Control of Brushless DC Motor by using Multilevel Converter

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Abstract: This paper has studied The current trend of modulation control for multilevel converters is to output high quality power with high efficiency. For this reason, popular traditional PWM methods and space vector PWM methods are not the best methods for multilevel converter control due to their high switching frequency. Brushless DC Motors (BLDCM) are widely used in automated industrial applications like Computer Numerical Control (CNC) machinery, aerospace applications and in the field of robotics. But it still suffers from commutation torque which mainly depends on speed and transient line commutation interval. This paper presents a reduction of torque ripple performance of brushless DC (BLDC) motor drive system using different converter and inverter.

KEYWORDS: Brushless direct current motor (BLDCM), dc-bus voltage control, modified single-ended primary-inductor converter, 5-level diode clamped multilevel inverter (5-level DCMLI).

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INTRODUCTION

The idea of employing electric power instead of fossil fuels as motive energy of vehicles is not new. Scientists and manufacturers have attempted to design an Electric Vehicle (EV) since long time ago. Rodert Anderson had built the first electric carriage in 1839 and David Salomon developed an electric car using a light electric motor in 1870 [1]. Since then, the heavy electric batteries and poor performance electric motors were the main concern. Interest on electric vehicles reduced due to development of electric self-starters for the gasoline vehicles and low price of oil, until early 1980's when environmental concerns raised up [2]. Nowadays, hybrid electric vehicles are more popular than pure electric vehicles due to the better range and lack of enough infrastructures for charging battery.

Conventional electric vehicles have a central electric motor that actuates two or all four wheels of the vehicle [3]. In-wheel motor technology is of interest for high performance electric vehicles by researchers and auto-mobile manufacturers in recent years. However the in-wheel motor idea first introduced in 1884 by Wellington Adams who have built and attached an electric motor directly in the vehicle's wheel through complicated gearings. In-wheel motor electric vehicles employ motors embedded inside each wheel. Since in an in-wheel motor EV individual control of each wheel is possible; better vehicle speed, torque and acceleration control can be achieved. Using in-wheel motor technology improves drive train efficiency, dynamic stability control and safety of electric vehicles.

As mentioned earlier, poor performance of the electric motors has been of concern by researchers and various electric motor types have been used in electric vehicles so far. There is always an important question, what is the most suitable electric motor for electric vehicles? The answer to this question depends highly on the type of the EV application. The scope of this thesis is on high performance pure electric vehicles comparable with other gasoline vehicles. As there is no comprehensive comparison on electric motors for the high performance electric vehicle application; in this thesis various common motors such as brushed DC, induction, switched reluctance and permanent magnet BLDC motor are compared in the context of an in-wheel motor vehicle.

As a result of this study, the BLDC motor is introduced as the most suitable in-wheel motor for high performance electric vehicles. BLDC motors were first introduced by T.G. Wilson and P.H. Trickey in 1962 for some specific low power applications and named as "a DC machine with solid state commutation" [6]. Higher power BLDC motors came on the market after the development of the high power transistors and permanent magnet materials. The first high power BLDC motor (50 horsepower or more) was designed by Robert E. Lordo at Powertec Industrial Corporation in the late 1980s.

Switched Reluctance Machine (SRM) is gaining interest in hybrid (HEV) and Plug-in Hybrid Electric Vehicle (PHEV) applications due to its simple and rigid structure, four-quadrant operation, and extended-speed constant-power range [1-10]. SRM proves to be reliable and cost effective in harsh environment due to the absence of windings and permanent magnet on the rotor. However, compared with conventional electric drives, SRM suffers from high commutation torque ripple, acoustic noise and vibration. Torque ripple is mainly resulting from poor tracking precision of phase current, nonlinear inductance profiles, and nonlinear torque-current-rotor position characteristics.

Power electronic converters [1-2] for SRM drives play an important role in searching for cost effective solutions in SRM applications, because costs of switches take up a large amount of the total costs in motor drives. In this thesis, five popular power electronic converter topologies for three-phase switched reluctance motor (SRM) drives including asymmetric power electronic converter, N+1 power electronic converter, split AC power electronic converter, split DC power electronic converter, and C dump power electronic converter are investigated and compared in terms of device ratings, cost, efficiency, torque ripple, average torque, and copper losses.

LITERATURE SURVEY

Typically, the mathematical model of a Brushless DC motor is not totally different from the conventional DC motor. The major thing addition is the phases involved which affects the overall results of the BLDC model. The phases peculiarly affect the resistive and the inductive of the BLDC arrangement. For example, a simple arrangement with a symmetrical 3-phase and "wye"

internal connection could give a brief illustration of the whole phase concept.

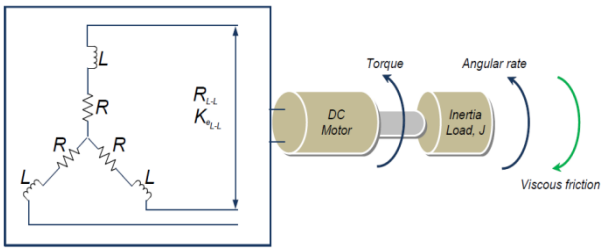

Figure 1 – Brushless DC motor schematic diagram

So from the equations 2 – 3, the difference in the DC and BLDC motors will be shown.

This difference will affect primarily the mechanical and electrical constants as they are very important parts of modeling parameters.

For the mechanical time constant (with symmetrical arrangement), equation 1 becomes:

$$t_m = \sum \frac{RJ}{k_e k_t} = \frac{J \sum R}{k_e k_t} \quad (1)$$

The electrical (time constant),

$$t_e = \sum \frac{L}{R} = \frac{L}{\sum R} \quad (2)$$

Therefore, since there is a symmetrical arrangement and a three phase, the mechanical (known) and electrical constants become:

Mechanical constant,

$$t_m = \frac{J.3R}{k_e k_t} \quad (3)$$

Electrical constant,

$$t_e = \frac{L}{3R} \quad (4)$$

Considering the phase effects,

$$t_m = \frac{3.R_f.J}{(K_{e(L-L)} / \sqrt{3}).K_t} \quad (5)$$

Equation 4.5 now becomes:

$$t_m = \frac{3.R_f.J}{k_e k_t} \quad (6)$$

Where K_e is the phase value of the EMF (voltage) constant;

$$K_e = K_{e(L-L)} / \sqrt{3} \quad (7)$$

PROPOSED METHOD

The proposed topology includes a dc-link that is common among the three phases. The dc-link provides three voltage levels +2E, 0, and -2E for the phase legs. Since all the phases have similar configuration, only one phase leg of the proposed topology has been shown in Fig. 2. All the components shown in the figure have equal operating voltage E i.e. one fourth of the dc-link voltage Vdc. The flying capacitors CA1 and CA2 are controlled to stay charged at the target voltage E.

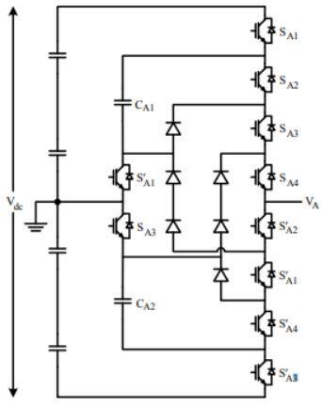

Fig. 2: A phase leg of the proposed 5-level hybrid topology

The available states of one phase leg are shown in table 1. To generate level 2E, all the top arm switches SA1, SA2, SA3, SA4 should turn on. For level E, two choices are available i.e. either through dc-link's positive point (EP) or through dc-link's

neutral point (E0). This redundancy can be used to balance the voltage of CA1. Level 0 is generated through clamping the dclink's neutral point to the output (00). Negative states can be generated similarly due to the symmetry of the topology.

Table 1 Switching states of the proposed inverter

Level	State	S_1	S_2	S_3	S_4	C_1	C_2
+2E	+2E	1	1	1	1	N.A.	N.A.
+E	+EP	1	0	1	1	i>0 Charge i<0 Discharge	N.A.
	+E0	0	1	1	1	i>0 Discharge i<0 Charge	N.A.
0	0	0	0	1	1	N.A.	N.A.
-E	-E0	0	0	1	0	N.A.	i>0 Charge i<0 Discharge
	-EN	0	0	0	1	N.A.	i>0 Discharge i<0 Charge
-2E	-2E	0	0	0	0	N.A.	N.A.

The operation of this topology is in essence similar to topologies such as stacked multicell (SMC) converter where the positive and negative stacks operate independently. Hence, the positive stack capacitor CA1 is used and balanced during the positive cycle and r st during the negative cycle, whereas the negative stack capacitor CA2 is used and balanced during the negative cycle and rest during the positive cycle. So, the flying

capacitors will see the switching frequency rather than line frequency and therefore the capacitor size is not too large.

Similar to the three-level NPC inverter, if the three phases of the load are balanced, the neutral point voltage will be constant in theory. However, the voltage might slightly drift away due to the imbalance in the elements' leakage current. In addition, although small, there is always some imbalance among the phases. A constant voltage drift, even though small, can cause higher voltage across part of the devices which can be lethal. Nevertheless, this drift can be compensated by

injecting a small common mode to the three phases. An important feature of the proposed topology is the even distribution of transitions among switching devices. Therefore, switching loss which is the major limiting factor of inverter's thermal performance is distributed among the switches. As the main result, the tradeoff between switching frequency and current derating is improved. This provides the opportunity to either increase the rated current and power of the inverter or increase the switching frequency resulting in lower capacitor size and improved voltage waveform quality.

RESULT

Diodes To verify the operation of the proposed topology and the performance of the modulation techniques provided in section III, a model is developed and simulated with PSIM software. The performance of the natural balancing technique for a three phase 12kV inverter supplying a 5MVA load at power factor of 0.7 is shown in Fig. 3. Centered space vector modulation (CSVPWM) is used at modulation index of 1.09 and carrier

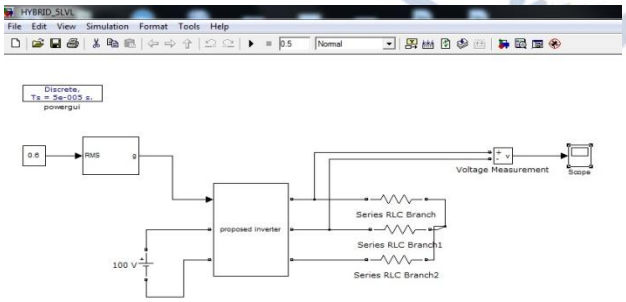

Fig. 3 Proposed Model

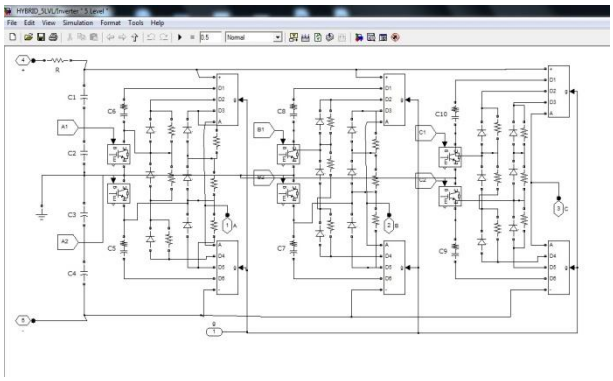

Fig. 4 Inner Proposed Model

frequency 5kHz. The dc-link voltage is set at 18kV and flying capacitors are 330μF. It can be seen that even without an RLC balance booster, the capacitor voltage errors are limited to less than 4%.

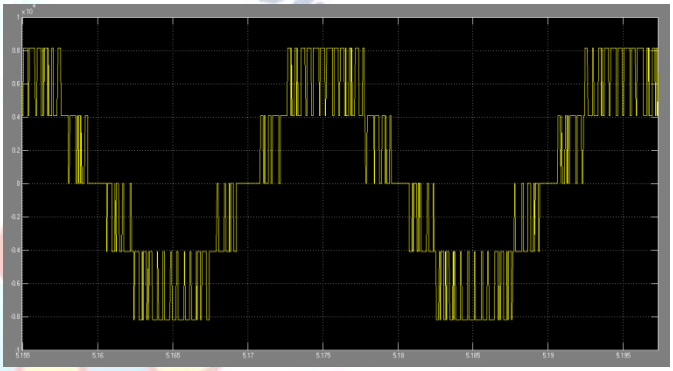

Fig. 5. Simulation result of Phase voltage

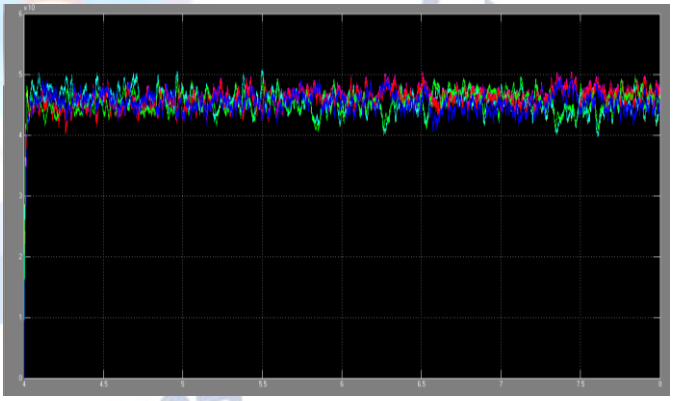

Figure 6. Simulation result of Flying capacitor voltages

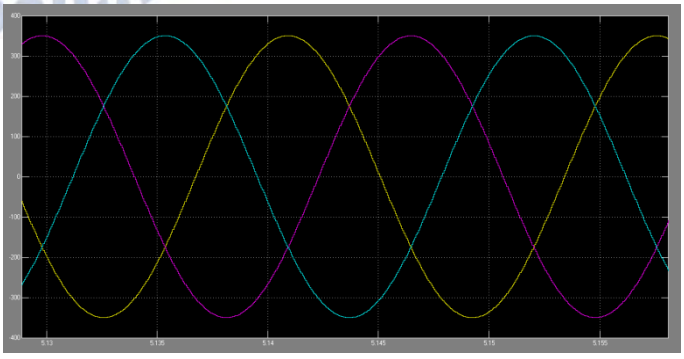

Figure 7. Simulation result of Load current

CONCLUSION

This paper has studied The current trend of modulation control for multilevel converters is to output high quality power with high efficiency. For this reason, popular traditional PWM methods and space vector PWM methods are not the best methods for multilevel converter control due to their high switching frequency. The selective harmonic elimination method has emerged as a promising modulation control method for multilevel converters. But the major difficulty for the selective harmonic elimination method is to solve transcendental equations characterizing harmonics, the solutions are not available for the whole modulation index range, and it does not eliminate any number of specified harmonics to satisfy the application requirements. To conquer the problem for the selective harmonic elimination method, the resultant method is used to find all the solutions to the harmonic equations and the active harmonic elimination method is proposed to eliminate any number of harmonics and can be applied to the whole modulation index range for multilevel converters to satisfy the application requirements.

A new hybrid 5-level inverter topology and modulation technique is proposed. Compared to 5-level ANPC as the most similar topology, this new topology requires two less switches at the cost of an additional capacitor and six diodes. However, since the capacitors still see the switching frequency and their size remain the same, it is expected to reduce the inverter's total cost. Also, unlike 5-level ANPC, all switches must withstand the same voltage which eliminates the need for series connection of switches and associated simultaneous turn on and off problem.

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