

New Converter for Switched Reluctance Motor Drive With Wide Speed Range Operation

Adel Deris Zadeh

Department of Electrical Engineering
Islamic Azad University – Najaf Abad Branch
Esfahan, Iran
adel_deriszadeh@iaun.ac.ir

Ehsan Adib, Hosein Farzanehfar and Seyed Mortaza
Saghaian-Nejad

Department of Electrical and Computer Engineering
Isfahan University of Technology
Esfahan, Iran
e.adib@cc.iut.ac.ir, hosein@cc.iut.ac.ir,
saghaian@cc.iut.ac.ir

Abstract—This paper offers a new converter for switched reluctance motor (SRM) drive which uses one switch in each phase. One switch for each phase is the least number of switches among the converters used in the switch reluctance motor drive. Also, the proposed converter enjoy from an important characteristic which makes it suitable for high speed drive applications. This is due to the fast phase current commutation capability of this converter. Therefore, the generation of negative torque and consequently, large generated torque ripples in SRM drive are resolved. SRM drive simulation using the proposed converter is presented and the results are compared with the asymmetric converter which is usually used in SRM drives.

Keywords- switched reluctance motor drive, fast commutation.

I. INTRODUCTION

Switched reluctance motor (SRM) drive technology has remarkably developed in the past two decades. The interest over SRM is due to its advantages over the induction motor or permanent magnet synchronous motor. These advantages include lower price, boosted performance, equal or better reliability, comparable or better efficiency, lower volume and ease of production and storage in comparison to AC and DC motor drives [1-3].

SRM drive has the crucial problem of large torque ripples due to lack of continuity in the generated torque. But this can be mitigated to a great extent by phase current overlapping. Therefore, the converters used for SRM drive requires separate control for each phase so that the torque ripples can be reduced by phase current overlapping. Another reason for torque ripples is that the stator current falls behind the reference current during the commutation of each SRM phase current because of back EMF. This means that during commutation, the phase current reaches zero after the reference current which causes negative torque and more ripples in the torque produced by the motor. Thus, the converter used in the SRM drive must have the quick commutation ability of phase currents, which will reduce torque ripples considerably. This is more important at higher speeds where commutation interval is very short. As shown in

Fig. (1), when SRM speed increases, if phase current at commutation interval is not reduced to zero, a negative torque would be produced.

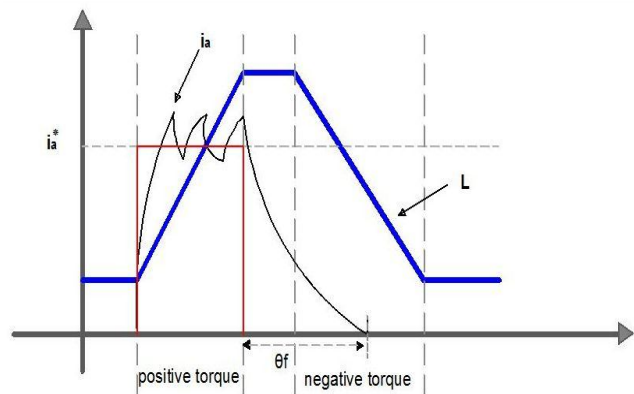


Fig. 1. SRM phase inductance and current.

The produced negative torque will create large torque ripples in SRM. To solve this problem, the converter used for SRM drive needs to be designed in such a way that it can perform phase current commutation more quickly. Major research has been carried out with this aim [3-13]. For example, Krishnan et al. [4] proposed a low cost converter with a dump resistance to waste commutation energy. In this converter the voltage across capacitor C, depends on the value of dump resistance and can provide fast commutation. The schematic of this converter is shown in Fig. 2. The advantage of this converter is the single switch used in each phase which results in smaller size and lower cost. The disadvantage of this converter is that the phase inductor energy is basically wasted in a resistance resulting in low overall efficiency of the drive. Ehsani et al. [5] have proposed a low voltage dual-decay converter for the SRM drive. This converter offers less energy losses and consequently, higher efficiency in comparison to the R-dump converter. The C-dump converter was proposed in [6-8]. The difference between this converter and the previously described

converters is that it stores the phase inductance energy in a capacitor rather than dissipating it in a resistance. This converter is shown in Fig. (3). The disadvantage of this converter is that an extra switch is used in its topology. Also, the reverse voltage used for the phase current commutation is limited to $V_{dc}-V_o$. The references [9-13] offer a variety of SRM drive topologies to reduce the commutation interval in order to solve the torque ripple problem and improve the performance at higher speeds. However, in all these converters, either the number of elements used has increased or the commutation process is not fast enough. A new converter for switched reluctance motor drive is proposed in this paper, which uses only one switch for each phase in its structure. It performs the commutation process with high speed which provides excellent drive performance at higher speeds.

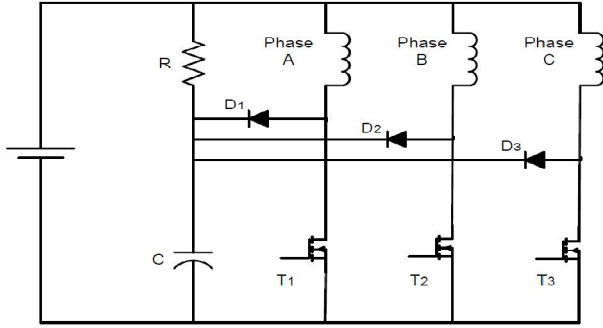


Fig. 2. R-dump converter.

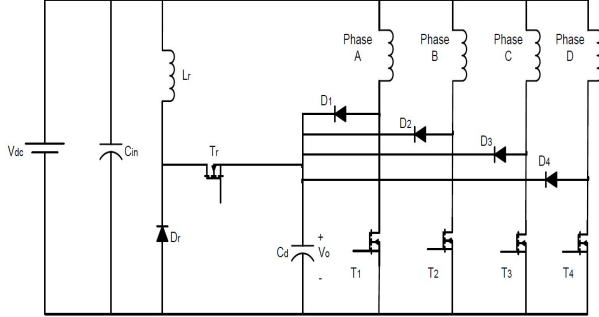


Fig. 3. C-dump converter.

II. PROPOSED SRM DRIVE CONVERTER

A. Converter Topology

Fig. (4) shows the per phase structure of the proposed SRM drive topology. The converter operation is simple with a minimum number of switches while performing phase current commutation quickly. Regarding the number of switches used, the converter is similar to the R-dump converter, and it functions like the C-dump converter since the phase inductance energy is recovered. In fact, in addition to its simple structure, this converter has higher efficiency than the

R-dump converter and a simpler structure and higher phase current commutation speed than the C-dump converter.

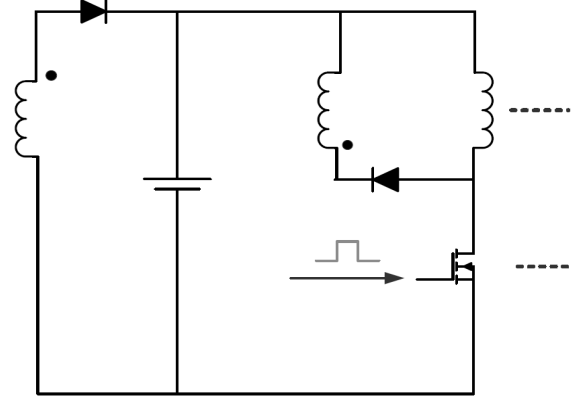


Fig. 4. Proposed SRM per phase converter

Fig. (5) shows the operating modes of this converter for 2 phase SRM. As shown in Fig. (5-a), in the magnetization mode, the switch T1 turns on in order to magnetize phase 'a'. As T1 turns on, the energy is transferred from the source to phase winding and the current in phase inductance increases. Also, in this mode if the magnetizing inductance of coupled inductors is not reset yet, diode D1 would conduct the magnetizing inductance current of the coupled inductors and the input voltage would reset this inductor. When the magnetizing inductance of coupled inductors is reset, Diode D1 turns off. The reset of coupled inductors magnetizing inductance is similar for other phases.

When the phase current reaches the reference, T1 is turned off and demagnetization starts. This mode is shown in Fig. (5-b). Since the voltage across phase winding is reversed, diode D1 turns on in this mode. When D1 turns on, Db1 turns on and a negative voltage is placed across the phase winding in proportion to the coupling ratio which accelerates phase current commutation. Fig. (5-c) and Fig. (5-d) show two overlapping modes of stator phase currents. In the first mode, the phase inductance 'a' is being demagnetized and phase 'b' is being magnetized. In the second mode, both 'a' and 'b' phases are being demagnetized. As it can be observed, this converter has the ability to separately control phase currents. Also, It is important to notice that the snubber circuit of each switch will absorb the voltage spikes across the switches that otherwise would occur due to leakage inductance of coupled inductors.

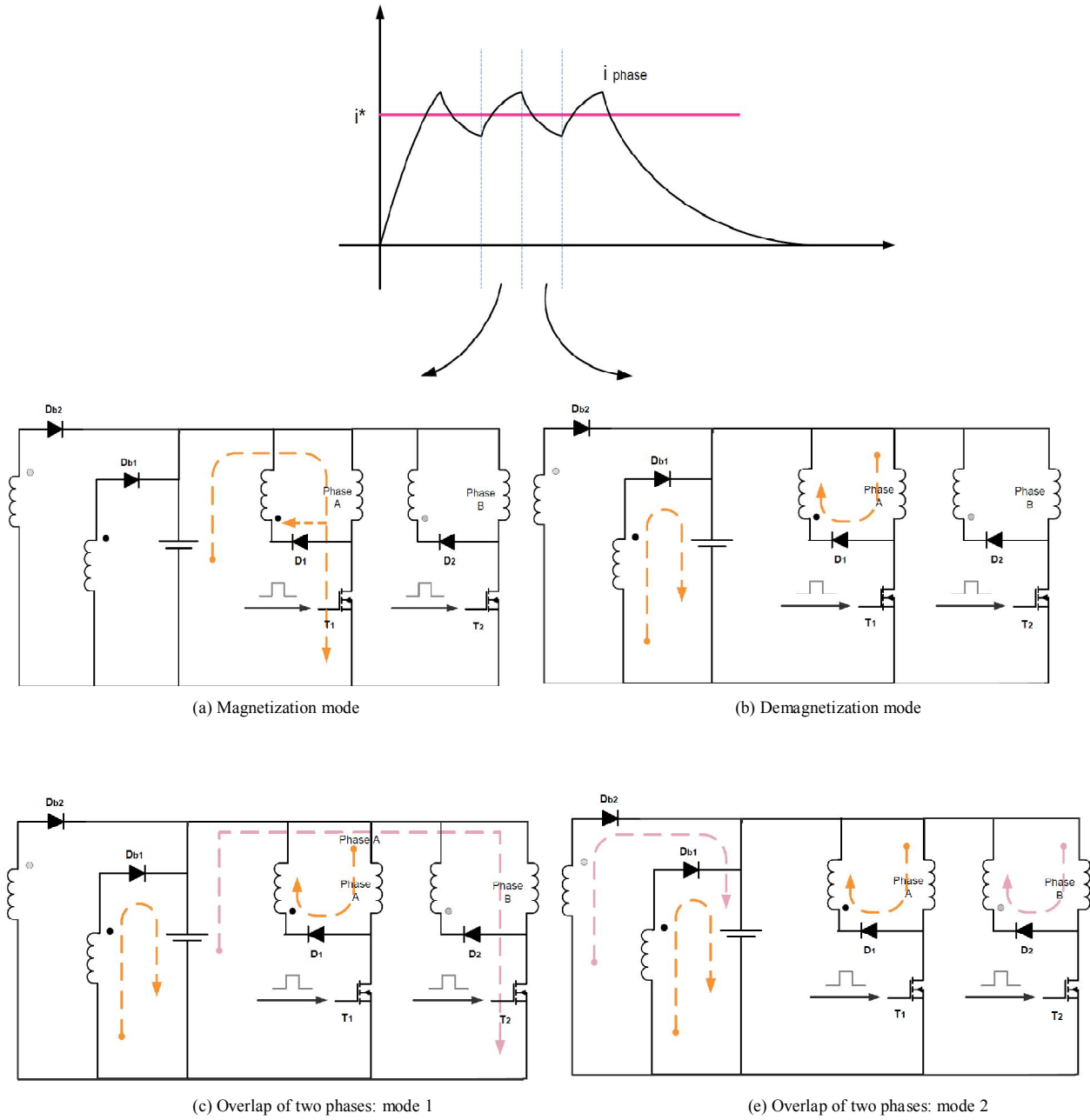


Fig. 5. Operating modes of the proposed converter

B. DESIGN CONSIDERATIONS

For designing this converter, the coupled inductors ratio has to be determined considering the performing speed of the drive. As shown in Fig. (1), if the phase current does not reach zero fast enough during the commutation, the phase current continues to exist in the negative torque production area and the phase torque becomes negative. This negative torque will cause large ripples in the torque generated by the

motor. This is especially important at higher speeds, because higher speed requires faster commutation. So, each SRM drive can function to an extent of speed with regard to its converters structure. The maximum SRM drive speed depends on the type of converter used and is illustrated by the following equation.

$$T_f = \tau_a \ln \left[1 + \frac{R_s I_p}{V_c} \right] \quad (1)$$

where T_f is the time needed for the current to reach from reference value to zero, τ_a is the electrical time constant of machine phases, R_s is the resistance of each phase winding, V_c is the reverse voltage applied to the phase inductance during commutation. The electrical time constant equation of the machine is as follows.

$$\tau_a = \frac{L_a}{R_s} \quad (2)$$

As shown in Fig. (1), the phase inductance at the current commutation area equals to aligned inductance, thus L and τ would take an “a” subscript. Current drop angle at speed ω is shown as θ_f in Fig. (1) and is calculated as follows.

$$\theta_f = \omega_m T_f = [\omega_m \tau_a] \ln \left[1 + \frac{R_s I_p}{V_c} \right] \quad (3)$$

As it can be observed from (3), when speed increases, θ_f becomes larger resulting in a larger negative torque and, consequently, more torque ripples. Therefore, it is needed to look for a way to reduce θ_f at higher speeds. As it can be observed from (3), commutation can be carried out faster by increasing V_c . In the proposed converter, the reverse voltage across the phase winding can be increased for faster commutation purposes by increasing the coupled inductors $L1$ and $L2$ turns ratio. Also it is important to notice that V_c is constant in most of the converters introduced so far. But, in this converter, V_c can be designed by changing the coupled inductors turns ratio considering the maximum SRM drive functioning speed.

III. SIMULATION RESULTS

In this section, the simulation results of SRM drive using the proposed converter is compared to the results of a SRM drive that uses a regular asymmetric converter. The schematic of this converter is shown in Fig. 6.

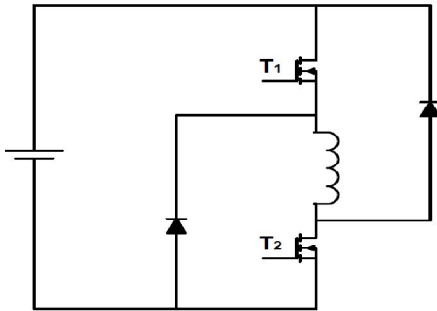


Fig. 6. Asymmetric converter

For simulation purposes coupling ratio is selected 2.3. Figure (7) shows the SRM phase currents that are driven by a regular asymmetric converter at 1500 rpm. Figure (8) shows the phase currents of the same motor at 4000 rpm.

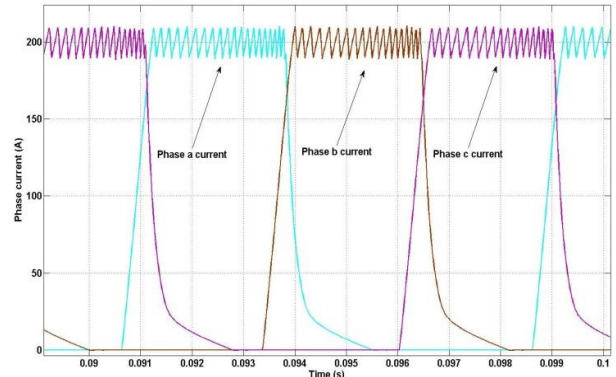


Fig. 7. Phase current waveforms of SRM driven by asymmetric converter at 1500 rpm.

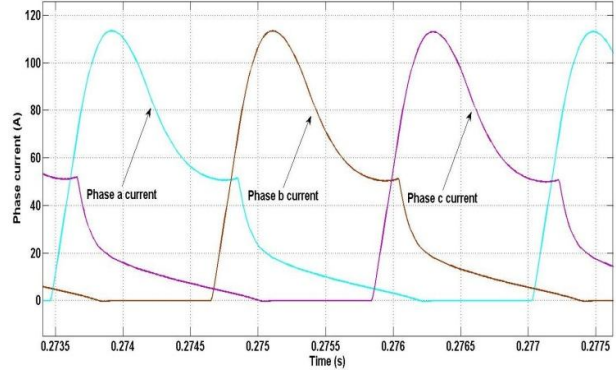


Fig. 8. Phase current waveforms of SRM driven by asymmetric converter at 4000 rpm.

As explained before, and also shown in Fig. 7 and Fig.8, the angle θ_f becomes larger as speed increases. Consequently, causes more torque ripples. Fig. 9 and Fig. 10 show the results of the SRM driven by the proposed converter.

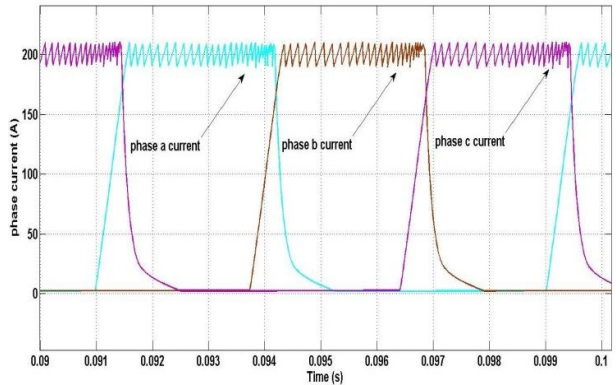


Fig. 9. Phase current waveforms of SRM driven by proposed converter at 1500 rpm.

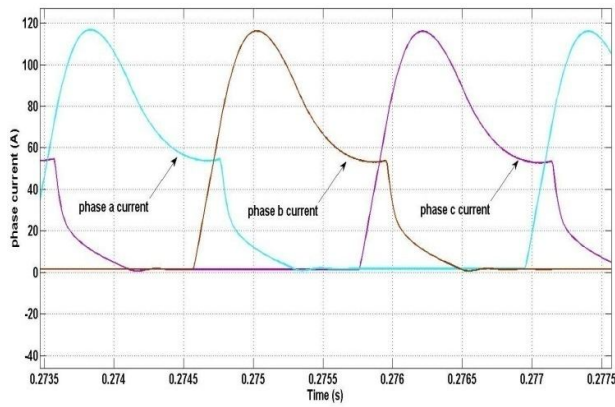


Fig. 10. Phase current waveforms of SRM driven by proposed converter at 4000 rpm.

As shown in Fig. 9 and Fig. 10, the commutation time has considerably decreased. For a better view of the commutation speed difference between the converters, the current waveforms of both drives are compared in Fig. 11.

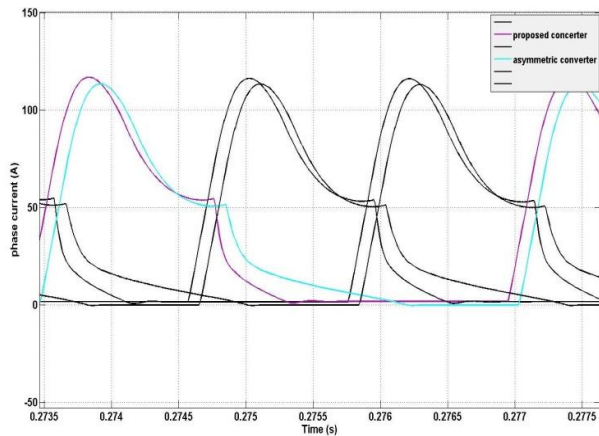


Fig. 11. Comparison between current waveforms of both drives at 4000 rpm.

In the simulation of each switch, a turn off snubber is used. Fig. 12 shows the switch current and voltage waveforms.

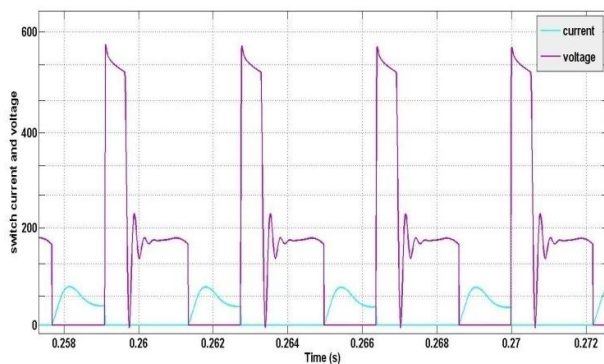


Fig. 12. Voltage and current waveforms of one switch.

IV. Conclusions

In this paper a new SRM drive is introduced. The proposed converter is analyzed and its operating modes are discussed. The proposed converter only uses one switch for each motor phase. Also, in the proposed converter the phase inductance energy is recovered to achieve high efficiency. Simulation results are presented to justify the validity of the theoretical analysis.

REFERENCES

- [1] R. Krishnan, "Switched Reluctance Motor Drives: Modeling, Simulation, Analysis, Design, and Applications," *CRC Press*, 2001.
- [2] Eyhab, E. Kharashi, "Design and Analysis of Rolled Rotor. Switched Reluctance Motor," *Journal of Electrical Engineering and Technology*, Vol. 1, No. 4, pp. 472-481, 2006.
- [3] M. N. F. Nashed, K. Ohyama, K. Aso, H. Fujii, H. "Automatic Turn-off Angle control for High Speed SRM, Eds. Drives," *Journal of Power Electronics*, Vol. 2, No. 1, pp. 81-88, 2007.
- [4] R. Krishnan, P.N. Materu, "Analysis and design of a low-cost converter for switched reluctance motor drives," *IEEE Transactions on Ind Appl*, Vol.29, No.2, pp. 320-327, 1993.
- [5] M. Ehsani, I. Husain, K.R. Ramani, J.H. Galloway, "Dual-decay converter for switched reluctance motor drives in low-voltage applications," *IEEE Trans. Power Electron*, Vol.8, No.2, pp. 224-230, 1993.
- [6] Miller, T.J.E, "Converter volt-ampere requirements of the switched reluctance motor drive," *IEEE Trans. Ind. Appl.*, Vol. 21, No. 5, pp. 1136-1144, 1985.
- [7] Ehsani, M., J.T. Bass, T.J.E. Miller, and R.L "Steigerwald, Development of a unipolar converter for variable reluctance motor drives," *IEEE Trans. Ind. Appl.*, Vol. 23, No. 3, pp. 545-553, 1987.
- [8] Miller, T.J.E. et al, "Regenerative Unipolar Converter for Switched Reluctance Motors Using One Switching Device per Phase," *U.S. Patent*, No. 4, 684,867, Aug. 4, 1987.
- [9] H. Farzanehfard, R. Krishnan, "A fully controlled converter for switched reluctance motor," *Proc. VPEC Ann. Sem.*, Nov. 4, Virginia Tech., Blacksburg, VA, 1986.
- [10] R. Hamdy, "Bidirectional starting of a symmetrical two-phase switched reluctance machine," *IEEE Trans. Energy Convers.*, vol. 15, No. 2, pp. 211-217, Jun. 2000.
- [11] CS. Edrington, M. Krishnamurthy, B. Fahimi, "Bipolar switched reluctance machines: a novel solution for automotive applications," *IEEE Trans Vehicular Technol*, Vol.54, No.3, pp. 795-808, 2005.
- [12] Z. Grbo, S. Vukosavic, E .Levi, "A novel power inverter for switched reluctance motor drives," *Facta Universitatis (Nis). Ser: Elec Energ*. vol. 18, no. 3, pp. 453-465, December, 2005.
- [13] J. Liang, D.-H. Lee, J.-W. Ahn, "Direct instantaneous torque control of switched reluctance machines using 4-level converters," *IET Electric Power Appl*, Vol.3, No.4, pp. 313-323, 2009.