Analysis of Brushless DC Motor Drive Using Cascade H-Bridge Inverter Topology

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***Abstract* – In this paper the output of a brushless DC motor drive supplied by a five-level inverter is analysed and explained. A cascaded H-Bridge inverter architecture was chosen for the research because of its many advantages. The simulation model of the brushless DC motor is produced using the brushless DC motor's mathematical model. The whole model of the inverter-fed drive is simulated in MATLAB/SIMULINK. Waveforms depict the inverter output voltage, engine torque, back EMF, and harmonic analysis of the inverter voltage. The output voltage of a five-level inverter is of excellent quality. When supplied by a five-level inverter, the efficiency of BLDC is high, according to the simulation study.**

***Key Words* :BLDC motor, Five Level Inverter, Control, Efficiency.**

I .INTRODUCTION

The pulse width modulated inverters with two levels of output voltage feed regular brush less direct current (BLDC) motors. The output of the BLDC motor drive is affected by the high dv/dt stress induced by the two-level AC voltage. In addition, the normal mode voltages generated lead to motor driving problems. To lessen the impact of the common mode voltage on the output voltage obtained by the inverter circuit, the design of the output voltage obtained by the inverter circuit must be modified[2]. This necessitates a change in the inverter circuit's architecture. For any application, this is achievable by using a multilayer inverter instead of a traditional two-level inverter to drive the BLDC motor.

Multilevel inverters are becoming more prevalent in the electricity business. These inverters are used in a variety of applications, with motor drives being one of the most significant in the electrical engineering arena. The most significant benefit of a multilayer inverter is that it reduces voltage stress during operation as compared to standard two-level inverters' output voltage[10]. Reduced voltage stress is a crucial quality that the BLDC motor requires. A multilayer inverter is one with more than or equal to three voltage levels in the output voltage. The multilayer inverter may be designed for any power level.

There are three types of multilevel inverters. Three kinds of inverters exist: diode clamped inverters, flying capacitor inverters, and cascaded H-Bridge multilevel inverters. In the power business, these three topologies are widely prevalent. Despite their widespread use, each kind of inverter has its own set of drawbacks. As a result, depending on the application, it is always best to use a certain kind of multilayer inverter.

Different kinds of multilevel inverters. In comparison to the other two typical inverters, cascaded H bridge inverters are the most popular. In comparison to the other two kinds of inverters, cascaded H bridge inverters need less components. Another advantage of cascaded inverters is that they may be simply extended to provide any number of output voltage levels [7]. The topology is straightforward and simple to implement. As a result, compared to the other two kinds, cascaded H bridge inverters are the most popular.

The modulation mechanism utilised in the multilayer inverter has a significant impact on the inverter's output voltage. SPWM is a simple and effective modulation method that works well with cascaded multilevel inverters (SPWM). SPWM is a kind of high-frequency modulation. There are numerous modulation methods, however SPWM is favoured in many inverters owing to its simplicity of implementation. The Cascade H bridge inverters are designed in a modular format. As a consequence, the SPWM outperforms all other approaches.

This article uses a five-step cascaded H bridge inverter architecture. The output voltage of the five-level cascaded H bridge inverter powers the BLDC motor. The output of the motor is computed and compared to that of a standard two-level inverter.

The remainder of the document is formatted in the same way. The five-level inverter is explained in Section II. The BLDC engine is modelled in Section III. The simulation performance of the BLDC motor push is shown in Section IV. The thesis is included at the end of the paper.

II. FIVE LEVEL CASCADEDH - BRIDGE INVERTER

The cascaded H bridge inverter consists of a series of cascaded H bridge cells. The number of H bridges required is dictated by the number of levels in the inverter. Each H bridge cell has the ability to provide three levels of output. Optimistic, negative, and empty are the three levels. Two H Bridge cells should be able to create five different output voltage values [3].

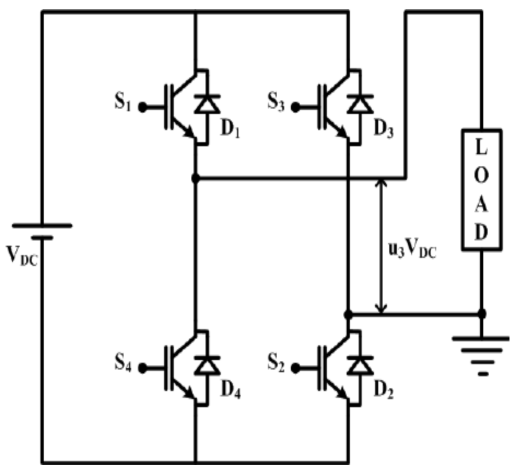

Figure 1: H-Bridge circuit.

The Fig 1 shows the H bridge circuit. This can generate three levels in output voltage waveform. The switching tables to generate three voltage levels are shown in Table 1, which is shown below.

TABLE I Switching states for three levels.

Switches Turn ON	Voltage Level
S1, S2	Vdc/2
S3,S4	-Vdc/2
S2,S4	0

The following Fig 2 shows the circuit of an N level cascaded H bridge inverter.

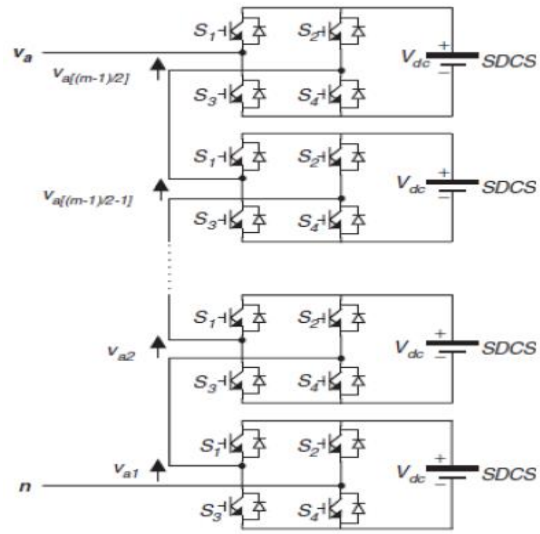

Figure 2: N Level H-Bridge circuit.

The entire number of floors is N, and the total number of H bridges is S. A five-level inverter requires two H-bridges, a seven-level inverter requires three H-bridges, and so on, according to this connection. The study in this paper takes into account a five-level inverter. The construction and function of the five-level inverter, as well as its switching states, are described further below.

A. *Five Level Inverter:*

The topology of the cascaded H bridge five level inverter is shown below. This circuit consists of two H-Bridges connected in cascaded mode.

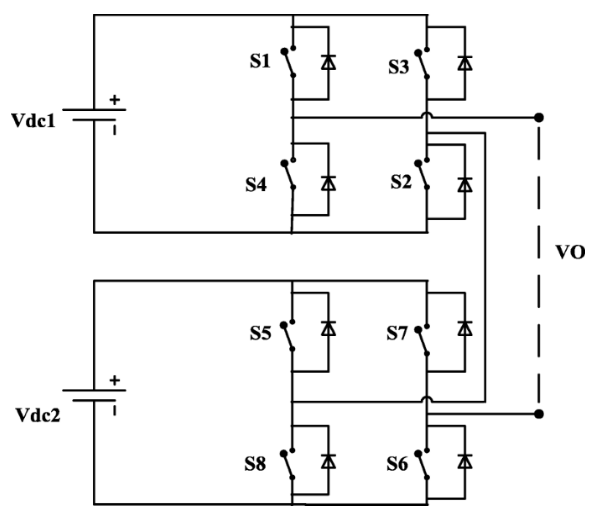

Figure 3: FIVE Level H-Bridge circuit.

In a five-level inverter, there are eight switches in total, four switches each bridge. The total voltage level of the cascaded H-bridge inverter is twice that of DC sources. This sort of inverter may be made in a short amount of time.

TABLE II Switching states for five levels.

Switches Turn ON	Voltage Level
S1, S2, S6, S8	Vdc/2
S1, S2, S5, S6	Vdc
S2, S4, S6, S8	0
S3, S4, S6, S8	-Vdc/2
S3, S4, S7, S8	-Vdc

The above table represents the switching of various states in a five level inverters to produce various levels. Minimum four switches are required to produce each level in output voltage. The load can be either resistive, inductive, and/or it can be a motor. In this case the load is BLDC motor.

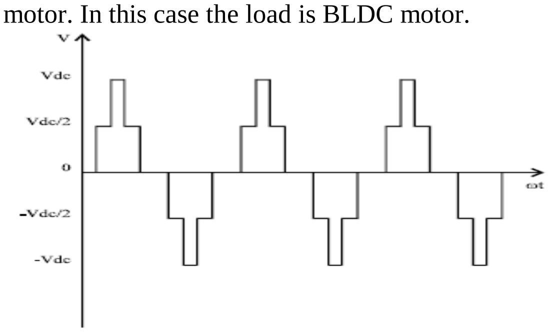

Figure 4: Five level inverter output voltage.

The device is called a symmetrical multilevel inverter when the DC sources have the same values. The output voltage's model wave form is shown in the diagram above. Two positive voltage levels, two negative voltage levels, and a zero voltage level make up a five-level output voltage waveform.

B. Modulation of Inverter:

The current study uses the sinusoidal pulse width modulation approach, as described in the introduction. SPWM stands for "single-phase, high-frequency modulation." A modulating wave and a carrier wave make up the signal. On the basis of the frequency of a carrier wave, pulses are generated and applied to the inverter switches. The modulation index of the inverter determines the frequency values..

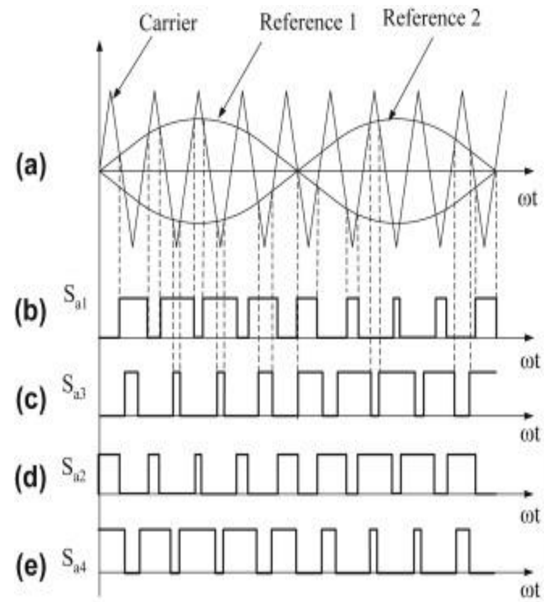

Figure 5 :Five level inverter PWM.

The above Fig shows the methodology of generating the PWM pulses for a five level cascaded H bridge multilevel inverters using SPWM method.

III. BLDC MODEL

As opposed to other types of engines, BLDC has very low ohmic errors. But for a few differences, BLDC motors are close to synchronous motors. These motors come in a variety of configurations. To feel the direction of the rotor, this motor needs an inverter circuit. This is attributed to the lack of a brush and a commutator. The diagram below depicts the design of a BLDC engine.

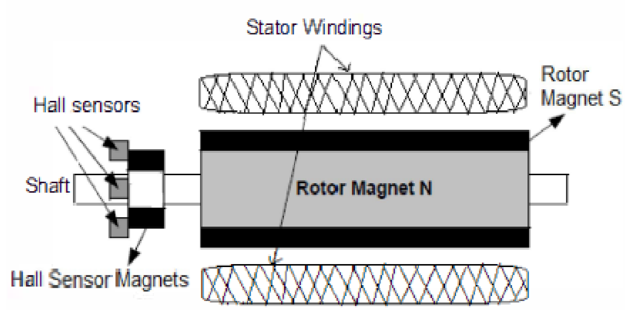

Figure 6 BLDC Motor.

BLDCs are employed in various applications in several industries. Following are the advantages of BLDC motors.

- Low noise.

- Fast dynamic response.
- Good torque.
- Long life.
- Good efficiency.

A. Mathematical Model of BLDC Motor:

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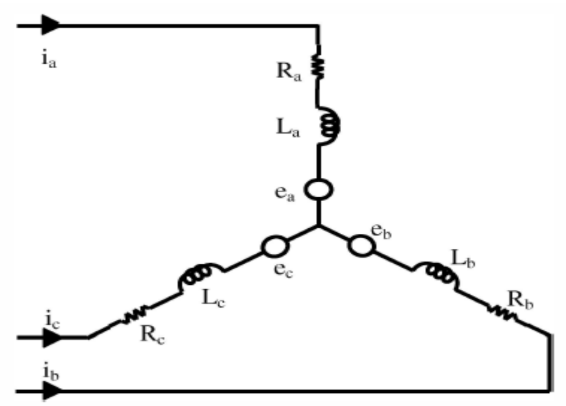


Figure 7 :Equivalent Circuit BLDC Motor.

The BLDC's statistical concept is used to derive its mathematical model. Permanent magnets are installed in the rotors of BLDC motors. This motor may be driven by some kind of alternating current waveform, such as sinusoidal or square wave. Several assumptions are made during the creation of this BLDC motor mathematical model.

The mathematical model of the BLDC motor is expressed as

$$V_a = Ri_a + L\frac{di_a}{dt} + e_a \quad (1)$$

$$V_b = Ri_b + L\frac{di_b}{dt} + e_b \quad (2)$$

$$V_c = Ri_c + L\frac{di_c}{dt} + e_c \quad (3)$$

The above series of equations is known as the BLDC motor's mathematical model. The same model can also be represented in matrix form, as seen below.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R+pL & 0 & 0 \\ 0 & R+pL & 0 \\ 0 & 0 & R+pL \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

In above mathematical model V is the voltage supplied, and e is the back EMF generated. The back EMF wave forms are shown in Fig 8 below.

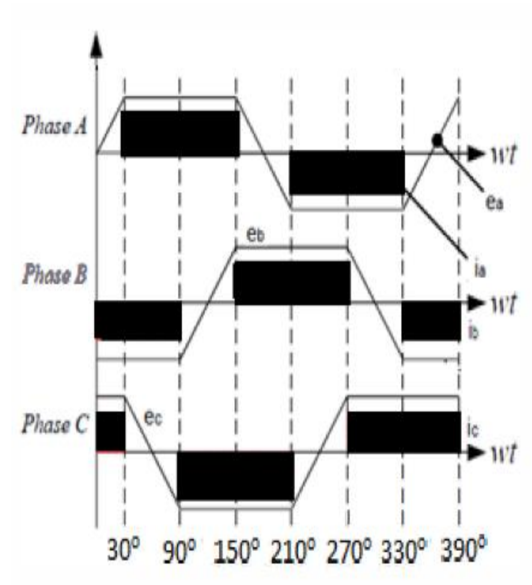


Figure 8: Back EMF of BLDC Motor.

Following are the equations for the back EMF in BLDC motor.

$$e_a = k.\omega.f(\theta)$$
$$e_b = k.\omega.f(\theta - \tfrac{2\pi}{3})$$
$$e_c = k.\omega.f(\theta + \tfrac{2\pi}{3})$$

The electromagnetic torque is

$$T_e = \frac{i_a e_a + i_b e_b + i_c e_c}{\omega} = i_a.K.f(\theta) + i_b.K.f\left(\theta - \frac{2\pi}{3}\right) + i_c.K.f\left(\theta + \frac{2\pi}{3}\right)$$

The resultant torque is

$$T_e - T_L = J\frac{d\omega}{dt} + B\omega$$

The above expression is used in torque calculation.

IV. SIMULATION RESULTS

This section discusses the simulation results of a five-level cascaded H bridge inverter and the BLDC drive supplied by the five-level cascaded H bridge inverter. Both simulations are run in the MATLAB/SIMULINK environment..

A. Five Level Inverter Simulations:

The simulation circuit of a five-level cascaded H bridge inverter with resistive load is shown in the diagram below. To achieve three phase voltages in a three phase inverter, two extra phases are necessary.

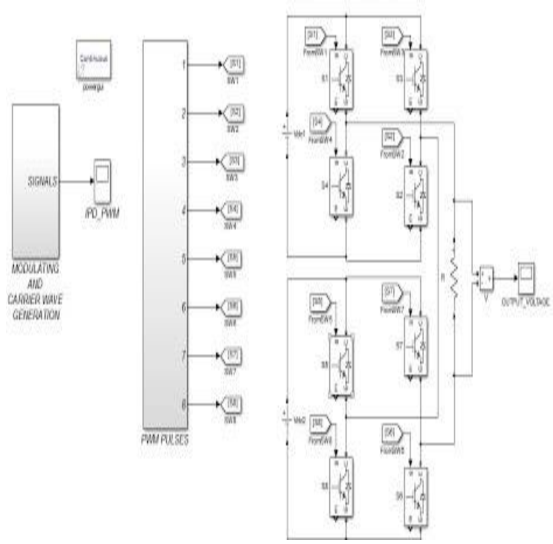


Figure 9: Simulation Circuit of a 5 Level Inverter.

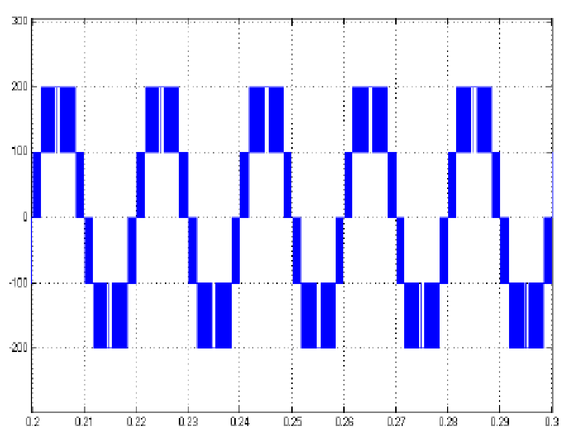


Figure 10: Output voltage of a 5 Level Inverter

The above Fig shows the output voltage obtained by a five level CHB inverter. The wave form consists of two positive levels, two negative levels, and a zero level.

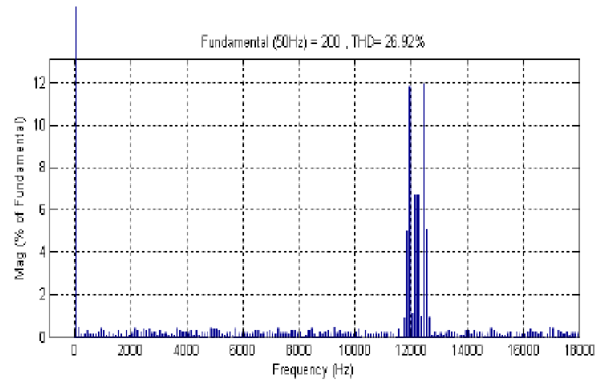


Figure 11: FFT of output voltage of a 5 Level Inverter.

The above Fig 11 shows the FFT spectrum of a output voltage obtained by five level CHB inverter. The THD value is 26.92%. The below table give the number of components required for the CHB inverter.

TABLE III Inverter components.

	CHB Multilevel inverter
Phase to neutral voltage levels	P_{nv}
Line to line voltage levels	$(2P_{nv}-1)$
No. of switches per phase	$2(P_{nv}-1)$
No.of power module per phase	$(P_{nv}-1)/2$
Output voltage THD	same
No. of isolated DC source per phase	$(P_{nv}-1)/2$
Modulation strategy	same
Power of each isolated Dc source	$2P/3(P_{nv}-1)$

B. BLDC Drive Simulations:

The block diagram of a inverter fed BLDC is shown in Fig below.

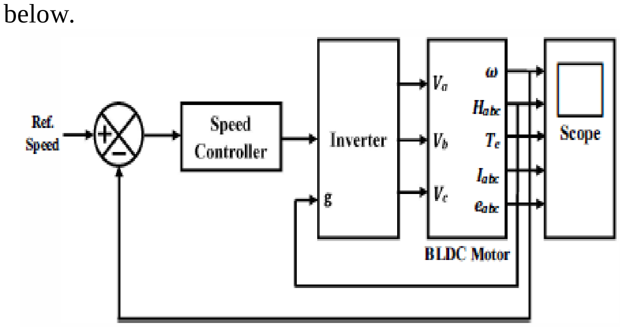


Figure 12: Schematic of BLDC drive.

The specifications of the BLDC motor considered in the analysis are shown in table below.

TABLE IV Motor Specifications.

Motor parameters	Values
No. of poles, P	4
Moment of inertia, J	0.0002 Kg-m^2
Stator Resistance, R	0.7 Ω
Stator Inductance, L	0.0272 H
Rated Speed , N_r	3000 rpm
Damping Constant, B	0.2
Back EMF Constant, K	0.513 volt/rad/sec
Load Torque, T_L	4 N-m

The below Fig is the MATLAB simulation diagram of a CHB inverter fed three phase BLDC motor drive circuit.

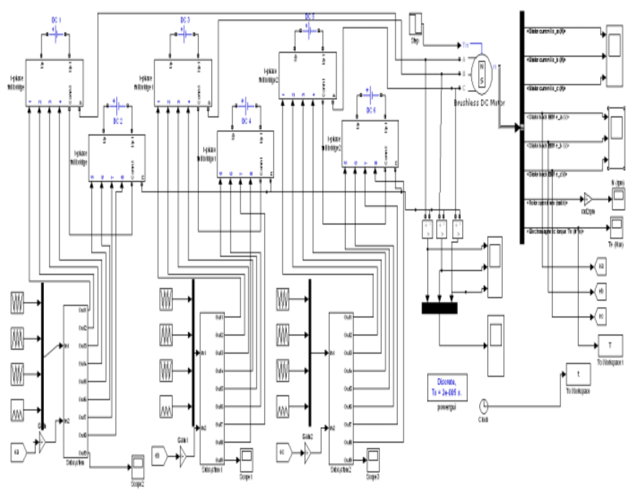
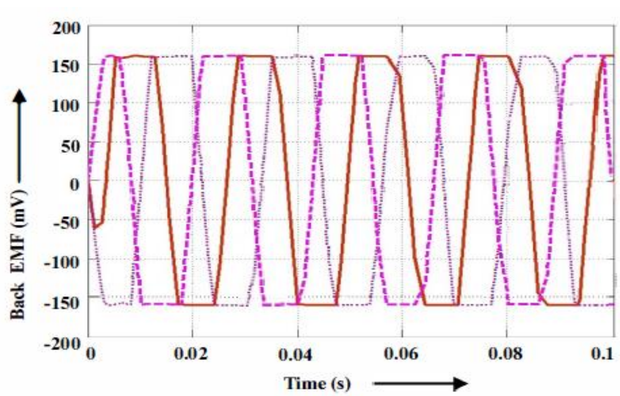
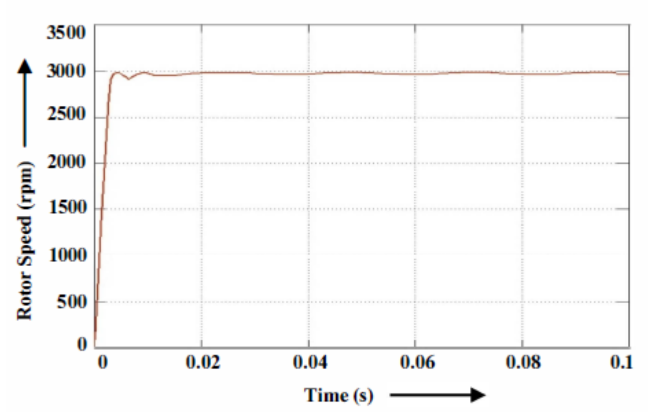


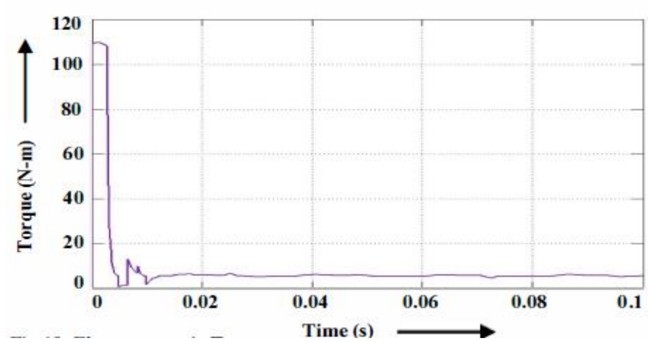
Figure 13: Simulation of BLDC drive.



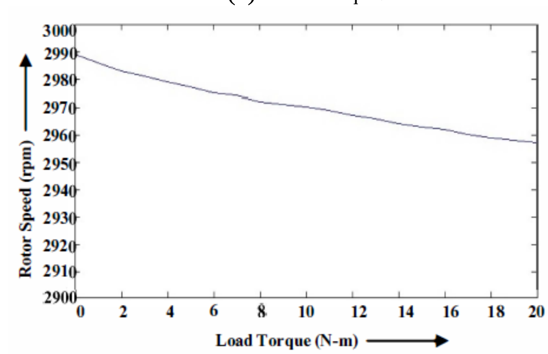
(a) Back EMF.



(b) Speed of motor



(c) Load torque.



(d) Torque variation.

Figure 14: Various waveforms of BLDC drive.

V. CONCLUSIONS

The performance of the five-level CHB inverter-fed BLDC motor drive has been evaluated, and it has been determined to be good. The back EMFs are extremely similar to trapezoidal waveforms, and the torque waveform is smooth. The variation of torque with load is also investigated, and the performance with load variation is satisfactory. Overall, it can be stated that when a BLDC is supplied by a multilayer inverter, the voltage stress is reduced, resulting in excellent back EMFs and sufficient torque..

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