A Prior Selection of Measurement Modality for Eccentricity Detection in Synchronous Machines using a Cramér-Rao Lower Bound Technique

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Rotating electrical machines are indispensable components in industry. These machines require dedicated systems to prevent catastrophic failures, especially when involved in critical industrial processes. Therefore, it is essential to use continuous online monitoring systems that can diagnose incipient faults at an early stage and allow for remedial action before development of severe fault mechanisms. A typical example is the synchronous machine which is commonly utilized in power generation schemes where early fault detection methods are imperative. In synchronous generators, an airgap eccentricity fault can deteriorate through a cascading effect and result in problems such as bearing failure amongst others [1].

Numerous methods are available for the diagnosis of an eccentricity fault in rotating machines [2]. Each technique is based on measurements which have an associated accuracy. Several methods are available to detect eccentricity in synchronous generators. Examples of other methods are shaft voltage (see Fig. 1) and magnetic flux monitoring, which have been found to have exceptional fault diagnostic capabilities [3] and are selected for the presented investigation.

In practice, the accuracy of the identification process depends on the measured quantity being used. On the one hand, the measurement noise may significantly influence the results. On the other hand, the sensitivity of the measured quantity on the eccentricity level may have a large impact on the identification results. Therefore, the selection of the optimal measurement shall ensure the accuracy of the eccentricity fault detection. In addition to the effect of the accuracy and sensitivity of the measurement quantity, the identification procedure is significantly influenced by the ambiguous knowledge of some model parameters. In rotating electrical machines, one of the most uncertain parameters is the one related to the magnetic material properties. The material properties of the magnetic core of rotating electrical machines are classically obtained by performing some standard measurements. However, these standard measurements may not give the actual properties of the material that exists in the machine. Therefore, knowledge of the real magnetic material properties located in the machine is uncertain. The effect of such uncertainties on the accuracy of the eccentricity identification process needs to be estimated.

The research presented in this paper aims at selecting the best measurement modality for diagnosis of a static eccentricity fault in a synchronous generator. The Cramér-Rao lower bound (CRLB) technique is adopted to estimate the error associated with shaft voltage and magnetic flux based measurement techniques. This method takes into account the effect of the measurement noise as well as the uncertainty in some model parameters. The technique has been recently used for estimating the error in the inverse problem solution of magnetic material characterization in different electromagnetic devices [4]. First, a numerical analysis is performed and thereafter these results are then validated experimentally by carrying out real measurements. To the best of the authors' knowledge, this type of investigation has not yet been presented and will definitely enhance the accuracy of the eccentricity identification procedure.

For the numerical analysis, four numerical case studies are performed using the CRLB technique together with a finite element (FE) model of a two-pole synchronous generator. The first one is related to no-load (NL) conditions, while the other case studies are done for different levels of a resistive loading, i.e. 4, 5, 6 . Each of the case studies are investigated for different eccentricity levels with and without model uncertainties. Some of these results are given in Fig. 2. The results indicate that the shaft voltage is a much more suitable measurement modality to detect the rotor eccentricity fault than the flux probe voltage, for the same measurement noise.

Numerical results, when uncertainty in the magnetic material is considered (not shown here), also indicate the superiority of the shaft voltage measurement modality. Additionally, it is found that the identification error becomes negligible for the shaft voltage measurement at saturation conditions. This means that the accurate knowledge of the saturation state of the magnetic material of the stator core will not affect the identification results.

Validation of the FE model and the proposed technique was carried out under laboratory conditions. A miniature synchronous generator, designed to mimic large turbo-generators, was used, see Fig. 1. The generator is fitted with flux probe and shaft voltage monitoring systems. The simulated flux probe and shaft voltage signals correspond to the experimental measurements indicating the effectiveness of the FE model. Furthermore, application of the CRLB technique on the experimental signal harmonics, measured under eccentricity fault conditions, yield a great correspondence to the numerical results thereby validating the proposed technique. Overall results of the work also indicate that the shaft voltages are more sensitive to an eccentricity fault and provide a significantly lower identification error. Furthermore, it is shown that the shaft voltage based technique performs exceptionally well past linear operating regions which is a desirable trait, especially in power generation applications.

References

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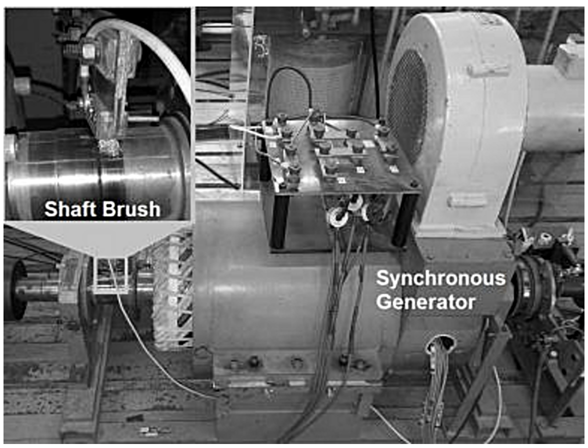

Fig.1: Experimental synchronous generator with view of shaft riding brush (driven-end) used for condition monitoring purposes.

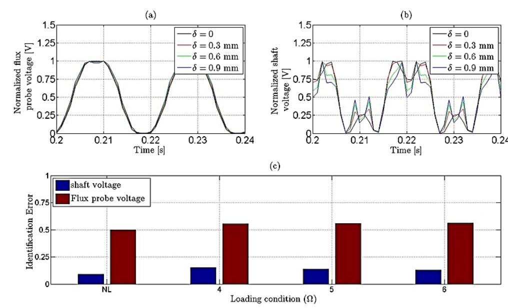

Fig.2: (a,b) Normalized values of the simulated flux probe and shaft voltage responses, for different eccentricity levels at no-load conditions. (c) The identification error of the two measurement modalities, when no uncertain model parameters are considered.