Automatic Processing of Air Gap Monitoring Signals in Hydro-Generators

Pierre FAURE--GIOVAGNOLI[1,2], Christophe TURBIDI[2], Vasile-Marian SCUTURICI[1]

[1]Univ Lyon, INSA Lyon, CNRS, UCBL, LIRIS UMR 5205, Villeurbanne, France
[2]Compagnie Nationale du Rhône, Lyon, France
pierre.faure--giovagnoli@liris.cnrs.fr

Abstract

Compact turbines are often designed at the cost of a small air gap which can lead to rotor-stator collisions. Such accidents lead to a temporary halt in production, can cause collateral damage and are very expensive to repair. Air gap monitoring is therefore the best solution to predict and prevent such collisions.
Due to recent industry needs, we consider the case of stator deformation with dynamic rotor eccentricity. If the literature in the field of air gap monitoring is rich in sensor instrumentation, it is rather poor in signal processing, especially for the case of stator deformation. In this work, we take a first step to fill this gap and propose a solution to automatically process the recorded signals. After showing how to obtain clean usable signals, we present two main results. (1) We show how to compute the stator profile by correcting the eccentricity of the measured air gap, which is useful for long-term maintenance. (2) For each point of the stator, we calculate the critical air gap that corresponds to its closest position to the rotor which is essential to protect the turbine in real time. We also propose visualizations that can be interpreted by experts in the field who have no prior knowledge of the techniques used.

1 Introduction

In run-of-the-river hydroelectric power plants, compact turbines are typically used to minimize disturbance to the river flow and preserve the ecosystem. However, compact turbines are often designed at the cost of a small air gap which can lead to rotor-stator collisions. Such accidents lead to a temporary halt in production, can cause collateral damage and are very expensive to repair. Air gap monitoring is therefore the best solution to predict and prevent such collisions. If the literature in the field of air gap monitoring is rich in sensor instrumentation (e.g. [4, 3, 1]), it is rather poor in signal processing, especially for the case of stator deformation. In this work, we take a first step to fill this gap and propose a solution to automatically process the recorded signals.

This study emerges from a collaboration with the Compagnie Nationale du Rhône (CNR). In particular, we consider the case of stator deformation with dynamic rotor eccentricity. After processing the signals to extract their CS1 component, we present two main results. (1) We show how to compute the stator profile by correcting the eccentricity of the measured air gap, which is useful for long-term maintenance. (2) For each point of the stator, we calculate the critical air gap that corresponds to its closest position to the rotor which is essential to protect the turbine in real time. Finally, we also propose visualizations that can be interpreted by experts in the field who have no prior knowledge of the techniques used.

First, we present the instrumentation. Second, we briefly describe our solution. Finally, we show an application of our solution to a recording made at CNR and conclude this study.

2 Sensor Instrumentation

We consider a turbine equipped with the following sensors which can be divided into two main categories:

- **Rotating sensors (wireless transmission).** The air gap is measured by 3 rotating capacitive sensors attached along the rotor (upstream, median, downstream) to get a comprehensive depth profile. Those 3 sensors are associated to a unique rotating keyphasor to detect full rotor revolutions.

- **Static sensors (wired transmission).** The displacement of the rotor shaft is measured by 2 proximity sensors. These sensors are associated to a static keyphasor with a rotating target attached to the rotor.

3 Solution overview

To help the domain experts anticipate maintenance, the objective of our monitoring solution is two-fold: we want to obtain a clean stator profile to locate deformations but also to know the current smallest air gap. To this end, multiple operations are carried out on the raw sensor data. The process is summarized in Figure 1.

First, we use *order tracking* to resample the time series with respect to the rotor angle, a more natural way to handle rotating machine data. Second, we apply *synchronous averaging* to extract the periodic component of the data. Notably, this helps reducing noise which can be especially important in such intensive electromagnetic fields and with wireless transmission. Third, we geometrically correct rotor eccentricity to reconstruct the *absolute air gap value*. This corresponds to the distance between the rotor and the stator in the absence of eccentricity. The word *absolute* emphasizes the difference with the raw values *measured* by the air gap sensors which are relative to the rotor angle and eccentricity at the time of recording. Finally, the *critical air gap* is computed by comparing the rotor movement to the absolute stator profile. This is crucial as the sensors can underestimate the critical air gap by an error of up to 2 times the maximum eccentricity amplitude [2].

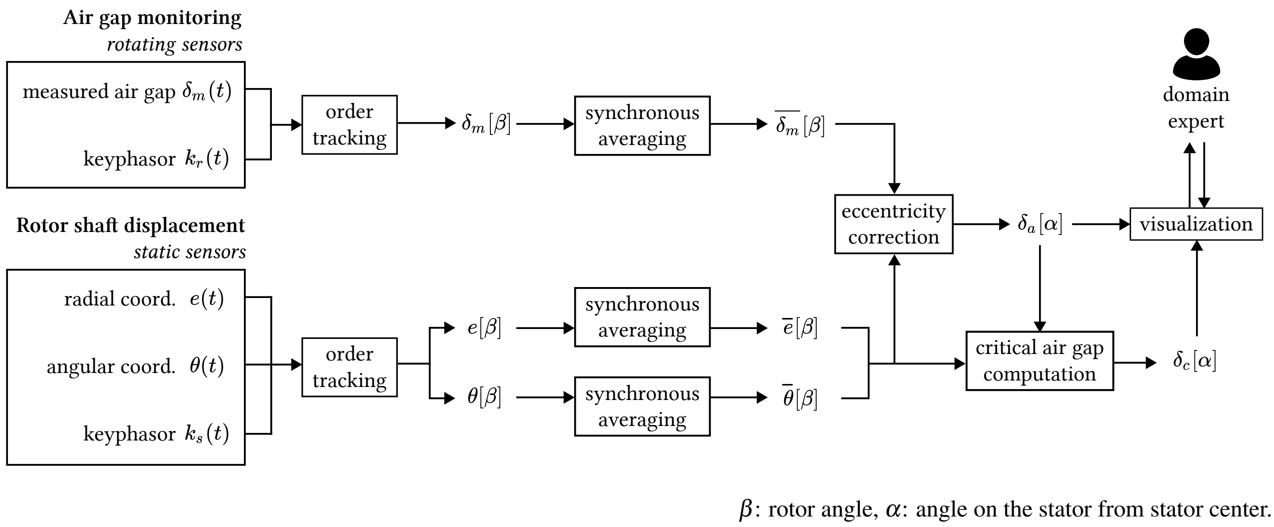


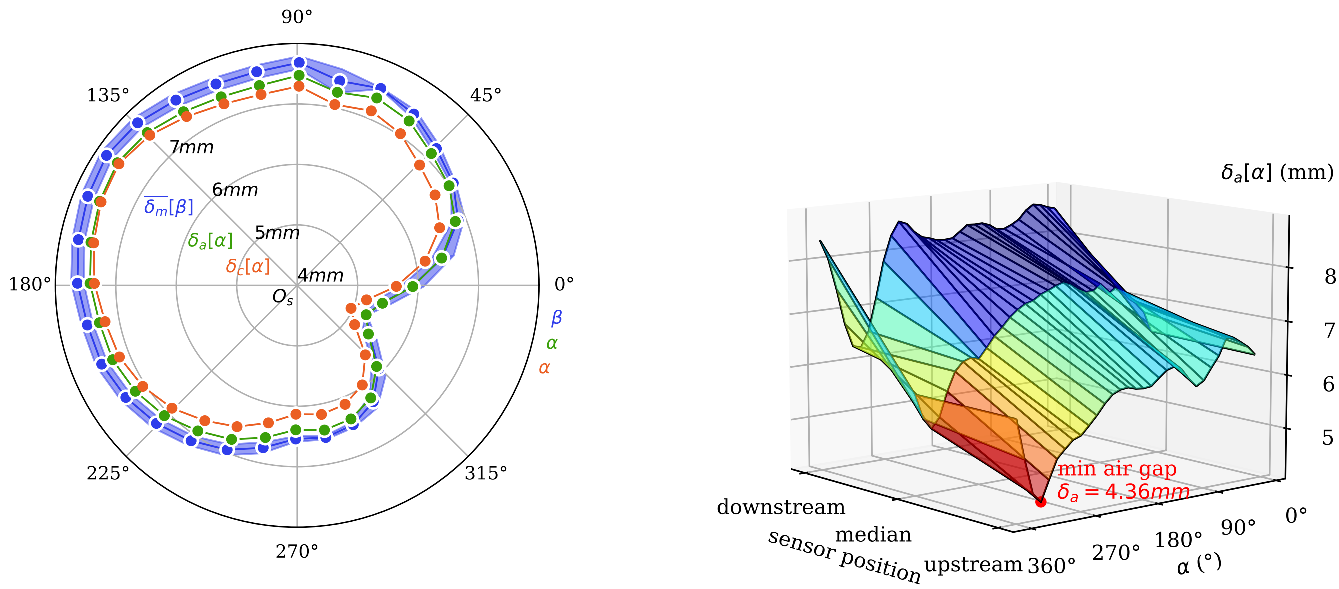
Figure 1: Schematic of the proposed processing pipeline.

4 Experiments and visualization

In this section, we apply our solution to a 1 minute 50Hz recording made in one of the CNR generators at the Péage-de-Roussillon power plant. The results of the experiments are presented in Figure 2. On the left, we observe the 2d profile given by the median air gap sensor (measured, absolute and critical). On the right, we see how the 3 sensors can be used obtain a 3d unfolded depth profile of the stator.

5 Conclusion

In this work, we presented a pipeline for the automatic processing of air gap monitoring data in the case stator deformation and dynamic rotor eccentricity. Our method allows to improve the quality and interpretability of the raw data by extracting the periodic component and removing the uninformative noise. Moreover, we also show how to recover the stator profile and the critical air gap values by correcting rotor eccentricity. Paired with the visualizations presented in Section 4, the results provided by this study provided a basis for the improvement of the air gap monitoring system of the CNR. Notably, it assists the development of a more effective predictive maintenance system.



(a) Polar plot of the measured ($\overline{\delta_m}[\beta]$), absolute ($\delta_a[\alpha]$), and critical ($\delta_c[\alpha]$) air gap profiles. Synchronous standard deviation for $\delta_m[\beta]$ is displayed as the blue area.

(b) Unfolded 3d air gap profile allowing to capture the general trends in stator deformation.

Figure 2: Application of our solution to an example of monitoring signal from CNR.

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