Five phase switched reluctance motor with short flux path for low speed applications and mechatronics

Krzysztof Bieńkowski, Bogdan Bucki, Adam Rogalski, Andrzej Pochanke
Institute of Electrical Machines
Warsaw University of Technology

Abstract: The construction and principle of operation of the five phase switched reluctance motor with short magnetic flux path were described in this paper. That kind of motor has better winding utilisation and smaller core losses in comparison to the typical SRM with diametrical circulation of magnetic flux. SRMs with short flux path are being able to applied in low speed drives and even as alternative for motoreductors in mechatronics.

1. Introduction

Switched Reluctance Motors [2] have been known earlier than induction motors. First constructions have rather poor performance due to the problems with mechanical commutator and difficulty control. Appearance of low losses magnetic materials, high power transistor switches and fast microprocessors was the reason of intensive researches on this old idea at the last decades of twenty century.

Nowadays performances of switched reluctance motors are comparable with induction motors [3] and manufacturing costs are lower due to simply construction. This aspect makes SRMs an interesting alternative for induction and direct current commutator motors at variable speed drives.

Switched Reluctance Motors has many types of geometrical structures. In every structure rotor and stator cores are made of soft ferromagnetic material and have even number of salient poles due to radial forces balancing. Solid coil is turned around each stator pole. On very common - diameter flux motor structure, coils on the reciprocal poles are series connected and makes the phase winding. Rotor poles are bore – no windings or permanent magnets exist on the rotor.

The fundamental parameter influencing on the performance and behaviour of the motor is number of phases. It is possible to SRMs operation with single or double phases, but that motors are unidirectional and need additional equipment to starting. The first number of phases, which allow build fully self-started and bi-directional motor, is equal three [4]. Four phases ensures low torque ripples on the shaft. Five and more phases are suitable for low speed applications.

Switched reluctance motors produce torque in consequence of the tendency of the rotor poles to align with the stator poles which are magnetically excited by phase current. The rotor has two cardinal positions:

- Unaligned - unstable position with zero-torque and maximum reluctance,
- Aligned - stable position with zero-torque and minimum reluctance.

Between those cardinal positions of the rotor the electromagnetic torque is produced. The excitation of stator coils is switched sequentially from phase to phase as the rotor moves beginning new duty cycle (fig.1). The torque can be expressed by the equation [5]:

\[
T(\theta,i) = \frac{1}{2} i^2 \frac{L(\theta,i)}{d\theta}
\]  

(1)

Where:

- \(i\) – phase current,
- \(\theta\) - angle position of the rotor,
- \(L(\theta,i)\) – phase inductance, versus current and rotor position.
2. SRM with short path of magnetic flux

The most widespread structure of SRM with diametric path of magnetic flux has two unfavourable features:
- at the given moment only one phase is excited,
- length of the path of magnetic flux in the stator yoke is equal half perimeter of the stator.

The diametric flux path SRM is not very effective structure for low speed application with numerous phases and big diameter, because of high drop of MMF in the stator yoke and low windings utilisation.

The SRM structure with short path of magnetic flux [1] has no features mentioned above. Schematic construction of this kind of motor is presented on figure 2. The stator possesses 10 poles, which are equal disposed. All stator poles are joint to the stator yoke. Poles and yoke must be made of material, which has good magnetic conductivity and must be laminated due to prevent of eddy currents. The pole pitch of the stator is equal:

\[ \tau_s = \frac{\pi}{p_s} \]  

Where: \( p_s \) – number of pole pairs of the stator.

Around each stator pole the solid coil is winded. The coils on reciprocal poles are series connected and makes one of the phase windings. The motor has 5 phases appointed on the figure with letters from A to E.

The rotor consists of four U-shape poles, which are equal disposed on non-magnetic frame. Every rotor pole has two dents connected together by magnetic yoke. The angle distance between dents axes is equal pole pitch of the stator. Distribution of poles and dents axes is presented on figure 3.

At the given moment two adjacent phases are excited simultaneously. The current direction in the coils must causing two magnetic fluxes in the cores. The paths of both fluxes are short and symmetrical due to radial forces balancing. Every path closing around two adjacent stator poles and two rotor dens belong into one rotor pole. The paths of magnetic fluxes are presented for excitation of phases A and B (fig. 2.) and for aligned rotor position (minimum of reluctance).

At the given rotor position the excitation of phases D and E will causing rotor turn of angle 18 ° in right direction to the next aligned position. To continue right direction of revolution, phases B and C should be excited in the next cycle.
Figure 2. Schematic construction of SR motor with short path of magnetic flux.

Figure 3. Distribution of stator poles axes and rotor dents axes at presented motor.
The sequence of phase switching is presented on the figure 4. The switching sequence: AB – CD – EA – BC – DE – AB will causing of flux circumrotating in right direction. In the same time rotor will rotating in left direction of angle π / 2 only. To bring about right direction of rotation, the excitation sequence: AB – DE – BC – AE – CD – AB should be applying. Presented SR motor has high speed reducing possibility – excitation of the phases, with frequency 50 Hz causing rotational speed of the rotor equal 150 rpm.

![Figure 4](image)

Figure. 4. Switching sequence for π/2 left rotation of the rotor.

The step angle of SR motors with presented construction can be expressed by the equation:

$$step\ angle = \frac{m m_e \pi}{m p_r q}$$

Where: 
- $m$ - the number of phases,
- $p_r$ - the number the peer of poles of rotor,
- $q$ - the number the peer of poles stator on phase,
- $m_e$ - the number of simultaneously excited phases.

3. **Power converter and the control system.**

The block scheme of supply and control system for switched reluctance motor is presented on figure 5. Five phases of SRM are excited from DC source by power converter, which consist of transistors IGBT and ultra fast diodes. The gating signals for switching transistors are generated by the microcontroller on the base of position signal of the rotor. The drivers are reinforcing gating signals and made insulation between microcontroller and power converter. Micro controller regulates the switching angles in dependence of the load and the rotational speed of the motor to archive of maximum efficiency and minimum torque ripples.
The simplified waveforms of phase currents are presented on figure 6. To archive the flux rotation phase currents have to be bi-directional. Typical power converter of diameter flux srm not fulfils that condition. Each phase of short flux SRM can be supplied by separate “H” bridge converter or by the split bridges system presented on figure 7.
The converter has two transistors with diodes per phase. In given moment current flowing throws two phases, which are not directly connected together and four transistors are conducting. For example: if transistors T1, T4, T6 and T7 are conducting, the current is flowing by phases A and B. Both nodes of phase D has the same potential and no current exist in there. Nodes between phases B – E and C-A has the same potential too, and no current exist in phases E and C.

![Figure 7. Power converter with two transistors per phase.](image.png)

4. Summary
Presented SR motor with short path of the magnetic flux produced more of electromagnetic torque than the classic five phase SRM with diametric path at the same dimensions and copper losses, because of energising by two phases simultaneously. The core losses are less too, because of shorten path of magnetic flux. The angular speed of the rotor is four times smaller than rotational speed of the magnetic field. The switched reluctance motors with numerous phases are suitable for slow-speed drives and could be interesting alternative for motoreducers. SR drives could be applied as actuators of robots, due to producing torque at zero speed.

REFERENCES:


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