PEPSE cannot handle schedules, but wait PEPSE uses schedules all of the time. Looking at the MRE curve supplied by Alstom, it was noticed how similar the curve seemed to be to other curves. Opening KC's book to the correct page, there was the identical MRE curve. Alstom just supplied a representative curve, not a DCPP turbine MRE curve[4]. **Note, the fist rotating blade set exhaust pressure in the Bogie is ~84 psia[5].** Also, not on the drawings, the new Alstom LPT's are 57" LSB which were the first and the largest LSB turbines built by this vendor to date, but there are now others being proposed or built. And these are low speed rotors, i.e. 1800 rpm.

Alstom's heat balance diagrams indicate full power to be 1191.5 MWe/hr for Unit 1 and 1187. 2MWe for Unit 2. The installed OEM HP turbines were designed to operate at ¾ arc admission and less than VWO. DCPP Unit 1 was intended to run at about 1165 MWe/hr after a company performed unit uprate. The absolute best it ran was 1161 MWe/hr uncorrected, and it was never subjected to PTC-6 testing. Unit 2, also an 1165 MWe/hr rated unit during testing to warranty conditions was corrected to 1167 MWe/hr after PTC-6 testing. It ran at 1160 MWe/hr for a brief period over the past 18 years. Due to turbine issues such as, aging, frequent expensive overhauls, inspections (every 1 ½ years a LP rotor was removed and replaced with a refurbished spare rotor), a LP turbine replacement project was implemented. Five bidders submitted proposals and bid on the replacement rotors. The winning bidder, Alstom, was chosen based upon a matrix of items such as ease of overhaul, generation reliability, length of time between overhaul, cost, and service reputation to name but a few. The rotors were replaced first on Unit 1 late 2005 and then in May of 2006 on Unit 2. Both unit's rotors met the vendors warranty conditions using a modified PTC-6 test procedure.

Mixing vendor data to create the models created a lot of questions. As an example, Westinghouse sort of uses 5% turbine extraction flange pressure drop and about the same loss in the extraction lines. Well, not so Alstom HBD's. Look at this example. Once again note the stage pressure in LPA turbine

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[2] Slide 2 PowerPoint PEPSE Model
[3] Slide 3 PowerPoint U-1 VWO
[4] Slide 4 MRE Curve
[5] Slide 5 84 psia stage pressure

as 83.94 psia. This is the same pressure shown in the extraction line all the way to feedwater heater 3A. Well, we all know “that aint right”. Now use that pressure and establish the saturation temperature for that pressure as 315.4°F. Then compute the TTD and it comes out 8.9°F. But Bogie is showing a TTD of 3.8°F. What, “don’t” those Europeans know how to calculate TTD’s? Well, not shown in the HBD is this pressure drop[6]. Thus there is additional hidden information on the Bogie that one must be aware of.

Now modeling 4 pass MSR’s was also a challenge. From the Alstom HBD[7], it is near impossible to determine what they are representing. Breaking this down, i.e. the vendor supplied additional information[8], line routing and modeling became possible.

Next, the agreement was reached on using group A PTC-6 corrections, and that these correction curves now needed to be generated. With 2 units being overhauled approximately 6 months apart, turbines being replaced in 40 day outages, the units being refueled, replacement steam generator project demanding time and PMAX being implemented, time to complete all of these tasks was just not available. Scientech was engaged to generate the correction curves based upon the DCPP PEPSE models, DCPP U1 Current R03-24-06.mdl set 1. Since both units are near identical, it was agreed that the correction curves generated from the Unit 1 PEPSE model would be used for Unit 2. Also, the PEPSE model for Unit 2 was not finished. Since Scientech was hired to do the work, fine tuning the models and “training” also occurred during this session. The end result was that the model to the HBD had a 0.1MWe/hr discrepancy.

The next Unit 1 model PEPSE set 2 was created for 100% power operations to Bogie. It implies full power generation to be 1190.7 while Alstom’s bogie implies 1191.5. Thus a deviation of 0.8 MWe/hr exists and insufficient time was, and still is not available to find and remove the discrepancy. It will most likely never be corrected as good test data for base line conditions now exist.

The important model is DCPP U1 Current R03-24-06.mdl set 3 (DCPP U2 R-03-21-06.mdl set 3) which is the near 100% power model with PTC-6 test data input into PEPSE model. Some of the key parameters for Unit 1 were, but not limited to:

- 1193.4 MWe/hr @99.45% power
- Final feed water temp 431.1°F
- Turbine Exhaust Pressure of 1.805” HgA
- Per contract agreed, corrections Unit 1 was corrected to 1202.5 MWe/hr

Automatic data input could have been used, but once again, time to learn this was not available due to other ongoing projects. PEPSE was then run using the data input into set 3 as set 4 with only the feed water flow adjusted to generate 100% thermal power. PEPSE output results indicate 1204.8MWe/hr. Thus between as corrected test data and PEPSE the difference was 2.3 MWe/hr. Thus the Unit 1 PEPSE model for 100% power has essentially been validated by testing. Next, the model has to be independently reviewed to assure the model and input data is correct and it will then be used for baseline data and unit rating.

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[6] Slide 6 FWH schematic representation
[7] Slide 7 HBD
[8] Slide 8 MSR schematic

Although Unit 2 testing has been completed, the PEPSE models for the as tested condition has not been completed due to time constraints.

Warranty Testing and Issues

Although the corrected generation was ~1200 MWE, this was a brand new low pressure turbine set. Since the amount of time to properly align the turbines was not taken due to excessive off line time, it is my speculation that nominal full power generation will be about 1195 to 1198 MWe/ hr for each unit. Why would anyone be concerned as to the full power ratings? One of the reporting requirements to the state and federal agencies is the rated full power of the units. Since the LP rotor vendor did not rate the T/G set and the previous ratings are no longer where the unit runs, possible re-rating should be accomplished. Recall, additional generation was not the reason for replacement of the turbines, but frequency of overhaul is. Also if one uprates by 50 MWe/hr there is some mandated threshold reached requiring additional "*something"*. Since the pre-rotor replacement ratings were 1165 MWe/hr, clearly the 50 MWe/hr uprate was not exceeded for either unit.

A tremendous amount of time was spent negotiating how corrections would be determined and made It was finally agreed upon that PEPSE models would be used to establish the off normal correction curves. This was accomplished by first verifying good fidelity to the Alstom bogie, then varying a single parameter and noting the change. This was done for throttle pressure, power factor, feedwater temp and reactor power, etc. Feed water flow instrumentation and accuracy was of course a major topic and took considerable effort to work through to acceptable by both parties. Special test instrumentation was purchased and installed by DCPP, and Alstom originally insisted that their check instruments were to be installed in parallel with the test instrumentation. Of course one can understand the vendor's position as there is a lot of money at stake if the turbine did not meet warranty. In addition, DCPP is not paid for generation, but a flat daily rate whether on line or not. Rephrasing that, the same amount of revenue is generated when the plant is shutdown as when operating at 100% power. Therefore any additional generation above the warranty is of no value to the utility and thus no reward or incentive was offered or agreed upon.

The California Public Utility Commission (CPUC) sets the electric rates and this was the "agreement" reached as the company became solvent again. Now, no one can predict the future, but it is my contention that DCPP is being paid for generation. The company, Pacific Gas & Electric Company is in the business of selling electricity to the consumers. If company generated electricity is not available, then higher priced electricity must be purchased on the open market. Also, the CPUC rate cases are routinely reviewed and reset. It is my speculation that in the future DCPP will once again be providing electricity and being paid for generation.

There was a significant discrepancy between the vendors HBD's for 100% power and what was the actual generation. Part was the conservative nature of Alstom since this was the first 57" LSB turbine they had ever built. Second, the exhaust loss curve is simply the exhaust velocity with no turning losses included. Since the LPT hoods were supplied by the OEM, little to no data was available and of course Alstom was concerned additional losses might be incurred here. The last interesting point is the first extraction LPT stage pressure. Alstom's design indicated 20 psi higher than what measured during testing. Why this occurred is a mystery to the end users, but I suspect Alstom is closely looking at the data and is working on, or has understood this issue. It is also my belief that Alstom will fine tune future proposals and market their successful DCPP LPT replacement project and then glean additional revenue from this substantial increase in generation

Conclusions

Future work remains as a result of this LP steam path replacement:

- Creation of new heat balance diagrams as the HBD's are not correct
- S/G replacement that will raise the operating pressure at the TV's to about 850 psia
- Future HP turbine replacement.