Novel BipolarPWM Method with Low Ripple Current for Position Control Applications of BLDCM

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Abstract- BLDC Motors are widely used in various speed control applications due to their ease of control and low cost. Generally, the unipolar PWM method is used for speed control applications. However, the unipolar PWM method has a current spike problem in the braking operation which can be a problem in speed reversal which generally happens in position control applications. However, the current spike problem can be solved by the conventional bipolar PWM method. Although the current spike problem can be solved, the conventional bipolar PWM method has the problem of a large current ripple. In this paper, a novel bipolar PWM method is proposed to solve this problem. The current ripple and the current spike problems are analyzed in this paper for the unipolar and bipolar PWM methods. At last, the merits of the proposed bipolar PWM method are proven by experiment.

Key Words: Bipolar PWM, Brushless DC motor (BLDC motor), PWM method, Unipolar PWM

I.INTRODUCTION

The brushless DC (BLDC) motor and the permanent magnet synchronous motor (PMSM) have been receiving a great deal of attention because of their inherent advantages of high power density, high efficiency, a large torque to inertia ratio, high starting torque, free maintenance, and ease of control. ABLDC motor has a trapezoidal electro motive force (EMF) waveform, so the current waveform of a BLDC motor has a square waveform to reduce torque ripple. Therefore, a BLDC motor controller requires a low resolution` position sensor and only one current sensor. On the other hand, since a permanent magnet synchronous motor (PMSM) has a sinusoidal EMF waveform, the current waveform of a PMSM must be sinusoidal. As a result, a PMSM requires an expensive high resolution position sensor such as an absolutely encoder and resolver. Therefore, a BLDC motor is generally used for low-cost applications due to its ease of control, and its low cost position and current sensors. On the other hand, a BLDC motor's electrical attribute is similar to a

DC motor, so a BLDC motor's pulse width modulation (PWM) method is similar to the PWM method of a DC Motor. The only difference is the commutation. The commutation of a BLDC motor is electrically achieved by a 3 phase inverter, while the commutation of a DC motor is carried out by a mechanical brush and commutator. There have been several studies on PWM methods for BLDC motors. In the PWM control of a BLDC motor, generally, the unipolar PWM method is used as a DC motor uses the unipolar PWM method for the chopping control in which only one switch is On and Off controlled by PWM among the selected two switches, while the other switch is in the On state continuously. In general, four unipolar PWM methods are used for controlling a BLDC motor, and the unipolar PWM methods are distinguished by the selection of the PWM switch among the 2 On-state switches.

Most of the studies on PWM methods are related to commutation torque ripple minimization under the freewheeling interval. The current spike problem seen in the unipolar PWM has been solved by the bipolar PWM; the symptoms of a large current ripple can be made by the bipolar PWM. Therefore, the torque ripple and the acoustic noise are remarkably increased, and the motor efficiency is reduced by the increased motor core loss of the bipolar PWM method. In this project, different PWM techniques unipolar bipolar and a modified bipolar PWM methods are simulated and studied. To analyze the current spike problem, the unipolar PWM method is explained and a mathematical model of the unipolar PWM is described in chapters, the modified bipolar PWM method is explained in chapters, simulation results are shown for the unipolar PWM method, the conventional bipolar PWM method, and the modified bipolar PWM method. From the simulation results, the merits of small current ripples and hence small torque ripples of the modified bipolar PWM method are proven.

II.BLDC MOTOR

Permanent magnet synchronous (PMSM) motors are now commonly known as permanent magnet ac motors (PMAC). They are classified based on the nature of voltage induced in the stator as sinusoidal excited (induced voltage has a sinusoidal waveform) known as sinusoidal PMSM and trapezoidal excited (induced voltage has a trapezoidal waveform) known as BLDC motor. A sinusoidal PMSM motor has distributed winding in the stator. It employs rotor geometries such as inset or interior. Rotor poles are so shaped that the voltage induced in the stator phase has a sinusoidal waveform. The stator of trapezoidal PMSM motor has concentrated windings and rotor with a wide pole arc. The voltage induced in the stator phase has a trapezoidal waveform.

It employs rotor geometries such as surface magnets. The speed of PMSM motors is controlled by feeding them from variable frequency voltage/currents. They are operated in self-controlled mode. Rotor position sensors are employed for operation in self-control mode. Alternatively induced voltage can be used to achieve self-control. Different inverter/converter circuits for PMSM motors are used. The MOSFET is used for low voltage and low power applications and IGBT for others. The self controlled variable frequency drives employing a trapezoidal PMSM motors are called brushless dc motors (BLDCM). There are many similarities between BLDC permanent magnet synchronous motor and a dc motor. Like a dc motor, voltage induced is proportional to speed, torque is proportional to armature current and stator and rotor fields remain stationary with respect to each other. However, it does not have brushes and associated disadvantages that is why they are called brushless dc motors as shown in Fig.1.

BLDCM are also called electronically commutated dc motors, because the inverter here performs the same function as the brushes and commutator in a dc motor, i.e. to shift currents between armature conductors to keep the stator and rotor fields stationary (and in quadrature) with respect to each other. BLDCM provide high efficiency, reliability, ruggedness and high precision of control when compared to conventional motors. It has the best torque vs. weight or efficiency characteristics. BLDCM finds applications in turn table drives in record players, tape drive for video recorders, spindle drives in hard disk drives for computers, and low cost and low power drives in computer.

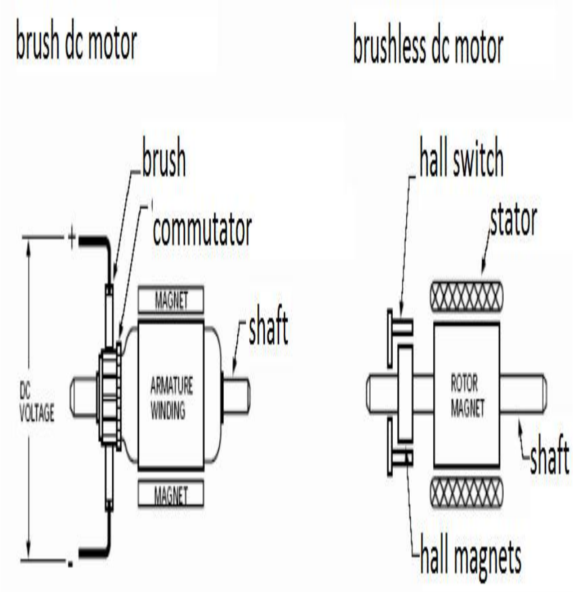


Fig. 1 Conventional dc motor &BLDCM.

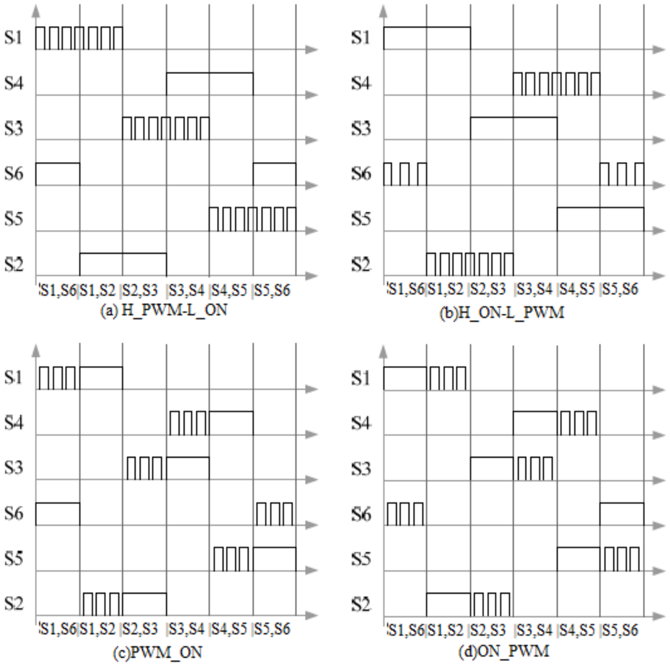
III.PWMCONTROL FOR BLDC MOTOR SPEED CONTROL

Fast acceleration and deceleration driving is essentially required in order to get the fast positioning control response of BLDC motor. Therefore, PWM method must be considered in which braking operation of the BLDC motor is possible to obtain fast position response. And there are different kinds of PWM methods followed in order to achieve this and different PWM methods and the current behavior are discussed below

DIFFERENT TYPES OF PWM METHODS

A UNIPOLAR PWM METHOD

To control of the voltage of the active phases, a PWM signal is applied to a BLDC motor. In general, unipolar PWM methods are used for the motoring operation of a BLDC motor. Unipolar PWM means that one switch of the active phase is in the PWM mode while the other switch of the other active phase is turned on continuously. Generally there are 4 types of PWM modes as shown. In general, the current dynamics of a commutation period can be changed by the selection of PWM methods, the switching states for sector are shown for the PWM on and off periods, respectively



(a) H_PWM-L_ON

(b)H_ON-L_PWM

(c)PWM_ON

(d)ON_PWM

Fig. 2 Unipolar PWM patterns for BLDC motor operation.

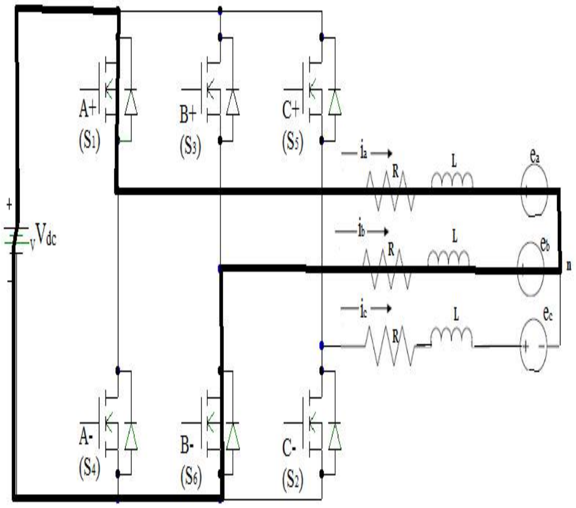


Fig. 3.a Switching states of motoring operation for PWM On case in sector1.

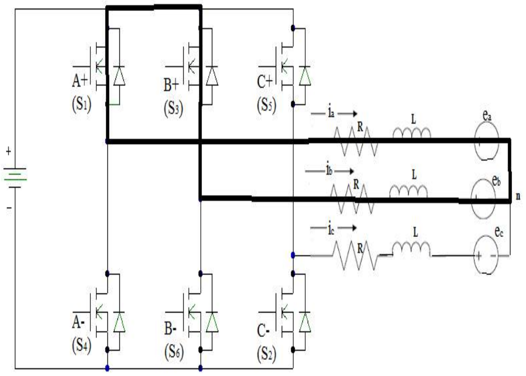


Fig. 3.b Switching states of motoring operation for PWM off case on sector1.

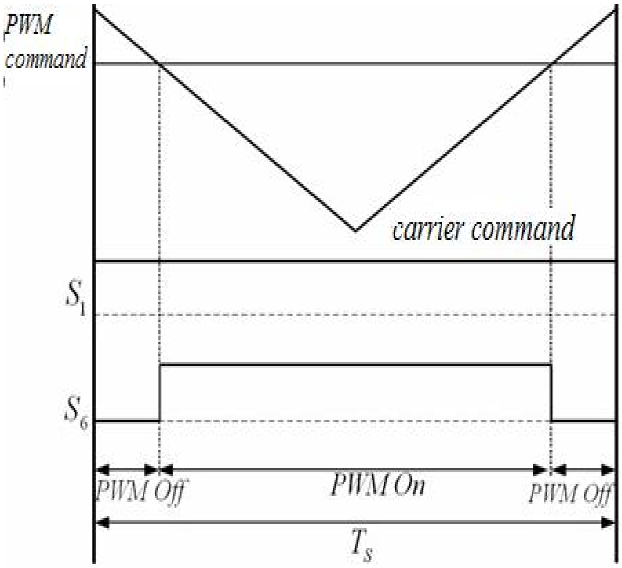


Fig.4 Implementation for Unipolar PWM using Carrier Comparison.

means that the A+ and B- switches are the active switches of the active phases, as can be shown in Fig. 4 In the case of Fig.4, it is assumed that the A+ switch is turned on continuously and that the B- switch is in the PWM mode. Therefore, the B- switch is in the off state during the PWM off period. The implementation of the unipolar PWM method using the carrier comparison method is shown in Fig. 3.3. In this method, the PWM command is compared with the PWM carrier signal, and the switching function S_1 of the A+ switch and the switching function S_6 of the B- switch are determined. Since the A+ switch is in the on state continuously, the positive line to line voltage, V_{ab}, can be applied to the motor for any value of the PWM command. The current dynamics of unipolar PWM can be calculated from the equivalent circuit . In the operation shown in Fig, if it is assumed that the current of the inactive C phase is zero after electrical commutation, then the voltage equation can be written as:

$$\begin{bmatrix} V_{dc} \\ (1-S_6)V_{dc} \end{bmatrix} = \begin{bmatrix} R & 0 \\ 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \end{bmatrix} + \begin{bmatrix} L & 0 \\ 0 & L \end{bmatrix} p \begin{bmatrix} i_a \\ i_b \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \end{bmatrix} + \begin{bmatrix} V_n \\ V_n \end{bmatrix} \tag{1}$$

In this equation, S_6 is the switching function for the B- switch. $S_6 = 1$ means that the B- switch is in the on-state and the B+ switch is in the off-state. $S_6 = 0$ means that the B- switch is in the off-state and the B+ switch is in the on-state by the freewheeling diode.

In sector 1 of the motoring mode of the BLDC motor, which is shown in Fig. 2.9, the phase currents and the EMF can be expressed as:

$$i_a \geq 0, e_a \geq 0, i_b \leq 0, e_b \leq 0. \tag{2}$$

The phase currents in this sector can be written as:

$$i_a + i_b = 0, i_c = 0. \tag{3}$$

The current dynamics of the A phase can be calculated from equation (1) by subtraction of the second row from the first row and ib =−ia. The current dynamics can be expressed as:

$$S_6V_{dc}=2Ri_a+2L\frac{di_a}{dt}+e_a-e_b \tag{4}$$

In sector 1, the EMF is constant as can be seen in Fig. 2.8. As a result, $e_a = E$, $e_b = -E$. Therefore, the current dynamics of the PWM On period and the PWM Off period can be written as follows:

$$L\frac{di_a}{dt}=\frac{V_{dc}}{2}-Ri_a-E \tag{5}$$

$$L\frac{di_a}{dt}=-Ri_a-E \tag{6}$$

In the PWM On period, the A phase current is increased because right side of equation (5) is positive. In the PWM off period, the A phase current is decreased because right side of equation (6) is negative. Therefore, the current can be controlled by the unipolar PWM method in the motoring operation.

IV.PROPOSED LOW RIPPLE BIPOLAR PWM

To overcome this large current ripple problem of bipolar PWM in the motoring operation, a new bipolar PWM method is proposed for BLDC motor control. The proposed method is shown. When the PWM command is given by the current or speed controller in sector 1, the +PWM command is imposed on the A phase pole voltage and the –PWM command is imposed on the B phase pole voltage. The +PWM command is equal to the PWM command and the –PWM command is calculated from the –PWM with the same absolute value but negative. The +PWM value can be a positive value or a negative value depending on the state of the current or speed controller. When the +PWM command is larger than the carrier wave in sector 1, the switching functions are S = 1, S = 0. If the +PWM command is less than the carrier wave, the switching functions are S = 0, S = 1. When the –PWM command is larger than the carrier wave in sector 1, the switching functions are S= 1, S= 0. If the –PWM command is less than the carrier wave, the switching functions are S = 0, S 6 = 1. The switching states for the new bipolar PWM

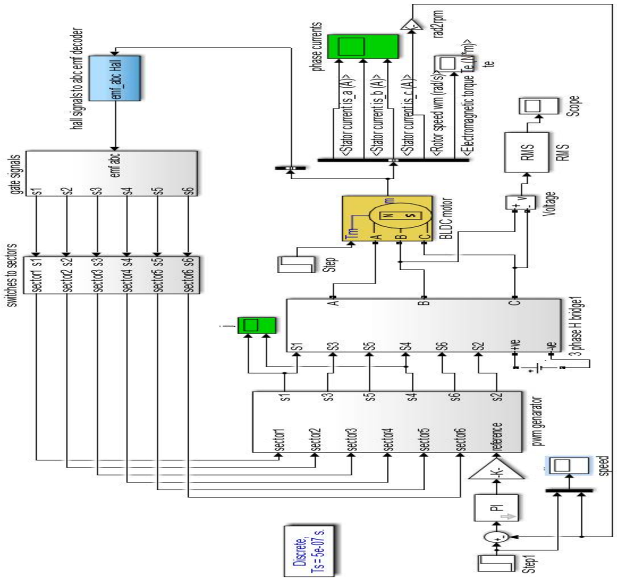


Fig. 5 Simulation block diagram for speed control of BLDC motor by different PWM methods

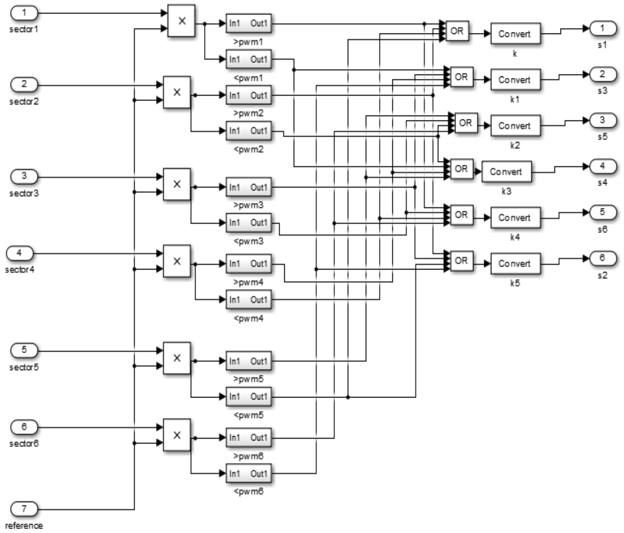


Fig.6 Bipolar PWM generator subsystem internal blocks.

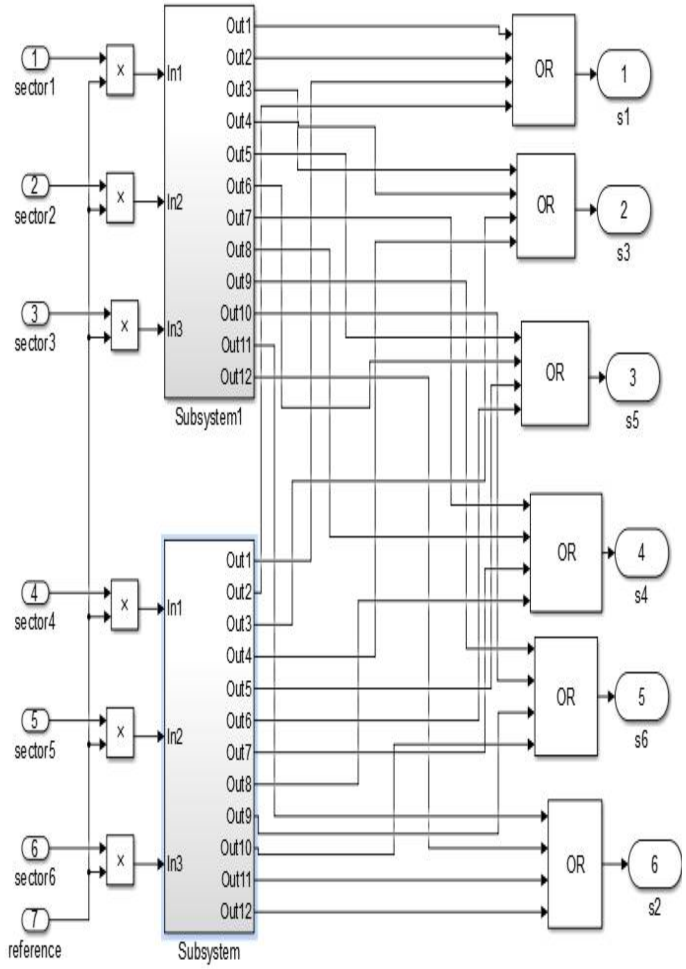


Fig.7 Internal blocks of modified bipolar PWM generator block.

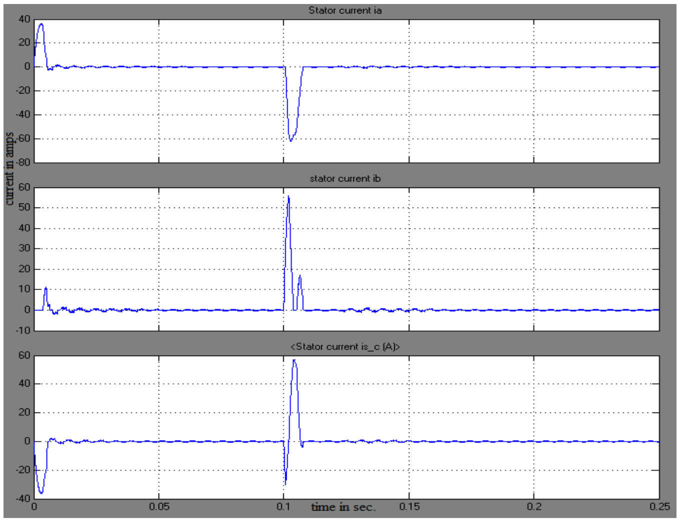


Fig. 8 Three phase currents in unipolar polar PWM

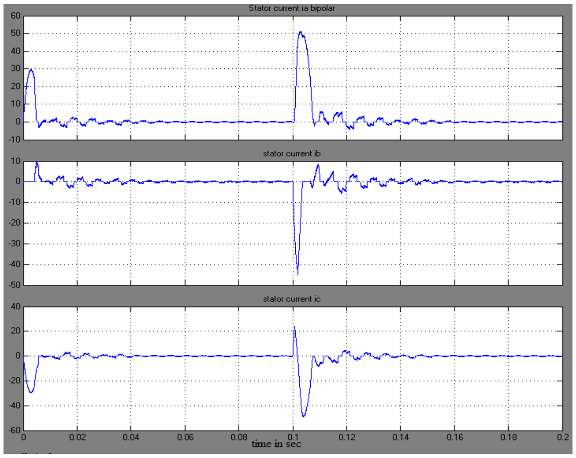


Fig 9 Three phase currents in bipolar polar PWM.

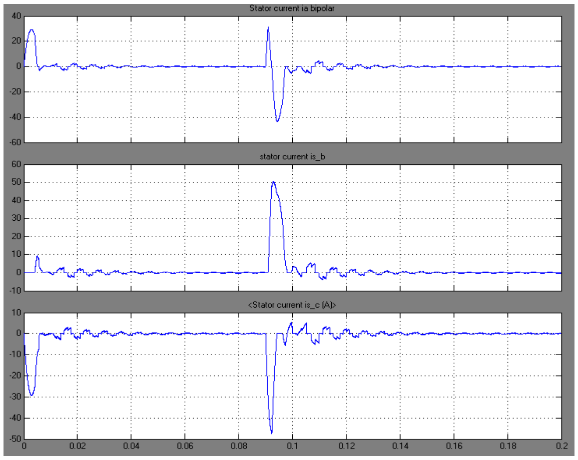


Fig.10 Three phase currents in modified bipolar polar PWM.

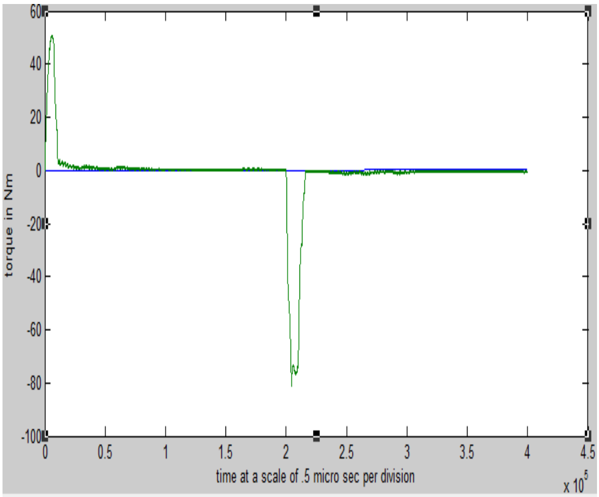


Fig.11 Torque out in Unipolar PWM method.

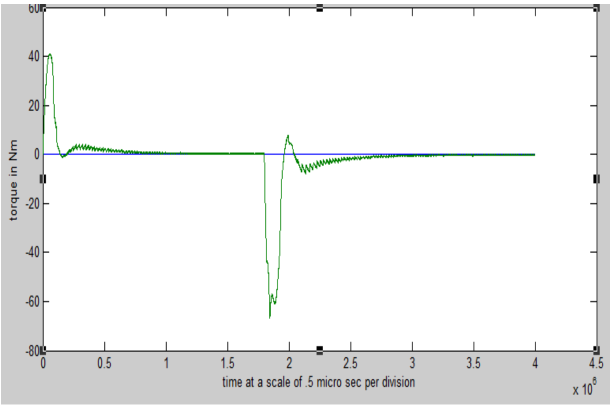


Fig. 12 Torque out in modified bipolar PWM method.

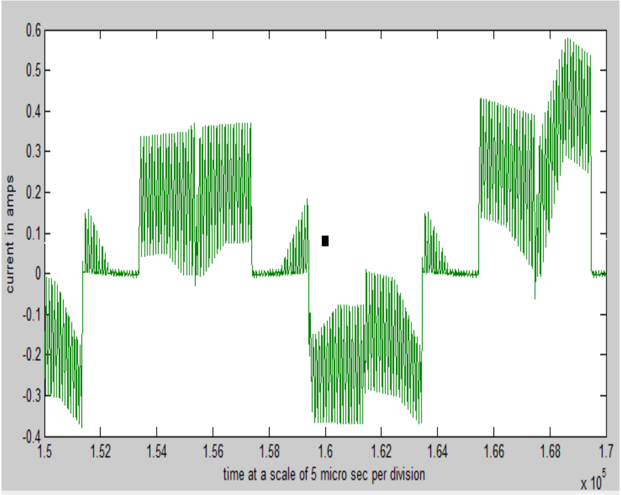


Fig. 13 Current ripple in Unipolar PWM.

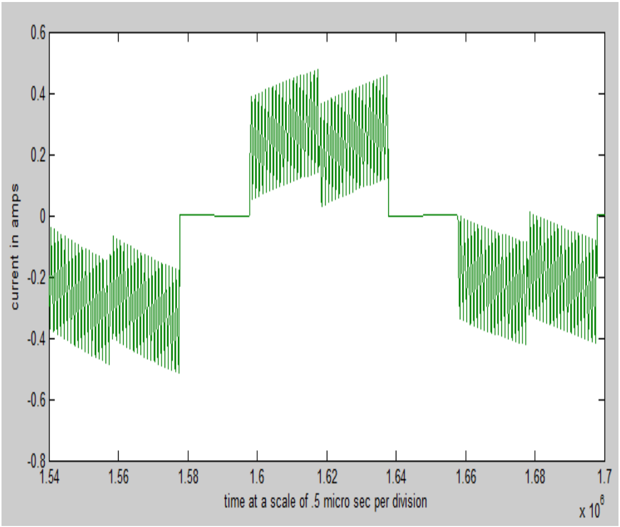


Fig.14 Current ripple in bipolar PWM.

IV.CONCLUSIONS

From the Results it is proved that the current ripple and the torque ripple in the modified bipolar PWM method are low when compared to the bipolar and unipolar PWM methods. And in modified bipolar PWM the speed can be controlled by simple reference signal comparison unlike in unipolar PWM it is necessary to change the selective switches.

Acoustic noise is proportional to the current ripple. Therefore, acoustic noise can be reduced by the modified PWM method. Also, the motor eddy current and hysteresis losses can be reduced by the modified bipolar PWM method. In the modified bipolar PWM method, the current ripples of the motoring mode and the braking mode are both small and the current is also well controlled in the motoring mode and the braking mode. The voltage stress on the switching devices is reduced. The power loss due non ideal nature of the switching devices due to increased allowed turn off time is reduced.

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