Analysis of converters for torque control in switched reluctance motor drive system– a comparative study

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Abstract. This paper illustrates the analysis of different types of converter used in Switched reluctance motor for torque Control. Torque control in switched reluctance motor is complicated by its highly nonlinear magnetization characteristics. Also minimization of torque ripple in Switched reluctance motor is a challenging task in applications like electric vehicle and servomechanism where high speed and smooth control is required. This paper compares the simulation results of different types of converters used in switched reluctance motor drive system. Performance of asymmetric converter fed closed loop switched reluctance motor, asymmetric bridge converter fed switched reluctance motor using proportional-integral-derivative controller, asymmetric converter fed open loop switched reluctance motor, n+1switch per phase converter has been studied , simulations has been done in MATLAB 2016a simulink environment and the results are compared . The observed factors like, Maximum torque, Minimum torque and torque ripple coefficient are presented. It is concluded that n+ 1switch per phase converter fed switched reluctance motor has less torque ripple compared to other three methods.

Keywords: Switched reluctance motor, Torque control, converter control

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1 Introduction

Switched Reluctance motors are widely used in adjustable speed motor drives. Its ruggedness, standardized arrangement of Magnetic behavior of the stator and rotor with its high level performance indices are the advantages of SRM [1]. This machine is insensitive to high temperature and because of the absence of magnetic sources on the rotor; SRM is relatively easy to cool. This particular behavior of SRM, makes its demand in automotive applications, which requires the ability to operate in harsh ambient conditions. Performance of Reluctance motor is comparatively higher than a high speed stepper motor. The appreciable characteristics of dc commutator motor drive, induction motor drive and PM BLDC motor drive are combined in switched reluctance motor drive (T J E Miller, 1989), also this motor will deliver 2 to 4 times the starting and accelerating torque of same size induction motor. But the main disadvantage in SRM is its High torque ripple and acoustic noise. This high torque ripple can be reduced by any of following ways. i) By modifying the physical geometry of the machine ii) by incorporating suitable controller for shaping the current waveform. In switched reluctance, rotor gets in line with the energized stator winding because of its least reluctance point. Many reviews has been done on this topic and the results were reported [2] .Control of SRM is examined both as motor as well as generator .Torque ripple can be reduced till the speed when the controller failed to regulate the phase current [3]. Summary and comparison of torque ripple reduction techniques have been reported [4].Torque ripple minimization through speed signal processing was done. Speed signal is processed to shape the current waveform applied to the winding of the motor [5]. This method does not require any prior knowledge about the torque-current characteristics. This method is faster with less commutation time. Torque sharing function concept is proposed in [6] for minimizing the torque ripple. Torque error of the incoming phase is added to the reference torque of the outgoing phase as a positive value to regulate the total torque of the motor.

Mutual Coupling effect also taken in to account for studying torque ripple minimization in all the four quadrants of speed and torque[7].A novel RTSP converter which utilizes resonance phenomenon to set right the torque ripple in SRM. By using this resonance converter ,not only the torque ripple is reduced, but also the performance has been increased[8]. Destructive interference technique can also be used to reduce the torque ripple[9].Intelligent controller techniques like fuzzy logic,neural network,ANFIS controllers can also be used to address this problem[10]

2 Block Diagram Of SRM Drive

Block diagram for the SRM drive system is shown in Fig. 1

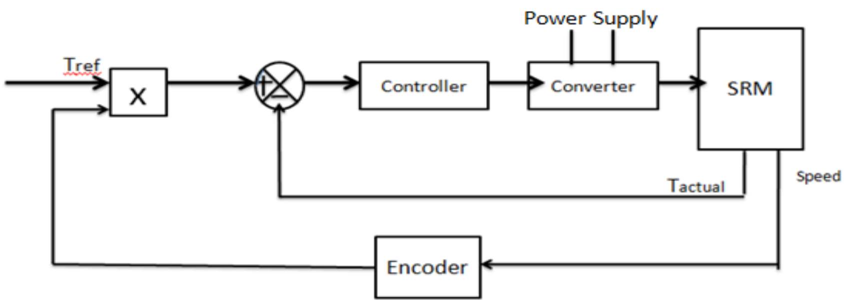

Fig. 1 Block Diagram of SRM drive

Actual torque of the motor is compared with the reference torque and the error is processed in the controller which may be a hysteresis, PI, PID controller .The controller feeds the gating signal of the converter so that the stator winding of the SRM gets energized. Based on the rotor position, encoder will give signal to the product block. Performance of the Switched Reluctance motor is analyzed by using i)Asymmetric converter (open loop) iii) PID controller fed SRM iii) Asymmetric converter (closed loop) iv)N+1 switch per phase converter. Torque produced by all these four methods are analyzed and torque ripple coefficient is calculated for each method and compared .Different types of converters are implemented in MATLAB 2016a simulink and the results have been given.

3 Simulation Of Different Types Of Converter Fed SRM

3.1 Asymmetric bridge converter fed Open loop SRM:

In order to achieve the high switching current to the windings, asymmetric bridge converter is used as shown in Figure.2.It consist of two switches and two diode per phase. It operates in three modes' magnetization of the winding ii) free wheeling period iii)demagnetization of the winding. Unipolar switching strategy is the main advantage of the converter through which less current ripple is obtained. Operation of PWM controlled open loop SRM drive is analyzed trough MATLAB simulation as shown in Fig. 3.

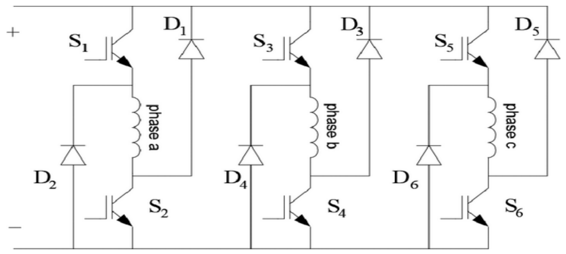

Fig. 2 Asymmetric bridge Converter

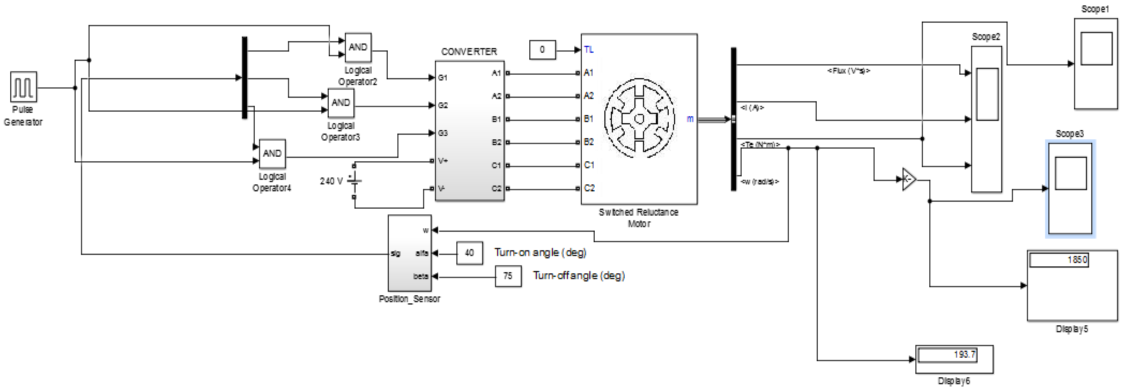

Fig. 3 Asymmetric converter fed open loop SRM

Simulation waveforms of torque and speed are given in Figure 4 &5.Since it is operating in open loop, motor torque is not tracked by any of the controller, hence the torque produced is reduced to 70 Nm, which is very less compared to other three methods. The torque requirement cannot be met by these types of circuit. Hence this type of drive is not used for applications which require high starting and operating torque. During the transition from one phase winding to another, torque dip is produced .Hence the torque ripple is very high compared to other circuits

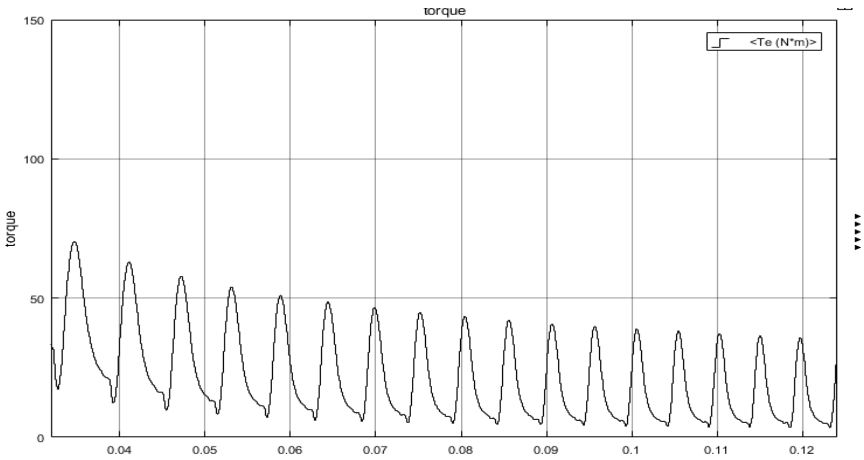

Fig. 4. Torque response

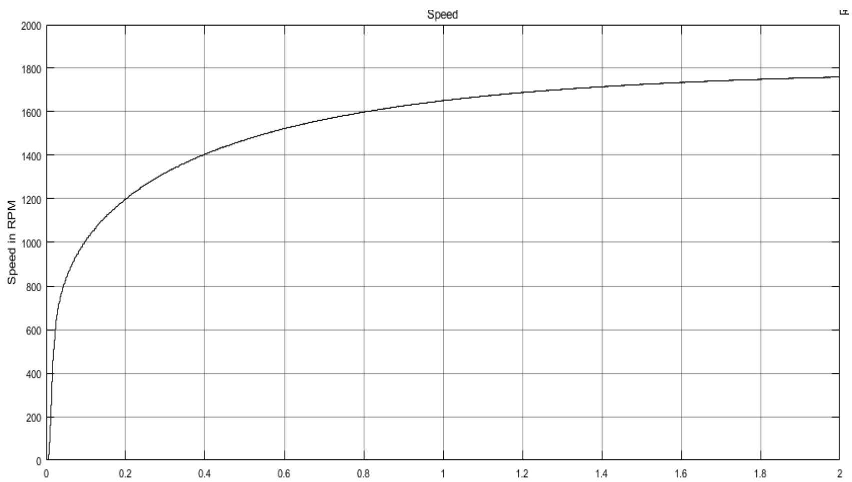

Fig. 5 Speed response

Figure 5 shows the speed response of the circuit. Maximum torque produced by the motor is 70N-m.Average torque is 21N-m.Hence the torque ripple coefficient value is high which is 3.07. Maximum and minimum torque is calculated and from that values,torque ripple coefficient can be calculated from the given formula.

$$\text{Torque ripple Coefficient} = \frac{Tmax - Tmin}{Tavg}$$

3.2 Asymmetric bridge converter fed SRM using PID control

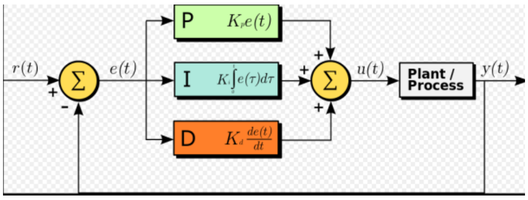

Fig. 6. PID controller

Simulation circuit of asymmetric bridge converter fed SRM using PID controller is shown in Figure 7.Here the type of controller used is PID. Because of the combined, proportional, derivative and integral controller, speed of the response can be increased and error is eliminated. The speed of SRM is controlled by PID controller. The PID controller has preferred to use in industrial applications. Compared to other types of controller PID controller tuning is easy, uses less sources, ease of implementation. The tuned values PID controllers are:

$$K_p=0.6, K_i=0.2, K_D=0.01$$

This PID controller is implemented with classic bridge converter for minimizing the torque ripple of switched reluctance motor.

In this system, speed can also be controlled by PID controller .Reference speed is compared with the actual speed of SRM and the error is processed with the torque error through a hysteresis controller. Outputs, one from the speed error and another one from the torque error are fed to logical operator, from which the converter switches are getting the signal to energize the windings of the stator. From the torque response Figure 8, It is noted that the torque dip was more deeper compared to the asymmetric converter fed closed loop SRM .Hence the torque ripple coefficient is high as 1.67 but less than the open loop circuit.

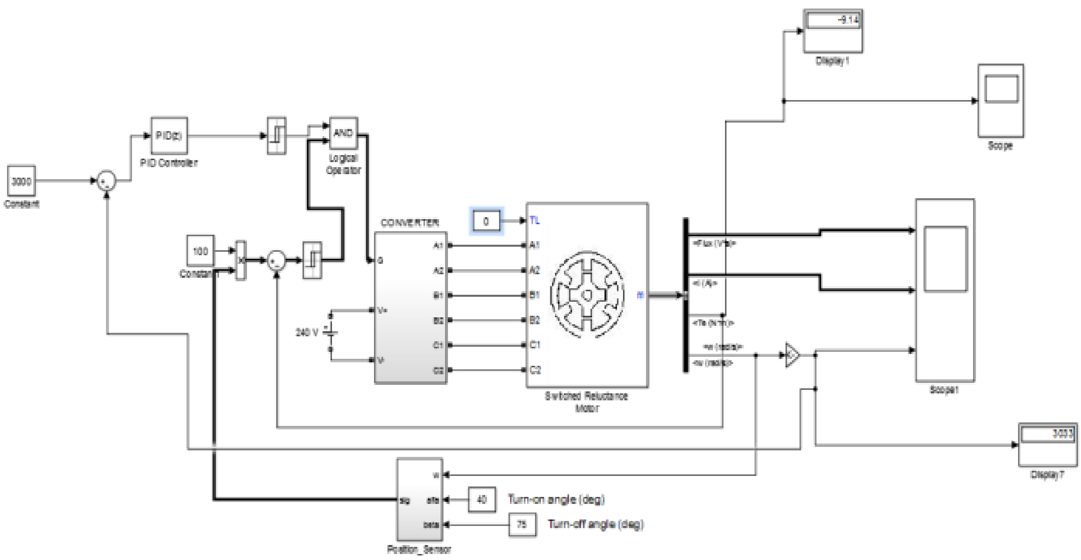

Fig. 7. Asymmetric bridge converter fed SRM using PID controller

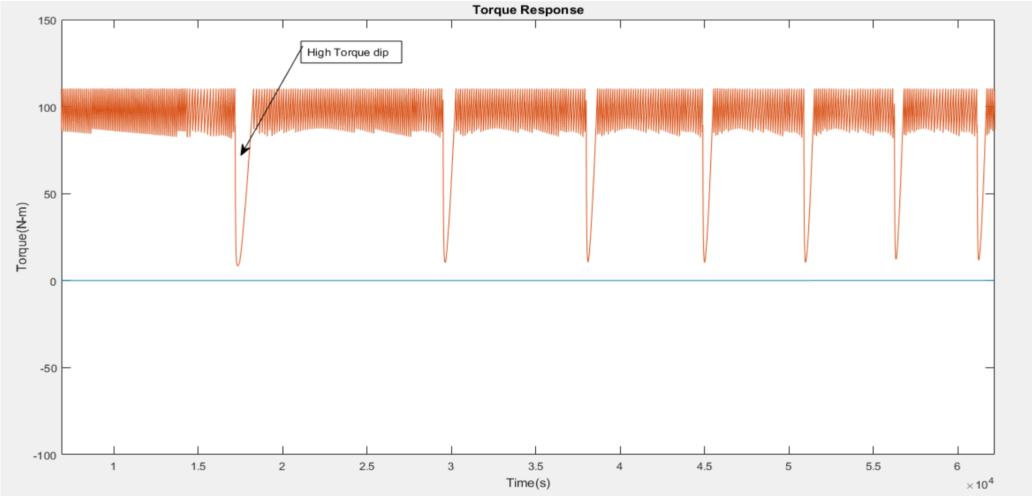

Fig. 8. Torque response

PID controller fed SRM has deep torque dip compared to the asymmetric close loop converter fed SRM. But the speed gets settles down at the set point value as shown in Figure 9.In this sytem, demagnetization of the off going phase take more time .Hence the torque ripple is high. Maximum torque produced is 110N-m, Average torque is 60N-m.Hence the torque ripple coefficient is 1.67 which is less than the asymmetric open loop converter fed SRM.

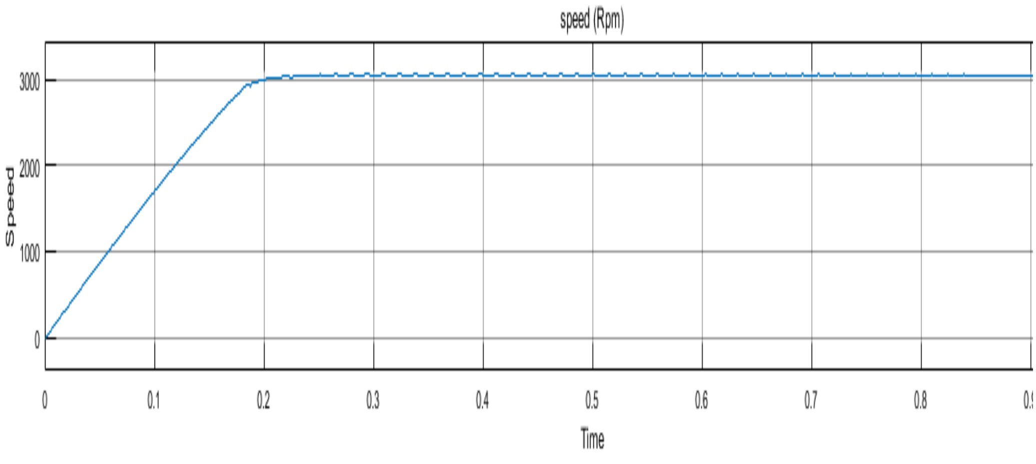

Figure9 Speed Response

3.3 **Asymmetric converter fed closed loop SRM**

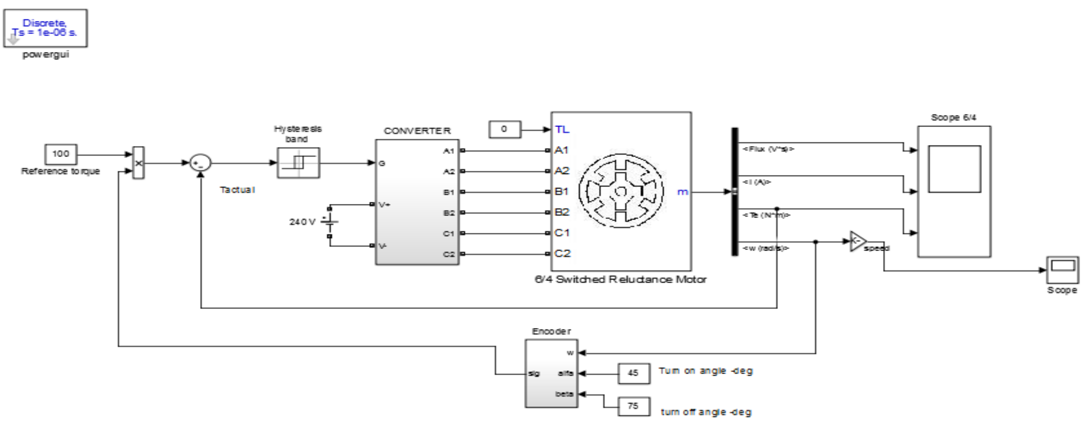

Fig. 10. Simulation Diagram of Asymmetric bridge converter fed Switched reluctance motor

Simulation Diagram of Asymmetric bridge converter fed Switched reluctance motor is shown in Figure 10.Three phase asymmetric power converter which has two IGBTs and two freewheeling diodes feeds the SRM. During ON period of the active switches, positive current is applied to the stator winding of the phase. During the off period that is during the freewheeling time, the stored energy is returned back through the diodes to the source. Hence during the commutation period ,the fall time of the outgoing phase can be reduced. Encoder is attached rotor of the SRM, the turn-on and turn-off angles of the motor phases can be accurately given. These switching angles can be used to control the developed torque waveforms. The reference torque is controlled by three hysteresis controllers which generate the IGBTs drive signals by comparing the measured torque with the reference torque. The IGBTs switching frequency is mainly determined by the hysteresis band. The Torque characteristics of the drive are shown in Fig.11.

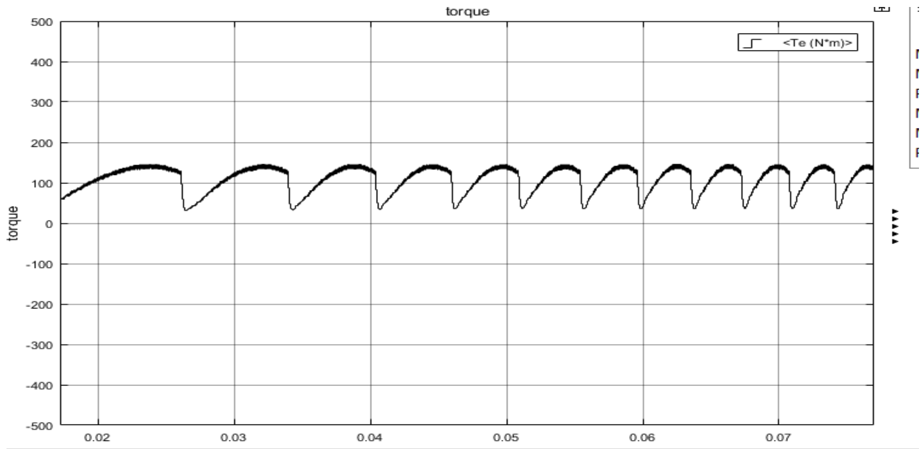

Fig. 11. Torque response

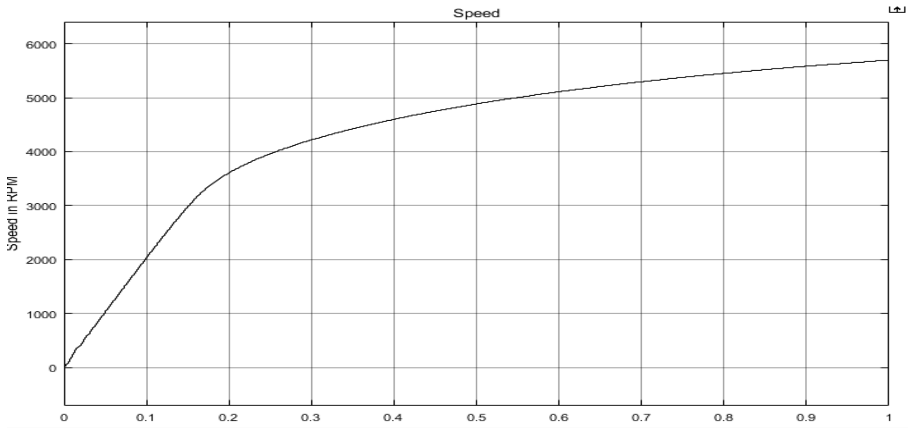

Fig. 12. Speed response

From the Characteristics, it can be concluded that torque dip occurs during the transition of current from one phase to another phase .Maximum and minimum torque is calculated and from that torque ripple coefficient can be calculated from the given formula as per equation (1).Maximum torque produced is 146Nm and the average torque is 108Nm.Hence the torqueripple coefficient is 1.06 which is lesser than PID controller fed SRM.

3.4 N+1switch per phase Converter fed SRM

In classic converter, number of switches used is higher. But in this type of converter as shown in figure 13, one switch is used for one phase and one switch is common for all the phases. In three phase converter 4 switches are used. This converter will freewheel during chopping time. Voltage rating of all the devices will be same. Effective use of energy can be done in this converter by resettling the energy back to source. But the efficiency is poor compared to other type of converter configuration.

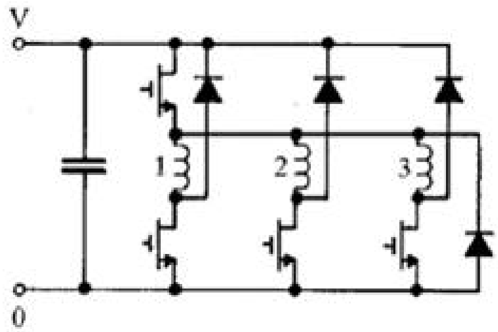

Fig. 13. N+1Switch per phase configuration

Simulation diagram of N+1switch per phase converter fed SRM is shown in Figure14. Reference torque is compared with actual torque of the machine and the error is processed through Hysteresis controller , where the hysteresis limit is set +10 to-10.Converter switches get the signal from the output of the hysteresis controller .Here the common switch conducts for the all the operating windings. Hence the strain on the switch is more.

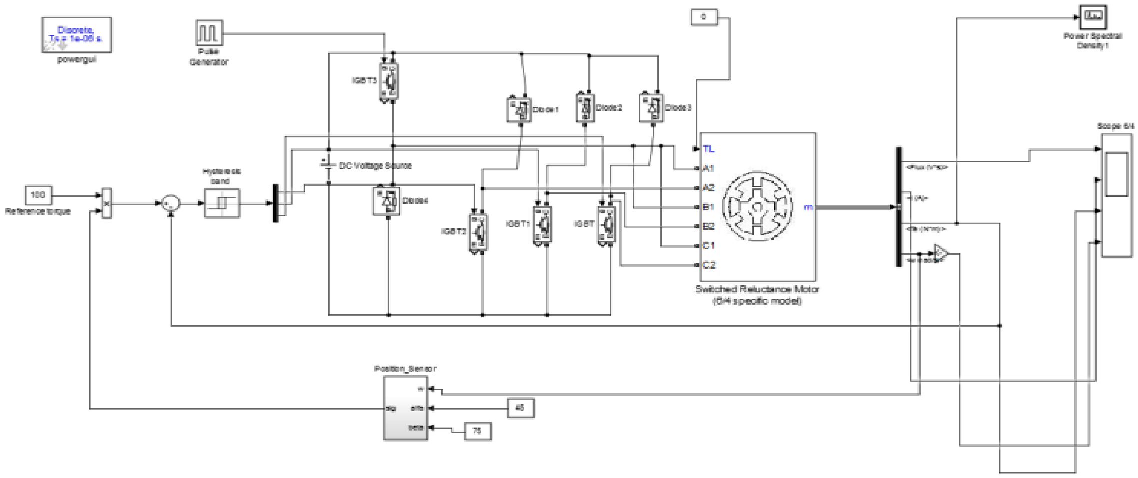

Figure 14 N+1 switch per phase Converter fed SRM

Figure 15 shows the performance of N+1 switch per phase converter output. Maximum torque produced is 110Nm, Average torque is 100 Nm. Therefore the Torque ripple coefficient is very less ie.0.212.This value is lesser than all the above three circuits.

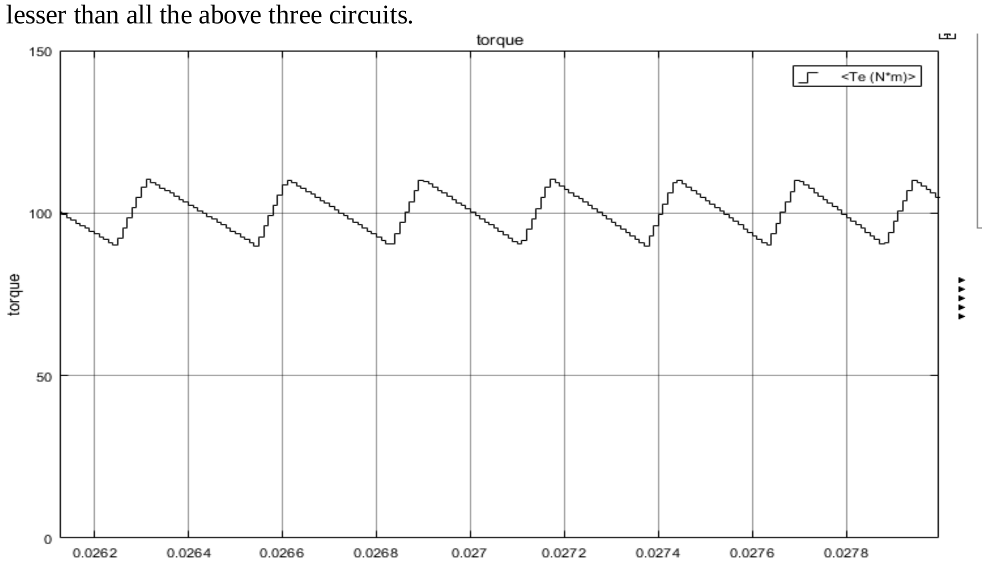

Figure 15 Torque vs Time Characteristics

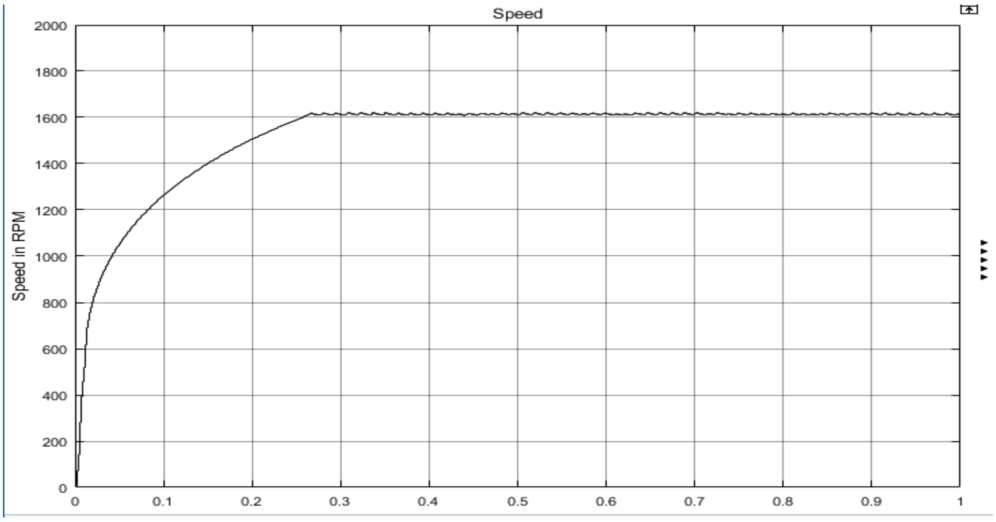

Figure 16 Speed vs Time Characteristics

Specification of SRM used in Simulation is given below.
Power =60kW
Unaligned Inductance =0.67mH
Aligned Inductance=23.6mH
Maximum current=450A
Maximum flux linkage=0.489V.s
Converter Voltage=240V

4 Results And Discussion

Results of the entire simulation diagram are compared and consolidated and given in Table 1.It is observed form the table that Asymmetric bridge converter fed open loop SRM has the highest torque ripple coefficient, its Coefficient value is 3.07.PID controller fed SRM has less torque ripple compared to open loop circuit. Asymmetric converter fed closed loop switched reluctance motor drive system gives comparatively lesser torque ripple than the previous two circuits. But N+1 switch per phase converter fed SRM has least torque ripple coefficient compared to all the circuits proposed. Results of all the above mentioned converter and controller fed SRM are synthesized and the comparison is shown in Table 1

Table1. Results of comparison

Methods	T_{max}	T_{min}	T_{avg}	Torque ripple coefficient
Asymmetric bridge converter fed open loop SRM	70	3	21	3.07
Asymmetric bridge converter fed SRM using PID controller	110	10	60	1.67
Asymmetric converter fed closed loop SRM	146	31	108	1.06
N+1 switch per phase converter fed SRM	110	90	100	0.212

5 Conclusion:

Torque ripple is the main disadvantage in Switched reluctance motor drive system which makes it unsuitable for High speed Industrial applications. Many investigations are going on, in reducing the torque ripples in the SRM. Number of techniques has been reported in the Literature. In this paper, four different techniques have been implemented in SRM, and the results are compared. Performance evaluation has been done based on the output obtained by simulating the proposed circuits in MATLAB .From the results, it is decided that N+1 switch per phase converter fed SRM drive has given the better performance than other three established methods. By implementing the advanced non linear and intelligent controllers, the torque ripple can be reduced further.

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