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Continuous dynamic monitoring of an onshore wind turbine

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ABSTRACT

Current utility-scale wind turbines are highly dynamic systems excited by a large variety of loading sources. The proper operation of wind turbines thus requires a complete knowledge of the actual dynamic behavior of the system, in order to ensure the expected longevity of their main structural elements. In that context, this paper describes the monitoring project developed for a 2.0 MW wind turbine, the description of the installed monitoring system, as well as the main steps included in the methodology developed for the continuous processing of the collected data. The main results achieved during one year of monitoring are shown in detail. They allowed to accurately characterize the variability of the dynamic properties of the wind turbine, with special emphasis on the natural frequencies and damping ratios of the most important vibration modes, throughout normal operating conditions of the turbine. In addition, several shutdown events were identified and used to estimate the modal damping of the wind turbine through the analysis of free-decay responses of the structure. This monitoring project contributes to improve the knowledge on the dynamic behavior of onshore wind turbines under normal operating conditions.

1. Introduction

Wind represents an important and unavoidable source for renewable and clean energy. Important measures are being taken to achieve ambitious targets of renewable energy in the European Union [1], leading to a consistent growth both for onshore [2,3] and, more recently, offshore locations [4]. In Portugal, 22.5% of the produced electrical energy in 2015 was from wind source [5]. This extensive exploitation of wind resources has been obtained through installation of large, multi-MW wind turbines. Modern wind turbines are composed of very tall support structures (comprised by the tower and foundation components) alongside with large rotor blades, leading to highly dynamic systems, prone to degradation problems.

The installation of wind turbines requires important investments, planned for a life period of, at least, 20 years. In order to evaluate the reliability of the investments during this period, the need of monitoring systems to continuously assess the condition of the wind turbines is becoming increasingly necessary. Different techniques aiming to detect damages at an early stage in different components have already been presented [6,7], being vibration-based techniques one of the most suitable to be implemented in wind turbines. One interesting method related to vibration-based techniques is referred to the extraction of the modal parameters from vibration data. These parameters (and especially the natural frequencies) can be used as health indicators of the wind turbine structure. In that sense, algorithms capable of identifying the modal properties of structures based on their response are used to extract these indicators.

Some results regarding the identification of the modal parameters of wind turbines have already been published. In [8], the study of a monitoring period of two years of a 5 MW wind turbine is described. Special attention is drawn to resonance phenomena and to the evolution of the vibration amplitude. The use of innovative sensors for modal identification of a 2.5 MW wind turbine is described in [9]. In Ref. [10], the modal results from an offshore wind turbine under non-operating conditions are presented for a period of two weeks. A detailed analysis of this offshore turbine have been developed both for the identification of the different contributions of damping [11] and experimental simulation of the structural, operational and environmental conditions [12]. Also, in the work described in [13], experimental results regarding the identification of the modal damping of the first tower bending of a 3.6 MW wind turbine mode are presented and correlated with a numerical model.

The present paper introduces the main steps of development of a vibration-based monitoring system installed in a 2.0 MW onshore wind turbine, aiming to identify abnormal structural changes at the support structure. This element, composed by the tower and foundation, is a crucial component of the wind turbine, representing an important share of the capital costs [14]. The main components of the developed

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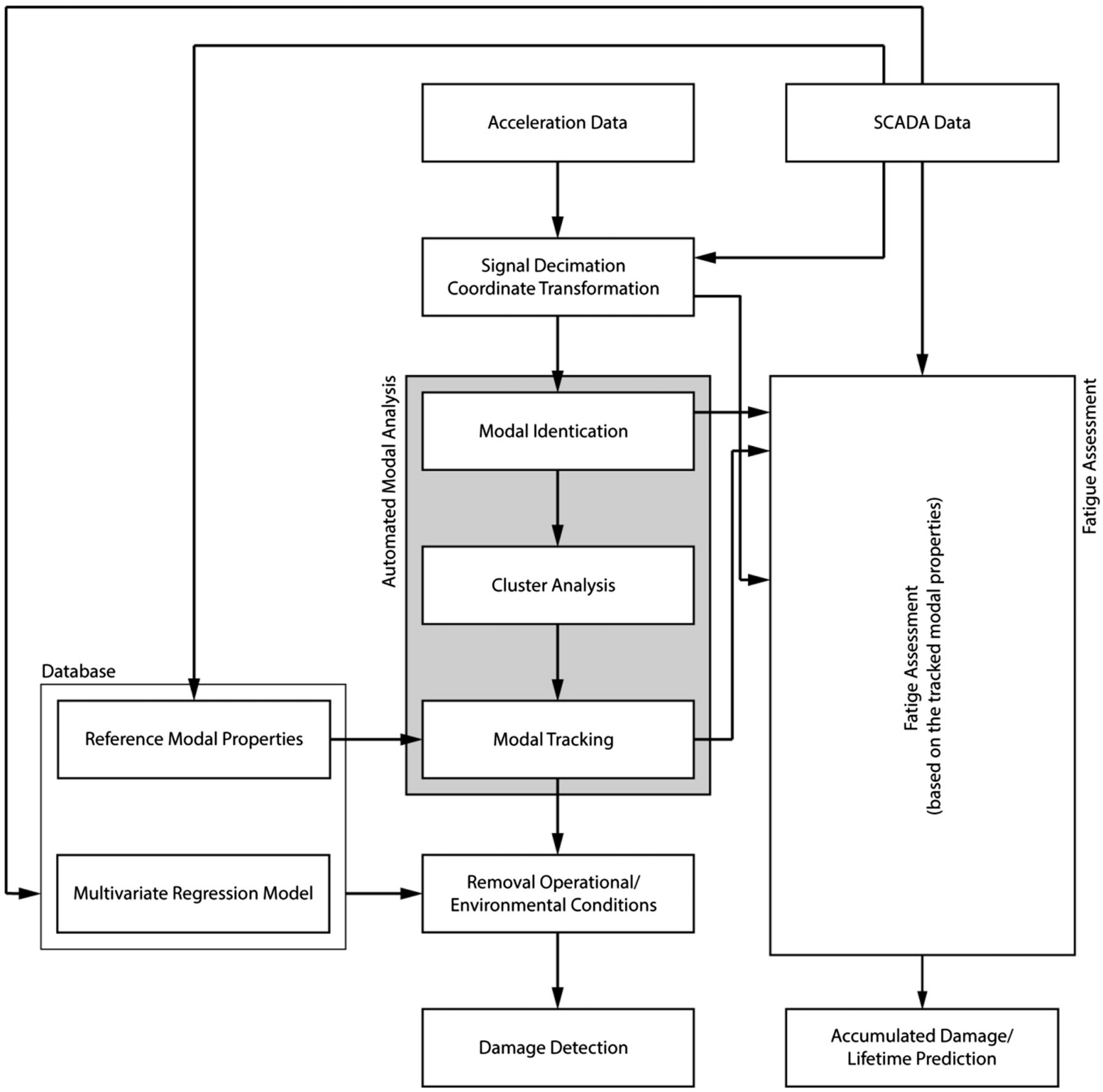

Fig. 1. Main steps of the vibration-based monitoring system (the grey box identifies the module related to automated modal analysis).

monitoring system are introduced in Fig. 1. This aims early detection of structural changes (damage) and the evaluation of fatigue life. In this paper, the main focus is directed towards the automated modal analysis component using Operational Modal Analysis (OMA) techniques [15]. It is demonstrated that these techniques are capable of continuously tracking the wind turbine modal properties (natural frequencies, modal damping ratios and mode shapes) throughout different operating conditions.

The paper starts with a description of the wind turbine and of the installed monitoring system. A simplified description of the different regions of operation of the wind turbine is introduced, using data from the turbine monitoring system, and their implication on the structure behavior is highlighted. After that, the main steps of the monitoring system processing strategy are succinctly presented. Finally, the results from the continuous modal identification from a monitoring period of one year are detailed, illustrated and commented. The evolution of the modal parameters of the most important vibration modes along the whole operating regime of the turbine is described. In addition, an analysis focused on the identification of the damping of the first tower bending mode is also performed based on the analysis of a large number of free-decay events.

In short, this paper introduces a thorough characterization of the dynamic behavior of a wind turbine under real operating and non-operating conditions. The capabilities of the developed methodology to accurately identify and track the modal properties of an utility-scale turbine, including rotor blades modes, are shown. In addition, important conclusions are drawn about the real damping of the wind turbine structure under operating conditions.

2. Description of the wind turbine

The dynamic monitoring system is installed in a 2.0 MW onshore wind turbine (Fig. 2), being in operation since 2007, at the north of Portugal (41°4′22″N; 8°20′34″W). It is characterized by a 82 m diameter, up-wind rotor with variable speed operation, with three pitch controlled blades. The generator is of the asynchronous type and the hub is located at 80 m high. The support structure comprises a reinforced concrete slab foundation and a steel tubular tower. The tower is composed by three segments, totalizing 76 m in height. These segments are connected by bolted flanged connections.

The wind turbine is equipped with a Supervisory Control And Data Acquisition (SCADA) system. This system records the mean, maximum and minimum values of several operational and environmental parameters from 10-min periods. Among them, some are important in the context of the structural health monitoring system: