On-line Condition Monitoring Solutions for JIRAU and SANTO ANTÔNIO Hydroelectric Projects

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ABSTRACT
This paper will present the technologies supplied by VibroSystM to monitor the critical parameters of the SANTO ANTÔNIO and JIRAU generating bulb units, as well as a sample of cases detected on bulb units by VibroSystM monitoring technologies.

Introduction

The RIO MADEIRA hydroelectric power complex is a major hydro scheme being developed on the second largest river of the Amazon basin in Brazil. It is located in the State of Rondonia near the border of Bolivia and upstream from the state capital Porto Velho. In all, the planned project will include 4 hydroelectric plants. The two run-of-the-river dams in the scope of this paper are being built entirely in Brazil, the other two still in planning would include one across the border with Bolivia and the last entirely in Bolivian territory. Almost all the energy produced throughout the Rio Madeira complex will be transmitted southeast via a new 2500 km transmission line to other states hosting electro-intensive industries, such as Sao Paulo, Rio de Janeiro and Minas Gerais.

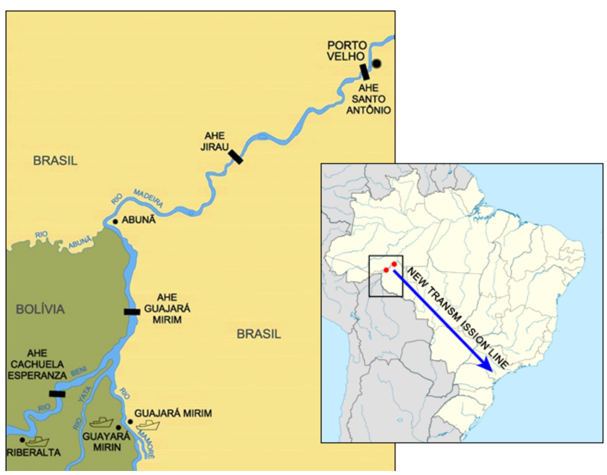

Figure 1: Map of Rio Madeira complex in north-western part of Brazil

The first stage of the RIO MADEIRA complex will consist of the 3300-MW JIRAU project and the 3150-MW SANTO ANTÔNIO project, with plans to expand the JIRAU project up to 3450 MW. A total of 88 bulb units – 94 units with expansion – will harness the river flow to provide electricity. Those will be the largest bulb machines in the world both in terms of capacity and dimensions (rotor: 7.5 m in diameter).

The SANTO ANTÔNIO plant is located 6 km upstream from Porto Velho. It will consist of 3 powerhouses of 8, 24 and 12 bulb units, each rated 72-MW with a 13.9 m head. It is owned by Santo Antônio Energia, a consortium formed by Furnas, CEMIG, Banif, Fi-FGTS, Odebrech and Andrade Gutierrez. The first unit is scheduled to start operation in December 2011.

Fig. 2: Model view of Santo Antônio project.

Fig. 3: Model view of Jirau project.

The JIRAU plant is located about 127 km upstream from Porto Velho. This project is owned by Energia Sustentavel do Brasil (ESBR), a consortium formed by GDF Suez Energy (Tractebel), Eletrosul, CHESF and Camarga Corrêo. It will consist of two powerhouses: one of 28 bulb units and one of 18 bulb units, all rated 75 MW with a 15.2 m head. The first unit is scheduled to start operation in March 2012.

The owners of both projects chose VibroSystM monitoring technology because of VibroSystM's experience with bulb unit monitoring at plants worldwide and their individual successful experiences with its highly precise measuring technology at other plants in Brazil.

Potential Problems with bulb units

A bulb unit is a horizontal machine inside a submerged shell that is slightly pressurized to prevent water ingress. Internal temperature control and gravity must be taken into consideration when designing such machines. Bulb units are typically used in low water head and/or water flow applications, therefore having dimensions of a few meters in diameter and producing up to 60 MW of capacity. In the case of the SANTO ANTÔNIO and JIRAU projects, the water head and flow, as well as technological advances, allow designing bulb units of 8 meters in diameter and generating up to 75 MW of electricity.

VibroSystM monitoring technologies have successfully monitored and detected various cases over the last 20 years. Examples of such cases described below include progressive sagging of the bulb casing or loose upper stator section, sagging of the rotational axis, cyclic stress due to rotor component looseness, excessive axial displacement of the rotational axis, deformation of the bulb shell that affect the generator air gap clearance, mussel build-up affecting the internal temperature and generator thermal expansion, etc.

Example 1:

On a recently built 27-MW bulb unit, the air gap monitoring system (AGMS®) detected a progressive stator sagging. In a short period of time, the stator deformed and adopted an oval shape. This condition was considered abnormal and alarming, especially considering the small air gap value of the design. It showed a 36.9% stator apparent circularity value over nominal air gap value and a 52.3% maximum air gap variation. The deformation seemed to originate from design or manufacturing, not from erection, seeing that the deformation was uniform and similarly present on other units. As much as the bracing system fails to support the upper stator section, it allows the stator to move outward laterally. This flexing is so consistent that the stator concentricity barely changes. At this rate of premature aging, the risk of rotor-stator contact is very high. And although it was not yet visible, the twice per rotation cycle of magnetic imbalance may eventually lead to shaft or rotor rim vibration and lead to failure from mechanical fatigue.

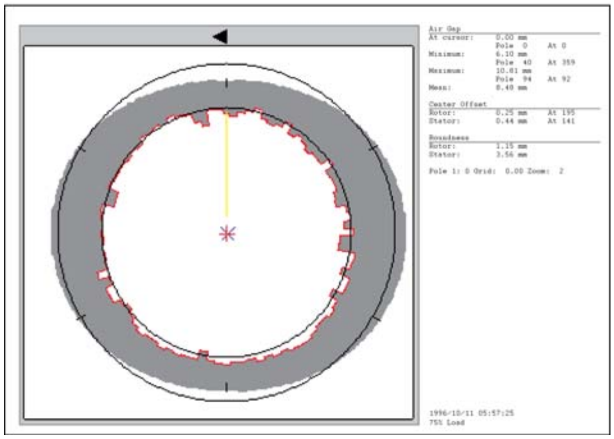

Figure 4: Polar view of bulb generator air gap showing stator sagging.

<u>Example 2:</u>

The 28-MW bulb unit featured in this example suffers a severe stator distortion, a condition known since the commissioning in 1977. At that time, cracks were found in the bulb supports. The hypothesis is that when they were rewelded, the bulb casing and the attached stator inside were somehow pulled out-of-shape. The buckling of the stator shape appears to be permanent. Although the mechanical dimensions of the generator are severe, the stability of both rotor and stator under all operating conditions, along with close alarm monitoring of the air gap, warrants reliable and safe operation which defers the need for a major refurbishment.

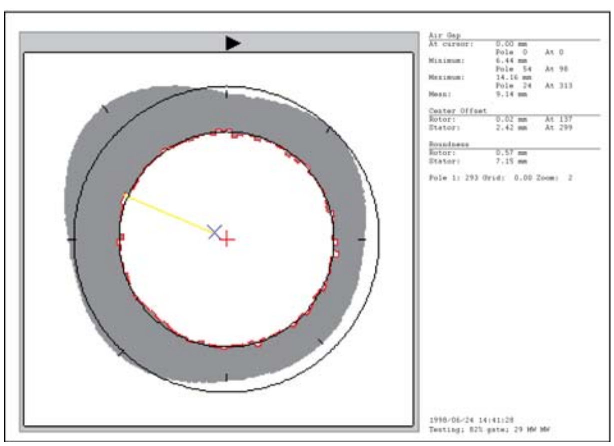

Figure 5: Polar view of bulb generator air gap revealing a bulge on the stator shape in the 300° area resulting from a structural problem during commissioning.

Example 3:
When air gap alarms occurred on the sensor on the upper part of a 25-MW bulb unit, the utility went to look at its air gap data to investigate. The data showed that the stator shape was encroaching into the air gap on the upper part. Trend data for this sensor indicated a constant value reduction over a period of time while the other sensors were stable. The utility stopped the machine to inspect and found that the suspect section of stator core had come loose and gravity helping was falling into the air gap. Without air gap monitoring, this condition would have gone unnoticed until a rotor-stator contact that would have incurred a prolonged forced outage.

Example 4:
A utility reported being able to trend the condition and wear of its bearing segments by tracking the sagging of the shaft inside the bearings as measured by the proximity probes and by comparing the air gap variations of air gap sensors at upper and lower parts of the bulb generator (reduction at bottom that matched the increase at the top). This information allows the utility to make timely interventions to readjust the concentricity of the machine.

Example 5:
On one of the 42-MW bulb units, the axial shaft displacement was abnormally greater than specified and it damaged the proximity sensors. The sensors for axial displacement were replaced by ones with greater measuring range on all bulb units.

Example 6:
Within months of its commissioning, a first 42-MW bulb generator of this 5 unit project experienced a rotor-stator contact resulting from rotor rim failure. At that time, the ZOOM® monitoring system was not operational due to project constraints.

While at site, VibroSystM technician and the plant supervising engineer reviewed data acquired by the system on all machines. They found a transient bump on one unit resulting from a loose section of the rotor rim. With gravity helping, the loose rim section protruded into the air gap when rotating towards the bottom, then returned to its position when passing at the top. This cyclic flexing was imposing stress on the rotor rim components. Comparison with data recorded nine days before clearly revealed the situation was deteriorating very quickly and a failure could potentially occur at any time. Meanwhile, the vibration monitoring instrumentation did not reflect these changes. Utility engineer realized the similarity with the previous incident, ordered the machine stopped and contacted the generator manufacturer.

The rotor rim was found to be in much worse condition than the unit that sustained the first incident. A detailed generator design review was performed and modifications were implemented on all five machines.

This example clearly demonstrates that air gap monitoring is capable of predicting an imminent air gap failure so that preventive action can be taken, while vibration monitoring did not provide any early indication.

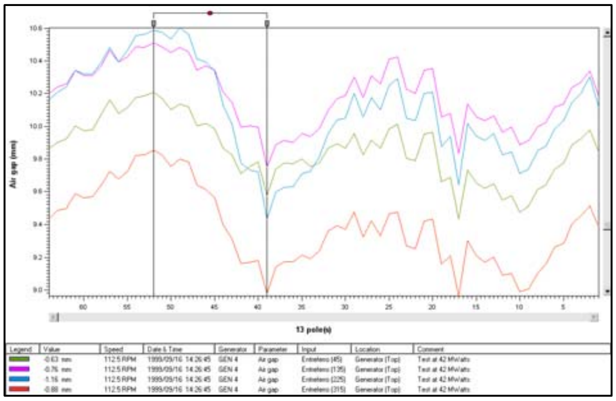

Fig. 6: Signature graph of all sensors showing a significant variation for the sensor at 225° (blue curve) between poles #29 and #52.

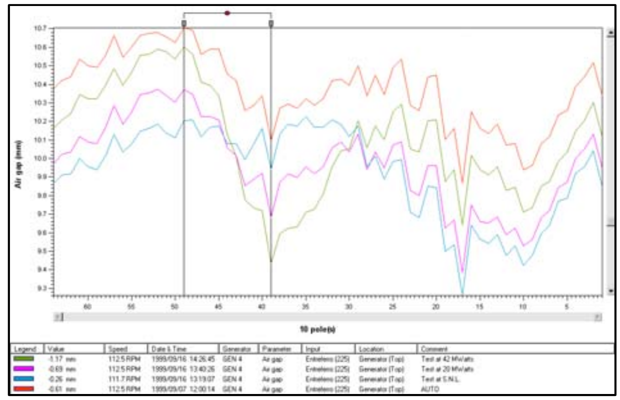

Fig. 7: Signature graph of rotor profile facing sensor at 225° comparison with result 9 days earlier.

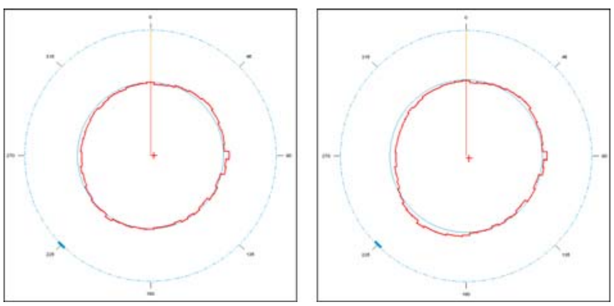

Fig. 8: Polar graphs of rotor profile 9 days apart measured by sensor at 225° (right) angle. Note the bump protrusion in the area between poles #29 and #52.

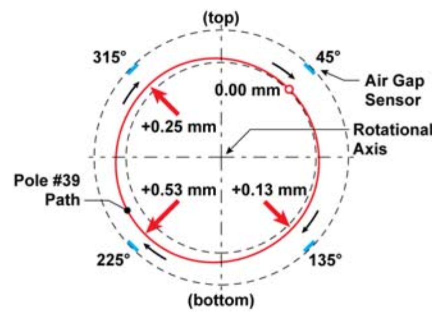

Fig. 9: Illustration of pole #39 (most critical of the loose section) path over one rotation relative to its position facing sensor at 45°.

<u>Example 7:</u>

Implementation of a ZOOM® system on a 10-MVA tidal power bulb unit revealed that the air gap was affected by an increase in the bulb internal temperature caused by a build-up of sea mussels on the bulb nose. The bulb unit has a closed air loop cooling design using the bulb casing as radiator against the sea water. Although the outside of the casing is specially coated to prevent fouling, sea mussel population still grows against the external bulb shell surface and interfere with the heat transfer function. The higher internal temperature meant that the rotor rim expanded more than the stator. A fouling check revealed a 10 cm thick mussel cover all over the bulb nose area. After mussel removal, bulb internal temperature dropped by 10°C and air gap recovered safer values.

Monitoring challenges with bulb units

The main challenges when implementing monitoring instrumentation inside bulb units are: space, access, temperature and the very small air gaps vs rotor diameter.

The space inside the bulb shell for mounting instrumentation, cables, protection boxes, and sensor brackets is very limited and competing with other equipment. In the same fashion, access to the measuring point locations is generally limited, with many physical constraints. So, advance planning is very important. For this reason, whenever possible, several sensors complete with cabling are mounted to the machine during assembly before the individual sections are lowered into place. However, this is not possible with existing bulb machine. So, it is not always possible to install the instrumentation at the best or desired locations, or to rout the signal cables following the easiest path or from generator side to turbine side.

To optimize their capacity, bulb machine designs are typically known for having very small air gap values versus the rotor diameter dimension. This leaves little margin of error for rotor and stator circularity and concentricity. Any variation has immediate impact on the machine behaviour. In addition, the air gap area is always hard to reach and requires sensors that are as thin as possible.

Another constraint is that, once a machine is closed, pressurized and operating, access inside the bulb for servicing the monitoring instrumentation must be regulated. Finally, materials used in the design and manufacture of the instrumentation and electronics must be capable to operate in ambient temperature that can exceed 50°C.

Description of monitoring systems at SANTO ANTÔNIO and JIRAU

The systems for both projects are very alike except for two parameters. They will both have air gap, stator vibration, shaft displacement, bearing vibration and phase reference. The differences are: SANTO ANTÔNIO will have integrated partial discharge monitoring while JIRAU will have turbine blade tip clearance monitoring.

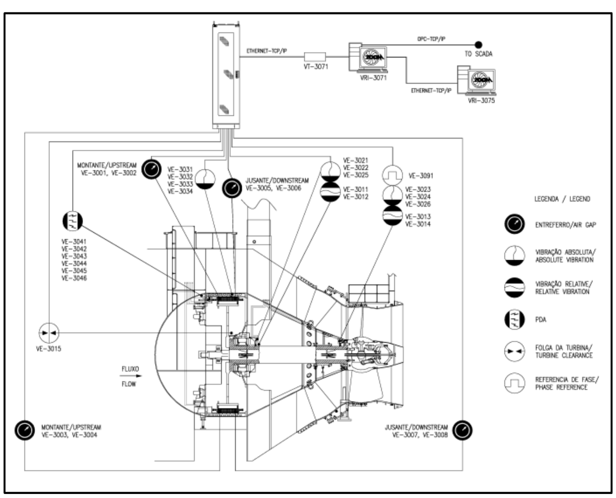

Fig. 10: Flowchart of Santo Antônio project.

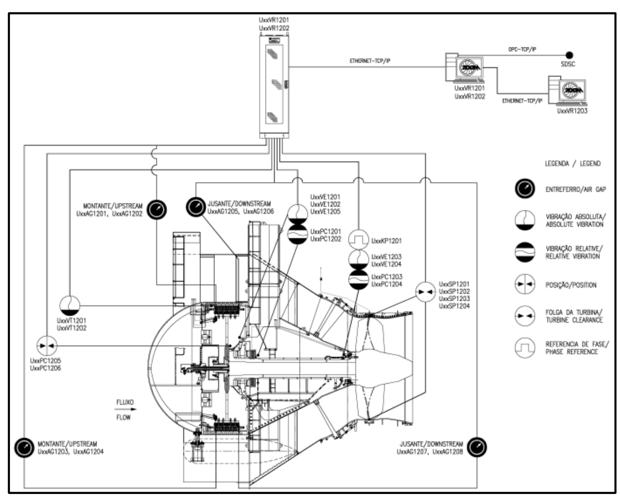

Fig. 11: Flowchart of Jirau project.

For air gap, four (4) VM6 capacitive sensors are installed 90° apart on the upstream side plane of the stator and 4 more on the downstream side. They are connected via 7m integral triaxial cables to eight (8) LIN-360 linearization modules, and their 4-20mA signal outputs are transmitted to the acquisition unit. The VM6 sensor small footprint blocks the smallest amount of ventilation holes while measuring air gap up to 50 mm.

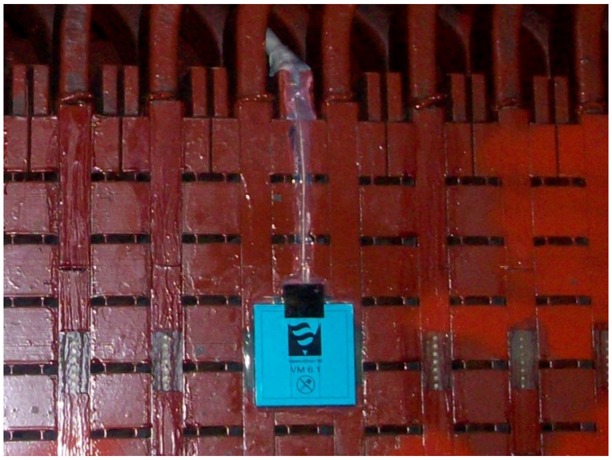

Fig. 12: VM 6 capacitive air gap sensor installed on a stator wall.

Fig. 13: PCS-302 capacitive proximity sensor facing a hydrogenerator shaft.

For stator core vibration, SANTO ANTÔNIO generators are being equipped with four (4) 797V velocimeters, 90° apart, to measure radial vibration, while JIRAU generator will be equipped with two (2) 797V velocimeters located in the same area to measure radial and axial vibration. The velocimeters outputs go through a marshalling box before being sent to the acquisition unit.

For shaft displacement, two (2) PCS-302 capacitive proximity probes are being installed 90° apart on each of the two guide bearings to measure radial relative displacement. For axial shaft displacement, the SANTO ANTÔNIO bulbs are equipped with one (1) PCS-304 probe at the combined guide and thrust bearing near the generator, while the JIRAU bulbs are fitted with two (2) PCS-302 probes at the same location. Capacitive proximity probes have been specified because of their immunity to electrical runout (residual magnetism, shaft current, material type, surface finish) and built-in signal conditioners allowing direct connection of the probes to the acquisition unit without need to mount probe drivers inside the bulb.

For bearing absolute vibration, the generator, the combined guide and thrust bearing near the generator are equipped with three (3) VSM797S accelerometers to measure radial and axial vibration, and the turbine guide bearing is equipped with two (2) accelerometers for radial vibration. The accelerometers outputs are connected directly to the acquisition unit without the need for marshalling boxes.

A synchronization probe is mounted near the turbine guide bearing to provide a one per rotation phase reference to synchronize the measurement on all inputs.

For SANTO ANTÔNIO bulbs, the generators are fitted with six (6) coupling capacitors for partial discharge monitoring, two (2) couplers per phase. They are connected to the PD acquisition unit via a coaxial cable. VibroSystM's PD technology was preferred as it is fully integrated with the machine monitoring system and the whole monitoring technologies are under the responsibility of a single supplier.

For JIRAU bulbs, the turbines are fitted with four (4) SPES-117 submersible proximity probes mounted 90° apart in the turbine liner at the level of the blade tips. The probes are connected to marshalling boxes mounted in the turbine access shaft and the signals are then transmitted to the acquisition unit.

Figure 14: Front (inside) and back views of an installed SPES-117 sensor in the throat ring.

The instrumentation cabinets housing the data acquisition units, power supplies, protection relays and Ethernet communication devices are located near the generator access shaft of each bulb units. Data is acquired via two (2) ZPU-5000 multi-channel monitor for a capability of up to 32 inputs. It continuously processes signals from each input and monitors them for alarms, it performs different types of automatic and on-demand measurements, and transmits data to the system controller via the dedicated Ethernet network. When an alarm is detected, the ZPU-5000 triggers the corresponding dry contact relay which is connected to the control system. A measurement is recorded and a warning message is transmitted through the network to all connected users. For partial discharge monitoring at SANTO ANTÔNIO, signals from the couplers are connected to a PDI-100 interface unit and to a PDA-100 analyzer unit, then transmitted to the system controller via the same Ethernet network. The cabinets are equipped for redundant DC voltage inputs with breakers and undervoltage relays to notify of power input failure on one of the power source. They also include ventilation system to avoid excess temperature and heaters against humidity.

Fig. 15: Front view of Santo Antônio cabinet.   Fig. 16: Rear view of cabinet.

The system at each plant will be managed by a distributed network of system controllers (server-grade computer) in each powerhouse, i.e. four (4) controllers at SANTO ANTÔNIO and four (4) at JIRAU. This is required because the way the powerhouses are being built and put into service, as well as to ensure performance and overall reliability to avoid overburdening the processors. Each system controllers will manage a set of acquisition units through the ZOOM dedicated Ethernet fiber-optic network, and store database. In addition, each controller will be interfaced with the SDSC system to collect valuable complementary information about its set of machines for trending and correlation. A human-machine interface (HMI) workstation (desktop computer), located in the control room of each power plant, will serve to display the monitoring status of any machine, annunciate alarm conditions and provide access to the various databases for analysis. Additionally, data from each plant could be accessed remotely via corporate WAN network by companies' engineers and decision makers from the head office or anywhere in Brazil.

Figure 17: One of Jirau rackmount controller.

The ZOOM software analysis features include: polar view of the generator rotor inside the stator referenced to tolerances, polar view of the turbine blade tips inside the throat ring, shaft orbit view referenced to the rotor pole angular positions, FFT, scatter plots and waveforms of partial discharges, and trends just to name a few.

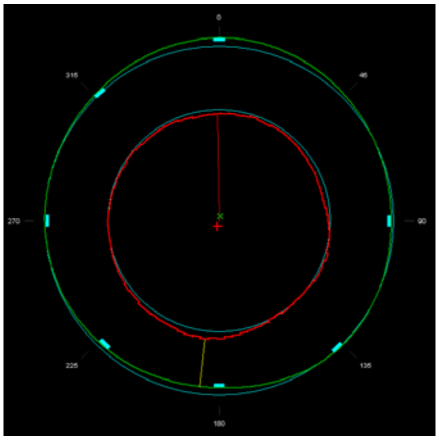

Fig. 18: Sample of polar graph of generator air gap.

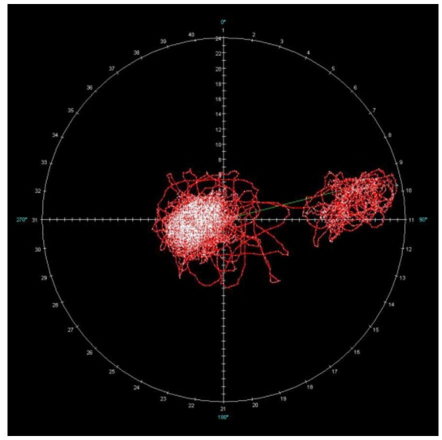

Fig. 19: Sample of orbit graph referenced to rotor pole position.

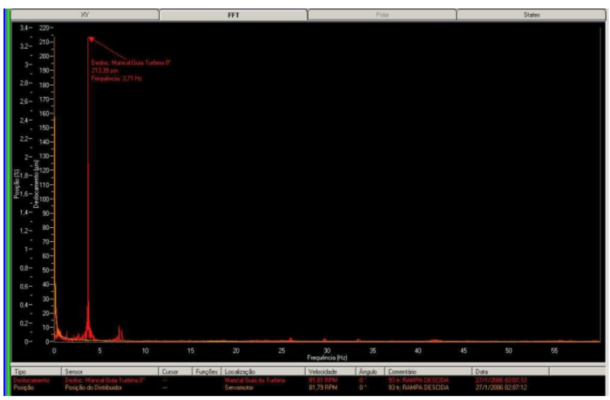

Fig. 20: Sample of spectrum graph.

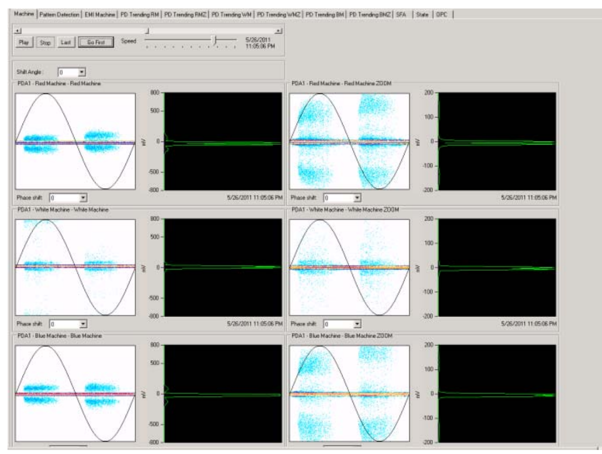

Fig. 21: Sample of PD scatter plots.

Completing the scope of supply for SANTO ANTÔNIO is VibroSystM's Results Interpretation Services (RIS). It consists of reports on a machine's mechanical condition and dynamic behaviour based on a series of tests recorded under a range of operating and transient modes, from standstill to full load hot and overspeed. A set of 3 reports per machine over a period of 1 year will be provided to trend the early evolution and ageing of the 44 machines.

Conclusion

All generating bulb units at JIRAU and SANTO ANTÔNIO projects will be equipped with state-of-the-art machine condition monitoring systems to monitor from the onset their behaviour and condition during the early ageing years. The monitoring program will build a database of results starting with baseline measurements that will ultimately be used for future reference. During the critical first years of operation and subsequent years, it will enable the plants owners to optimize operation and maintenance activities, detect premature ageing to enforce warranty terms, and reduce the risk of equipment failure.

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Biography

André Tétreault joined VibroSystM in 1995 as a technical support specialist. He has travelled extensively in order to install and commission our monitoring systems worldwide. He is presently head of the Tests & Diagnostics Division at VibroSystM headquarters in Longueuil, Quebec. He has 10 years of experience in analyzing monitoring data and has spent the last 5 years producing all Results Interpretation Reports (RIS) for hydro and turbo generators. He has published many papers on generator behavior at various conferences and works extensively with our customers, giving data interpretation and generator monitoring training courses, to help utilities manage their machines.

Wellington Gomes joined VibroSystM in 2010 as a sales representative for Brazilian market. He has 15 years of experience in sales/customer support. He studied system analysis and accounting in Brazil and project management in Canada. He is responsible for many projects in Brazil including the SANTO ANTÔNIO and JIRAU hydroelectric projects.