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Modeling of Flux Linkage Characteristics of Switched Reluctance Motor

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Abstract

The increasing popularity of the switched reluctance machine has created more challenges to present it as a good performer machine under different operational conditions. For modeling and simulation of the machine, the necessity of static characteristics, in particular, flux linkage characteristics which look like the base stone for initialization of simulation is unavoidable. The importance of flux linkage characteristics, and how other data tables such as inverter flux linkage characteristics, co energy and static torque table are obtained are presented in this work. This paper describes a set of equations for modeling of the flux linkage characteristics of switched reluctance machine and also hardware for the 3-phase machine is presented.

Keywords: Flux Linkage Characteristics, Inductance Profile, Switched Reluctance Machine

1. Introduction

Switched Reluctance (SR) motor is the advanced version of the stepper motor with a simple construction as rotor excludes the winding. Stepper motor is an open loop motor whereas the SR motor is a closed loop motor. SR Motor could be used for a variety of applications, starting from household to industry. This machine could not be connected directly with dc supply but it needs a suitable electronic converter. This machine is available in different phase count e.g. single phase to multiple phases.

The rotation in the machine is due to the magnetic attraction of stator poles on its nearest rotor poles. The electrical energy is supplied to the machine when electronic switches preferably IGBTs (Insulated Gate Bipolar Transistor), MOSFET (Metal Oxide Semi-Conductor Field Effect Transistor) are closed, the unutilized energy is then transferred back to same energy source as the switches are opened. Figure 1 shows a three-phase machine with 6/4 phase poles. The machine in motoring mode is switched on when the slope of inductance is positive and the value of inductance is decreased. Alternatively, if the machine is switched on at decreased slope of inductance, it will count a generating mode. The inductance profile is shown in Figure 2. A variety of converters are added for the operation of this machine[1–5].

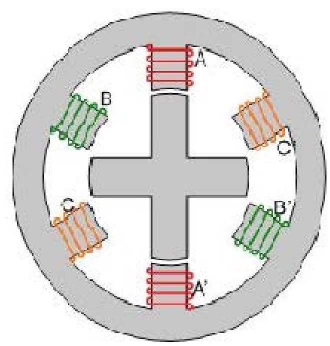

Figure 1. 6/4 pole switch reluctance motor.

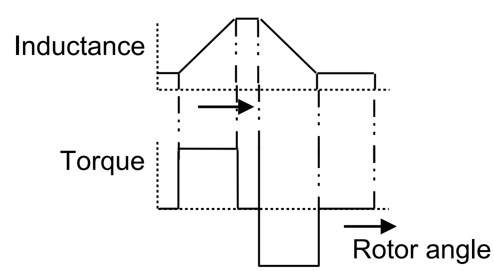

Figure 2. Inductance profile of SR motor.

2. Static Characteristics

The procedure of measurement and modeling of static characteristics are discussed in[6]. The characteristics have been measured in Lab VIEW. These characteristics have been compared with simulation results. Accurate prediction of the motor parameters and static characteristics of SRM play an important role in the simulation of SRM drive[7]. In this paper, the performance of the 4-phase motor is experimentally analyzed under a fixed current and angle control. A different technique for measurement of static characteristics is used in[8]. The Ψ-i for the different angle used in this method. The author claims the avoidance of electrical/electronic problems of measurement. Another work is reported in[9]. An experimental study is performed in[10] to obtain the magnetization and static torque characteristics of commercially available Switched Reluctance motor. The obtained results are compared with the calculated results of static torque. Static torque is calculated from the data of Flux linkage. The D.C excitation method is used in[11]. This method evaluates the rising and falling current. For determination of static flux linkage characteristics of Switched Reluctance Motor, the rising current method generates the initial transients that have a computation discrepancy. The electromagnetic characterization of 8/6 SRM is described. Finite element method is used to obtain the magnetic characteristics.

A series of experimental tests are performed in[12]. The experimental test concludes that FEM has some limitations when the phase current has very low values.

A Digital Signal Processor (DSP) based SRM drive system is used for the investigation of static characteristics. Matlab/Simulink models are generated[8]. Inductance and torque characteristics are also obtained by experimental methods.

An online winding resistance estimation technique is used to find flux linkage values for linear SRM. Theoretical derivation and the actual implementation of the proposed method is addressed in[13]. By comparison of the search coil method scheme and the static resistance schemes with the experimental results, the validity is addressed.

Flux linkage and static torque characteristics of Switched reluctance motor are calculated by the digital signal processing method[14]. Errors in measurement are discussed in different aspects. The moving average filter is used to reduce noise and errors. The accuracy of the proposed method is verified by different methods like co-energy, FEM and LCR meter. The static flux-linkages versus current characteristics with different angles from unaligned to fully aligned position. These characteristics are used as a lookup table. The same data is then obtained for computation of co-energy which is required for the next needed data of static torque.

3. A Mathematical Modeling of Switched Reluctance Motor based on Static Characteristics

There is no denying fact that the significant performance of the machine requires the of static characteristics. Mathematical equations of instantaneous torque and co-energy of the magnetic field are defined respectively as,

$$T = \left(\frac{\partial w'}{\partial \theta}\right)_{i=\text{constant}}, \; w' = \int_0^i \psi \, di, \tag{1}$$

where, T represents torque, w' is a co-energy, θ indicates an rotor angle, i is instantaneous current, ψ denotes flux linkage and $\frac{\partial}{\partial \theta}$ is the differential operator.

In eq. 2, given below

$$T = -\left(\frac{\partial w_f}{\partial \theta}\right)_{\psi=\text{constant}}, \; w_f = -\int_0^\psi i \, d\psi, \tag{2}$$

where w_f is the stored energy. It is noted that the data of static characteristics are very suitable to describe the prediction of instantaneous, the magnetic nature and steady-state performance of switched reluctance motor. Meanwhile, the governing differential voltage equations for the handling of the data can be written as in the form of an ordinary differential operator as

$$T = \frac{i^2}{2}\frac{dL}{d\theta}, \;\; \psi = iL, \;\; w_f = w = \frac{i^2 L}{2}, \tag{3}$$

Equation ($3_{1,2,3}$) represents the ordinary governing differential equations of torque, flux linkage, and co-energy respectively. Here, a small "dwell" at maximum inductance will happen if the rotor and stator pole arcs are different, but conversely, if the inter-polar arc of rotor exceeds the stator pole arc, of course, a small "dwell" at minimum inductance will occur.

The governing ordinary differential equations of a Switched reluctance motor with phase voltage can be described as

$$V = \frac{d\lambda}{dt} + Ri, \;\; V = \frac{dL(\theta)}{d\theta} i\omega + \frac{d\lambda}{dt} L(\theta), \quad Vi = \omega i^2 \frac{dL}{d\theta} + Li\frac{di}{dt}. \tag{4}$$

The equation (4) is obtained by multiplying the voltage with current, such equation is usually called the governing differential equation of the rate of flow of energy. While for equations (4), V shows the DC bus voltage, λ is flux linking the phase coil, R denotes is the phase winding resistance and i represents the instantaneous phase current. For equations (4), $L(\theta)$ is the instantaneous phase inductance, ω presents the rotor speed and θ denoted the rotor angular position.

4. An Experimental Setup

The experimental rig of a three-phase switched reluctance machine is shown in Figure 3.

Figure 3. An existing SR machine.

The obtained results are shown in Figures 4 and 5 with a difference that on x-axis, one labeled as current whereas, in Figure 5 it is against rotor position.

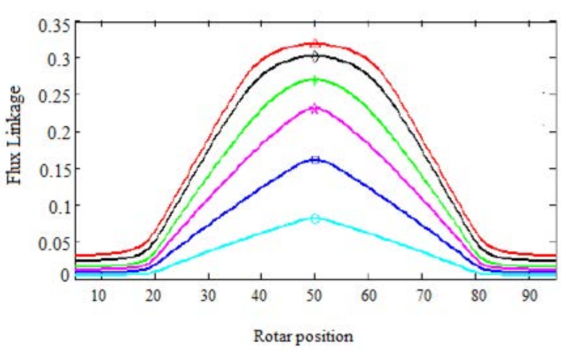

Figure 4. Magnetization characteristics at different current values.

5. Conclusion

The set of flux linkage characteristics are produced at a different range of stator current and rotor position. The

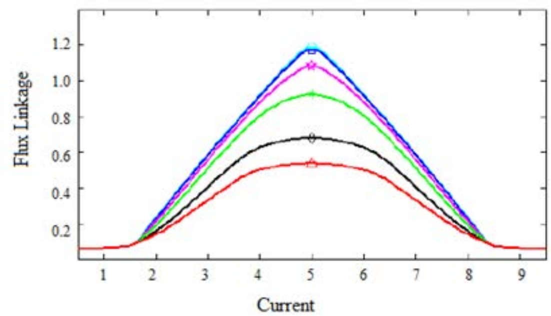

Figure 5. Magnetization characteristics at different rotor positions.

hardware is successfully developed and flux linkage characteristics are extracted from the data of induced EMF. The trend of obtained results shows good agreement with those seen in literature for different pole machines.

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