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A1-301

CIGRE 2012

Tidal Power Plant Bulb Unit Management Through Air Gap Monitoring

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SUMMARY

The La Rance tidal power plant, the first of its kind, located in Saint-Malo on the northern shore of Brittany, France, is a unique example of engineering in regards to power generation. Its unique management of tidal waters in order to produce electrical energy is a clear example of applied engineering, in order to make use of existing geography to produce clean, renewable energy for the future.

After 2 rotor/stator rubs on its bulb Units, one in 1995 and a second one in 2005, it became clear that unexpected displacements and/or deformations were occurring in these Units. With the help of an on-line monitoring system, which included a dynamic air gap monitoring system, the utility was able to record and analyse particular behaviour, which allowed for actions to be undertaken ensuring the long term operation of these Units. In fact, the correlation of air gap, vibration and associated machine parameters allowed for a better understanding of rotor displacement and shape, as well as stator position and shape, by revealing the mechanisms involved and provided the necessary information to intervene efficiently. The monitoring system consisted of sensors, signal processing and data management. Various issues were raised and analysed during this process. Initially, 3 bulb Units were fitted with dynamic air gap monitoring in order to quantify the suspected rotor deformations.

The first issue raised was fretting corrosion, which had been occurring at the shrink fit areas between the rim and the rotor hub, leading to shrink fit reduction (but without any possible quantification). The air gap monitoring system provided clear data so as to determine the actual situation in regards to the fretting of the rim.

The second issue was the confirmation of a rotor clover deformation, which was expected however, the amplitude observed was surprising.

The third issue raised was the discovery of the air gap behaviour in reference to thermal variations, which was contrary to common expected behaviour.

This paper will show the importance of air gap monitoring, especially in regards to Units which are designed with very small air gap clearances. The design of tidal powered Units makes them ideal candidates for air gap monitoring because they gather almost all stresses influencing air gap.

KEYWORDS

Air gap, Tidal Bulb Unit, rotor/stator rubs, fretting corrosion, shrink fit reduction, rotor deformation, thermal variations.

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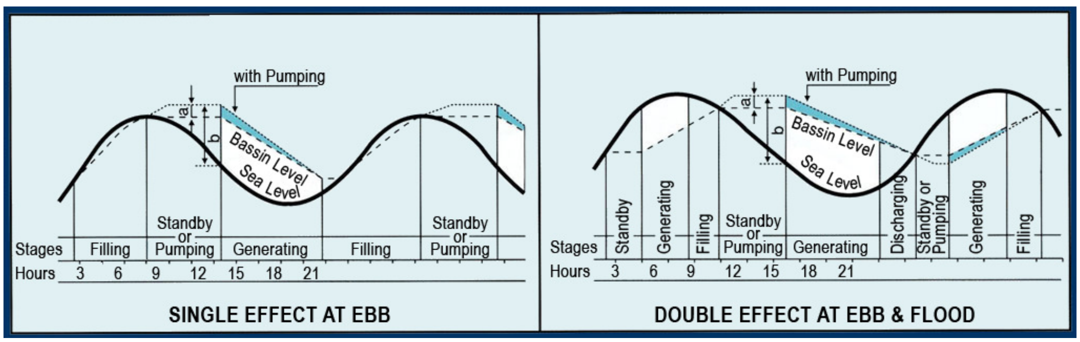
INTRODUCTION

Electricité de France operates roughly a 100 GW generation fleet in France, among which tidal power plays a special role with the La Rance power plant.

La Rance tidal power station is located on the northern shore of Brittany in France near St-Malo; this region is reputed for its large tide amplitude (among the world largest, up to 13,5 meters). It was built in the early 60s and commissioned from 1966 to 1967. It generates annually 550 GW·h.

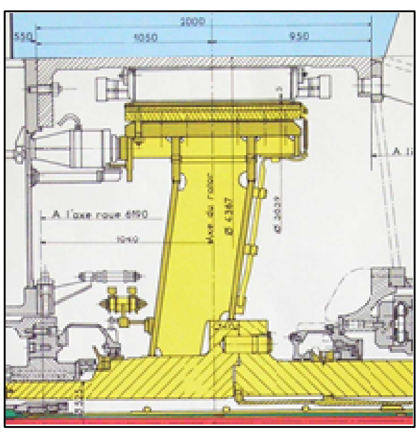
It includes 24 bulb Units, 10MVA each, with 93,7rpm rotating speed (64 poles). The generator theoretical air gap is 4,5 or 5 mm, depending on generator manufacturer.

As part of its operation scheme, the generating sets must be able to generate energy during flood and ebb tides, but also be able to pump extra water in the reservoir at high tide, so as to store more energy and increase water head for the next turbine cycle. With 2 tides per day, the operating cycle occurs twice a day; depending on tide amplitude. The power plant only generates at ebb tide (single effect) or at both ebb and flood tide (double effect) therefore; up to 4 grid connection and up to 4 heat run cycles occur per day. Hence, specific care and innovative technology were used in the generating



Tidal power plant operation with single or double effect generation (white areas).

sets to cope with heavy cycle stresses: e.g. shrink fit rotor rim on rotor spider arms. However, after more than 40 years of service, signs of wear were noticed which called for specific attention.



Rotor rim and spider arm sketch.

Fretting corrosion at rim/hub junction.

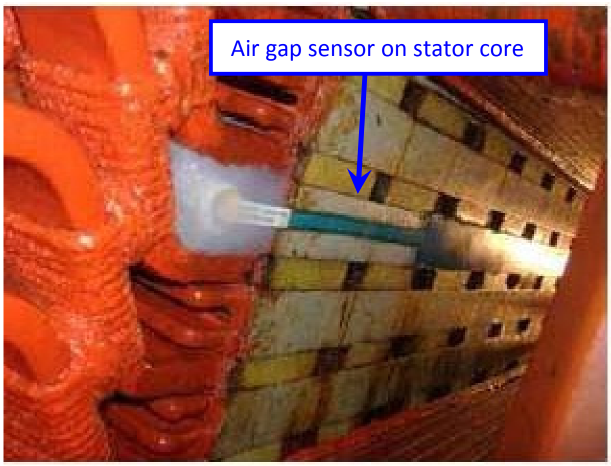
Indeed, for a few years, fretting corrosion phenomena had been occurring at the shrink fit areas between the rim and rotor hub, leading to shrink fit stress reduction (but without any possible quantification). Evaluating the remaining shrink fit stress became an issue after 2 stator/rotor (1995 and 2005) rubs, where rotor rim displacement appeared to have played a significant role but without any fully satisfactory explanations. Also, during outages, periodic off line air gap checks were performed; through these readings, reduction of air gap values were noticed without any logical answer.

DYNAMIC AIR GAP MONITORING

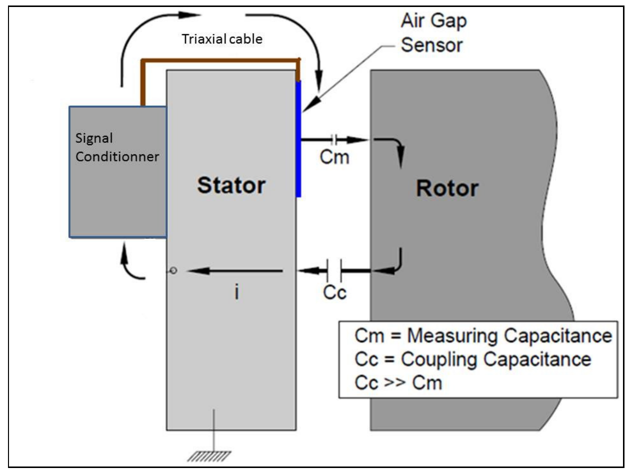
Initially, it was decided by plant management to fit 3 Units with dynamic air gap monitoring in order to get real time picture of the generating sets deformation.

The system was supplied by a specialized foreign vendor with worldwide references The Units were fitted with the following:

- 6 capacitive air gap sensors selected for low air gap range;
  (sensor thickness 1,2mm ; measuring range : 1 to 10mm)
- 1 real time signal processing unit with 16 fast acquisition channels, used to collect air gap and additional dynamic data.

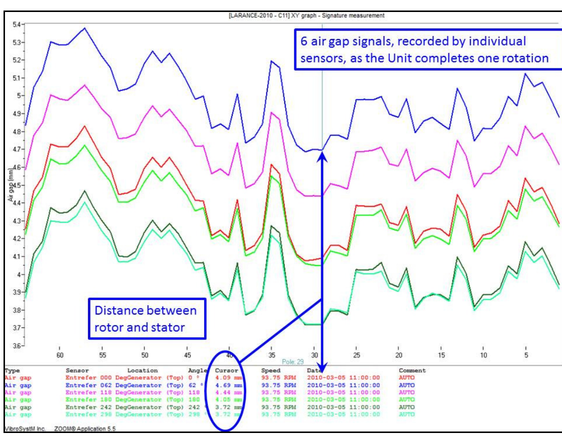


Air gap sensor glued to stator core.

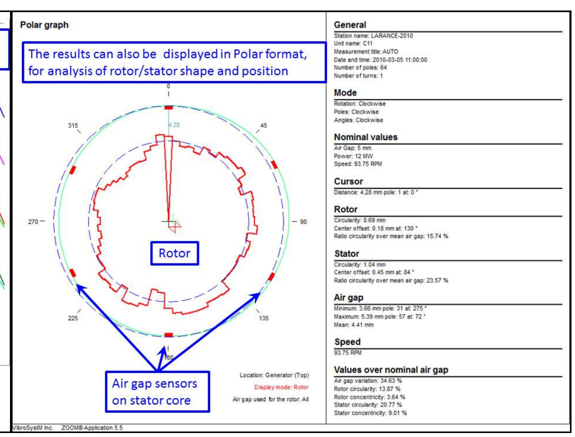


Air gap measuring principle.

The data provided by the air gap sensors allows for the analysis of the rotor/stator shape and position, while the Unit is rotating. The sensors record the air gap dynamically therefore; the following graphs can be created.



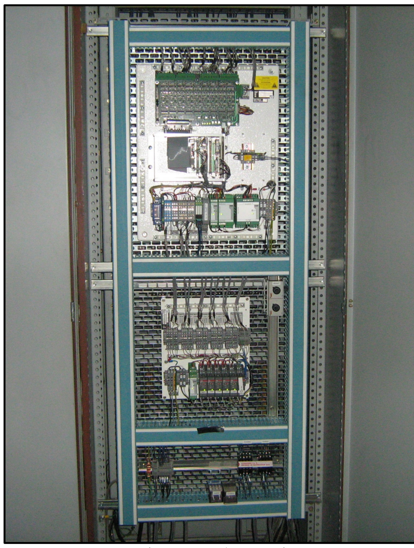
XY graph of air gap signals.

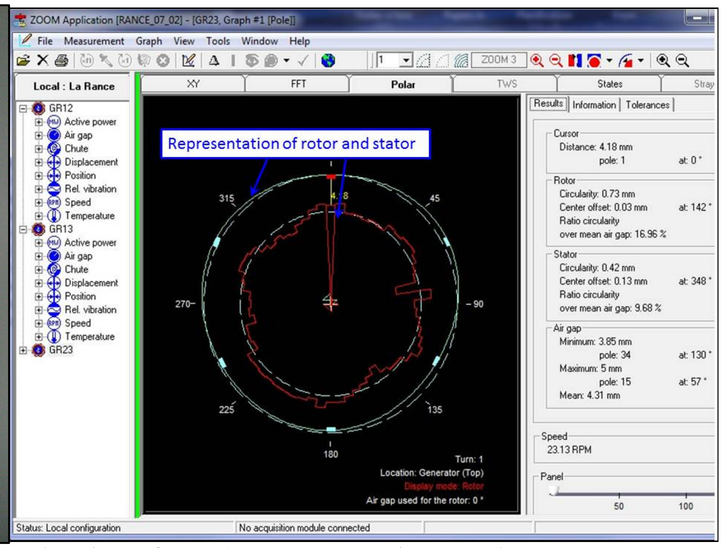


Polar representation of rotor and stator.

Data management included:

- 1 server, located in plant control room allowing graphic display, time based trend analysis and synchronous analysis.
- Operating parameters of the Units are also recorded in order to perform data correlation: Active power, water head, stator temperatures, shaft vibration, rotating speed – especially during load rejection, blades and wicket gate position.
- 1 Internet remote link with EDF expert team.



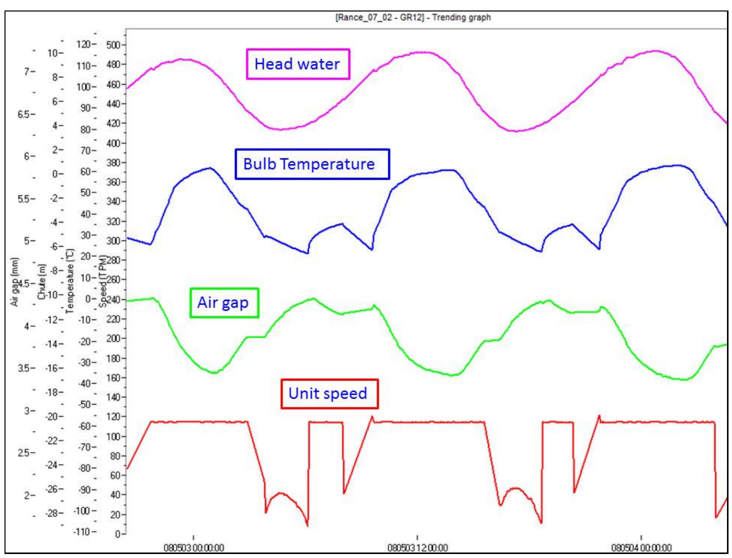


Instrumentation rack at site.   Polar view of rotor/stator at server in control room.

AIR GAP ANALYSIS AND FINDINGS

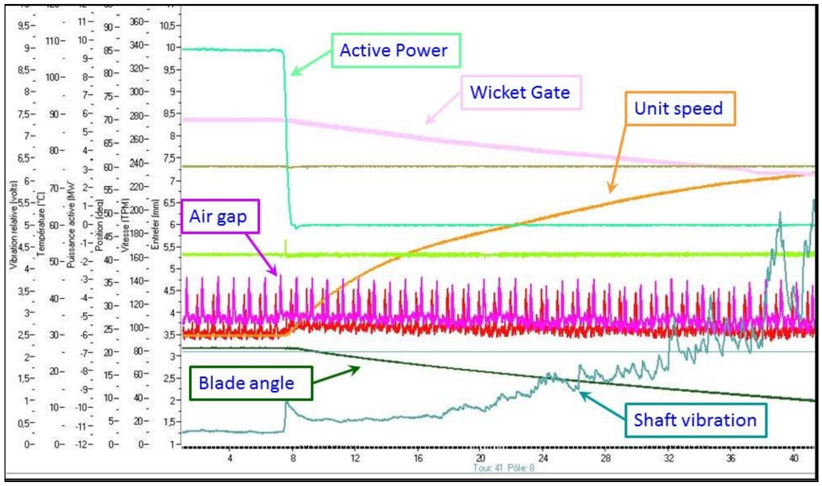
The data initially recorded provided very interesting results as follows:

- Contrary to commonly observed air gap behavior, the air gap in these Units decreases, according to an increase of internal bulb Unit temperature (-25% during an operating cycle – about 1 mm).
- The Units did not suffer from the usual vertical stator sagging due to gravity.
- During tide cycles, the Units temperature never stabilizes, as shown in the figure below.



Data plot showing the various parameters monitored by the system.

- Total air gap reduction is most likely a sum of rotor centrifugal expansion and stator centripetal expansion due to the external cooling of stator frame by cold sea water.
- Centrifugal rotor expansion due to rated speed is approximately 0,2 mm, leading to a similar air gap reduction.
- Generator excitation and network coupling causes magnetic attraction to position the rotor in its bearing in line with the minimum air gap angle, thus reducing it by an extra 0,3 mm (bearing clearance).



Load rejection data plot.

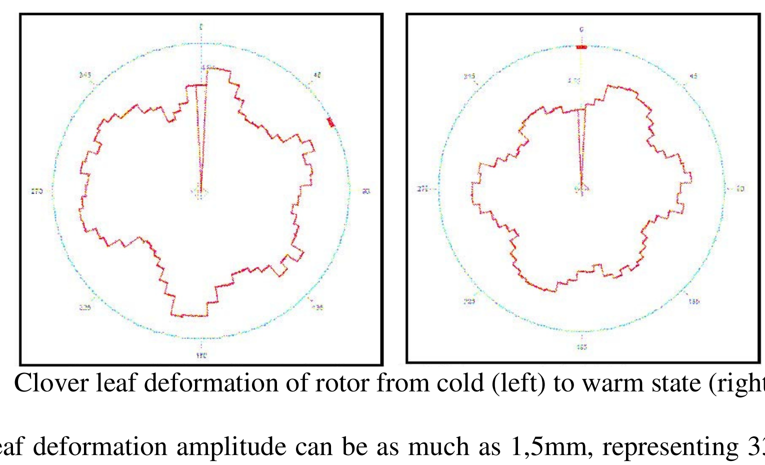
- During load rejection overspeed, the centrifugal deformation of the rotor is not as critical as feared, since the magnetic field removal compensates for the air gap reduction due to speed.
- The shape of the rotor varies during operating cycles.
- Evidence of bulb Unit fouling was also observed.

ROTOR CLOVER DEFORMATION

One of the most interesting behavior patterns observed was the rotor shape evolution over each operating cycle.

Closer analysis of the data showed that the rotors, which are usually relatively round in cold state, developed a 6 leaved clover deformation during Unit temperature rise. This deformation was fully reversible and occurred at each and every Unit load cycle. The deformation amplitude was dependant on Unit temperature therefore; it ultimately depended on tide amplitude, providing a logical answer to some air gap alarms that only occurred during largest tides.

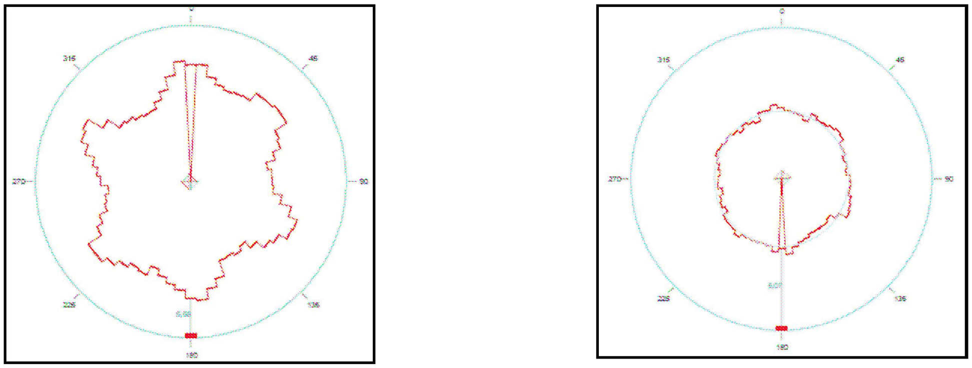
To explain this particular behavior, it was pointed out that the rotor deformed in the area between its 6 shrink fit positions (rotor hub arms), under the combined effects of centrifugal forces and thermal expansion. Movement at the 6 shrink fit position does not occur, whereas rim portions located between 2 adjacent arms do move as a beam under almost uniform load.



Clover leaf deformation of rotor from cold (left) to warm state (right)

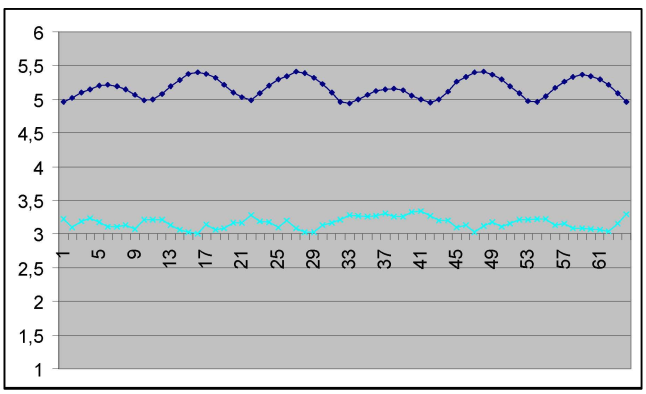
The clover leaf deformation amplitude can be as much as 1,5mm, representing 33% of air gap value. Although this behavior was not unexpected, since finite element modelling predicted such clover leaf behaviour of the rotor rim; the amplitude of the deformation however was definitely higher than anticipated.

Based on this information, it was clear that thermal deformation of the rotor played a significant role in the rotor/stator rub incidents and that safety margins between rotor and stator needed to be increased in order to prevent any further damage. To achieve this, a pre-deformation of the rotor was proposed. Using the results provided by the air gap sensors, each rotor pole was positioned so as to cancel the clover deformation and reach a cylindrical shape in operation. These adjustments allowed the air gap to maintain itself close to its design value while in operation. This adjustment of the rotor shape took into account the various foreseeable rotor deformations.



Pre-positioning of rotor pole to compensate rotor deformation; rotor shape in cold (left) and warm state (right)

Therefore, after rotor pole positioning, cold state air gap shows a wave form (from 5 to 5,5mm) whereas it recovers a more cylindrical shape in warm state.



Air Gap (mm) vs. Pole number: Original (light blue) and modified air gap (dark blue) plot

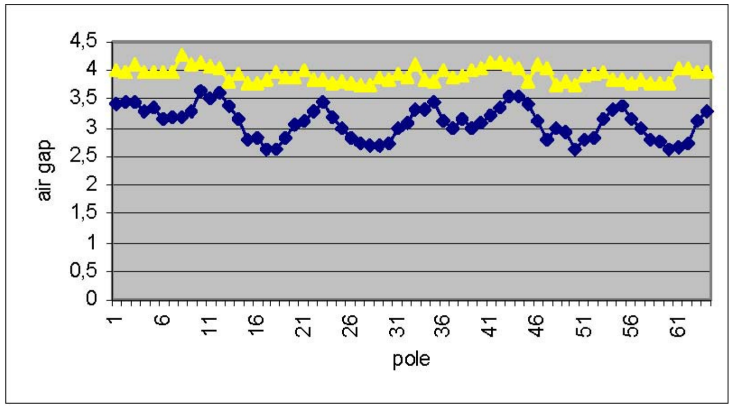
BULB UNIT FRAME FOULING

The bulb Units are fully air cooled. Air is slightly pressurized to prevent sea water ingress and to improve heat transfer capacity. This air closed loop is cooled by design against sea water, with the bulb Unit frame acting as a radiator.

Even though specific coating was used to prevent fouling, mussel population grows against the frame external surface. These mussels are usually removed when the bulb water conduit remains dewatered for several days as a sanitary precaution.

However, through air gap monitoring, it was possible to show the influence of mussel fouling not only on bulb Unit temperature but also on air gap values. One of the 3 monitored Units showed very low air gap in service; fouling check was performed and a 10 cm thick mussel cover was found on the bulb frame. After mussel removal, the internal bulb temperatures dropped by 10° and the air gap increased to more acceptable values.

La Rance bulb Unit frame



Air gap (mm) influenced by mussel fouling: before (blue) and after (yellow) mussel removal

CONCLUSION

After more than 40 years of questioning the La Rance bulb Units deformation, up to date air gap monitoring allowed to quantify generating set deformation, in order to gain a better understanding of the generator behaviour in operation and to recover air gap safety margins. Although the original goal of the air gap monitoring was to provide live generator “pictures”, it quickly became an effective maintenance tool. Even though the rotor shrink fit rim residual stress still needs to be assessed, further in depth data analysis might provide the answer. As a broader conclusion, let us note that tidal powered Units are ideal candidates to be fitted with air gap monitoring since they gather almost all stresses influencing air gap:

- Highly cycled Units (up to 4 starts/stops per day)
- Rather low air gap (in the case of older design bulb Units)
- Shrink fit rim (with fretting corrosion phenomena)
- Rather high operating temperature (60 to 80°C ambient)
- High over speed (≈300 % rated speed).

Hence, with such informative findings, La Rance plant management decided to equip all 24 Units with air gap monitoring. Rotor shape pre-deformation of all Units has also been performed, so as to increase air gap in cold state, together with a compensation of the 6 leaved clover deformation, thus leading to a minimum air gap of at least 4 mm in service whatever the Unit load conditions.