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Analysis of Energy Efficient Current Control Methods in Switched Reluctance Motor

Dr.M.Ravindran [1], V.Maharajan [2] & S.Selvakumar[3] M.Alex Pandian[4] K. Balamurgan[5]

[1] Professor of EEE Department,, Unnamalai Institute of Technology, subanagar, Kovilpatti,Tamilnadu

[2] Assistant Professor of Mech Department,, Unnamalai Institute of Technology, subanagar, Kovilpatti,Tamilnadu

[3] Assistant Professor of Mech Department,, Unnamalai Institute of Technology, subanagar, Kovilpatti,Tamilnadu

[4] Assistant Professor of EEE Department,, Unnamalai Institute of Technology, subanagar, Kovilpatti,Tamilnadu

[5] Assistant Professor of Mech Department,, Unnamalai Institute of Technology, subanagar, Kovilpatti,Tamilnadu

Abstract:

A major problem in any country is availability of energy source. Energy saving is most important than identifying the new energy sources. Hence continuous energy saving is necessary for all developed countries. Electric motors consumed most of the energy from source. Energy efficient current control methods increases the efficiency of Switched Reluctance Motor (SRM). Comparative analysis of current control methods in Switched Reluctance Motor (SRM) is needed for energy efficient operation. This paper compares the different types of current control methods in 4/2 prototype SRM. Modification of pole arc in stator and rotor current regulation method **is best** than other control method. The stator pole arc is modified from 32° to 36° and rotor pole arc is modified from 30° to 28°. Hence the useful torque is increased from 4.94 Nm to 5.2 Nm. Based on the analysis; energy efficient control method is identified.

Keywords: —SRM, Current Control methods, Controller, Modification of pole arc, Efficiency, Energy saving.

1 Introduction

Switched Reluctance Motor (SRM) is a high speed home appliances motor like vacuum cleaner because there is no rotor winding and permanent magnet [1]. Energy efficient operation of SRM is depending upon the useful torque. The useful torque of SRM is increased by reducing the torque ripple. Minimization of torque ripple is essential for increasing the efficiency. Two approaches are considered for increasing the efficiency. First one is to modify the shape of stator and rotor pole arc for increasing the efficiency of SRM. It has been explained in [3]. The sensitivity of geometrical parameters like shape of stator and rotor pole in SRM is studied from [4]-[6] in literature review. Optimum pole arc configuration in SRM is described in [7] for reducing the torque ripple. Nowadays, some researchers have been [8]-[11] worked in the area of SRM for increasing the efficiency by reducing the torque ripple. Torque ripple is reduced by changing the pole shape of stator and rotor. Electronic torque ripple reduction technique is additionally described for developing the optimum geometric of SRM [12]. Second one is to control the motor current and inductance profile for increasing the efficiency by reducing the torque ripple.

It is very helpful to find the phase current for getting minimum torque ripple. Selection of controller for an SRM is more important for efficient operation. Separate switches are provided for each winding at existing system. Number of controller are described by several authors, Chan explained converter design with control circuit. M. Barnes and C Pollock introduced different types of converters. J. Y. Lim introduces machine design with both a radial and an axial air gap. Barnes and Pollock illustrated the selection procedure of the converter. Similarly, a number of converters are introduced for SRM. The disadvantage of the above technology is the power rating of each component is high and it requires additional control circuit. The main objective of this paper is to compare the energy efficient current control methods.

2. Types of current Control Methods

Torque is one of the main factors in SRM. Current controller is used to control the torque of SRM. The drive in current controller is used to control the speed for various applications with firing angle. It is explained by Bose with efficiency optimization block. Turn ON of current control is determined by rule of Bose and turn OFF is calculated by Gribble. This firing angle is used to minimize the electrical drive input. Efficiency optimization in current control drive is already described by Acarnley et al. He has explained the Chopping current detection technique and it is used to describe the relationship between inductance, phase current and rotor position. The SRM is controlled by closed loop current control method, namely

1) Hysteresis current control
2) Delta Modulation
3) Current regulation with PWM.
4) Current regulation with modification of pole arc in stator and rotor

2.1Current regulation with Modification of pole arc in stator and rotor

A schematic block diagram of current controlled SRM drive is given in Figure 1. Maximum efficiency condition, developed torque (useful torque) is equal to the load torque. But load torque varies with torque ripple at different load conditions. Hence current controller is used to control the developed torque for minimizing the torque ripple and increase the efficiency of SRM. Hence the torque command is executed by varying the current in above loop.

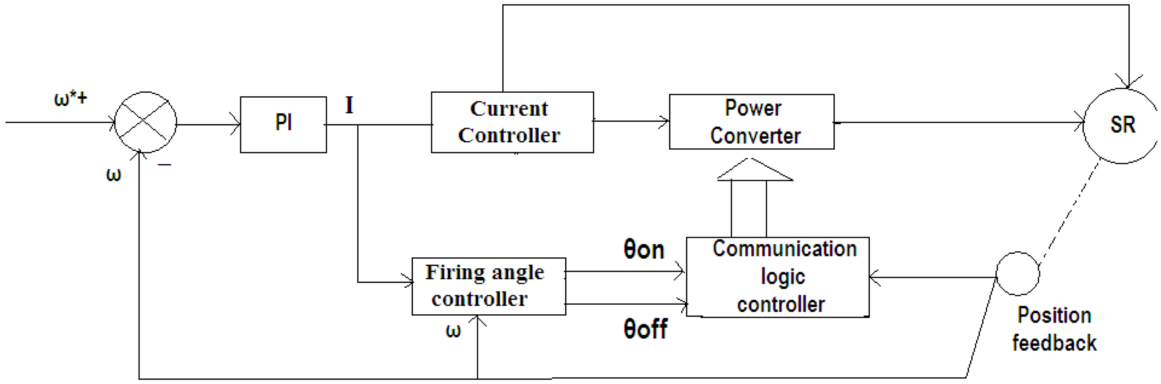

Figure 1 Block diagram of current controlled Switched reluctance drive

SRM is controlled by correct positioning of the phase current pulses with respect to the rotor position. The turn ON time and the total conduction period are used to calculate the torque and efficiency of the SRM. The phase current builds up very quickly after turn ON due to the negligible back EMF. The current of SRM should be limited by controlling the voltage. The rotor position is identified by position feedback. Error signal between the reference speed and motor speed is based on the current command. It is generated by speed controller and Proportional Integral (PI). The current in each phase winding is regulated with reference current by current controller. Each and every instant the firing angle calculator is used to regulate the turn ON and turn OFF angles with respect to actual speed and reference current. The reference current is calculated from the load condition. The controller needs current feedback information from each winding. The drive also has efficiency optimization block for energy saving applications.

A circuit diagram of current controlled SRM drive is shown in Figure 2. Control signal which depends upon rotor position. The rotor of SRM is in aligned position with stator coil, control signal turns ON Transistor T and hence motor winding Ph_1 is energized.

The rotor of SRM is in unaligned position with stator coil and control signal turns off Transistor T. The current in phase winding Ph_1 takes path through diode D_1 and phase winding Ph_2 connected with capacitor C_d, Energy from phase Ph_1 is partially transferred to C_d. The stored energy from off-going phase winding Ph_1 is dumped into C_d by freewheeling diode FD_1. Hence suppressing voltage present in off-going phase windings is once again reused in the system. The motor winding Ph_2 is energized by voltage across phase winding Ph_1 and dumped capacitor C_d. Now current path in phase winding Ph_2 is diode D_2 and dumped capacitor C_d.

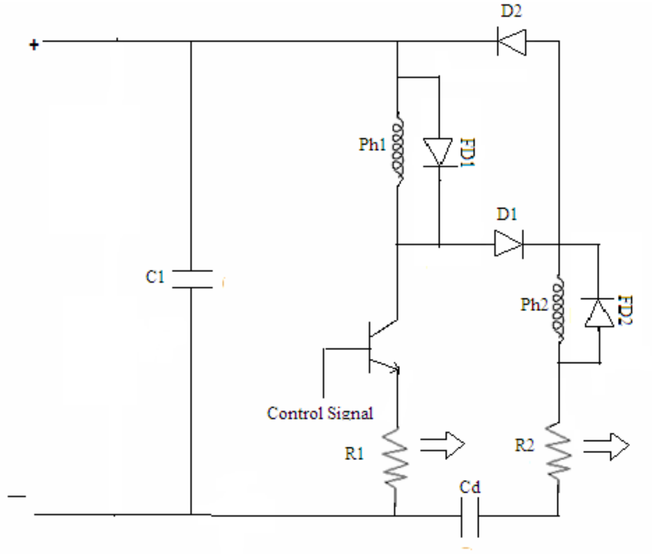

Figure 2 Circuit diagram of Current control drive with sensing resistance

Due to change of rotor position, the transistor T moves to ON position. The stored energy from off-going phase winding Ph_2 is dumped into C_d by freewheeling diode FD_2. The same procedure is repeated. Two current sensing resistors (R_1 &R_2) are used to sense the phase current at load and no load conditions. It is also used to regulate the current with respect to load for increasing the efficiency of motor. Based on the reference speed, firing angle calculator is used to regulate the turn-on and turn-off angles. Hence the proposed current control drive is used to regulate the current in each phase winding with respect to reference current.

The advantages of the current control circuit can be summarized as follows.

- Circuit uses only one switch for total winding.
- Topology endows independent phase current control in SRM.
- During the current control and commutation period, energy present in the dumped capacitor is utilized.

Table 1 Result Analysis of Currents at Existing and Proposed method

Sl.No.	Without Modification of Pole for Current Analysis			With Modification of Pole taper for Current Analysis.		
	Torque (Nm)	Current (A)	Efficiency (%)	Torque (Nm)	Current (A)	Efficiency (%)
01	0	0.3	0	0.0	0.18	0.0
02	**0.58**	0.9	43.4	**0.72**	0.69	52.4
03	0.76	1.4	51.5	0.81	0.8	58.7
04	0.84	2.1	63.4	0.97	1.7	64.9
05	**0.905**	3.5	**68.9**	**1.03**	2.8	**73.04**
06	1.08	4.2	72.4	1.16	3.4	75.86
07	1.12	5.3	75.0	1.27	4.2	78.98
08	**1.23**	5.8	78.2	**1.32**	4.9	80.22

An observation of tables 1 and 2 shows that the torque ripple is sufficiently decreased and useful torque is increased. Hence the total output power for the proposed method is also increased thereby power consumption in proposed method is decreased.

2.2 Experimental setup and Result Analysis

2.2.1 Calculation of Current

The Prototype SRM is shown in Figure 5. Different efficiency levels are calculated and tabulated in Table 3. The speeds of SRM for various turn ON and turn OFF are tested. Current is calculated at aligned and unaligned position of air gap in between the stator and rotor poles.

Figure 3 Experimental Plat form of SRM

Table 2 Current – Efficiency analysis of SRM.

Sl. No.	Voltage (V)	Current (A)	Input (W)	Torque (Nm)	Speed (RPM)	Output (W)	Efficiency (%)
01	230	0.3	69	0	14,900	0	0
02	230	0.9	207	**0.14**	14,790	89.83	43.4
03	228	1.4	319.2	0.36	14,600	164.39	51.5
04	224	2.1	470.4	0.48	14,000	298.23	63.4
05	218	3.5	763	**0.56**	13,400	861.81	**61.0**
06	207	4.2	869.4	0.72	12,800	629.44	72.4
07	206	5.3	1112.4	0.86	12,000	834.30	75.0
08	204	5.8	1183.2	**0.98**	12,000	925.26	78.2

An observation of Table 3, the useful torque is sufficiently increased by increasing the load current. Hence the total output power for the proposed method also increased.

3 Conclusion

In summary, the review of current control method in 6/4 prototype SRM is as follows

i) Efficiency of SRM

ii) High Switching frequency

iii) Noise

iv) Power converter Design

v) Operating Switch

vi) Energy stored in dumped capacitor is reused.

Based on the above factors, Current regulation with modification of pole arc in stator and rotor method is very suitable for energy efficient operation of SRM.

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