Mossyrock Powerhouse Upgrade Optimization

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ABSTRACT

Tacoma Power owns and operates two hydroelectric projects on the Cowlitz River in Western Washington: Mossyrock and Mayfield. The Mossyrock Project, which was commissioned in 1968, contains of two units, each rated at 150 MW, and contains a currently unused space for a third unit. Tacoma Power engaged Acres International Corporation (Acres) to perform a study evaluating the various upgrade opportunities for the project.

In order to capture the effect of the interaction of these two projects on the Cowlitz River, Acres used its AUTO Vista operations model to compare the revenue potential of the project under various upgrade scenarios over a 20-year hydrologic period. The economic model used for this study indicated a positive Net Present Value for several of the alternative configurations studied with a slight economic advantage to a scenario that included rebuilding both units with differing performance characteristics for purposes of achieving better efficiency over a wider range of output levels and heads.

Based on the results, Tacoma Power issued a Request for Proposals that allowed for selection of a combination of two units with identical performance characteristics, or a combination of two units with different performance characteristics.

Tacoma Power then requested Acres to expand the AUTO Vista model to consider their entire power system portfolio including their own generating facilities on two additional river systems, their contractual power resources, load serving obligations and the transmission system. It was theorized that the initial single river basin model would potentially understate the value of including two units with differing performance characteristics, and perhaps overestimate the value of capacity. The purpose of the expanded model was to account for the role of the Mossyrock project in providing reserves, load obligations, and the interaction of the project with other elements of the utility's power supply portfolio in the hour-by-hour system optimization as determined by AUTO Vista. The full portfolio model was then used to evaluate the proposals as submitted by turbine manufactures leading to the selection of the final configuration for the turbine upgrade program.

Introduction

The two hydroelectric projects owned and operated by Tacoma Power on the Cowlitz River include the Mossyrock and Mayfield developments. Mossyrock is the larger of the two, and is located upstream of Mayfield. The impoundment of Mossyrock Dam is Riffe Lake.

Mossyrock was commissioned in 1968 and includes a concrete arch dam with a gated spillway and short penstocks leading to a surface powerhouse as shown in **Figure 1**. The powerhouse contains two generating units (Unit 51 and Unit 52) each rated at 150 MW at 310

Figure 1. Mossyrock Project

feet of head. The powerhouse has a space for a third unit. This study comprised of an evaluation of the existing equipment and of various possible unit upgrade scenarios, including installation of a new, third unit.

Performance Characteristics

Upgrade of the existing units will include turbine runner replacements, major upgrades to the generators and replacement of other major ancillary equipment. To evaluate the benefits of possible turbine upgrades, the performance characteristics of the existing units were compared with improved turbine runners of new units, using the same historical flows and pricing schedules. Improved turbine runners have the potential to increase the hydraulic capacity for maximizing generation in high price periods, higher efficiency, or both.

The performance curves for the existing Units 51 and 52 modeled in the study were developed based on the original index test report, recent flowmeter measurements at the site, and model test results.

The efficiency curves for the two new units to be considered were based on model test results for similar Francis turbines installed recently on other projects. Efficiency curves for the upgraded units were developed by estimating the efficiency of a new unit, and then adjusting this efficiency to account for differences between the new, ideal unit and the actual upgraded unit.

Table 1 below summarizes the parameters of both the existing and upgraded new units that were considered. The parameters were chosen based on previous Tacoma Power studies, past generation profiles, and other scenarios based on potential plant configuration and operation. Of particular note, the Type A_0 and Type A_1 turbine runners have identical design parameters with regard to peak efficiency flow and output, but are designed for different net heads. The Type A_0 turbine runner simulates a unit with best efficiency point at the nameplate rating of 150 MW at a traditional wintertime operating elevation of 345 feet net head. The Type A_1 turbine runner design simulates a unit with best efficiency point at the nameplate rating of 150 MW at the traditional summertime operating elevation of 310 feet net head. Their pairing is considered in this analysis on the virtue of potentially achieving better efficiency over a wider range of operational output and head. The Type A_0 Unit parameters are identified in Table 1 on the basis of 310 feet net head for purposes of comparison.

Table 1. Summary of Unit Parameters

Unit Type	Peak Efficiency Flow	Peak Efficiency Output	Full Load Flow
Type E - Existing	6,000 cfs	150 MW	7,400 cfs
Upgrade of Existing Units 51 and 52			
Type A_0	5,200 cfs	125 MW	6,900 cfs
Type A_1	6,000 cfs	150 MW	7,400 cfs
Type B	6,900 cfs	205 MW	8,800 cfs
New Unit 53			
Type C	3,000 cfs	75 MW	4,000 cfs
Type D	6,800 cfs	210 MW	9,000 cfs

Table 1 Note: All Unit parameters are identified in Table1 on the basis of 310 feet net head.

Cost Estimates and Schedule
Acres developed cost estimates for upgrading the existing units and for installation of a new unit. These estimates were included in the economic analysis and form part of the basis for the risk analysis. Acres also developed a schedule for the upgrade of existing units and for installation of a new unit. The upgrade schedule includes a 26-week outage. The new unit installation schedule calls for eight months of installation preceded by 31 months of planning, design, bidding, and delivery.

Phase I AUTO *Vista* Analysis
AUTO *Vista* is a component of a computer model developed by Acres for optimizing dispatch of hydroelectric projects to maximize revenue using historical flows and projected prices. It considers operating characteristics, water, pricing, and constraints in its calculations. It is used as an analysis tool to evaluate the economic value of alternative project configurations and methods of operation.

The defining feature of the Phase I study in contrast to the Phase II study as discussed later herein is that the Phase I AUTO *Vista* model did not include Tacoma Power's other hydroelectric resources, power purchase agreements, load serving obligations, and spinning reserve requirements. Rather, the Phase I model simply included the Mossyrock / Mayfield system on the basis that all energy from the two facilities could be directly marketed to the region at prevailing market rates. The resulting graphical representation of the Phase I model is shown in **Figure 2**.

Tacoma Power provided average daily inflow data for 20 water years, and hourly prices for a period of one year based on projections for 2003. These prices were used to optimize the revenue and estimate the incremental generation benefit for each scenario.

Table 2 below describes the existing and eleven upgrade scenarios that were evaluated in the Phase I study.

Figure 2. Phase I AUTO Vista Model

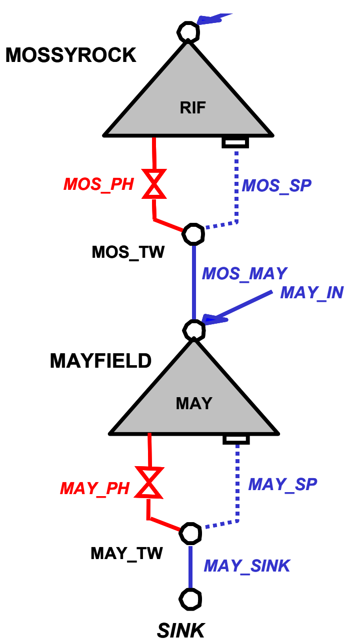


Table 2. Mossyrock Plant Upgrade Cases (Phase I)

Case	Unit Type		
	Unit 51	Unit 52	Unit 53
EEX	*Existing*	*Existing*	*None*
A_0A_0X	A_0	A_0	None
A_1A_1X	A_1	A_1	None
A_1A_0X	A_1	A_0	None
BBX	B	B	None
A_0BX	A_0	B	None
EEC	Existing	Existing	C
A_0EC	A_0	Existing	C
A_0A_0C	A_0	A_0	C
A_1EC	A_1	E	C
A_1A_0C	A_1	A_0	C
EED	Existing	Existing	D

Risk Analysis

In order to determine risk related costs and avoided operation and maintenance costs associated with each upgrade scenario, Acres utilized their HydroVantage Risk Analysis model. HydroVantage is an engineering decision support tool for optimizing interventions, including replacement, rehabilitation, and upgrade, of hydroelectric equipment. HydroVantage includes a consideration of the cost due to risk of failure from aging equipment in its calculation. This risk-cost is based on a database of historical failure probabilities as well as estimated consequence costs from a future failure.

HydroVantage uses the daily outage cost to compute the full cost of failures as well as planned interventions. Daily outage cost is based on the revenue from generation lost due to the failure. This lost revenue is calculated using AUTO *Vista*.

HydroVantage analyses were conducted for the following components:

- Turbine runners
- Generator stator windings
- Generator rotor poles
- Generator excitation system
- Generator step-up transformers

Phase I Economic Analysis

Tacoma Power then developed an economic analysis model to incorporate the results of the AUTO *Vista* analyses, cost estimates, and HydroVantage analyses, thereby bringing them together for each upgrade scenario analyzed. The total net present value for each scenario is the present value of the total incremental cost, including capital cost for implementation, incremental generation benefits, avoided risk, avoided O&M, and indirect costs such as tax and administration and engineering.

The resulting economic analyses clearly indicated that the BBX, A_0BX and EED upgrade scenarios did not provide sufficient promise to warrant further consideration. The net present values (NPVs) of the remaining cases as developed in the Phase I Study are summarized in **Table 3** below based on a 30-year NPV analysis.

Table 3. Summary of Present Value Analysis ($1,000)

	Upgrade							
	A_0A_0X	A_1A_0X	A_1A_1X	EEC	A_0EC	A_1EC	A_0A_0C	A_1A_0C
Thirty Year Analysis								
Benefits	34,947	37,144	36,197	26,237	42,224	40,263	55,322	48,073
Generation	13,354	16,277	14,603	19,350	28,630	27,070	35,457	29,031
Avoided Risk	17,337	16,741	17,337	9,916	14,576	13,722	18,925	17,772
Avoided O&M	4,257	4,127	4,257	(3,030)	(981)	(530)	941	1,271
SubTotal	34,947	37,144	36,197	26,237	42,224	40,263	55,322	48,073
Costs	29,589	29,223	29,589	30,809	43,740	42,398	56,305	54,609
Construction	19,165	18,908	19,165	21,640	30,723	29,780	39,549	38,357
Indirect	10,424	10,315	10,424	9,169	13,017	12,618	16,757	16,252
SubTotal	29,589	29,223	29,589	30,809	43,740	42,398	56,305	54,609
Net Benefit								
TOTAL	**5,358**	**7,921**	**6,608**	**(4,572)**	**(1,516)**	**(2,135)**	**(983)**	**(6,535)**

Phase I Conclusions
The results of the Phase 1 Analysis, illustrated in the above table, demonstrated the following:

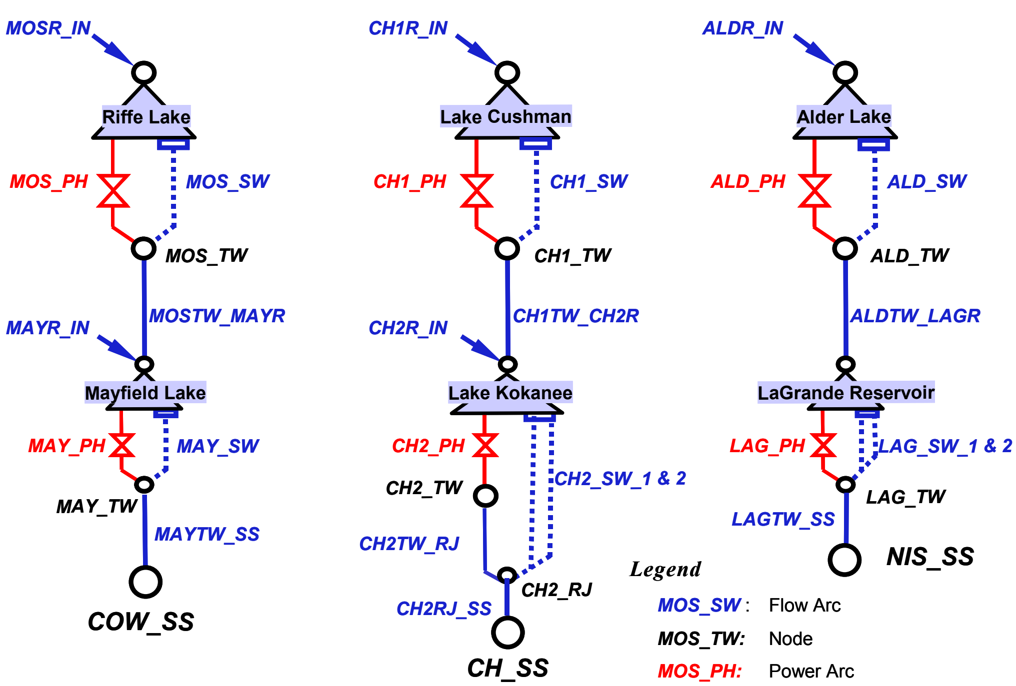
- Upgrade cases A_0A_0X, A_1A_0X and A_1A_1X all show positive NPV's over a thirty-year term of analysis.
- Upgrade case A_1A_0X would provide a slightly higher NPV than A_0A_0X, or A_1A_1X due to greater flexibility in responding to flow and price signals over the period of operation.
- While those cases including the addition of a smaller third unit all would provide higher annual energy and revenue benefits, the NPVs thereof are all lower than those without the third unit owing to the higher capital costs associated therewith.
- Those cases including the addition of a smaller third unit would benefit from the lower peak efficiency flow as provided by the Type A_0 unit for Units 51 and 52.

Phase I Recommendations
Based on the results of the Phase I upgrade studies for the Mossyrock Powerhouse as summarized above, Tacoma Power has implemented Acres recommendations as follows:

1. Consideration of specification of two units with different performance characteristics for any upgrade program that only includes the existing Units 51 and 52.
2. Expansion of the existing AUTO *Vista* model to include the balance of Tacoma Power's resource portfolio in combination with projected load and reserve requirements to test the effect of these considerations on the final selection of an upgrade program.

Phase II AUTO Vista Analysis
Following receipt of proposals from five equipment manufacturers for the Mossyrock Project rebuild, a comprehensive AUTO Vista model was developed to include all generating and

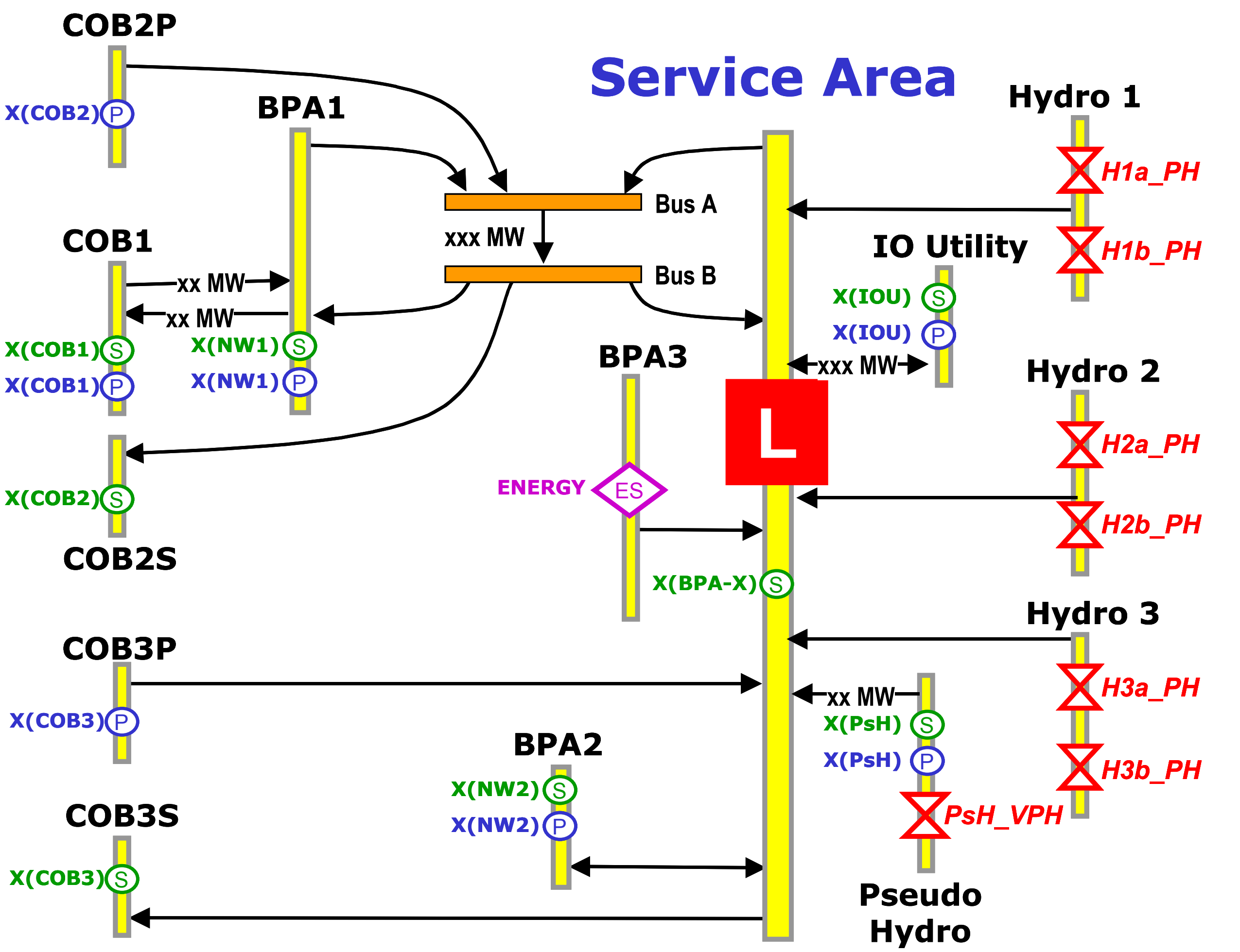
Figure 3. Phase II AUTO Vista Hydro System Model



contractual resources available to meet Tacoma Power's system load. Accordingly, the hydropower system included Tacoma Power's other hydroelectric projects, the Nisqually and Cushman projects in addition to the Cowlitz Project. Both of these river systems are similar in configuration to the Mossyrock / Mayfield system in that each includes an upstream storage reservoir coupled with a smaller downstream re-regulating reservoir and a powerhouse that is associated with each reservoir. The graphical representation of this hydropower system as modeled within AUTO *Vista* is shown above in **Figure 3**.

In addition, the Phase II model includes a complete representation of the transmission system in order to account for the costs and other provisions associated with existing transmission contracts. A simplified version of the resulting bus diagram is shown below in **Figure 4**. The diagram depicts the location of each aspect of Tacoma Power's portfolio including its hydroelectric projects, contractual resources, load service obligations (L) and wholesale market opportunities.

Figure 4. Phase II AUTO Vista System Bus Configuration



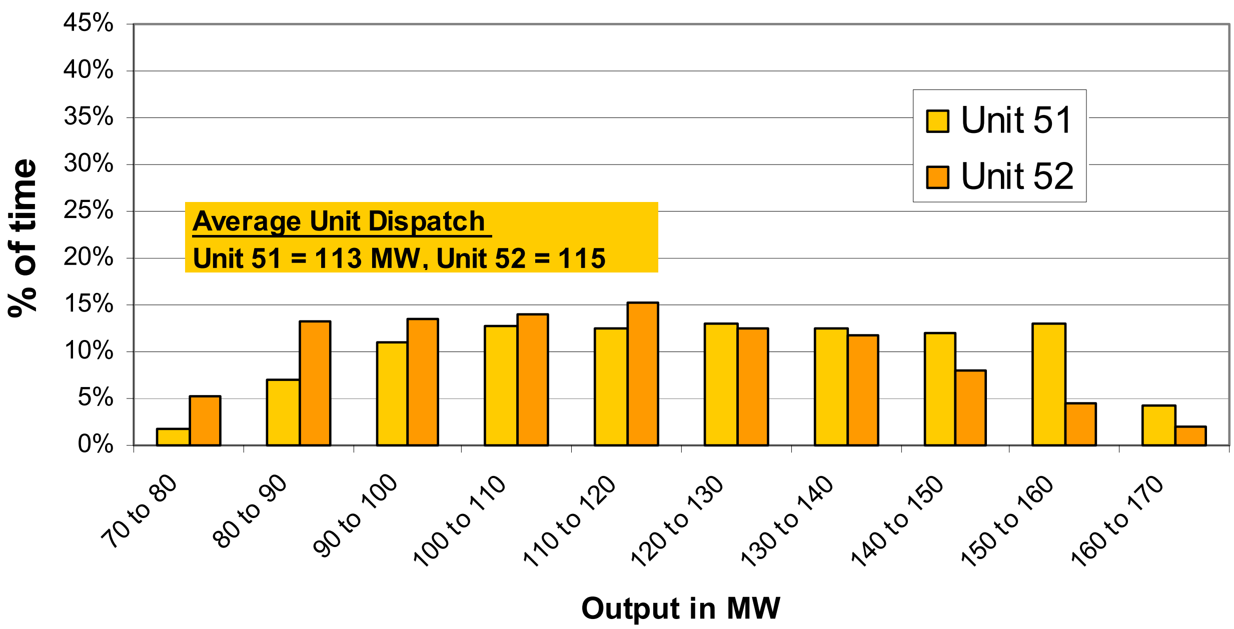
The principal reason for consideration for the expansion of the AUTO *Vista* model as defined by Figures 3 and 4 above is that the Phase I model did not provide for operation of the Mossyrock project as a resource used to supply system reserves or load service. As a result, the Phase I AUTO *Vista* model dispatched the units at their peak efficiency point much more often than observed in practice. Accordingly, the purpose of the Phase II model was to evaluate the benefits of unit upgrades as proposed by equipment manufacturers on the basis of a more realistic unit dispatch for the Mossyrock facility. The comparative results of the two modeling approaches are discussed below.

Comparison of Phase I and Phase II Results

In order to ensure confidence with the results of an Auto *Vista* analysis, it is imperative that the operations model realistically simulate the dispatch of the power supply portfolio. For this reason, careful examination was made of the plant dispatch output from both the Phase I and Phase II analyses. As discussed above, the Auto *Vista* operations model used for Phase 1 of the analysis only included the Mossyrock / Mayfield system, and did not include the balance of Tacoma Power's power supply portfolio, or obligations such as spinning reserves and load service. Tacoma Power theorized that because of this, the model's dispatch of the Mossyrock plant might be unrealistic.

Examination of the historical record for the actual plant dispatch over a sample period, as shown in **Figure 5**, confirmed this theory, and introduced a question as to whether such unrealistic dispatch might bias the results of the study.

Figure 5. Historical Hourly Plant Dispatch



Figures 6 and 7 compare examples of unit dispatch from the Mossyrock plant, including dispatch from the Phase I results and Phase II results. As illustrated, Phase I dispatch tended to be concentrated between 140 and 170 MW. This range generally represents the best efficiency of the units amongst the range of head in which they operate. This concentration represents Vista's capability to maximize the output of the plant in a relatively unconstrained world – where load service and reserves are not required, and all output is optimally shaped and sold into an hourly market. In turn, there was a concern that this unrealistic dispatch may cause overestimation of the value of capacity and underestimation of the value associated with the flexibility of having two units with differing performance characteristics (offering better efficiency over a wider range of output and head). In the Phase II analysis, which more realistically modeled load and reserve constraints, optimal dispatch is much more representative of historical dispatch.

Figure 6. Phase I Hourly Plant Dispatch

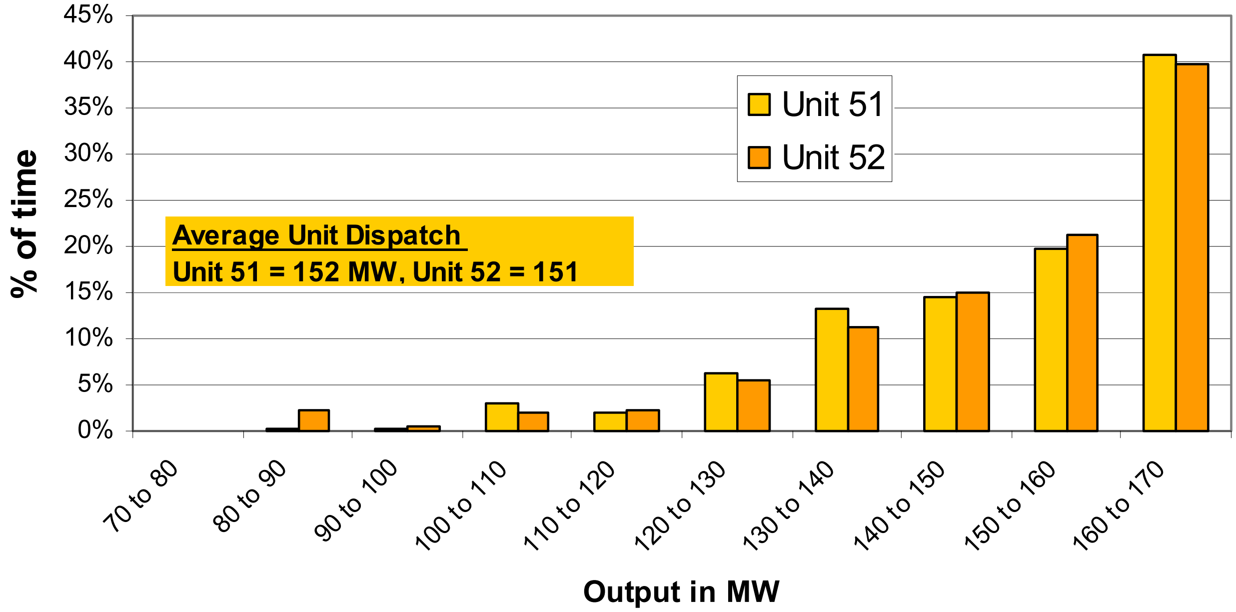
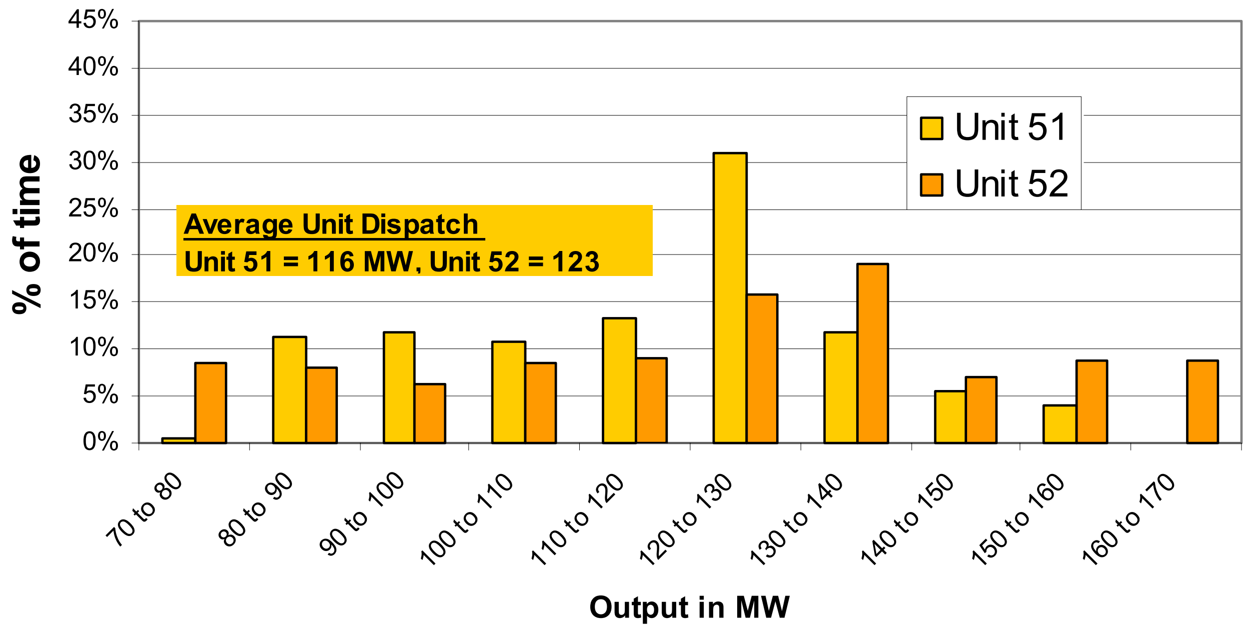


Figure 7. Phase II Hourly Plant Dispatch



Following the review of the respective dispatch characteristics of the Phase I and Phase II studies, Tacoma Power performed NPV calculations based on the Phase II results. The calculations confirmed the incremental value of the A_1A_0X over both the A_0A_0X, and A_1A_1X configurations. At the time of this writing, Tacoma Power is in final contract negotiations with potential equipment suppliers for the Mossyrock upgrade program. Preliminary indications are that the incremental power benefits of the A_1A_0X scenario will overcome any incremental cost thereof.

Phase II Conclusions
The conclusions of the Phase I analysis identified a preferred upgrade scenario for the Mossyrock plant. However, due to unrealistic dispatch of the plant in the Phase I model simulation, confidence in the results was inadequate. Expansion of the AUTO *Vista* model to include the balance of Tacoma Power's resource portfolio in combination with projected load and reserve requirements (Phase II model) produced a realistic simulation of the power supply portfolio, and substantially increase confidence in the results.

In summary, the Phase II studies of the Mossyrock Unit Upgrade demonstrate the following:

- The expanded AUTO *Vista* full resource portfolio model (Phase II) provided a robust, real-world review of the upgrade scenarios for the Mossyrock project that realistically simulate the operation of Tacoma Power's power supply portfolio.
- Upgrade case A_1A_0X, the scenario that includes rebuilding the two Mossyrock units with differing performance characteristics, continues to show a positive NPV over a thirty-year term of analysis.
- Upgrade case A_1A_0X continues to show a greater NPV as compared to upgrade case A_1A_1X, the scenario that includes rebuilding the two Mossyrock units with identical performance characteristics, and therefore is deemed to be the preferred upgrade scenario.

References:

Authors

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