

Field reconstruction and active harmonic elimination techniques implemented in advanced PM motor drive system

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This paper presents a methodology based on Field Reconstruction Method (FRM) and Active Harmonic Elimination (AHE) techniques enabling development of an advanced low-speed surface-mounted Permanent Magnet Synchronous Motor (PMSM) drive scheme. The FRM enforces periodicity between rotor and stator fields, significantly enhancing the precision of Finite Element Analysis (FEA) by accurately representing space harmonics and changes in local saturation effects due to loading variations. This way harmonic periodicity is ensured while torque ripple and motor losses are minimized, resulting in optimization of the AHE strategy and significant enhancement of the computational efficiency. Experimental validation on a prototype system has confirmed the proposed method effectiveness and demonstrated its superior characteristics in terms of motor performance and harmonic mitigation. This methodology is particularly beneficial for electric vehicle applications, where high efficiency and dynamic control are essential under various loading conditions.

Index Terms—Finite element analysis, motor drives, permanent magnet machines, total harmonic distortion.

I. INTRODUCTION

IN ELECTRIC vehicle applications, particularly in direct-drive configurations that avoid mechanical gearboxes and the motor shaft's rotational speed is the same as the wheel speed, low angular speeds are encountered. This leads to increased Total Harmonic Distortion (THD) in stator currents, contributing to higher torque ripple and reducing efficiency.

In distributed windings of surface mounted Permanent Magnet Synchronous Motors (PMSMs), current harmonics arise from non-sinusoidal back Electromotive Force (EMF) and armature reaction impact, influenced by the air gap geometry variation with rotor rotation and the non-linear B-H characteristics of iron laminations [1].

Previous studies [2], [3], [4], have proposed several harmonic mitigation techniques, such as to apply active compensation of EMF harmonics measured under no-load conditions by using Discrete Fourier Transform (DFT), or to implement optimized voltage harmonic injection schemes through modified controllers to reduce torque ripple and copper losses under various operating conditions.

The paper proposes a control scheme that combines optimized magnetic field analysis with modified electrical circuit algorithms, providing stable and efficient motor operation under a wide range of operating conditions. Its effectiveness is demonstrated through simulation and experimental validation, highlighting its potential for improving motor performance in electric vehicle applications, under different local saturation levels due to load variations.

II. METHODOLOGY AND RESULTS

A. Static FEA and FRM implementation

An 8-pole, 2kW, 320rpm surface mounted PMSM has been studied, by using static 2D Finite Element Analysis (FEA) as

well as Field Reconstruction Method (FRM) enabling efficient evaluation of the motor representation involving modest computational effort available. Under such low speed conditions, dynamic effects and impacts of eddy currents are practically negligible, becoming significant only in important over-speed cases.

The magnetic field analysis in distributed winding motors can be performed by using only one pole part solution domain with appropriate anti-periodical lateral boundary conditions. Moreover, by using “frozen” local reluctivities the total magnetic field can be reconstructed by superimposing constituent excitation contributions via appropriate angular shifts for each phase current [5]. These procedures are shown schematically in Figs. 1(a), 1(b) respectively.

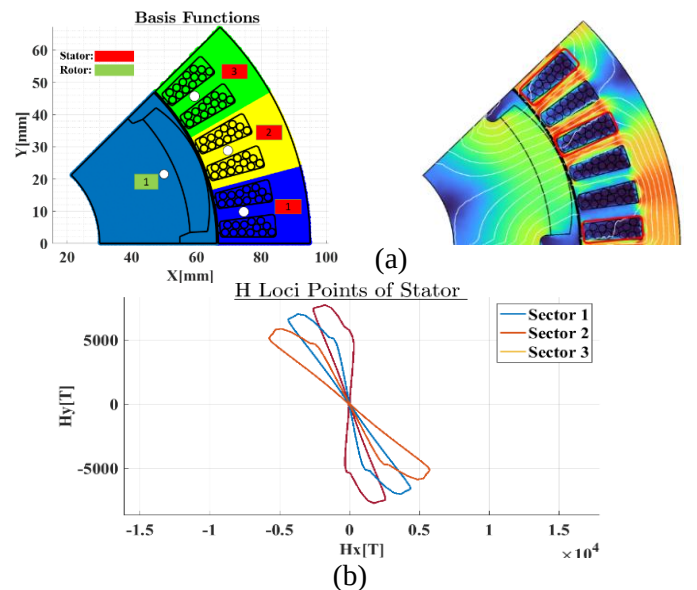


Fig. 1. Field Data. (a) Basis functions for FRM utilization and single pole's respective field distribution (b) Field intensity H locus (H_x vs H_y) of stator's reference points.

The FRM enforces periodicity, ensuring accurate rotor local flux density and torque calculations [6]. The computed results in the considered motor for phase current components $I_d=0$ and $I_q=50A$ by detailed FEA and FRM techniques concerning the flux density in the middle of the air-gap and the torque with rotor rotation are compared in Figs. 2(a) and 2(b), respectively. These figures illustrate the good precision obtained by FRM necessitating importantly reduced computational means with respect to the detailed FEA.

B. Voltage harmonics and AHE

The motor back EMF has been measured under nominal speed and its time variation is shown in Fig. 2(a) compared with the respective simulated result. Figure 2(b) presents the corresponding spectrums of these measured and simulated curves involving small higher harmonic content, which is illustrated in magnified representation in this figure inset.

The higher harmonics of the back EMF create non-negligible current harmonics in case of voltage supply when using Sinusoidal Pulse Width Modulation (SPWM) technique, which are more important under lower load conditions, creating torque ripple and additional copper losses. To that respect the dominant harmonic orders voltage amplitudes and phases evaluated by DFT, that is the ones of orders 5,7,11, and 13, have been implemented to appropriately modify the inverter reference voltage signals, in order to eliminate stator current harmonics, in a proposed Active Harmonic Elimination (AHE) scheme.

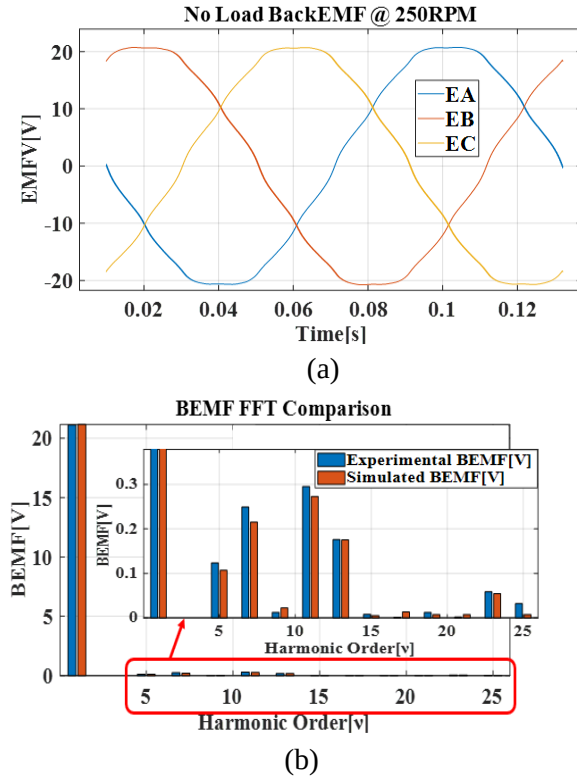


Fig. 2. Comparison of computed and measured no load phase voltage (EMF). (a) Voltage time variation (b) Voltage spectrum and detail

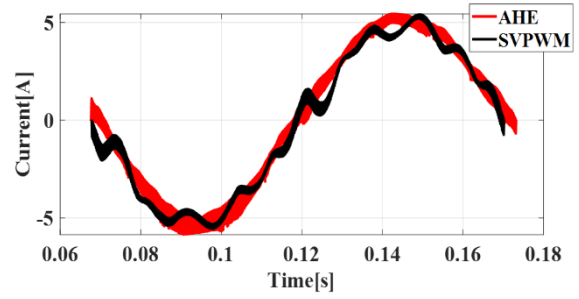


Fig. 3. Experimental current for Phase A under low loadpoint (3.5A rms) conditions.

A. Experimental Validation

The proposed methodology has been applied in the motor considered and the simulated reduction of the harmonic distortion in stator currents has been validated by measurements. To that respect the simulated time variations of stator currents under low load conditions obtained for voltage source inverter applying the conventional SVPWM technique are compared to the respective measured ones in Fig. 3. Figure 3 compares the same results in case of voltage source inverter applying the proposed modified PWM with AHE technique.

III. CONCLUSION

A methodology has been introduced based on FRM in conjunction with FEA enforcing rotor and stator field periodicities and enabling accurate AHE in low-speed surface-mounted synchronous PMSM drive. The proposed method involves adaptation to local saturation effects caused by load changes and has been validated by measurements in a prototype. The authors believe that this technique can offer great services in harmonic losses reduction of surface mounted permanent magnet electric vehicle applications.

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