Design and performance analysis engineering essay

Engineering

R. Rajasekaran1 K. Senthilkumar21 Asst. Professor, Department of EEE, SNS College of Technology, Coimbatore. 2 Associate Professor, Department of ME, SNS College of Technology, Coimbatore. 1 rare457@gmail. com 2meksenthilkumar@gmail. com. com222222

Abstract – A machine design of a switched reluctance motor having competitive torque and efficiency as well as compactness with respect to an Interior Permanent-Magnet Synchronous Motor (IPMSM). This paper presents a detailed study about the design of high speed switched reluctance motor and its applications in various fields of industries. This paper contains the basic principles of a motor and various SRM designs and its performance. The design of SRM drive system focused here is for achieving a maximum speed of about 10, 000 RPM with an input voltage of 24V. This analysis is performed by MATLAB/SIMULINK.

Keywords- Basic principles of SR motor, Characteristics, Drive of SR Motor. I. INTRODUCTIONSwitched Reluctance Motors operate on the principle of uni-polar current, i. e., the current flows only in one direction in the windings regardless of whether positive or negative torque is required. This is due to the combined operation of reluctance torque and the permanent magnet interaction torque. Compared with conventional single-phase switched reluctance motors, it has a high torque density for reducing the torque ripple. The cogging torque is highly beneficial. It is demonstrated that such a motor drive system can be very advantage with the existing motor drive systems for low-cost applications. Finite-element models are used to analyze and predict the motor’s performance that is depicted in [1]. In [2] a detailed analysis about copper and iron loss models of a classical switched reluctance motor (SRM) and a Mutually Coupled Switched Reluctance Motor (MCSRM). The iron losses in different parts of machines are investigated. Based on the power losses models, a lumped parameter (LP) transient thermal analysis during driving cycles are performed. validated by the Finite-Element (FE) transient thermal model cycles is performed, the analytical results are validated by the Finite-Element (FE) transient thermal model. Special attention has been essential for model the salient rotor and a method to transform the salient rotor into a non salient one has been proposed. A comparison between the maximum temperatures are obtained by different heat sources (average power losses or instantaneous power losses during driving cycles) is explained. In [3], three-phase switched reluctance motor direct torque control method is generally a simple transplantation of the three-phase AC asynchronous motor direct torque control method. Which is not suitable for arbitrary-phase switched reluctance motor. The direct torque control methods for the application of a wide range of four-phase switched reluctance motor will be researched. The main objective of direct torque control system are structural methods of a four phase switched reluctance motor flux vector and the principle choice of voltage vector. In [4], A new method to obtain flux linkage characteristics of the switched reluctance motor (SRM) is presented. The usage of a clamping device or a search coil is completely avoided in the proposed system so that it is sometimes more applicable for practical implementations. The proposed method used to calculate the flux linkage with the measured rotor position, phase voltage and phase current of the SRM running in steady states. An error analysis indicates that errors are due to speed ripple and mutual coupling that are limited in a reasonable range. The obtained flux linkage is compared with the voltage pulse injection method that is a conventional one.

BASIC PRINCIPLES OF SRM

Switched Reluctance Motor (SRM) drive technology has remarkably developed in the past two decades These advantages include lower price, boosted performance, High Speed equal or better reliability, better efficiency, lower volume , ease of production and storage in comparison to AC and DC motor drives

Fig. 1. Simple reluctance machine with single phase and two poles.

This constraints possibly explains why it is popular with academics but rare in the factory. Since the emergence of large numbers in switched reluctance drives during 1970s. Only a few practitioners have made successful from this, while a large number of research papers have a little effect at the factory gates and some of them make claims which are misleading or incorrect. The nature of the switched reluctance motor is discussed in particularly with a view to understanding its design characteristics and how it compares with other common motor types. Definition: A Reluctance Machine is one in which torque is produced by the tendency of its moveable part, to move in a position where the inductance of the excited winding is maximum. This definition applicable for switched as well as synchronous reluctance machines. The switched reluctance motor has salient poles on both the rotor and the stator and operates like a variable-reluctance stepper motor except that the phase current is switched on and off when the rotor is at precise positions, which may vary with speed and torque. It is this switching which gives the switched reluctance motor its name. This type of motor cannot work without its electronic drive or controller. Although the switched reluctance motor can serve important roles like this, the underlying factors will not change in the foreseeable future.

II. CONTROL STRUCTURE OF SRM DRIVE

The SRD (Switched reluctance motor drive) system is mainly consists of SRM, power converter, controller and detector. The structure of SRM is shown in Fig. 2. It's a four-phase, 8/6 pole SRM. Power converter is mainly used for energy transfer by controlling the switch of the motor's winding current. Controller is the core part of SRD system, which have the provision to adjust the phase current and the motor speed of SRM, and its property can directly affect the performance of SRD system. Detector module generally comprises of rotor position detection and winding current detection. Its major functions are 1. Providing the essential information of rotor position 2. The control of switch state of motor winding. The main function of SRD system is to regulate the SRM speed to the required parameters, and torque control is the crucial point for a driving system.

Fig. 2. 8/6 pole SRM

The controllable parameters of SRD are turn-on angle, turn-off angle, phase voltage and phase current. And the control strategies commonly used in this SRD are main angular position control, chopped current control and voltage pulse width modulation (PWM) control. Angular position control refers to controlling the speed and torque of SRM by regulating the turn-on angle and turn-off angle of main switch devices, while keeping the input voltage unchanged. Angular position control strategy is very suitable for high-speed, efficient and torque optimal control, but not for low-speed control because of the high current peak. Chopped current control is analysed by controlling the switch devices IGBT to limit the winding current peak, so as to achieve torque control while keeping the turn-on angle and turn-off angle unchanged. Chopped current control strategy is essential for low-speed regulating system. The PWM control strategy is implemented by controlling PWM duty cycle to adjust wind voltage while keeping the turn-on angle and turn-off angle unchanged. The advantages of voltage PWM control lie in that it can indirectly regulate the winding current by adjusting the average voltage value of phase windings

III. DESIGN OF HIGH SPEED SRM

Controlled parts of the system including current control, speed control and motor commutation control are fulfilled by software of digital signal processing. Output logic level PWM signal from DSP will drive the power circuit to control the SRM current and speed.

Fig. 3. Basic block diagram for SRM drive

A inverter CircuitThe inverter consists one switching transistor per phase. IGBT's are used in all four phases. Furthermore the supply unit consists variable voltage source by mean of potential divider to get a variable voltage. Fig 4. Shows a inverter configuration with one IGBT and one diode. A set of two capacitors in series provides three wire dc supply Equal value resistances are connected across each capacitor1 to balance the voltage.

Each phase windings is energized by turning on the respective phase device. If phase " A" is to be energized, the transistor T1 has to be turned on, then the current circulates through T1, phase " A" and the capacitor and when T1 is turned off, the current continues to flow through winding, D2 and Capacitor1 . The energy stored in the phase " A" winding during on period is dumped to C2. The phase " A" during off period is subjected to negative supply through C2, which helps in quick demagnetization of the Motor phase " A" and reducing the effect of negative torque. Similar process is followed for other phases.

Fig. 4. Inverter schematic circuit for SRM.

B. Position sensorTwo photo diodes and two infra –red (IR) diodes are used as sensors. Two number of IR diodes are directly connected in series to the inbuilt dc supply, which is regulated through a current limiting resistor in order to ensure constant current. The photo diodes are individually reversed biased from dc regulated source. The photo diodes and the IR diodes are placed facing each other. The infra red light emitted by the IR diode directly fall on the photo diode. A slotted disc is mounted on rear end of the rotor with similar number of slots to that of the rotor so that the slots appear in between the space of the IR diode and the photo diode. Thus while the rotor makes a rotation the IR light falling on the photo diode is interrupted through the slots of the disc. While the light is interrupted the photo diode resistance falls sharply to a low value. This fall of resistance forms a difference in potential to a comparator made out of Op-Amp, thus the output of the comparator is either 0 or 1. Two comparators are used to get states such as 01, 11, 10, 00, which fall in synchronization with rotor position. For the starting purpose the corresponding state decides triggering of appropriate stator pole and while running it follows the sequence from there onwards.

Fig. 5. Rotor position sensor for SRM.

C. Gate Drive circuit

Fig. 6. Gate Drive circuit

The output from rotor position senor is given to microcontroller. Microcontroller will control the switching sequence of upper and lower group IGBTs.

IV. OBJECTIVE FUNCTIONS

For a driver to be designed its poles, phases and windings has to be determined or considered using the following equations. The fundamental switching frequency in single phase is given byF1 = n* N r = rpm* N r / 60 Hz ------------ (1)Electromagnetic torque developed by variable reluctance motor is given byT = (w'm * Nr* q)/ (2*) N-m--------------(2)w'm:- Mechanical Energy Transferred /Stroke in joules. Nr:- No of Revolutionsq - No of Phase windingThe step angle or stroke is given by= 2/qN r rad ----------------(3)Mechanical Power developedPm = ½wi2 -----------------(4)Electromagnetic Torque, T= ½ i2 ----------------(5)Pm= w *TW= ----------------(6)Average Torque developed by SRM depends upon the current waveform of SRM phase winding. Current depends upon the conduction period and chopping details. It also depends upon the speed.

Fig. 7. Torque-Speed Characteristics of SRM

Normally, the designer fixes the number of stator poles Ns and the number of rotor poles Nr and deviates from this fixed value only for very special applications because then converter configurations and feedback devices can be standardized.

Fig. 8. Switched Reluctance motor drive circuit.

The above diagram represents the SR motor drive circuit. The stator pole arc angle is less than the rotor pole arc angle, i. e., ßs < ßr. The stroke angle is definedas--------------------- (3)Switched reluctance motors operate on the principle of uni-polar current, i. e., the current flows only in one direction in the windings regardless of whether positive or negative torque is required. This principle requires only one switch to be in series with a phase winding. The turning on or off of this switch regulates the flow of current in the phase. The resistance R is given byR = P/I2 ---------------------------- (4)where P is the input power and I is the dc current. The inductance L is given byL = 1/ω((V 2/I2) − R2)1/2 ------------------------ (5)where V and I are the rms values of voltage and

V. DRIVE DESIGN

For the proper operation of SR motor three logic strategies is used low, medium and high speed logic. The high-speed strategy implemented in control card using NAND logic. A PWM IC is used to generate 2. 5 KHz PWM signals and is mixed with the above common signals. The duty cycle of the PWM is varied by using potentiometer, which in turn controls the speed of the motors, by varying the duty cycle of the control signal. By using the buffer IC control signals are driven in to the next stage, which is a MOSFET driver. At the speeds above 750 rpm the machine is controlled by pulse width control. The raw enable signal is mixed with a controlled turn – on angle and controlled turn- off angle. These turn- on and turn- off angles are to be made a function of the operating speed and desired torque.

Fig. 9. Hysterisis-type current regulator

The ‘ Hysterisis-type’ current regulator may require current transducers of wide bandwidth, but the SR drives has the advantage that they can be grounded at one end with the other end connected at the negative terminal, of the lower phase leg switch. Above is the figure of an alternative regulator using fixed frequency PWM voltage with variable duty cycle.

VI. SIMULATION STUDY AND RESULTS

Fig. 10. Simulink block shows the torque and speed variation in high speed Switched Reluctance Motor

Fig. 12. Simulink block shows the variation of electrical parameters.

Fig. 11. PWM signal generation for each phases in an inverter circuit

Fig. 12. Magnetic Flux and current variation in Switched Reluctance Motor

Fig. 13. Torque variation

The given waveforms shows the variations of speed ranges from (4000-10, 000 m/s).

Fig. 14. Speed variation (8000-10, 000)

Fig. 15. Speed variation (6400-8000)

Fig. 16. Speed variation (4000-5000)

Table. 1. Variation of electrical parameters for different ranges of speed

SPEED

(m/s)

TORQUE

(N-m)

CURRENT

(A)

VOLTAGE

(V)

EFFICIENCY

(%)

4000-5000810150506400-8000911050908000-10, 0001012550100

Fig. 17 variation electrical parameters in SRM

VI. APPLICATION

AutomobilesIndustrialHouse hold applicationsTextile industries

VII. CONCLUSION

Thus a low cost, low weight and highly efficient Switched Reluctance motor has been designed which has high speed characteristics and is applicable in major home and industrial appliances. Characteristics of Switched Reluctance motor is analyzed by SIMULINK/MATLAB block set. Simulation results show that for a low voltage of 24V the speed variation is about 10, 000m/s. For different range of speed variation, the changes in electrical parameters (torque, current, voltage and efficiency) are tabulated. So these types of high efficient motor have a capability to satisfy high degree of applications in industries.

VIII. REFERENCES

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