AIR GAP MONITORING SYSTEM
KEY ELEMENT TO CORRECTLY DIAGNOSE
GENERATOR PROBLEMS

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SUMMARY

In the summer of 2002, a complete air gap and vibration monitoring system was installed on a 52 MVA hydroelectric generator at the Mascarenhas de Moraes power plant, in the state of Minas Gerais, Brazil. During the commissioning stage of the unit, part of a major refurbishment project of this power station, unusual behaviour was recorded by the monitoring system that created serious concerns about the unit integrity. Initial vibration and air gap measurements recorded at low speed and at nominal speed showed no abnormal activity, although the vibration values were high. However, field application drastically changed the unit behaviour, especially in the area of 0º upstream. This paper will attempt to provide a fascinating look into the art of diagnosing generator problems from a different perspective, with the use of the ZOOM ® system, an on-line comprehensive diagnostic monitoring system provided by VibroSystM.

KEYWORD

Monitoring, National Event, Generation of Electrical Energy

1,0 INTRODUCTION

The air gap portion of the system consisted of four capacitive air gap sensors (VM3.12 type with a range of 2 @ 20 mm) located on the upper plane of the stator at 90º intervals. The vibration portion of the system consisted of capacitive proximity sensors (PCS-200ES type with a range of 0,3 @ 4,3 mm) located on the X (90º) and Y (0º) axis at the upper guide and turbine guide bearing levels. In addition to these sensors, four 797L accelerometers were installed on the stator core at 90º intervals, one capacitive displacement sensor (PCS-200ES type with a range of 0,3 @ 4,3 mm) was installed vertically at the thrust guide bearing level to monitor axial displacement and a wicket gate position parameter was also integrated to the system. Finally, a BRIDGE gateway that allows the transfer of hundreds of parameters using the MODBUS+ protocol was installed between the power plant existing digital system and the ZOOM on-line monitoring system to integrate temperature readings amongst other parameters. The whole system is controlled by comprehensive monitoring software interacting on various computers.

2,0 Observations (Vibration)

The monitoring system was commissioned during the unit commissioning stage. Throughout this process, multiple measurements were taken with the unit running under different conditions. It is during these tests that unusual behaviour was recorded by the monitoring system that created serious concerns about the unit integrity. Vibration measurements recorded at the early stages of testing, before excitation, were high while the air gap measurements recorded concurrently were acceptable. Figure 1 shows the upper guide bearing vibration readings at Speed No Load during the initial stages of a Start Up.

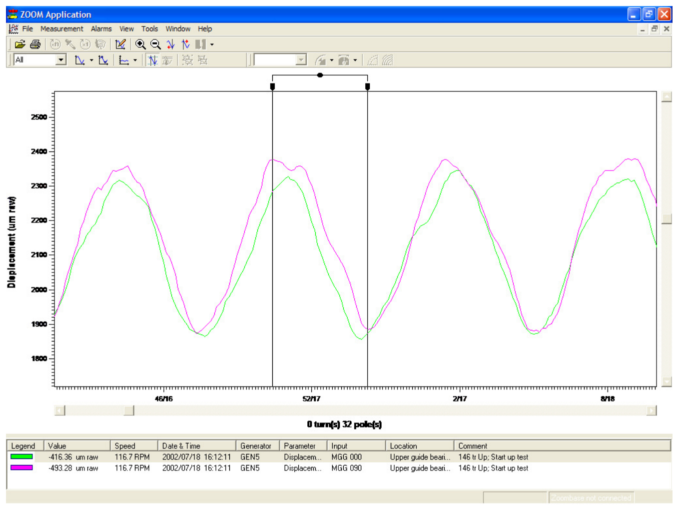

Figure 1. Speed No Load vibration readings. (See Figure 3 also).

We can see that the vibration readings for both axes were in the range of ≈ 500 µm pk-pk. However, the unit behaviour changed drastically with field excitation, especially in the 0º area located upstream. Vibration levels were high during start up but decreased significantly after excitation, as we can see in Figure 2.

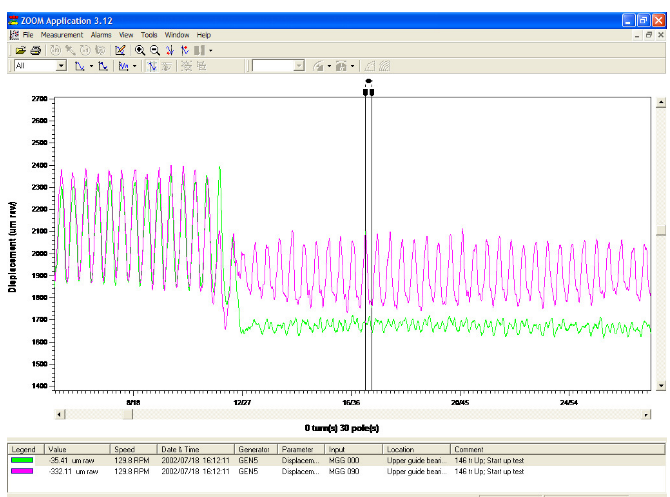

Figure 2. Vibration readings before and after field excitation. (See Orbit in Figure 3).

We can see that the vibration readings in the 90º axis have reduced to the range of ≈ 350 µm pk-pk whereas the vibration readings in the 0º axis have significantly decreased to a range of ≈ 50 µm pk-pk. Furthermore, we can easily observe a shift in the shaft position in the 25º upstream direction of ≈ 470 µm and. This shift is confirmed by tracing an orbit graph of the same measurement with the help of VibroSystM comprehensive diagnostic software. Figure 3 shows the shift towards upstream very clearly.

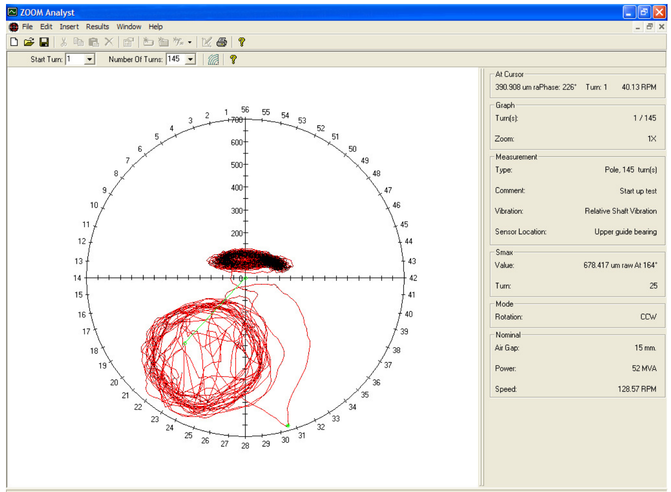

Figure 3. Orbit graph of start-up including field excitation at upper guide bearing.

The shift was thus established but not its cause. Troubleshooting this problem with the sole information provided by a vibration monitoring system is, at best, extremely difficult.

3,0 OBSERVATIONS (AIR GAP)

While the vibration measurements were being recorded, critical air gap measurements were also being taken along with other parameters. The sensors being mounted on the stator, air gap results are thus relative to the stator. When evaluating air gap results on a unit that satisfies mechanical tolerances, a small variation of 0,13 mm is acceptable and is attributed to shaft vibration (<100µm pk-pk), stator core vibration (<25µm pk-pk) and other factors. Stator core vibration exceeding 50 µm pk-pk and shaft vibration exceeding 300µm pk-pk are considered critical [1]. The same start-up measurement that was used for the previous vibration graphs produced the following air gap results shown in Figure 4.

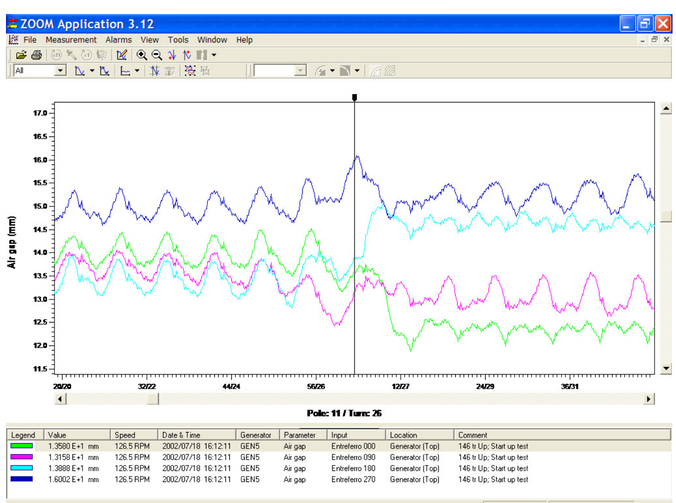

Figure 4. Air gap readings during start-up.

The graph shown above is a representation by VibroSystM software of the minimum air gap reading of each individual pole for each of the four air gap sensors. Each coloured curve represents one air gap sensor with a representation of the passing rotor poles for a certain number of rotations.

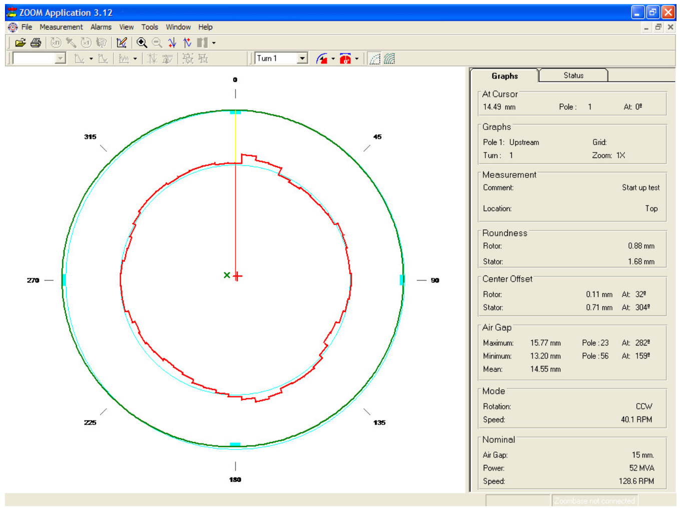

Figure 5. Polar graph of rotor/stator before field excitation.

Figure 5 shows the state of the rotor and stator before excitation while Figure 6 shows the state after field excitation.

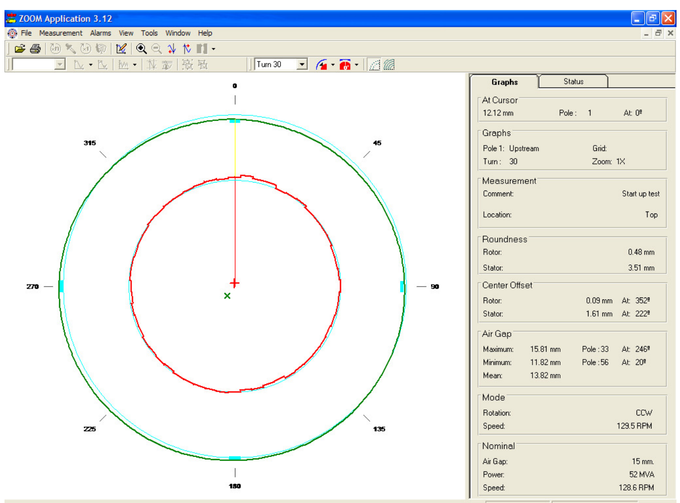

Figure 6. Polar graph of rotor/stator after field excitation.

Typical rotor/stator behaviour during field excitation displays a slight noticeable air gap reduction caused by the sudden magnetic pull between both components. In some cases where the air gap is uneven before excitation, the air gap decreases slightly more in the smaller gap location in relation to the other areas. Figure 7 is a good example of this phenomenon.

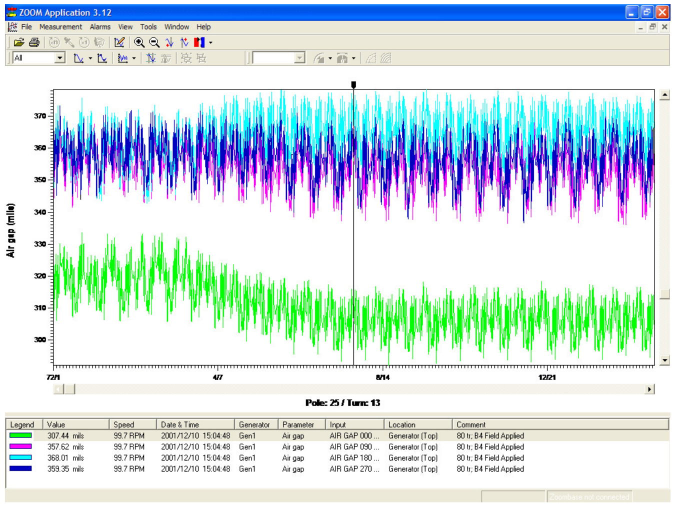

Figure 7. Example of an air gap behavior during excitation on an off-centered rotor-stator creating an uneven air gap.

In this example, we can clearly see that before excitation, the smallest air gap is found in the area of 0º upstream as recorded by the air gap sensor at that location. When the field is applied, the air gap decreases at a higher rate in that area than at the other locations (0º,-400 µm; 90º, -180 µm; 180º, +165 µm; 270º, -140 µm) because the magnetic forces are greater there than elsewhere causing greater stress on the rotor rim and on the stator core as well. As we would expect, the air gap at the opposite side (180º) increases slightly because of the shift towards upstream. By producing a Polar Graph (VibroSystM software representation of the rotor/stator shape for one rotation as seen by the air gap sensors) we can see the small air gap at 0º as shown in Figure 8.

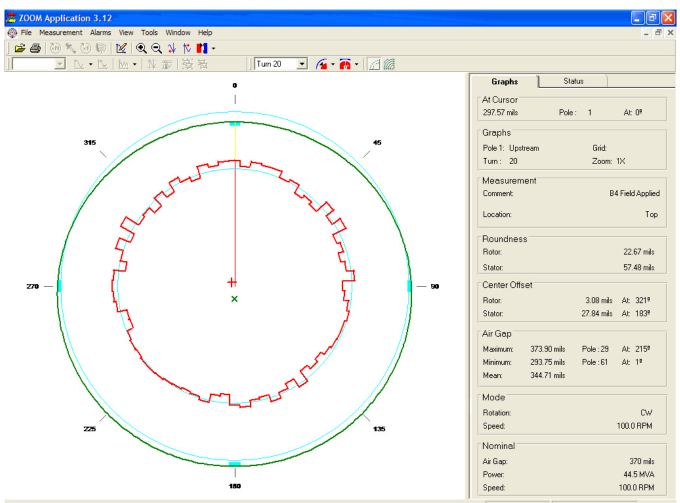

Figure 8. Polar Graph of rotor/stator after field excitation for generator in Figure 7 example.

In the case under study (as shown in Figure 4), we can see that the greatest decrease in the air gap is not recorded at the location where the air gap is initially the smallest (180º) but at the opposite location (0º). The air gap at 0º decreased significantly (-2,24 mm) as well as at 90º (-1,18 mm) while the air gap decreased only slightly at 270º (-0,30 mm) and increased at 180º (+ 0,80 mm). These values were obtained from VibroSystM software which calculates the average air gap of each sensor during one rotation. The increase in air gap at 180º is caused by the rotor shift toward the 25º upstream direction which was close to 470 µm as recorded by the shaft displacement sensors. If the unit is not behaving as expected, then some other factor must be influencing its behaviour.

4,0 OBSERVATIONS (STATOR)

In Section II, we have observed that the shaft displacement in the 0º upstream direction was ≈ 350 µm and at 90º, was ≈ 300 µm. Furthermore, Section III showed a decrease in the air gap at the 0º upstream location of 2,24 mm and at 90º, was 1,18 mm. This leaves a difference of -1,89 mm in the 0º upstream direction and 0,88 mm in the 90º direction. Although some of the discrepancy between the shaft displacement and the air gap values can be attributed to rotor rim movement, we believe that the abnormal behaviour in the air gap at 0º and 90º can only be explained by a significant flexing of the stator in the downstream direction. The movement of the stator, induced by the magnetic pull, contributes in decreasing the air gap significantly, thus increasing the stress between both rotor/stator components pulling the rotor even closer to the stator at the 0º upstream location. We have seen in Figures 2 and 3 that the unit is pulled towards 25º upstream to a point where the unit is almost unable to move anymore in the 0º-180º direction. Most of the displacement at that time (after excitation) is in the 90º-270º direction. We can also see in Figure 4 that the air gap sensors do not record the same behaviour before and after field excitation. This is also due to the unit inability to move in the 0º-180º direction after excitation. Accelerometers installed on the stator core at 90º intervals recorded excessive vibration during the field excitation as shown in Figure 9.

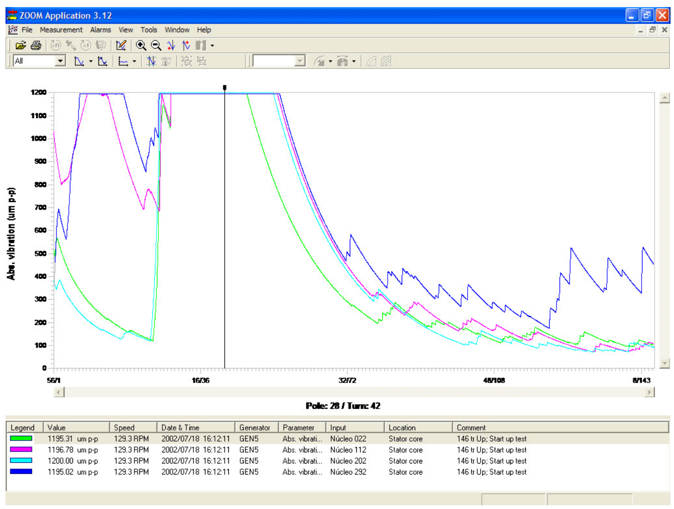

Figure 9. Stator core vibration during field excitation.

The data represented in this graph was obtained via a PCU-100 instrumentation rack processing the acceleration signal into a pk-pk displacement reading. The vibration is so high that it exceeds the accelerometer 1200 µm pk-pk range on all four transducers. This excessive vibration is caused by the flexing of the stator in the downstream direction. To confirm this phenomenon, stator displacement sensors should be added all around the stator at 90º intervals, preferably behind air gap sensors or accelerometers to facilitate their correlation. To further corroborate our assertion that the stator is encroaching at 0º when the field is applied, we have verified the stator behaviour as the unit heats up. We observe in Figure 10, which shows a measurement taken at normal operating temperature five days later, that the stator slowly shifts back close to its original position due to the thermal expansion and regains a better roundness.

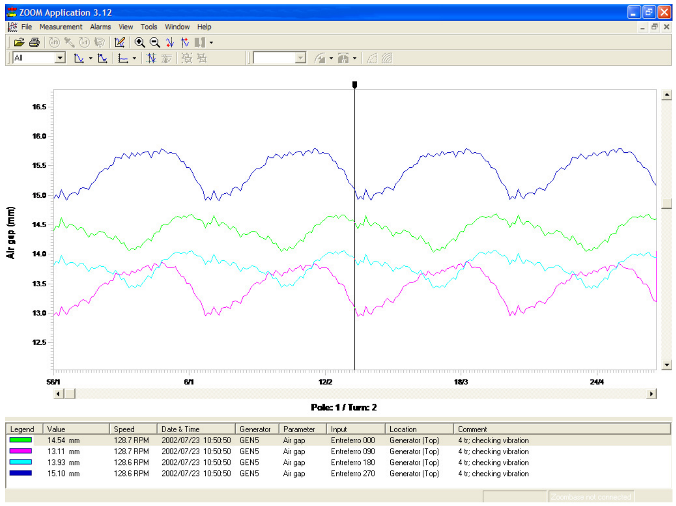

Figure 10. Air gap after thermal expansion of the stator.

The air gap at 0º increased by 2,07 mm while at 90º, it increased by 0,41 mm. The air gap at 180º decreased by 0,90 mm which confirms the stator shift in an upstream direction. The air gap at 270º remained stable with a slight increase of 0,23 mm. Once again the values were obtained from VibroSystM software which uses the average air gap at each sensor during one rotation. It is also interesting to note that at the same time, as shown in Figure 11, the vibration at the UGB 0º increased from ≈ 50 µm pk-pk to ≈ 170 µm pk-pk while the vibration at the UGB 90º decreased from ≈ 280 µm pk-pk to ≈ 130 µm pk-pk. Seeing that the stator moved back in the upstream direction and improved its circularity, the magnetic stress on the rotor in the area of 0º decreases thus allowing the rotor greater movement in the 0º-180º direction and less movement in the 90º-270º direction.

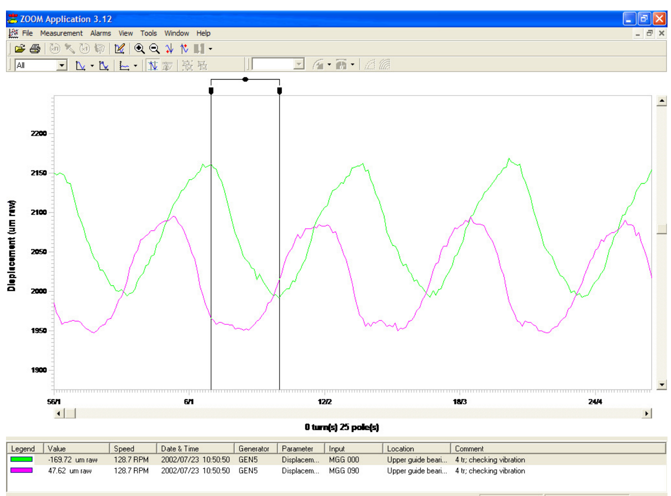

Figure 11. Vibration variation after thermal expansion of the stator.

We can also observe the drastic change in the shaft displacement using an Orbit graph as shown in Figure 12.

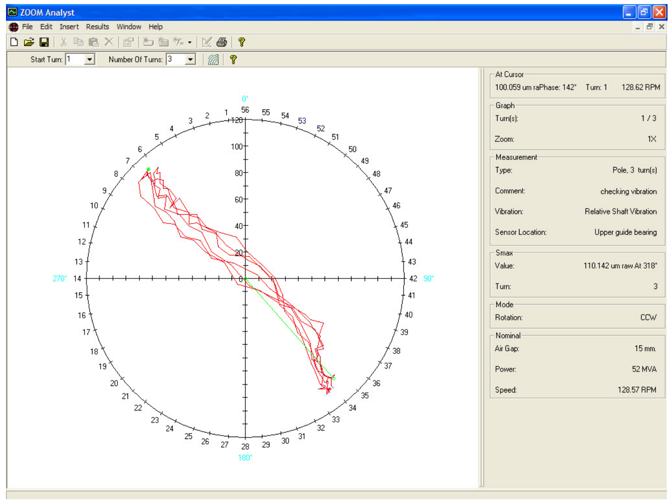

Figure 12. Orbit of Upper Guide bearing displacement after thermal expansion of the stator.

5,0 FOLLOW UP

The Unit was stopped again to resolve the discovered problem and other issues. The stator was moved 1,0 mm upstream in an attempt to improve the Unit behaviour. Although this procedure helped in decreasing the shaft vibration values when the field was applied, the major problem remained. The Unit still experienced instability when the Unit was at Speed No Load (with field applied) condition. The Unit would experience significant change in its behaviour when the field was applied and would see an increase in the shaft vibration values after time. So far, four Units (Units #5 to #8) have been refurbished and all of them have experienced similar behaviour. Two Units (#6 and #7) have been shutdown for almost a year waiting for a solution from the manufacturer. Units #5 and #8 have experienced similar behaviour however, the problem is not as severe (although the Units performed better before being refurbished) and both Units are in operation at this time. The manufacturer is studying the problem and believes that it is related to the upper guide bearing stiffness. One of the major parts of the refurbishment project was to upgrade the stator insulation from class B to class F. The Unit stators were comprised of four bar circuits prior to the modifications. With the change in insulation, the manufacturer introduced a one bar circuit approach, which increased the magnetic pull, without re-designing the upper guide bearing stiffness. This could explain the erratic behaviour of the Units. The manufacturer is now planning to reinforce the upper bracket, which supports the upper guide bearing, to increase the bearing stiffness. The upper bracket is bolted to the powerhouse concrete. This modification is expected to be implemented no later than next December.

6,0 CONCLUSION

It is clear in this case, that the VibroSystM ZOOM monitoring system, integrating air gap with other parameters, was instrumental in understanding this unit abnormal behaviour. As we were able to observe, although the vibration monitoring equipment showed a definite movement of the unit in the upstream direction, only the information provided by the air gap parameter allowed us to correctly identify the behaviour of a moving stator. The use of shaft vibration monitoring alone would not provide the necessary information to perform such complete analysis and diagnosis. Engineers could easily perform unnecessary adjustments or repairs on rotor or bearing components, which significantly increases downtime as well as costs, without actually solving the problem, unless they have access to air gap data. In cases like these, the critical information provided by the air gap monitoring system allows the maintenance engineers to make informed decisions and plan their interventions in a cost efficient fashion. Reducing downtime and preventing major faults is possible with the proper information. In the case of new or newly refurbished units, the information provided by an integrated monitoring system is very important to ensure that the units meet the minimum specifications before they are handed over to the utility company. Moreover, the information provided is used as reference to ensure that the units remain within the minimum tolerances during the first critical months of operation and throughout the warranty period.

7,0 ACKNOWLEDGMENT

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8,0 REFERENCES

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