

AIR GAP MONITORING KEY ELEMENT TO AVOID UNNECESSARY AND COSTLY REPAIRS

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Introduction

In the summer of 2010, Portland General Electric decided to install an on-line monitoring system on their 95 MWatts hydro-electric generator, in order to closely monitor the air gap with the help of four (4) air gap sensors, which were installed at the upper part of the stator core a few years previously

The Utility suspected rotor structural integrity problems, namely floating rotor rim issues because of existing condition on other Units at the plant. The Utility wanted to verify if this was the case, prior to a planned outage in the fall of 2011; where significant repair work was scheduled for the rotor.

Dynamic behaviour tests were performed in June of 2010, in order to produce a comprehensive analysis report. Tests were performed while the Unit was under most operating conditions. With the use of the ZOOM© diagnostic software, it was possible to determine the rotor and stator shapes, as well as their relative position.

This paper will show how this type of technology is very valuable when verifying the rotor and stator integrity under all operating conditions. No other tool is capable of providing the necessary information to ensure the safe operation of a generator in regards to rotor/stator interaction.

In this particular case, the monitoring system, more specifically the air gap data, prevented major unnecessary repairs on the rotor. In addition, the monitoring system was able to reveal other issues which had remained undetected at that point. A discrepancy between the magnetic center and mechanical center was observed. This new information would allow for corrective actions to be undertaken during the planned outage, which would not have been performed otherwise.

Finally, data recorded by radial shaft displacement probes located at the upper guide bearing showed that the behaviour was suspect and required close investigation. Phenomena's such as skating (sub-harmonic frequencies) and negative orbits were observed which suggested problems with the bearing itself.

1. Background

In the summer of 2010, Portland General Electric decided to install an on-line monitoring system on their 95 MWatts hydro-electric generator, in order to closely monitor the air gap with the help of four (4) air gap sensors, which were installed at the upper part of the stator core at 90° intervals with the first sensor located at 0° upstream. In addition to the air gap sensors, radial capacitive shaft displacement probes were also installed at the upper and turbine guide bearings.

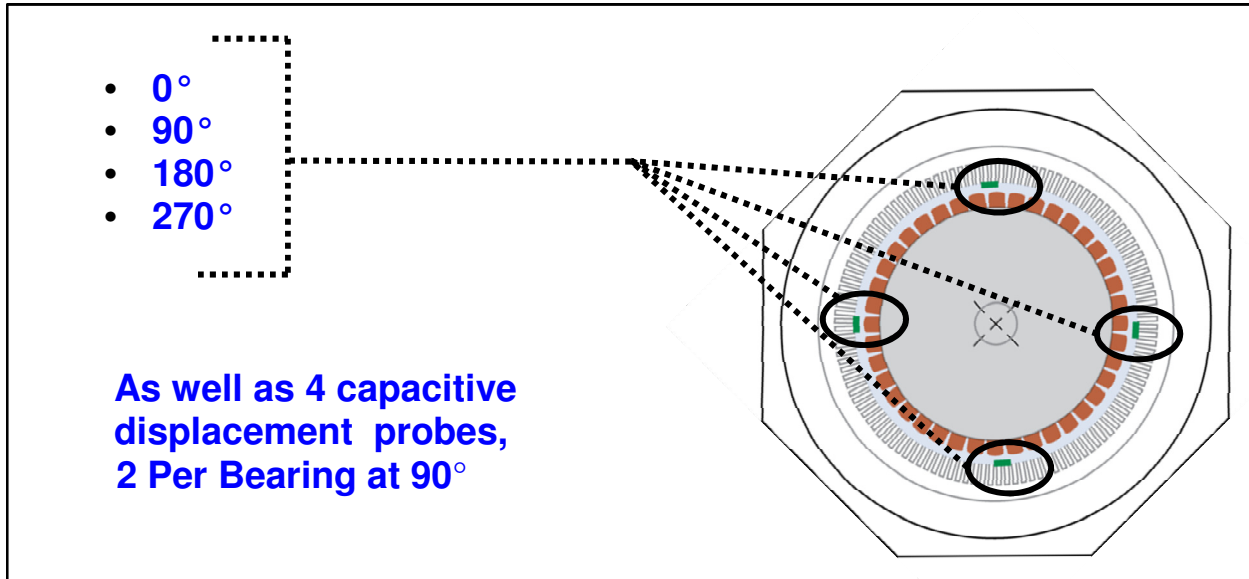


Figure 1 Location of air gap sensors on stator core

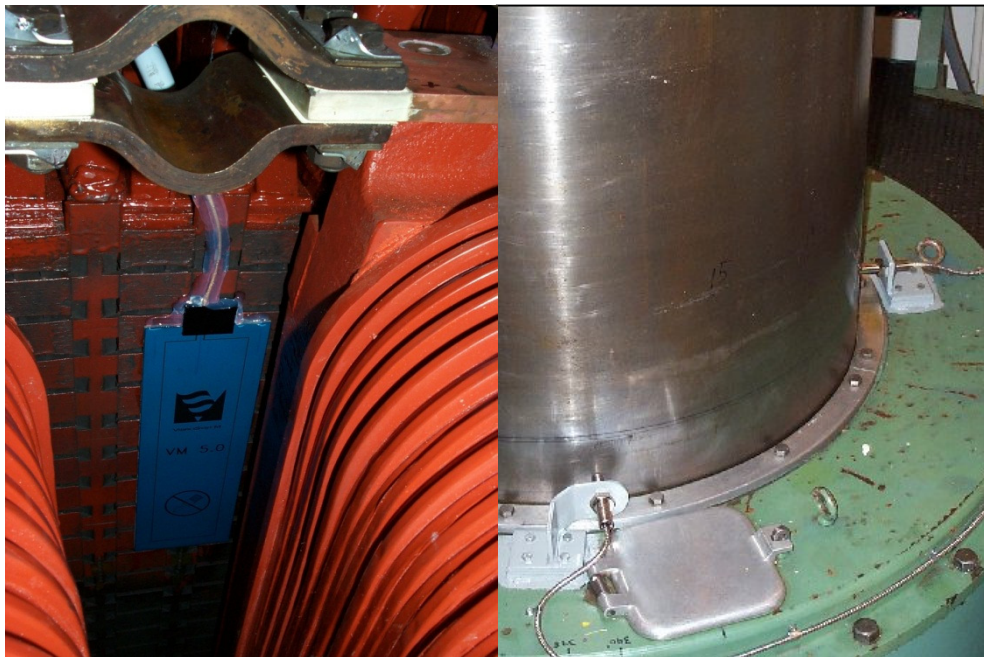


Figure 2 Air gap sensors installed on stator core and radial shaft displacement probes.

The Utility suspected rotor rim issues, based on problems observed on Units 2 and 3 of the same power station. Mechanical tell-tale devices were installed and rotor vector variations were detected. These results seem to indicate

possible floating rim problems. The results of the testing with the air gap monitoring system were to be used to propose recommendations prior to the planned outage of fall 2011. At that time, a complete rotor/stator rewind was planned.

2. Results – Rotor structural integrity

Dynamic behaviour tests were performed in June of 2010. The tests were performed while the Unit was under most operating conditions. With the use of the ZOOM© diagnostic software, it was possible to determine the rotor and stator shapes, as well as their relative position.

The following *TABLE* includes the results for both rotor and stator circularity (shape) and concentricity (position). In addition, values for shaft displacement were recorded therefore; they are also available in the *TABLE*.

TABLE 1 - RESULTS VS. MECHANICAL TOLERANCES (June 2nd, 2010)

Parameters	TOLERANCES			
	Results**	Assembly	Acceptable	Critical
Max. Air Gap Variations	10.7%	< 13 %	13 to 30 %	> 30 %
Stator app. Circularity	8.1%	< 7 %	7 to 20 %	> 20 %
Stator Concentricity	3.7%	< 5 %	5 to 10 %	> 10 %
Rotor Circularity	2.5%	< 6 %	6 to 10 %	> 10 %
Rotor Concentricity	0.9%	< 1.2 %	1.2 to 4 %	> 4 %
Upper guide vibration*	140 µm	< 100 µm	100 to 300 µm	> 300 µm
Turbine guide vibration*	65 µm	< 75 µm	75 to 230 µm	> 230 µm
Minimum air gap	72.4%	> 85%	85% to 50%	< 50%

* Vibration values are expressed in µm, pk-pk.

** Results are in reference to a nominal air gap of 21,5 mm.

These results clearly indicated that the rotor and stator dynamic behaviour was quite acceptable under full load conditions. The rotor dynamic results were excellent while the results for the stator were well within acceptable tolerances, with the exception of the stator apparent circularity, where values slightly above accepted tolerance levels were observed. The minimum air gap value observed was 15,6 mm, representing 72.4% of the nominal air gap. This result is considered low however, lower than nominal air gap results are quite common in hydroelectric generators.

The shaft vibration results were also quite good, especially at the turbine guide bearing. Values at the upper guide bearing were only slightly above tolerances.

TABLE 2 of the following page shows the air gap and rotor/stator results throughout the various operating conditions of the Unit. The results indicated that the rotor performed very well under all operating conditions. Rotor circularity and concentricity values remained excellent at all times. In addition, the concentricity angle varied very little throughout the tests, confirming a very good structural stability for this rotor. The minimum air gap remained below nominal, as is usually the case for hydroelectric generators, but was constant throughout. Clearly, the results showed no evidence of a floating rim problem, or any other rotor structural problems.

TABLE 2 – SUMMARY OF AIR GAP MEASUREMENTS

Operating conditions	Date	Time	Average air gap	Stator		Rotor	
				Concentricity Value/Angle	Apparent Circularity	Concentricity Value/Angle	Circularity
Air gap test results							
(41 RPM)	1/06/2010	15h28	16,2	0,5 / 267°	1,1	0,1 / 211°	0,3
(97 RPM)	1/06/2010	15h42	17,2	0,7 / 281°	1,5	0,1 / 207°	0,3
(130 RPM)	1/06/2010	15h53	16,9	0,7 / 281°	1,7	0,1 / 203°	0,4
Speed no load	2/06/2010	10h15	16,9	0,7 / 293°	1,4	0,1 / 203°	0,3
Field applied	2/06/2010	10h33	16,8	1,2 / 272°	2,6	0,1 / 195°	0,3
25 MWatts	2/06/2010	10h48	16,9	1,2 / 271°	2,6	0,1 / 197°	0,3
50 MWatts	2/06/2010	10h53	16,8	0,9 / 265°	1,9	0,1 / 214°	0,3
60 MWatts	2/06/2010	10h54	16,8	1,0 / 266°	2,2	0,1 / 216°	0,4
95 MWatts	2/06/2010	10h59	16,8	0,9 / 254°	1,9	0,1 / 215°	0,4
96 MWatts	2/06/2010	11h03	16,8	0,8 / 255°	1,8	0,1 / 215°	0,4

3. Results – Rotor mechanical vs. magnetic centers

Figure 3 of the following page shows the rotor behaviour as the magnetic field is introduced into the air gap. We can clearly see that the rotor is pulled in the direction of 90° (blue trace), while moving away from 270° (purple trace). The moment the magnetic field appears, the rotor and stator are subjected to very high electromagnetic forces. The position of the rotor, in regards to the stator, is crucial at this moment if the Unit is to maintain an electromagnetic stability. In this case, the air gap prior to the field flash is smaller at 90° (~ 16,0 mm) than at 270° (~ 17,5 mm) therefore; the forces in the area near 90° are much greater than those present near 270°. The end result is that the rotor is instantaneously pulled towards the smallest air gap, found at 90°. In this case, the rotor moved from its mechanical centre to its magnetic centre by a distance of ~ 500 µm. At the same time, the upper guide bearing shaft displacement probes recorded a movement of ~ 370 µm (See Figure 4). The variation between the rotor movement and the shaft movement is due to additional factors; such as stator core movement towards the air gap as well as rotor expansion.

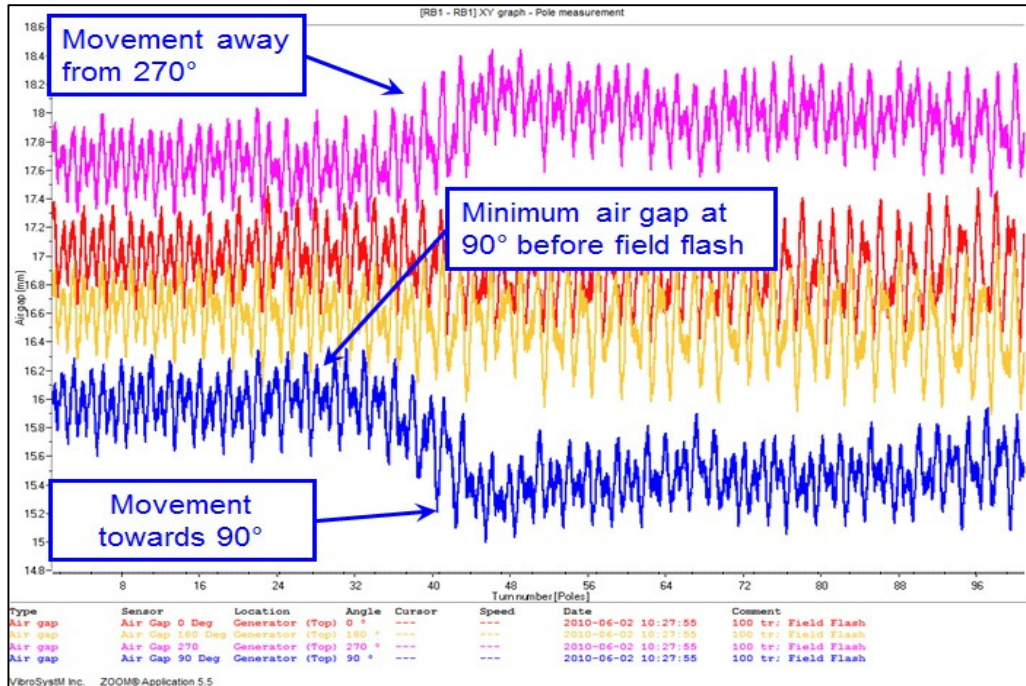


Figure 3 – Magnetic center vs. mechanical center

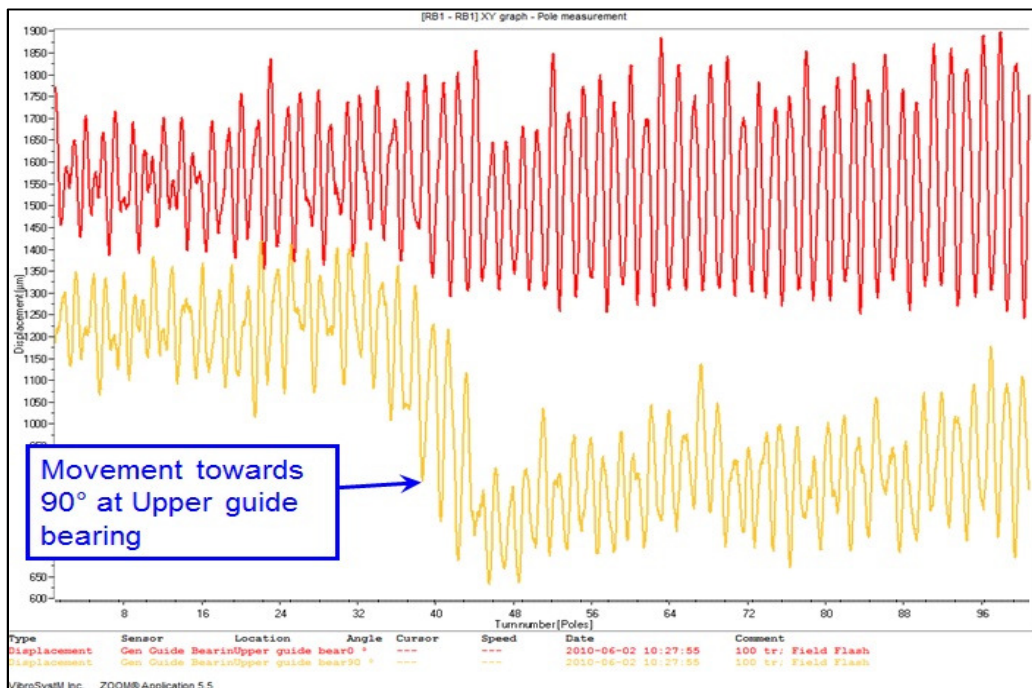


Figure 4 – Magnetic center vs. mechanical center at upper guide bearing

Figures 5 and 6 below represent polar views of the same movement towards 90° upon field flash. An air gap decrease of ~ 500 μm was observed.

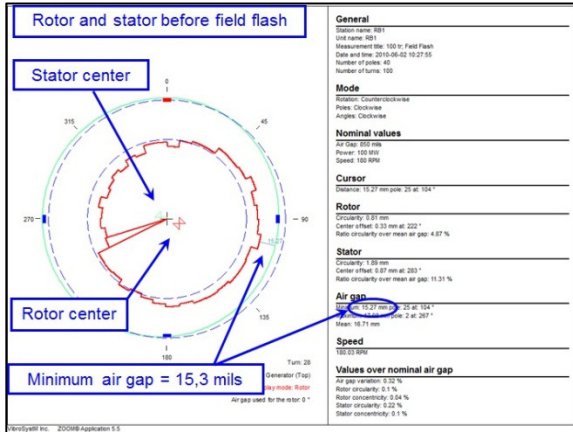


Figure 5 – Rotor and stator before field flash

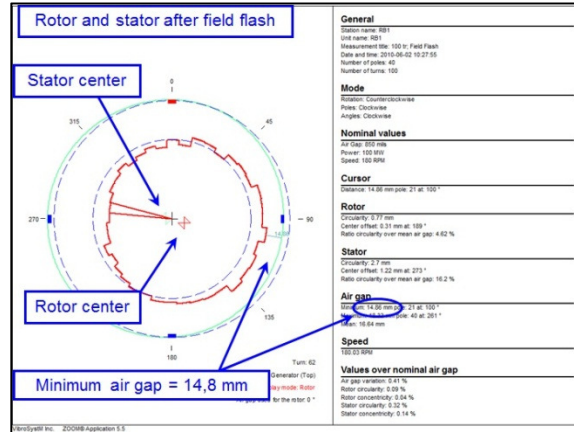


Figure 6 – Rotor and stator after field flash

4. Results – Relative shaft displacement

Figures 7 and 8 below show the vibratory behaviour of the shaft while the Unit was operating at 25 MW. A sub-synchronous frequency can clearly be observed at the upper guide bearing (1.8 Hz). The fundamental frequency for this Unit is 3 Hz (180 RPM). The Orbit graph indicates clear evidence of skating whereas the Unit requires more than one (1) rotation to complete its Orbit. This skating phenomenon is represented in the FFT graph as a sub-synchronous frequency. In addition, reverse orbits were recorded when the Unit was operating at this load. We can see in the Orbit graph that although this Unit's rotation direction is counter-clockwise, the Orbits path is clockwise (the first rotation is in white while the second rotation is presented in red).

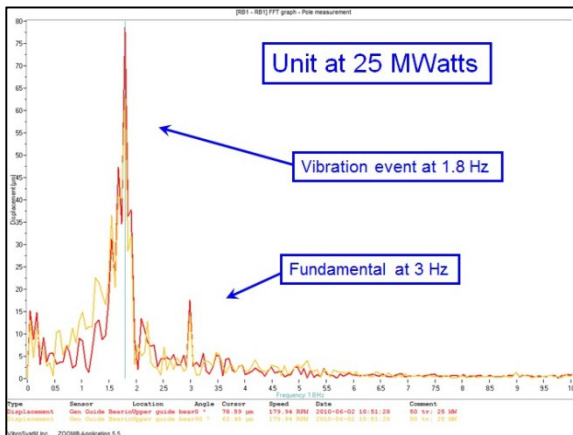


Figure 7 – Sub-Synchronous frequency at 25 MW

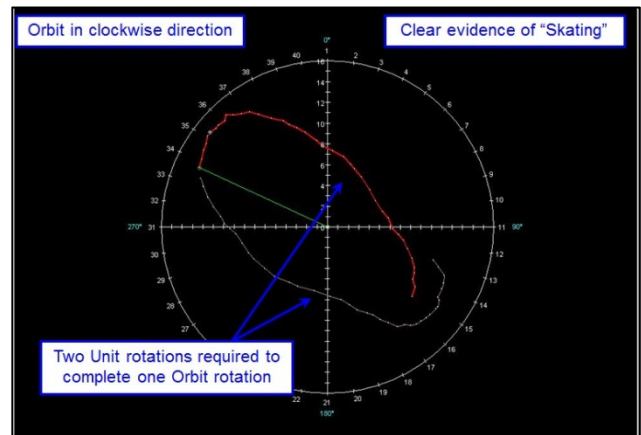


Figure 8 – Evidence of skating at upper guide bearing

Figures 9 and 10 of the following page show the vibratory behaviour of the shaft while the Unit was operating at 96 MW. The aforementioned sub-synchronous frequency values have greatly decreased. The fundamental frequency values have increased but are still at acceptable levels (~ 130 μm, pk-pk). The Orbit graph indicates that the Orbit path was now stable in that one rotation per turn was present and no reverse orbits were observed.

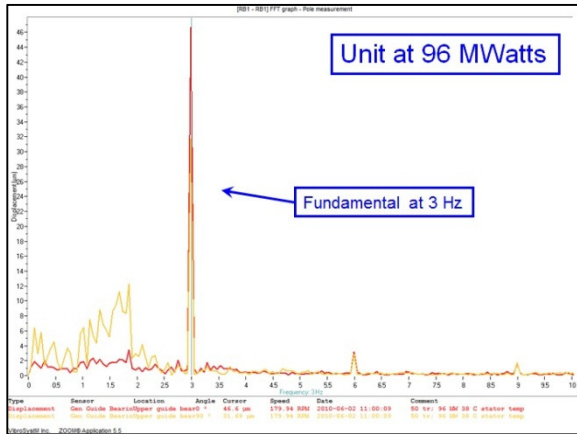


Figure 9 –Fundamental at 96 MW

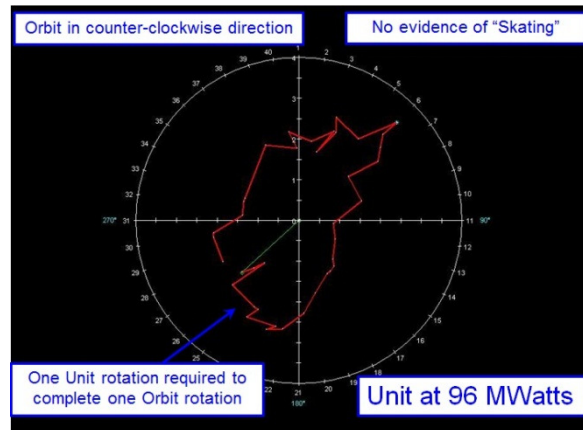


Figure 10 – Skating absent at 96 MW

5. Recommendations

After analyzing the data recorded by the monitoring system, the following recommendations were submitted.

- 1- Unless visible signs of rotor wear and tear are present, structural work on the rotor is not warranted in this case. If during visual inspection of the rotor and its components, signs of red powder, stress cracks are found, these would be clear signs of compromised structural integrity.
- 2- If re-centering of the rotor is not possible during the next outage, then repositioning of the stator should be considered to align the magnetic and mechanical centres of the rotor/stator.
- 3- The upper guide bearing should be verified in order to determine the source of the sub-synchronous frequencies, as well as the reverse orbits found at 25 MW. The possible causes are misalignment of shaft, problems with oil film distribution and bearing integrity issues.

6. Conclusions

The customer has scheduled a full Unit alignment with re-positioning of the stator based on the monitoring system results and analysis. The rotor work will now consist of removing and rewinding the poles only. Rotor rim shrinking is no longer planned. Based on the data recorded during the tests, the emphasis has shifted from a rotor problem to a rotor/stator misalignment issue. The customer plans to investigate the upper guide bearing displacement behaviour during this same outage.

This paper has clearly shown the importance of recording reliable generator behaviour data in order to better manage these assets. The potential savings are significant and more often than not, much greater than the initial costs of the monitoring system itself. It is also very important to have access to trained personnel when analysing the data because, quite often, the observed discrepancies are quite small, often unnoticed to the untrained eye. Furthermore, the source of the problem is not always easily detectable and quite often is the result of multiple problems.

7. The Author

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, Québec. He has over 10 years of experience in analyzing monitoring data and produces all Results Interpretation Reports (RIS) for hydro, turbo generators, as well ball and SAG mills in the mining industry. 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.

8. Acknowledgements

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