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A current controlled matrix converter for wind energy conversion systems based on permanent magnet synchronous generator

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Abstract

The main challenges of wind energy conversion systems (WECS) are to maximize the energy capture from the wind and injecting reactive power during the fault. This paper presents a current controlled matrix converter to interface Permanent Magnet Synchronous Generators (PMSG) based WECS with the grid. To achieve fast dynamic response with reduced current ripples, a hysteresis current control is utilized. The proposed control system decouples the active and reactive components of the PMSG current to extract the maximum power from the wind at a given wind velocity and to inject reactive power to the grid. Reactive power injection during the fault satisfying the grid-codes requirement. The proposed WECS has been modeled and simulated using PSCAD/EMTDC software package.

Keywords: Hysteresis current control; Matrix converter; Permanent magnet synchronous generator; Reactive power control; Wind energy conversion systems

1. Introduction

Wind power has become a rapidly growing technology as a source of power generation since it is being most economical, clean and emission free technology. WECS are used to capture the energy available in the wind to convert into electrical energy. Variable-speed wind turbine has a series of advantages; it increases the energy conversion efficiency and reduces mechanical stress caused by wind gusts (Ofualagba and Ubeku, 2008). The gear box couples the wind turbine to the generator causes many problems especially during faults and requires regular maintenance. The reliability of the variable speed wind turbine can be improved significantly by using a direct-drive based on PMSG. The PMSG has many advantages such as high efficiency, high power density, high power factor, low noise and easy

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Nomenclature

λ_{opt}	optimal tip speed ratio
ω_m, ω_{ref}	actual and reference generator speed (rad/s)
β	pitch angle
Δi	the current error
H	the hysteresis band width
$i_{d\,ref}$, $i_{q\,ref}$	the direct and quadrature current components of the PMSG
$i_{r\,ref}$, $i_{s\,ref}$, $i_{t\,ref}$	the reference values for the three-phase currents of the PMSG
I_{rated}	the rated current of the matrix converter
Q	the active power fed to the grid
P	the reactive power fed to the grid
R	radius of the turbine
V_{ppc}	the voltage at the point of common coupling
V_w	wind velocity (m/s)
V_d, V_q	the direct and quadrature voltage components of the PMSG
V_a, V_b, V_c	the three-phase grid voltage at the PCC

control (Yang et al., 2012; Inomata et al., 2013). These advantages rendered the PMSG to receive much attention in wind energy application. Due to absence of the rotor windings, a high power density can be achieved, reducing the size and weight of the generator. In addition, there are no rotor winding losses which lead to a reduced thermal stress on the rotor.

The main limitation of the traditional AC–DC–AC converter is the bulk DC capacitor used for energy storage. The matrix converter does not require any intermediate storage element as the matrix converter provides a compact solution for a four quadrant frequency converter. The key element of a matrix converter is the fully controlled four-quadrant bidirectional switch (Li et al., 2012; Haque et al., 2010), which allows high frequency operation (Kang et al., 2011; Reddy and Kumar, 2013; Jahangiri and Radan, 2013). Various modulation techniques for the matrix converter are introduced in literature (Rodriguez et al., 2012; Youm, 1999; Marei, 2012). The Hysteresis Current Control (HCC) has the advantage of its fast response and simplicity. The HCC is probably one of the most efficient techniques because of its fast response in controlling the current and inherent peak current limiting capability.

A maximum power point tracking is essential to determine the turbine speed to extract the maximum electric power from the wind (Howlader et al., 2013; Khajuria and Kaur, 2012; Sun et al., 2015; Mingming et al., 2014; Li et al., 2014; Tang et al., 2014; Abdullah et al., 2012). In addition, the pitch angle control is important to protect the turbine from damage (Khajuria and Kaur, 2012). The matrix converter controller should manage the grid-side quantities such as grid-side reactive power to improve the system stability and power quality (Sun et al., 2015; Mingming et al., 2014). The control system presented in Li et al. (2014) shows good and fast dynamic response in extracting maximum power at various speed besides the fully controlled reactive power (Tang et al., 2014).

In this paper, a modified HCC technique is used for the matrix converter to reduce the current ripples of the injected power to the grid. The proposed control uses active and reactive parts of the PMSG current to increase the control capability of the active and reactive power production at both the PMSG side and the grid side during variable speed operation. Furthermore, a dynamic limiter is used to control the reactive power injected to the grid without exceeding the rated current of the matrix converter. The pitch-angle controller is used to prevent exceeding the rated power of the generator at high wind speed by limiting the PMSG's speed.

2. System description

This paper presents a comprehensive study for the dynamic performance of the gearless WECS based on PMSG using a matrix converter connected to the grid through LC filter in order to inject a pure sin wave shape voltage and current. The major components of the proposed WECS are the wind-turbine, the permanent magnet synchronous generator, the matrix converter, the proposed control system based on HCC, and the pitch controller.