

-Design and Control of Switching Synchronous Motor Dedicated to Electric Cars - Motorization

Souhir Tounsi
Sfax University

ABSTRACT

In this paper, we present a design and control methodology of an innovated structure of switching synchronous motor. This control strategy is based on the pulse width modulation technique imposing currents sum of a continuous value and a value having a shape varying in phase opposition with respect to the variation of the inductances. This control technology can greatly reduce vibration of the entire system due to the strong fluctuation of the torque developed by the engine, generally characterizing switching synchronous motors. A systemic design and modelling program is developed. This program is validated following the implementation and the simulation of the control model in the simulation environment Matlab-Simulink. Simulation results are with good scientific level and encourage subsequently the industrialization of the global system.

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INTRODUCTION

Electric motors dedicated to electric cars motorization, is a current project against the advantages of the electric motors compared to their thermal equivalent engines to knowledge [1, 2].

- Reliable production cost.
- Ability to monitor optimizing energy consumption.
- Ease of use.
- Low maintenance costs.
- Reduction of air and noise pollution.
- Ability to use embedded energy sources to address oil crises.

The switching motors have took the relief to other types of electric motors due to their benefit such as the progress in the field of the electronic control area of these types of engines as their advantages over other types of electric motors, especially the low cost of production and of maintenance. However, these engine types have a drawback of a large vibration due to the large variation of the saliency of these motor types. In this context, we provide a control strategy for an innovated structure of a synchronous motor with variable reluctance minimizing vibrations acting on the shapes of the supply currents by pulse width modulation with reduced switching frequency, to reduce the losses in the power converter. This control technique is suitable for a systemic design and modelling program of an innovated structure of two-phase switching synchronous [1, 2].

In this direction, this paper has three main parts to Knowledge:

- Description of systemic design and modelling program of the switching motor.
- Description of the e control strategy proposed and its advantage over the state of the art.
- Presentations of components models of the power chain.
- Presentations and descriptions of simulation results.

MOTOR STRUCTURE

The engine is with two-phase structure (Figure 1) and with two pairs of poles (two rotor teeth). This structure has two teeth per phase. The slots are straight and open leading to a significant reduction of the production cost of this type of engine. The coils are a concentrated type which facilitates the automation process of the insertion of coils in one block. Each winding is formed by two diametrically opposite coils connected in series. The mechanical torque developed by the motor is caused by the variation of the motor saliency along the air gap. The rotor teeth are of low height to minimize the effect of the rotor inertia variation in function of rotor position.

For triangular inductances shifted by an angle equal to π , we must respect the following rules:

- The angular opening of the stator teeth is equal to the angular opening of the rotor teeth.
- The angular opening of the space among stator teeth is equal to half of the opening of a stator tooth.

The structure of the studied motor is illustrated in Figure 1



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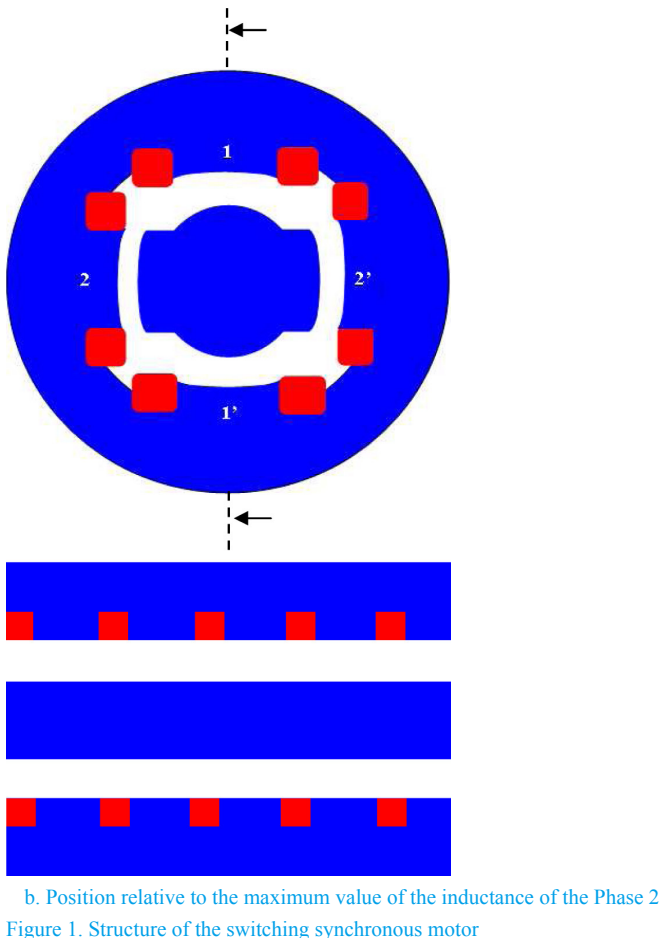
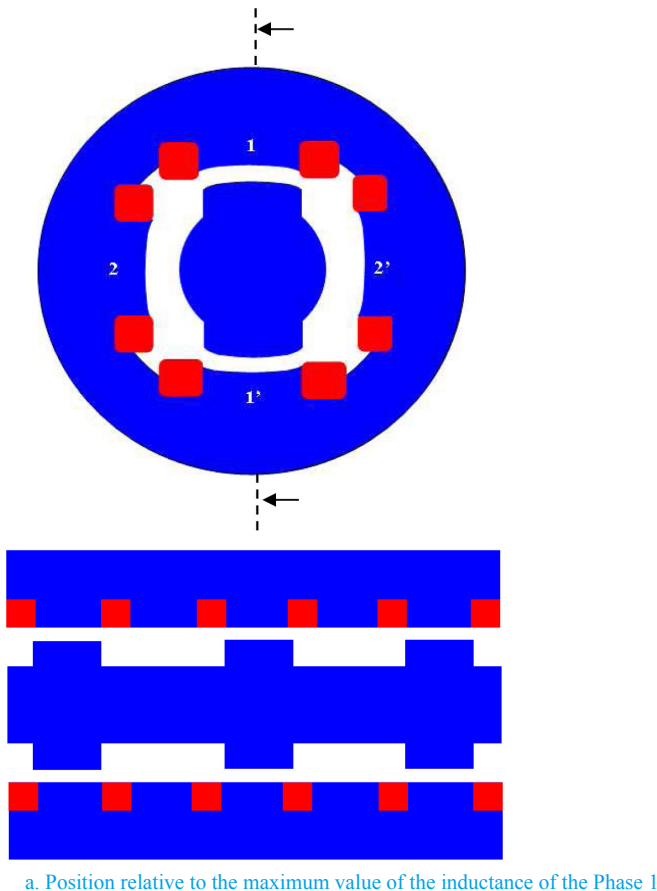


Figure 1. Structure of the switching synchronous motor

SIZING AND MODELLING PROGRAM

Generally, electrical machinery design problems are solved by the finite element method in two dimensions or three dimensions to have an important accuracy of results. Moreover, this method requires a large simulation time making the resolution of the problems complex and incompatible to optimizations approaches of designed machines performance. In this context, our choice fell on the analytical method to solve the actuator design problem. In addition, this method is the most flexible to vary solutions depending on the power requirement. This method is based on the application of general theorems relating to the design of an electrical device to Knowledge [3, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26]:

- Theorem of Ampere.
- Theorem of the Flow conservation.
- Theorem of magnetic fields superposition.

This method is also based on simplifying assumptions justified to knowledge.

- Absolute Permeability of iron is infinite.
- Negligible magnetic field in the iron.
- The magnetic flux loop through the shortest magnetic path.
- Linearity of the B-H characteristic of iron.
- Air Permeability equal to $4\pi \cdot 10^{-7}$.

This method is supplemented and adjusted by the finite element method.

The magnetic induction in the air-gap is calculated by applying the Ampere Theorem for a maximum flow position in a manner to not saturate iron and have a the lower mass of the engine. This implies that the magnetic induction in the iron must be close to the saturation bend of the iron B-H curve.

$$B_e = \mu_0 \times \frac{N_{sph} \times I_n}{2 \times e} \quad (1)$$

Where μ_0 is the air permeability, N_{sph} the stator winding number of turn and I_n is the rated current.

The thickness of the stator yoke and the thickness of the rotor yoke are calculated by applying the flow conservation theorem.

$$H_{cs} = \frac{B_d \times S_d}{2 \times B_{cs} \times L_m} \quad (2)$$

$$H_{cr} = \frac{B_e \times S_d}{2 \times B_{cr} \times L_m} \quad (3)$$

where B_d is the stator tooth flux density, S_d is the stator teeth section, L_m is the length of the active part of the stator, B_{cs} is the stator yoke flux density and B_{cr} is the rotor yoke flux density.

The height of the stator teeth can reserve space for the copper while taking account of the space occupied by the electrical insulator and the allowable current density in the copper.

$$H_d = \frac{N_{sph} \times I_{dim}}{\delta \times L_{enc} \times K_f} \quad (4)$$

Where I_{dim} is the dimensionning current, δ is the allowable current density in the copper, L_{enc} is the stator slot width and K_f the filling coefficient of the slots.

The winding resistance is calculated at a temperature of copper equal to 90 °C considering an automated cooling system of the motor maintaining the temperature costant to this value.

$$R(T_c) = \frac{\rho(T_c) \times N_{sph} \times L_{sp}}{\frac{I_{dim}}{\delta}} \quad (5)$$

Where $\rho(T_c)$ is the copper resitivity at a temperature equal to T_c , L_{sp} is a winding turn length.

The phase's inductances of the motor are expressed by the following equations.

$$\begin{aligned} \text{if } 0 \leq \theta \leq A_{dent1}; \quad L_1 &= L_{c1} + C_i \times \theta \\ \text{if } A_{dent1} \leq \theta \leq 2 \times A_{dent1}; \quad L_1 &= L_{c1} + C_i \times A_{dent1} - C_i \times \theta \end{aligned} \quad (6)$$

$$\begin{aligned} \text{if } \frac{A_{dent1}}{2} \leq \theta \leq \frac{3}{2} \times A_{dent1}; \quad L_2 &= L_{c1} + C_i \times \left(\theta - \frac{A_{dent1}}{2} \right) \\ \text{if } \frac{3}{2} \times A_{dent1} \leq \theta \leq \frac{5}{2} \times A_{dent1}; \quad L_2 &= L_{c1} + C_i \times A_{dent1} - \\ C_i \times \left(\theta - \frac{3 \times A_{dent1}}{2} \right) \end{aligned} \quad (7)$$

where:

$$C_i = \frac{N_{dsp}}{2} \times \frac{\left(\mu_0 \times \frac{D_{st}}{2} \times L_m \right) \times \left(\frac{N_{sph}}{\left(\frac{N_{dsp}}{2} \right)} \right)^2}{2 \times e} \quad (8)$$

$$L_{c1} = \frac{N_{dsp}}{2} \times \frac{\left(\mu_0 \times H_d \times L_m \right) \times \left(\frac{N_{sph}}{\left(\frac{N_{dsp}}{2} \right)} \right)^2}{L_{enc}} \quad (9)$$

The evolution of inductances according to the mechanical angle is illustrated in Figure 2.

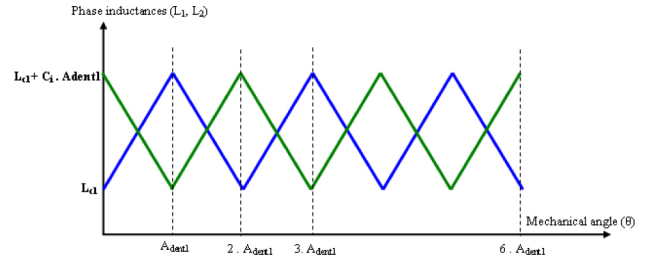


Figure 2. Evolution des inductances en fonction de l'angle mécanique

A_{dent1} is the angular opening of a stator tooth, μ_0 is the air absolute permeability, N_{sph} is the phase number of turns, N_{dsp} is the number of main teeth of the stator, L_m is the engine length, H_d is the height of a main stator tooth, L_{enc} is the slot width, D_{st} is the bore diameter and θ is the rotor position.

CONTROL STRATEGY

The speed of the electric car is regulated by a Proportional-Integral-Derivative (PID) speed regulator type to minimize the error between the reference speed and response speed. Indeed, the regulator provides the amplitude of the reference currents to be adjusted to ensure continuous shapes generating a motor torque with little fluctuation by adding two adjustment loops for converting reference currents fluctuating in opposite phase with inductances to ideal reference voltages. The triangular shape of the motor phase inductance led us to apply the pulse width modulation technique with fixed switching frequency for reproducing the real shapes of the supply voltages produced by the DC-AC converter. This control strategy allows an interesting reduction in error between the response speed and the reference, which leads to a significant reduction of the mechanical vibrations of the transport system studied [3, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26].

CONTROL MODEL

Simulink Model of the Inductances

The Simulink model of inductances is shown in Figure 3.

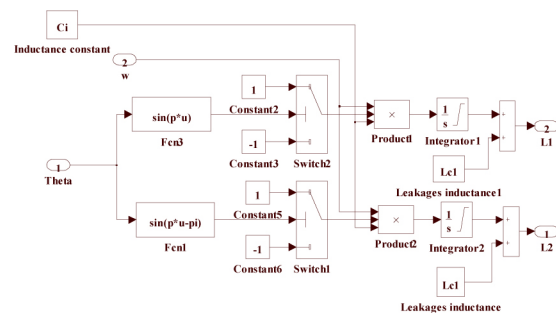


Figure 3. Simulink model of inductances