Evaluating an HP/IP Turbine Replacement

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Background

Many US power producers are stretching the useful lives of their existing power plants because of the favorable economics as compared to other alternatives. Environmental issues, licensing delays, public outcry, and structural costs top the list of reasons for delaying, canceling, or even considering planned and future generation projects. The US power plant fleet is rapidly aging, with many of the plants 30 years old or older. To extend the life of these aging plants the power producers are refurbishing or replacing older systems and equipment to prolong life, increase efficiency, lower emissions, save money, and squeeze the last ounce of power from their existing plants.

The replacement equipment being installed in aging plants, because of new technologies developed in recent years, is more efficient than the existing equipment was when it was brand new. However, how will this new technology improve performance, and just as important, how will it affect the older systems and components in the plant? To determine how this new equipment will perform and interact with the existing older equipment before any contracts are signed, power producers are employing analytical techniques that are outside of those offered by the equipment manufacturers. These independent checks have proven valuable to the power producers and have uncovered some surprising results.

Summary

As one example of equipment replacement at an older plant, in 2007 a large US utility sought to replace the high pressure (HP) and intermediate pressure (IP) turbines at one of their 300 MW coal-fired units to increase the efficiency of the plant and raise generation “without burning one more pound of coal”, as stated by an executive of that utility.

Requests for bid were sent to various turbine manufacturers, with two manufacturers responding with proposals. To verify each vendor’s performance claim and to determine the new turbines’ effect on the rest of the unit, the utility used the PEPSE (Performance Evaluation of Power System Efficiencies) heat balance software program, employing a PEPSE simulation model of the unit’s turbine and boiler systems.

Based on the results of a PEPSE analysis of the proposed new turbines, the turbine manufacturers’ proposals did indeed meet their performance guarantees. However, because the new turbines were more efficient than the existing HP and IP turbines, they removed more energy from the steam than the existing HP and IP turbines, leaving less energy available for the downstream low pressure (LP) turbine. The net effect was an increase in the HP and IP turbine output, but a decrease in LP turbine output. While there was an overall increase in unit output, this increase was lower than expected when factoring in the decreased output of the now energy-starved LP turbine.

Additional PEPSE analyses were performed. First, rebuilt HP and IP turbines, rather than new turbines, were analyzed. As expected, the rebuilt turbines were not as efficient and did not produce as much additional power as the proposed new turbines, but their cost vs. new turbines is significantly lower. Finally, various additions to boiler surface area in the superheat (primary and secondary), reheat, and economizer sections were analyzed using the new turbines.

The utility performed a cost/benefit analysis based on the PEPSE results. Their three turbine options included: (1) do nothing, (2) replace the HP and IP turbines with new turbines, and (3) rebuild the HP and IP turbines. Their various boiler surface area choices included superheat, reheat and/or economizer surface area additions. The results of this cost/benefit analysis are that they will rebuild the turbines at the next major outage rather than replacing with new, and they will forgo any boiler surface additions.

The Unit

The unit under study is one unit of a multiple-unit plant. It was designed to produce 310 MWe at full load conditions of 2 x 10^6 lb/hr main steam flow, 1050 ^oF main steam temperature, 2400 psig main steam pressure, and 1000 ^oF reheat temperature. This unit originally came online in the early 1970's.

The boiler continues as its original design built by Combustion Engineering. It burns pulverized coal purchased from a variety of sources including term contracts and the spot market.

The current HP, IP, and LP turbines were built by General Electric. The unit is a cross-compound arrangement, with single-flow HP and IP turbines powering one 3600-rpm generator, and a double-flow LP turbine powering one 1800-rpm generator. There are seven feedwater heaters in the cycle.

The Problem

Having the original HP and IP turbines from the early 1970's made their improvement or replacement a key issue at the plant. Their deteriorating performance and increased maintenance were the primary factors contributing to the focus on these turbines. New turbine technologies offering higher efficiencies, in addition to environmental issues and rising energy costs also contributed to the decision to explore options for the turbines. A major outage, already planned for 2010, would allow enough lead time to plan any project involving the turbines and allow enough plant downtime to install the new turbines.

The Solution

In early 2007 the utility sent a request for proposal (RFP) to various turbine manufacturers with specifications required for replacement of the HP and IP turbines. Two of these turbine manufacturers, or original equipment manufacturers (OEM's), responded with quotations and performance specifications for their proposed new turbines. For both respondents, the primary performance specification was a single heat balance diagram. This diagram showed the new HP and IP turbines, but the performance of other components and systems, including the system boundary conditions, were unchanged from the original 1970's turbine vendor heat balance diagram. While a heat balance diagram may be a basis for the turbine manufacturers' guarantees, it does not reflect adequately how the new turbines will perform in the actual plant today. Component performances are usually different, either through their own deterioration or replacement over the years. Turbine cycle boundary conditions such as steam properties from the boiler may also be different for the same reasons. Other conditions, for a variety of reasons, may have also changed. Guarantees are one thing, but what's the real story?

The Evaluation

Actual turbine and plant performance can only be learned after the turbines are installed and tested in the plant. However, a close approximation of that performance can be derived by performing a system analysis using one of the available heat balance programs currently on the market. This utility chose PEPSE because of their long history with this software program.

PEPSE is a steady-state energy balance software program that calculates the performance of the plant. This plant analysis is done using a model that mimics the actual plant configuration. A model is developed in a Windows interface setting by dragging and dropping plant component icons onto the screen from a component library. This library contains all the types of components found in any power plant including turbine cycle systems for nuclear plants and fossil plants, fossil boilers, gas turbines, combined cycles, cogeneration plants, and any other process steam or other fluid system.

PEPSE models of this unit's turbine cycle and boiler have existed for years. However, they were modified for this analysis to account for current plant data. Representative PEPSE turbine and boiler models can be seen in Figures 1 and 2. With PEPSE, these models were developed and tuned separately, then combined using one of PEPSE's special features.

One other model was developed for this study – a submodel of the HP and IP turbines only – see Figure 3. This submodel allowed the input and tuning of each of the two OEM's turbine performance claims to be analyzed without influence from the other components and systems in the cycle. Recall that these other components and systems were left unchanged in the new proposed OEM's turbine cycle heat balances as compared to the original heat balance. Then, after running and tuning the turbines using this submodel, the tuning parameters were transferred to the main turbine model shown in Figure 1. The result is a PEPSE model of the unit's boiler and turbine cycles tuned to current plant data but using each of the OEM's proposed new turbines.

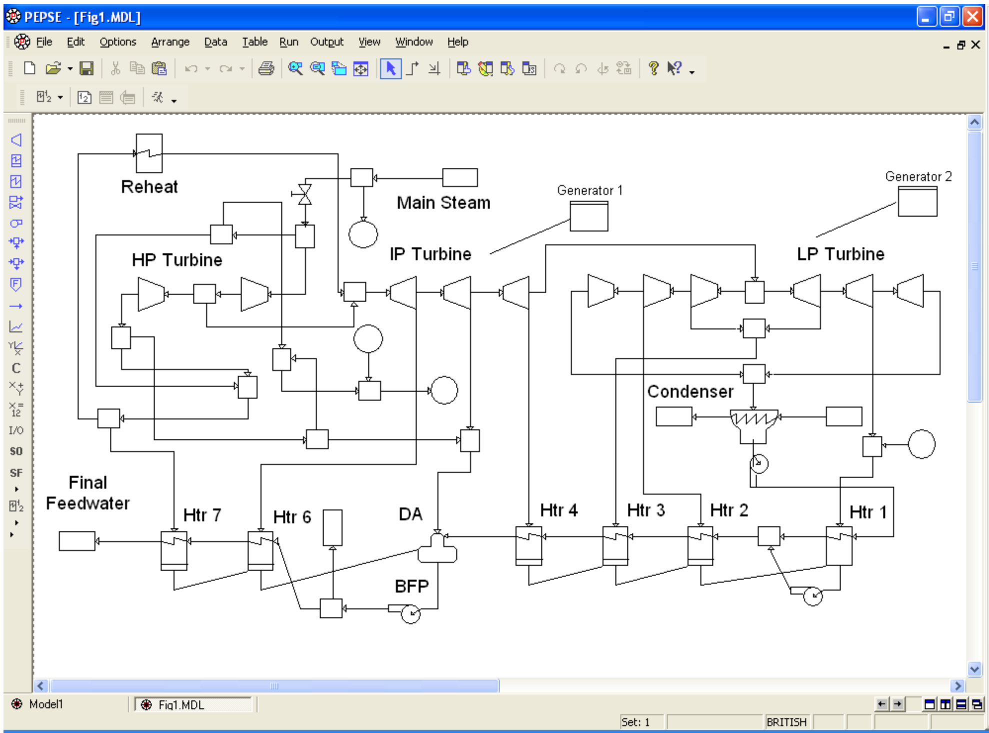

Figure 1 – PEPSE Turbine Cycle Model

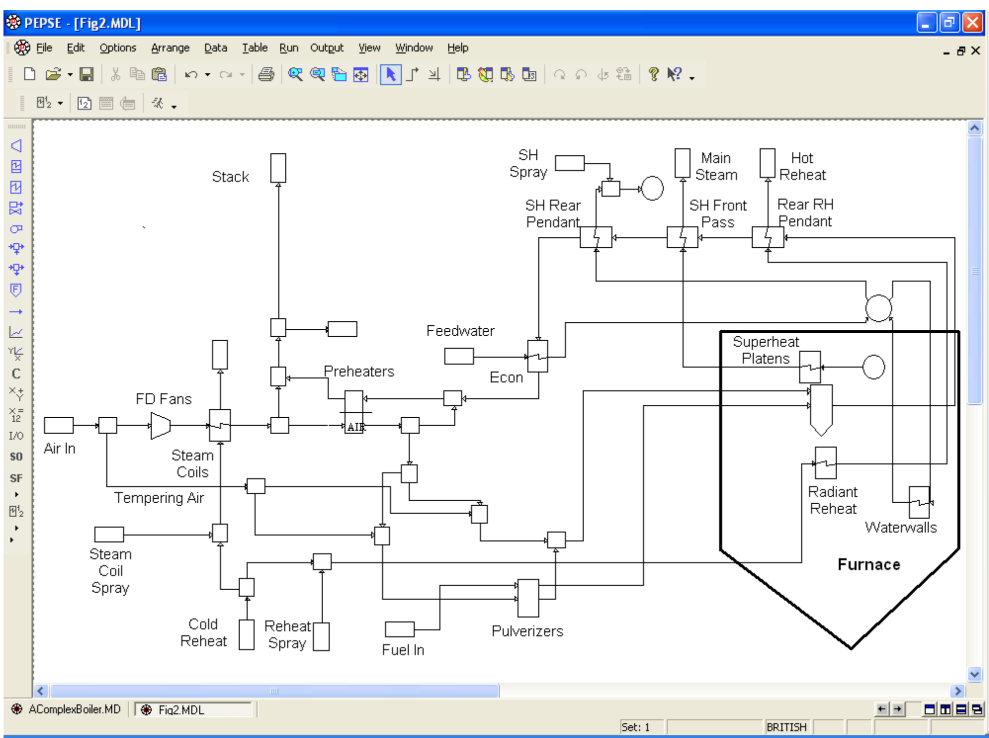

Figure 2 – PEPSE Boiler Model

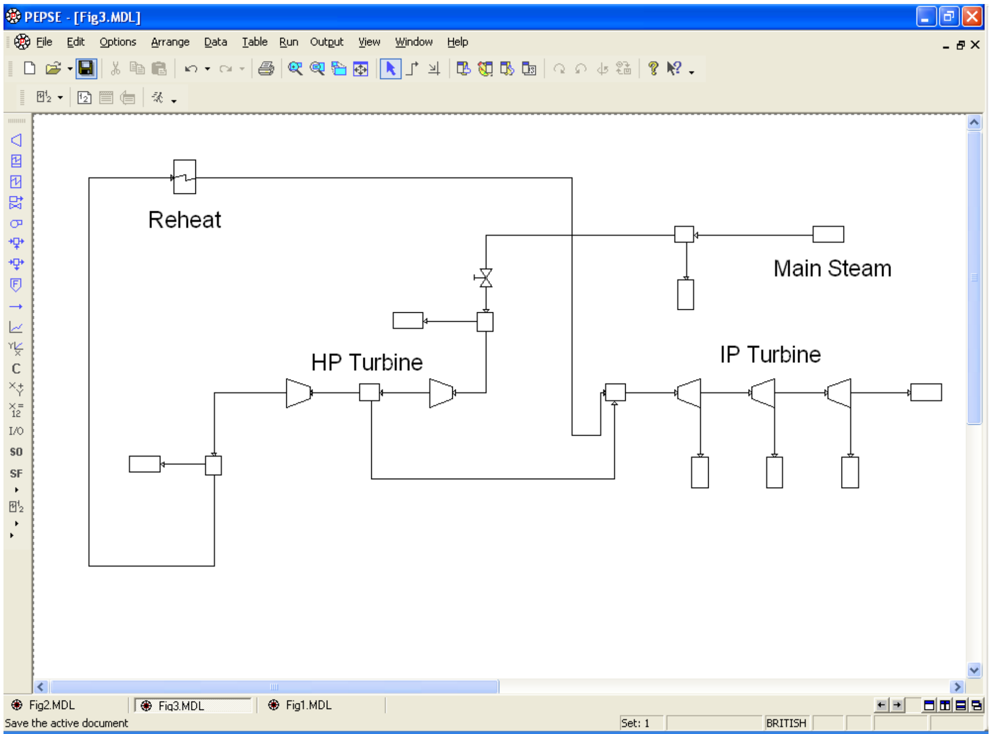

Figure 3 - HP/IP PEPSE Submodel

The Results

Results of the PEPSE analysis showed that the replacement turbines for both OEM's behaved as proposed. However, the new turbines removed much more energy from the steam than the original turbines, thus energy-starving the LP turbine. This caused the LP turbine output to decrease. The net effect for both OEM's compared to current plant operation was an increase in the HP and IP generation of about 11 MW, but a decrease in the LP generation of about 5 MW, giving a net increase of about 6 MW. These results, showing such a small net increase in the total plant output, caused the turbine replacement project to look much less attractive than originally planned. Results are summarized in Table 1, columns B and C for the two turbine manufacturers compared to current operation, column A.

Table 1 – Comparison of Vendor Results with Current Operation

	A	B	C
	Current Operation	**OEM-1**	**OEM-2**
HP Turbine Power, MW	86.2	92.6	93.8
IP Turbine Power, MW	78.8	82.8	82.3
LP turbine Power, MW	146.0	141.5	141.0
Total Gross Generation*, MW	306.5	312.4	312.6
Plant Heat Rate, BTU/kW-hr	9104	8935	8930

* After Generator Losses

But More. . . .

In an attempt to keep the turbine replacement project alive, various boiler modifications were suggested by the utility and then investigated using PEPSE. The most practical of these was increasing the surface area of some of the boiler sections. This would possibly allow more energy transfer from the boiler to the turbine cycle through main steam and reheat, potentially making up for the energy lost going to the LP turbine. The PEPSE model was again used, this time to investigate increases in boiler superheat (both primary and secondary), reheat, and economizer surface along with the turbine replacement. This involved adding additional rows of tubes to these boiler sections in the PEPSE boiler model. Additions of 5% to 25% were investigated. As a practical matter, an increase of 25% is virtually impossible due to space limitations in the boiler backpass. A practical limit of 10% was considered more realistic and was used as the basis for comparisons. Each boiler section's tube row increase was analyzed separately, i.e., no two sections were increased at the same time.

Two separate versions of the boiler tube row increase analysis were performed. The first was with no superheat or reheat temperature control, i.e., the fuel flow remained constant at its current plant operating value at 100% load. Secondly, the fuel flow was adjusted to maintain temperature control at the original design values of 1050 ^{o}F main steam temperature and 1000^{o}F reheat temperature.

The results of this boiler surface PEPSE analysis using the new turbines showed very small increases in generation over that with just the new turbines alone, about 1 MW or less. The results with no temperature control are presented in Table 2 (OEM-1) and Table 3 (OEM-2). Those results with temperature control appear in Table 4 (OEM-1 only). Results with temperature control for OEM-2 show about the same differences when compared with OEM-1 as they did with no temperature control, and therefore will not be presented here.

Table 2 – Results with Boiler Surface Increases, No Temperature Control, OEM-1

	A	B	C	D	E
	OEM-1 Only	**OEM-1 RH+10%**	**OEM-1 SSH+10%**	**OEM-1 PSH+10%**	**OEM-1 Econ+10%**
HP Turbine Power, MW	92.6	91.8	92.8	93.3	93.0
IP Turbine Power, MW	82.8	83.0	82.7	82.9	83.0
LP turbine Power, MW	141.5	141.9	141.4	141.7	141.9
Total Gross Generation*, MW	312.4	312.1	312.4	313.2	313.3
Plant Heat Rate, BTU/kW-hr	8935	8941	8934	8911	8907

*After Generator Losses

RH = reheat, SSH = secondary superheat, PSH = primary superheat, Econ = economizer

Table 3 – Results with Boiler Surface Increases, No Temperature Control, OEM-2

	A	B	C	D	E
	OEM-2 Only	**OEM-2 RH+10%**	**OEM-2 SSH+10%**	**OEM-2 PSH+10%**	**OEM-2 Econ+10%**
HP Turbine Power, MW	93.8	93.0	94.0	94.5	94.2
IP Turbine Power, MW	82.3	82.6	82.3	82.5	82.6
LP turbine Power, MW	141.0	141.5	141.0	141.3	141.5
Total Gross Generation*, MW	312.6	312.6	312.8	313.7	313.7
Plant Heat Rate, BTU/kW-hr	8930	8929	8921	8900	8896

*After Generator Losses

RH = reheat, SSH = secondary superheat, PSH = primary superheat, Econ = economizer

Table 4 – Results with Boiler Surface Increases, Temperature Control, OEM-1

	A	B	C	D	E
	OEM-1 Only	**OEM-1 RH+10%**	**OEM-1 SSH+10%**	**OEM-1 PSH+10%**	**OEM-1 Econ+10%**
HP Turbine Power, MW	93.4	93.5	93.8	93.5	93.8
IP Turbine Power, MW	84.1	84.3	84.1	84.1	84.1
LP turbine Power, MW	143.6	143.9	143.6	143.7	143.7
Total Gross Generation*, MW	316.4	317.0	316.8	316.7	316.9
Plant Heat Rate, BTU/kW-hr	8910	8897	8897	8898	8890

*After Generator Losses
RH = reheat, SSH = secondary superheat, PSH = primary superheat, Econ = economizer

<u>And More. . . .</u>

The results of the boiler surface area study were inconclusive relative to whether the turbine replacement was feasible. So, one more analysis was performed with the PEPSE model, this time looking at rebuilt HP and IP turbines rather than new turbines. Rebuilt turbines represent a lower cost/lower return alternative when compared to new turbines.

Turbine performance characteristics based on the utility's best estimate of rebuilt turbines (83.5% efficiency for the HP turbine, 90% efficiency for the IP turbine) were used in the PEPSE model. Just using rebuilt turbines (no boiler surface changes), the PEPSE model results showed that the HP and IP output, collectively, increased by about 4 MW and the LP output decreased by about 2 MW, for a net output gain of about 2 MW. These results are shown in Table 5, column B along side current operation, column A.

Finally, this PEPSE analysis continued using these rebuilt turbines and including temperature control to the original design values of 1050 ^{o}F main steam temperature and 1000^{o}F reheat temperature. These results are presented in Table 5, column C.

The Decision

With all the performance numbers in, and all the feasible scenarios analyzed, what is left is to put dollars to the numbers to determine the best cost/benefit. Looking at upfront costs, replacing the HP and IP turbines is about $12 million. Rebuilding the turbines instead of replacing them is about $1.5 million. Doing nothing is $0. But what about later? The paybacks are reversed, with the new turbines paying back the most, doing nothing the least, and the rebuild somewhere in the middle.

The utilities decision, after careful and detailed analysis, is to rebuild the turbines during the next major outage. No additional boiler surface will be added.

Table 5 – Comparison of Rebuilt HP/IP Turbines with Current Operation

	A	B	C
	Current Operation	**Rebuilt HP/IP No Temp Control**	**Rebuilt HP/IP Temp Control**
HP Turbine Power, MW	86.2	89.3	90.3
IP Turbine Power, MW	78.8	79.8	81.1
LP turbine Power, MW	146.0	144.1	146.3
Total Gross Generation*, MW	306.5	308.7	313.1
Plant Heat Rate, BTU/kW-hr	9104	9042	9004

* After Generator Losses