WHAKAMARU POWER STATION REHABILITATION PROJECT

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ABSTRACT

Whakamaru Power Station in the North Island of New Zealand is one of nine hydro power stations on the Waikato River owned and operated by Mercury NZ Ltd (formerly Mighty River Power). Whakamaru consists of four vertical Francis turbine units that were originally commissioned in 1956 and since then only one of the four units has been completely disassembled and refurbished, Unit 1 in 2010. The Whakamaru station is now at a stage in its life cycle where the generators are experiencing end of life stator winding failures and require replacement. The turbines are nearing end of life, are well worn and require refurbishment as a minimum, however replacement with new equipment offers a significant output and efficiency uprate opportunity. The governor equipment is the original Woodward mechanical governor equipment and replacement is required to match the uprated turbines. The project to replace generator, turbine and governor equipment was initiated in August 2011, equipment supply contracts commenced with Alstom (now GE) and Andritz Hydro in August 2013. The first machine outage began in October 2016 and is due to be returned to service in May 2017 with rehabilitated generator, turbine and governor equipment.

This paper provides an overview of how the project was developed to replace the aging assets and maximise the benefits of modern hydro equipment to Mercury. With Whakamaru being the fourth of nine hydro stations in the Waikato hydro system it has traditionally been a bottle neck station, the turbine uprate provided the opportunity to reconfigure the station to suit the desired future operating characteristics. The paper will also outline the unique features of the project through the planning and procurement stages, key lessons learned and an overview of the turbine and generator performance achieved on the first machine due to be returned to service in May 2017.

Figure 1: Whakamaru Power Station, New Zealand

1. INTRODUCTION

Whakamaru Power Station is located in the North Island of New Zealand and is the fourth of nine hydro power stations on the Waikato River owned and operated by Mercury NZ Limited. Whakamaru Power Station has four 26.1 MW Francis turbines designed and built by Dominion Engineering and 27.8 MVA generators designed and built by Metropolitan Vickers. The Whakamaru station was fully commissioned in June 1956 and only one machine (Unit 1 in 2010) has had a major overhaul since. ***Figure 2*** shows the location of Whakamaru Power Station in the North Island of New Zealand and its position along the Waikato River.

Figure 2: Whakamaru Power Station Location

The Whakamaru generators began to suffer from end of life failures, mainly stator winding failures and rotor earth faults. Dissection of a failed stator winding revealed the extremely poor state of the strand insulation and confirmed that replacement was required in order to reduce breakdown risk. The turbine runners still had some remaining life left but following their 60 years of operation the turbines were generally well worn and required at least an overhaul like Unit 1 received in 2010. At a minimum the project scope would include generator replacement work and refurbishment of the existing turbine equipment. This led to the consideration of varying options for the project scope and an opportunity to reconfigure the flow and output of the Whakamaru Power Station.

2. PROJECT BACKGROUND AND DEVELOPMENT

With major work required to replace the generator equipment and then refurbish the remainder of the machines back to as near to original condition as possible, many options were available for consideration. With the turbine equipment still holding some remaining life left, this led to the analysis of two main options for the project scope:

- Option 1 – Risk Reduction; and
- Option 2 – Uprate.

The Risk Reduction scope of work included the generator replacement works to reduce the plant breakdown risk and to disassemble and refurbish the turbine and governor equipment to bring it back to near new condition. This option didn't include any performance uprate; focussing on reducing plant breakdown risk and hence was assessed as a Net Present Value (NPV) negative project.

The Uprate option took advantage of the units already being disassembled to complete the generator replacement and other refurbishment work and added in replacement of turbine and governor equipment to uprate the performance of the units. This option reduced the overall outage time required over the long term and removed the need for a second round of disassembly and reassembly (at the end of turbine life) and the associated costs. Earlier replacement of turbine equipment also bought forward the additional generation and revenue benefit for Mercury. A further benefit, not always as obvious, is that by replacing turbine and governor equipment, a greater percentage of the original equipment could simply be disposed of rather than spending large amounts of time and money to refurbish it, removing or significantly reducing some large risks during the outage works. Mercury's experience in the previous decade refurbishing equipment back to as near to new condition as possible was often met with challenges and in some cases complete replacement would have been only incrementally more expensive but would have reduced outage time and the equipment would have been new.

Option 2 - Uprate generates an estimated 28 GWh per annum additional generation through an approximate 20 MW station capacity increase and increase in efficiency. This uprate opportunity was NPV positive but was sensitive to the electricity price moving forward. Demand has remained flat for several years in New Zealand and at the time project approval was being sought, there was also uncertainty over possible reform of the electricity market. That risk didn't materialise and even with a flat electricity price project Option 2 - Uprate was still a valid investment for the company and was selected.

Existing Constraints and Project Benefits

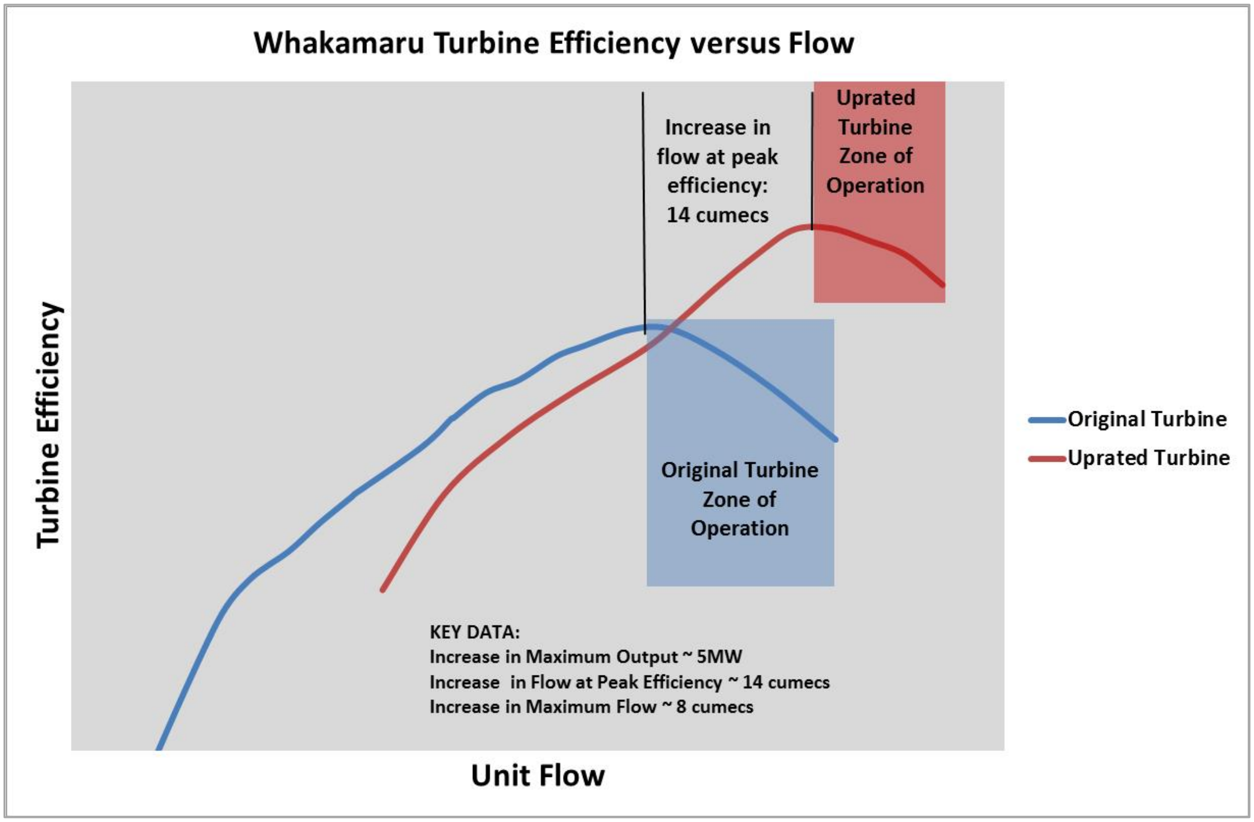
By selecting project Option 2 – Uprate, the opportunity also allowed for some reconfiguration of the power station to be made. Whakamaru has a lower flow capacity than the stations upstream and downstream of it, meaning it is one of the least flexible stations for Mercury to operate and maintain. The units have a high utilisation and typically run between their peak efficiency point and maximum continuous rating. ***Table 1*** shows Whakamaru relative to the two upstream and two downstream stations in both the original configuration and the configuration at the end of the project.

Table 1: Summary of Station Flow Capacities.

STATION	NO. OF UNITS	MAXIMUM FLOW (m^3/s)	ADDITIONAL DATA
Ohakuri	4	403	Turbines re-runnered 2011-2014
Atiamuri	4	392	Original equipment
Whakamaru (Original)	**4**	**344**	**Original equipment**
Whakamaru (Uprated)	**4**	**376 (increase of 32 m^3/s)**	**Additional 28 GWh p.a. station generation**
Maraetai	10 (Two power houses with 5 units each)	720	Original equipment
Waipapa	3	357	Original equipment

During the early feasibility and planning stages of the project, a Registration of Interest process was run where expected uprated performance figures were submitted by potential suppliers. Using in house resource, the expected performance curves were run through Mercury's Waikato hydro system model to determine the best configuration for the Whakamaru units. The selected option sees the turbine flow at peak efficiency increased by 14 m^3/s, the peak turbine flow increased by 8 m^3/s, the turbine output increased by approximately 5 MW and an efficiency increase. ***Figure 3*** shows the original and uprated turbine curves and outlines the key differences.

Figure 3: Whakamaru Turbine Original vs. Uprated Comparison



Planning and Procurement

As the Whakamaru project was being evaluated and beginning to be developed into a live project, Mercury was fortunate to have some major rehabilitation projects already in progress, providing experience to help shape the delivery of Whakamaru. At Arapuni Power Station four generators were being replaced using a design, build and install model. At Ohakuri a turbine rehabilitation project[1] was in progress using a design, build and supervise model. Adding in the governor replacement created a project larger in scale than the two projects in progress by Mercury at the time. The project was split into three manageable phases:

- Phase 1 – Feasibility and Planning;
- Phase 2 – Design, Testing, Manufacture, Delivery and Site Works Planning; and
- Phase 3 – Installation and Overhaul Work.

Due to the knowledge and experience Mercury had at the time and the need to evaluate all project scope options, Phase 1 of the project was created specifically to work through this with an appropriate allocation of time. This also allowed planning of the remainder of the project to take place with the benefit of building on the lessons learned from

[1] Refer to HydroVision 2012 paper by Glen Twining.

recent projects. This phase of the project had dedicated funding for two years and included activities such as feasibility studies on the uprating of the units, a registration of interest process to select a shortlist of suppliers, development of the main equipment supply contracts and tendering for those contracts.

With the generator plant breakdown risk high, the replacement generators needed to meet all minimum technical and performance requirements set by Mercury and the relevant regulations in New Zealand, and have the ability to be operated and maintained throughout their life cycle by Mercury and their maintenance contractor (rather than having to use the original equipment manufacturer). For the turbine, to ensure that the project benefits were realised, the turbine that offered the best increase in annual generation was preferred. For governor equipment, all minimum technical and performance requirements set by Mercury and the relevant regulations in New Zealand needed to be met.

In parallel with the evaluation of equipment supply tenders, a business case for the second and third phases of the project was being prepared with actual performance and cost data from suppliers. This enabled Mercury to present a business case with guaranteed performance data and certainty of price for the equipment supply. Full approval for the generator equipment supply and installation part of the project (the Option 1 scope described above) was requested at this stage. For the Option 2 part of the project, approval only up to the completion of turbine model testing was requested. This was done to include a final decision point in the project prior to fully committing to the full uprate scope of the project. A special termination window was written into the turbine equipment supply contract so that there was the option to cancel following completion of the turbine model test should there be a failure to meet the contracted performance guarantees.

Phase 2 of the project began with the signing of equipment supply contracts for turbine and generator equipment. Phases 1 and 2 were run in series. Phase 3 of the project is overlapped with Phase 2 as the installation work started once the first set of new equipment had arrived on site.

3. SUMMARY OF THE PROJECT SCOPE

Generator

The generator work includes complete replacement of the stators, replacement of rotor poles, relocation and rebuilding of the slip rings and replacement of the rotor leads system. Interfacing a new through shaft turbine air admission system into the machine resulted in a rotor lead system not seen before by the Mercury team. This presented additional challenges for implementing the refurbishment work on the generator to accept the new parts.

Figure 4: New Stator Installation and Refurbished Rotor for Unit 3

Turbine

The turbine work includes the replacement of the headcover, bottom ring, turbine runner, wicket gates and shaft seals. A through shaft air admission system was designed and installed. All original bearings were retained, including the thrust bearing.

Figure 5: New Turbine and Governor Components for Unit 3

Governor

The governor work is a complete replacement of the old Woodward mechanical governor and hydraulics with a modern high pressure digital governor.

Balance of Plant Scope

Various refurbishment or upgrade work is being completed on the remaining parts of the unit from water to wire. The top intake screen panels are being strengthened, the intake gate lifting gear is being refurbished, the intake gates are having seals replaced and other minor repair work. The embedded intake gate frames are being abrasive blasted and painted where required, along with patch painting of the upper and lower sections of the penstock, scroll case and draft tube. A separate but integrated project involves installing new three phase transformers with increased capacity to suit the uprated machines.

4. PROJECT SUCCESSES AND LESSONS LEARNED

There have been many successes and lessons learned in the project to date, a sample of the higher level but key examples have been selected and discussed.

Manufacturing Locations and Factory Inspections

For the Whakamaru project significant effort was put into evaluating the options presented in order to protect the long-term value of the project to Mercury. Manufacturing locations were evaluated specifically for the equipment that was proposed to be manufactured at that location, considering the risks involved in each piece of equipment. For example, a high level of importance was placed on the welding process for the manufacturing of the turbine runners to provide confidence that the new turbine runners would last at least as long as the equipment they are replacing, and considering the high cost to perform in-situ repairs or replace the item earlier than expected. Following a desktop analysis and reference checking process, the project team visited manufacturing locations in China and Europe, generally the higher cost or premium manufacturing option was selected for this project. This experience again reinforced previous lessons learned that every manufacturing facility (including subcontractors) needs to be considered as there are no guarantees of good quality solely based on what country or part of the world equipment is manufactured in. It is also worth pointing out that the capability, skill and experience of manufacturing locations can change rapidly, therefore historical knowledge cannot always be relied on. Once a location is selected, an appropriate quality inspection program is required to check the key steps along the way, ensure any identified risks are well managed in order for the right level of product quality to be achieved and the project benefits to be protected.

Design Review Process

The turbine and generator equipment supply contracts were both signed in August 2013 and work on the design continued through to mid-2014. A key lesson from Mercury's previous projects and from other generation companies was to implement a robust design review process. So often in a project the early stages of planning and procurement take longer than expected for various reasons, however due to the desire to maintain overall completion dates the additional time is usually cut from the design and manufacturing schedule. This forces the project into a reduced design duration and overlaps the design and manufacture stages of the procurement, significantly increasing the risk in the project. It can be an easy trap to fall into at the time as there are usually a large number of minor things that continue to put pressure on the project schedule. The Whakamaru project was planned with significantly more time for the design period and due to the way the project approvals were setup, the manufacturing was placed in series with design (not overlapping). While it is common to use many different standards for the technical aspects of a project and even standards for project management, standards for running a design process appear to be less common. To ensure a process was in place and to provide evidence of good practice to the project governance groups, the project team chose IEC 61160 Design Review as a basis for a design review process. Allowing adequate time, using an international standard and being disciplined in adhering to the process were key items to ensure that the equipment on its own would meet the requirements and that equipment from the different suppliers would interface together successfully during the installation phase. Additionally, while starting out with a robust process in the beginning is the right approach, some changes along the way are required meaning it is also important to be able to apply it to individual items that may be done outside the main design process.

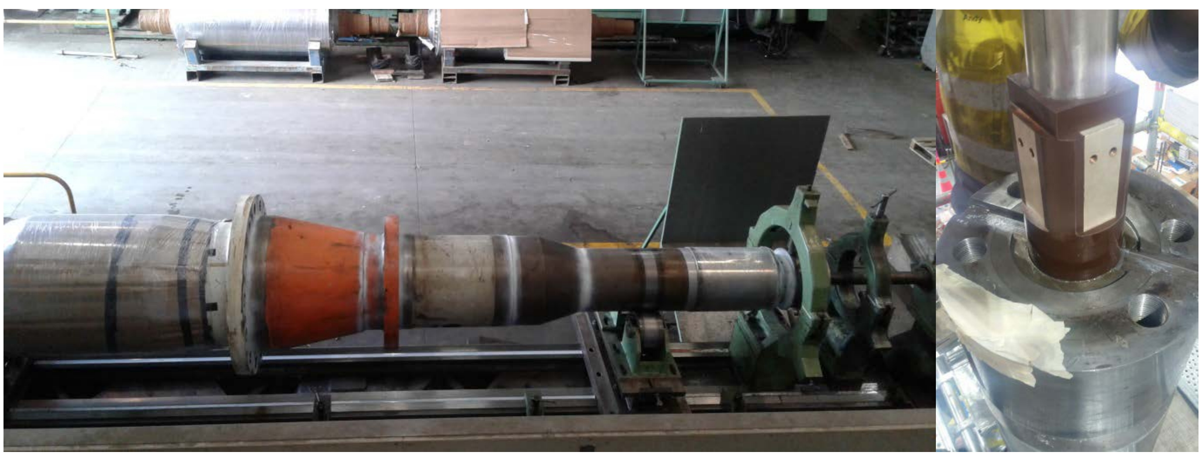
With the above in place there were still lessons learned for the overall design review process. For future projects Mercury would include a stronger constructability review at the appropriate stages of the design to ensure that all planned work can be done successfully using the locally available resources. At the design stage it can be difficult for the project team to shift from a design review of individual items of equipment to a detailed constructability analysis. Bringing together a team with experience and expertise in building hydro machines, including detailed knowledge of assembly procedures, operations, maintenance, offsite machining experts and other relevant members would add significant value to the project by reducing constructability risks.

Risk Management

Having a pragmatic and robust risk management plan in place for the project was critical for the success of the project to date given the scale, complexity and amount of interfacing to existing equipment required. The most obvious risk at a high level was not meeting the project benefits, so to provide certainty before committing to the full scope of the project a multi staged approached was taken as outlined above.

There were also some technical challenges identified in the site works where a failure to execute correctly would have a large impact on project time and cost, and significant business interruption given the nature of Whakamaru in the hydro scheme. Increasing the diameter of the generator shaft bore over approximately half its length for the new rotor leads shaft connection sleeve assembly provided a technical challenge for the installation contractor and their subcontractor. Mercury considered this work a risk to time and cost and together with the installation contractor a trial was completed to fully develop the machining procedure and fine tune tooling and feed rates to meet the tolerances required for the new equipment. This piece of risk management work demonstrated its value as the work on the actual generator shaft was completed in eight days and the shaft was installed back into the rotor ahead of schedule for the rotor refurbishment works to be completed by the generator equipment supply contractor. The installation of the new rotor leads shaft connection sleeve was completed as shown in the right hand side of ***Figure 6:*** Generator Shaft Boring (Left), Post-Modification with Shaft Connection Sleeve (Right).

Figure 6: Generator Shaft Boring (Left), Post-Modification with Shaft Connection Sleeve (Right)



5. UPRATED MACHINE PERFORMANCE

With commissioning of the first rehabilitated unit scheduled to begin in late April 2017 and performance testing of the new equipment scheduled to be completed at the end of May 2017, performance test results were not available to include in this paper.

Figure 7: Mercury and MB Century (Installation Contractor) Teams on Whakamaru Unit 3 – April 2017

AUTHOR SUMMARY

Glen Twining is a degree qualified Mechanical Engineer and PMP certified Project Manager with fifteen years' experience in the power generation industry. The majority of his experience is as a Project Manager setting up and running major capital refurbishment and rehabilitation projects of hydro equipment.

About Mercury NZ Ltd

Mercury is an electricity retailer and generator that provides energy services to homes, businesses and industrial customers throughout New Zealand.

We have a long heritage in renewable energy in New Zealand serving homes and businesses under the Mercury brand and other specialty brands, including the leading prepay service GLOBUG. We also have proven capability and technical expertise in smart metering services, solar and off-grid solutions.

Our electricity generation is from renewable sources. Hydro and geothermal power stations operated by Mercury generate renewable electricity sufficient for 850,000 New Zealand homes. To achieve energy freedom for New Zealand through the electrification of transport, we encourage the adoption of electric vehicles (EVs) and electric bikes (e.bikes) and partnering on non-home charging infrastructure and data.

Our goal is to be the leading energy brand in New Zealand, by delivering value, innovation and wonderful experiences..

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