HARDY UNIT NO. 3 TURBINE REHABILITATION

BY

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The 1931 vintage Consumers Energy's Hardy Hydroelectric Project is located on the Muskegon River in west central Michigan approximately 40 miles north of Grand Rapids Michigan. The Hardy station consists of three original identical 10 MW vertical Francis turbines with 99 ft design heads and flows of approximately 1,300 cfs and 1,500 cfs for peak efficiency and maximum discharge respectively. The long reliable performance of these turbines is reflected in that all of these turbines were original equipment with none of them having been disassembled since their 1931 commissioning.

This station has a substantial 134,000 acre-foot reservoir that is utilized for peaking operation of Hardy and to supply the nearby 9 MW Croton station that is approximately 7 miles downstream and operates to provide re-regulated flow to the lower Muskegon River. Because the average annual 1,442 cfs unregulated flow into the Hardy reservoir is only approximately 1/3 of the station's total plant 4,620 cfs capacity, the three turbines are typically operated at maximum efficiency during day time peak demand periods, with the length of operation and number of turbines adjusted to release the available river flow and maintain the required FERC license headpond levels.

DISSOLVED OXYGEN CONCERNS

The Hardy project has a split intake design. A portion of the water is extracted from a mid pond depth and a portion of the water is extracted from a second inlet closer to the bottom of the pond. The centerline difference in elevation between the two inlets is about 80 feet, with the water depth at the lower inlet approximately 100 feet. Distribution of water into the turbines from the two sources depends upon several factors, one of which is the temperature of the water in the impoundment. Cooler water naturally collects at the bottom on the pond and stratifies. During operation, this cooler water with lower dissolved oxygen (DO) levels contributes more of the turbine flow mixture resulting in lower tailrace DO levels below 5.0 parts per million during the warmer later portions of summer. Since these lower DO levels can present problems for fish and other aquatic life, Consumers had been working with the resource agencies since the middle 1990's on studying and reducing low tailrace DO levels.

Initial 2005 testing of the existing turbines over a range of gate positions from 40% to 100% showed that runner venting by controlling air flow through an existing 4 inch vacuum breaker lines was technically feasible for Hardy and that tailrace DO levels increased dramatically and occurred within seconds of opening the valve. Dissolved oxygen uptake varied with gate setting and even with relatively high incoming DO concentrations (i.e. close to 5 mg/l), opening the air valve

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produced an increase of about 0.6 mg/L for each unit. Based on the results of this initial testing Consumers installed hub baffles on the Unit No.1 runner cone to increase the amount of air intake. While these baffles successfully increased the air flow at all gate settings, and extended the gate opening range at which suction occurs, the resulting hydraulic inefficiency reduced the No. 1 turbine's output by approximately 400kw.

In addition to these DO concerns, several other conditions contributed to Consumers rationale in later 2005 to evaluate Hardy station turbine upgrade opportunities.

- Although the Hardy turbines have operated reliably, testing in the early 1990's showed that they were experiencing inevitable declines in efficiency.
- The Energy Policy Act of 2005 amended Section 45 of Internal Revenue Code of 1986 to apply the renewable energy tax credits of 0.9 cents per kWhr to incremental production gains from efficiency improvements or capacity additions to existing hydroelectric facilities placed into service after August 8, 2005 and before January 1, 2010.
- Michigan was heading towards a mandated Renewable Portfolio Standard (RPS).
- The RPS that was subsequently enacted in 2008 requires energy suppliers to provide 10% of the energy supplied from qualified renewable sources by 2015. Consumers currently has about 4% of existing generation attributable to renewable sources with hydro generation contributing about 1%.

PLANNING AND PROCUREMENT PHASE

Consumers began the planning process by working with Kleinschmidt Associates on a 2006 comprehensive upgrade evaluation of the turbines and controls that considered turbine condition, controls, electrical protection, station operation, water management, and project environmental/licensing issues and concerns.

ENERGY EVALUATION

An energy model was prepared to calculate the expected increased generation provided by a replacement runner. Total river flows were determined by pro-rating nearby USGS gages, but because Hardy is operated in a peaking mode the unit gate settings and daily length of operation were determined from reviewing four representative years of recent station log book data. The model incorporated the current FERC license requirements where daily generation typically begins with the headpond between Elevations 822.3 to 822.2 and a 0.5 ft daily drawdown. The actual January through March drawdowns that account for varying snow melt runoff from previous years were averaged and used in the model.

Individual unit flows were calculated using the actual operating hours and typically constant 80% gate settings from the station log books and comparing with the pro-rated USGS gage river flows for days between 1997 and 2002 when only one turbine was operated. Similarly, the water to wire peak efficiencies were calculated utilizing these four years of Consumers' operator log book data including daily output, number of hours each turbine was operated, and elevations of headwater and tailwater. Using the pro-rated gage flow data we calculated the individual unit efficiency for days when only one turbine operated. This resulted in water to wire efficiencies of 78%, 80%, and 79% for Units No. 1, No. 2, and No. 3 respectively. These compared reasonably with the 1991 turbine testing peak efficiencies of 82% for Units No. 1 and No. 2, and 86% for Unit No. 3. These water to wire efficiencies were converted to runner efficiencies assuming generator efficiencies of 93% for the original and 95% for any rehabilitated generator. For the initial study the upgraded replacement runner efficiency was conservatively assumed a constant 90%, although after vendor quotations were obtained the guaranteed manufacturer's efficiencies were used for generation values in the equipment bid comparison evaluations.

The model's calculated average annual generation of 90,952 MWh for 1996 to 2005 closely matched this period's actual generation of 90,603 MWh.

EXISTING GENERATION EQUIPMENT CAPACITY & RELIABILITY

The capacity and reliability of the existing generation equipment from the runners through the station's step up transformer was evaluated by a review of existing documentation including recent testing reports. This review showed that of the three turbines the Unit No. 3 generator was the most deteriorated with the stator windings having very low megger and Polarization index readings. In addition, the generator field turn insulation was degraded and had developed turn-shorts. Also the shaft mounted rotary exciters for Units No. 2 and No. 3 had turn shorts in most of their poles.

This review showed that the station's existing switchgear, circuit breaker, cabling, and transformers were in good condition with no foreseeable reliability problems and were adequately sized for any moderate turbine capacity increases. The station's protective relaying though was found to not meet present IEEE Standard 242, so any generator upgrade investment should also incorporate updating the generator's protective relaying.

RUNNER UPGRADE ALTERNATIVES

The generation and annual values for seven alternative options were developed based upon Kleinschmidt's experience with previous similar vintage turbine runner rehabilitation projects and some Hardy site specific vendor information. These alternatives considered various combinations of turbine operating priorities, runner capacities, efficiencies, and replacing one, two or three runners. The most favorable option was to replace one turbine runner with the largest hydraulic capacity increase that did not reduce maximum runner efficiency and rewinding the unit's generator. It was also determined that the maximum economic benefit would result by operating a new upgraded turbine as the priority first on and last off turbine. Also a significant annual benefit of over 1,300 MWh could be realized by incorporating turbine venting capability into a new replacement runner that would allow the removal of the Unit No. 1 hub baffle retrofit.

Because the Unit No. 3 generator was in the poorest relative condition of the three turbines, Unit No. 3 was selected as the best candidate for initial turbine rehabilitation.

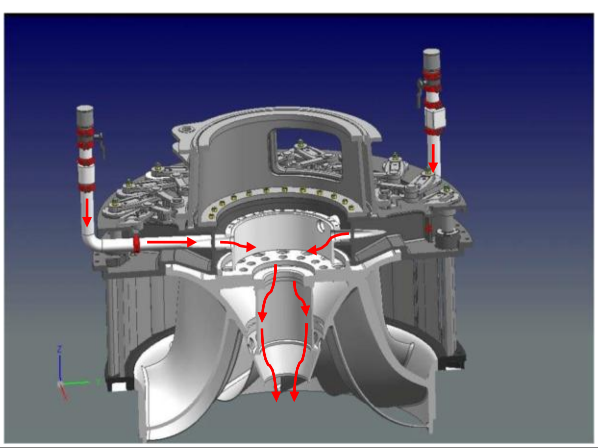
EQUIPMENT PROCUREMENT

In the spring of 2007 Consumers and Kleinschmidt prepared the runner replacement procurement specifications and bidding documents. An equipment vendor and installation contractor pre-bid meeting for both runner and generator vendors occurred in late May 2007. The turbine was dewatered and temporary discharge ring access installed so that the bidding runner vendors and installation contractors could observe the actual turbine runner conditions. A separate more detailed inspection of the turbine runner and distributor occurred during this dewatering that allowed Consumers and Kleinschmidt personnel to more closely determine and document the equipment's existing condition. This information was forwarded to the bidders and allowed a better definition of the runner rehabilitation work scope. During this initial inspection the visually observable distributor components appeared in good condition. Consequently substantial rehabilitation alternatives such as replacement wicket gates and linkages were listed as bidding alternatives whose purchase would depend on the results of more detailed inspections that could be performed after disassembly.

Runner replacement equipment and installation bids were received in June 2007 and American Hydro Corporation (AHC) was awarded the runner supply and installation contract in September 2007. The runner detailed design was begun and approved by December 2007 so that runner fabrication could begin in early 2008.

The new runner, designed and supplied by AHC, has 13 buckets as opposed to the original runner with 16 buckets. Because the 77 year old existing runners did not exhibit any material related deterioration such as cavitation or erosion damage, a carbon steel runner alternative was selected to reduce costs.

The figure below shows a graphic cross section of AHC's new runner illustrating the turbine venting system that incorporated modifications to the existing head cover to mate with the new runner. The original head cover was modified with the addition of a header with four air lines. Operation of the aeration system is very simple and consists of opening the butterfly valves allowing the natural draft tube vacuum to draw atmospheric air from the dry turbine pit through the inside of the runner crown and holes in the runner nose cone where it enters the draft tube and is mixed with the turbine's discharge.



Parallel to the runner rehabilitation work, the Unit No. 3 generator rotating and stationary rewinding was bid and awarded to National Electric Coil (NEC) in March 2008. To assure that the runner upgrade would not surpass the generator capacity the generator rewind requirements were finalized after the final maximum runner output was determined by AHC.

The Unit No. 3's original voltage regulator and rotating exciter were replaced with a new Basler static exciter and voltage regulator. Hardy Dam is listed on the National Register of Historic Places, so to maintain the original powerhouse historic aesthetics Consumers decided to maintain the original exciter assembly in place, but leave it unpowered.

The station protective relaying was upgraded with a Beckwith 3425A relay including a ground protection option. The Permanent Magnet Generator ("PMG") still serves as the speed sensor and it was sent to GE for inspection and to set the Over Speed Trip setting. Based upon the results of a comprehensive preventative maintenance inspection the original governor was maintained without any changes.

EXECUTION PHASE

Consumers prepared a detailed outage schedule for the complete disassembly and upgrade of the Hardy 3 turbine generator. The pre-planning included items such as confirming the condition of the station service crane to prevent any unscheduled problems that could delay the project. To help prevent any potential lost revenue the outage began on May 5, 2008 after most of the spring freshet had passed to help avoid the need for non-generation spillage. Prior to this outage, except for one recorded case of a thrust bearing inspection, the extent of work performed on this unit had been limited to annual inspections resulting in minimal runner, wicket gate, and linkage maintenance, as well as generator testing. This outage marked the first time any of the three units at Hardy Dam had their generator rotor, turbine runner and distributor components removed since the units originally went into service in 1931.

DISASSEMBLY AND DETAILED COMPONENT INSPECTION/EVALUATION

The turbine disassembly was completed by early June 2008 allowing a more thorough inspection of the components. The inspection of the distributor components after cleaning confirmed the condition indicated by the previous May 2007 assembled inspection that the primary distributor components were in very good condition. Repairs to these items such as the wicket gates and distributor ring consisted primarily of minor machining to clean up critical mating surfaces and application of a fresh coat of paint.

The original Unit #3 came equipped with a GE Spring Bed Thrust Bearing. Consideration was given to upgrading to a self leveling thrust bearing. However, it was determined the thrust bearing cavity in the bridge did not have enough axial room to accommodate such an upgrade. A pivot pad bearing was also considered. In the end, a pivot pad bearing upgrade was not implemented since the existing bearings had operated for over 200 combined operating years without a spring bed thrust bearing failure for the three Hardy units. The original spring bed was set up on a Blanchard grinder to verify that the spring cups and bottom surfaces were parallel. A new babbitted thrust blade was manufactured by Kingsbury. The thrust runner was replaced with a spare that Consumers had in stock.

One upgrade option that Consumers did pursue was replacing the existing gate and linkage bushings that required periodic greasing with new greaseless bushings. This upgrade required installing stainless steel sleeves over the carbon steel gate stems to interface with the greaseless bushings. Along with the greaseless bushing, the conventional gate stem packing was replaced with Chesterton hydraulic seals. The sliding surfaces of the operating ring were also converted to greaseless.

The disassembled runner shaft and other mating components were shipped to AHC's York Pennsylvania shop in late June 2008 for rehabilitation and to ensure correct mating with the new components. Consumers' project manager and engineers from Kleinschmidt's nearby Strasburg, PA office made periodic shop visits to AHC's York PA facility from the later summer through the fall of 2008 to inspect the new and refurbished components at critical milestones, and also to help expedite delivery.

GENERATOR REWINDING

After the turbine disassembly was complete the on-site generator rewinding occurred between June and October 2008 including reverse engineering and manufacture of windings and refurbishment of pole pieces. Nothing unexpected was discovered during the generator rewind except that the generator core iron had loosened up considerably over the years. Although the core was found to be slightly out of round (oblong) it was radically secure to the generator frame through its dovetails. As a result, the decision was made to clean the core iron and tighten it in place.

TURBINE REASSEMBLY AND ALIGNMENT CORRECTIONS

The most significant challenge in the assembly preparation was alignment corrections that were needed.

Optic level readings had been taken on head cover and bottom ring ledges of the stay ring after the runner and distributor parts had been removed. These readings showed the stay ring had settled over the years and was tilted (leaning) upstream. The degree of tilt resulted in upstream readings being about 0.200" lower than the downstream readings across the head cover diameter of approximately 11 ft.

With a tight wire suspended from the center of the bridge the generator stator was checked for level and plumb. It was also found to be leaning upstream. Some quick box level readings on the other 2 units' turbine shafts showed a similar upstream lean. From this cursory inspection the team concluded the powerhouse has settled into an upstream lean over time.

Correction of this condition was determined to be needed so the unit could be aligned plumb when the reassembly took place. This started with determining a zero point of reference to align to and then machining and realigning the various sections to that zero point. Selecting the head cover as the zero point to align to provided the least amount of major component realignment throughout the unit. With this established the bottom ring ledge and head cover ledge were field machined as needed for each to be parallel and perpendicular to the center line. This machining resulted in the head cover resting about 0.100" lower than its original position. The resulting newly machined lower ring ledge was lowered more than this 0.100". To maintain gate upper and lower clearances the lower ring had to be shimmed a small amount at final assembly. Because of the new position of the lower ring, its bolt holes were opened enough to use the existing stay ring ledge threaded holes.

To correct the generator stator alignment it was necessary to step shim and slide the stator frame. At original construction of the generator the frame was set on its 9 sole plates with no shims for adjustments. Therefore, the step shimming required to plumb the stator resulted in raising the centerline of the stator approximately 0.175". The frame foot bolt holes of the generator also needed to be opened for installing hold down bolts due to the alignment changes.

With the newly aligned turbine distributor parts being lower and the newly aligned generator being raised it was necessary to fabricate a coupling spacer and incorporate it into the generator shaft to turbine shaft coupling.

The wicket gate servomotors were also affected by the unit alignment correction. These two servomotors are mounted on the turbine pit wall, with stems that stroke in a horizontal line to the operating ring. The operating ring is on the head cover which was realigned. To keep the servomotor stem stroke parallel to the operating ring (head cover), tapered shims were added at the servo assembly mounting flanges on the turbine pit wall.

The turbine reassembly began in earnest on December 3, 2008. The figure below shows the new runner delivered to the site before assembly.

The Hardy Unit No. 3 was returned to service on March 3, 2009, before the beginning of the spring freshet. Because this extended unit outage was scheduled between spring freshets, the Hardy station did not experience any lost generation due to this project. Other than a short outage during which gate squeeze was adjusted, the unit has been available and operating without incident.

When the new runner with its air entrainment capabilities was installed in Unit No.3, the Unit No. 1 hub baffles that had been installed in 2006 were removed.

PERFORMANCE AND BENEFITS

INCREASED GENERATION

The refurbished generator capacity increased from 10,000kW to 11,500kW. With the turbine runner upgrade and associated generator rewinding, Unit No.3 was determined to have a best gate generator output increased from 10,114kW to 10,485 kW at a net head of 99 feet, with a best gate position of 78%. Total Project best gate capacity has increased from 29,229kW to 29,600kW.

On February 25, 2010 the Hardy license amendment order was issued by the Federal Energy Regulatory Commission revising the annual charges to reflect the increased capacity of the Project. And on March 3, 2010 FERC Staff issued the order certifying the incremental Production Tax Credit for the upgrade.

TURBINE TESTING RESULTS

Following the return to service of Unit No.3 in March of 2009, Consumers began preparation for performing testing to reestablish the best gate capacity for Unit No.3. The Hardy project provides for a winter drawdown (between January 1 and April 30) to reduce impoundment water levels by up to 12 feet. Best gate testing therefore needed to wait until the pond was returned to full head at the end of April.

The Hardy turbines were originally installed with Winter Kennedy taps allowing for a relative measure of turbine discharge flow. These taps had not been utilized in a number of years, and while cleaning the piping in preparation for the test it was discovered that the taps had apparently been sealed over from inside the turbine scroll case. Rather than take a unit outage to drain and investigate the internal openings, Consumers began evaluating the possibility of utilizing ultra sonic methods to determine turbine flows. Each turbine has a 14 foot diameter inlet pipe with acceptable geometry that could be accessed to install the sensors. However, after several unsuccessful attempts Consumers abandoned the use of the ultrasonic flow meters and during an inspection outage in November, the Winter Kennedy tap ports were located, opened and cleaned. In December of 2009 Kleinschmidt and Consumers completed the Unit No.3 index test utilizing the Winter Kennedy taps in accordance with the ASME PTC-18 Power Test Code of Hydraulic Turbines. In addition to the previously mentioned turbine capacity increase, the shape of the relative Index Test curve closely matched AHC's predicted efficiency and discharge (cfs) curves, which is a good indication that the relative curves are an accurate representation of the absolute curves. This testing also confirmed the minimum part load cavitation zone as being between 55% to 65% of total gate, and high end operating level cavitation zone as being above 90% gate.

DISSOLVED OXYGEN

Consumers and Kleinschmidt performed dissolved oxygen testing in August of 2009 when ambient dissolved oxygen concentrations are typically at the lowest. The US Geological Survey (USGS) maintains a water quality station in the Hardy tailrace. For the turbine vent testing a continuous monitor was installed in the vicinity of the USGS Station building on the opposite riverbank from Unit No.3. In addition, handheld monitors were deployed directly in the outflow from Unit No.3. Data from the hand held unit was used to determine when the dissolved oxygen levels had stabilized after a change in configuration. After making any configuration change (gate setting or vent valve opening) dissolved oxygen levels were allowed to stabilize to establish a baseline condition. Stable plant operating data was recorded for the following parameters; gate position, dissolved oxygen concentration, temperature, vent valve settings, headwater, tailwater and unit output.

After the initial test at 60% gate setting, visual observation confirmed with hand held instrumentation, indicated that the aerated water was not reaching the location of the continuous monitor deployed near the USGS Station. For subsequent testing the continuous monitor was moved across the river from the USGS Station, immediately downstream of the Unit No.3 outflow. As expected the level of dissolved oxygen enhancement varied with gate setting and the number of air intake valves opened. The maximum enhancement observed was approximately 1.5mg/L at the lower gate settings of 60 and 70% open. Testing with all four vents open showed greater enhancement than with two vents open, but the data collected indicated that the level of increase was not linear.

The turbine runner purchase order stipulated a target dissolved oxygen enhancement of 2.0mg/L. While the 2009 testing did not show this level of enhancement, during this year the initial dissolved oxygen level was slightly higher than historically experienced in August. The level of enhancement experienced was sufficient to determine the potential of the turbine vent to enhance dissolved oxygen in the Hardy tailwater and address agency D.O. concerns.

PUBLIC OUTREACH AND HISTORIC PRESERVATION

When the Hardy Project was originally built and operated, Consumers provided housing for the station operators. There were four houses constructed in an area along the impoundment immediately upstream of the dam. By the late 1960’s, operators no longer lived in the houses and the houses were eventually sold and removed from the site. Today, the area formerly occupied by the houses is known as the Operators Village. It was developed into a day park by Consumers in 1998 and is operated the local township government. As shown in the figure below, the old Unit No.3 runner has been permanently placed in an outdoor display within the Operators Village Day Park to enhance both public understanding of the Hardy project and its historic significance.

LESSONS LEARNED

Although every project has site specific conditions and challenges, based on our experience with this project we offer the following recommendations for similar rehabilitation projects.

1) Since equipment conditions cannot be conclusively determined until after final disassembly and detailed inspection, it is cost effective to obtain quotations for possible rehabilitation alternatives that can then be implemented only if they are needed.
2) Since these outages are generally for extended periods they need to be carefully scheduled and pre-planned to reduce any impact on generation availability and associated revenues. Similarly, it is important to comprehensively consider the entire station during the project planning phase to see if other work requiring turbine interruption/shutdown can be cost effectively combined with the runner replacement outage.
3) Although it is frequently inconvenient, consider conducting a documented baseline test to be able to more accurately determine the actual upgrade results.
4) Prior to removing a turbine from service, check any existing test connections or ports to ensure their availability following the turbine's return to service. This could prevent taking a second outage to open plugged or damaged test connections.
5) A single sample location for dissolved oxygen concentrations may not be adequate to determine compliance to stipulated concentrations, especially in an environment as dynamic as a project tailrace. Continuous monitoring in several locations may be required to determine compliance.