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Optimization study on a 0.6 kW PMSG for VAWTs and determination of open and short circuit performances by using external circuit method

Durmus Uygun [a,*], *Yucel Cetinceviz* [b], *Gungor Bal* [c]

[a] *Gediz University, Electrical and Electronics Engineering Department, 35665, Menemen, Izmir, Turkey*
[b] *Kastamonu University, Mechatronics Department, 37200, Merkez, Kastamonu, Turkey*
[c] *Gazi University, Electrical and Electronics Engineering Department, 06560, Beşevler, Ankara, Turkey*

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ABSTRACT

As is known, machine design is a time-consuming and complicated process. And consequently, the verification of the designs and machine performances with known optimization methods prior fabrication are becoming more complex and expensive. Relating to this issue, many studies have been achieved to realize optimization and analyze dynamic performance of the designed machines. In this paper, optimization and short/open circuit fault analysis along with transient performance of a designed 0.6 kW radial flux permanent magnet synchronous generator (RFPMSG) for a stand alone wind turbine was studied. The main feature of this study is to use RMxprt dynamic generator model which is linked with the ANSYS Simplorer external circuit simulator. The co-simulation method has been used to analyze the performance of the generator considered for feeding an ohmic load. This method also yields the waveforms of load voltages and load currents for different load and wind speed conditions along with experimental studies.

Introduction

Permanent magnet synchronous machine plays an important role in electromechanical energy conversion [1,2]. The PMSM now is becoming a popular choice in various industrial fields [3] such as the electrical vehicle [4], wind energy conversion systems [5–9] for offshore application [10], aerospace, railway and automotive sectors [11–13], induction heating genset [14] and water turbines [7] because of its high efficiency, high power density, high torque density, etc. [2,4,5,14]. PMSG and drive system have significance in wind energy conversion systems, where increased reliability and availability are necessary [10]. On the other hand, dynamic modeling is considerably significant during increasing reliability. Although PMSG has proposed for energy conversion systems, some failures are inevitable [4]. The failures include demagnetization of permanent magnets; single-phase open circuit and terminal short circuit conditions [4,10,12]. Especially there will be large current and torque under sudden short circuit fault for PMSG. Then here at it causes demagnetization or mechanical damage of PM machine. Thus the peak current is

* *Corresponding author.*
E-mail addresses: durmus.uygun@gediz.edu.tr (D. Uygun), yucelcetinceviz@kastamonu.edu.tr (Y. Cetinceviz), gunbal@gazi.edu.tr (G. Bal).
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much larger stator and rotor pole shoes. So short circuit performance of PM machines has to be carefully studied to improve the fault tolerance [15].

Many studies have been developed for short circuit transient analysis [2,3,8,10,11,13,15–17]. One of them has achieved fault analysis in detail [16]. It presents a multi-domain co-simulation based approach involving coupled circuit subsystems of the electric with electromagnetic field solution to identify faults. The time-stepping coupled field-circuit method was also used for studying the short circuit performance of the PMSG in Ref. [3]. The expression of symmetry sudden short circuit current is derived based on the mathematical model of 3 phase PM machine, and calculation of sub-transient inductance is analyzed in Refs. [13,15].

In this paper, the design optimization of a RFPMSG for vertical axis wind turbine, with rated power of 0.6 kW and rated speed of 750 rpm will be discussed. This study also provides opportunity observation of the parameters and extensive dynamic performance and the effects of various failure modes of 0.6 kW inner-rotor PMSG supplying different loads at variable speeds combined with experimental studies. Different than the references provided above, the study considers an optimization approach of which main idea is to optimize many parameters such as stack length, pole embrace, slot opening, magnet thickness, etc. by taking into account power loss minimization. As a result of this approach; best operation values for load line voltage, efficiency, rated torque and total loss parameters of the generator have been reached.

Studies on 600 W VAWT prototype

Wind turbines are categorized based on their aerodynamic functions and their design. So, they can be classified based on their axis of rotation, called as horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). In that study, optimization and simulation cases are reported for a 600 W micro-scale wind turbine including a permanent magnet synchronous generator of which mechanical details are given in Fig. 1.

There are many differences in both turbine designs. VAWTs are more suitable for direct drive applications compared to HAWTs. Electric machine in direct drive wind system usually operates with low speed and high torque. For a constant power rating and constant torque density of a machine, weight is positively correlated with the torque rating. Consequently, design with higher torque in direct drive will have more weight. In HAWTs, higher weight of the machine in direct drive puts more mechanical stress on the tower. Unlike HAWTs, this is not an issue for a VAWT, as the machine is located on the ground [18].

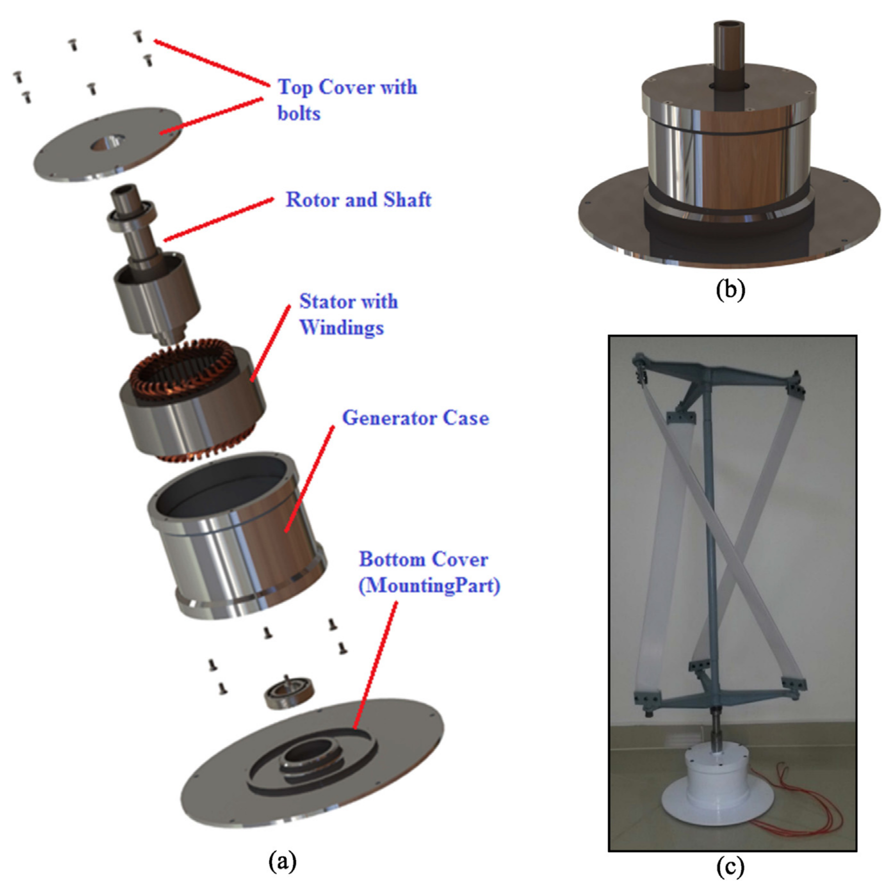

Fig. 1 – Prototype of vertical axis wind turbine with RFPMSG topology: (a) Designed and manufactured parts, (b) 600 W permanent magnet synchronous generator, (c) Manufactured prototype.