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Open Loop and Closed Loop Performance of Switched Reluctance Motor with Various Converter Topologies

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ABSTRACT

Switched reluctance motor (SRM) is becoming popular because of its simple construction, robustness and low-maintenance. This motor is very useful for high speed applications because no windings are placed on rotor and can also be used for variable speed applications in industries. Converter is one of the important elements in SRM which plays a very crucial role. In this paper various converter topologies for 6/4 switched reluctance motor and Asymmetric bridge converter topology for 8/6 switched reluctance motor are discussed. Finally a closed loop for each converter topology is proposed. The converter topologies are simulated by using MATLAB/SIMULINK. Constant speed is achieved in closed loop control.

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1. INTRODUCTION

Switched reluctance motor is gaining much importance when compared with other motors like induction motors and permanent magnet synchronous motors. The advantages are better performance, low cost, higher efficiency and high fault tolerance [1]-[3]. Various types of converters are used for controlling the SRM drive.

The major drawback of SRM drive is large torque ripples. But this can be limited to a large extent by phase current overlapping. That’s why the converters which are used in SRM drive must have separate control for each phase. The torque ripples are reduced by phase current overlapping. One more reason for the torque ripples is that the stator currents fall before the reference current which takes place during the commutation of SRM phase current due to the back EMF. During the commutation process, the phase current reaches to zero after the reference current, that causes negative torque and more torque ripples will be produced. As the commutation ability of phase currents is increased the torque ripples will be reduced [4]. As shown in Figure 1 when the speed of SRM increases, the commutation of phase current interval is not reduced as required and this causes negative torque. The negative torque which is produced will create large torque ripples. To overcome this problem the commutation of phase current should be achieved more quickly. The converter has to be designed to achieve this. The torque production and efficiency is increased, if at turn on and turn off instants di/dt is more, so that the negative torque production will not takes place and the average torque produced by the motor is more.

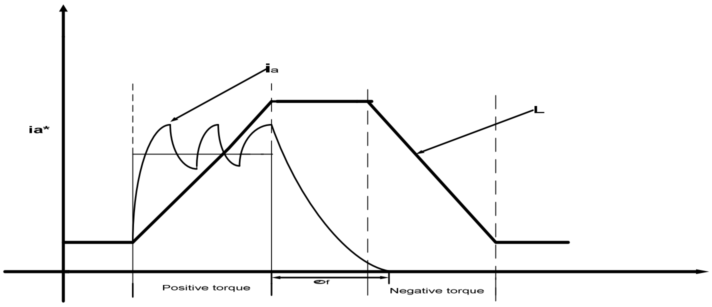

Figure 1. SRM phase inductance and current

The torque production and efficiency is increased, if at turn on and turn off instants di/dt is more, so that the negative torque production will not takes place and the average torque produced by the motor is more.

2. CONVERTERS

2.1. ASYMMETRIC BRIDGE CONVERTER

This converter consists of two power switches and two diodes per phase of SRM [1]**.** Here the numbers of elements used are more per phase. It is one of the major disadvantages of this converter. In this converter the two switches go off when the current exceeds the commanded current value. The energy stored in the motor winding keeps the current in the same direction until it is depleted. The two diodes then come in to action leading to recharging the source.

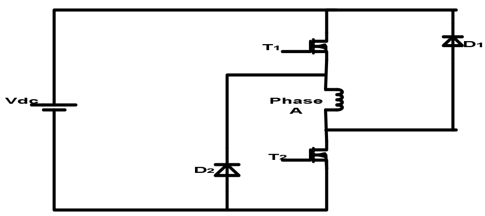

Figure 2. Asymmetric bridge converter per phase SRM

The major drawback is utilization of the power devices is very poor and the cost is also high. Figure 2 shows the asymmetric bridge converter for one phase of SRM.

2.2. R-DUMP CONVERTER

This low-cost converter was proposed by R.Krishnan [5]. The capacitor C value always depends up on the dump resistance R. Figure 3 shows the converter consisting of one diode and one switch per phase of the SRM. The switch T1 is on only when the current is below the commanded current value, otherwise the switch T1 is off. When switch T1 is off the diode D1 comes in to action. This similar process takes place for the remaining phases also. In R-dump converter the numbers of switches used are less compared to the asymmetric bridge converter.

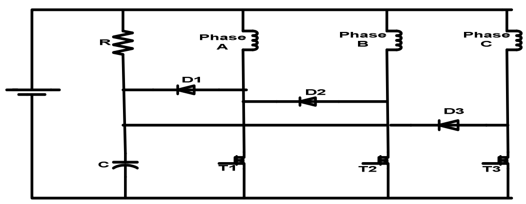

Figure 3. R-dump converter for three phase SRM

The major drawback is that phase inductor energy is wasted by the dump resistance, which leads to low overall efficiency of the drive.

2.3. C-DUMP CONVERTER

This low voltage dual decay converter for the SRM was proposed by Eshani etal [6]. In this converter the phase inductance energy is stored in capacitor. The energy loss of this converter is very less. So the overall efficiency is more when compared with R-dump converter. This converter is shown in Figure 4. In this converter the switch T1 is off when the current is above the commanded current value, then the diode D1 comes into action. Similar thing takes place for the remaining phases also. The c-dump converter also uses less number of switches compared with asymmetric bridge converter.

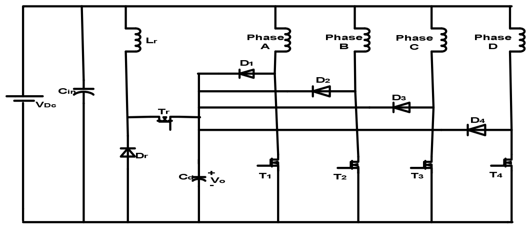

Figure 4. C-dump converter for three phase SRM

This c-dump converter consists of one more switch, this is one of the disadvantages and the other one is the reverse voltage is limited to $V_{dc} - v_o$, which is used for phase current commutation.

2.4. 3-LEVEL CONVERTER

Figure 5 shows the 3-Level converter for one phase of the SRM. This converter has three modes. They are fast demagnetisation (state 1), fast magnetisation (state 2) and magnetisation (state 3) [7]. Generally the fast de-magnetisation is done to reduce the phase current to zero in the shortest time possible after the aligned position and the fast magnetisation is done to increase the phase current according to the reference value in the shortest time possible. The fast magnetisation and fast-demagnetisation are done to reduce the torque ripple, to increase the positive torque and to reduce the copper losses. Here in this converter the turns ratio of coupled inductors depends up on the speed of the SRM drive.

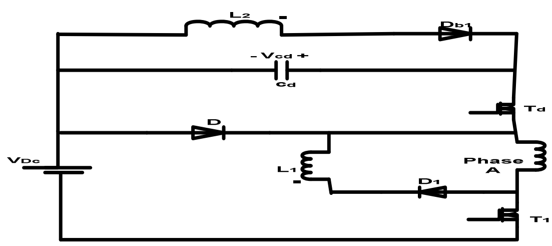

Figure 5. 3-Level converter per phase SRM

(a) Fast Demagnetisation:

In the Fast magnetisation mode the switch T1turns off and the diode D1 turns on and the diode Db1 turns on, the reverse voltage is present across the phase winding in proportion to the inductor turns ratio, which accelerates the phase current commutation.

(b) Fast Magnetisation:

In this mode switch T1 and switch Td turn on. The Dc link voltage i.e V_{Dc} and the dump capacitor voltage i.e V_{CD} are applied to phase winding and the phase current is built up quickly because of high voltage which is equal to $V_{DC} + V_{CD}$.

(c) Magnetisation**:**

In this magnetisation mode the switch T1 is turned on, and the energy is transferred from the source to the phase winding. Hence the current in phase inductance increases. The magnetising inductance of inductors is not reset in this mode and the diode D1 turns on. Then the magnetising inductance of the coupled inductors is reset, and then the diode D1 turns off. For other phases magnetizing inductance of coupled inductors is similar.

2.5. MILLER CONVERTER

The Miller converter consists of (N+1) switches, where N is the number of phases [8]. In this converter the upper switch is used to control the current while the lower switches are used for sensing the position of rotor with the help of sensor.

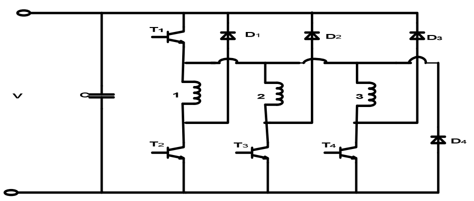

Figure 6. Miller converter for three phase SRM

Figure 6 shows the Miller converter for 3 phase SRM. When T1 and T2 are turned on the current flows through phase winding 1.When T2 is turned on and T1, T3 are turned on the current flows through phase winding 2.When T3 is turned off and T1, T4 are turned on the current flows through phase winding 3. The phase 1 and Phase 2 currents not reduce to zero when the drive is running at higher speeds because it freewheels through T1, D1 and T2, D2. Again when phases 1 is switched on the currents in phase 2 and phase 3 not reduce to Zero. The negative torque and the excessive heat in the windings are produced because the current in each phase reduces to zero at higher speeds. The phase shifts between adjacent legs during the normal operation. But the frequency of transition is so high at higher speeds, that the phase current does not drop to zero before the next turn on, and the current goes on rising in the phase windings.

2.6. MODIFIED POWER CONVERTER

The number of devices of modified power converter is less than asymmetric bridge converter and more than Miller converter [8]. The Overlapping of phase currents problem has been improved, since the current in phase winding reach to zero. Here in this converter also, the upper switches are used to control the current and the lower switches are used for position sensing of rotor.

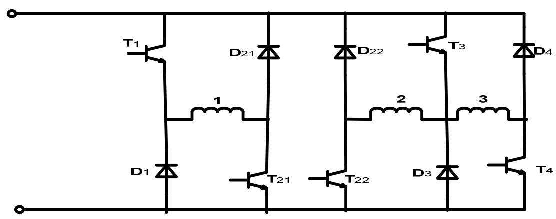

Figure 7. Modified power converter

The Modified power converter is shown in Figure 7. When the switches T1 and T21 are turned on the current flows through phase1. When T1 and T21 are turned off and T22, T3 are turned on the current flows through phase 2 and the current in the phase 1 reduces to zero through D21 and D1.When the switch T22 is turned off and T3, T4 are turned on the current flows through phase 3 and the current in the phase 2 does not reduce to zero. It freewheels through T3 and D22.when the phase 1 is switched on the current in phase winding 3 and phase winding 2 reduce to zero. Here only the current in phase 2 will take some time to reduce to zero. In this converter all phase currents will reduce to Zero.

3. SIMULATION RESULTS

The simulation of the converters is done in MATLAB/SIMULINK. Here the simulation of every converter is done in two configurations.

a) Open loop configuration

In this configuration the speed error cannot be processed because here no controller has been used. so the torque cannot be limited and hence the current also cannot be limited.

b) Closed loop configuration

In this configuration the speed error is processed through proportional integral (PI) controller and the limiter yields the torque command and from the torque command the current command is obtained. In this case the torque and speed are controlled as desired.

3.1. ASYMMETRIC BRIDGE CONVERTER

Case 1: Open loop model of Asymmetric bridge converter

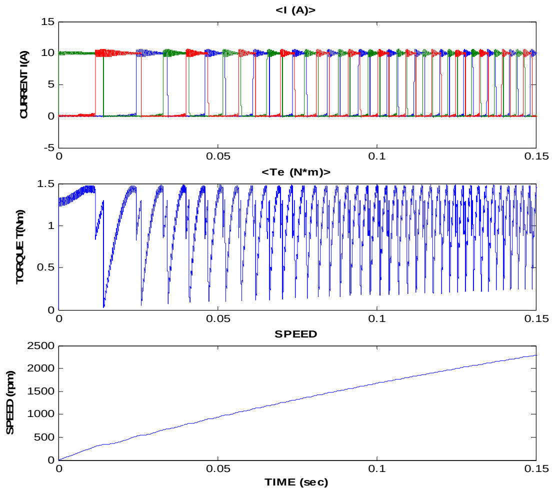

Figure 8. Simulation results show the Phase currents, Torque, Speed of Asymmetric bridge converter in open loop configuration of 6/4 SRM

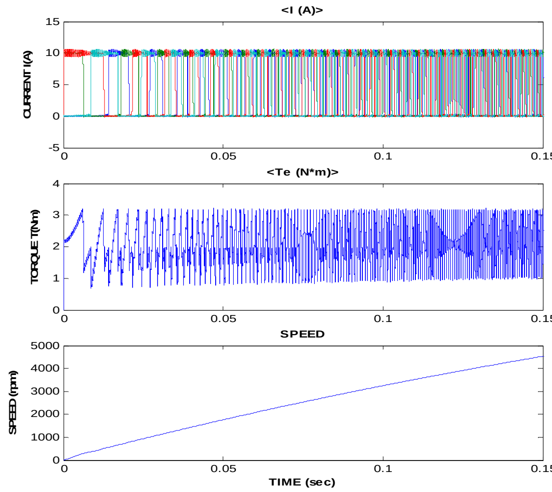

Figure 9. Simulation results show the phase currents, Torque ,Speed of asymmetric bridge converter in open loop configuration of 8/6 SRM

Case 2: Closed loop model of Asymmetric bridge converter

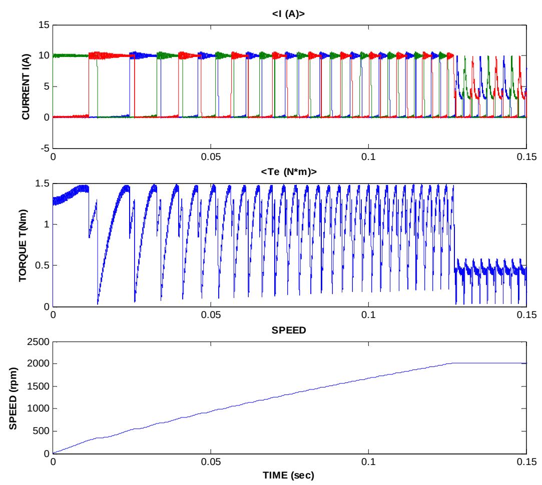

Figure 10. Simulation results show the Phase currents, Torque, speed of asymmetric bridge converter in closed loop configuration of 6/4 SRM

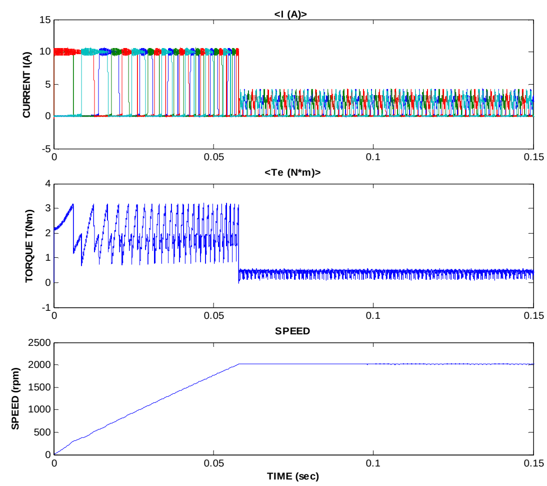

Figure 11. Simulation results show the Phase currents, Torque, Speed of Asymmetric bridge converter in closed loop configuration of 8/6 SRM

3.2. R- DUMP CONVERTER

Case 1: Open loop model of R-dump converter

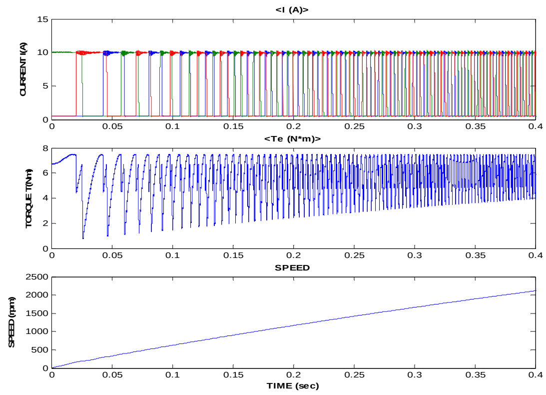

Figure 12. Simulation results show the Phase currents, Torque, Speed of R-dump converter in open loop configuration of 6/4 SRM

Case 2: Closed loop model of R-dump converter

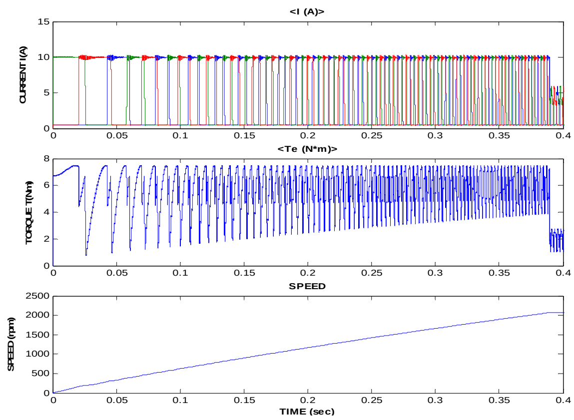

Figure 13. Simulation result show the phase currents, Torque, speed of R-dump converter in closed loop configuration of 6/4 SRM

3.3. C-DUMP CONVERTER

Case 1: Open loop model of C-dump converter

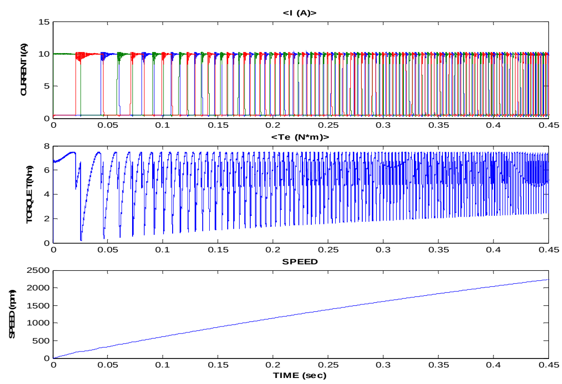

Figure 14. Simulation results show the phase currents, torque, speed of C-dump converter in open loop configuration of 6/4 SRM

Case 2: Closed loop model of C-dump converter

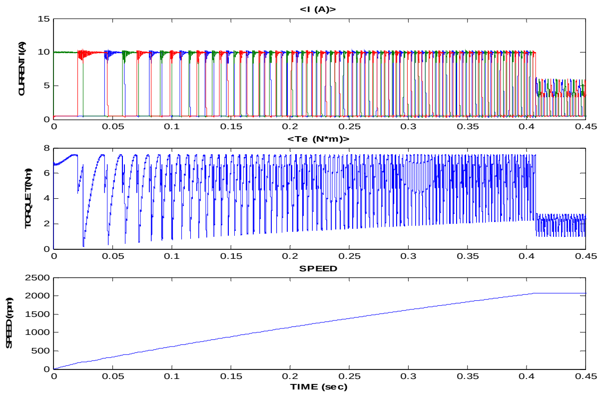

Figure 15. Simulation results show the Phase currents, Torque, Speed of C-dump converter in closed loop configuration of 6/4 SRM

3.4. 3-LEVEL CONVERTER

Case 1: Open loop model of 3-Level converter

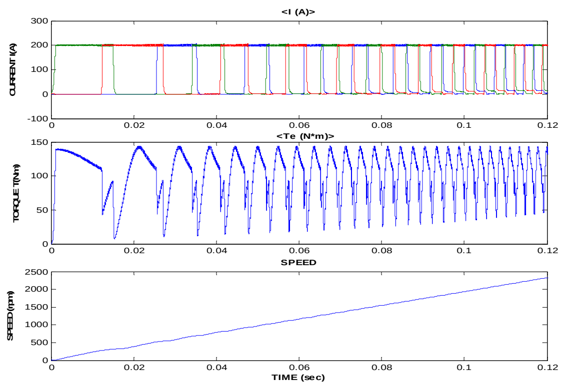

Figure 16. Simulation results show the Phase currents, Torque, Speed of 3-Level converter in open loop configuration of 6/4 SRM

Case 2: Closed loop model of 3-Level converter

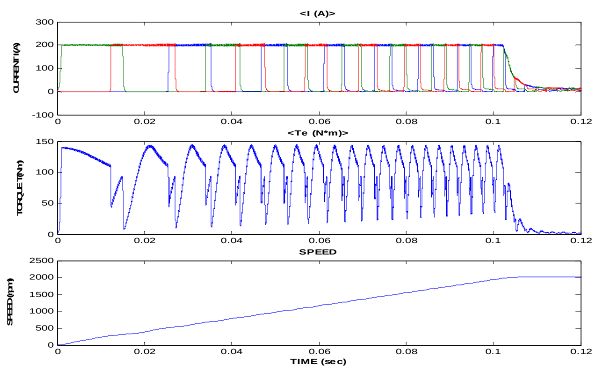

Figure 17. Simulation results show the Phase currents, Torque, Speed of 3-Level converter in closed loop configuration of 6/4 SRM

3.5. MILLER CONVERTER

Case 1: Open loop model of Miller converter

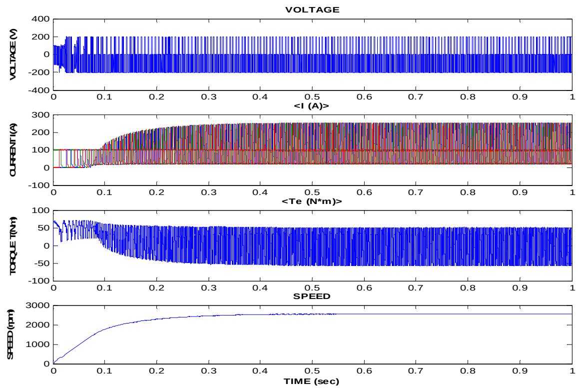

Figure 18. Simulation results show the Voltage, Phase currents, Torque, Speed of Miller converter in open loop configuration of 6/4 SRM

Case 2: Closed loop model of Miller Converter

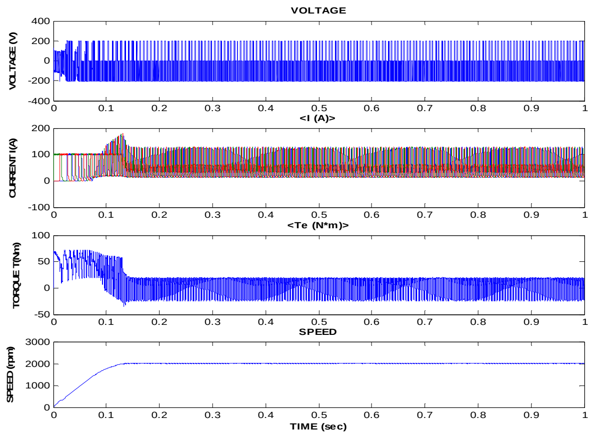

Figure 19. Simulation results show the Voltage, Phase currents, Torque, Speed of Miller converter in closed loop configuration of 6/4 SRM

2.6. MODIFIED POWER CONVERTER

Case 1: Open loop model of Modified power converter

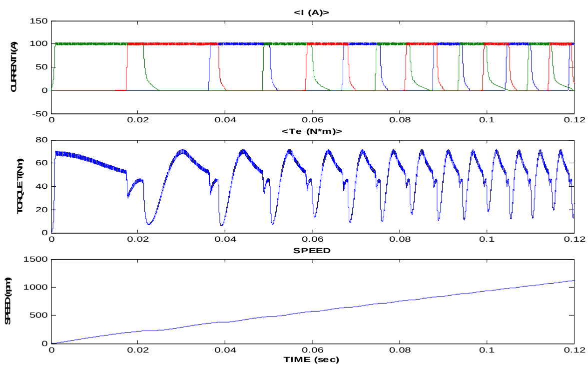

Figure 20. Simulation results show the Phase currents, Torque, Speed of Modified power converter in open loop configuration of 6/4 SRM

Case 2: Closed loop model of Modified power converter

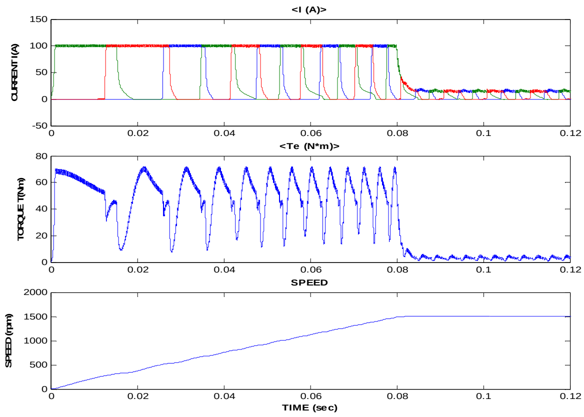

Figure 21. Simulation results show the Phase currents, Torque, Speed of Modified power converter in closed loop configuration of 6/4 SRM

3. CONCLUSION

In this paper various converter topologies for switched reluctance motor have been discussed. Closed loop performance of each converter system is obtained through simulation. In the closed loop configuration the proportional Integral controller has been used for fast response and error minimising. In closed loop configuration the torque and the current could be limited and we could run the motor at a particular speed where as it is not possible in open loop configuration. The torque ripples are also very less in closed loop configuration.

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