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Design, analysis and implementation of a constant-voltage power generation system based on a novel memory machine

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ABSTRACT

In this paper, a constant-voltage power generation system based on a novel memory machine is proposed and implemented. The memory machine can offer direct and efficient air-gap flux control due to its creative integration of the memory concept and doubly-salient machine structure. By utilizing such memory machine in a direct-drive wind power generation, the resulting system can realize the constant-voltage operation under different load conditions. After addressing the memory machine design and characteristics analysis by using finite element method, this paper presents the detailed implementation and control principle of the constant-voltage power generation system. Both the numerical simulation and prototyping test are conducted to verify the validity of the proposed machine and system.

1. Introduction

The constant-voltage operation of a generator means that the DC (direct current) output voltage at the terminal of rectifier can maintain constant under different load conditions, such as varying rotor speed or varying load current. There are several applications needing such operation. In EVs (electric vehicles), when the vehicle decelerates, runs downhill or brakes, the traction motor usually works as a generator to absorb energy from the wheels and then feedbacks to the on-board battery with a constant-voltage output [1]. Additionally, for commercialized charger stations for EVs, they are also required to operate in constant-voltage charging mode to perform an efficient and fast charging process [2,3]. In a small scale stand-alone power generation system with renewable energy sources, such as wind power, solar power, thermal power, etc., a constant-voltage output is usually preferred for battery charging and storage [4–6]. Different from the realization of constant-voltage operation by means of power electronics in above-mentioned literature, this paper will focus on the constant-voltage operation based on a novel electric machine and its application to the wind power generation system.

Generally, the wind power generation can be classified as CSCF (constant-speed constant-frequency) type and VSCF (variable-speed constant-frequency) type [7]. In the CSCF system, the induction generator is usually adopted [8]. It offers several advantages, such as a simple structure and high robustness. Furthermore, it can directly connect to the power grid without using any power converters. However, since the turbine speed is kept constant regardless of the variation of the wind speed, the CSCF system suffers very low efficiency and high mechanical stress. With development of power electronics, low-cost power converters make it possible to produce constant-frequency electric power with a variable turbine speed. Since the turbine speed changes with the wind speed to capture the maximum wind power, the efficiency of the VSCF system is much higher. For the VSCF system, several types of generators have been adopted or proposed, such as the doubly fed induction machine [9,10], multi-phase synchronous machine [11], switched reluctance machine [12], flux switching PM (permanent magnet) machine [13], vernier PM machine [14], and magnetic-geared PM machine [15]. However, mechanical gears are generally engaged to match the low speed operation of the wind turbine and the relatively high speed operation of the generator. This not only increases the cost of manufacture and maintenance but also reduces the efficiency and robustness. In order to eliminate the drawbacks arising from mechanical gears, the direct-drive PM machine has become popular in the wind power application in recent years [16,17].

Due to high efficiency, high power density and mature control method, PMBL (permanent magnet brushless) machines are widely accepted for industrial, vehicular and wind power applications

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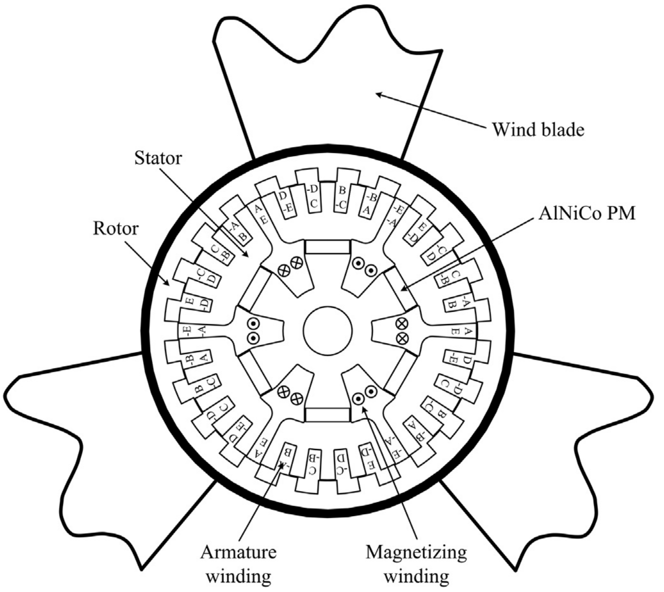

Fig. 1. Proposed memory machine.

[18,19]. However, they cannot easily perform air-gap flux control because of the fixed PM excitation. Different from many flux regulation techniques relying on control strategies or machine structures to indirectly vary the air-gap flux, the concept of hybrid-field excitation directly focuses on the regulation of PM excitation source by incorporating an extra DC field winding in the machine [20]. Hence, the resulting hybrid-field PM machine can effectively enable both flux-weakening and flux-strengthening by properly tuning the field current. Nevertheless, the machine efficiency is degraded since the corresponding DC field winding needs to be continually energized.

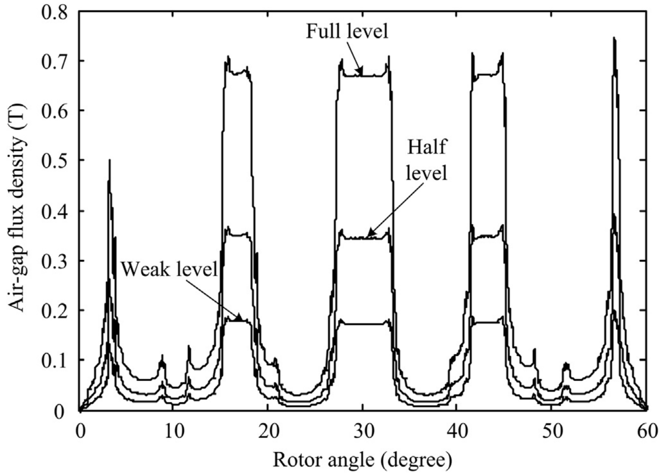

Fig. 3. Air-gap flux density distributions under different PM magnetization levels at no load.

The memory machine is a new type of hybrid-field PM machines, which can easily regulate the magnetization level of PM excitation [21,22]. The concept of memory is due to the nature of the AlNiCo (aluminum–nickel–cobalt) magnets in the machine can be online magnetized or demagnetized to various magnetization levels and then be memorized automatically. Therefore, this kind of flux control can solve the problem of continuous DC copper loss. In Ref. [21], the memory machine adopts a conventional sinusoidal-fed PM machine structure, where the AlNiCo magnets are sandwiched by soft iron and then mechanically fixed to a nonmagnetic shaft. The regulation principle of this machine is to use the d-axis current in the stator armature winding to perform the magnetization or demagnetization of the AlNiCo magnets on the rotor. Although this is an efficient flux control method due to its

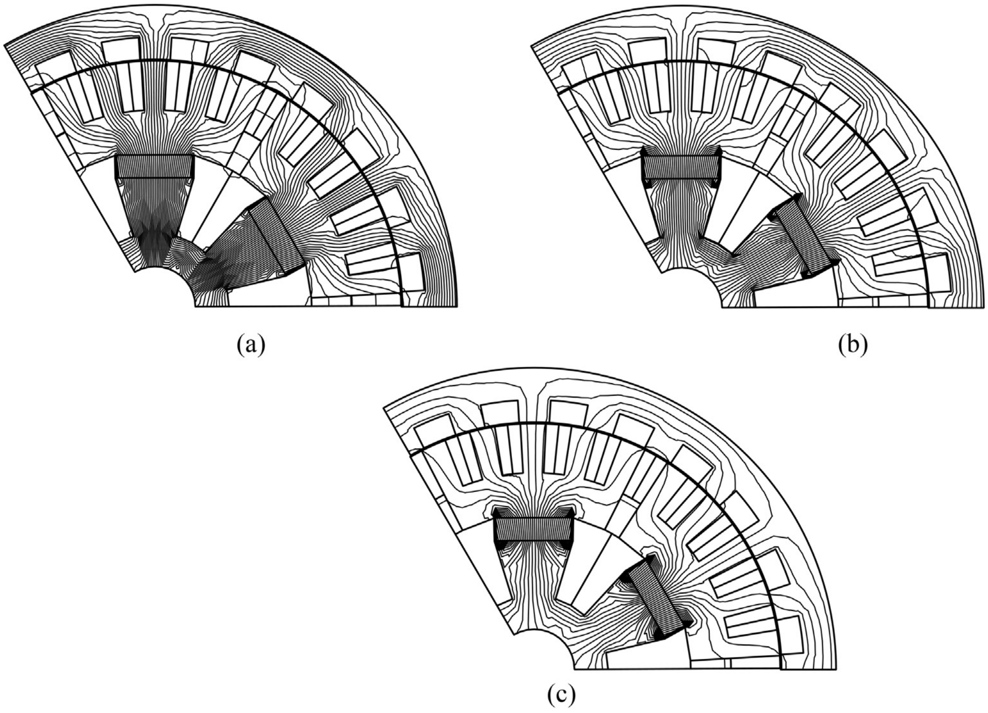

Fig. 2. Magnetic field distributions under different PM magnetization levels at no load. (a) Full level. (b) Half level. (c) Weak level.