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IMPLEMENTATION OF FIVE LEVEL DIODE CLAMPED MULTILEVEL INVERTER BASED BLDC MOTOR DRIVE

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Abstract:

BLDC motors are frequently utilized in high power, high voltage applications because of their improved efficiency, straightforward construction, reduced cost, minimal maintenance requirements, and high torque or high output power per unit volume. Electrical commutators (inverters) are necessary to drive BLDC motors. Though performance of the Classical inverter is good, harmonic issues exist with two level inverters. So to reduce the harmonics multilevel inverters are chosen. In this paper a five level neutral diode clamped multilevel inverter is used for this purpose. By analysing the various parameters of BLDC motor such as stator current, rotor speed, Electromagnetic torque and bus voltage its proved that efficiency of BLDC motor is improved in this method. The analysis is done using simulation utilizing the MATLAB Simulink tool and results shows the improvement in efficiency of BLDC motors.

Keywords **—Five level Multilevel Inverter, BLDC Motor, THD.**

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I. INTRODUCTION

A brushless DC motor is an electric motor that uses electronic commutation instead of brushes and a mechanical commutator. Based on their inherent advantages, BLDC motors are perfect for a variety of applications applications requiring quick dynamic speed responses since they are incredibly efficient and simple to control across a wide speed range, including industrial automation, electric cars, and renewable energy systems. These advantages include high efficiency, low maintenance, decreased weight, and more compact construction.

In the motor drive sector, Multi-Level Inverter (MLI) topologies have been frequently introduced [1]. The five-level order [2] has the advantage of making multilayer voltage waveform generation possible using devices with lower voltage ratings. In multilevel inverters, sinusoids with different voltages and frequencies can be produced using pulse width modulation (PWM) techniques [9]. Three-phase sinusoids for varied voltages can be created by sending the MOSFETs multiple gate signals.

There are several PWM implementation methods for inverters that have been developed [9]. Sine-Triangle PWM (SPWM) and Space Vector PWM (SVPWM) are the two primary methods of PWM generation for multilevel inverters. In order to generate the PWM signal for multilevel Sine Triangle PWM, a reference signal and a number of level-shifted carriers are compared. In this thesis, a five-level diode clamped multilevel inverter fed BLDC motor is described [7]. The voltage across the switches only contains 50% of the dc bus voltage. These characteristics almost quadruple the power rating of the voltage source inverter for a particular semiconductor device [5]. The recommended inverter reduces the harmonic contents using a multicarrier PWM method. It produces excellent motor currents. Here, the speed of a BLDC is precisely controlled by a five level diode clamped multilevel inverter.

In a diode-clamped multilevel inverter, also known as a flying capacitor or a capacitor-clamped inverter, a series of capacitors is used to clamp the voltage levels at specific points [10]. The clamping capacitors are connected in parallel with the power switches. The diode-clamped multilevel inverter can achieve multiple voltage levels by connecting the clamping capacitors to different voltage levels. The output voltage waveform is determined by the power switches' switching states [14]. To obtain the necessary voltage levels, the switches must be properly sequenced as part of the control strategy for a diode-clamped inverter [17]. During operation, the clamping capacitors charge and discharge, ensuring that the voltage levels are maintained at specific values. In comparison to two-level inverters, the diode-clamped multilevel inverter delivers less voltage stress on the power switches and less harmonic distortion. However, it is more complicated and expensive since a greater number of clamping capacitors are needed.

The five-level diode-clamped multilevel inverter is used in various applications [19] that require high-quality power conversion and precise control. It finds applications in motor drives, renewable energy systems, uninterruptible power supplies (UPS), and electric vehicle charging infrastructure, among others. The five-level diode-clamped multilevel inverter utilizes clamping diodes and capacitors to achieve multiple voltage levels. It offers improved voltage resolution, reduced harmonic distortion, and lower voltage stress on the switches. This technology is suitable for applications that require high-performance power conversion and precise control.

II. PROPOSED SYSTEM

The five-level diode-clamped multilevel inverter-based BLDC motor drive system utilizes a diode-clamped multilevel inverter topology to efficiently control and drive the BLDC motor. The diode-clamped multilevel inverter consists of several H-bridge modules connected in series. Each H-bridge module comprises four power switches (typically Insulated-Gate Bipolar Transistors or IGBTs) and clamping diodes. The H-bridge modules are stacked on top of each other to form a cascaded structure. The objective of the diode-clamped multilevel inverter is to generate multiple voltage levels to drive the BLDC motor effectively. In the case of a five-level configuration, the inverter can produce five distinct voltage levels: Vdc (positive), Vdc/2, 0V (neutral), -Vdc/2, and -Vdc (negative). The clamping diodes and capacitors connected to the H-bridge modules help to maintain these voltage levels. Pulse Width Modulation (PWM) techniques are commonly employed to generate the required voltage waveforms and control the speed and torque of the BLDC motor accurately. To ensure voltage balance across the clamping capacitors and prevent voltage imbalances, the control strategy needs to monitor and regulate the capacitor voltages. This helps maintain the desired voltage levels and prevents overvoltage conditions. The five-level diode-clamped multilevel inverter-based BLDC motor drive offers several advantages. It provides improved voltage quality with reduced harmonic distortion, resulting in smoother motor operation and reduced torque ripple. The topology helps minimize voltage stress on the power switches, leading to enhanced reliability and longevity of the inverter system. Additionally, the system can achieve precise motor control and high energy efficiency.

A. PROPOSED BLOCK DIAGRAM

The block diagram for a diode-clamped five-level multilevel inverter typically consists of several functional blocks that describe the major components and operations of the inverter. Here's a basic block diagram for a diode-clamped five-level multilevel inverter: DC source, Voltage Regulator, Multilevel inverter, PWM driver circuit, BLDC motor.

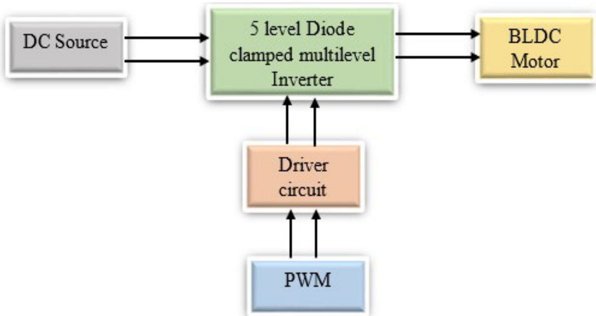

Fig.2.1: Proposed Block diagram for Diode clamped five level multilevel inverter based BLDC motor drive.

DC Power Supply block represents the source of DC power that provides the input voltage (Vdc) to the inverter. It can be a battery, rectified AC supply, or any other DC power source. The voltage regulator block ensures a stable and consistent DC link voltage (Vdc) for the multilevel inverter's proper operation. It maintains the desired voltage level required for the multilevel inverter. Multilevel Inverter is the core component of the system. The multilevel inverter consists of H-bridge modules with power semiconductor devices (IGBTs) and diodes. It generates multiple voltage levels (Vdc, 2Vdc, 0V, -Vdc, -2Vdc) to drive the output.

The PWM control block generates signals based on the reference signal (usually a sinusoidal waveform) and a high-frequency carrier signal. The PWM signals control the switching of the IGBTs in the multilevel inverter to achieve the desired output voltage levels. The output filter block is used to smooth the output voltage waveform, removing high-frequency switching harmonics and reducing total harmonic distortion (THD). It ensures that the output voltage supplied to the BLDC motor is nearly sinusoidal. The BLDC motor is the load driven by the diode-clamped five-level multilevel inverter. The smooth and multilevel output voltage from the inverter controls the speed and torque of the motor. In summary, the block diagram showcases the essential components of a diode-clamped five-level multilevel inverter system driving a BLDC motor. The inverter generates multiple voltage levels using PWM control, ensuring efficient and precise control over the BLDC motor's operation.

B. VOLTAGE REGULATOR

In a diode-clamped five-level multilevel inverter, a voltage regulator is not a standard or mandatory component. The DC voltage source itself, such as a battery or rectified AC supply, typically acts as the voltage source for the inverter.

The primary role of the voltage regulator, if present, is to stabilize the DC link voltage and prevent it from exceeding or dropping below safe operating limits. By keeping the voltage at an optimal level, the voltage regulator helps in achieving stable and reliable multilevel inverter performance, minimizing the risk of overvoltage or under voltage situations that could potentially damage the inverter components.

The need for a voltage regulator in a diode-clamped five-level multilevel inverter largely depends on the specific application and the characteristics of the power source. In many cases, the DC voltage source itself can provide a reasonably stable voltage, making the addition of a voltage regulator unnecessary. However, in situations where voltage fluctuations or variations are significant, a voltage regulator can be beneficial to ensure the smooth and efficient operation of the multilevel inverter and the connected load, such as a BLDC motor.

C. DIODE CLAMPED MULTILEVEL INVERTER

Diode-Clamped Multilevel Inverters are a particular kind of multilevel inverter used in high-power applications to produce various voltage levels from a DC power source. They are sometimes referred to as Neutral Point Clamped Inverters or NPC Inverters. To produce effective and low-harmonic output voltage waveforms, it is frequently employed in electric drives, grid-connected applications, and renewable energy systems.

A power source, such as a battery or a rectified AC supply, provides a DC voltage (Vdc) to the diode-clamped multilevel inverter. There are multiple H-bridge modules in the inverter. Four power semiconductor devices (IGBTs) are stacked in a bridge arrangement within each H-bridge module. These components regulate the voltage and current flow across the output terminals. Each capacitor in the DC circuit is connected in parallel with a pair of diodes, which limits the voltage to a certain range. These diodes make sure that each capacitor's voltage stays within a specific range. The quantity of capacitors utilized affects how many voltage levels the inverter can produce. Three capacitors are utilized in a conventional three-level diode-clamped multilevel inverter, enabling the voltage levels of 0V, Vdc, and 2*Vdc. More voltage levels can be achieved with different combinations. A Pulse Width Modulation (PWM) technique is utilized to produce the required output voltage waveform. Each H-bridge module's IGBT switching periods are modified by the PWM control to produce the necessary output voltage levels. Compared to conventional two-level inverters, the output voltage waveform of the diode-clamped multilevel inverter is a stepped approximation of a sine wave with less harmonic distortion. Multiple voltage levels can be produced, allowing for greater control of the output voltage, smoother motor running, and less electromagnetic interference. The diode-clamped multilevel inverter is a versatile and reliable solution for various high-power applications, especially when high-quality output voltage waveforms and efficient power conversion are required.

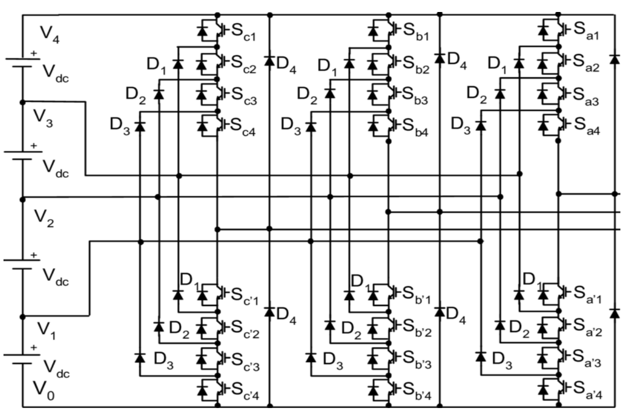

Fig.2.2: Five level Diode clamped Multilevel Inverter Circuit Configuration

D. PULSE WIDTH MODULATION IN FIVE LEVEL MULTILEVEL INVERTER

Pulse Width Modulation (PWM) is used to create the appropriate output voltage waveform with different voltage levels in a five-level diode-clamped multilevel inverter. The PWM technique controls the ON and OFF times of the semiconductor switches (usually IGBTs) in the H-bridge inverter, which in turn determines the effective voltage across the output terminal. This allows the inverter to produce the desired output voltage levels - Vdc, 2Vdc, 0V, -Vdc, and -2Vdc.

The reference signal that represents the desired output voltage waveform must be created first. A sinusoidal waveform with the desired frequency and amplitude commonly characterizes this reference signal. The resolution of the PWM technique and the calibre of the output waveform are determined by the number of levels in the multilevel inverter (in this case, five levels).

Next, a high-frequency carrier signal (usually a triangular waveform) is generated. This carrier signal has a much higher frequency than the desired output voltage waveform. The reference signal is then compared with this carrier signal to determine the switching times of the semiconductor switches.

One of the most important variables in the PWM approach is the modulation index (MI). It shows the proportion of the reference signal's to the carrier signal's amplitude. The PWM waveform's pulse width is governed by the modulation index. PWM pulses are generated based on a comparison between the reference signal and the carrier signal. When the reference signal's amplitude is greater than the carrier signal at a specific instant in time, the matching switch in the H-bridge inverter turns ON. If the reference signal's amplitude is smaller than the carrier signal, on the other hand, the switch is switched OFF. The switching pattern is created by repeatedly comparing the reference signal with the carrier signal throughout the course of one complete cycle of the reference waveform. The switches in the H-bridge inverter are thus controlled by a series of pulses that are created. The high-frequency carrier signal component is taken out of the PWM waveform by passing it through a low-pass filter after it has been created. The intended multilayer output voltage waveform with fewer harmonics is the result of this.

By properly controlling the PWM technique and the switching pattern, a five-level diode-clamped multilevel inverter can produce a nearly sinusoidal output voltage with reduced harmonic distortion, making it suitable for various high-power applications.

E. WORKING PRINCIPLE

The working principle of a diode-clamped five-level multilevel inverter driving a Brushless DC (BLDC) motor involves using multiple voltage levels to control the speed and torque of the motor. The multilevel inverter provides an efficient and smooth power supply to the BLDC motor, allowing precise control over its rotational speed and enabling regenerative braking. Here's a brief explanation of the working principle:

The diode-clamped five-level multilevel inverter consists of H-bridge modules with power semiconductor devices and diodes. Three capacitors are connected in series with the DC power supply to achieve the five voltage levels - Vdc, 2Vdc, 0V, -Vdc, and -2Vdc. To control the BLDC motor's speed and torque, Pulse Width Modulation (PWM) techniques are employed. The inverter generates PWM signals by comparing the desired motor voltage waveform (typically sinusoidal) with a high-frequency carrier waveform.

Three stages are normal for BLDC motors. The H-bridge modules are switched on and off by the inverter's PWM signals, which also control the current flow through the motor's phases in the right order. The BLDC motor's rotor is driven by a revolving magnetic field produced by the commutation of the phase currents. The diode-clamped five-level multilevel inverter can achieve the various voltage levels needed to operate the BLDC motor by controlling the switching of the power semiconductor devices through PWM. By changing the PWM signals' duty cycle, the effective voltage delivered to the motor can be managed.

The duty cycle of the PWM signals determines the average voltage supplied to the BLDC motor, which, in turn, controls its speed and torque output. Higher duty cycles result in higher motor speeds, while lower duty cycles lead to lower speeds. This allows for precise control over the motor's rotational speed and torque. The diode-clamped five-level multilevel inverter also facilitates regenerative braking in BLDC motor applications. During braking, the motor can act as a generator, converting mechanical energy back into electrical energy. The inverter can control this regenerative process to charge the DC link voltage or feed energy back to the power supply, increasing overall system efficiency.

The multilevel inverter's ability to produce multiple voltage levels results in a nearly sinusoidal output voltage waveform, reducing harmonic distortion. This leads to smoother motor operation, less electromagnetic interference, and improved power quality. In summary, the diode-clamped five-level multilevel inverter effectively controls the BLDC motor's speed and torque through PWM techniques and voltage level modulation. Its application in driving BLDC motors enables efficient and reliable motor operation, making it suitable for various industries, including electric vehicles, industrial automation, and consumer appliances. In below table, "ON" represents that the corresponding switch is turned ON, allowing current to flow through it. "OFF" represents that the corresponding switch is turned OFF, blocking current flow through it. "D1," "D2," and "D3" represent the diodes connected to the midpoint of the DC link, clamping the voltage at specific levels. "Vdc" represents the positive DC link voltage. "0V" represents the reference or neutral voltage level. "-Vdc" represents the negative DC link voltage.

Switching State	G11	G12	Diode D1	Diode D2	V_{OUT} at Terminal A (VA)	V_{OUT} at Neutral Point (VN)
State 1	ON	OFF	Reverse	Forward	Vdc	0V
State 2	OFF	ON	Forward	Reverse	0V	-Vdc

Table.1 The switching states in one part of the Five-level diode clamped inverter

III. RESULT AND DISCUSSION

THD is a measurement of the harmonic content of the inverter's output voltage or current. Fig. 3.1 illuminates the output voltage or current waveform's THD percentage. THD is a measure of harmonic-induced signal distortion.

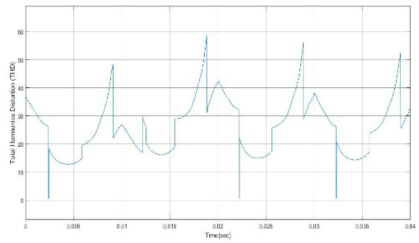

Fig. 3.1: Output of the Total Harmonics Distortion

The stator current in a BLDC (Brushless DC) motor drive refers to the electrical current flowing through the stator windings of the motor. The motor's stator, which is a stationary component, houses the wire coils. For a steady state load torque of 10Nm, the BLDC motor's maximum amplitude of stator current is 13 A. The stator current and time are plotted on the graph. The output of the BLDC motor drive's stator current is shown in Fig. 3.2.

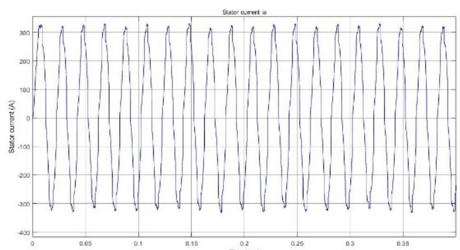

Fig.3.2: Stator current of BLDC motor drive

The rotating speed of the motor's rotor or shaft is referred to as the "rotor speed" in BLDC (Brushless DC) motor drives. A BLDC motor drive system must carefully monitor and regulate this speed because it has a direct impact on the output performance of the motor. The relationship between Speed in RPM and Time in Sec is used to plot the graph of the BLDC motor's rotor speed. The Rotor Speed of the BLDC Motor Drive is shown in Fig. 3.3.

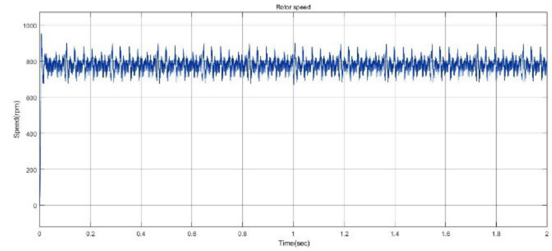

Fig.3.3: Rotor speed of BLDC motor drive

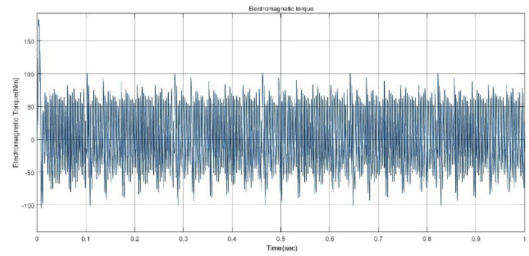

Fig.3.4: Electromagnetic torque of BLDC motor drive

The mechanical torque generated by the interaction of the magnetic fields of the stator and the permanent magnets of the rotor is referred to as the electromagnetic torque in a BLDC (Brushless DC) motor drive. The electromagnetic torque of a BLDC motor drive is shown in Fig. 3.4.

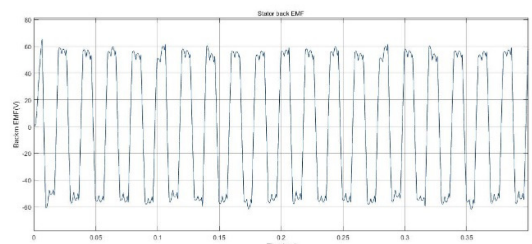

Fig.3.5: Back EMF of BLDC motor drive

The Back Electromotive Force (Back EMF), in a BLDC (Brushless DC) motor drive is an electrical voltage that is induced in the motor's windings when the rotor (the rotating part of the motor) is in motion. It is an important phenomenon to understand in BLDC motor drives. Fig3.5 shows the result of Back EMF of BLDC motor drive.

IV. CONCLUSION

A diode clamped multilevel inverter for BLDC motor drive applications has been discussed in this paper. The multicarrier PWM technique can be utilized to produce an output with low harmonics, which results in a high-quality output voltage. A five level multilevel BLDC motor drive was modelled and simulated using Simulink. Overall harmonic distortion is very low as compared to a conventional inverter. The inverter system, which has fewer harmonic losses and can save a significant amount of energy, can be used by industries that require adjustable speed drives. The future scope of a diode-clamped five-level multilevel inverter driving BLDC motors is promising, as it combines the benefits of multilevel inverter technology with the advantages of BLDC motor systems. The future scope of diode-clamped five-level multilevel inverters driving BLDC motors lies in continued research and development to improve power capacity, efficiency, control strategies, and integration in various applications. As technology advances, these systems have the potential to become more widespread and play a crucial role in advancing electric mobility, industrial automation, and renewable energy integration.

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