JUSTIFICATIONS FOR INSTALLING VIBROSYSTM'S ON-LINE MONITORING SYSTEMS

I. Condition-Based Maintenance (CBM) Approach

Today, more and more power utilities are switching to money-saving and effective Condition Based Maintenance Programs for scheduling of machine maintenance and testing. According to a 1988 multi-industry survey, ("Predictive O&M" by John O'Connor, HYDRO REVIEW/JULY 1992) the benefits of CBM are obvious (refer to table 1):

<table>
<thead>
<tr>
<th>Table 1: Benefits of Condition-Based Maintenance*</th>
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<tbody>
<tr>
<td>Maintenance costs</td>
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<tr>
<td>Machinery breakdowns</td>
</tr>
<tr>
<td>Spare parts inventories</td>
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<tr>
<td>Total machine downtime</td>
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<tr>
<td>Overtime expenses</td>
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<tr>
<td>Machine life</td>
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<tr>
<td>Overall productivity</td>
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<tr>
<td>Profit</td>
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*Pat March, senior mechanical engineer at TVA (Tennessee Valley Authority) Engineering Laboratory, prepared this summary based on the results of a 1988 multi-industry survey conducted by TEC of firms that had used or were using condition-based maintenance techniques.

The ultimate goal of the Condition-Based Maintenance approach is to "eliminate routine maintenance and allow the utility to service equipment only when the monitoring system indicates that such service is needed."

VibroSystM Inc. offers precise, reliable and efficient on-line monitoring systems to implement CBM programs at power plants.
II. VibroSystM’s On-line Monitoring Systems

Air Gap Monitoring System (AGMS®)

The stator-rotor air gap is the heart of the unit since this is where mechanical energy is converted into electrical current.

The dynamic air gap is an important parameter that reveals structural weaknesses and/or strengths. It summarizes the effects of various internal and external physical forces interacting within a hydroelectric machine. These forces are of hydraulic, centrifugal, magnetic, mechanical, thermal and geotechnical nature.

The unbalanced air gap can cause split phase current, stress on rotor and stator, local overheating, machine vibration and other problems that decrease unit’s efficiency and lead to premature ageing of the unit, while exhausting maintenance budgets.

VibroSystM’s AGMS is the only system available today that can assess dynamic air gap with sufficient precision. High accuracy and repeatability of measurements are achieved through the use of our unique capacitive technology.

AGMS features:

• High accuracy (3%) and repeatability of measurements (0.7%);

• Full range of measurements:
  6000 samples per second (Sampling);
  1 unit revolution (Signature);
  1 to 246 unit revolutions (Air Gap transitional tests, on a 32-pole machine);
  Up to 1,000,000 measurements per Trending plot;

• Automatic and manual measurements;

• Automatic recording of data collected before and after alarm (20 turns);

• Comprehensive set of tools to process collected data includes spectrum analysis (FFT);

• Excellent reliability and track record (with over 350 systems installed over 10 years);

• Proven fast return on investment by decreasing maintenance costs and increasing unit availability.
Zero Outage On-line Monitoring System (ZOOM®)

The philosophy of the ZOOM system is to see through the hydroelectric unit by referring all machine behavior to the smallest electrical and mechanical step: passage of the rotor field pole. Graphical presentation of various parameters as plots with common time scale discloses hidden correlations for thorough unit analysis.

The in-depth machine analysis with the ZOOM system can reveal foresigns of problems that cannot be detected by examining non-synchronized data supplied by standalone systems.

Zoom System Features:

- Measurements of all parameters are synchronized to the smallest electro-mechanical step of the machine - passage of the rotor pole;
- Parameters are displayed as graphs for precise unit diagnosis;
- Covers FULL RANGE of measurements;
  - 6000/750 samples per second (Sampling);
  - 1 unit revolution (Signature);
  - 1 to 246 unit revolutions (Transitional tests, on a 32-pole machine);
  - Up to 1,000,000 measurements per trending plot;
- Significantly enhances unit analysis capabilities;
- Automatic and manual measurements;
- Automatic recording of data collected before and after alarm (20 turns);
- Comprehensive set of tools to process collected data includes spectrum analysis (FFT);
- Provides data and software diagnostic tools for component behavior analysis;
- Excellent reliability and track record (with over 60 systems installed over 4 years);
- Proven fast return on investment by decreasing maintenance costs and increasing unit availability.
Stator Bar Vibration (SBV) Evaluator

VibroSystM's Stator Bar Vibration (SBV) Evaluator offers on-line winding condition evaluation by using unique capacitive sensors installed in specific stator slots to measure bar vibration.

Trending stator bar vibration amplitude provides on-line dynamic information on condition of windings to determine when it is necessary to rewedge the unit, before damages occur (abrasion of the Faraday shield and insulation, laminations damage, bar overheating, partial discharges increase, etc.).

SBV Features:

- Evaluates loosening of wedging system;
- Measures the in-slot displacement (or vibration levels) of stator bars while the unit is in operation;
- Makes long-term planning of stator rewedging possible;
- Warns against excessive vibration levels which trigger an avalanche of destructive effects such as:
  - an abrasion of the bar’s semiconductive paint and insulation;
  - increased partial discharges;
  - bar overheating.
Experience has shown that on-line dynamic monitoring of a hydroelectric unit with the ZOOM system translates into hundreds of thousands of dollars, saved or earned. The reasons behind those additional profits are listed below.

1.0 THE ZOOM SYSTEM DECREASES MAINTENANCE COSTS AND INCREASES EFFICIENCY OF O&M

1.1 Detects foresigns of a problem for a timely correction and at minimal cost;

FACT: Kpong Generating Station in Ghana Africa has four (4) 50 MW units and is critical to country’s power system. The AGMS clearly showed all units at risk, and saved unit 2 from an ultimate two to three million dollar rub accident. The unit was saved, the problem was corrected at a minimal cost and operators readjusted the use of the machine to keep it healthy.

Reference: Horst Mielke - Acres Engineering Consultant. See case study “Station structural problems which cause stator distortion” at the lower right corner of page 3 of the AGMS pamphlet.

1.2 Provides information to fine-tune the unit's mechanics for optimal performance to minimize stresses and avoid premature ageing of the unit;

FACT: Arnprior Generating Station at Ontario Hydro has two (2) 80 MW units used for peaking purposes and synchronized condensing. The ZOOM system showed that the gradual detachment of the rotor rim was causing high stator vibrations at the bottom air gap. The cause of the localized vibrations was found and justifications were put together to repair the problem and extend the life of the unit.

Reference: Gord Haines - Ontario Hydro

1.3 Verifies the effect of any mechanical job or adjustment and decreases time and effort to achieve required tolerance;

FACT : Saunders Generating Station of Ontario Hydro had the experience of correcting a high shaft oscillation after just two attempts.

Reference : Dave Casselman - Ontario Hydro. See case study ;"Generator shaft runout results correlated with each rotor pole” at the upper left corner of page 2 of the AGMS pamphlet.

FACT : The same power plant routinely uses the ZOOM system to efficiently balance units' rotors.


1.4 Provides fast and precise unit diagnostics;

FACT : Grand Coulee Power Station of the US Bureau of Reclamation is presently refurbishing three of it's six 800-MVA units. The AGMS system used during the commissioning period of the 1st refurbished unit, was instrumental in getting the unit on-line before the Christmas holidays. A split-phase current breaker was activated during tests indicating a dangerous air gap (imbalance). A quick glance at the AGMS display confirmed that the rotor-stator gap was stabilized and within operational tolerance. If it would not have been for this additional information, the Bureau was required to halt tests, remove shrouds from the rotor and spend 4 to 5 days to investigate the possible fault. This would have delayed the units in-service date by three weeks because of upcoming Christmas holidays with unnecessary overtime hours by plant and generator manufacturer personnel during the holiday season.

Reference : Gerald Metcalf - USBR.

1.5 Determines maintenance and refurbishment priorities;

FACT : Sir Adam Beck Generating Station at Ontario Hydro. An 80.5 MVA unit had been experiencing high vibration that had to be diagnosed. Air gap monitoring determined that the generator was not the source of vibration. Further investigation pinpointed the hydraulic problem that was corrected by cleaning the water passage channels.

1.6 Permits unattended monitoring of the remote units;

FACT: Manic Station of Hydro-Québec has two (2) hydrogen-cooled 300 MVAR synchronous condensers. This is Hydro-Québec's largest transmission station, it is isolated and unmanned. The units had a history of field pole attachment failures and loose wedging causing bar vibration.

The electrical engineer located in the regional Hydro-Québec's office is monitoring the changes in the overall unit’s condition by assessing the air gap for each pole as well as bar vibrations. This surveillance is made possible through the ZOOM and SBV systems installed on the generator. Time and manpower are saved with this particular installation.


1.7 Improves safety;

FACT: Moses Power Station, New York Power Authority, St-Lawrence river, 16 units, 65 MW each. The access to the air gap was very difficult, multiplying the risk to personnel as well as the risk of damaging the unit with tools or materials accidentally left behind. This situation was significantly improved by installing the AGMS system.

Reference: Mike Serth - NYPA

1.8 Detects areas with an increased probability of failure for mechanical, electrical and maintenance personnel.

FACT: High Falls Power Station, owned by McLaren Energy, had refurbished a 25 MW unit. SBV system was installed with the new wedging system and one of the channels indicated extremely high stator bar vibrations compared to others (which were normal for a new wedging system). The utility was able to address this problem with the manufacturer during the warranty period. Without the SBV this problem would have been left unworked.


FACT: Saunders Generating Station. Increase in bearing vibration levels of a 60-MW unit, compounded with high temperature values of oil in a specific bearing (all monitored with the ZOOM system), helped identify a low oil level of the bearing before the scheduled maintenance check.

1.9 Enhances operation and maintenance skills of personnel and utility;
2.0 THE ZOOM SYSTEM INCREASES UNIT AVAILABILITY

2.1 Provides an early warning of a developing problem and permits long-term planning to minimize the risk of an unscheduled outage during the peak demand season;

2.2 Permits maintenance manager to delay or cancel the scheduled outage (introduce condition-based maintenance practices);

FACT : R. H. Saunders Generating Station at Ontario Hydro has 16 units, 60 MW each, used for base load supply. This plant is a very important producer of profit for Ontario Hydro. The ZOOM system's capacity of monitoring and trending turbine blade clearance, bearing clearance and air gap clearance allowed the plant manager to override the Head of Production's decision to stop two (2) generators from operating while a concrete cut of the dam was performed. This saved Ontario Hydro $300,000 in revenue per concrete cut. The plant manager confirmed that the ZOOM data allowed him to safely operate units adjacent to the cut while the work was being performed. Total savings reported by OH due to the use of VibroSystM's monitoring systems is $10,000,000 since 1991.

Reference : Dave Casselman - Ontario Hydro.

2.3 Helps maintenance superintendent efficiently plan the upcoming outage (eliminate some tests, order parts in advance, distribute human resources, etc.). Efficient planning decreases the outage period;

FACT : USACE’s Power Plant A at the Nashville District has a 31-MVA unit manufactured in 1969. On-line monitoring is performed with our ZOOM system that incorporates Air Gap Monitoring System (AGMS®), Stator Bar Vibration (SBV™) Evaluator, and other systems. The client was able to reduce unit outage required for periodical inspection by 27 hours. This is a significant increase of unit availability that can be translated into thousands of dollars worth of extra generated power each time the unit is inspected (once every 36 months).


2.4 Provides true information on machine condition that allows to decide whether it is necessary to stop the unit for inspection in cases when other protection devices signal a problem;
3.0 THE ZOOM SYSTEM HELPS GET MORE FROM THE UNIT

3.1 Increases unit efficiency by eliminating imbalances that cause split phase current;

FACT: Rapid Des Iles Generating Station of Hydro Quebec.
Reference: See “Rotor Roundness and Structural Design” case study in our AGMS brochure, p.4 lower left corner.

3.2 Allows increased capacity by overloading or uprating monitored units;

3.3 Provides data to operate critical units safely and with confidence;

FACT: Kipling Generating Station at Ontario Hydro has 65 MW and 70 MW units with increased stator movement that caused rubs before. Monitoring of these units with the ZOOM system is performed "in lieu of replacing stator frames at a significant cost."

3.4 Extends life of older units by delaying untimely refurbishment.
4.0 OTHER ECONOMICAL BENEFITS

4.1 Provides basis to negotiate lower insurance costs;

4.2 Eases component behavior analysis to avoid overstocking of spare parts;

4.3 Provides data to take full advantage of the unit warranty for refurbished and new units by verifying tolerances during refurbishment. Discloses the need for specifications correction;

**FACT:** Grand Coulee Generating Station of Bureau of Reclamation, unit G23 was refurbished. Based on the air gap data collected, USBR elected to adjust the specifications for unit G24. Managers directed the contractor to reshrink the rotor rim tighter to the spider.


4.4 Eliminates periodical unit outages for static air gap measurements;

4.5 Prevents multimillion rotor-stator rubs through the Protection Relay Extension to warn of critical air gap or to trigger a run-down procedure.