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Conduction Angle Control of Switched Reluctance Motor

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Conduction Angle Control of Switched Reluctance Motor

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Abstract. This paper presents a microcontroller based closed loop speed control of Switched Reluctance Motor (SRM) drive powered through Asymmetric Half Bridge Converter (AHBC). Conduction angle control method is adopted for speed control and it is done by adjusting the duty cycle of PWM signal using a potentiometer. The performance comparison of speed control of SRM drive through single switch per phase converter and AHBC is performed with the help of soft chopping in conduction angle control method.

1.Introduction

The Switched Reluctance Motor (SRM) is an electrical motor which operates based on the principle of variable reluctance [1]. Now a days more research scholars working on this machine due to its simple and robust construction and advancements in the high speed digital controller. The stator of a SRM has inward projected poles and coils of the winding are placed on the diametrically opposite poles. The rotor of a SRM has outward projected poles and free from winding and magnet [2]. The SRM is heart of the SRM drive system. It is an electronically switched machine and to use it in real time it needs power converter, digital controller and rotor position sensor. The SRM is used in many variable speed applications [3, 10].

Due to doubly salient structure of the SRM, the torque contributed by the machine has ripples and it can be minimized by proper design, control algorithm and artificial intelligent techniques [4]. The design of SRM includes selecting optimum values of stator and rotor pole arcs using standard optimization techniques. The development control algorithm involves choosing the range of conduction angle to avoid negative torque production, deciding current level, voltage level and synchronising current pulse according to the rotor position to reduced torque ripple [5].

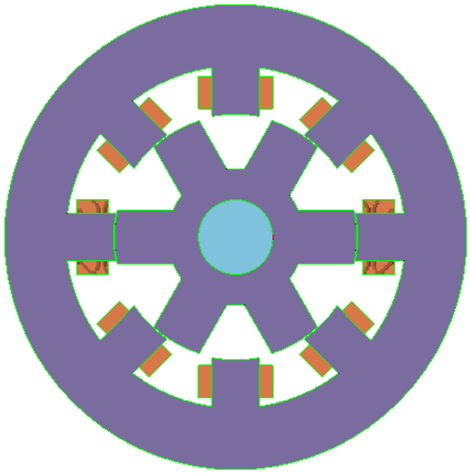

Figure 1. Cross-sectional view of Four Phase 8/6 SRM

The cross section of 4 phase 8/6 SRM is shown in Figure 1. It has 8 stator poles and 6 rotor poles. The pair of stator poles makes a phase. The total torque contributed by the machine is algebraic sum of the torque due to individual phases [6]. The expression for torque due to single phase is described as

$$T = \frac{1}{2} i^2 \frac{dL(\theta,i)}{d\theta} \tag{1}$$

where L is the inductance of the winding, i is the phase current and θ is the rotor position. From equation (1), torque due to each phase is directly proportional to the square of the phase current. Therefore, sign of the torque is independent of the current direction and depends on the variation of inductance w.r.t rotor position. For motoring operation dL/dθ is positive. To excite stator windings of the SRM, unipolar power converter is used [8]. The inductance profile of the SRM is shown in Figure 2.

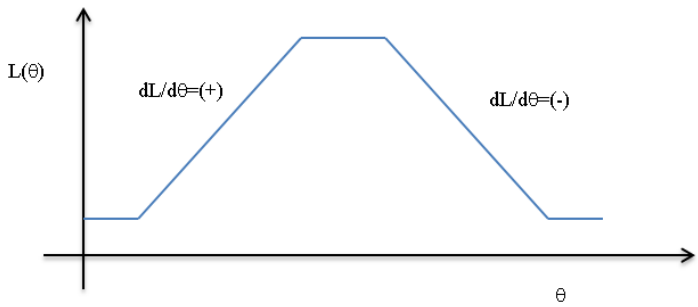

Figure 2. Inductance profile

The major objectives of the work are (i) to design and implement a control system which supplies control signals in an ordered manner to the power circuit for the smooth operation of SRM. (ii) to implement conduction angle control Strategy to control speed of the SRM.

2. Descriptions

The various components of the SRM based speed control system incorporating conduction angle control technique is shown in Figure 3.

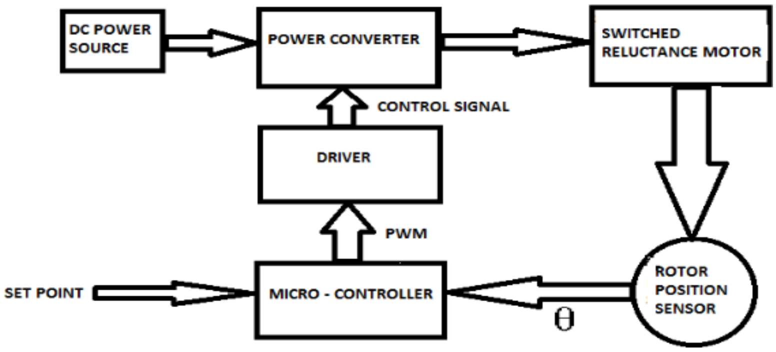

Figure 3. Block Diagram of SRM Drive System

2.1 MOSFET Gate Driver

The voltage level of PWM signals generated by the microcontroller is not sufficient enough to trigger the power semiconductor device present in the power converter [9]. Therefore, it is necessary to magnify the PWM signal. Also, it is necessary to provide electrical isolation between the power circuit and low power electronic circuit. To meet these requirements, integrated circuit PC 817 opto-coupler is used in this work.

2.2 Power Converter

The power converter is used to power the stator coils of SRM. There are many topologies of the power converter are available. In this work, the stator coils are energized using single switch per phase converter and Asymmetric Half Bridge Converter (AHBC) which are shown in Figures 4 & 5 respectively.

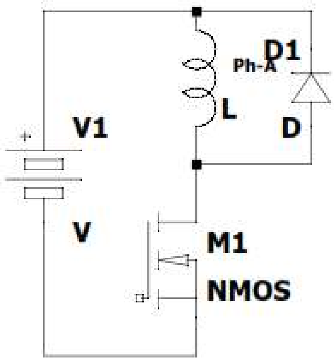

Figure 4. Circuit Diagram of Single switch per phase convertor for single phase

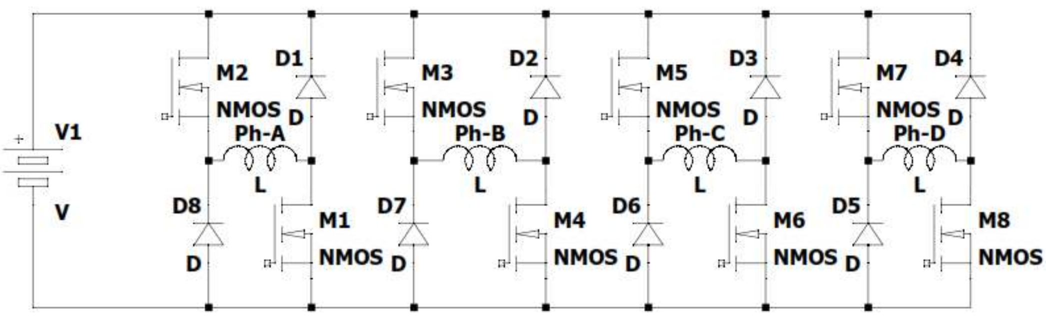

Figure 5. Circuit Diagram of AHBC for 4 phase 8/6 SRM

2.3 Rotor Position Sensor

To produce torque in a correct direction and to determine the phase winding to be excited it is necessary to coincide the current pulse with the position information of the rotor [7]. Two IR sensors are mounted at the rear end of the machine to obtain the rotor position information.

The electrical specifications of various components used in implementing conduction angle control are listed in Table 1.

Table 1. Hardware Requirement and Specifications

Component	Specification	Value
SRM	Stator/Rotor pole configuration	8/6
	Rated Power	1 HP (746W)
	Rated Speed	3000 rpm
	Rated Voltages	330 V DC
	Rated Current	5A
Auto-Transformer	0-230 V	5A
Rectifier Bridge		
KBPC3510	Maximum voltage	1000 V
	Maximum Current	35 A
Capacitor		1000µF, 250V
Arduino Board	Arduino MEGA	ARmega2560
Power Convertor		
PCB Board		
MOSFETs IRF 540	Type of control channel	N -Channel
	||	100 V
Power Diode 6A	Voltage maximum	400 V
	Current Maximum	6 A
Connectors		
Gate Driver		
Optocoupler PC817	Operating Voltage	6-15 V
Resistors		
Male pins		
RPS (Rotor position)		
IR sensor		5 V

3.Demonstration

The response of SRM is tested with single switch per phase converter and AHBC. It is observed that the speed of SRM with AHBC differed to a notable level and provides wider control range. To address the objective of the project Conduction Angle Control method is used.

3.1 Experimental Set-up

The experimental setup consists of auto-transformer, rectifier, microcontroller, driver, converter, SRM and IR sensors is shown in Figure 6.

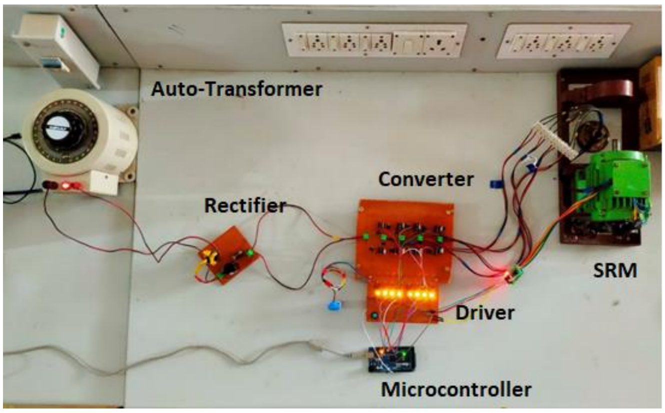

Figure 6. Experimental Set-up

The Single switch per phase converter with its driver circuit is presented in Figure 7 and AHBC with driver circuit is presented in Figure 8.

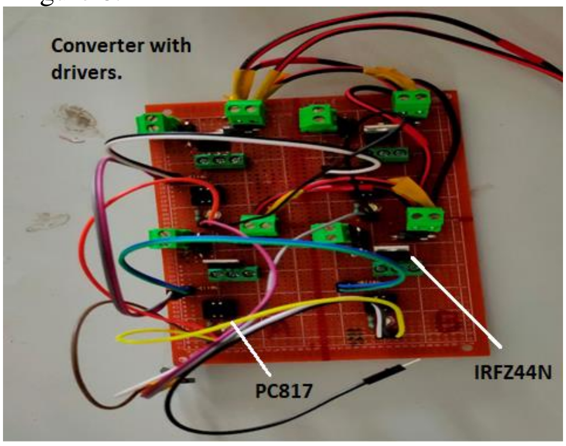

Figure 7. Hardware of Single switch per phase convertor

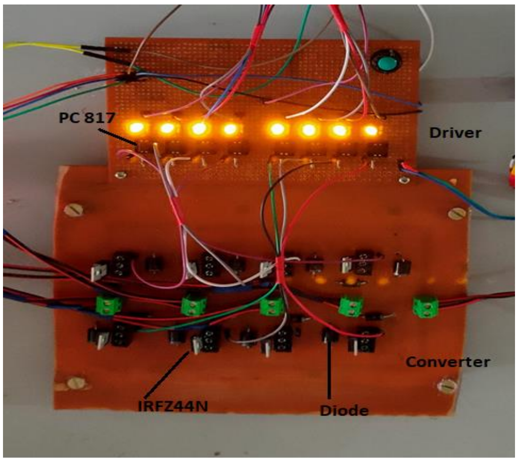

Figure 8. Hardware of AHBC

Soft chopping method is incorporated with AHBC to excite phase windings of the SRM. Low side switches of the AHBC are given a solid pulse based on the feedback from the IR sensor. And simultaneously the high side switches of the AHBC are given PWM signal. This helps in good discharge of phase winding of SRM. Speed of SRM is controlled by adjusting the duty ratio of the control signal. Conduction angle control method is implemented using soft switching technique. The value of duty cycle is mapped to a potentiometer using Arduino code. By varying the potentiometer, the duty cycle of the PWM signal varies which in turn changes the effective Input Voltage given to the motor and thus changing the speed of motor.

3.2 Speed Control

Arduino's analog pin get the Potentiometer's output and that in turn is scaled with the PWM using analogeWrite() function of Arduino IDE. The output from the Arduino Board i.e. the PWM signal depends on the input given by the Potentiometer, hence by adjusting the potentiometer the speed control is done by the method of conduction angle control. Also, by varying the duty cycle the average power supplied to motor varies thus speed control is achieved by varying the power supplied to motor. Based on the feedback from the sensor the excitation of phases is done which results in clockwise rotation of motor. The scaling factor is presented in Table 2.

Table 2. Scaling PWM signal to Arduino

Voltage	Value	Duty cycle
0	0	0
5	255	100

3.3 Direction of Rotation

Sequential excitation of the phase windings causes continuous rotation of the machine and the direction of rotation of the machine is changed by changing the excitation sequence. Excitation pattern for the clockwise rotation is given in Table 3.

Table 3. Excitation pattern for clockwise rotation

Sensor Feedback		Phase to Excited			
IR1 Sensor	IR2 Sensor	Phase A	Phase B	Phase C	Phase D
0	0	✓	×	×	×
0	1	×	✓	×	×
1	1	×	×	✓	×
1	0	×	×	×	✓

4.Hardware Results

4.1 IR Sensor

Rotor position information obtained from the IR sensors mounted at the rear end of the machine are shown in Figure 9.

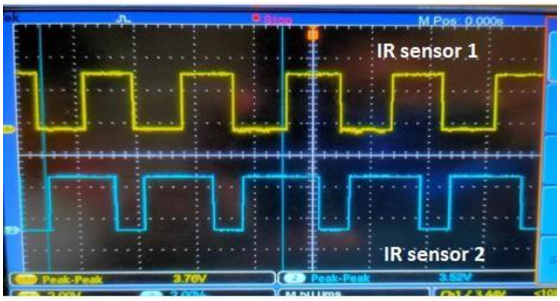

Figure 9. Rotor position information from IR Sensors

4.2 Control Signals

The IR sensors output signals are connected to the analog pins of the microcontroller through signal conditioning circuit. The microcontroller process the position details and generates control signals according to the embedded logic. In the case of hard chopping technique, phase winding is energized by triggering the pair of MOSFETs (high side and low side) simultaneously by means of single PWM signal. For the four phase 8/6 SRM, it needs four control signals to sequentially magnetize the phase windings and are shown in Figure 10 and 11.

Figure 10. Control signals for A & B phase windings

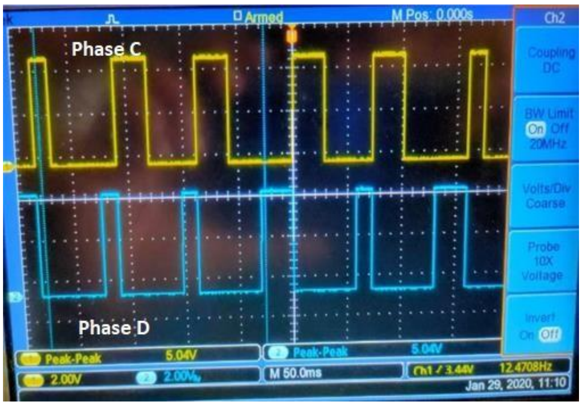

Figure 11. Control signals for C & D phase Windings

In the case of soft chopping technique, high side MOSFETs are activated using chopped current pulse and low side MOSFETs are triggered using solid current pulse. Therefore, it needs eight control signals and are shown in Figure 12 & 13. By varying the PWM signal's duty cycle the speed could be controlled in both soft chopping as well as hard chopping method.

Figure 12. Hard - Chopping Signal for a Single Phase

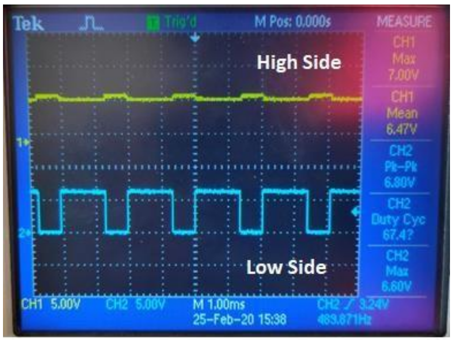

Figure 13. Soft-Chopping Signal for a Single Phase

Speed range comparison of SRM powered by single switch per phase converter and AHBC are reported in Table 4.

Table 4. Speed range comparison

Single switch per phase converter		AHBC	
Voltage(V)	Speed (RPM)	Voltage(V)	Speed (RPM)
5	160-170	5	200-210
10	380-410	10	450-480
15	600-620	15	830-860
		20	990-1020
		25	1450-1500

5. Conclusion

Initially the SRM is powered by single switch per phase converter and operated in closed loop. The order in which phase winding to be excited is fixed and speed control of the drive is performed. The same excitation pattern is used to operate the SRM powered by AHBC in closed loop and speed control of the drive is achieved using conduction angle control. Comparing the speed control range of SRM powered by two different converters, it was found that SRM powered by AHBC gives wider range of speed control.

6. References

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