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Determination of fault operation dynamical constraints for the design of wind turbine DFIG drives

Davide Aguglia [a,b,*], Philippe Viarouge [a], René Wamkeue [c], Jérôme Cros [a]

[a] L.E.E.P.C.I. Laboratory, Laval University, Electrical & Computer Engineering Department, Quebec, QC G1K 7P4, Canada
[b] CERN - European Organization for Nuclear Research, 1211 Geneva 23, Switzerland
[c] Université du Québec en Abitibi-Témiscamingue (UQAT), Rouyn-Noranda, QC J9X 5E4, Canada

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Abstract

This paper presents an efficient design tool for the estimation of the transient electromagnetic peak torque and transient rotor over-voltages of wind turbines (WT) doubly-fed induction generators (DFIG) during severe fault conditions on the grid side. This versatile and robust tool is well adapted to the implementation in a DFIG drives CAD environment using iterative optimization procedures. In such an application, it is used to compute the dynamical constraints function during the integrated design process of the whole drive including the generator, the gearbox and the power converters. Results show that it is necessary to take into account the dynamical constraints under fault operation, during the early steps of the system design process. Another application of the tool is also illustrated in the paper: the design of the protection system (i.e. the crowbar resistance) for a given generator, a given gearbox and a given power converter.

Keywords: Wind turbine; Integrated design; Non-linear optimization; Dynamical constraint

1. Introduction

Doubly-fed induction generators (DFIG) electrical drives are presently widely used by manufacturers in wind turbines (WT). The main advantage of a DFIG drive is a reduced power converter size of around 30% of the rated power [10], leading to a reduced initial cost. The DFIG system can also provide a suitable variable speed range of the turbine and reactive power control capability. The increase of annual energy production associated to variable speed operation have been well established [14,4] and the control strategy of such systems is also well documented [11]. Wind turbines in the MW range have a maximum rotating speed of about 20 rpm. Since DFIG performance is better for low number of poles the maximum rotating speed can reach roughly 2000 rpm with a four poles generator for example. A gearbox is necessary to adapt the turbine and generator speeds. The initial and maintenance costs are increased and the contribution of the gearbox to the mass of the nacelle is important as well. It is also important to

* Corresponding author at: L.E.E.P.C.I. Laboratory, Laval University, Electrical & Computer Engineering Department, Quebec, QC G1K 7P4, Canada. Fax: +1 418 656 3159.
E-mail addresses: davide.aguglia@gel.ulaval.ca, davide.aguglia@cern.ch (D. Aguglia), philippe.viarouge@gel.ulaval.ca (P. Viarouge), rene.wamkeue@uqat.ca (R. Wamkeue), jerome.cros@gel.ulaval.ca (J. Cros).

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notice that a WT gearbox that operates at variable speed and load cannot be specified with an average rated torque only like a conventional gearbox that operates at constant speed and load. The gearbox in DFIG WT systems is sometimes a source of many problems due to wear and failures [13]. In case of a gearbox failure, a long WT downtime can have a drastic influence on the plant rentability. The WT gearbox wear is increased by the variable speed and load operation. Dynamic loads torques can increase the wear process and the fatigue or eventually lead to failure. Small dynamic loads are caused by the wind speed variations and gusts on the site and high torque transients of several p.u. can occur during fault operation like short circuit on the grid side [13]. In this paper, the authors present a methodology for the determination of the dynamical electrical and mechanical constraints that can appear under fault operation of the plant. A robust and efficient design tool has been developed that can be included in a CAD environment of WT DFIG drives. During the integrated design process of the whole drive system, this tool is used to investigate the optimal compromise between steady-state and transient performances. The versatility and the efficiency of the proposed tool are illustrated in this paper by the optimal design of the crowbar protection system [8], using a non-linear optimization algorithm, for several operation and fault conditions of a WT DFIG system.

2. System under study

2.1. Introduction

The system under study is presented in Fig. 1. Its main components are the turbine, the gearbox, the DFIG and the power converter. The gearbox is used to adapt the low mechanical speed of the WT to the higher speed value of the DFIG that is usually designed with a low number of poles to provide an acceptable performance in terms of efficiency and power factor. The power converters are connected between the grid (i.e. the stator of the DFIG) and the slip rings of the wounded rotor. The variable frequency rotor side converter (RSC) is used to perform the variable speed operation of the drive. The RSC can manage the active and reactive power flow, in order to control the electromagnetic torque and the power factor of the generator respectively. The grid side converter (GSC) is usually controlled to perform a constant DC-bus voltage and it is operating at unity power factor. The blade pitch angle β can also be used to control the power conversion of the turbine on the whole speed range.

Different steady-state operation modes can be characterized by examining the active power flow through the power converters. A simplified active power flow where all the machine losses are neglected (1) can be used to analyze the DFIG operation modes [10].

$$\begin{aligned} P_r &= sP_s \\ P_t &= (1-s)\,P_s \end{aligned} \tag{1}$$

s is the rotor slip, P_r, P_s are the active powers flowing respectively through the power converter and through the DFIG stator armature and P_t is the mechanical power at the generator shaft (the sign convention is defined on Fig. 1). On one hand, according to (1), when the machine is operating as a generator ($P_t > 0$) in the hypo-synchronous operation (slip $s > 0$), some active power is entering the rotor circuit and some is coming out from the stator of the DFIG. On the other hand, in the hyper-synchronous operation (slip $s < 0$), the active power flowing through the power converters is reversed. In hyper-synchronous operation the sum of the stator and rotor active powers is injected to the grid. When

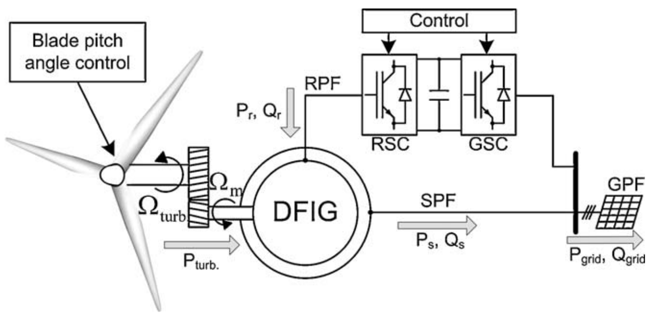

Fig. 1. DFIG wind turbine system components.