CONTROL METHOD WITH DISTRIBUTION OF PHASES WINDINGS FOR SWITCHED RELUCTANCE MOTOR

C. Labiod, K. Srairi and B. Mahdad
LESM: Laboratory of Energy Systems Modeling
Department of Electrical Engineering, University of Biskra
BP 145, Biskra 07000, Algeria.
E-mail: labiod.chouaib@gmail.com, ksrairi@yahoo.fr and bemahdad@mselab.org

Abstract: *This paper presents control method with distribution of phases windings applied to 6-phases 12/10 switched reluctance motor (SRM). The proposed distribution of the phase's windings with control method allows getting short flux path instead of long flux path. This decreases the current required to establish the flux in the airgap. Control method relies on excited two phases for every rotor position, thus contributing to the improvement of torque. Circuit-coupled time stepping finite element analysis was used to obtain the magnetization characteristics for dynamical modeling applications.*

Key words: *Switched reluctance motor, Control method, Dynamical modeling, Finite element method, Coupled circuits, Time stepping.*

1. Introduction

Switched reluctance motor (SRM) has many advantages over other types of motors used in a growing number of applications in various industries because the development of the power electric and control technology [1-7]. The feature's monopoly of SRM such as lack of any coil or permanent magnet on the rotor, simple structure and high reliability, make it a suitable candidate for operation in variable speed, harsh or sensitive conditions.

The difficulties of the SRM design are mainly attributed to the following reasons [6-13]:

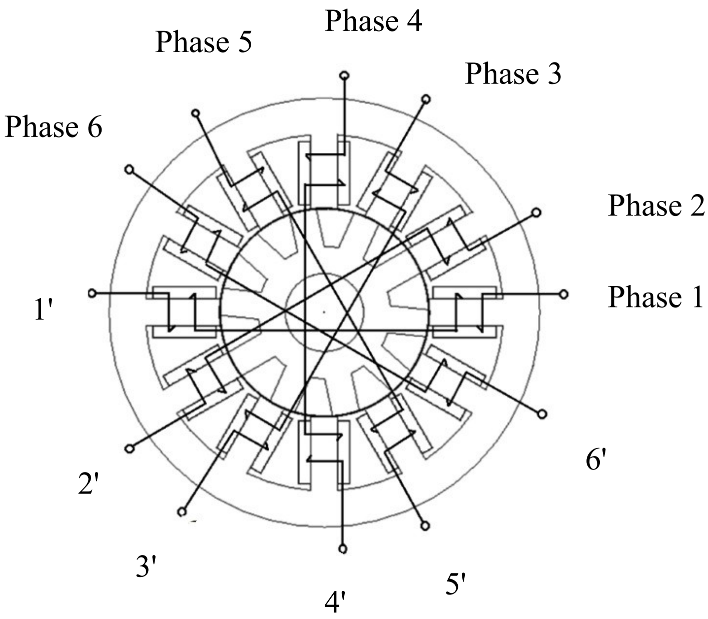
a. High magnetic and control nonlinearities.
b. Many flexible design parameters, including those that high torque ripples affect vibrations and acoustic noises.
c. Interdependence on the design of the converter and control parameters.
d. Variable-speed operations.
e. Thermal management bottleneck due to the concentrated coils.
f. Difficulty of thermal rating manufacturing tolerance.

Many papers proposed for design and construction of novel SRM. Authors in [14] proposed a new two-phase 4/5 switched reluctance motor with short flux path, in [15] a novel 12/14 hybrid pole type bearingless switched reluctance motor with short flux path and no flux-reversal in the stator is proposed, authors in [16] described the design and modeling procedure of a novel five-phases segment type switched reluctance rotor (ST-SRM) under simultaneous two-phases (bipolar) excitation of windings. This paper proposes a configuration adequate to using a specified control method.

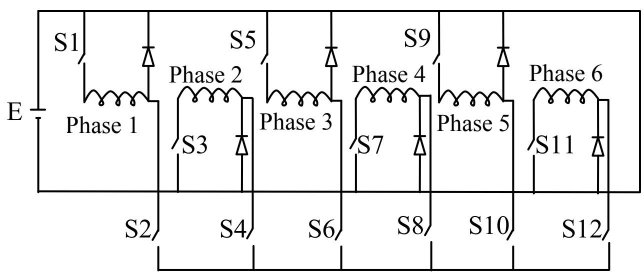
After a general introduction presented in section 1, section 2 explains the processes control of the distribution of the phase windings applied to a prototype 6-phases 12/10 switched reluctance motor. Section 3 presents finite element method analysis for defined aligned of flux distribution in different rotor position. Section 4 presents sample application by using dynamical modeling based time stepping finite element method (TSFEM). Finally, simulation results such as flux distribution in different positions, torque and current characteristics are analyzed and discussed.

1. SRM configuration based on proposed control method

The first step in building the model consists of specifying the geometry with distribution of phase's windings and circuit control for six phases winding 12/10 SRM. The structure and circuit control of SRM is shown in Figure 1. The Geometry 12/10 SRM with distribution of the phase windings is shown in figure 1.a.



(a). Geometry 12/10 SRM with distribution of the phase windings.



(b). Circuit control for six phases windings.

Fig. 1. Structure and circuit control of SRM.

Converter topology where each phase has two switched and freewheeling diodes is shown in Figure 1.b.

The objective of this distribution is that every two adjacent phases working like one phase and each phase works in coordination with the precedent and the next phase by controlling the switches, for example when the switches S1, S2, S3 and S4 turn on simultaneously, the external power supply the phase 1 and the phase 2 in series of SRM and in the next position we have S3, S4, S5 and S6 turn on, the external power supply phase 3 and phase 4 in series, until the last position S11, S12, S1 and S2 turn on to get energize phase 6 and phase 1 in series. It is important to note that the control of switches is related to rotor position.

2. Finite element analysis

The computation of the flux linkage (a function of time, rotor position θ and phase current i) in one phase of the SRM is the first step in finite element modeling of the machine. The flux linkage ϕ can be determined by computing the magnetic vector potential **A** over the machine cross section magnetodynamic problems. Computing the magnetic vector potential **A** in cartesian coordinates (x, y) is described by nonlinear Poisson's equation as follow:

$$\frac{\partial}{\partial x}\left(\nu\frac{\partial A_z}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu\frac{\partial A_z}{\partial y}\right)-\sigma\frac{\partial A_z}{\partial t}=-J_z \qquad (1)$$

Where ν is the magnetic reluctivity, J_z the source current density and σ the electrical conductivity.

The flux linkage in each phase is given by:

$$\phi=\frac{1}{i}\int_v \vec{J}\ \vec{A}\ dV \qquad (2)$$

This, after finite element discretization, becomes:

$$\phi=\frac{Nl}{S}\sum_{k=1}^{n} A_k S_k \qquad (3)$$

Where N is the number of turns per phase, l is the axial length and S the area for the phase winding.

Taking into account the machine parameters, the magnetic co-energy W'_{em} can be calculated on the basis of flux linkage ϕ as:

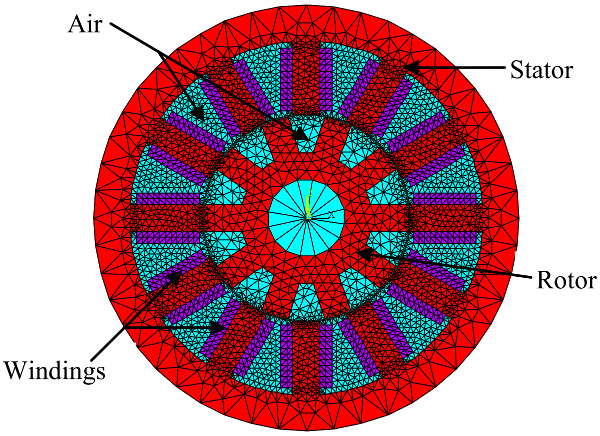
$$\partial W'_{em}=\phi\,\partial i \qquad (4)$$

Torque is calculated from the co-energy derivative with respect to θ angular position as:

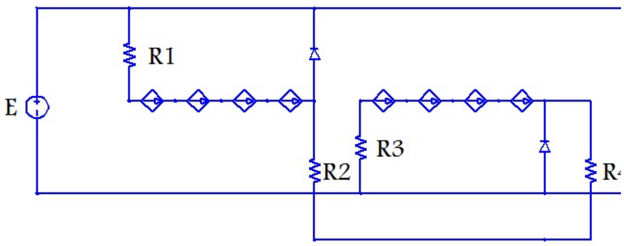
$$T=\frac{\partial W'}{\partial \theta} \qquad (5)$$

Figure 2 shows the circuit-coupled FEM model of the SRM. The finite element mesh model adopted for the studied SRM is shown in Figure 2.a. Figure 2.b. illustrates a simplified equivalent circuit based on two phases winding. The voltage applied to each phase is controlled in accordance with the rotor positions, by its top and bottom transistors. The transistors are represented by resistors R1, R2,..., R12. Resistance is equals to 10^{-6} Ω for the on-state and 10^{6} Ω for the off-state [17].

The phase current and the torque output are determined by the turn-on and turn-off angles of the phase voltage. Field weakening for high-speed operation is achieved by advancing the turn-on angle. An advanced turn-on angle means that the turn-on time of the phase voltage occurs before the unaligned rotor position.



(a). The adopted finite element mesh for the SRM.



(b). Simplified equivalent circuit based on two phases winding.

Fig. 2. Circuit-coupled FEM model of the SRM.

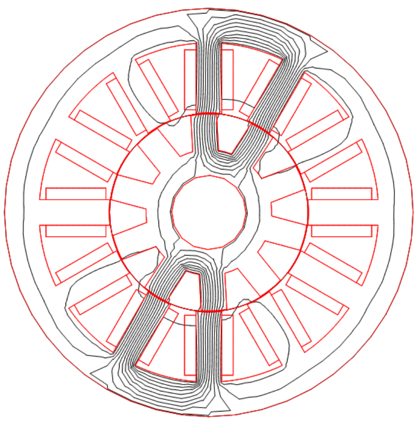


Fig. 3. Aligned flux distribution for Phase 3-4 with rotor at position 3°.

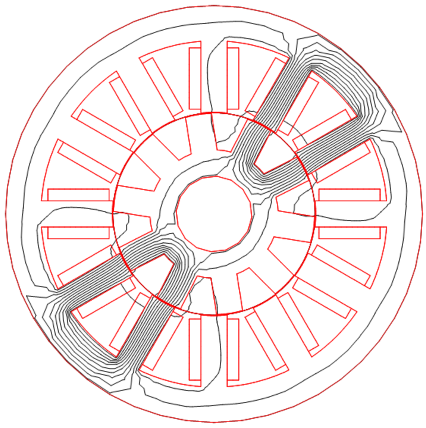


Fig. 4. Aligned flux distribution for Phase 2-3 with rotor at position 9°.

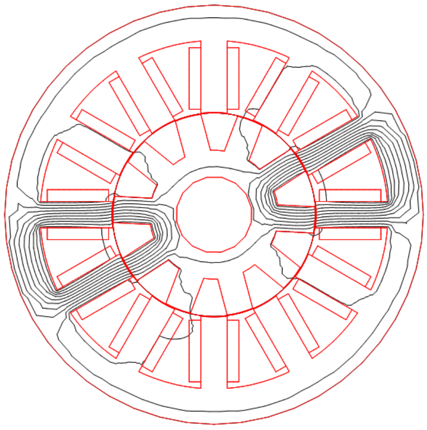


Fig. 5. Aligned flux distribution for Phase 1-2 with rotor at position 15°.

The aligned position of the stator and the rotor poles for excited phases 3-4, phases 2-3 and phases 1-2 with rotor position are shown in Figures 3, 4 and 5.

When two phases are excited, the most adjacent rotor pole-pair is attracted towards the excited stator pole which will achieve alignment between both stator poles and rotor poles. The magnetic flux of the structure and circuit of SRM (Fig. 1) flows in a shorter loop within adjacent pole-pairs.

The two loops shown in Figures 3, 4 and 5 represent the short flux paths of the excited two phases where the rotor position aligned. The advantages of using a short flux path are important for reduction of the eccentric forces between the stator and the rotor poles. The core losses are significantly reduced due to the short distance of the travelling magnetic fields. In addition, flux reversals in the back iron are also eliminated.

4. Application for dynamical modeling by using TSFEM

The time stepping finite element method (TSFEM) is recommended to analyze dynamic performance of motors [17-21]. The electromagnetic field is treated by the use of finite element method, circuit and mechanical ones. The proposed coupled model is used for simulate the dynamic operating process of motors.

In this study the circuit-coupled time stepping FEM model is used to predict the dynamic performance of a six phase SRM with 12/10 poles. The flow chart of the modeling dynamic strategy is shown in Figure 6.

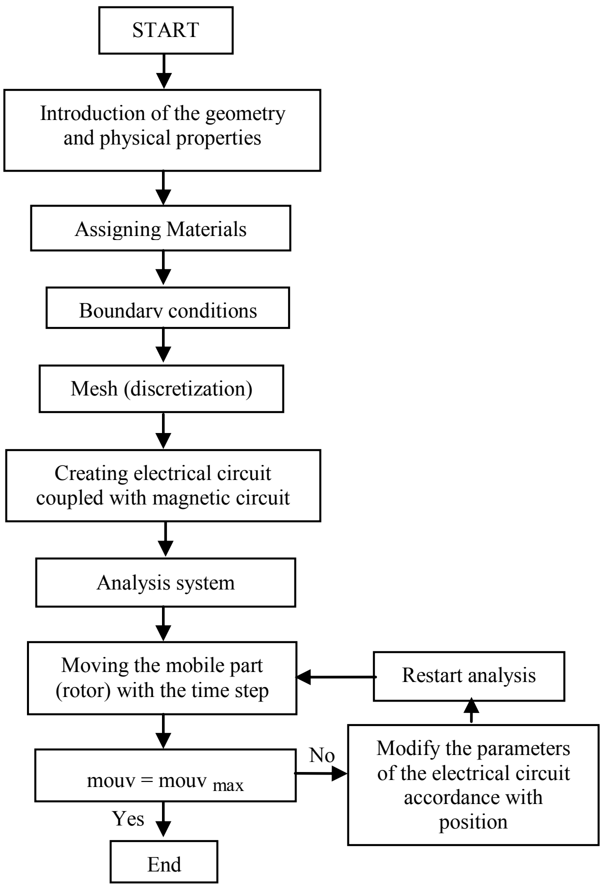


Fig.6. Flow chart of the dynamical modeling strategy.

The parameters adopted in this study are: the turn-on angle is 3°, the turn off angle is 15°, the unaligned rotor position considered is $\theta = 0°$ for every first one pole-pairs of phase.

Figure 7 shows the sequence short flux paths between two adjacent poles corresponding to different rotor positions for dynamic modeling case, which explain the principle function of our studied SRM.

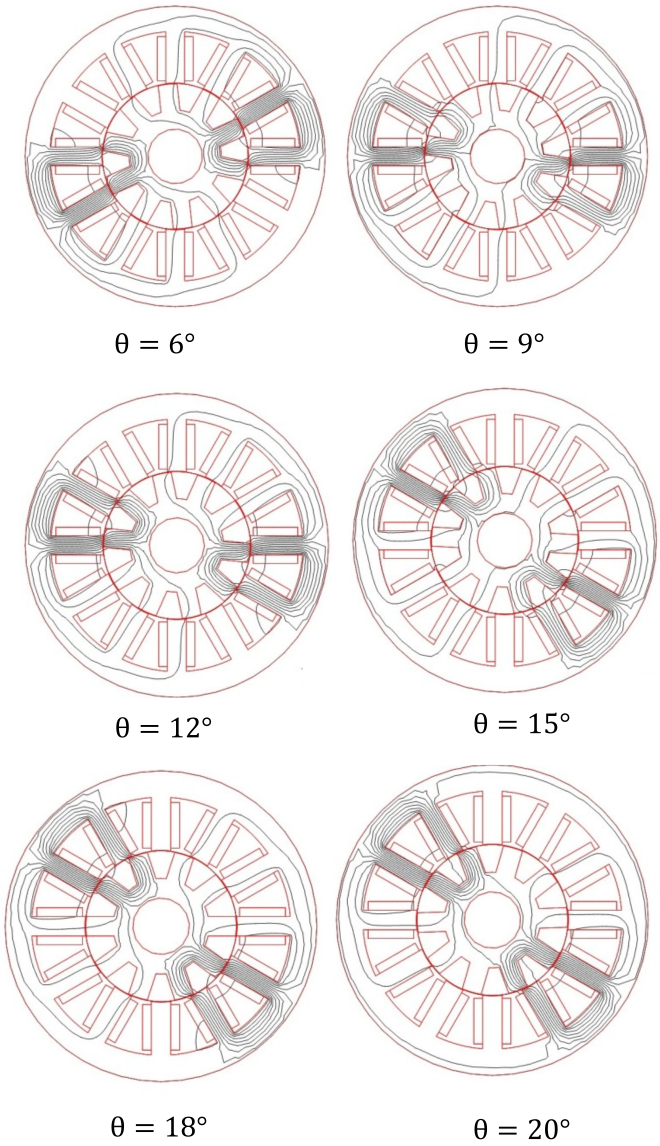


Fig. 7. Flux distribution at different positions.

Figures 8, 9 and 10 show the calculated starting characteristic of this SRM, which are, respectively, rotating speed, starting current and starting torque versus time.

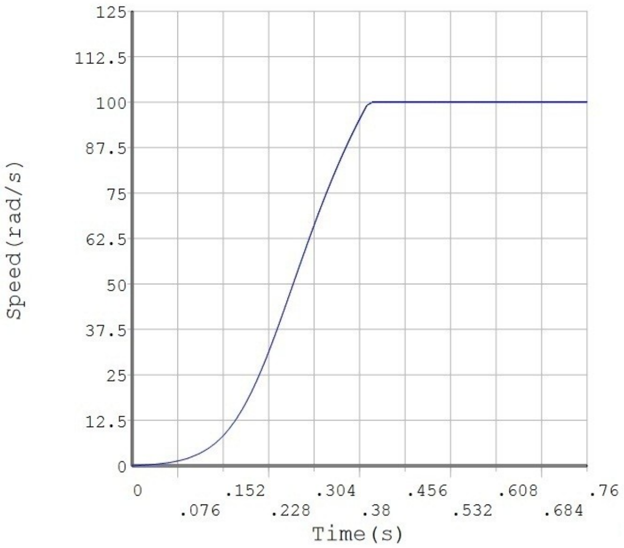


Fig. 8. Starting rotating speed versus time.

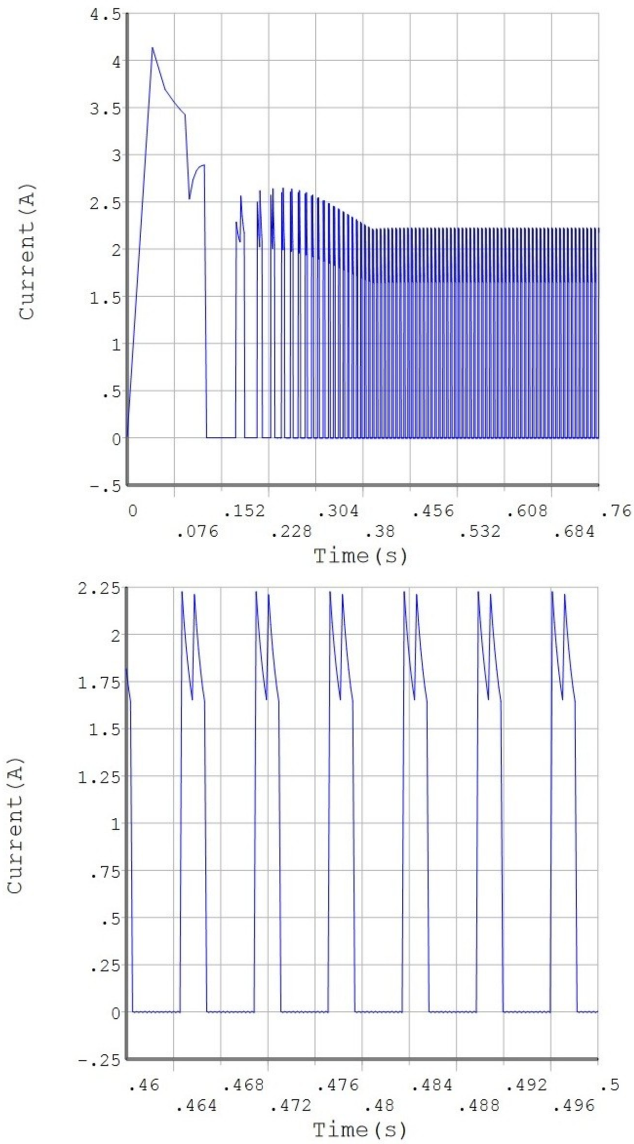


Fig. 9. Starting current versus time for phase 1.

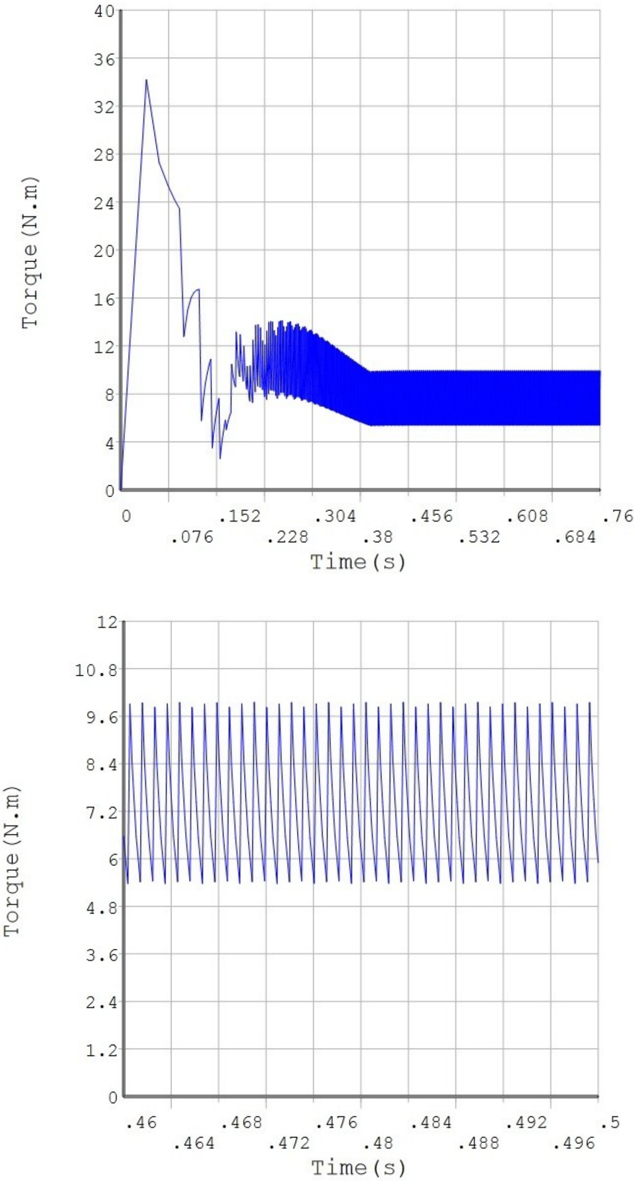


Fig. 10. Total torque versus time.

The rotating speed of motor rises slowly due to inertia torque and friction torque at the starting phase as well shown in Figures 8 and 10. The phase current increases up to the maximum of chopping current rapidly and electromagnetic torque reaches the maximum value at the starting phase. As the rotating speed increasing, the current and torque decrease gradually, then the torque reaches an acceptable value. The ripple torque is relatively low and can be reduced by choosing a specified technical control.

5. Conclusion

By using distribution windings structure with the proposed control method, for a 6 phases 12/10 SRM. The obtained short flux path magnetic distribution helps to reduce the core losses due to the short distance of the travelling magnetic fields. The performances of torque are improved by exciting two phases for every rotor position.

Circuit-coupled time stepping finite element method has been used to investigate the dynamic characteristics and explains the principle function of 6 phases 12/10 SRM. In the future we will strive to validate the efficiency and robustness of the proposed configuration and control strategy with experiment results.

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