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Leakage current and commutation losses reduction in electric drives for Hybrid Electric Vehicle

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HIGHLIGHTS

- Decreasing the global inverter losses by using discontinuous SVPWM techniques.
- Using a new PWM technique which adapt itself to the load characteristics to reduce commutation losses.
- Leakage current sources identification and method to reduce this current.

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ABSTRACT

Nowadays, leakage current and inverter losses, produced by adjustable-speed AC drive systems become one of the main interested subject for researchers on Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) technology. The continuous advancements in solid state device engineering have considerably minimized the switching transients for power switches but the high dv/dt and high switching frequency have caused many adverse effects such as shaft voltage, bearing current, leakage current and electromagnetic interference (EMI). The major objective of this paper is to investigate and suppress of the adverse effects of a PWM inverter feeding AC motor in EV and HEV. A technique to simultaneously reduce the leakage current and the switching losses is presented in this paper. Based on a discontinuous space vector pulse width modulation (DSVPWM) and a modular switches gate resistance, inverter losses and leakage current are reduced. Algorithms are presented and implemented on a DSP controller and experimental results are presented.

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1. Introduction

For Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) drive-train, the inverter controls the electric motor, this is a key component in the vehicle as it determines driving behaviour. The inverter is often controlled by Pulse Width Modulation (PWM) strategies which should be designed to reduce switching losses, leakage current and maximize thermal efficiency. On the other hand, the inverter captures energy released through regenerative breaking and feeds this back to the battery. As a result, the range of the vehicle is directly related to the efficiency of the inverter.

When EV/HEV motor drives operate in high output torque region, the loss and thermal robustness of inverters are an important concerns. Further considering the power density and cost targets of EV/HEV, it is crucial to reduce the inverter switching loss when the output electric current is large (Fig. 1).

Among the disadvantages of Electric Vehicles (EV) is their weak autonomy, whereas for Hybrid Electric Vehicles (HEV) it is the limited space under the hood for another drive train; to improve the autonomy, the battery energy should be used efficiently, on the other hand lower losses would need a smaller and lighter cooling system. In hard switched power converters the switching losses are significantly high, and often represent the bulk of the inverter losses. The greater the switching losses, the greater the need for cooling the power switches. Whereas pulse width modulated converters have carrier and sideband harmonics which is source of electromagnetic pollution which can be divided into two categories, common mode and differential mode noise [1,2].

Space Vector PWM is a digital Power Converter modulation technique where the duty cycle of inverter switches are calculated directly using mathematical transformations based on complex representation of inverter voltages. SVM was chosen over ordinary PWM techniques for the following reasons: better DC voltage utilization [3] and decreased switching losses. Reduced switching losses can be explained by the freedom that one has in generating the pulses when the duty cycles are known before hand [3,4]. The

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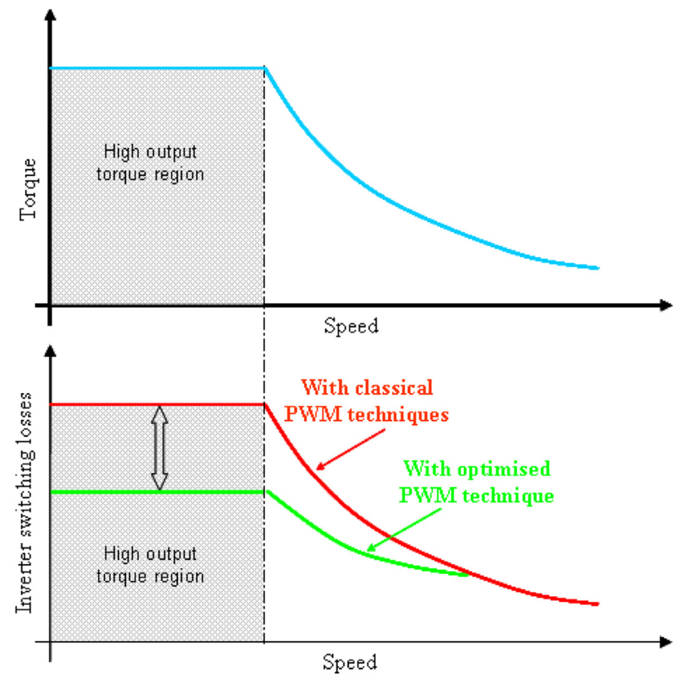

Fig. 1. Switching losses reduction according to torque/speed characteristic for EV/HEV application.

idea is to use the zero vectors (passive vectors) in a way to avoid voltage commutations when it matters the most.

Another weakness of EV and HEV drive train, is the Electro-Magnetic Interference (EMI) aspect which is rarely taken into account at the conception of electric drives which increases the cost and time to market of the drive train due the tedious and tiresome process of EMI suppression [5]. The problem of common mode current or leakage current arises due to the parasitic capacitive coupling between the stator winding and the stator frame (Fig. 2) along with high rate of change of voltage 'dv/dt' in the windings giving path to non negligible common-mode currents (5 A) for switching transients of 200 ns for DC link voltages as low as 200 V. The recent trend of using high speed switches has only worsened

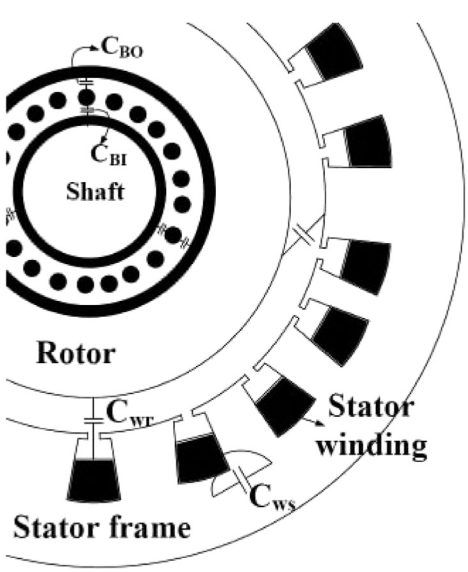

Fig. 2. High frequency representation of an electric drive.

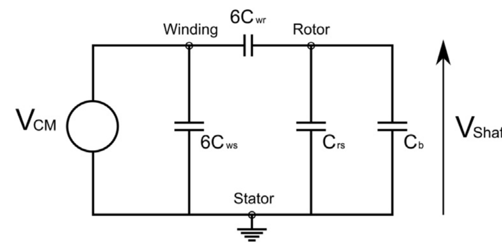

Fig. 3. High frequency equivalent model.

the situation and has created the need for an EM filter to eliminate this noise from the electric drive. In this paper, we present a technique for reducing the leakage current as well as the switching losses.

Some researchers have provided different solutions for these problems; some of them concerning passive and active EMI filters have focused on eliminating high frequency leakage current, shaft voltage and bearing current. Other solutions are based on motor design and variable switching frequency PWM strategies. In Ref. [6], based on the analytical expression of current ripple of common three-phase inverter fed by constant DC-link voltage source, variable switching frequency PWM methods were proposed to effectively reduce the switching losses and/or the conducted EMI noise. Ref. [7] proposes a method for suppressing shaft voltage by modifying the shape of the rotor and the permanent magnets; in order to minimize shaft voltage, a magnet rearrangement and rotor restructuring of the motor are designed. Ref. [8] proposes a passive cancellation method for the purpose of elimination the adverse effects of PWM inverter in electrical machine system. This method is based on a two small passive EMI filters which can compensate for common mode voltage produced by PWM inverter and leakage current. These methods can effectively reduce the inverter and motor leakage current, the switching losses or system noise. However, these methods are not fit for EV and HEV applications seen on the more weight, volume and cost they introduce. It is more preferable to reduce both the inverter–motor leakage current, switching losses and the system noise by improving the PWM strategy and power components (IGBT) commutations. Taking the EV and HEV application into account, this paper proposes two solutions based on an improved PWM strategy and a technique to control commutation dynamic, which helps to reduce both the inverter switching loss and system leakage current.

This paper includes six parts. First part gives introduction. Second part gives the high frequency behaviour of the drive system. Third part gives the proposed solutions to reduce switching losses and leakage current. Part 4 gives the experimental setup and results for a two level IGBT inverter feeding a 15 kW permanent magnet synchronous motor (PMSM) and finally the conclusion and references are given in part 5 and 6 respectively.

2. High frequency behaviour

Numerous papers have been published by electric drive-train manufacturers in the last several years that attempt to understand the causes of shaft voltage in motors and to find a solution to eliminate electrical bearing damage. Shaft voltage and current flow thru motor bearings represent a significant part of electric drive train problems when operating under Voltage Source Inverter (VSI) controlled with classical PWM techniques.

The shaft voltage magnitude measured is commonly used as an indicator of the possible bearing current that results. It is the magnitude and passage of electrical current thru the bearing that results in a mechanical damage.

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