Harmonics and Torque Ripple Minimization using L-C Filter for Brushless DC Motors

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***Abstract*—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. The dynamics of this motor should be smooth for many industrial and automated applications and free from unwanted interference. But due high speed switching circuits used in the commutation circuits, the BLDC motor voltage contains harmonics component and this causes high electromagnetic interference problems. During commutation the trapezoidal current pass through each phase causes pulsation in torque during its operation. This work proposes an improved methodology to reduce the high frequency harmonics components and torque ripples using a RC filter connected at the input of the motor. This work is simulated using PSIM and the effect of filter is analyzed with FFT analysis. An experimental setup is developed to analyze the performance of the drive with the proposed system and the experimental outputs were compared with the simulated values and the improvement in performance is analyzed.**

***Index Terms*—Brushless DC Motor (BLDCM), Electro-Magnetic Interference (EMI), Zero Volt Switching (ZVS), Zero Current Switching (ZCS), Total Harmonic Distortion (THD).**

I. INTRODUCTION

The brushless dc motor (BLDCM) has found to be more efficient than the existing DC motor and induction motors Due to the simplicity in control scheme, high power density, reliability, and maintenance free operation, BLDC motors are used in the field of industrial automation, Computer numerical control machines and in the field of robotics. The mechanical losses are minimized since no brushes and no mechanical commutator present in the motor. The dynamics for this motor should be smooth for many industrial and automation applications. Due to the power electronic commutation, the usage of high frequency switching of power devices, imperfections in the stator and the associated control system, the input supply voltage to the motor contains various harmonics components. During its operation, high frequency components present in the voltage input will cause serious electromagnet interference (EMI) problem and the pulsating current input due to electronic commutation causes torque ripple. So an efficient controller is required to reduce the harmonics present in the input voltage to the motor and to reduce the pulsating variation of line current to the motor.

Now a days researchers are trying to reduce the torque ripple and harmonics component in the BLDC motor. An active filter topology to reduce the torque ripple in synchronous motor is presenter in [1]. This paper [1] discusses the hysteresis voltage control method. A suspension control method of motor control method of motor frame vibration and rotational speed vibration of Permanent Magnet Synchronous Motor (PMSM) by utilizing feed forward compensation control signal that suppress the harmonics in d-q control signals by repetitive control and Fourier Transform is discussed in [2] and [3].

A method for commutation torque ripple minimization in direct torque controlled PMBLDC drives is presented in [4]. This paper [4] describes the method of hybrid commutation, both 60^{o} and 120^{o} electrical, combined that the torque ripple can be minimized. FPGA implementation of higher degree polynomial acceleration profile for peak jerk reduction in servomotors is presented in [5]. A hardware polynomial based profile generator was used for minimizing the torque. Novel resonant pole inverter for Brushless DC motor drive system is presented in [6].

The resonant converters are having higher complexity in controllers and uses additional components to employ ZVS and ZCS to enhance the performance of the inverter and increase the efficiency.

This paper describes the implementation of a controller with minimized torque ripple and EMI effects using a filter placed at the input of the BLDC motor. The design of the filter components and the methodology of reduction of harmonics components are simulated and verified in real time application.

The BLDCM is energized by the three phase inverter through an inductor - capacitor filter for reducing the high frequency component. The capacitor voltage value has to be selected in such a way that it can charge and discharge in an effective manner to reduce the high frequency component. The inductor present in series with each phase will reduce the commutation current pulsation and thereby reducing the jerk produced by commutation effects.

II. Functional Units

The BLDC Motor requires a power electronic drive circuit and a commutation system for its operation. The Fig. 1 describes the functional units present in the drive circuit and the associated commutation controller for the BLDC Motor.

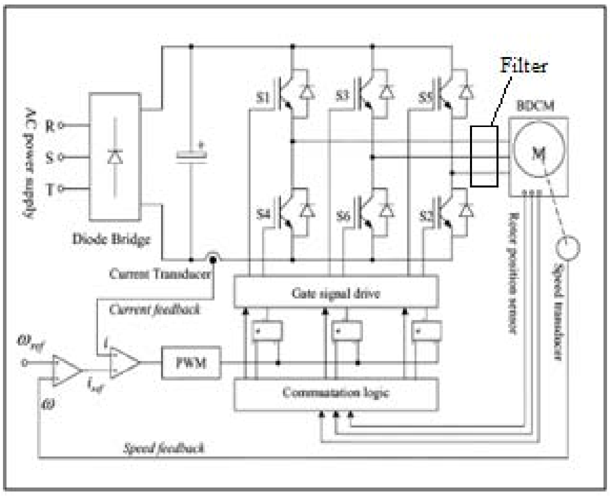


Figure.1. Controller for BLDC motor with filter

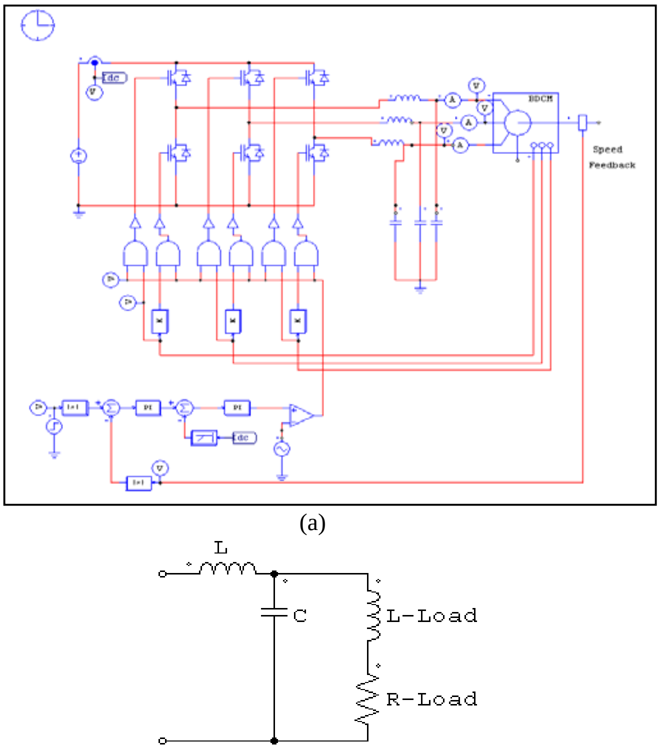
A 4 pole BLDC motor is driven by the inverter for 120 degree commutation. The rotor position can be sensed by a hall-effect sensor or slotted optical disk, providing three square wave signals with phase shift of 120^o. These signals are decoded by a combinational logic to provide the firing signals for 120^o conduction on each of the three phases. The inverter voltage for the motor is filtered by the filter circuit provided, which minimizes the high frequency switching voltage ripple component.

The inductor- capacitor filter for the proposed work is connected in the interface of the drive and the motor. The LC filter in this system acts as a low pass filtering circuit which offer high impedance to high frequency component of the voltage and very minimum impedance to the power frequency voltage components and thereby minimizes harmonics in the supply voltage to the motor and the series inductance opposes the sudden changes in the current due to electronic commutation and thereby reduces the torque ripple.

The switching frequency of the circuit is set as 5 KHz. The dynamic duty ratio of the gating PWM signal is controlled by the speed feedback from the motor and the current feedback from the DC line. The input voltage from the source is set as 60V DC. A simulation analysis is made on this proposed work which is presented in Fig. 2.

III. Filter Design

The selection of LC component present in the filter plays a major role in the performance of the drive. The charging and discharging of the capacitor improves the quality of the voltage given to the motor.



(b).

Figure 2 (a) Circuit for simulation analysis, (b) equivalent LC filter for one phase

To design the reactive elements present in the filter, it is assumed that the capacitor which is connected across the load is large enough to charge and discharge, hence the capacitor voltage may be considered to be nearly constant. The inductor current rating should be equal to the current ratings of the motor.

Now the peak inductor current equal to

$$I\ Peak = \frac{2\,Vm}{Zmin} \tag{1}$$

Where Z_{min} is the minimum value of load impedance, V_m is the peak magnitude of the phase voltage.
The capacitance of the filter is

$$C = \frac{Vm}{2\ Zmin\ fsw\ \Delta V} \tag{2}$$

ΔV is the ripple voltage at the input of the filter.
fsw is the switching frequency of the inverter power devices, that is equal to the ripple frequency.
t_{on} and t_{off} are the on time and off time of the power devices.

$$ton + t\,off = \frac{1}{fsw} \tag{3}$$

The value of the inductance is calculated as

$$L = \left(\frac{Vs-Vo}{Ipeak}\right)\ ton \tag{4}$$

V_s is the source Voltage of the filter and V_o is load voltage.

IV. Sample Calculation

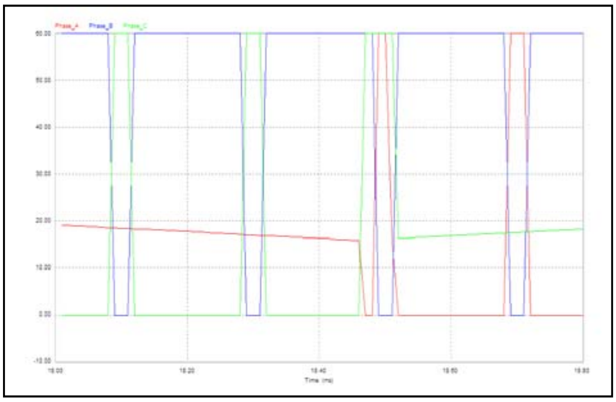
For this work, the source voltage to the filter (V_s) is 60 V and the load voltage (V_o) is 50 V, $\Delta V = 10\,V$ approximately. For a 5 KHz switching frequency with 60% duty ratio, t_{on} will be approximately 1.2x 10^{-4} sec. The minimum impedance of the load Z_{min} = 30Ω. The peak Current is calculated as I_{peak} = 1.3 A. The calculated inductance value L = 0.1mH, the calculated value of Capacitance = 0.01µF.

V. Simulation And Experimental Results

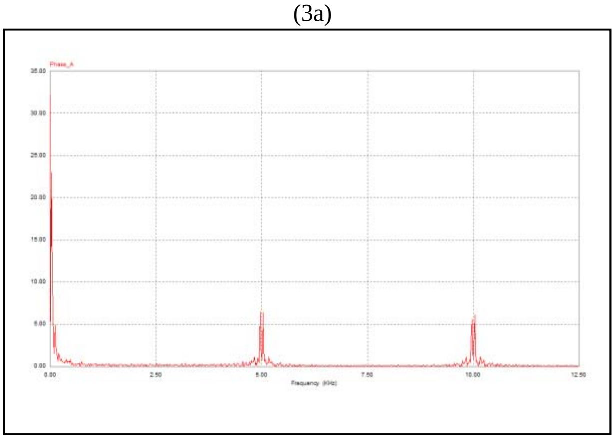
Various simulations are done using simulation software for the converter circuit presented in Fig 2.The simulation values are set based on the sample calculation and simulated results for the drive circuit is compared for the system with filter and without filter. In this paper, simulated and experimental results are presented as follows.

A. Simulated Results for Without Filter Operation

Simulated results of the various parameters without applying the filter are shown in Fig 3. (a) to (e). The different phase voltages and the phase currents and the associated harmonics are plotted with FFT analysis in percentage values.



(3a)



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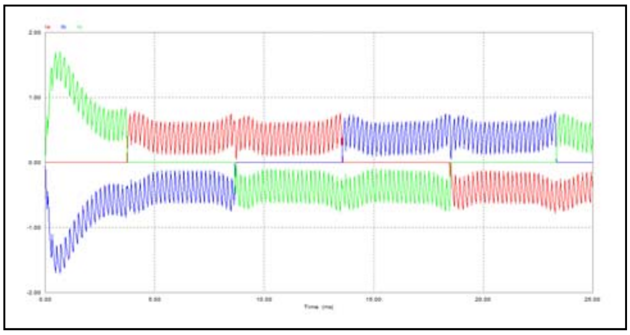
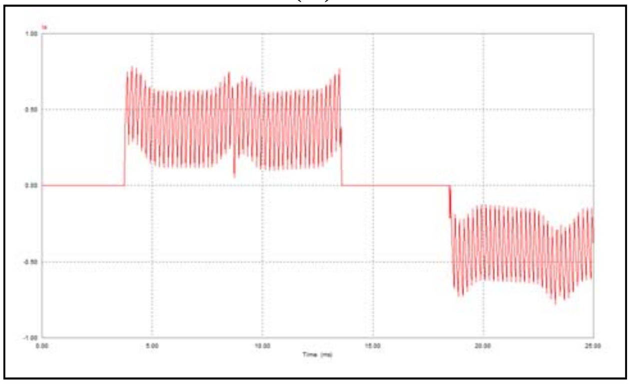


(3c)



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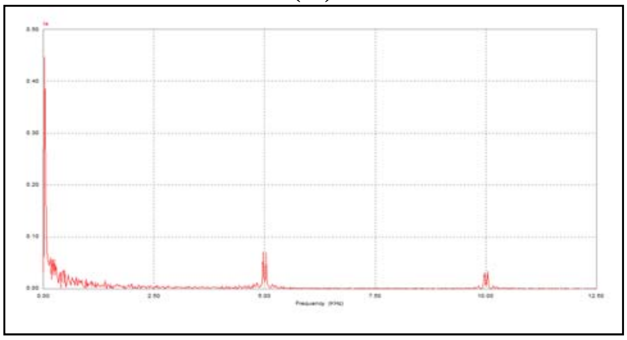


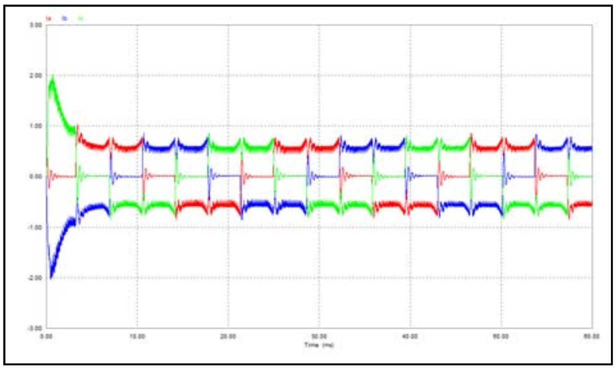
(3e)

Figure 3. Current and Voltage analysis without filter (3a) Three phase magnified voltage input to motor. (3b) the FFT analysis for Phase -A voltage. (3c) the three phase current simulate waveform. (3d) magnified phase current for phase-A. (3e) the FFT analysis for line current in Phase –A.

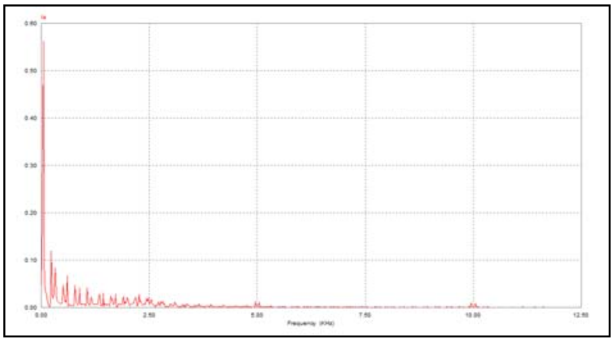
Fig 3. (a) shows the magnified voltage of the motor input voltage at the time of commutation. The three phase voltages at any particular instant is shown in 3 colored waveform. Fig. (3b) shows the harmonics present in the phase-A of the voltage to the motor. The harmonics are present in the switching frequency of the power devices and the multiples of switching frequencies. Fig. (3c) shows the combined waveform for the three phase current input to the motor. The magnitude at the starting is higher. Fig. (3d) shows the magnified line current (I_a) (e) shows the FFT analysis of the harmonics presents in the line current (I_a). At 5 KHz and 10 KHz the harmonics component is around 30%. The line current varies abruptly during commutation. This causes the jerk in the motor due to sudden variation of torque. For higher speed of operation this jerk causes vibration and acoustic noise.

B) Simulated Results for With Filter Operation

Simulation results for voltage and current for the motor with filter is presented and analyzed. Fig 4. (a) shows the combined waveform for the line currents. Fig 4. (b) shows the harmonic analysis of line current (I_a). The harmonic components in the switching frequency are reduced. Fig. 3c shows the FFT analysis for the voltage in Phase A. The high frequency switching harmonics are reduced in the phase voltage.



(a)



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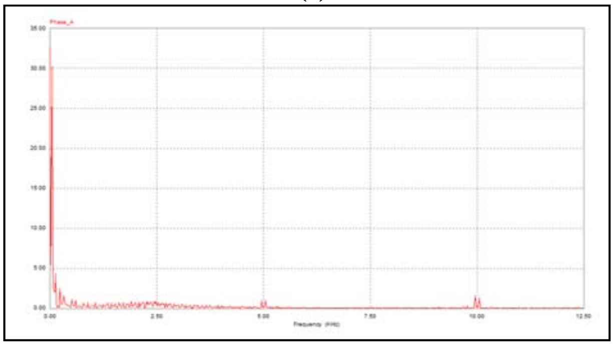


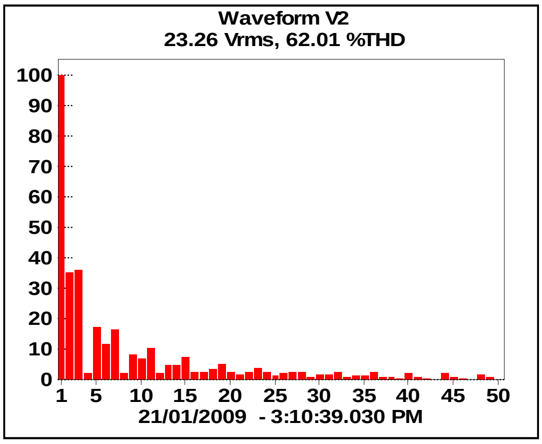
(c)

Figure. 4. Current and Voltage analysis with Filter (a) line currents for the motor input (Y axis-Current). (b) FFT analysis for line current (Y axis-Current) (c) FFT analysis for phase -A voltage (Y axis-voltage)

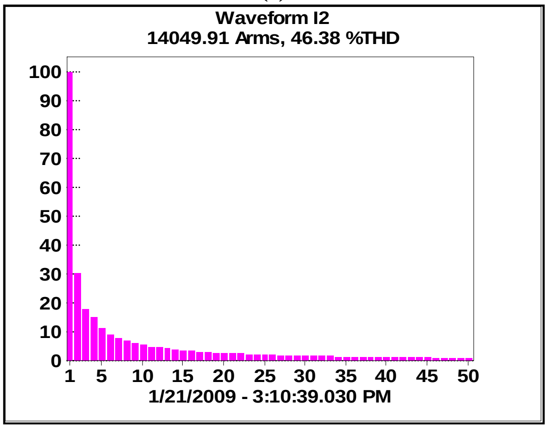
While analyzing the outputs with and without filter, Fig 3. (b) a and (e) with Fig 4. (b) and (c) the harmonic components are reduced from 30% to less than 5%.

C) Experimental Results for Without Filter Operation

The experimental results of voltage and current with filter are compared with the results of voltage and current harmonics present without the filter. Fig 5.(a) is the harmonics analysis bar graph for the proposed work without filter. The Total Harmonic Distortion (THD) is measured in this bar graph for analysis. The THD for the voltage is found to be high around 62.02%. Fig. 5. (b) shows the bar graph harmonics analysis for the line current without filter. The THD is 46.38%.



(a)



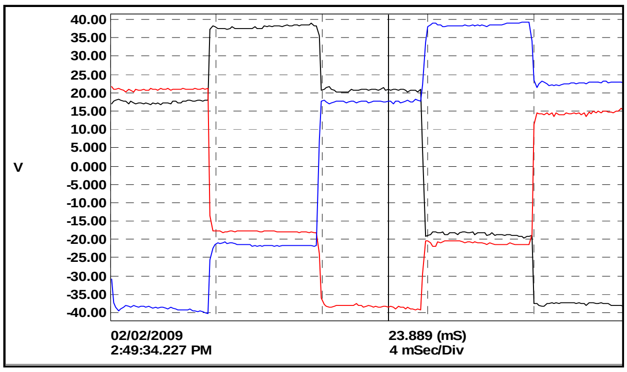
(b)

Figure. 5 Experimental result of harmonics analysis for phase voltage and line current without filter. (a) harmonic analysis for the voltage. (b) harmonic analysis for line current. (X axis – Harmonic order, Y axis- Magnitude in Percentage of fundamental)

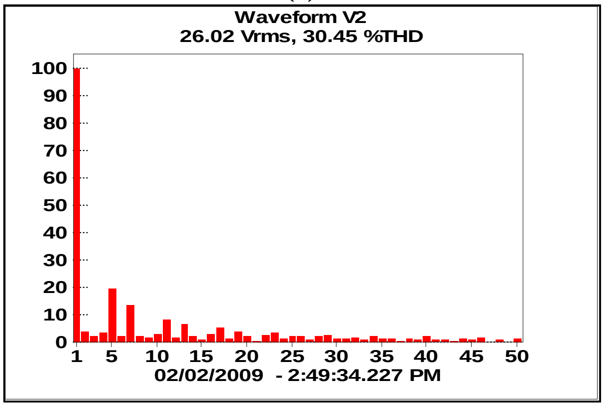
D) Experimental Results for With Filter Operation

The experimental results with filter are presented here for the current and voltage. Fig 6(a) is the phase voltages of the motor with filter. The harmonic components are greatly minimized by the filter. The Fig. 6(b) shows the harmonics bar graph of the voltage in phase 2. The THD is 30.46%. The Fig 6.(c) shows the bar graph harmonic analysis of the line current. It is found that the THD is 14.97%.

Fig. 6(d) expresses the currents in different phases of the motor. The profile of the current is been transferred from trapezoidal profile to sinusoidal profile by the filter. This improves the commutation effect of the motor. The drastic variation of the currents in each phases are smoothened by the filter. This minimizes the commutation losses of the drive and minimizes the torque ripple.



(a)



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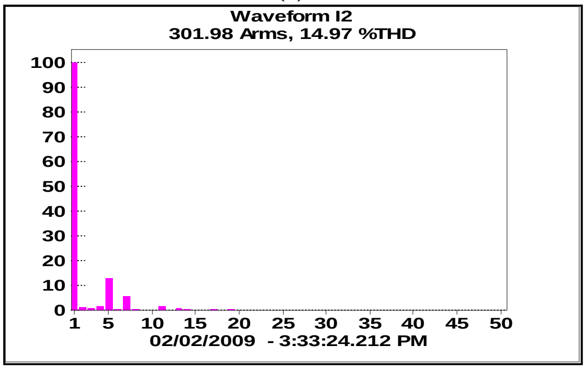

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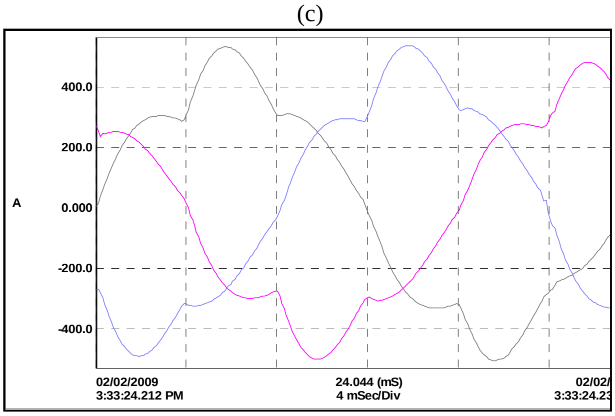

(d)

Figure. 6. Experimental result of harmonics analysis for phase voltage and line current with filter. (a) Phase voltages of the motor with filter (b) harmonic analysis for the voltage. (c) harmonic analysis for line current. (X axis –Harmonic order, Y axis- Magnitude in Percentage of fundamental) (d) Phase currents of the motor

VI. Inference From Experimental Results

The harmonics components are greatly reduced by applying the proposed filter in the interface of the inverter and the motor. In Fig. 6. The harmonics components of phase voltage and line current are shown. The THD for phase voltage is 30.46% and the THD for line current is 14.97%. Comparing the effect of filter, the total harmonic distortion is minimized from approximately 62% to 31%. The line current harmonics is minimized from approximately 47% to 14.97%. The performance of the filter may be fine tuned for reducing the harmonics to further minimum values. The torque ripples are reduced due to the smoothness of the current waveform since the inductor improves the current profile

VII. Conclusion

In this paper the harmonics content of the voltage and current for a BLDC motor is analyzed. From the simulated results it is evident that the harmonics components at the switching frequency and multiples of switching frequency are reduce by the filter. From the experimental results, it is found that more than half of the harmonics components are reduced with filter. The current waveforms are smoothened by the filter during the operation and the commutation frequency harmonics minimized and thereby the torque ripple is reduced.

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References

[1] Kayhan Gulez, Ali Ahmed Adam, and Halit Pastaci, "Torque Ripple and EMI Noise Minimization in PMSM Using Active Filter Topology and Field-Oriented Control," *IEEE Trans. Industrial Electronics*, Vol. 55, No. 1, pp. 251-256, Jan 2008.

[2] S. Harrori, M. Ishida, and T. Hori, "Vibration suspension control method for PMSM using repetitive control with auto tuning function and Fourier transform." *In Proc 27th Annu. Conf. IEEE IECON*, 2001, PP 1673-1679.

[3] J.S Kim, s. Doki and M.Ishida, "Improvement of IPMSM sensorless control performance using Fourier Transform and repetitive control," *in proc.27th Annu. Conf. IEEE IECON, 2002.* PP. 597-602.

[4] Yong Liu, Z. Q. Zhu, "Commutation-Torque-Ripple Minimization in Direct-Torque-Controlled PM Brushless DC Drives" *IEEE trans. Industry Applications*, Vol. 43, No. 4, August 2007. PP 1012- 1021.

[5] Roque Alfredo Osornio-Rios, Rene de Jesus Romero-Troncoso, Gilberto Herrera, and Rodrigo Castaneda-Miranda, "FPGA implementation of higher degree polynomial acceleration profiles for peak jerk reduction in servomotors.", Robotics and Computer-Integrated Manufacturing (2008) Science Direct, Jan 2008.(doi: 10.1016/j.rcim.2008.01.002)

[6] Zhi Yang Pan, and Fang Lin Luo, "Novel resonant pole inverter for Brushless DC motor drive system", IEEE Trans on Power Electronics, Vol. 20, No. 1, Jan 2005. PP 173-181.

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