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Analysis and Control of Commutation Errors in Sensorless Drive of BLDC based on Compensation Techniques

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Abstract: Brushless dc motor has permanent magnets which rotate around fixed armature. The current in armature rotates as it is electronically commutated. The commutation angle errors reduce the performance and overall efficiency of the motor. The novelty of the work is reducing commutation errors that are obtained based on the relationship between commutation point phase shift and the difference of dc-link current. Based on these relationship analysis is made under ideal, advanced and delayed commutations. The self-compensation method of commutation instant deviation delays the commutation angle by 10º thus eliminating the impact caused by commutation ripple thereby improving dynamic performance and control. The dc-link current difference decrease gradually and phase deviation converges to adjust the commutation angle. The proposed correction method can achieve ideal commutation effect thereby attaining fast convergence speed, current and torque.

Keywords: Brushless DC motor, Commutation signal deviation, dc-link current, Phase shift circuits, Sensorless control.

I. INTRODUCTION

Brushless DC motors are used in applications ranging from household to automobiles and industries due to its high power density, efficiency and torque to inertia ratio. These motors are often selected for its high torque performance over long life working and also the rugged construction makes them suitable in extreme environments. BLDC motor is a type of DC motor in which the commutation process is done electronically instead of the use of any brushes. Permanent magnet rotor and electronic commutation cause BLDC to have advantages over brushed DC motor and induction motor. The motor’s permanent magnets display higher efficiency that is thus used for industrial heavy load applications. The BLDCM commutation ripple can be compensated using wide range of methods. The ripples cause substantial the motor to damage permanently as it generates temperatures at defect locations causing mechanical deformations. The kind of failures do not cause immediate breakdown, but deteriorates the operation of machine decreasing the performance of the machine. Voltage drop occurs while switching therefore a buck converter is used for maintaining the voltage and reducing the variations thus increasing current. Self-compensation method resolves the commutation errors based on actual back EMF waveform, which refers to switching current in phases to generate motion thereby adjusting the commutation angle. The rotor position can be brought by sensing the Back-EMF indirectly from one of the motor terminal voltages. Sensing each terminals extract two commutation instants. The method is obtained based on the relationship between commutation point phase shift and the difference of dc-link current. This project proposes a BLDC motor that can be used in industrial applications. Most of the commercial system uses induction motor where power drops at low loads and also starting torque is poor. When compared to induction motors BLDC motor has high efficiency and high energy saving with low start up current capacity, as it is powered by DC electric source and the switching power supply produces AC supply to drive the motor, hence BLDC motor has higher torque ratio for its application in industries and also positioning and controlling is possible which is more efficient than induction motors.

II. PROPOSED METHOD

Rapid self-compensation method is used to solve commutation angle error as it reduces the overall performance. The commutation error is eliminated using a dc-link current difference. The effects of commutation position deviation occurs due to electric component delay, measurement noise etc. These commutation errors can be reduced by self-compensation method. The ideal commutation point is the intersection of every two-phase back EMFs. The self-compensation method analyses the sampled current difference and commutation phase point shift.

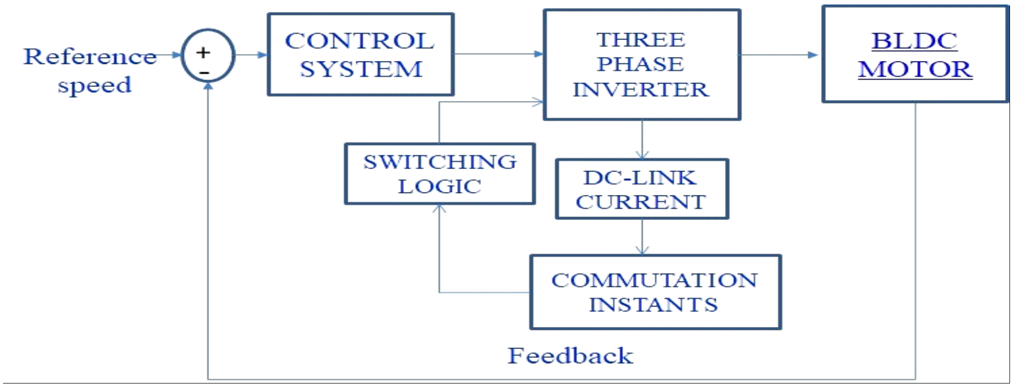

Fig 1: Block diagram representing self-compensation technique

The self-compensating method is composed of a buck converter for stepping down the voltage and increasing the current value, velocity controller to regulate the motors speed and a current controller to restrain the motor current to below the maximum value. The combination of these processes produce high frequency ripple compensation by testing the current difference under certain instants to solve the problems related to commutation angle errors as otherwise it will reduce the overall performance and efficiency of the motor. By identifying the commutation position of a BLDC motor the change in dc-link current induced by commutation phase shift is analysed for any current ripples. The difference of the dc-link current and phase currents are compared and analysed for any ripples and the compensated current is driven to the switching circuit and back to the inverter circuit to that of the motor. Thereby the compensation of commutation time errors with the dc-link current obtains good steady state response and smooth operation of motor therefore can be applied for heavy load applications.

The advantage of this analysis compared to other existing methods is its simplicity to implement, and it is influenced by the current sampling from the source and phase currents of the motor not disturbed by any other sources of magnetic interferences present in industrial environment.

III. COMMUTATION POSITION IN BLDC

Commutation point is determined by finding the angular position and then applying current to the phases of stator to produce magnetic field that leads to the attraction of rotor to a new position. The motor operates in three phase six states and transistor commutates at every 60º. The three phase armatures are symmetrical,

i.e; Ra = Rb = Rc = R and

La = Lb = Lc = L. Then motor terminal voltage can be written as:-

$$U_x = Ri_x + (L - M)\frac{di_x}{dt} + e_x + U_N \quad (1)$$

BLDC motor phase back EMF waveform lies between the trapezoidal waveform and sinusoidal waveform. The phase diagram of commutation signals and phase back EMFs are shown below. The ideal commutation point is the intersection of every two-phase back EMFs. However, under effects of low pass filters, commutation delay, electric component delay, measurement noise, etc., the extracted commutation position deviation occurs. The current transfers from upper bridge of phase A to that of phase B. The law of dc-link current commutation ripple can be achieved by analysing the current in non-commutation phases.

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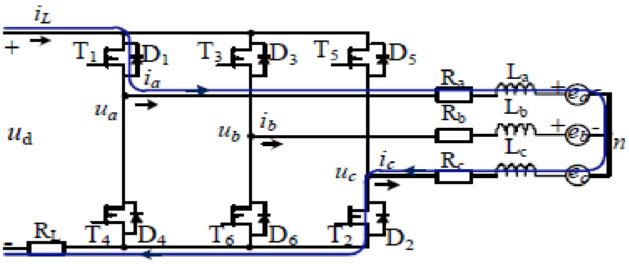

Fig 2: Current circuit before commutation T_1 to T_3

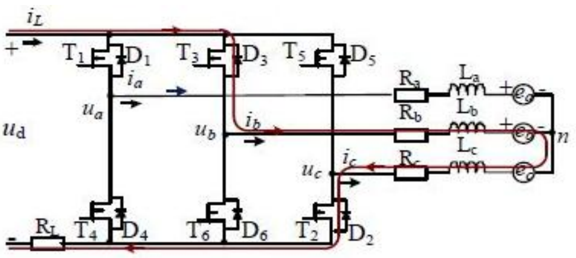

Fig 3: Current circuit after commutation from T_1 to T_3

The electrical and mechanical mathematical equations of BLDC are:

$$V_a = Ri_a + (L-M)\frac{di_a}{dt} + E_a \tag{2}$$

$$V_b = Ri_b + (L-M)\frac{di_b}{dt} + E_b \tag{3}$$

$$V_c = Ri_c + (L-M)\frac{di_c}{dt} + E_c \tag{4}$$

BACK EMF EQUATIONS:

$$E_a = K_e \omega_m f(\theta_e) \tag{5}$$

$$E_b = K_e \omega_m f\left(\theta_e - \frac{2\pi}{3}\right) \tag{6}$$

$$E_c = K_e \omega_m f\left(\theta_e + \frac{2\pi}{3}\right) \tag{7}$$

TORQUE EQUATIONS:

$$T_a = K_t i_a f(\theta_e) \tag{8}$$

$$T_b = K_t i_b f\left(\theta_e - \frac{2\pi}{3}\right) \tag{9}$$

$$T_c = K_t i_c f\left(\theta_e + \frac{2\pi}{3}\right) \tag{10}$$

$$T_e = T_a + T_b + T_c \tag{11}$$

MECHANICAL EQUATIONS:

$$T_e - T_l = J\frac{d^2\theta_m}{dt^2} + \beta\frac{d\theta_m}{dt} \tag{12}$$

$$\theta_e = \left(\frac{p}{2}\right)\theta_m \tag{13}$$

$$\omega_m = \frac{d\theta_m}{dt} \tag{14}$$

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CURRENT EQUATIONS:

$$i_a = \int \left(\frac{1}{3L}\right)[2V_{ab} + V_{bc} - 2E_a + E_b + E_c - 3Ri_a] \quad (15)$$

$$i_b = \int \left(\frac{1}{3L}\right)[-V_{ab} + V_{bc} + E_a - 2E_b + E_c - 3Ri_b] \quad (16)$$

Where K: a, b, c
V_a, V_b, V_c : Phase voltage applied from inverter to BLDC
I_a, I_b, I_c : Phase current
R : Resistance of each phase of BLDC
L : Inductance of each phase of BLDC
M : Mutual inductance
E_a, E_b, E_c : Phase back- EMF
T_a, T_b, T_c : Electric torque produced in each phase
K_e : Back EMF- constant
K_t : Torque constant
ω_m : Angular speed of rotor
Θ_m : Mechanical angle of rotor
Θ_e : Electrical angle of rotor
$F(\Theta_e)$: Back- EMF reference as function of rotor position.

IV. SIMULATIONS AND RESULTS

A. Modelling of a BLDC Motor

Modelling of BLDC Motor using commutation logic is been simulated and the output waveforms are attained using MATLAB. A PI controller has also been used for generating the rated speed. The Simulink representation of the overall system is shown below.

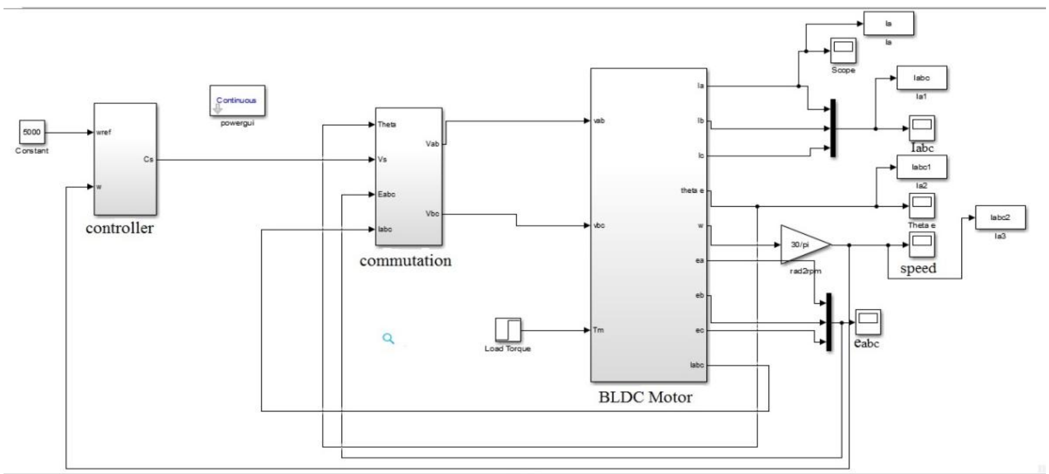

Fig 4: Model of BLDC Motor

For simulating the proposed system, a 1.5 kW motor is modelled and the input signals to that of the controller are attained through a buck converter.

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B. Modelling of a Buck Converter

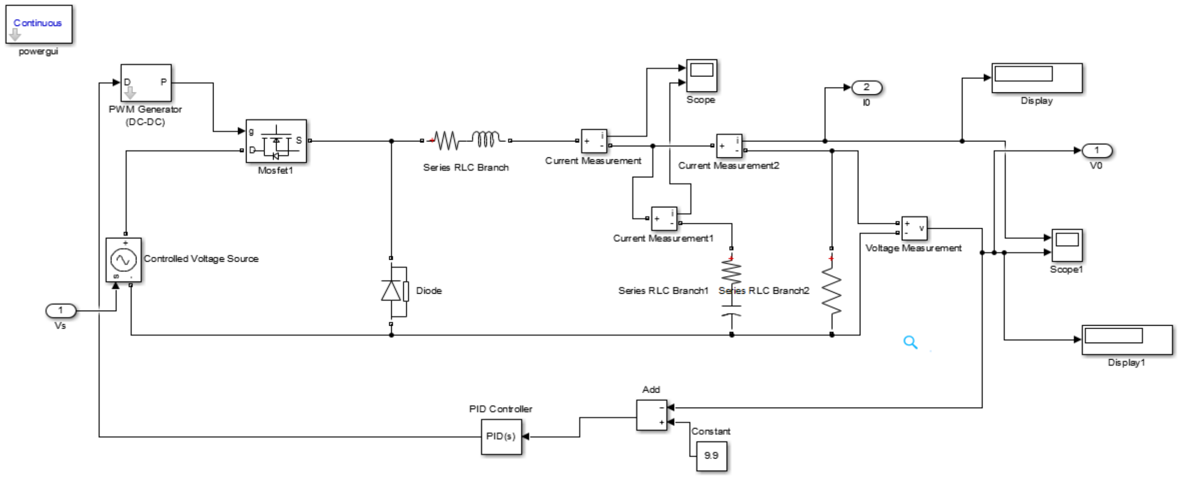

Fig 5: Model of Buck Converter

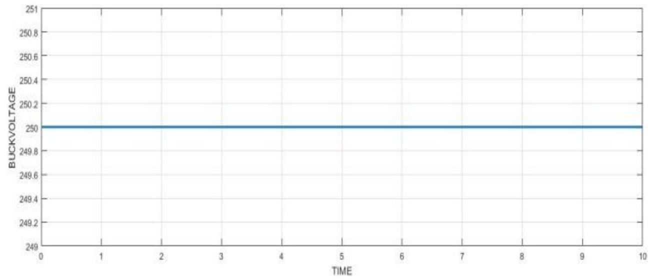

Fig 6: Output Voltage

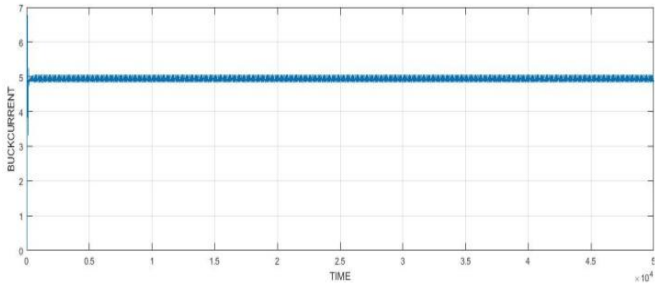

Fig 7: Output Current

The buck converter is implemented in front of the 3Φ inverter to weaken the influence caused by inductances that leads to the minimisation of ripples in torque that is caused by commutation errors thereby attaining desired voltage. Therefore the input signals given are 250 V and a 5 A current to the converter to attain the desired output that is been fed to the commutation circuit for generating voltage.The output waveform of the Simulink block diagram with delayed commutation angle and with advanced commutation angle is also shown below.

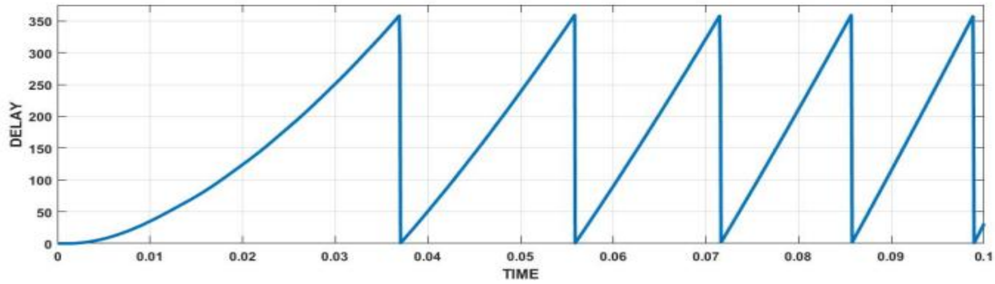

Fig 8: Position angle without delay

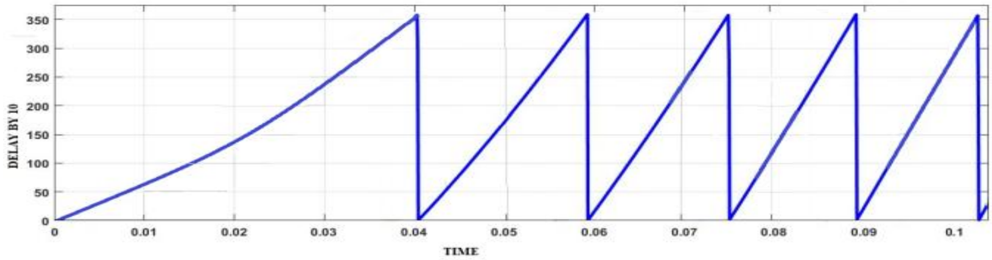

Fig 9: Position angle with 10º delay

The dc-link current waveforms changes with the commutation point shift. If the commutation point is advanced, then the dc-link current sampled before commutation instant is smaller than that of the after value. Commutation phase delay of 10º leads to reducing the speed accordingly. Thus decreasing the errors caused by commutation in the overall system.

Simulation results of current waveforms of the three phases and dc link current of the motor with non- ideal back EMF's is shown in the figure below

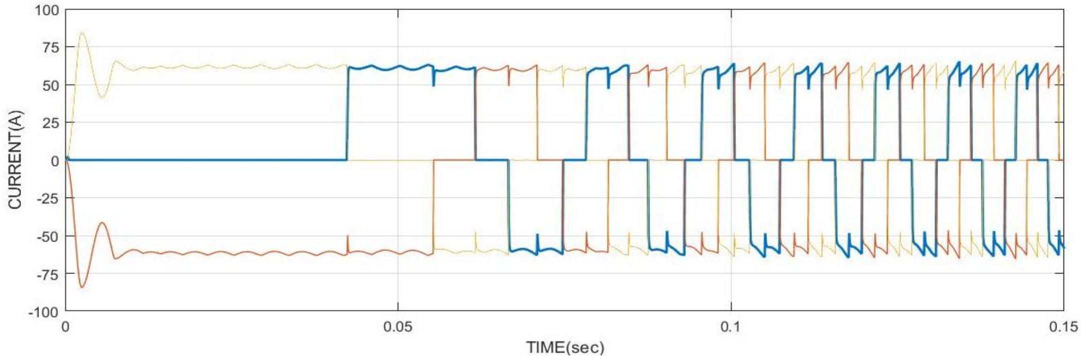

Fig 10: Current Vs Time

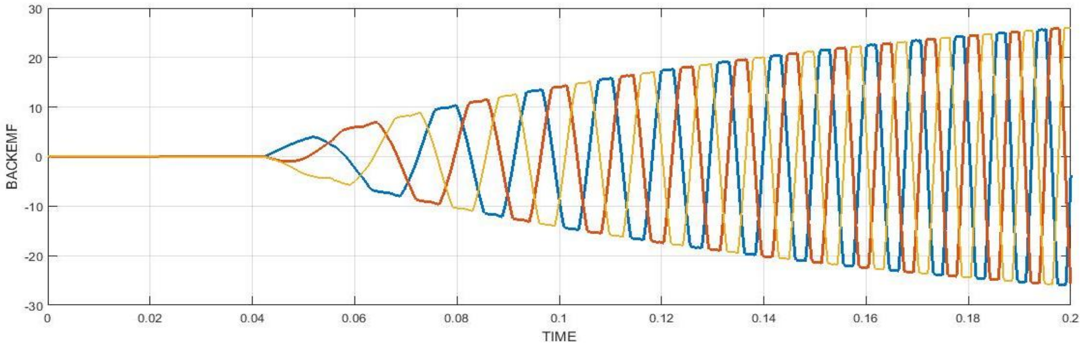

Fig 11: Back EMF Vs Time

The open loop starting assures that the rotor will align with the rotating magnetic field generated from multi-phase stator coils. When the input voltage is higher than the back EMF is high enough for the detection circuit, the sensorless commutation signals will be sent to the commutation table and the motor is changed to the self-commutation mode.

The speed response of the machine is shown in Fig. 12 the rated speed of the machine is 5000 rpm. The torque waveform is shown in Fig. 13 and Fig. 14 and it is analysed that the variation of torque after compensation occurs between 0.95 Nm to 2.75 Nm.

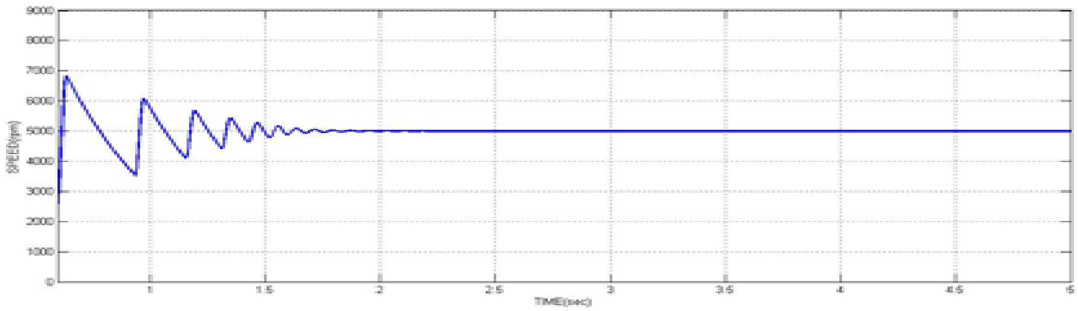

Fig 12: Speed Vs Time

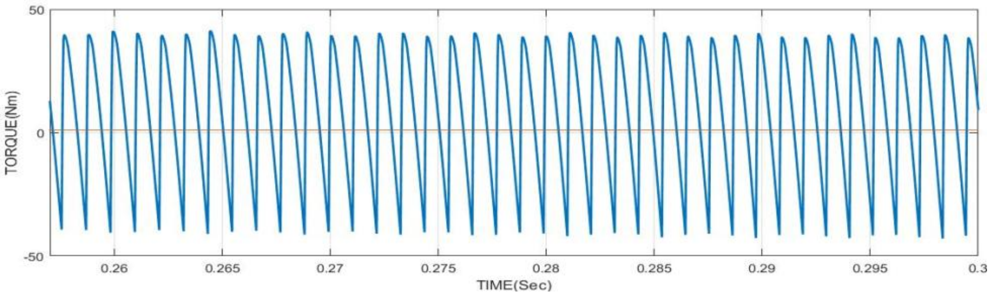

Fig 13: Torque ripple before compensation Vs Time

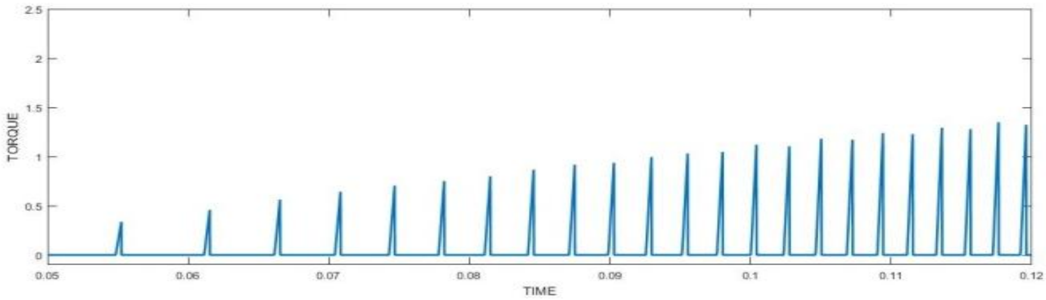

Fig 14: Torque ripple after compensation Vs Time

V. CONCLUSION

Considering that the unbalanced three-phase back EMFs and the commutation ripple would make the commutation error compensation disabled, a new compensation method of commutation instant deviation is proposed in this paper. Control techniques for minimizing the pulsating torque apply certain advanced method that depends on the machine parameters. It is derived based on the actual back EMF waveforms, and it eliminates the impact caused by commutation ripples. From the experimental results it is found that the proposed method start reliably with this method obtains fast convergence speed, avoids the freewheeling current of the non-conduction phase thereby eliminating commutation error. In addition it also improves the dynamic performance and is effective and can be easily implemented.

REFERENCES

[1] A. H. Niasar, A. Vahedi, and H. Moghbelli, "A novel position sensorless control of a four-switch, brushless dc motor drive without phase shifter," *IEEE Trans. Power Electron.*, vol. 23, no. 6, pp. 3079–3087, Nov. 2008.

[2] J. S. Park, S. M. Jung, H. W. Ki, and M. J. Youn, "Design and analysis of position tracking observer based on instantaneous power for sensorless drive of permanent magnet synchronous motor," *IEEE Trans. Power Electron.*, vol. 27, no. 5, pp. 2585–2594, May 2012.

[3] S. Po-ngam and S. Sangwongwanich, "Stability and dynamic performance improvement of adaptive full-order observers for sensorless PMSMdrive," *IEEE Trans. Power Electron.*, vol. 27, no. 2, pp. 588–600, Feb. 2012.

[4] S. V. Tewari and B. I. Rani, "Torque ripple minimization of BLDC motor with un-ideal back EMF," in *Proc. 2nd Int. Conf.* Emerging Trends Eng. Technol. (ICETET), 2009, pp. 687–690.

[5] S. J. Kang and S. K. Sul, "Direct torque control of brushless dc motor with non-ideal trapezoidal back EMF," *IEEE Trans. Power Electron.*, vol. 10, no. 6, pp. 796–802, Nov. 1995.

[6] S. Bhogineni and K. R. Rajagopal, "Position error in sensorless control of brushless dc motor based on average line to line voltages," in *Proc. IEEE Int. Conf. Power Electron., Drives Energy Syst.*, 2012, pp. 1–6.

[7] S. Ogasawara and H. Akagi, "An approach to position sensorless drive for brushless DC motors," *IEEE Trans. Ind. Appl.*, vol. 27, no. 5, pp. 928–933, Sep.–Oct. 1991.

[8] N. Urasaki, T. Senjyu, K. Uezato, and T. Funabashi, "Adaptive dead-time compensation strategy for permanent magnet synchronous motor drive," *IEEE Trans. Energy Convers.*, vol. 22, no. 2, pp. 271–280, Jun. 2007.

[9] T. H. Kim and M. Ehsani, "An error analysis of the sensorless position estimation for BLDC motors," in *Proc. Conf. Rec. Ind. Appl. Conf.*, 2003, vol. 1, pp. 611–617.

[10] G. Pellegrino, P. Guglielmi, E.Armando, et al, "Self-Commissioning Algorithm for Inverter Nonlinearity Compensation in Sensorless Induction Motor Drives," *IEEE Trans. Ind. Appl.*, vol. 46, no.4, pp.1416–1424, Jul./Aug. 2010.