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Dynamic modeling of wind turbines. Experimental tuning of a multibody model

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Abstract

This work is part of a research project funded by the Italian Ministry of the University and Research (MIUR), under the call for "National Interest Research Projects 2015 (PRIN 2015)", titled "Smart Optimized Fault Tolerant WIND turbines (SOFTWIND)". Within this project, the research unit of the University of Perugia (UniPG) aims to develop dynamic modeling and simulation methodologies and fatigue behavior evaluation ones for wind turbine as a whole. The development of these methodologies will be aimed at predicting the life of generic wind turbines, also providing important and fundamental parameters for optimizing their control, aimed at reducing the failures of these machines.
In the present paper, a small turbine, developed at the Department of Engineering of the University of Perugia, will be analyzed. The multibody modeling technique adopted and the experimental activity conducted in the wind tunnel of UniPG, needed for the tuning of the model, will be described.
The analysis of both model behavior and experimental data has allowed for the definition of a robust multibody modeling technique that adopts a freeware code (NREL - FAST), universally considered to be a reference in this field.
The goodness of the model guarantees the capabilities of the simulation environment to analyze the real load scenario and the fatigue behavior of this kind of device.

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Keywords: Wind Turbines; Multi Body Simulation; Wind Tunnel Testing

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Nomenclature

n	system degrees of freedom
m	modes number
t	time vector
L	flexible body length
w	number of representative nodes of finite element model
$\boldsymbol{F}_r$	generalized active forces
$\boldsymbol{F}_r^*$	generalized inertia forces
${\boldsymbol{u}_f}^i$	i-th point position of the body in the deformed configuration
${\boldsymbol{u}_o}^i$	i-th point position of the body in the undeformed configuration
u_{fj}	deformation field components
$\emptyset_a$	modal shapes
q_a	natural coordinates
φ_b	shape functions
C_{ah}	interpolating polynomium coefficients
$\overline{\boldsymbol{C}}$	matrix of the interpolating polynomium coefficients
$\overline{\emptyset}^{FE}$	finite element model mode shapes

1. Introduction

This work is part of a research activity funded by the Italian Ministry of the University and Research (MIUR) of the Italian Government, under the call for "National Interest Research Projects 2015 (PRIN 2015)". The project, titled SOFTWIND (Smart Optimized Fault Tolerant WIND turbines, http://www.softwind.it/), is coordinated nationally by University of Camerino and is developed by four operating units (University of Camerino, Polytechnic University of Marche, University of Lecce and University of Perugia).

The three-year time-frame project aims to develop intelligent control systems to minimize loads and thus to maximize the duration of large generators (Corradini et al. (2016), Castellani et al. (2017), Scappaticci et al. (2016)).

The working unit of the authors of this paper aims to develop fatigue behavior prediction techniques (Mršnik et al. (2018), Carpinteri et al. (2017), Wang et al. (2013) and Abdullah et al. (2009)) of the generic generator, also utilizing theoretical or numerical models to predict dynamic behavior and damage as detailed in Braccesi et al. (2016), and Cianetti (2012). To this aim, the activity also provides an experimental phase for the validation of simulation models and damage evaluation techniques.

In this paper, the problem of modeling and dynamic simulation of the generator is addressed. The reference software adopted is the international reference multibody (MBS) code adopted by the scientific community for modeling wind turbines: NREL FAST (Jonkman (2005) and Moriarty (2005)).

Paragraph 2 of the paper will introduce the main mechanical characteristics of a generic wind turbine. In the same paragraph, the MBS model code and code simulation logic will be schematically described and particular attention will be paid on modelling of the distributed flexibility of its main components: tower and blades.

In order to evaluate the goodness of the code both in standard and in non-classical conditions (i.e. wind tunnel simulation) a generator to be tested was identified. In view of the size of the wind tunnel available at the Department of Engineering of the University of Perugia (Italy), a micro generator was chosen which, although exempt from the PRIN project (large generators), still allows to verify the capacity of the code to simulate and apply real conditions and validate damage prediction models that will be developed. The test campaign conducted in the wind tunnel aimed at characterizing the dynamic behavior of the wind turbine (i.e. experimental modal analysis) and then addressing some tests under load at various wind pressure conditions (alias at various speed conditions). Paragraph 3 will describe the turbine and its multibody model made in FAST. In particular, the procedure to obtain the modal flexible tower model will be described.

Paragraph 4 describes the tuning of the modal tower model based on a series of numerical simulations both for finite elements (FE) and State-Space types, as shown by Braccesi et al. (2016), as well as MBS and on simple