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Comparative Control Strategy of Asymmetric Bridge Converter For Switched Reluctance Motor

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ABSTRACT

Switched Reluctance Motor has many advantages such as high efficiency, starting torque and reliability, simple construction, robustness, and low maintenance become the best achievement of this motor, but there is still major drawback like large torque ripple, acoustic noise and vibration. This paper present the comparative strategic in controlling of Switched Reluctance Motor using asymmetric bridge converter base on magnetizing-demagnetizing mode and magnetizing-freewheeling mode applied on 6/4 Switched Reluctance Motor using Matlab/Simulink. The comparison between the magnetizing demagnetizing and magnetizing freewheeling started with increasing the turn on angle while keep the turn off angle constant and run the simulation until the highest speed reached, then the turn on angle kept constant while the turn off angle increased until high speed reached. The result of the paper is that the asymmetric bridge converter under magnetization demagnetizing achieve better performance in reaching higher speed, and more efficient since draw the smaller current, and the top speed catch earlier compare to the magnetizing freewheeling mode.

CCS Concepts

• Hardware→Electronic design automation→Modeling and parameter extraction

Keywords

Switched reluctance motor; asymmetric bridge; magnetizing; demagnetizing; freewheeling.

1. INTRODUCTION

The increasing consciousness in keeping environment better and in order to reduce emission especially from internal combustion engine vehicle and improving fuel economy, the automotive companies developing electric vehicle, hybrid vehicle, and plug in hybrid electric vehicle[1]. The challenge is to achieve higher efficiency, smaller size, ruggedness and low cost in operation. The battery and electric motor together with the power converter become the major part of the electric vehicle. One of the electric motor is Switched Reluctance Motor, this electric motor has many advantages such as simple construction, cheaper in manufacturing, robustness, less maintenance, and high reliable [2],[3]. This motor has been demonstrated to be applicable in number of application, both industrial and road traction [4]. Beside those achievement there are also some weaknesses, the torque ripple because of switching process and acoustic noise since the construction of switched reluctance motor consist of two salient pole both stator and the rotor[5][6]. Application of electric drive in the electric vehicle require high torque, smooth and better efficiencies, improving design of both stator and rotor also can be reach those requirement[7]. The construction of switched reluctance motor is simple in geometry which rotor has no winding or permanent magnet which leads to robust and low maintenance, low production cost and operated at higher speed[8]. The stator is similar to Brushless Direct Current. Converter used to create commutated voltage across stator winding to energize the stator phase. The converter also regulate the motor performance to indicate the switching time on and off that need rotor position sensor or using either sensor or sensor less control procedure [9]. Performance of the switched reluctance motor depends upon the suitable position of the current relative to the rotor position. Suitable positioning of current relative to position of the rotor determine the optimal performance of switched reluctance motor [10][11]. There are some different types of converter to meet the higher torque, reduce switching loss [9], and some different converter are used to obtain better performance of switched reluctance motor drive by minimizing torque ripple [10], reduced switches to minimize the number of switch from standard converter [7]. The asymmetric bridge converter has ability to be independently controlled between each switch, and the three mode of operation can be used to reduce the switching loss, increase the efficiency and improve the average torque of switched reluctance motor [9]. The torque of switched reluctance motor produced because the tendency of the rotor to make parallel with exited phase. The direction of rotation is a function of rotor position corresponding with energized phase, it does not depend on direction of flowing current from each winding. Then each excitation phase shifting from side to side to produce continuous

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torque. This can be done with converter from power electronic switches. In comparative performance analysis of SRM using converter technology prove that asymmetric bridge converter has more ripple compare to miller converter [3]. The control strategy has capability to operate the asymmetric converter in lower frequency and higher efficiency [9]. The simulation of SRM based on Matlab/Simulink environment have proved that the influence of the turn-off angle in its dynamic behavior dependent on the machine's operating point and that exists a turn off angle value, which allow torque ripple reduction [12].The converter become the major role in switched reluctance motor that is why this paper emphasis on comparative controlling strategy on asymmetric bridge converter in order to achieve better torque, efficiencies and higher speed using Matlab/Simulink.

2. EQUIVALENT CIRCUIT OF SWITCH RELUCTANCE MOTOR

The equivalent circuit consist of resistance and inductance with some condition. The effect of magnetic saturation, fringing flux around the pole corners, leakage flux and mutual coupling are not considered. The voltage equation can be derived as :

$$V = R.i + e(\theta.i) = i + \left(\frac{d\lambda(\theta,i)}{dt}\right) \ldots\ldots (1)$$

Switched reluctance motor equivalent circuit shown in Figure 1. Where V is the applied voltage to phase, R is the resistance, i is the current and e is back EMF, ordinary e is a function of phase current and rotor function, and λ can be express as the product of inductance and winding current [12].

$$T = \frac{1}{2} i^2 p \left(\frac{dL(\theta)}{d\theta}\right) \ldots\ldots\ldots (2)$$

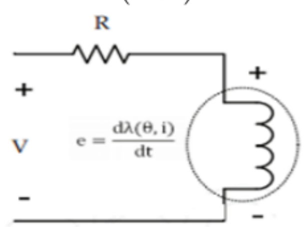

Figure 1. Switched reluctance motor equivalent circuit.

The equation (2) show the slope of phase winding inductance and the instantaneous value of phase current that produce the torque. If the profile of phase winding inductance is assumed linear, the motor torque will determined by the square of the phase current. The switched reluctance motor converter must be capable to excite the phase winding when the phase inductance is positive and cut the phase current soon as the slope of inductance begin to be negative. The higher value of developed torque can be reach when there is synchronization between phase current excitation and the rotor position.

The torque generated in the switched reluctance motor is proportional to the square of phase current and the slope of the inductance that controlled by drive circuit. The converter topology created in order to reduce the number of switch, higher efficiency, faster magnetization and demagnetization etc. Because the torque is proportional to the square current and not current direction, and because polarity of torque changed due to the slope of inductance therefore a negative torque is produced according to the rotor position [13] as seen in Figure 2. To propel the rotor then switching excitation must be synchronized with rotor position angle. From Figure 2 the inductance profile classified into increasing (θ min1 to θ max1), constant region (θ max1 to θ max2) and decreasing region (θ max2 to θ min2)[13].

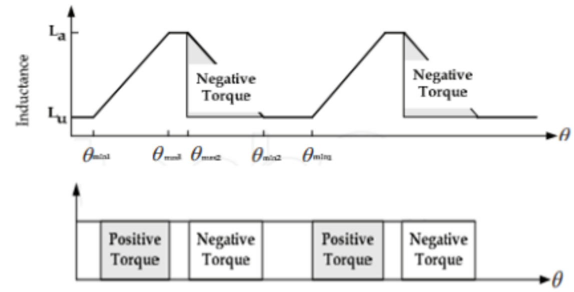

Figure 2. Inductance profile.

3. TYPE OF CONVERTER

To give sequential excitation to the phase stator use the static converter. Here in this paper use the asymmetric bridge converter topology, that have the ability to be controlled independently between each switches in order to meet the best performance, higher torque and faster rotation. The topology of this converter for 6/4 switched reluctance motor are 3 phase converter and consist of two switches, two diode for each phase. This converter can be operated in three mode, magnetizing, demagnetizing or freewheeling. Figure 3. show this converter topology[9].

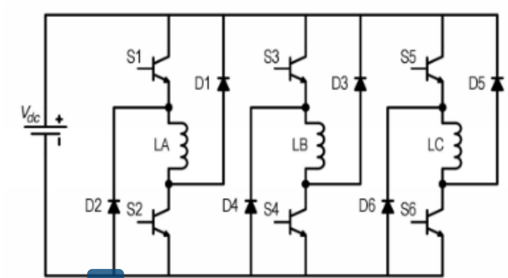

Figure 3. Three phase asymmetric bridge converter.

For the mode of operation magnetizing in Figure 4. (left side) explain magnetizing process when both the switch S1 and S2 are closed, than the current flows through inductance LA and make the inductance absorbs the energy (magnetize) and this will energize the phase A of the motor (the magnetizing mode).

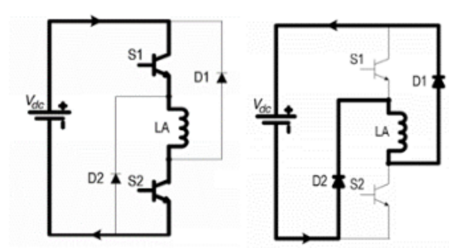

Figure 4. Magnetization and demagnetization mode.

And when the switches S1 and S2 are open, than the current stop to flow, and the rest of energy in inductance will continue to flow through diode D1, V dc and diode D2. This step called demagnetizing mode, this step will sent back the energy to the DC source through the diodes. This demagnetizing step also used to minimize the negative torque that produce by decreasing slope of the inductance as seen on Figure 4 (right side). The freewheeling mode is the next step after the magnetizing mode. See Figure 5, after magnetizing mode (S1 and S2 conduct) so the switch S1 turn to open but the switch S2 is still closed this will make the circular current flows through D2 and the decreasing slope of the inductor. Here in this paper will make a comparison between the magnetizing demagnetizing and the magnetizing freewheeling mode.

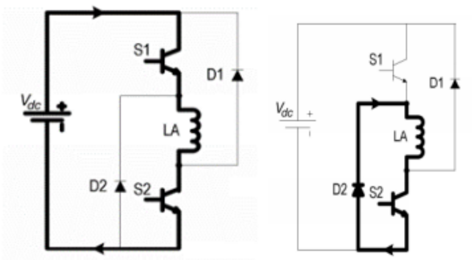

Figure 5. Magnetization and freewheeling mode.

4. CONTROL STRATEGY

The comparison of control strategy verified using Matlab/Simulink in testing the on and off angle to find the highest speed. Start the turning on angle from 35 ° and turning off angle from 70 °, then running the simulation. After that increasing the turning on angle, while the turning off angle keep constant and running the simulation until high speed reached. And after the highest speed reached then the turning on will be kept constant while the turning off angle increase until high speed reached. After applied this method to both magnetizing demagnetizing and magnetizing freewheeling, then make comparison between the two mode.

4.1 Magnetizing Demagnetizing

The magnetizing mode start when switches S1 and S2 closed (see Figure 4), and the current flow to the inductor LA then energized, this will make induction slope increase. Then before fall to the negative torque (see Figure 2) switches S1 and S2 open, and current from inductor LA flow through diode D1 and D2 then dissipated (demagnetizing mode). The turn on angle setting start from 35 ° ,and turn off angles start from 70 ° then increase the turn on angle (the turn off keep constant) and until the highest speed reached, then increase the turn off angle (the turn on angle keep constant) until the highest speed reached.

4.2 Magnetizing Freewheeling

The magnetizing mode start when switches S1 and S2 closed (see Figure 5), and the current flow to the inductor LA then energized, this will make induction slope increase. Then before fall to the negative torque (see Figure 2) switches S1 open but S2 still closed and current from inductor LA flow through switch S2 then D2 and dissipated (freewheeling mode). Switch S2 then opened and the cycle continues. The turn on angle setting start from 35 ° ,and turn off angles start from 70 ° then increase the turn on angle (the turn off keep constant) and until the highest speed reached, then increase the turn off angle (the turn on angle keep constant) until the highest speed reached.

5. SIMULATION AND RESULT

The parameter used in this simulation has the same data both for magnetizing demagnetizing mode and magnetizing freewheeling mode. Time for every simulation running for 2 second, 40, 60, and 100 second. The display shows every 0.5 second record.

Table 1. SRM specification

Note	Amount	Unit
Number of rotor poles	4	
Number of stator poles	6	
Aligned inductance	23.6e-3	H
Unaligned inductance	0.67e-3	H
Saturated aligned inductance	0.15e-3	H
Stator resistance	0.05	ohm
Inertia	2	Kg.m.m
Friction	0.02	N.m.s
Maximum current	450	A
Maximum Flux Linkage	0.486	V.s

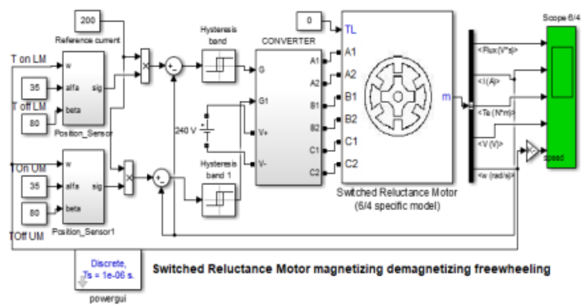

Figure 6. Block diagram SRM with asymmetric bridge converter.

5.1 Magnetizing Demagnetizing mode

Using Matlab/Simulink simulation program, the turn on angle started from 35 ° and off angel started from 70° and then step 1° to the turn off angel until the maximum speed reached. The simulation than continue with the step 1 ° to the turn on angle, become 36 ° and so on until the maximum speed reached. In this SRM starting simulation use the interval time every 2 second, and when the speed decreased or constant than the step stopped. And from magnetizing demagnetizing mode at the angle turn on 43° is get the maximum speed. While the turn off angle stopped at angle 90 ° and the speed of the motor reach 1307 rpm, while the torque average is 160.79 newton-meter. After extend the simulation time up to 40, 60, and 100 second than the details can be seen in Figure 7 and table 2.

Table 2. Result data for magnetizing demagnetizing mode

Time (sec)	V (volts)	Ia (amps)	Flux (mH)	Torque (N.m)	Speed (rpm)
2	237.99	211.11	450.64	161.12	1307
40	237.99	55.53	305.29	25.43	5337
60	237.99	51.55	290.95	22.91	5624
100	237.99	48.86	281.16	17.75	5838

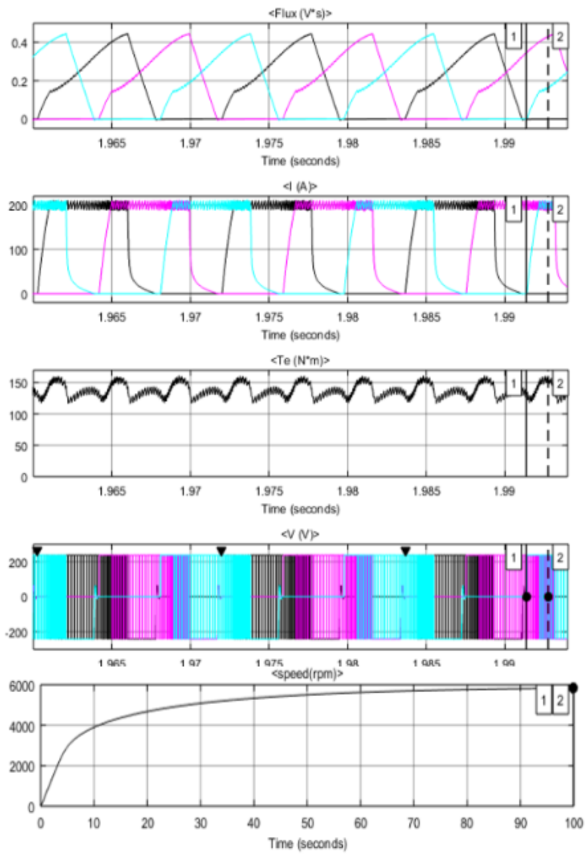

Figure 7. Simulink display of magnetizing demagnetizing mode (flux, current, torque, voltage, speed).

5.2 Magnetizing Freewheeling mode

With the same method as magnetizing demagnetizing mode, magnetizing freewheeling mode has different longer turn off angel for about 2° for every step of the simulation. For example when turn off angle set to be 87° for magnetizing demagnetizing, the freewheeling set at 90°. and the result from the simulation in magnetizing freewheeling mode the average speed of the motor reach 1306 rpm, less than magnetizing demagnetizing mode, while the torque average is 157.45 newton-meter. Details can be seen in Figure 8 and table 3.

Table 3. Result data for magnetizing freewheeling mode

Time (sec)	V (volts)	Ia (amps)	Flux (mH)	Torque (N.m)	Speed (rpm)
2	237.99	211.19	445.47	161.12	1297
40	237.99	59.74	319.37	25.43	5075
60	237.99	56.65	307.57	22.59	5296
100	237.99	53.89	299.92	21.27	5447

From table 2 and table 3 the simulation data measurement starting at 2 second, and then extended to 40, 60, and 100 second and we can see that the combination of magnetizing followed by demagnetization mode obtain the higher achievement for the speed 5838 rpm compare to the Magnetizing Freewheeling reach 5447 rpm.

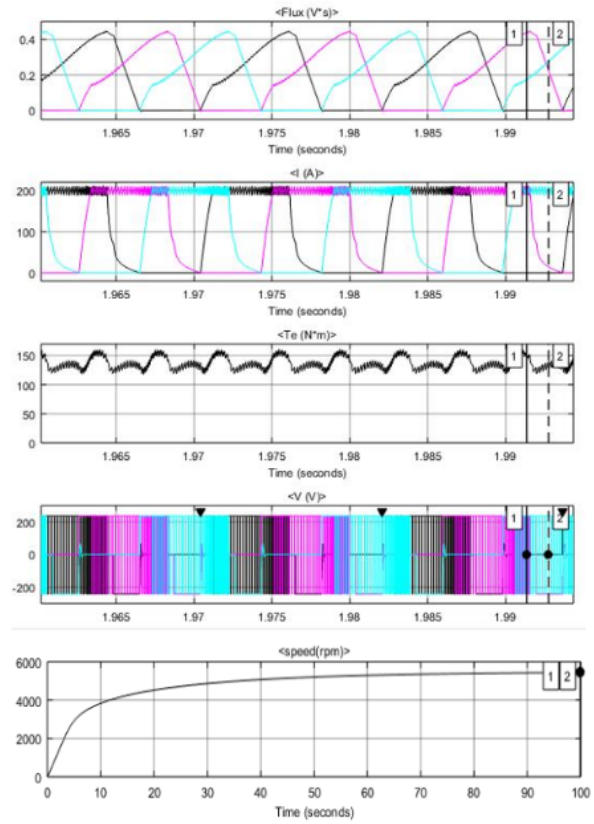

Figure 8. Simulink display of magnetizing freewheeling mode (flux, current, torque, voltage, speed).

The phase current Ia 48.86 amps in magnetizing demagnetizing has lower value than magnetizing freewheeling (53.89 amps) means that lower energy used by the magnetizing demagnetizing. Flux 281.16 mH for magnetizing demagnetizing and 299.92 mH for magnetizing freewheeling. The voltage are constant at 237.95 volts for every step. The average torque 17.75 N.m for magnetizing demagnetizing, compare to 22.27 Newton meter from magnetizing freewheeling means that magnetizing demagnetizing reach the faster time to reach the top speed compare to the magnetizing freewheeling. From the simulation we can see that the shape of induction flux from magnetizing freewheeling is not sharp (see Figure 8), this because the energy from inductance are dissipate through Diode D1 and D2 hence time for the slope of flux to dissipate is slower than the magnetizing demagnetizing. In magnetizing demagnetizing mode, the inductance current injected by the current from battery from the opposite direction (see Figure 4), hence the current faster decline to zero. This simulation proof that the magnetization demagnetizing achieve better performance in reaching higher speed, and more efficient since draw the smaller current, and the top speed will be catch earlier compare to the magnetizing freewheeling mode. All the simulation depicted in Figure 7 and Figure 8.

6. CONCLUSION

The asymmetric bridge converter has some mode of operation, from the simulation measurement of the performance using Matlab/Simulink proof that the magnetization demagnetizing mode has better performance compare to the magnetization freewheeling mode, the higher the speed, and faster time to reach the top speed. And the next research are the performance, energy consumption, and combination of both method in SRM will be held.

7. ACKNOWLEDGMENTS

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