Performance Analysis of Four Phase 8/6 Switched Reluctance Motor Drive using Various Converters

Suvarna sudarsanan
PG Scholar, Department of EEE,
Hindusthan College Engineering and Technology
Coimbatore, Tamilnadu, India.

G Muthuram
Assistant Professor, Department of EEE,
Hindusthan College Engineering and Technology,
Coimbatore, Tamilnadu, India.

***Abstract*—The Switched Reluctance Motor (SRM) is a finest member of the Electric Machines Family. SRM has inherent advantages such as simple construction, robustness, low cost etc., it has various applications in the field of low, medium and high power drives. Torque ripple is the major drawback of the SRM drives. There are various types of switching angle control methods to achieve the optimal efficiency. The choice of the right control system is critical for the SRM system design. Torque Sharing Function (TSF) is the most effective control technique in order to minimize the torque ripples. TSF is a simple but powerful and popular technique among the indirect torque control method. In the TSF method reference torque is directly translated into the reference current. The TSF method is concerned with secondary objectives, such as minimization of copper losses or maximization of drive performance etc. The proposed system deals with four phase 8/6 drives, it will reduce the torque ripple. In this paper two converters such as Asymmetric full bridge full bridge converter, and component sharing converter along with the implementation of TSF control technique is comparing using MATLAB/ Simulink.**

Keywords— Switched Reluctance Motor, Total Harmonics Distortion, Torque Sharing Function

I. Introduction

At an age of more than 150 years, and counting, the switched reluctance motor (SRM) represents one of the oldest and finest electric motor designs around. The recent demand for variable-speed drives and primarily as a result of the development of power semiconductors, a variation on the conventional reluctance machine has been developed and is known as the switched reluctance (SR) machine.

SRM have inherent advantages such as simple structure with non winding construction in rotor side, fail safe because of its characteristic which has a high tolerances, robustness[2], low cost with no permanent magnet in the structure, and possible operation in high temperatures or in intense temperature variations. Thus, SRM have drawn great attention from industry and researchers as an alternative among other electrical machines. SRM construction with doubly salient poles and its non-linear magnetic characteristics, the problems of acoustic noise and torque ripple are more severe than these of other traditional motors. Thus it was not successful in its wide acceptance due to its nonlinear nature of torque production. The lack of proper power electronics converters also made the SRM drive found to be less acceptance.

The torque ripple is an inherent drawback of switched reluctance motor drives. At high speed this torque ripple has a high frequency and is filtered out. In contrast, at low speeds this torque ripple could cause significant speed fluctuations and oscillations in the drive train. The causes of the torque ripple include the geometric structure including doubly salient motor, excitation windings concentrated around the stator poles and the working modes which are necessity of magnetic saturation in order to maximize the torque per mass ratio and pulsed magnetic field obtained by feeding successively the different stator windings. The phase current commutation is the main cause of the torque ripple. The torque ripple can be minimized through magnetic circuit design in a motor design stage or by using torque control techniques.

The torque ripple minimization is done by choosing efficient control technique and proper converter. There are many classical torque controlling technique inorder to minimizing torque ripple are discussed in previous paper, they are Direct Instantaneous torque control technique [13]-[15], Pulse width Modulation Method [9], Neuro Fuzzy Compensation Method etc, In this paper dealing with Torque Sharing Function, which most effective control technique to minimize control technique Another method for torque ripple minimization is by using appropriate converters. A number of power electronics converter topology has been developed over the year exclusively for use in conjunction with SRM drives. The converter is the power supply unit .It regulates the current to meet the specific requirement of the SRM drives.

In this paper deals with the torque ripple minimization using two converters such as asymmetrical full bridge converter and component sharing converters along with the implementation of torque sharing function.

II. TECHNOLOGIES

A. Four Phase 8/6 SRM Drives

The choice of the number of poles to be used in the SRM is important due to the vibration that is produced. The Structure of Four Phase 8/6 SRM is shown in Fig 1 [1]-[2]. The Four Phase 8/ 6 (8 stator and 6 rotor poles) provides lower mechanical vibration compared to the 6/4 structure. The four-phase motor is known for reducing torque ripple. The large number of power electronic devices and connections is a major drawback, limiting four phase motors to a specific application field. A practical limitation to consider larger phase numbers is the increase of the converter phase units, hence of the total cost.

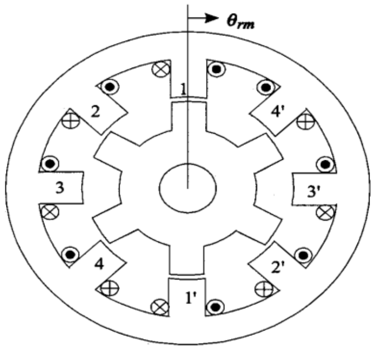

Fig. 1. Structure of 8/6 SRM

B. Converters Used

The amount of current flowing through the SRM winding is controlled by switching on and off power electronics device such as MOSFET and IGBT. The selection of converter topology for a certain application is an important issue. Basically, the SRM converter has some requirements, such as:

- Each phase of the SR motor should be able to conduct independently of the other phases. It means that one phase has at least one switch for motor operation.
- The converter should be able to demagnetize the phase before it steps into them regenerating region. If the machine is operating as a motor, it should be able to excite the phase before it enters the generating region.

In order to improve the performance, such as higher efficiency, faster excitation time, fast demagnetization, high power, fault tolerance etc., the converter must satisfy some additional requirements. Some of these requirements are listed below.

Additional Requirements:

- The converter should be able to allow phase overlap control.
- The converter should be able to utilize the demagnetization energy from the outgoing phase in a useful way by either feeding it back to the source (DC-link capacitor) or using it in the incoming phase.
- In order to make the commutation period small the converter should generate a sufficiently high negative voltage for the outgoing phase to reduce demagnetization time.
- The converter should be able freewheel during the chopping period to reduce the switching frequency. So the switching loss and hysteresis loss may be reduced.
- The converter should be able to support high positive excitation voltage for building up a higher phase current, which may improve the output power of motor.

The converter should have resonant circuit to apply zero-voltage or zero-current switching for reducing switching loss.

a. Asymmetric Full Bridge Converter

The full bridge converter consists of four switches in the single phase. There are sixteen switches in the four phase SRM drives. A direct converter is an electrical circuit made of switches. It is unable to store the energy. The energy transfer is directly take place from input to the output.

A full bridge circuit including first and fourth switching devices constituting a first leg of said full bridge and a second and third switching devices constituting a second leg of said full bridge, said first and second switching devices being main switches, said third and fourth switching devices being auxiliary switches.

b. Component Sharing Converter

The component sharing converter circuit for four phase SRM drive, which is illustrate in Fig 2. It can be observed that the asymmetrical converter it need needs eight IGBT modules and eight diodes but in the component sharing converter eight IGBT modules and four diodes, in comparison. On the other hand, each phase is controlled by different switching devices [10]. It is helpful to reduce the temperature rise and extend the lifetime of IGBT components.

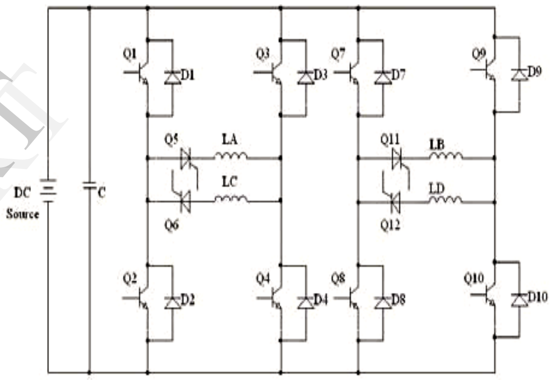

Fig. 2. Component sharing converter topology for four-phase SRM drives

According to the operation principle 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. In the developed converter, therefore, alternate phases are grouped together, such as Phase A and Phase C, or Phase B and Phase D. This allows independent current control of each phase with overlapping currents not exceeding one phase cycle duration [12].

In component Sharing Converters there are three stages of operations, they are Charging, Freewheeling, and Discharging. It will help to reduce the switching losses and very cost effective converter.

C. Control Technique

The choice of proper control technique is very important for SRM drives. If the proper control technique is used, it will give better motor operation, lower energy usage, greater reliability, fewer system components, and a better dimension of the power elements. The most effective control technique

Torque Sharing Function and It is indirect control Technique [6].

The torque ripple is the main drawback of SRM drives. It is the consequence of non linear torque -current - angle characteristics and discrete nature of torque producing mechanism. In this method Torque is divided among the individual phase. The instantaneous torque of individual phase is defined by suitable TSF. The primary objective of low torque ripple is provided by ideally sharing torque among individual phases. Secondary objective is very important, it may be minimization of the copper losses, minimization of the phase voltage or minimization of the peak phase current that are related to the drive efficiency, torque-speed capability, and peak current requirement for the power converter, respectively. These secondary objectives help to optimal TSF and optimize parameters.

1) TSF block diagram

The input torque reference is divided into four-phase torque command according to the rotor position which is shown in Fig 3. Torque references of each phase are changed to the current command signal in the "Torque to Current" block according to the rotor position. Since the output torque is determined by inductance slope changed by rotor position, so the reference current of each phase is determined by the target torque and rotor position. The switching rule is generates an active Switching signal of power converter according to the current error and hysteresis switching table [7] - [14].

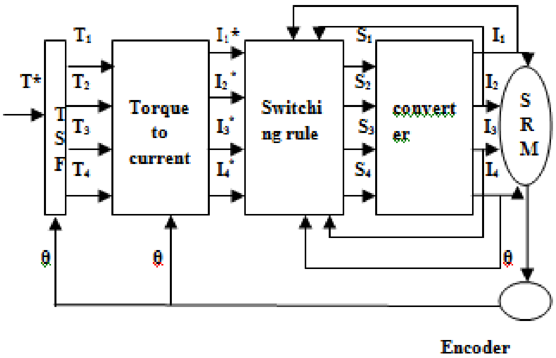

Fig. 3. Block Diagram of TSF methods

The reference phase torque T^*_k of each phase is obtained by proper shifting of TSF. The TSF is divided into the region with zero and nonzero values. The nonzero region of TSF is divided into the subregion, where the considered phase *k* alone should develop the whole torque in $(T^*_k = T^*)$, and the subregion, where it the torque with one or more phase $(0 < T^*_k < T^*)$.

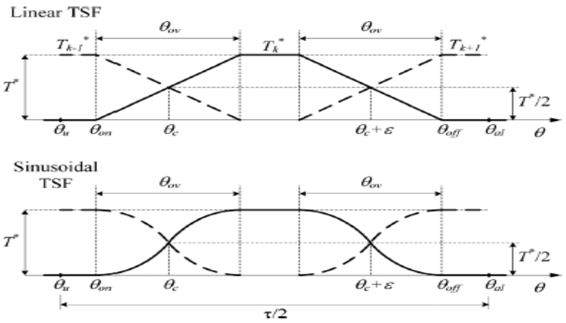

Fig. 4. Typical profiles of linear and sinusoidal TSF

The simultaneous excitation of no more than two phases in overlap region will be considered, since that is the condition any phase in most of three-phase and four phase SRMs does not produce negative torque. According to the torque sharing curve in overlap region, the most popular of the conventional TSFs can be classified as linear, exponential, cubic, and sinusoidal TSF The reference torque T^*_k of the phase *k* can be defined as

$$T^*k(\theta) = \begin{cases} 0, & 0 \le \theta \le \theta_{on} \\ T^*.f_{rise}(\theta), & \theta_{on} < \theta < \theta_{on} + \theta_{ov} \\ T^* & \theta_{on}+\theta_{v} \le \theta \le \theta_{off} - \theta_{ov} \\ T^*.f_{fall}(\theta), & \theta_{off} - \theta_{ov} < \theta < \theta_{off} \\ 0, & \theta_{off} \le \theta \le \theta_{al} \end{cases}$$

The phase *k* is energized between turn-ON θon and turn-OFF θoff angles. According to the torque production capability, these angles must satisfy conditions: $\theta u \le \theta on < \theta off \le \theta al$. Overlap angle θov denotes intervals when phase *k* shares torque with outgoing phase $(k - 1)$ or with incoming phase $(k + 1)$.

D. PI Controller

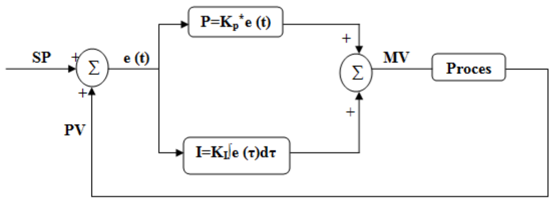

Fig. 5. Basic block of a PI controller.

A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used.

The controller output is given by

$$K_P\Delta+K_I\int\Delta dt \qquad -(1)$$

Where is the error or deviation of actual measured value (***PV***) from the set-point (***SP***).

A PI controller can be modeled easily in software such as Simulink using a "flow chart" box involving Laplace operators:

$$C=G(1+TS)/TS \qquad -(2)$$

Where

$G=K_P$= proportional gain

$G/T=K_I$= integral gain

Setting a value for G is often a tradeoff between decreasing overshoot and increasing settling time. The lack of derivative action may make the system steadier in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs. Without derivative action, a PI-controlled system is less responsive to real (non-noise) and relatively fast alterations in state and so the system will be slower to reach set point and slower to respond to perturbations than a well-tuned PID system.

III. SIMULATION

The simulation model of this SRM is given in Figure 6 .Four Phase 8/6 SRM drives is proposed. The control technique here implemented is Torque Sharing Function, which advanced and most efficient method. Here in this project the two converters are compared for analysis. Here ie, the two converters are Asymmetric Full Bridge converter, and Component Sharing converters are used. In this THD device is used to digitally display the harmonics presented in the each phase of the SRM drives. The TSF is implemented in this simulation to achieve better control over the motor using the torque produced by the motor; the system for TSF The speed from the motor is taken and given to speed controller along with the reference speed the speed controller converts actual speed and reference speed to flux and torque values (ie estimated values), then the estimated flux and torque value is given to flux and torque hysteresis block which in turn process the flux and torque (estimated value) to simple error value and it is given to the switching tables which produces gate pulsed for the switches in the converter using SRM technique. The produced gate pulses are given to the converter which conducts the current which in turn controls the torque produced by the motor.

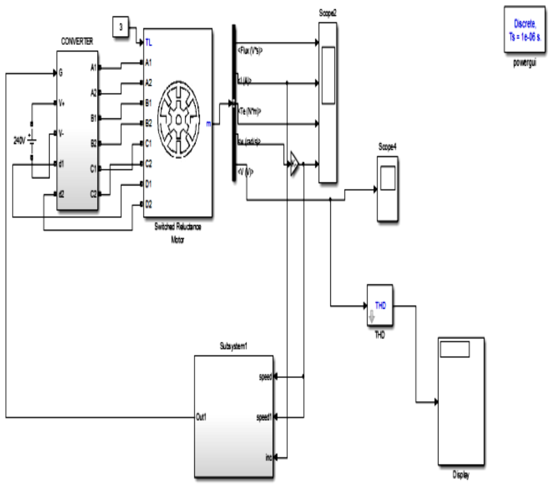

Fig. 6. General simulation model

IV. RESULT AND DISCUSSIONS.

From the output wave illustrated in the Fig 7 and Fig 8 , it is clear that Component Sharing Converter along with TSF control Technique produces less torque ripple when compare with Asymmetric full bridge converters. Due to reduction in the components, total harmonic distortion is less in the component sharing converter.

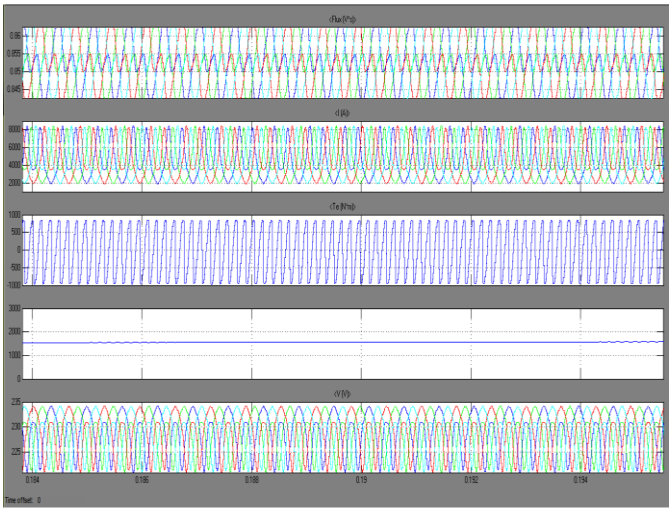

Fig. 7. Output using full bridge converter

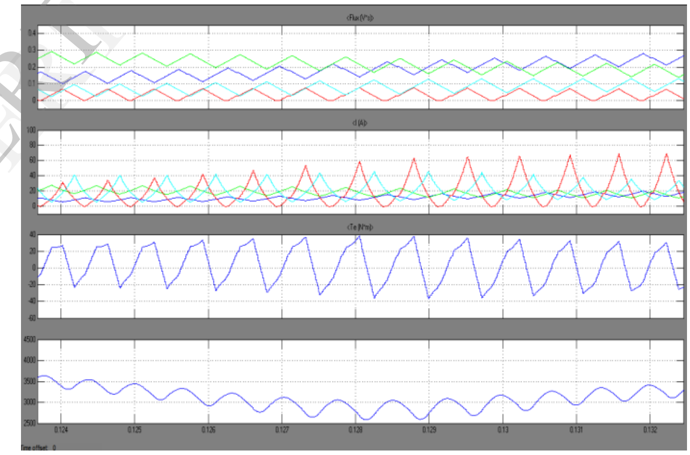

Fig. 8. Output waveform using Component Sharing Converter

SRM has doubly salient poles and non-linear magnetic characteristics; the torque ripple is more severe than other traditional motors. Four-phase 8/6 SRM motors are popular for reducing torque ripple. In this project the control technique used is TSF, which is the most efficient control method for the minimization of torque ripples. By choosing appropriate converter torque ripples can be reduced. The implementation of TSF (torque sharing function) is done in two different converters for four phase SRM drive

The converters designed are

1. Asymmetric Full Bridge Converter
2. Component sharing converter.

By analyzing simulation result, it can be determined that the TSF function can be fully achieved in Component Sharing converter. The harmonics produced in the voltage while using various converters is measured by THD meter. THD value is less in the Component Sharing converter than Asymmetric Full Bridge Converter. Thus by choosing appropriate converter ie Component Sharing converter, the efficiency of the SRM drives is high.

ACKNOWLEDGMENT

Author is thankful to the Electrical department in Hindusthan college of Engineering and Technology for providing required experimental setup.

REFERENCES

[1] R. Krishnan, Switched Reluctance Motor Drives. Boca Raton, FL: CRCPress, 2001.
[2] P. L. Chapman and S. D. Sudhoff, “Design and precise realization of optimized current waveforms for an 8/6 switched reluctance drive,” IEEE Trans. Power Electron., vol. 17, no. 1, pp. 76–83, Jan. 2002.
[3] D. S. Schramm, B. W. Williams, and T. C. Green T, “Torque ripple reduction of switched reluctance motors by PWM phase current optimal profiling,” in Proc. IEEE Power Electron. Spec. Conf., 1992, pp. 857–860.
[4] X. D. Xue, K. W. E. Cheng, and S. L. Ho, “Simulation of switched reluctance motor drives using two-dimensional bicubic spline,” IEEE Trans. Energy Convers., vol. 17, no. 4, pp. 471–477, Dec. 2002.
[5] P. C. Kjaer, J. J. Gribble, and T. J. E. Miller, “High-grade control of switched reluctance machines,” IEEE Trans. Ind. Appl., vol. 33, no. 6, pp. 1585–1593, Nov./Dec. 1997.
[6] Xue X. D ,Cheng K. W. E, and Ho S. L, “Optimization and evaluation of torque-sharing functions for torque ripple minimization in switched reluctance motor drives,” IEEE Trans. Power Electron., vol. 24, no. 9, pp. 2076–2090, Sep. 2009
[7] Vladan P. Vujiˇci´c, Member, IEEE Minimization of Torque Ripple and Copper Losses in Switched Reluctance Drive,IEEE Trans. Power Electronic jan 2011
[8] T. J. E. Miller, Electronic Control of Switched Reluctance Machines. Oxford, U.K.: Newnes, 2001
[9] I. Husain and M. Ehsani, “Torque ripple minimization in switched reluctance motor drives by PWM current control,” IEEE Trans. Power Electron., vol. 11, no. 1, pp. 83–88, Jan. 1996.
[10] Sindhuja S , PG scholar, Susitra D , Assistant Professor Design of a Novel High Grade Converter for Switched Reluctance Motor Drive using Component Sharing. Energy Efficient Technologies For Sustainability (Iceets), 2013 International Conference
[11] V. P. Vujiˇci´c, S. N. Vukosavi´c, and M. B. Jovanovi´c, “Asymmetrical switched reluctance motor for a wideconstant power range,” IEEE Trans.Energy Convers., vol. 21, no. 1, pp. 44–51, Mar. 2006.
[12]] Souvik Ganguli Analysis of an Asymmetric Bridge Converter for Srm Drives Using Pspice Simulation, International Journal of Advanced Engineering Technology E-ISSN 0976-3945
[13] Fuengwarodsakul N., Menne M. , Inderka R., and. De Doncker R. W, “High dynamic four-quadrant switched reluctance drive based on DITC,”IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1232–1242, Sep./Oct. 2005
[14] V.Vujiˇci´c and S. N.Vukosavi´c, “A simple nonlinear model of the switchedreluctance motor,” IEEE Trans. Energy Convers., vol. 15, no. 4, pp. 395–400, Dec. 2000.
[15] R. B. Inderka and R.W. De Doncker, “DITC—Direct instantaneous torque control of switched reluctance drives,” IEEE Trans. Ind. Appl., vol. 39,no. 4, pp. 1046–1051, Jul./Aug. 2003.