From geometry to controller parameters : an embedded model for sensorless vector control of axial flux permanent magnet machines

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This work proposes an analytical model to determine the parameters needed for the sensorless vector control of coreless axial flux permanent magnet machines. A reluctant model is used to compute the flux linkage constant while the phases resistances and inductances are calculated from coils geometry. The model is computationnaly light and can be easily embedded in a low-cost microcontroller to tune the control law. The approach was validated with finite element analysis and experiments. The domain of validity of the model was explored through a sensitivity analysis. Experimental tests were conducted on a 1 kW wind turbine axial flux generator to validate the proposed approach. By enabling embedded model-based controller tuning from the generator geometry, this study intends to contribute bridging the gap between magnetic computations theories and practical high performance control of electrical machines.

***Index Terms*—Axial Flux Permanent Magnet Machines, Analytical Model, Finite Element Analysis, Sensorless Vector Control**

I. Introduction

AXIAL FLUX Permanent Magnet (AFPM) machines with coreless concentrated windings are well known for their low cogging torque and high efficiency [1], [2]. These machines are also easy to manufacture which makes them well suited to low cost small wind turbine or pico-hydro applications [3]. Recent works have shown that active rectification could provide significant gains in terms of energy harvest for small wind turbines [4]. The method developed uses a mechanical sensorless vector control law embedded in a low-cost microcontroller. To ensure good performance of the control strategy, the controller parameters should be tuned according to the machine dynamic model parameters. In the case of locally manufactured small wind turbines, there are numerous generator models, mainly depending on the turbine size, the type of magnet that can be sourced locally and the system voltage. Hence, there are plenty of different set of dynamic model parameters, corresponding to each generator model. This means that a generic set of parameters could not be used, implying that the controller should be tuned for each wind turbine. The conventional method to tune the controller is to calculate the gains offline and then flash the microcontroller with the adapted firmware. However, this approach requires (1) the knowledge of the machine dynamic model parameters (2) a method to calculate the controller gains from machine parameters (3) an appropriate software to flash the microcontroller. These complexity barriers might compromise the appropriation of this technology by practitioners, despite its advantages in terms of energy production. This research work aims at simplifying the controller tuning process. To this end, we propose a method allowing the practitioner to tune the controller by sending some key information of the machine design to the microcontroller, without having to flash it. Thus, the originality of this work is to propose the computation of the machine parameters from the machine geometry directly in a microcontroller thanks to an analytical model.

II. Problem statement

As illustrated by the Fig. 1, the focus of this work is to establish an embedded model to determine the model parameters needed for the sensorless vector control of a coreless axial flux permanent magnet machine (in this case, a wind turbine generator). To give some of the inputs and outputs of the model, the geometrical and dynamic models are introduced in the following sections.

The AFPM machine considered in this work is a coreless single layer concentrated windings topology [2]. A linear representation of a circumferential cut is proposed on Fig. 2. For the sake of concision, all the geometrical variables are not specified in this abstract.

According to the literature, the dynamic model of this machine topology corresponds to a classical surface mounted permanent magnet synchronous machine [5]. In the d-q Park frame, the current dynamics are given by

$$L_s \frac{di_{dq}}{dt} = v_{dq} - R_s i_{dq} - \lambda_{dq} \tag{1}$$

with v_{dq} the phase-to-neutral voltages, i_{dq} the currents and λ_{dq} the flux linkages written as

$$\lambda_{dq} = p\omega L_s \mathcal{J} i_{dq} - p\phi_f \omega \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{2}$$

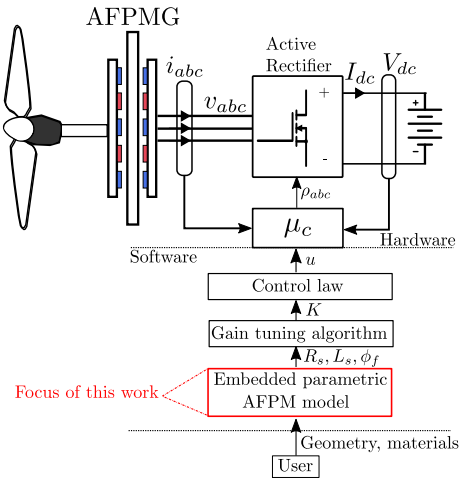


Fig. 1: Typical architecture of an AFPM machine-drive system for a small wind turbine application. The focus of this work is highlighted in red.

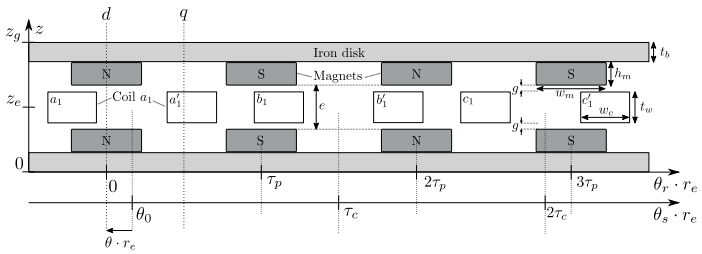


Fig. 2: Linear view of a circumferential cut with geometrical parameters of the AFPM machine topology.

with p the pole pairs number, ϕ_f the peak value of the flux linkage and $\mathcal{J} = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$ a rotation matrix. A classical vector control strategy can be implemented to impose the currents' dynamics [6]. The tuning of the controller, usually a proportional-integral (PI), requires the knowledge of the parameters R_s, L_s. In the case where a currents observer is needed for position sensorless control, the knowledge of ϕ_f is also needed [7].

The goal is to propose an analytical model to obtain the parameters R_s, L_s and ϕ_f that is light enough to be embedded in a microcontroller.

III. Embeddedable Model of the Axial Flux Coreless Machine

In this section, the embeddable model is established to calculate the parameters R_s, L_s, ϕ_f of coreless AFPM machines.

IV. Model Validation with Finite Element Analysis

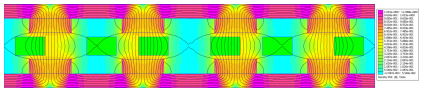


Fig. 3: Finite element analysis of a 1 kW coreless AFPMG.

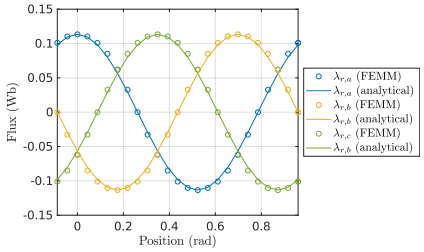


Fig. 4: Flux linkage in function of angular position (analytical vs. FEA).

A finite element magnetics model was established to validate the analytical embbedable model. A snaphsot of the analysis is shown on Fig. 3. The flux linkage was calculated against angular position for the FEA and analytical model. It is shown on Fig. 4. Further simulation results will be included in the final version of the paper.

V. Sensitivity Analysis of the Model

A sensitivity analysis was performed to investigate the domain of validity of the proposed model regarding the variations of the air gap, pole arc to pole pitch ratio and permanent magnet material.

VI. Experimental Results

Experiments were conducted on a 1 kW wind turbine AFPMG to validate the proposed approach. The experimental tests allowed to determine the machine inductances in d and q axis as well as the flux linkage constant and the phase resistance.The experimental results will be included in the final version of the paper.

VII. Conclusion

This work proposed an embeddable model to calculate the dynamic model parameters for coreless AFPM machines with concentrated windings. In the final paper, the model will be validated with both finite element magnetics including a sensitivity analysis and experimental tests.

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