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Magnetically geared wind generator technologies: Opportunities and challenges

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HIGHLIGHTS

- Prominent wind turbine generator drive-train concepts were reviewed and discussed.
- Challenges associated with existing wind turbine drive-trains were identified.
- Comparing geared and gearless systems outlines their advantages and disadvantages.
- High performance MG technologies for wind power applications were investigated.
- Potential benefits and challenges of MGWG systems were evaluated and discussed.

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ABSTRACT

In the past decade, wind power generation has taken center stage in renewable energy development. Currently, the mainstream power-train of a wind turbine system consists of mechanically geared doubly-fed induction generator with a partially rated converter. However, gearbox failures account for the largest amount of downtime, maintenance and loss of power generation. Recently, magnetic gears emerged as an alternative technology to mechanical gears as they offer distinct advantages, such as high torque density, reduced acoustic noise and vibration, lower maintenance and improved reliability, inherent overload protection and contact-less power transfer. In this paper, magnetic gear technologies for wind power applications are investigated in some detail. The distinct merits of magnetic gear technologies are explored together with the challenges associated with this technology for wind energy applications.

1. Introduction

Global energy challenges and environmental concerns prompt the world to focus on renewable energy more than ever. Wind energy has been identified as one of the most promising renewable energy sources. The past 20 years saw an increasing share of wind power in the total electrical energy supply in Europe, Asia–Pacific and North America. The worldwide wind power generation capacity has been growing at a substantial rate during this fast growing period, doubling the capacity every 3 years [1–3]. As shown in Fig. 1, the world's total installed wind power capacity has reached a record of 239 GW at the end of 2011 with China and the US being the largest players [3].

Europe is still the world leader in wind energy with a high wind penetration. In Denmark, wind power provided 28.3% of total power generated in 2011 [3]. Government support remains the most important driving force behind the rapid growth of wind power generation. The general prediction is that wind power will continue to grow at a fast pace reaching a 10% global penetration level by the year 2016. However, this future growth is also dependent on further technological advances in wind power generation (both on shore and off shore).

This paper will review and compare the current wind turbine generator drive-train concepts including their market status, provide a background on wind turbine gearbox problems, and evaluate the potential benefits and challenges of using magnetically geared wind turbine technology as an alternative wind turbine drive-train.

2. Wind turbine generator systems

2.1. Typical wind turbine drive trains

The development of modern wind power conversion technology started in the 1970s, and rapid development took place from 1990. Various wind turbine drive train technologies have been developed and implemented. As shown in Fig. 2, typical wind generator

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Nomenclature

Abbreviation

CF	capacity factor
DD	direct drive
DFIG	doubly fed induction generator
EESG	electrically excited synchronous generator
FAC	forced air cooled
FRTC	fault ride through capability
FEM	finite element method
FFT	fast fourier transform
HMG	harmonic magnetic gear
HS	high speed
IS	inner stator
LC	liquid cooled
LCM	least common multiple
LS	low speed
MG	magnetic gear
MGPMG	magnetically geared PM generator
MGWG	magnetically geared wind generator
MTTR	mean time to repair
OS	outer stator
PEC	power electronic converter
PM	permanent magnet
PMG	PM generator
SCIG	squirrel cage induction generator
TFPM	transverse flux permanent magnet
WG	wind generator
WRIG	wound rotor induction generator
1G	single-stage gearbox
2G	two-stage gearbox
3G	three-stage gearbox
mG	multi-stage gearbox

Symbols

f_c	cogging torque factor
G_r	gear ratio
N_c	least common multiple of n_s and p
n_s	number of pole pieces on flux modulator
p	number of pole pairs of a PM rotor
p_h	number of pole pairs of high speed rotor
p_l	number of pole pairs of low speed rotor

systems for large wind turbines can be classified into the following types [4–9]:

- Type A: fixed-speed, directly grid-tied squirrel cage induction generator (SCIG) with a multi-stage gearbox (Fig. 2a). This type wind generator system has advantages such as robust and relatively low cost. However, the fixed speed operation limits the turbine aerodynamic efficiency and thus a relatively low capacity factor [5–7].
- Type B: limited variable-speed, directly grid-tied wound rotor induction generator (WRIG) with a multi-stage gearbox (Fig. 2b). These wind generator systems use wound rotor together with an externally controlled resistor to realize limited variable speed operation. The overall generator efficiency of this type generator system is less than that of Type A as a result of the additional losses in the external resistor [5,7].
- Type C: variable-speed, doubly-fed induction generator (DFIG) with a partial-scale power electronic converter (PEC) feeding the rotor winding and a single or three-stage gearbox (Fig. 2c). This type of generator system is similar to Type B except that the rotor is connected to the grid through a PEC, which controls the rotor frequency and thus the rotor speed. Comparing with Type B, a wider variable speed range operation can be realized for Type C. The rating of the PEC is typically about 30% of the generator's nominal power capacity, which is attractive from an economic perspective [5–7]. However, the fault tolerance and fault ride through capability (FRTC) needs a complicated control strategy.

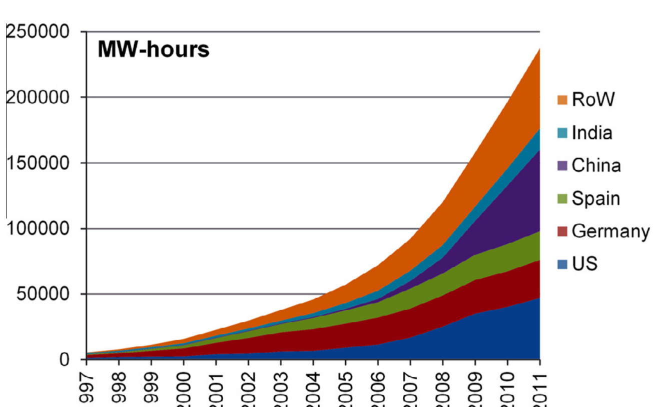

Fig. 1. World-wide installed wind generation capacity [3].

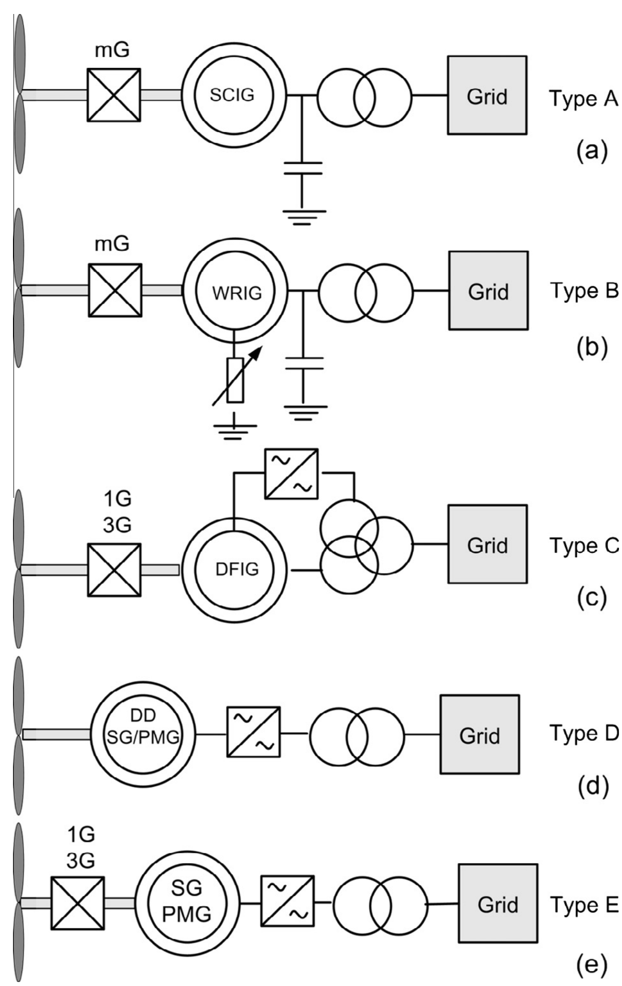

Fig. 2. Typical wind generator system drive trains [4–8].