Torque Ripple Reduction in BLDC Motor using CUK Converter and Three-level Inverter

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Abstract- This paper investigates the torque ripple reduction in the Brushless Direct current (BLDC) motor drive with three-phase two- level Inverter and three-level Inverter. The Neutral Point Clamped Multi level Inverter is employed to reduce thevoltage stress on each power device due to the use of three levels on the DC bus. TheNPCMLI requires only one dc voltage source similar to two level Voltage Source Inverter. The brushless dc motor has more efficiency compared to all other motor drives. BLDC motor is electronically commuted depends on Hall Effect rotorsignals to reduce the switching losses. The CUK converter is fed to the BLDC motor drivewhich intern provides supply to the drive and improves the power factor. The CUK converteris a type of DC-DC converter that has an output voltage magnitude that is either greater thanor less than the input voltage magnitude. Then, both VSI and NPCMLI connected to BLDC motor is simulated using MATLAB Simulink software.

IndexTerm- CUK,BLDC, VSI, NPCMLI,SPEED, TORQUE.

I. INTRODUCTION

Brushless DC (BLDC) motors are chosen for low power applicationsdue to its high performance, noiseless operation, compact size and low maintenance. The BLDC motors are mostly used in the aviation, medical, aircraft, vehicular and robotic applications. Torque ripples are one of the major drawbacks of the BLDC motors which occur during variable speed operations. In recent trends due to the development of technology in power electronic devices and controllers the ease of providing controls and developing the brushless permanent magnet motors had increased. BLDC motor provides square wave signal at output which is similar to the DC motor. Permanent magnet in the motor helps to provide compact size of the motor and increases its efficiency and reliability.[1]

BLDC motor has high torque to inertia ratio, low maintenance and provides wide range of speed control. The permanent magnet in the BLDC motor acts as rotor and provides continuous flux and the stator contains three phase windings. BLDC motor has low commutation losses due to the presence of inbuilt electrical commutation. BLDC motor results in the generation of low PF and high harmonics when it is excited by uncontrolled bridge rectifiers. Hence these motors are excited by controlled AC/DC converters for providing better power quality at input supply mains. The semiconductor devices used in the converters injects current harmonics which is caused by the distorted voltage waveforms and results in poor power quality and hence required high power filters.

In BLDC motor the torque is primarily depends on the altered waveform of BackEMF. The BLDC motorshave trapezoidal back-EMF waveforms and are fed withRectangular stator currents, which give a theoretically constanttorque. However, in practice, torque ripple exists, mainly dueto EMF waveform imperfections, current ripple and phasecurrent commutation. The current ripples areresulting from the sinusoidal PWMcontrol in Voltage source inverter to the BLDC motor.

DC-DC Convertors commonly known as switching mode regulators used to transform Unrestrained Dc input voltage to a controlled DC output Voltage. The power devices like an inductor, a capacitor and a diode can be operated a switch in the converter.The transfer of power in the CUK converter takes place from starting of the circuit to end of the circuit.CUKconverter is major type of DC-DC Converter is generally referred as Inverter Circuit. Consequently, the CUKconverter employs an additional capacitor and inductor to couple the energy and to decrease the ripple current. The CUK converter is similar to the Buck-Boost Converter or Boost Converter followed by a Buck Converter.

The 2-level inverter is employed to raise the dc-bus voltage to maximum value for the Converter. The voltage control strategy for inverter has been developed to limit the phase currentsandvoltage waveforms from a dc power supply at particular frequency. The 2-level inverter can be designed with low switching frequency and produces high currents and torque ripples are recorded.

The Proportional integral is one of the most used control system with outer current loop and speed control loop. The PI control scheme is used to generate the error between measured speed and reference speed. The parameter variations in the output voltages of CUK Converter are used to regulate the speed of the motor.

II. CUKConverter

CUK converter is a one of the converter with negative output voltage used to reduce the current ripples in the circuit.

The CUK Converter is connected to both 2-level Inverter and three level Inverter to reduce the distortions in the voltage and current in the Circuit.

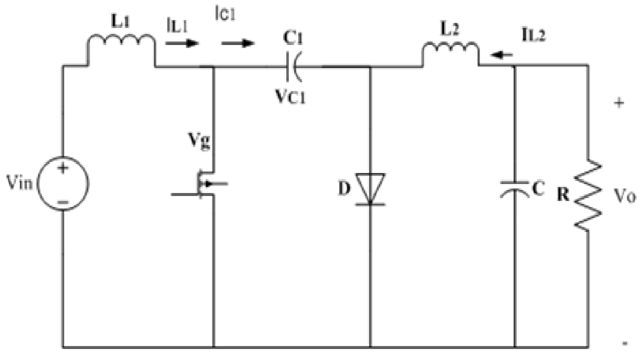

Fig.1: Circuit diagram of CUK converter

For calculating the Inductors and Capacitors for L_1, L_2, $C_1$and C_2.

$$L_1 = \frac{V_{in}\, D}{f_s \Delta_{L_1}} \quad , \quad L_2 = \frac{V_{in} D}{f_s \Delta_{L_2}}$$

$$C_1 = \frac{I_S(1-D)}{f_s \Delta_{v_{C_1}}} , C_2 = \frac{D(V_{in})}{8 \Delta V_C {f_s}^2 L_1}$$

Parameters of Cuk Converter	
Input Voltage	220V
Switching Frequency	50Khz
Inductor(L1)	2.2Mh
Inductor(L2)	1.1mH
Capacitor(C1)	$15\mu F$
Capacitor(C2)	$2500\mu F$

Table 1 Specifications of CUK Converter

A. CONTROL SYSTEM

The Proportional integral technique is a control method that offers multiple benefits like stability, even for wide line and output variations, scaling back the steady state error, robustness, sensible dynamic response and easy implementation. The primary advantage of PI control schemes is its harder response to plant/system. The parameter variations that result in invariant dynamic and static response within the ideal case The PI controller to be developed for the control of CUK convertor permits to regulate the CUK for numerous changes within the parameters.

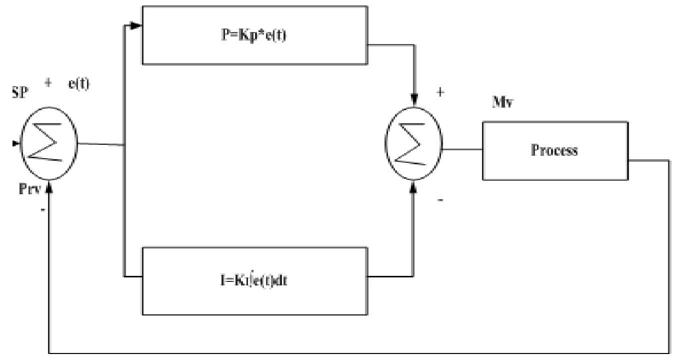

Fig.2: Block diagram of Closed loop Proportional Integral Controller

III. THREE PHASE VOLTAGE SOURCE INVERTER

The main aim of these inverter is to produce an ac output voltage waveform from a dc power supply at fixed or variable frequency used for high power applications .The types of waveforms used in the inverter required for few applications such as commutation torque control, variable speed drives ,flexible ac transmission systems (FACTS) devices and voltage compensators. The output voltage waveform of perfect inverters is based on the width of the pulse and gating signals should be sinusoidal.

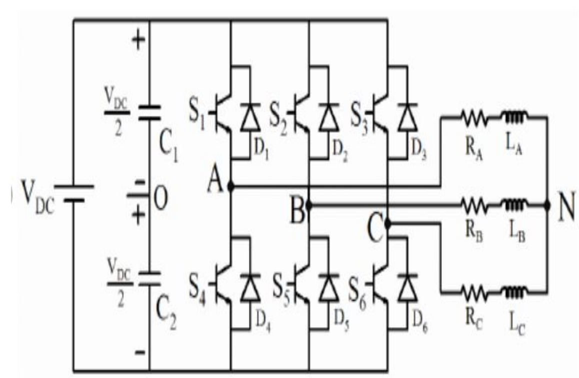

Fig.3: Three Phase Voltage source inverter

IV. BLDC MOTOR

The BLDC motor made up of plastic-coated steel and built with a permanent magnet that consists of rotor and a stator to carry windings of the magnetic coils. The conversion of Electrical energy to mechanical energy is done by the magnetic attractive forces placed between the permanent magnet rotor and a rotating magnetic field which are induced in the stator at same frequency. Hence, motor operation is mainly based on the attraction or repulsion among magnetic poles. The simple back emf trapezoidal commutation is continuously energized all three phases of the motor with sinusoidal current shaped waveforms and gives much smoother torque generation.

The final electromagnetic torque of BLDC motor is given by

$$T_e = \frac{k_t}{2}\left[F(\theta_e)i_a + F\left(\theta_e - \frac{2\pi}{3}\right)i_b + F\left(\theta_e - \frac{4\pi}{3}\right)i_c\right] \quad (1)$$

A. MathematicalModellingof BLDC MOTOR

Brushless Dc Motor phase currents connected to the inverter are turned on at different commutation time period based on the variable speed range. The causes of torque ripple coming from the BLDC machine is due to pulsating torque, vibrations in motor and distortion in trapezoidal back EMF waveform. The suppression of torque ripple is studied during commutation process of the three phase currents for the two level Inverter and three level inverter by current sensing.

The line to line voltage equations which are governing the BLDC motor are given by

$$V_{ab} = R(i_a - i_b) + L\frac{di}{dt}(i_a - i_b) + e_a - e_b \quad (2)$$

$$V_{bc} = R(i_b - i_c) + L\frac{di}{dt}(i_b - i_c) + e_b - e_c \quad (3)$$

$$V_{ca} = R(i_c - i_a) + L\frac{di}{dt}(i_c - i_a) + e_c - e_a \quad (4)$$

$$T_e = K_f w_m + J\frac{dw_m}{dt} + T_L \quad (5)$$

The Back EMFs forthe modelling of Brushless dc motor given by

$$e_a = \frac{k_e}{2} w_m F(\theta_e) \quad (6)$$

$$e_b = \frac{k_e}{2} w_m F\left(\theta_e - \frac{2\pi}{3}\right) \quad (7)$$

$$e_c = \frac{k_e}{2} w_m F\left(\theta_e - \frac{4\pi}{3}\right) \quad (8)$$

$$F(\theta_e) = \begin{cases} 1, 0 \le \theta_e \le \pi \\ 1 - \frac{6}{\pi}\left(\theta_e - \frac{2\pi}{3}\right), \frac{2\pi}{3} \le \theta_e \le \pi \\ -1, \pi \le \theta_e \le \frac{5\pi}{3} \\ -1 + \frac{6}{\pi}\left(\theta_e - \frac{5\pi}{3}\right), \frac{5\pi}{3} \le \theta_e \le 2\pi \end{cases} \quad (9)$$

$$\begin{bmatrix} i_a' \\ i_b' \\ w_m' \\ \theta_m' \end{bmatrix} = \begin{bmatrix} \frac{-R}{L} & 0 & 0 & 0 \\ 0 & \frac{-R}{L} & 0 & 0 \\ 0 & 0 & \frac{-B_v}{J} & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ w_m \\ \theta_m \end{bmatrix} + \begin{bmatrix} \frac{2}{3L} & \frac{1}{3L} & 0 \\ \frac{-1}{3L} & \frac{1}{3L} & 0 \\ 0 & 0 & \frac{1}{J} \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_{ab} - e_{ab} \\ V_{bc} - e_{bc} \\ T_e - T_L \end{bmatrix} \quad (10)$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \\ w_m \\ \theta_m \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ w_m \\ \theta_m \end{bmatrix} \quad (11)$$

Parameter	Symbol	Value
Stator resistance	Rs	1.43Ω
Stator Inductance	Ls	9.4MH
Permanent Magnetic fux	Λθ	0.175Wb
Pole pairs	P	4
Moment of inertia	J	0.002kgm-2

Table2 electrical parameters af BLDC motor modeling

V. SIMULATED RESULTS

The CUK Converter connected to BLDC motor simulation diagram is shown in figure4.

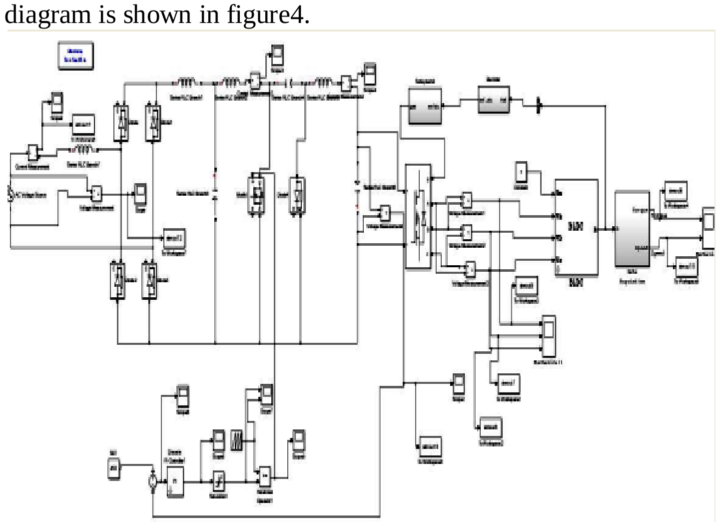

Fig.4: Simulation Diagram of CUK Converter fed BLDC Motor

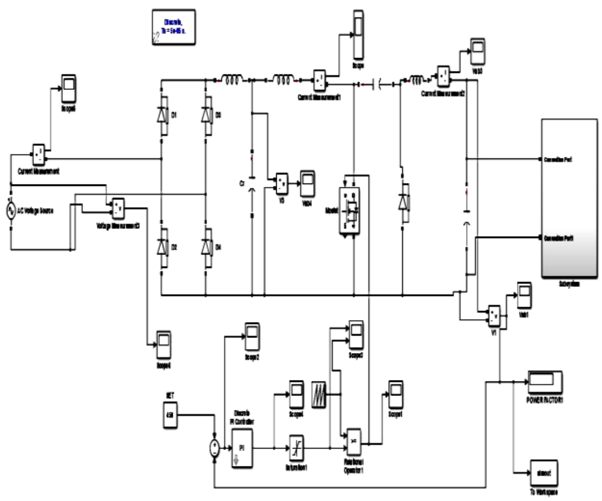

Fig.5: Simulation Diagram of Neutral point Clamped Multilevel Inverter fed BLDC Motor

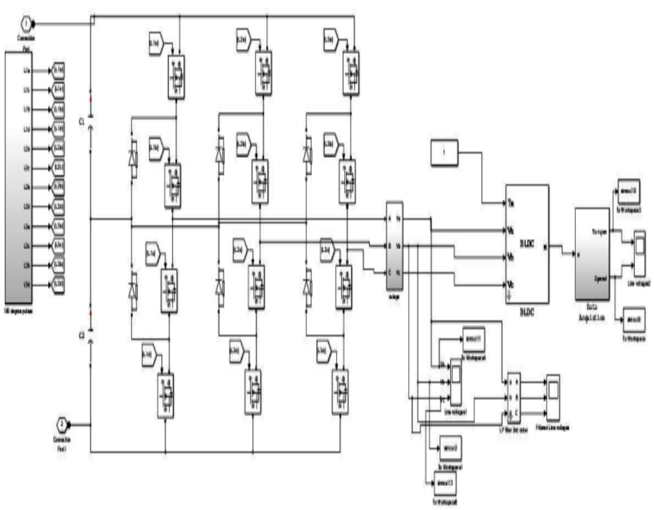

Fig.6: Neutral point Clamped Multi level Inverter

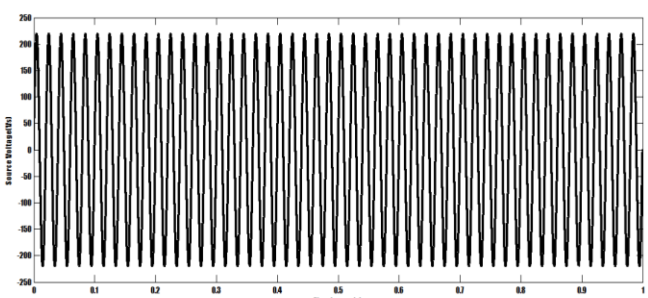

Fig.7: Supply voltage of the system

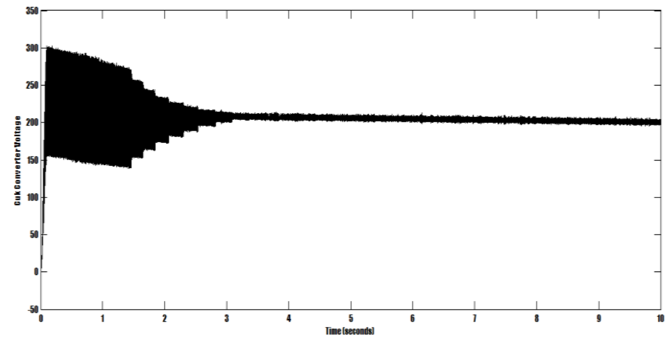

Fig.8: Cuk converter output voltage

The CUK output value increases approximatelyto 300volts.

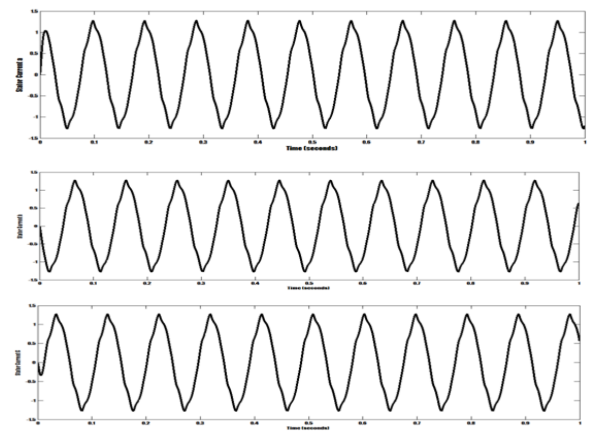

Fig.9: Three phasestator currents ofVoltage Source Inverter fed BLDC motor

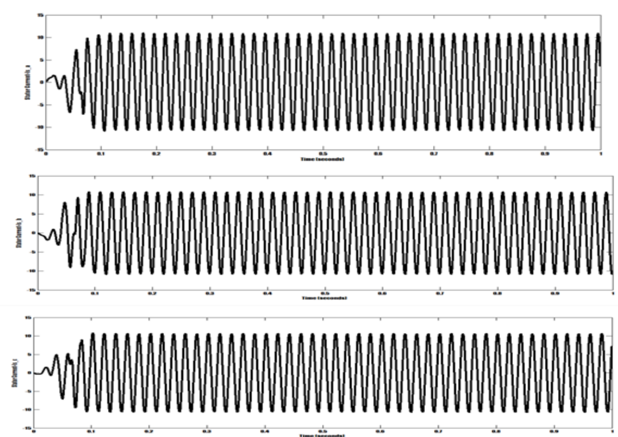

Fig.10: Responses of three phase stator currents of Neutral point Clamped Multi level Inverter fed BLDC motor

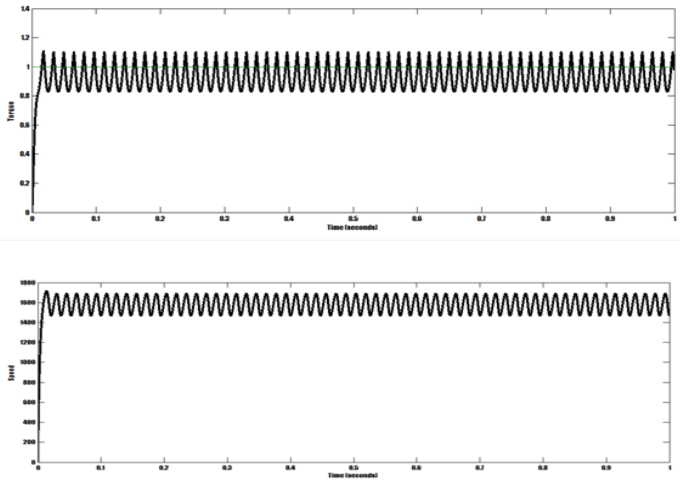

Fig.11: Speed and electromagnetic torque responses ofCuk Converter fed VSIBLDC Motor

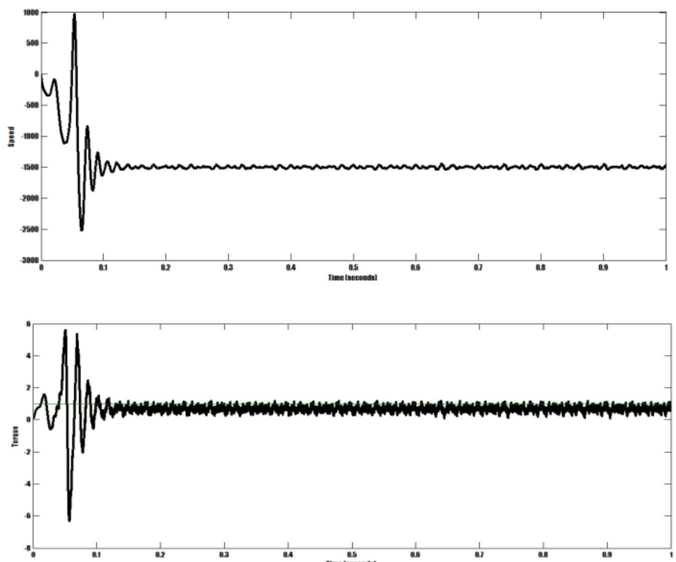

Fig.12: Speed and electromagnetic torque responses of Neutral Point Clamped Multi level Inverter fed BLDC Motor

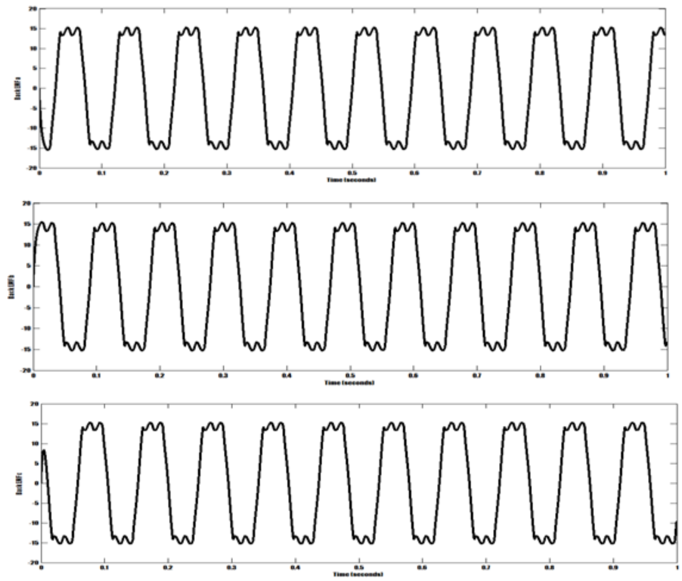

Fig 13.Back EMF waveforms ofthree phase inverter fed BLDC motor

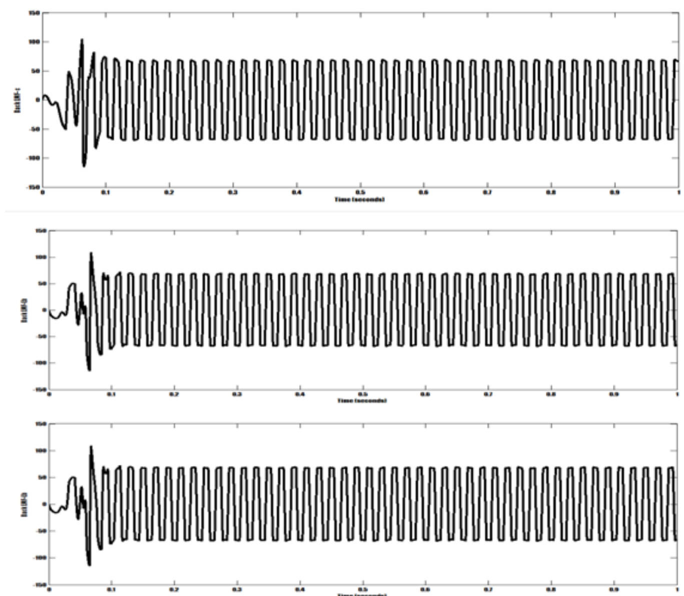

Fig.14: Back EMF waveforms of three phase Neutral Point Clamped Multi level inverter fed BLDC motor

A.Comparison of Cuk converter fed BLDC Motor with two level inverter and three level inverter

Speed(rpm)	Switching Frequency	Torque ripple(Load Torque=1.5 Nm)	Total Converter losses
1000	40k	33.73	4.12
2000	45k	38.67	4.56
3000	50k	39.43	4.67
4000	55k	45.63	4.78

Table 3 Cuk converter connected Voltage Source inverter for BLDC motor load

Speed(rpm)	Switching Frequency	Torque ripple(Load Torque=1.5 Nm)	Total Converter losses
1000	40k	13.73	7.12
2000	45k	18.67	6.56
3000	50k	19.43	8.67
4000	55k	25.63	9.78

Table 4 Cuk converter connected Neutal point clamped Multilevel inverter for BLDC motor load

IV. CONCLUSION

Finally, the torque ripple mitigation is established in the BLDCM. The voltage selector for the circuit is applied to inverterand commutation to acquire significant torque ripple reduction. The simulation results of the BLDCMotor drive system are shown at higher efficiency and mitigation of the torque ripple in the circuit. The outputs of speed and torque of BLDC motor for Voltage source Inverter and Neutral Clamped Multilevel Inverter is verified.

V. REFERENCES

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