

## A Closed Loop Speed Control of a Switched Reluctance Motor with a New Converter Topology

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**Abstract:** Switched Reluctance Motor (SRM) has become a competitive selection for many applications of electric machine drive systems recently due to its relative simple construction and its robustness. This paper describes the design of new converter, consisting of “half-bridge” IGBT modules and SCRs, for closed loop control of switched reluctance motor drives are proposed. The proposed converter topology is a variation of the conventional asymmetric bridge converter for switched reluctance motor drives. However, utilization of switch modules is enhanced considerably. The requirements of converters for switched reluctance motor drives and the operation of the proposed new converter are analysed and discussed. In this paper a new converter topology for speed control of a switched reluctance motor (SRM) is proposed. The topology is verified through MATLAB simulation.

**Keywords:** Switched reluctance motor drives, Converter topology.

### I. Introduction

The Switched Reluctance Motor (SRM) drives have recently gained considerable attention among researchers due to several reasons. Firstly, stator can be easily manufactured as the stator windings are concentrated around the salient stator poles. Also the salient rotor poles are made up of steel laminations, without conductors or permanent magnets or cage. Due to this rotor structure, extremely high speed can be obtained as compared to rotors with magnets or windings. Secondly, the motor is cost-effective in comparison to conventional induction and synchronous motors, and also it is claimed to have a comparable or even higher efficiency over wide range of speed. Thirdly, due to unidirectional current requirement, the converter has a minimum number of switching devices compared to a conventional inverter-fed synchronous or induction motor drive and thereby greatly simplifying the design of power and control circuit. The other advantages include possible operations in high temperatures or in intense temperature variations. Also a high starting torque can be achieved without large inrush currents and the torque produced is independent of current direction. Therefore SRM is promising as an easy-to-manufacture, low priced, variable speed motor due to its very simple structure with reduced cost and the mechanical simplicity together with the recent advances in the power electronics components.

Fig.1 shows the cross-section of a small developmental SR motor. It has been realized [1], [3] that the reluctance motors requires only unipolar or unidirectional currents and this gives rise to the possibility of operating with only one switching device in series per phase, instead of two in series in each phase leg of an ac or brushless dc drive.

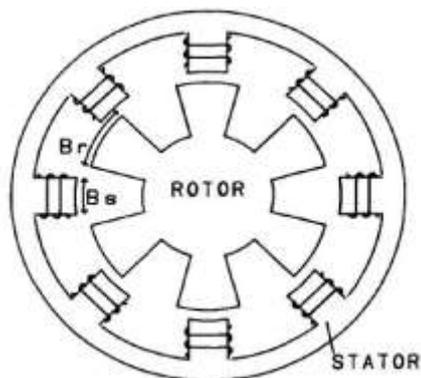


Fig. 1: Basic Switched Reluctance motor

The torque is proportional to the square of the current, hence the current can be unipolar to produce unidirectional torque. Note that this is quite contrary to the case for ac machines. This unipolar current requirement has a distinct advantage in that only one power switch is required for control of current in a phase

winding. Such a feature greatly reduces the number of power switches in the converter and thereby makes the drive economical. The torque constant is given by the slope of the inductance vs. rotor position characteristic. It is understood that the inductance of a stator winding is a function of both the rotor position and current, thus making it nonlinear. Because of its nonlinear nature, a simple equivalent circuit development for this motor is not possible. Since the torque is proportional to the square of the current, this machine resembles a dc series motor; hence, it has a good starting torque. Such circuits use fewer semiconductor devices than their ac counterparts, and they have only one forward voltage drop in series per phase, so that the power losses may, in principle, be lower than in conventional inverters.

Other factors being equal, both of these factors should permit a reduction in the physical size of the converter and an increase in its reliability. The SR drive has additional advantages compared with the conventional adjustable-speed ac or brushless dc drives (including permanent-magnet motor drives). First, shoot through faults are impossible [3]. This is true for all SR converter circuits because there is always a motor winding in series with each main power switching device.

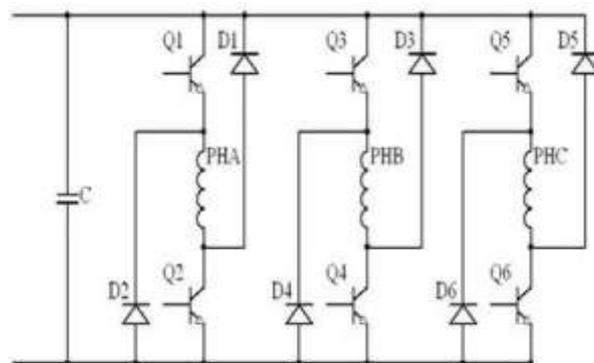
Second, there is a greater degree of independence between the phases than is possible in conventional ac or brushless dc drives. There is very little mutual inductance between machine phase windings in SRM, and for all practical purposes it is considered to be negligible. Since mutual coupling is absent, each phase is electrically independent of other phases. This is a feature unique to this machine only. Due to this feature, note that a short-circuit fault in one phase winding has no effect on other phases. For one thing, it makes possible operation of other healthy phases of the machine and their operation will not be derated, as the voltage requirement is the same before and after the fault. Such independence of machine phases has tremendous consequence in aircraft actuators and generators, actuators used in defense applications, motors used in coolant pumps in nuclear power plants, and traction and electric vehicles, to mention a few applications. In extreme contrast to the operation of SRM under short-circuit fault, consider a permanent magnet synchronous motor with a single-phase, short-circuit fault condition. A fault in one phase (whether in the motor or in the converter) generally affects only that phase the other phases can continue to operate independently.

For switched reluctance motors the converter is not fixed till now also, the research is going on and various topologies viz. resonant, bifilar, split dc supply, r-dump, asymmetric bridge converter. In this paper, a new effective converter topology, which can be regarded as a variation of the asymmetric bridge topology, is developed. It inherits the advantages of the asymmetric bridge topology. Furthermore, it has higher utilization of switch devices. Thus, the proposed converter circuit can be designed with more compact configuration, smaller size and lower cost.

Among those converters, the asymmetric bridge converter is the most popular and best-performed one, in which each phase branch consists of two discrete switching components and two freewheeling diodes, as shown in Fig 2. It is efficient for fault-tolerant and independent current control can be accomplished. However, the high switching component counts and the poor utilization is the main disadvantages of this topology.

In this paper, a new converter topology, which can be regarded as a variation of the asymmetric bridge topology, is developed. It inherits the advantages of the asymmetric bridge topology. Furthermore, it has higher utilization of switch devices. Thus, the proposed converter circuit can be designed with more compact configuration, smaller size and lower cost. Advantages by using asymmetric converter are Ideal for high performance current and torque control. Allows greater flexibility in controlling machine current. Capable of Positive, Negative, and zero voltage output. Voltage stress across the switching element is restricted to  $V_{dc}$ . The followings are the major disadvantages of the asymmetric bridge converter configurations of a switched reluctance motors. There are high switching losses occur in asymmetric bridge converter. Presence of larger heat sinks. Asymmetric bridge converter not suitable for high power applications.

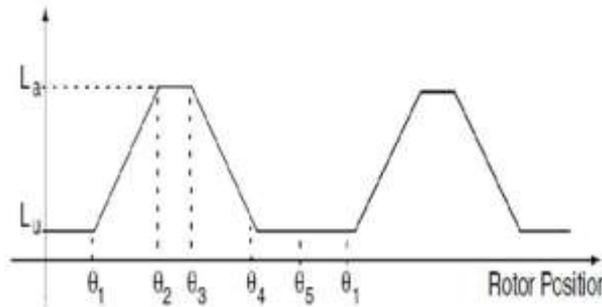
The major application of asymmetric bridge converter is in low power levels inverters fed from a voltage source.



**Fig. 2: Asymmetric bridge converter for three-phase SRM drives**

**II. Operation Of Srm Drives And Requirements To Converter**

The structure of an 8/6 switched reluctance motor is shown in Fig 1. There are no windings or magnets on the rotor, thus SRM is a doubly salient and singly excited motor. The operation of an SRM drive is according to the minimum reluctance principle, which means that the rotor tries to align its poles with the position with minimum reluctance for the magnetic circuit. A position sensor is required to synchronize the stator conduction sequence by determining the rotor position. Also, the torque of an SRM drive is related to the rotor position and the inductance or flux linkage. The typical inductance characteristics in a four-phase SRM drive are shown in Fig



**Fig. 3: Inductance characteristics**

Another important feature of an SRM drive is that the mutual coupling between phases can be neglected. It makes the independent current control possible. Meanwhile, the lack of mutual coupling brings about a problem of dealing with the stored magnetic field energy. An additional path has to be provided for the magnetic field energy during phase commutation. Otherwise, it will result in excessive voltage across the windings and hence on the power switches leading to their failure. Neglecting the mutual coupling between phase windings and regarding all components as ideal ones, the operation of an SRM drive can be described as

$$V = R_s i + \frac{d\lambda(\theta, i)}{dt} \tag{1}$$

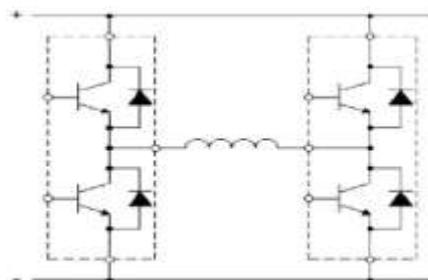
$$\lambda = L(\theta, i) i \tag{2}$$

$$T = \frac{1}{2} i^2 \frac{dL(\theta, i)}{d\theta} \tag{3}$$

**Proposed Converter**

**Proposed Converter Topology**

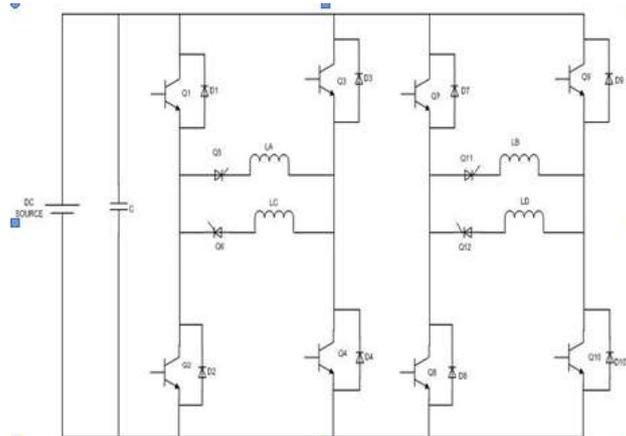
Half-bridge IGBT modules are the popular choice to build asymmetric bridge converters and many other converters in industrial applications, instead of discrete IGBT modules. Because the diodes for freewheeling are necessary even there are build-in diodes in the discrete IGBT modules. It makes the circuit less trustworthy and more complicated. Fig 4 illustrates the phase branch with half-bridge modules for typical SRM converters. It can be seen that each phase branch needs two half-bridge switch modules. Consequently, a four-phase SRM drive requires eight half-bridge switch modules. Therefore, the use of half-bridge switch modules in asymmetric bridge converter brings low utilization and high count of switch devices.



**Fig. 4: Phase branch using half-bridge switch modules**

To figure out the problem, a new converter for SRM drives is developed in this paper. Fig 5 illustrates

the proposed converter circuit for four-phase SRM drives. It can be observed that the proposed converter needs four half-bridge IGBT modules and four SCRs, in comparative to eight half-bridge IGBT modules in asymmetric bridge converters. On the other hand, each phase is controlled by different switching devices. It is helpful to reduce the temperature rise and extend the lifetime of IGBT components.

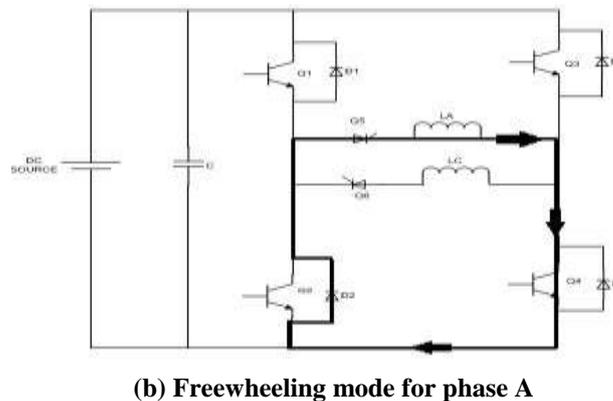
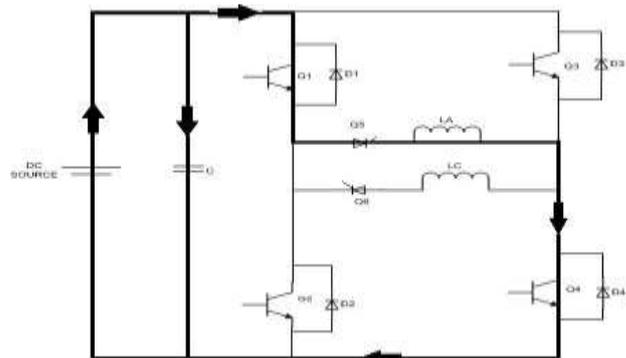


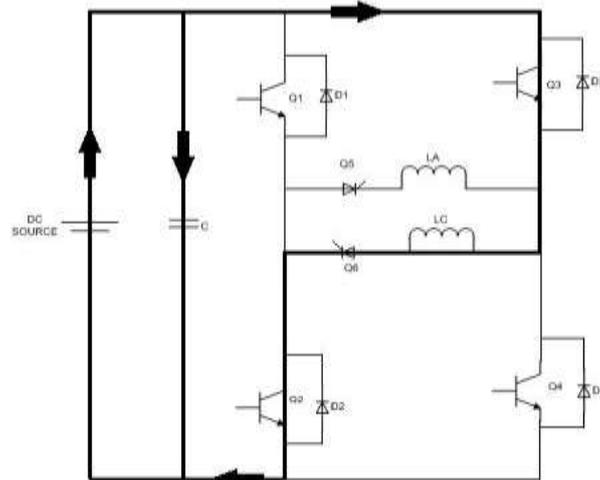
**Fig. 5: Proposed Topology for four-phase SRM drives**

According to the principle of operation of SRM drives, the energy conversion process may occur simultaneously in two adjacent phases, in order to acquire high starting torque and low torque ripple. This mode of operation may cause a current overlap [1]. In the developed converter, therefore, alternate phases are grouped together, such as Phase A and Phase C, or Phase B and Phase D, shown in Fig 6.

**Operation Of Proposed Converter**

As for the developed converter, the operation of each phase includes three modes, which are named as charging, freewheeling and discharging, respectively. For the sake of simplicity of the illustration, the operation of two phases in a group is analyzed in the following discussion. Fig 6 and Fig 7 depict the operations of phase A and Phase C in a group, respectively. The typical gate signals and corresponding current profile are shown in Fig 6.

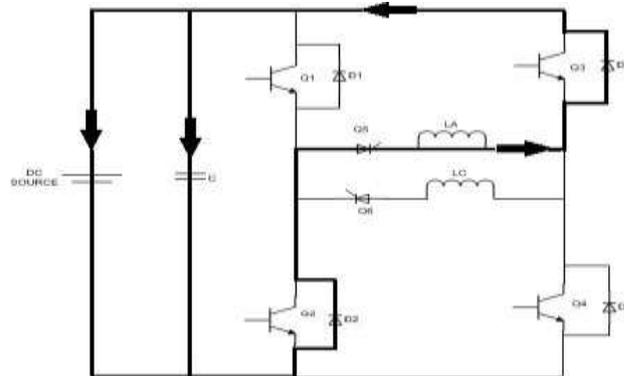




(c) Discharging mode for phase A  
 Fig. 6: Operation modes of Phase A

**Mode 1: Charging**

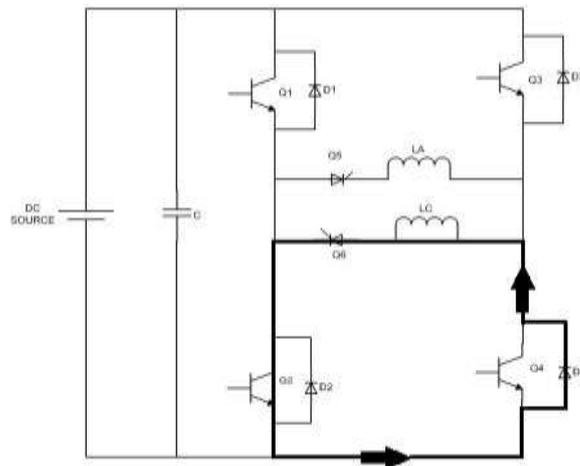
Referring to Fig 6a, if the switching devices Q1, Q4, and Q5 are turned on, the DC link voltage is then applied to Phase A and the current rises rapidly in the phase winding. In the same way, seeing Fig 7a, if the switching devices Q2, Q3, and Q6 are switched on, Phase C is charged through the switches Q2, Q3 and Q6.



(a) Charging mode for phase C

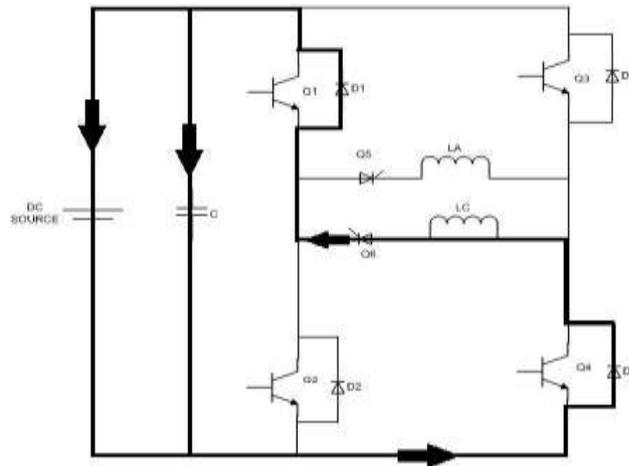
**Mode 2: Freewheeling**

It can be seen from Fig 6b, if the switch Q1 is turned off and the switches Q4 and Q5 are still on, then current circulates through the switches Q4, Q5 and forward-biased diode D2. In this mode, there is no energy transfer between phase winding and DC source.



(b) Freewheeling mode for phase C

It can be seen from Fig 7b, Phase C freewheels through switches Q2 and Q6 and the diode D4 when the switch Q3 is turned off and the switches Q2 and Q6 are still on. Similarly remaining phases also performs the three modes charging, freewheeling and discharging. By this converter we can achieve the three modes of control i.e single pulse voltage control, the hysteresis current control and the PWM voltage control.



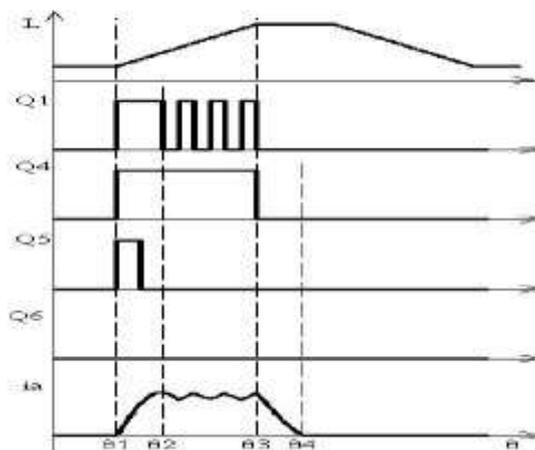
**(c) Discharge mode for phase C**  
**Fig. 7: Modes of Operation of C**

**Mode 3: Discharging**

As is shown in Fig 6c, the switches Q1 and Q4 are turned off and the switch Q5 is still turned on in this mode. Consequently, Phase A discharges to the DC link capacitor, through D2, D3 and Q5. In the same way, from Fig 7c, Phase C discharges to the DC link capacitor through the switch Q6 and the diodes D1 and D4 if the switches Q2 and Q3 are switched off and the switch Q6 is still on.

**3. Control Methods**

From the above analysis and discussion, it can be seen that three conventional control methods for typical asymmetrical bridge converters of SRM drives can be realized in the proposed converter. They are the single pulse voltage control, the hysteresis current control and the PWM voltage control. The single-pulse voltage control includes the charging and discharging modes. The hysteresis current control consists of the charging, freewheeling and discharging modes. The PWM voltage control is composed of the charging, freewheeling and discharging modes.



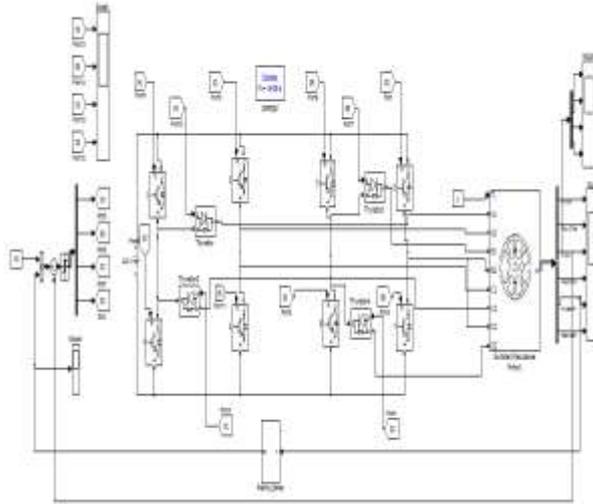
**Fig. 8: Typical gate signals and current waveform**

**Matlab/Simulink Modelling And Simulation Results**

In order to verify the proposed converter for SRM drives, the simulation based on MATLAB/SIMULINK was carried out. Fig 8 shows the developed simulation block diagram in MATLAB/SIMULINK. Here simulation is carried out in two cases,

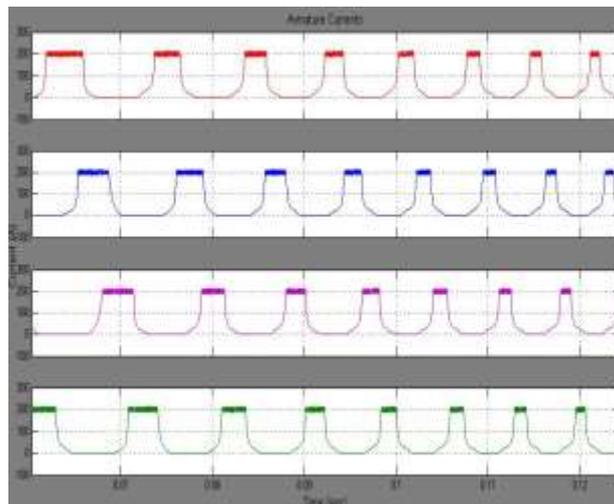
- 1) Open Loop model of Proposed Converter.
- 2) Closed Loop model of Proposed Converter.

Case 1: Open Loop model of Proposed Converter



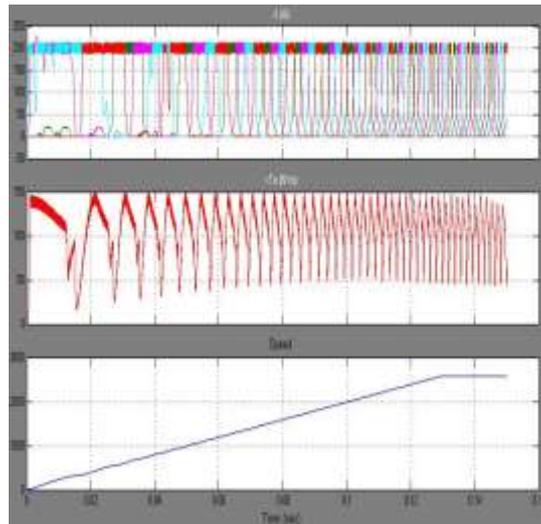
**Fig. 9 Matlab/Simulink Model of Proposed Converter in Open Loop Configuration**

Fig.9 shows the Matlab/Simulink Model of Proposed Converter in Open Loop Configuration to drive a simple switched reluctance machine.



**Fig.10 Armature Currents for four phases of SRM**

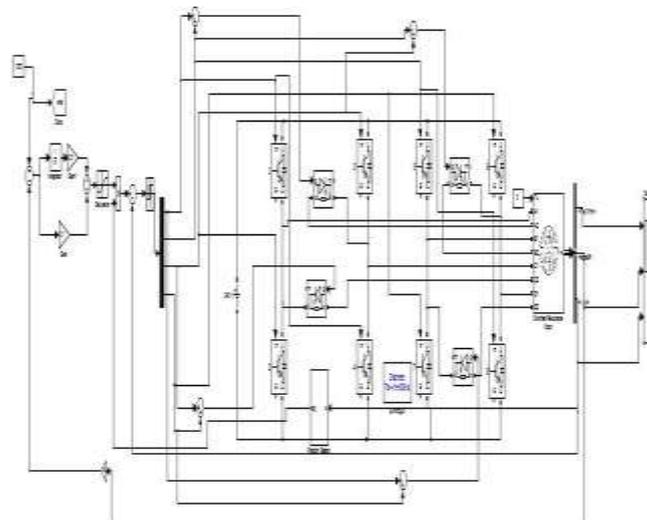
Fig.10 shows the armature current of SRM drive using proposed converter.



**Fig.11 SRM Drive Characteristics**

Fig.11 shows the characteristics of proposed converter fed SRM drive, we get Armature Current, Electromagnetic Torque, Speed.

Case 2: Closed Loop model of Proposed Converter

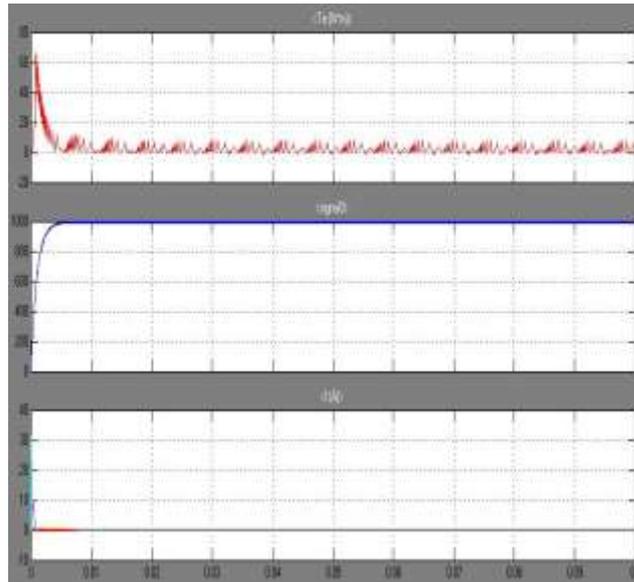


**Fig. 12 Matlab/Simulink Model of Proposed Converter in Closed**

**Loop Configuration**

The concept of control from the machine characteristics of inductance vs. rotor position for a fixed excitation is introduced here. The variables of control such as advance rise and commutation angles are recognized and their dependence on machine inductance, speed, and the requirement to maximize torque are discussed.

Fig.12 shows the Matlab/Simulink Model of Proposed Converter in Closed Loop Configuration to drive a simple switched reluctance machine, to achieve constant speed by using ref speed calculation.



**Fig.13 SRM Drive Characteristics**

A closed-loop, speed-controlled SRM drive is shown in Fig12. The speed error is processed through a proportional plus integral (PI) controller and a limiter to yield the torque command, From the torque command, the current command is obtained using the torque constant, This torque constant is for the linearized inductance vs. rotor position characteristics for a particular value of current. The current command is added and subtracted from the hysteresis window, to obtain the that determine the switching of the phase and main switches of any converter. Fig.13 shows the characteristics of proposed converter fed SRM drive in closed loop operation, we get Electromagnetic Torque, Speed, Armature Current.

## II. Conclusion

In this paper, a new effective converter topology for switched reluctance motor drives with open loop and closed loop models has been proposed. Compared to the conventional asymmetric bridge converter, the proposed one using half-bridge switch modules is more compact and has higher utilization of power switches and lower cost, without degrading in performance. The developed converter has three conventional operating modes that are charging, freewheeling and discharging modes. Hence, the single pulse voltage control, the hysteresis current control and the PWM voltage control are implemented in the developed converter. The simulation in Matlab/Simulink has demonstrated the proposed converter. As a result, this study provides the valuable converter for SRM drives in industrial applications. The proposed new method arrangement allows the reduction in circuit components by nearly half and mainly the main performance of the motor drive. The method can be applied for all the even number of phases of the switched reluctance motor drive. Here we proposed closed loop operation for getting constant speed of a machine.

## References

- [1] Slobodan Vukosavic, Victor R.Stefanovic, "SRM inverter topologies: A comparative evaluation," IEEE Transactions on industry applications, Vol.27, No.6, pp.1034-1047, 1991.
- [2] R. Krishnan and P. Materu, "Design of a Single-Switch-Per-Phase Converter for Switched Reluctance Motor Drives", IEEE Transactions on Industrial Electronics, vol. 37, no.6, pp469-476, 1990.
- [3] R.M. Davis and R.J. Blake, "Inverter Drive for Switched Reluctance Motor Circuits and Component Ratings", IEE Proc., pp. 126-136, 1981.
- [4] W. A. Harris, "Switched Reluctance Motor Control Circuit with Energy Recovery Capability", U.S. Patent No. 5,075,610, Dec. 24, 1991.
- [5] C. Pollock and B.W. Williams, "Power Converter Circuits for Switched Reluctance with the Minimum Number of Switches", IEE Proc., vol. 137, Pt. B, no. 6, pp. 373-384, 1990.
- [6] M. Ehsani, J.T. Bass, T.J.E. Miller, and R. L. Steigerwald, "Development of a Unipolar Converter for Variable Reluctance Motor Drives", IEEE Transactions on Industry Applications, vol. 23, no. 3, pp. 545-553, 1987.
- [7] P.K. Sood, "Power Converter for a Switched Reluctance Motor", U.S. Patent No. 5,115,181, May 9, 1992.
- [8] P. Pillay, R. Samudio, M. Ahmed, and R. Patel, "A Chopper Controlled SRM Drives for Reduced Acoustic Noise and Improved Ride through Capability Using Super Capacitors", IEEE Transactions on Industry Applications, vol. 31, no. 5, pp. 1029-1037, 1995.
- [9] C. Pollock and B.W. Williams, "A Unipolar Converter for a Switched Reluctance Motor", IEEE Transactions on Industry Applications, vol. 26, no. 2, pp. 222-228, 1990.
- [10] R. Krishnan, Switched reluctance motor drives: modeling, simulation, analysis, design and applications, CRC Press, 2001.
- [11] X. D. Xue, K. W. E. Cheng, and S. L. Ho, "Simulation of Switched Reluctance Motor Drives Using Two-Dimensional

Bicubic Spline\*\*", IEEE Transactions on Energy Conversion, Vol. 17, No. 4, December 2002, pp471-477.

- [12] "Design of a novel high grade converter for switched reluctance motor drive using component sharing" Sindhuja, S. Susitra, D. Energy Efficient Technologies for Sustainability (ICEETS), 2013

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