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## Flux-linkage Characteristics of Switched Reluctance Machine

<sup>1</sup>\*Laila KADI, <sup>2</sup>Adil BROURI, & <sup>2</sup>Abdelmalek OUANNOU.

<sup>1</sup>Lailakadigi@gmail.com, Ecole Nationale Supérieure d'Arts et Métiers (ENSAM), Morocco

<sup>2</sup>Ecole Nationale Supérieure d'Arts et Métiers (ENSAM), Morocco

The Switched Reluctance Machine (SRM) have a wide range of speed operation, thermal robustness high performances, is cheap and easy to construct and to maintain for this is investigated as an alternative generator in many aspects like wind energy conversion, aircraft actuators and generators, and electric vehicles. Since the SRM is nonlinear in nature, estimation and calculation of the flux-linkage characteristics are very difficult. This paper presents nonlinear numerical characteristics of flux-linkage for SRM using finite element method. The simulations are carried out using FEMM software, and it is shown that the characteristic of flux-linkage is highly nonlinear.

The principle of operating for SRM is based on the variations of reluctance due to double saliency or magnetic (sheeted rotor or axially laminated) during the relative displacement of the rotor and stator [1]. Each pure SRM consists of two parts in relative motion whose stator and rotor (Fig.1). The first one comprises a salient magnetic circuit provided with coils traversed by a current, the second is only a ferromagnetic circuit, also, salient but without any conductor or magnet [2].

Neglecting the mutual inductances between phases. The equations for the SRM phase are written as:

$$V(t) = Ri + \frac{d\varphi(\theta, i)}{dt} \quad (1)$$

$$\varphi(\theta, i) = L(\theta, i) i \quad (2)$$

$$V(t) = Ri + L(\theta, i) \frac{di}{dt} + i \left( \frac{\partial L(\theta, i)}{\partial i} \frac{di}{dt} + \omega \frac{\partial L(\theta, i)}{\partial \theta} \right) \quad (3)$$

$$T = \frac{\partial W(\theta, i)}{\partial \theta} = \frac{\partial \left\{ \int_0^i [L(\theta, i) i] di \right\}}{\partial \theta} \quad (4)$$

In the above expressions  $\phi$ ,  $i$ ,  $R$ ,  $L$ ,  $\omega$ ,  $\theta$ ,  $V$ ,  $T$ ,  $W(\theta, i)$  are flux linkage, phase current, phase resistance, phase inductance, rotor speed, rotor position angle, phase voltage, phase torque, and co-energy, respectively.

Because of the magnetic saturation effect, the flux-linkage in the stator phases varies according to the rotor position  $\theta$  and the current of each phase.

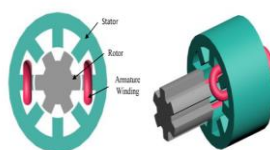


Figure 1. Example of 8/6 SRM

Due to saturation effects in the SRM, establishing the accurate nonlinear mapping relationship of the flux-linkage with respect to phase current and rotor position is the basis of performance calculation. Several modeling techniques have been suggested by worldwide researchers [3-5]. We use here finite element method.

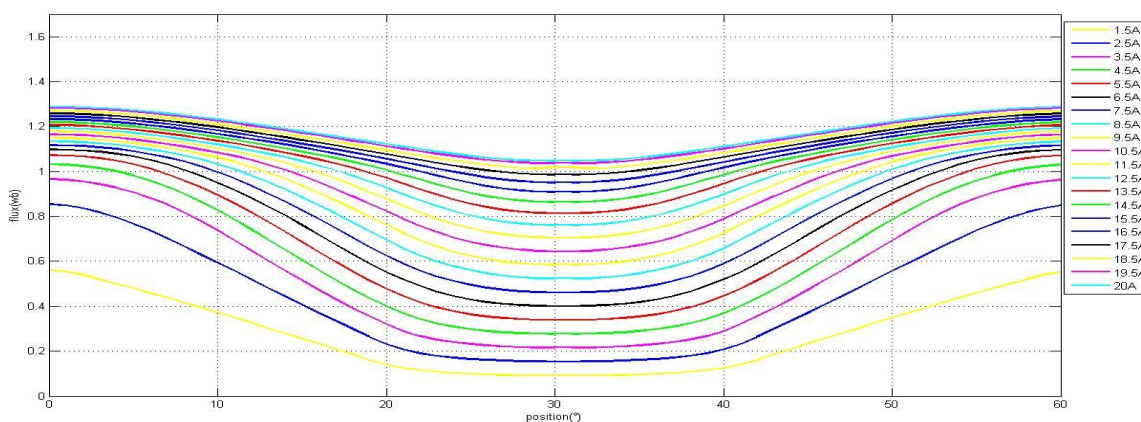


Figure 2. Flux-linkage characteristics .vs rotor position of a 8/6 SRM

Fig. 2 shows the flux-linkage profile of the 8/6 SRM for different values of rotor position and phase currents. The stator phase flux-linkage in SRM vary periodically with rotor position and also vary with the instantaneous phase current due to magnetic saturation. Typical characteristics of flux linkage for different rotor positions and phase currents are shown in Fig. 3. This figure shows the increasing effect of saturation as a rotor pole with the stator phase poles approaches at ( $\theta=0^\circ$ ) the aligned position (Fig 4 .b). The position ( $\theta= 30^\circ$ ) (Fig 4.a) corresponds to the unaligned position between stator and rotor poles. The degree of

magnetic saturation is high, which results in severe nonlinearity in flux-linkage curves, since it is not possible to represent the SRM using a simple linear model as it is done for the induction machine and synchronous machine.

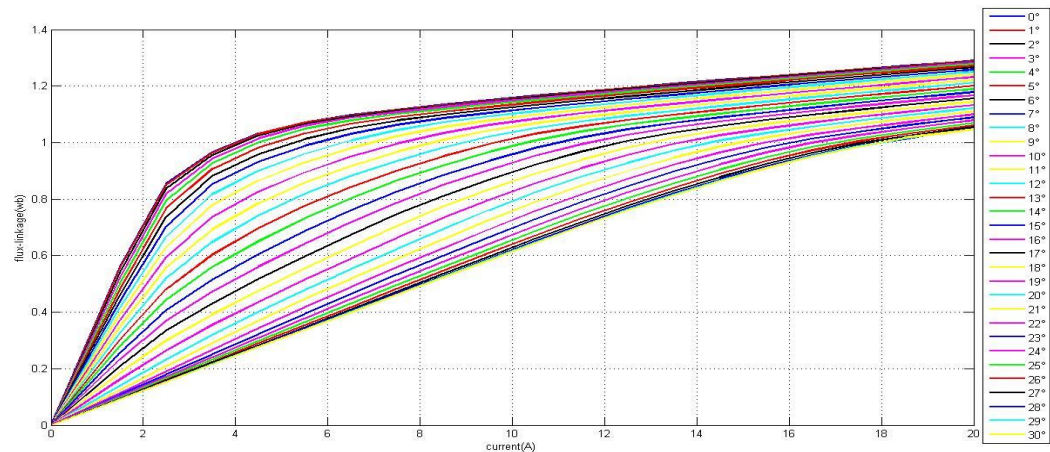


Figure 3. Flux-linkage characteristics .vs current of a 8/6 SRM

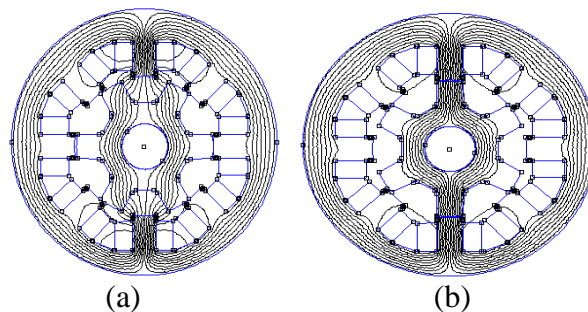


Figure 4. (a) unaligned position ,(b) aligned position

The aim of this work is to present the characteristics of flux-linkage of 8/6 Switched Reluctance Machine using finite element method under software femm, the result indicates that the linear model is unsuitable because the behavior of SRM is highly saturated. So it is difficult and complex to build the model by a simple use of a mathematical model.

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