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Dynamic modeling of wind turbine based axial flux permanent magnetic synchronous generator connected to the grid with switch reduced converter

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Abstract This paper studies the power electronic converters for grid connection of axial flux permanent magnetic synchronous generators (AFPMSG) based variable speed wind turbine. In this paper, a new variable speed wind turbine with AFPMSG and Z-source inverter is proposed to improve number of switches and topology reliability. Besides, dynamic modeling of AFPMSG is presented to analyze grid connection of the proposed topology. The Z-source inverter controls maximum power point tracking (MPPT) and delivering power to the grid. Therefore other DC–DC chopper is not required to control the rectified output voltage of generator in view of MPPT. As a result, the proposed topology requires less power electronic switches and the suggested system is more reliable against short circuit. The ability of proposed energy conversion system with AFPMSG is validated with simulation results and experimental results using PCI-1716 data acquisition system.

1. Introduction

In recent years, use of renewable energies has grown more quickly due to environmental problems of fossil fuel sources [1]. Among the other renewable energy sources, wind energy is now the world fastest growing energy owing to advantages: being clean and cost effective [2].

Generator type of the wind energy systems can be classified into four main groups: (1) fixed-speed squirrel-cage induction generator; (2) wound rotor induction generator with variable rotor resistance; (3) doubly fed induction generator based on a power electronic converter among the grid and its rotor windings; and (4) synchronous generator, which is in two types: wound rotor synchronous generator and a permanent-magnet synchronous generator (PMSG) [3–5].

The variable-speed wind energy conversion systems (WECS) are mostly fabricated using synchronous generators (SGs). The technical requirements of WECS in different power rating can be achieved with great flexibility of SGs structures [6–8]. The PMSGs structure has ability of designing in large

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number of poles which makes the generator shaft operate at a speed of turbine blades. So, the gearbox can be eliminated in WECS based PMSGs. As a result, the costs of installation and maintenance are reduced as compared to induction generator (IG) based turbines where the existing of gearbox is a must.

Basically, the PMSG structure is categorized into two groups of radial-flux and axial-flux machines in view of flux direction in air gap. Various factors have been studied for performance comparison of radial flux and axial flux (AF) PM machines to select proper choice [9,10]. Compared to radial flux structures, the AF machines have inherent features of modularity and can obtain the high level of torque density, especially if they are designed in high number of poles. In radial flux PM machines, it is impossible to accomplish a high pole number, because the decreasing number q of slots (pole · phase) is required to satisfy a minimum possible size of the tooth pitch, consequently the performance quality is aggravated [10]. Several trials [9–13] have been reported in the literature to wind turbines in order to present advantages of AFPMSG, but these papers have no study about AFPMSG connection to grid. These papers study the design and performance of AFPMSG without paying to grid connection and control parts. This paper studies the power electronic converters for wind turbines based AFPMSG. The power electronic converter based Z-source inverter is proposed for grid connection of AFPMSG in this paper.

WECS based AFPMSG is normally connected to the grid by full-rated power electronic converters to achieve maximum efficiency in variable speed performance. Besides, the WECS based power electronic converters obtain advantages such as reactive power control and fault ride-through operation.

A common topology of ac–dc–ac converters for AFPMSG is shown in Fig. 1(a). This topology consists of rectifier based diode, dc–dc boost converter and three phase inverter. In this topology, dc–dc boost converter is utilized to achieve maximum power point tracking (MPPT) control and inverter is controlled to provide power quality indexes of power delivered to the grid.

Z-source inverter (ZSI), a novel power converter with boost capability was first proposed in 2002 [14]. The Z-source inverter includes DC voltage source, LC network and inverter switches [15–18]. Despite conventional inverters, the Z-source inverter uses shoot-through (short circuit) states to increase the input voltage of inverter switches circuit. Short circuit taking is a problem in the conventional inverters; however the Z-source inverter is more reliable against short circuit. As compared to traditional inverters, the Z-source inverters achieve higher efficiency, more reliability and lower complexity [19–22].

In this paper, a new WECS structure based AFPMSG and Z-source inverter are proposed as shown in Fig. 1(b). As a result, the proposed topology needs fewer switches as compared to traditional structures. Besides, it is more reliable against short circuit. The axial type of PMSG based Z-source inverter was presented in [23] recently, the authors used radial type of PMSG model and the axial model of PMSG has not been discussed. This paper examines axial flux modeling in simulations.

This paper is organized as follows. Section 2 introduces AFPMSG structure and its dynamical model. Z-source inverter topology and study of its circuit are presented in Section 3. Section 4 explains the control algorithm of proposed topology. Simulation results on a proposed wind turbine are provided in Section 5. Section 6 describes the experimental results and finally Section 7 draws the conclusions.

2. AFPMSG modeling

There are different structures for AFPMSG, such as one stator-one rotor, double rotor-one stator, double stator-one rotor and so on. The double rotor-one stator has two PM rotors and one stator disk as shown in Fig. 2. Windings are placed encircling the stator core which are linked back-to-back. A nonmagnetic matter as an example of epoxy resin is utilized to fill the empty places of stator windings to raise the strength and heat conductivity in non-slot ted arrangements. In this topology, the principle flux does not move in the rotor disk, therefore the steel disk is not utilized in the rotor topology. The rotor is constructed just with NdFeB PMs in the form of fan which are magnetized axially. Like rotor structure, nonmagnetic matter is utilized to replace

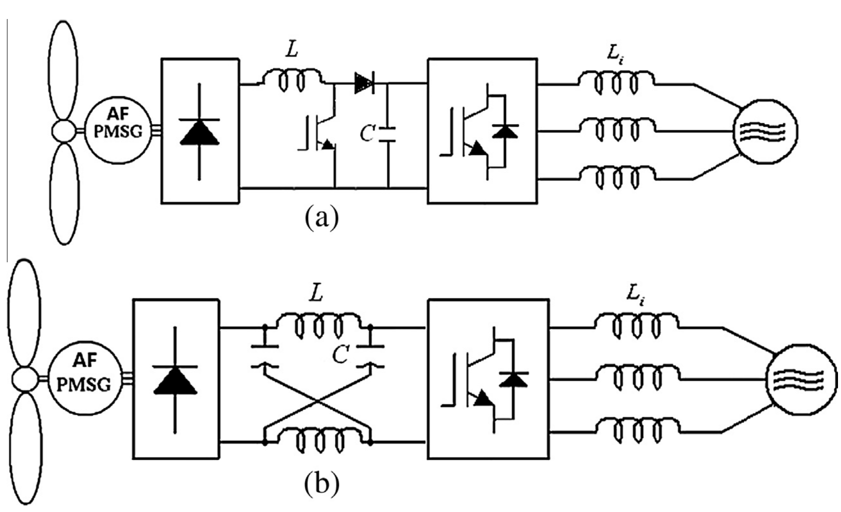

Figure 1 (a) Conventional APMSG based wind turbine with boost chopper and (b) AFPMSG-based WECS with Z-source inverter.