Performance Analysis of Four Topologies of Ferrite Permanent Magnet Synchronous Generators for a Small Wind Energy Turbine

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This paper presents a performance analysis of four topologies of permanent magnet synchronous generators using ferrite and generating power for a 3kW, 220V, three phase, resistive load. The optimal design of the machines, intended to small wind turbines, was conducted by using a multidisciplinary model and a deterministic algorithm of optimization. The optimal design of these machines, three conventional and one vernier machine, was implemented in the framework CADES. The vernier machine presents the highest power density at the lowest active material cost among the four machines topologies.

Index Terms— **Permanent Magnet Synchronous Generator, Ferrite, Wind Turbine, Optimal Design, Vernier.**

I. INTRODUCTION

RARE EARTH permanent magnet synchronous generators (PMSG) are widely used in small wind turbines because of their high efficiency and power density. However, the high cost of rare earth magnets has led to the search for alternatives and the ferrite magnets are the natural choice. Several studies have addressed the optimized design of synchronous machines with ferrite permanent magnets, but usually the works focus only on a particular machine topology, as in [1], where the design and analysis of a ferrite permanent magnet vernier synchronous machine with dual stator was presented.

Previous works of the authors have proposed using reluctance network for modelling ferrite conventional PMSG, including vernier machines, like in [2], but a performance analysis of different topologies of generators using ferrite was not done yet. In this work, the performance characteristics of four topologies of ferrite permanent magnets synchronous generators, optimized using the methodology described in [3], are compared to each other. The proposed machines were designed to deliver 3kW, 350 rpm, 220 V phase to phase to a three-phase Y connected resistive load. The framework CADES [4], employing the sequential quadratic programming (SQP) optimization algorithm, was used for the optimal design of these machines. The optimization-oriented sizing model includes six sub-models: mechanic, thermal, electric, geometric, magnetic and economic. The minimization of active material mass was chosen as objective function. The aim is to highlight the advantages and disadvantages of each ferrite machine topology, and analyze the more appropriate pole number for each topology.

II. TOPOLOGIES AND SPECIFICATIONS

Three conventional ferrite permanent magnets synchronous machines, two with inner rotor and one with external rotor, were designed. A permanent magnet vernier machine with external rotor, fractional slot per pole per phase (q) was also designed. The four machines have magnets with tangential magnetization, which allows concentration of magnetic flux in the air gap. Table I presents the main design specifications of these machines.

TABLE I
MAIN DESIGN SPECIFICATIONS OF THE OPTIMAL DESIGN

Parameters	Type of Restriction	Value
Stator yoke (mm)	restricted	hsy ≥ 10
Rotor yoke (mm)	restricted	hsy ≥ 10
External diameter (mm)	restricted	Dext ≤ 300
Width tooth (mm)	restricted	bd ≥ 5
Width slot (mm)	restricted	ha ≥ 5
Mechanical Speed (rpm)	fixed	350
Pole number	variable	16 to 70

A. Inner rotor, integer q, conventional generator

Fig. 1 shows a symmetrical sector of an inner rotor, integer slot per pole per phase (q), conventional generator (generator A), where the magnets (in gray) have arrows indicating the direction of magnetization. Three phase winding and parts of ferromagnetic material (in yellow) are also indicated. This machine presents a variable airgap that allows reducing the cogging torque to a reasonable value without using slot skew.

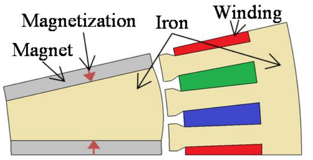

Fig. 1. Permanent magnet synchronous generator with inner rotor and one slot per pole per phase.

B. Inner rotor, fractional q, conventional generator

An inner rotor, fractional slot per pole per phase, conventional generator, with q = 0.75 (generator B) is shown in Fig. 2 (a). Because of the fractional q, a lower cogging and therefore a lower toque ripple, even using a constant airgap, is expected in this generator.

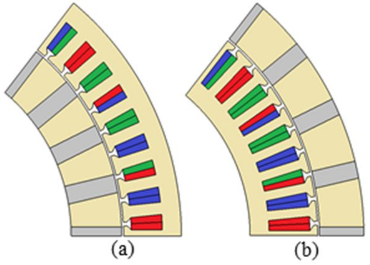

Fig. 2. Permanent magnet synchronous generator, fractional number of slot per pole per phase, with (a) inner rotor and (b) external rotor.

C. Exterior rotor, fractional q, conventional generator

The machine presented in Fig. 2 (b) is an exterior rotor, fractional q, conventional generator, with q=0.75 (generator C).

D. Exterior rotor, fractional q, vernier generator

Fig. 3 illustrates an exterior rotor, fractional q (q=0.75), vernier generator (generator D). The model of this machine was presented in [2]. Here, the performance of this machine will be compared to the three conventional ones.

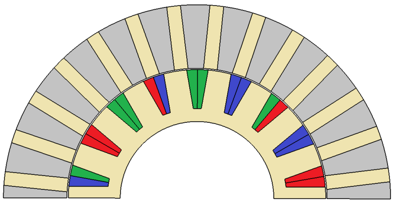

Fig. 3. Exterior rotor vernier permanent magnet synchronous generator with fractional number of slot per pole per phase.

III. RESULTS

Initially, the performance parameters of the optimized machines were verified by using a finite element analysis software (FEA) at no-load and at full-load conditions. After that, the main performance parameters of these machines, for different pole numbers, were analyzed in order to determine the more appropriate pole number for each topology. Finally, the best topology was identified for this application.

A. Optimal machines and performance verification by FEA software

Three conventional and one vernier machine, all of them with 28 rotor poles were designed and their performances were verified by a FEA software. The differences between the parameters obtained from the optimized project and those obtained with FEA are less than 4%, which validates the design of these machines.

B. Performance analysis

In order to analyze the influence of the pole number on the performance of each machine, the conventional generators were optimally designed and analyzed for 16, 20, 24 and 28 poles. The conventional machines were not able to meet the design specifications indicated in Table I for a pole number higher than 28. Similarly, the vernier generator was optimally designed with 8/28, 12/42, 16/56, and 20/70 poles (stator pole number / rotor pole number).

Fig. 4 shows that generator B with 24 poles (B24) has the highest power density and the lowest active material cost among the conventional machines.

Fig. 5 shows that the pole number combination for which the vernier machine has the highest power density and the lowest active material cost is 16/56 (generator D16/56).

Fig. 6 shows the power density and active material cost of the conventional and vernier generators with the pole numbers that result in the highest power density and the lower active material cost. When the power density is considered, the superiority of vernier generator (D15/16) over the conventional ones is clear, whereas its active material cost is only a little lower than that of the best conventional machine (B24).

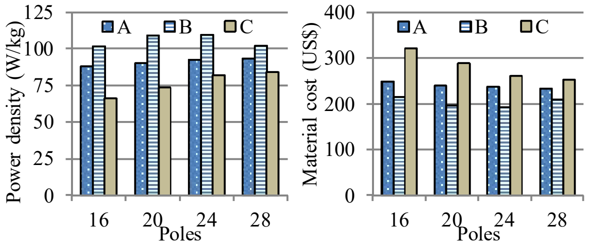

Fig. 4. Power density (left) and active material cost (right) of conventional generators as a function of pole number.

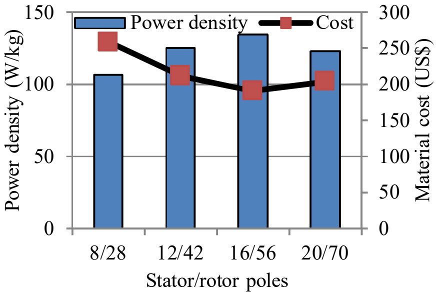

Fig. 5. Power density of vernier generator as a function of armature and rotor pole numbers.

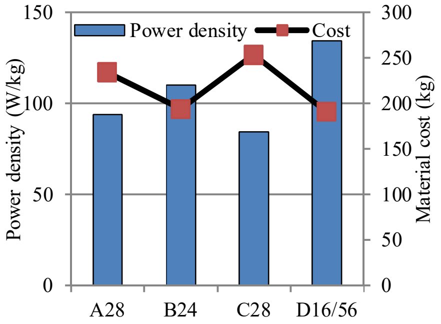

Fig. 6. Power density and active material cost of the best conventional and vernier generators.

In the full paper, other parameters, such as toque ripple, voltage regulation will be also discussed, and the reluctance and thermal models used on the optimal designs of each topology will be included.

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