Application Note

Case study – Machine condition monitoring strategy at the Zarnowiec pumped storage power station

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ABSTRACT

Machine uptime and availability is of paramount importance for the Zarnowiec pumped storage hydroelectric power station, and this was one of the underlying reasons for installing a condition monitoring system with advanced vibration monitoring capability. The system is used for detecting and diagnosing machine faults at an early stage of development, and for monitoring flow instability during part-load turbine operation on the four 179 MW generating units. Case stories on both of these functions are described in this article. Monitoring results have been good up to now and there are plans for extending the system.

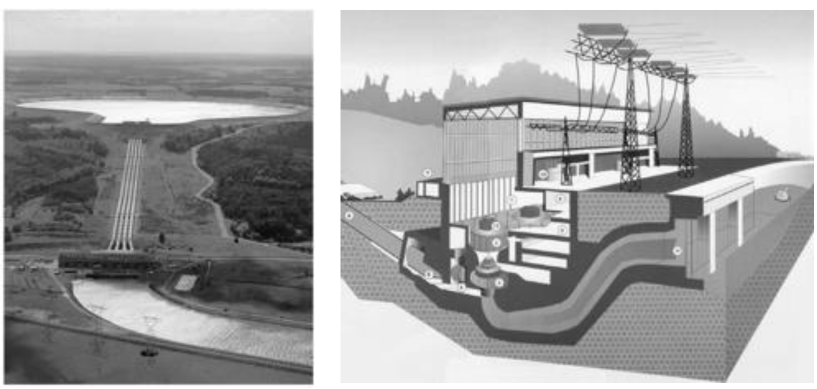

Figure 1. Zarnowiec pump storage hydroelectric power station. The 10.5 m diameter generators produce 179 MW from a 180 m³/s flow at 166.7 rpm.

Zarnowiec power station

The 716 MW Zarnowiec pumped-storage hydroelectric power station shown in Figure 1 is located between an upper artificial reservoir and the glacial lake Zarnowiec in Northwestern Poland. Owned by Elektrownie Szczytowo Pompowe SA (Pumped Storage Power Plants SA) and operated by Elektrownia Wodna Żarnowiec SA (Żarnowiec Hydropower Plant SA), it is the largest hydroelectric power station in Poland. Zarnowiec power plant - one of five pumped storage power plants in Poland - uses the upper reservoir to generate power during peak demand. During night and those hours when the demand is lower, water is pumped from the Lake Zarnowiec back into the upper reservoir so it can be used again during the peak consumption hours. The units are also used for synchronized compensation between the generating and pumping operations for optimizing the power factor and stabilizing the grid. This allows the base-load power stations to continue producing energy without shutting down any units or operating them uneconomically at low load.

Because the Zarnowiec pumped-storage hydroelectric power station is used as a peaking station, machine availability and uptime is critical. Much of Poland's generating capacity was built during the 1970's and up to 40% of the current capacity is more than 30 years old[1]. This means there is a greater risk for downtime for the base-load power station generating units. This risk, however, is partly mitigated by Zarnowiec, provided of course its hydro-generating units are readily available and in good order.

Hydro-generating units

The four former Czechoslovakian-built reversible Francis turbine-pump units were installed in the Zarnowiec powerhouse in 1983. From a maintenance point-of-view, all four units have performed well with no major maintenance problems. The units are aging, however, and have already exceeded their 20-year

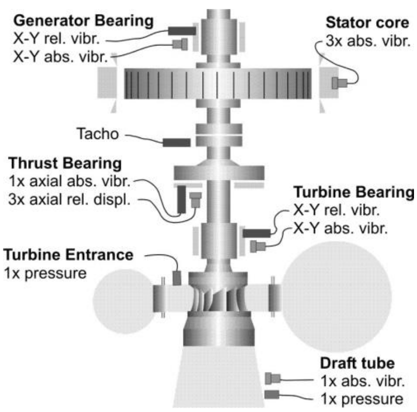

Figure 2. Monitoring strategy for each of the four units.

recommended lifetime. Units 1 and 2 were upgraded with rewound and re-wedged generators. Unit 2 was also fitted with a new VA Tech Hydro runner and a new guide vane profile. The other units are planned to be upgraded next year.

From an operational point-of-view, the units are subjected to vortex rope turbulence from time to time during part-load operation. If the units are allowed to operate for extended periods of time in this condition, the vortex turbulence reduces the efficiency of the unit and the resulting vibrations put excessive load on the bearings and runners.

Monitoring strategy

An integrated on-line/off-line vibration and process parameter monitoring system was installed in 1997. This was an important step in moving towards a conditioned-based maintenance strategy from the interval-based maintenance strategy. The monitoring system was implemented for:

- Detecting and diagnosing faults at an early stage of development so maintenance can be planned ahead of time
- Optimizing part load operation

A permanently installed monitoring system (on-line) is used to monitor the stator, generator and turbine guide bearings, thrust bearings and the turbine inlet and draft tube as shown in Figure 2.

A number of measurements are done on the on-line vibration and pressure pulsation signals, including:

- **Vector measurements** - 1st and 2nd order (magnitude and phase) and ½ order (magnitude only)
- **FFT spectra** – Set up for different frequency spans
- **S_{max}** – Maximum magnitude from an X-Y measurement
- **X-Y vibration time signals** – Displayed individually and combined in an orbit plot
- **Scalar values** – These include DC, LP and BP
- **Calculated measurements** – Standard and user-defined formulas for calculating values for statistical or performance monitoring purposes.

All of the on-line measurements are individually monitored to specific machine states, namely pumping, generation, and synchronized compensation with the runner turning in the pumping and generation modes without water.

While the on-line portion of the monitoring system is used for the generating units, portable hand-held data collectors (off-line) are used for monitoring the auxiliary equipment. This includes:

- Lubrication pump and motor
- Exciter ventilators
- Cooling water pumps and motor
- Air compressors
- Water intake pipelines
- Electrolyte pumps and motors
- Oil pumps and motors
- Technical water pumps and motors
- Dewatering pumps and motors
- Cooling fans

Most of the measurements used for on-line monitoring are also used off-line. As some of the off-line instruments are used for monitoring pumps, ventilators and motors with rolling element bearings, the data collectors include specialized measurements that are well suited for this purpose:

- **Constant percentage bandwidth (CPB) spectra** – Filtered measurement for detecting a wide range of faults
- **Envelope spectra** – Low pass, rectified measurement for identifying modulated rolling element bearing fault frequencies

The off-line as well as the on-line monitoring data is compared to alarm limits and stored in the same monitoring system server database, as shown in Figure 3. The database makes it possible to trend vibration and pressure data and correlate it to process parameters.

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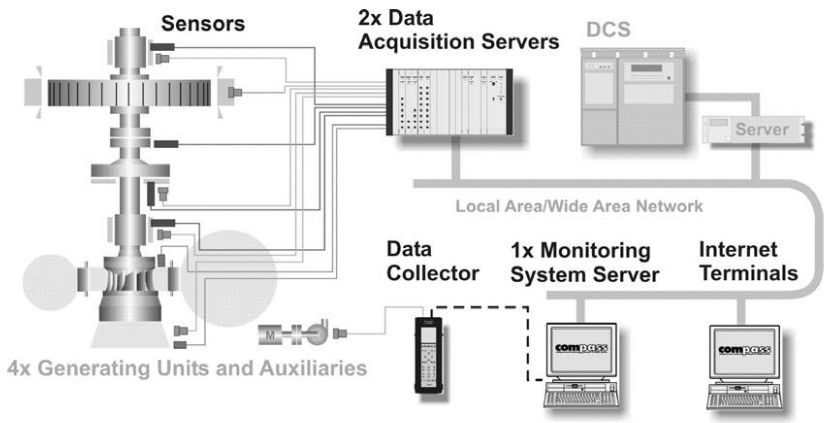

Figure 3. Monitoring system configuration (shown in colour).

Operating experience with the condition monitoring system

The monitoring system has been successively used for 9 years. The condition monitoring team who uses the system consists of a manager, a diagnostic consultant, and two technicians who collect data with the portable instruments. The same team is also responsible for other monitoring systems such as the partial discharge monitoring system and the air gap monitoring system. The monitoring system has been used for field balancing, optimizing operational states and detecting and diagnosing a number of faults.

Case story #1: Vortex rope turbulence

One of the important functions of the monitoring system is to ensure that the generating units can safely operate at part load for extended periods of times without being adversely affected by rope vortex turbulence. The precise load at which this occurs and its severity depends on the head and water temperature, but is generally between 60-80 MW and 120-130 MW. The severity of the vortex is based on the amplitude of the sub-harmonic peak shown in the spectra in Figure 4. If the peak is greater than 300µm, then action must be taken to change to a higher operating load.

Case story #2: Unit 1 rotor rim support bar broken

In 25 January 2003, the 1x radial vibration magnitude from the y-position displacement transducer monitoring the unit 1 generator guide bearing exceeded the alert alarm limit of 40 µm, as shown in Figure 5. Upon closer inspection, it was noticed that both the 1x magnitude and phase had been increasing linearly since around 30 December in 2002. In 2 February 2003 the 1x radial vibration phase from the unit 1 generator guide bearing also exceeded its alert alarm limit - over 50 degrees from its reference value. As the vibration levels were not so high, the unit was allowed to operate so the situation could be further

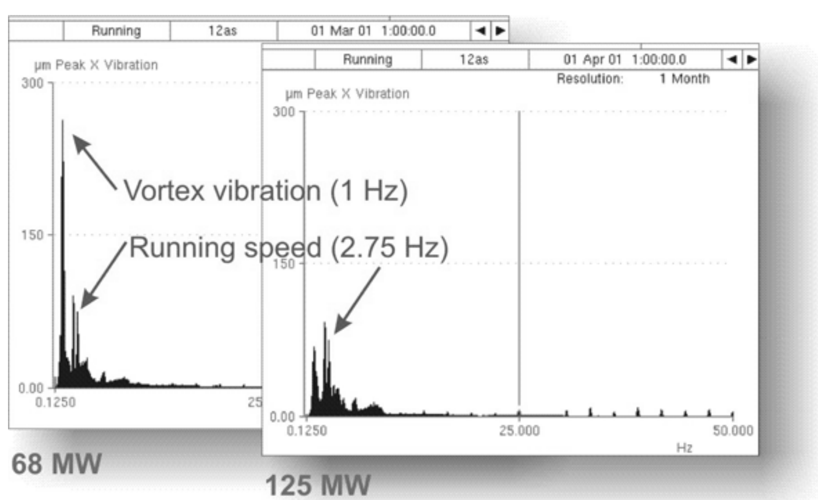

Figure 4. Detection and severity evaluation of the vortex rope turbulence using a spectrum plot. The example above shows the dominating presence of a frequency component indicative of a vortex (1/3x to 1/2x running speed) at 68 MW load (left). One month later at the same measurement point but at a higher load of 125 MW (right) there is little evidence of a vortex.

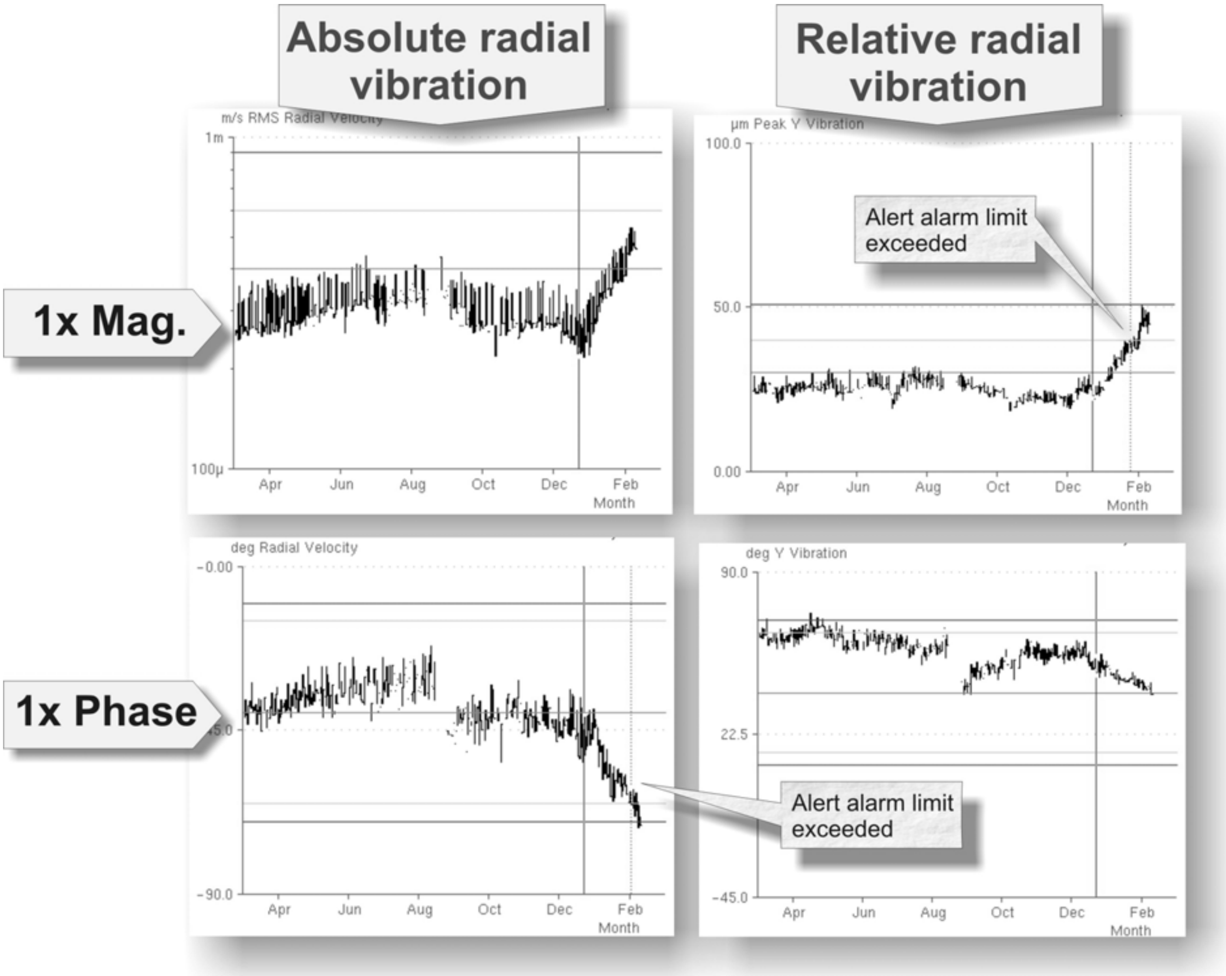

Figure 5. Vibration measurements from a radially-mounted accelerometer and displacement transducer on the unit 1 generator guide bearing showing a rapid change in magnitude and phase at around Christmas, 2002. As seen in the lower plots, accelerometers were more sensitive to phase change than the displacement transducers.

investigated. After three weeks the trend still continued to increase so it was decided to stop the unit 12 February 2003.

Broken rotor rim support bar

Nothing was found wrong with the generator guide bearing, so attention was focused on the rotor rim. One of the 12 spider arm support bars that supported the rotor rim plates was found to be broken. Fortunately when the support bar web broke it did not damage the rotor windings. The broken support caused a 30-degree circumferential section of the rotor rim plates to be completely unsupported resulting in the plates to gradually sag over a one-month period.

Post analysis and repair

It was determined the support prematurely broke due to fatigue. The original design was based on

Figure 6. Modified rotor rim support structure.

a single web support contact point for the entire stack of rotor rim plates for each support. This was considered insufficient so it was decided to make a modification with three support webs for each support as shown in Figure 6. This was eventually done for all the units.

The monitoring system was not able to detect the fatigued support prior to breakage, but it was possible to detect and trend the resulting vibration and phase immediately after breakage and long before it became critical. The gradual change of the rotor's centre of mass is reflected by the gradual increase in the 1x vibration magnitude and change in the 1x phase.

Future prospects

The monitoring system has been designed with an open architecture so it can exchange data with other systems. As shown in Figure 3, the LAN/WAN based configuration also makes it possible to import process data from the DCS into the monitoring system database so it can be correlated with the vibration and pressure pulsations measurements from the monitoring system. Data from other monitoring systems can also be imported into the monitoring system database, such as measurements from the existing stand-alone partial discharge analysis (PDA) system.

In addition to the PDA system, Zarnowiec also had a stand-alone rotor-mounted air gap monitoring system installed on each of the units. But this system is no longer manufactured and serviced, so it was decided the vibration monitoring system described in this article would be extended with stator-mounted air gap and magnetic flux monitoring capability. This would be an integrated solution, meaning that the air gap and magnetic flux parameters could be directly correlated with other vibration and process data in the same database.

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