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Performance of Three Level Diode Clamped Multilevel Inverter for Closed Loop v/f co Technology

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Abstract: This paper focuses on the implementation of a three-level diode-clamped multilevel inverter (DCMLI) using eight MOSFET-based switching devices, designed to control a three-phase induction motor through a closed-loop V/f control strategy. The system utilizes Space Vector Modulation (SVM) to optimize inverter performance and motor response. Simulation and real-time testing are conducted to evaluate essential parameters such as total harmonic distortion, efficiency, power factor, and system dynamics under various load conditions. The V/f control method ensures consistent voltage-to-frequency ratio, contributing to reliable motor operation over a range of speeds. Findings highlight the inverter's suitability for energy-efficient and high-precision industrial motor control applications.

Keywords: Three-level Diode Clamped Multilevel Inverter (DCMLI), Mosfet, Closed Loop, Matlab Simulation

I. INTRODUCTION

Multilevel inverters are now a popular option, particularly for medium or high-power scenarios, due to the growing need for accurate, dependable, and efficient motor control systems in contemporary applications. Superior output waveforms using fewer harmonic distortion and switching losses may have been produced by these inverters. positioning them ahead of conventional power electronic converters. This research specifically investigates the Three-level DCMLI topology using 8 switches, integrated with a closed-loop V/f (voltage-to-frequency) control strategy for driving three-phase asynchronous induction motors.

Traditional two-level inverters have been widely used in industrial motor drives; however, they often suffer from drawbacks such as increased harmonic distortion, electromagnetic interference, common-mode voltage issues, and high switching stress. Multilevel inverter topologies mitigate these issues by generating output voltages from multiple discrete DC levels. The Three-level DCMLI finds a balance among performance and system complexity enhancement, making it a suitable candidate for medium-power motor drive systems.

The V/f control technique is a popular scalar control approach in industrial environments due to its simplicity, effectiveness, and robustness. It maintains a constant voltage-to-frequency ratio to ensure proper magnetic flux in the motor at all speeds, thereby avoiding over-excitation at low speeds and under-excitation at higher speeds. The incorporation of a closed-loop feedback mechanism further enhances the control system's dynamic response and stability under fluctuating load conditions.

This study utilizes the SVM technique for controlling the DCMLI, known for its benefits such as optimal switching sequence, lower switching losses, and better utilization specifies the voltage within the DC-link. The MOSFETs are utilized as the switching elements owing to their high-speed switching performance, low on-state resistance, and suitability for the selected power range. The control system is equipped with voltage and current sensors to provide real-time feedback signals, enabling accurate closed-loop operation.

The induction motor, widely recognized for its ruggedness, cost efficiency, and minimal maintenance needs, is selected as the load for this study. Despite its advantages, the nonlinear characteristics and sensitivity to parameter variations of induction motors make them challenging to control, making them an ideal platform for evaluating inverter performance.

This research is significant in its potential to enhance industrial motor drive systems where energy efficiency, high power quality, and operational reliability are critical. By evaluating the performance of a Three-level DCMLI under closed-loop V/f control using SVM, this study offers valuable insights for engineers and designers working in sectors such as industrial automation, HVAC systems, water treatment, and renewable energy systems.

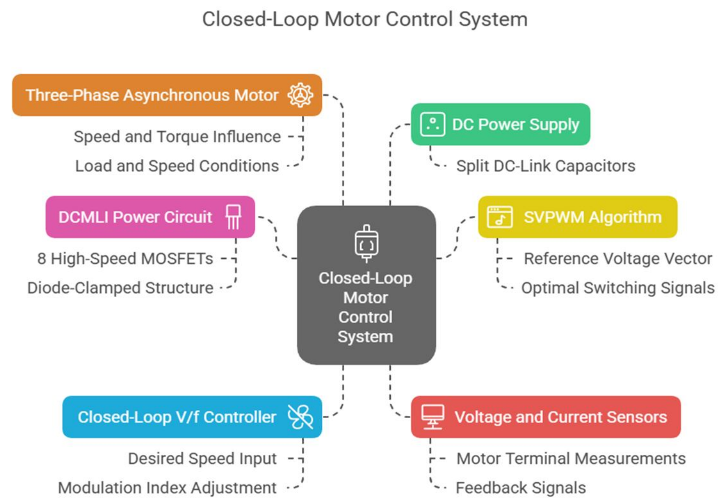


Fig 1 shows the flowchart of system

II. DIODE CLAMPED MULTILEVEL INVERTER

The DCMLI, also called the NPC inverter, consists of:
Multiple DC bus capacitors to split the input voltage into equal parts.
A set of power semiconductor switches (IGBTs or MOSFETs) arranged per phase.
Clamping diodes that connect intermediate levels to the set the voltage across switches to the neutral point and restrict it..
For an n-level inverter, it requires:
(n–1) capacitors,
2(n–1) switches per phase,
(n–2) clamping diodes per phase.

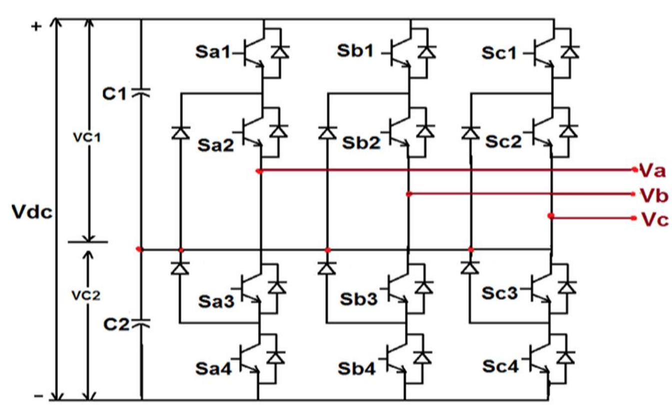


Fig 1. Three phase Three level Diode Clamped MLI

From fig.1 show the three-phase three level DCMLI consists of three legs connected to a shared DC bus. Several capacitors are used to divide this DC bus voltage. The number of switches above each diode in the circuit determines the voltage level that each diode must block., multiplied by the input DC voltage. For a DCMLI with “n” output levels, a single leg includes (n−1) capacitors and (n−2) clamping diodes. The total number of power switches needed is 2(n−1) per leg. In a three-level configuration, 12 switches are employed, typically labeled in sequence as Sa1, Sa2, Sb1, Sb2, Sc1, Sc2, Sa1', Sa2', Sb1', Sb2', Sc1', and Sc2' respectively. The two capacitors used by the DC bus are designated C1 and C2., and each phase leg incorporates two clamping diodes, totaling six for the inverter. These clamping diodes function to constrain the voltage across the switches, enabling the inverter to produce a stepped (staircase) AC output voltage.

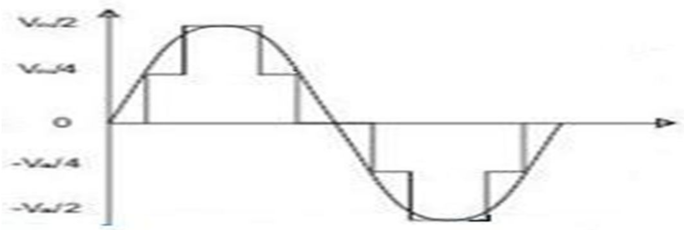


Fig.2 output waveform of 3level diode clamped MLI

A. Advantages

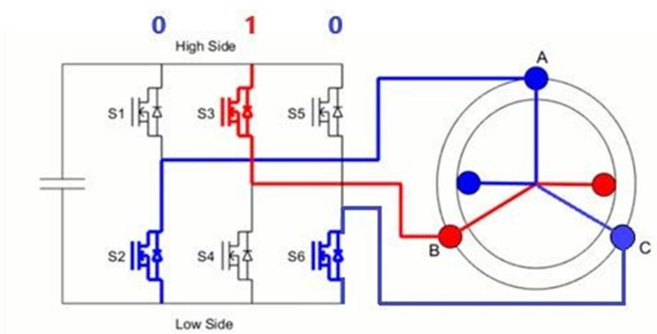
Improved Output Quality: Generates smoother voltage waveforms with lower harmonics.
Reduced Voltage Stress: Each switch blocks only a portion of the total DC voltage.
High Efficiency: Due to low switching losses and reduced filter requirements.
Modular Design: Suitable for medium- to high-voltage applications.

B. Limitations

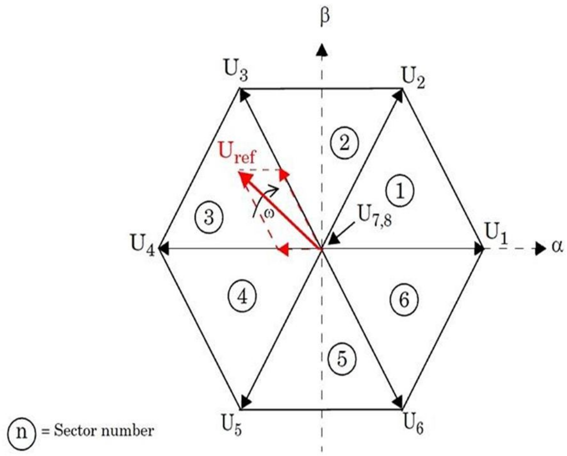
Increased Number of Components: More switches and diodes required as voltage levels increase.
Complex Control: Balancing capacitor voltages and switching strategy is difficult.
Limited Scalability: Diode count increases rapidly for higher levels, making it less practical beyond five levels.

III. PWM TECHNIQUE

In the pulse width modulation technique we use SVPWM. SVPWM is a powerful method for controlling multilevel inverters, particularly the three-level diode-clamped type, which is widely used for high-performance motor drives. This technique generates a modulated waveform by approximating the desired voltage vector through the use of appropriate switching states over each switching cycle



Typically, an inverter has three legs with six power switches (S1 through S6), each of which represents a motor phase. With each lower switch (S2, S4, S6) being the complement of its matching upper switch (S1, S3, S5), these switches are operated in pairs.This ensures that both switches in a leg are never ON simultaneously to avoid short circuits.
Each switching combination in the three-phase inverter generates a specific voltage pattern at the motor terminals. These output voltages can be represented as space vectors, which are defined by both their magnitude and direction within a two-dimensional coordinate system. When plotted, these space vectors form a hexagonal structure, frequently known as the space vector hexagon.
The six active vectors correspond to the inverter states where power is delivered to the motor, each pointing in a unique direction spaced 60 degrees apart. These vectors vary in orientation but maintain equal magnitude. The remaining two zero vectors do not contribute to the rotation of the magnetic field, as they apply zero voltage to the motor windings. By appropriately combining these vectors over time, Space Vector Modulation (SVM) enables smooth and efficient control of the motor’s electromagnetic torque and flux.



Space vector hexagon with basic vectors U1-U8.

Space Vector	S1	S3	S5
U1	1	0	0
U2	1	1	0
U3	0	1	0
U4	0	1	1
U5	0	0	1
U6	1	0	1
U7	0	0	0
U8	1	1	1

During each PWM cycle, the Uref is constructed by applying a combination of two adjacent active vectors (such as U3 or U4) for specific durations, and inserting a zero vector (such as U7 or U8) during the remaining interval. By adjusting the duration of time each vector is active through careful control of the switching pattern and pulse timing the inverter can produce an output voltage vector with a desired angle and magnitude.

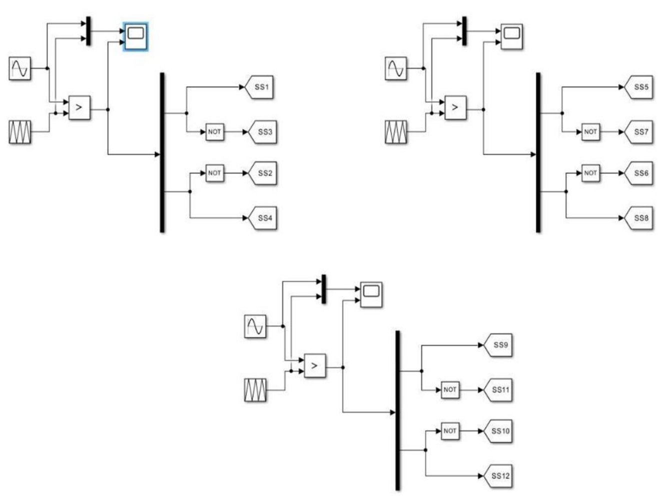


Fig3 Simulation of SVPWM

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This process enables the generation of a smoothly rotating voltage vector, matching the desired performance criteria of the motor control system. The primary objective of SVM is to ensure that the synthesized output closely tracks the reference vector in every PWM cycle, resulting in efficient and precise motor operation.

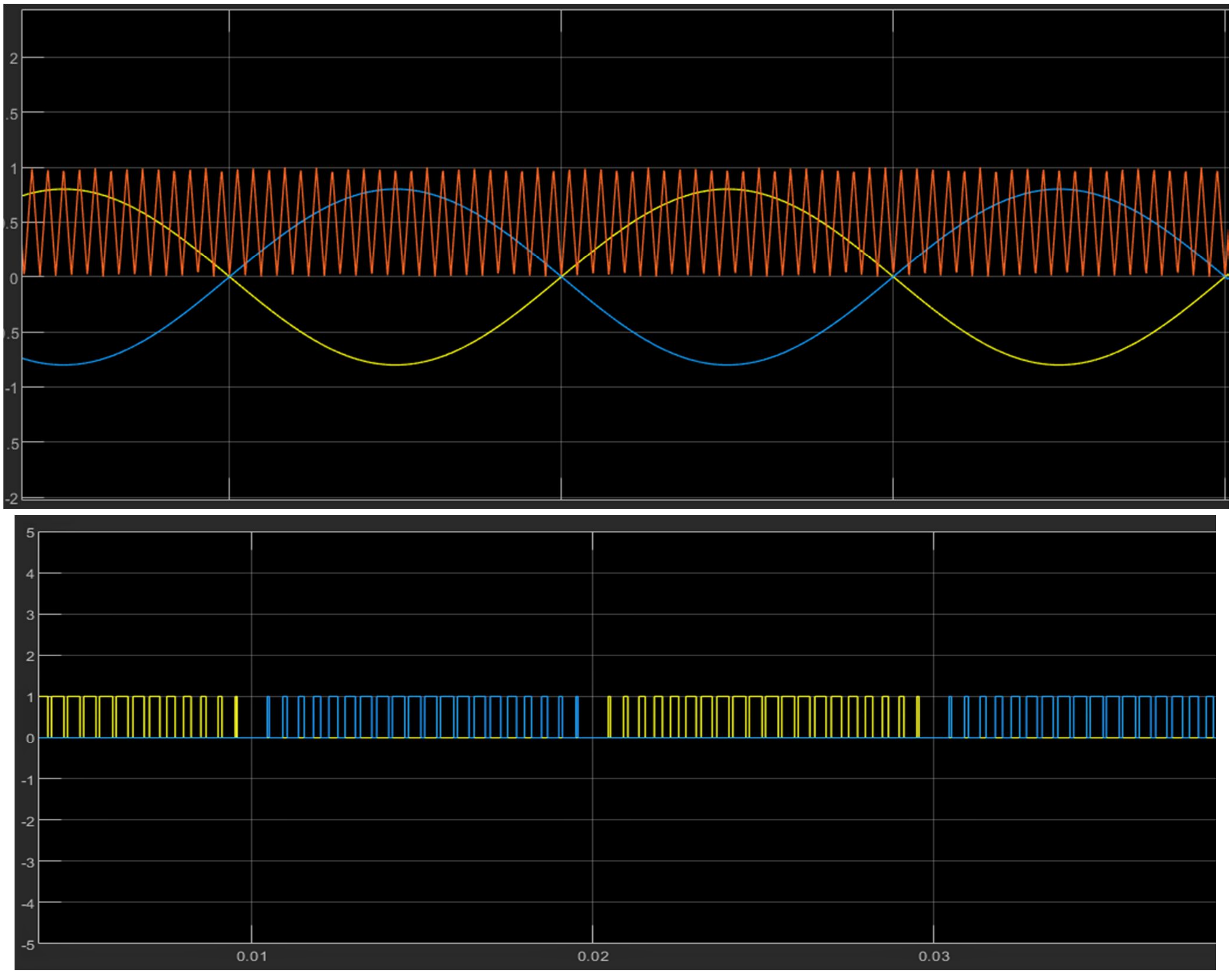
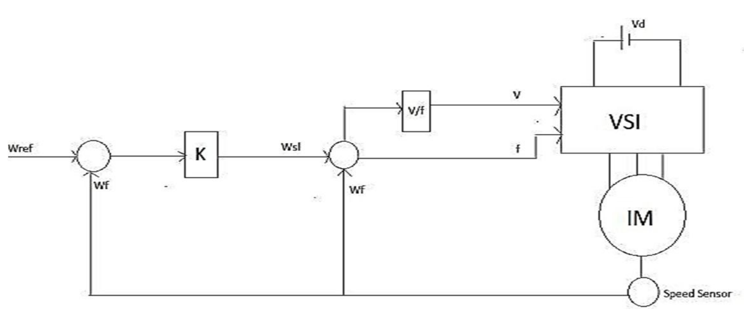


Fig4 When the modulation wave & the carrier wave are compared, a gate pulse is produced.

IV. CLOSED-LOOP V/F CONTROL

The applied voltage and frequency to an induction motor are adjusted to control its speed and torque in a closed-loop voltage/frequency (V/f) control system. 1. The supply frequency and motor speed are directly correlated. In this control technique, the frequency is adjusted according to the desired speed of the motor. The frequency-to-voltage ratio is changed to make sure that the voltage-to-frequency ratio remains constant. This prevents saturation in the motor and ensures efficient operation.



A feedback loop continuously monitors the motor's actual speed, typically using a tachometer or encoder. The feedback is compared with the reference speed, along with any deviation from the desired speed triggers adjustments in the frequency and voltage supplied to the motor.

The closed-loop nature of the system means that the motor speed is continuously adjusted based on feedback, ensuring precise control and better performance, especially under varying load conditions.

This approach offers smoother motor operation and improved performance compared to open-loop control, where no feedback is used.

V. IMPLEMENTATION OF SIMULINK MODEL

This simulation illustrates a closed-loop V/f controlled three-level DCMLI system driving a three-phase induction motor. The setup begins with an AC power source, rectified to DC using a diode bridge, followed by a filter to provide a stable DC bus. This DC is then split into three levels and fed into a DCMLI composed of 8 power switches and clamping diodes, generating a stepped three-phase AC waveform. The gate pulses for these switches are controlled via SVPWM logic to ensure harmonic reduction and efficient power conversion. A V/f control loop governs the output frequency and voltage according to the reference speed input, maintaining the motor's torque stability across various speeds.

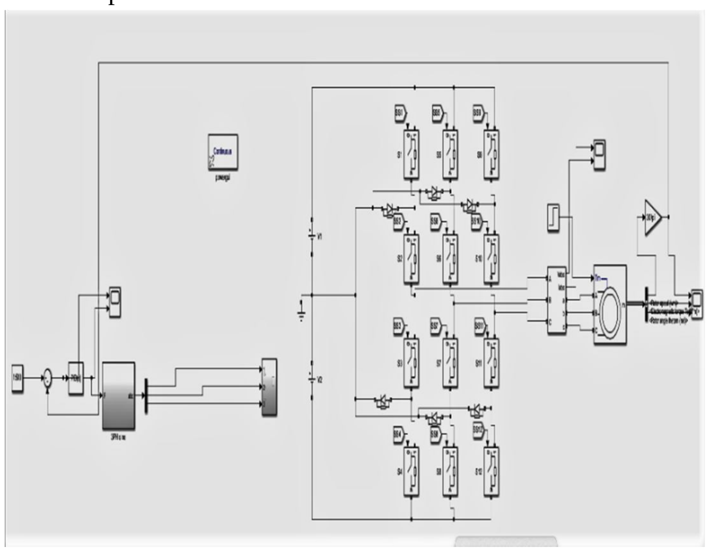
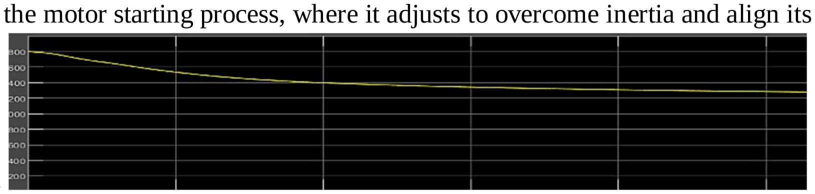


Fig 1 shows the simulink model

The system includes feedback sensors for speed, voltage, and current, all feeding into the controller to ensure dynamic stability and precise speed tracking. The output drives a three-phase induction motor, along with scopes are used to monitor performance in real-time.

A. *Three Phase Induction Motor Graph*

The provided graph shows the dynamic performance of an asynchronous motor drive system under closed-loop V/f (voltage/frequency) control that is managed by a Three-Level DCMLI. control. The top plot represents a variable labeled as "Gain," which appears to show a controlled, monotonic decrease over time. This behavior likely corresponds to a gradually decreasing reference voltage or frequency, typically applied in speed ramp-down scenarios. The smooth descent in this signal indicates stable operation without oscillatory behavior or abrupt changes. The middle plot displays the electromagnetic torque (Te) in Newton-meters. Initially, there are significant oscillations, with the torque swinging between approximately -10 N·m and +6 N·m. These transients are characteristic of the motor starting process, where it adjusts to overcome inertia and align its magnetic fields.



Rotor speed

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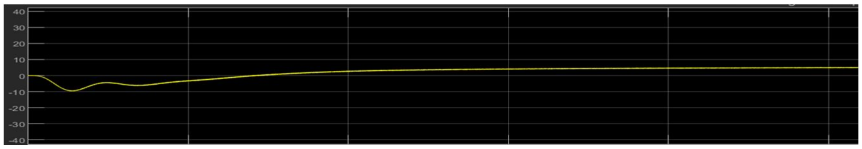
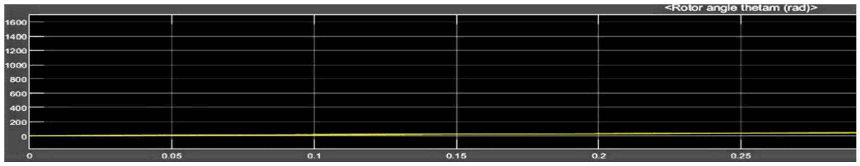


Electromagnetic torque

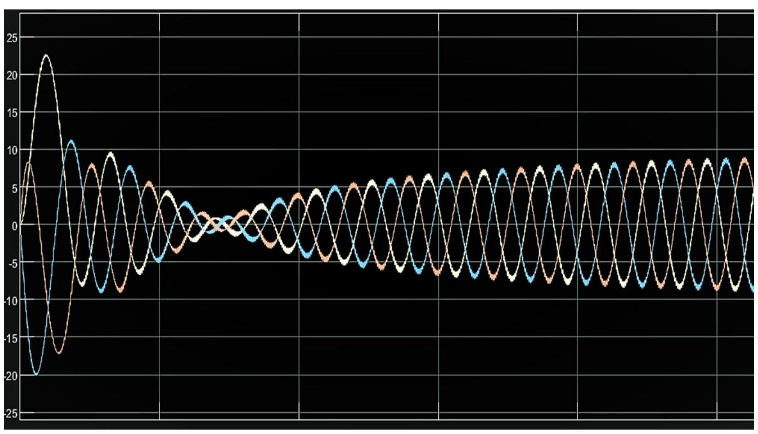


Rotor angle

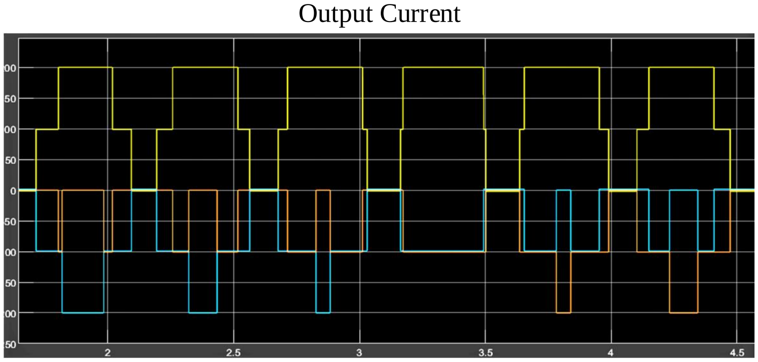
Fig 2 shows The Three Phase Induction Motor a)Rotor Speed b)Electromagnetic Torque c)Rotor Angle

As time progresses, the torque stabilizes around a steady value near 2 N·m, suggesting that the closed-loop controller effectively dampens the oscillations and brings the motor into a controlled state with constant torque output.The bottom plot shows the rotor angle (θ) in radians. It increases linearly over time, reflecting consistent angular velocity after the torque stabilizes. This linear growth indicates steady motor rotation, implying that the system has reached a uniform operating condition without sudden changes in speed or torque. Overall, the graph confirms that the system achieves stable, efficient performance after initial transients, with effective damping and accurate torque regulation through closed-loop V/f control.

Waveform of Three Phase MLI



Output Current



Output voltage

Fig3 shows the three level MLI a)current b)voltage

This simulation illustrates a V/f controlled three-phase induction motor powered by a three-level DCMLI. The upper graph shows its motor's three-phase stator currents, which begin with transient oscillations and then stabilize into clean, balanced sinusoidal waveforms, indicating effective control and smooth motor operation.

The lower graph displays the inverter's multilevel PWM voltage output, with distinct stepped waveforms that reflect the multilevel switching pattern used to reduce harmonic distortion and improve waveform quality. Together, the plots confirm that the DCMLI is delivering efficient, low-THD power to the motor while it is in a constant state.

VI. RESULT

The simulation results in the V/f controlled three-phase induction motor system using a Diode Clamped Multilevel Inverter (DCMLI) demonstrate successful operation with enhanced waveform quality and system stability. The inverter output voltage waveform, as seen in the lower plot of the graph, exhibits distinct multilevel steps, with voltage levels peaking around +200V and -200V. This confirms the stepped output characteristic of the DCMLI, which plays a key role in minimizing THD. In the upper plot, the stator current waveforms for phases R, Y, and B progressively settle into balanced sinusoidal shapes, reaching peak values close to ±10A after an initial transient period that stabilizes near 0.05 seconds. These results indicate that the motor is supplied with clean and stable voltage and current waveforms, facilitating smooth torque generation and efficient speed control. Overall, the system showcases improved power quality, lower switching losses, effective harmonic reduction.

VII. CONCLUSION

An induction motor with three phases that is powered by aV/f controlled Diode Clamped Multilevel Inverter (DCMLI) highlights the inverter's ability to deliver high-quality voltage outputs. The multilevel nature of the DCMLI generates stepped voltage waveforms, which significantly lower harmonic distortion in contrast to standard two-level inverters. This is evident from the smooth, symmetrical sinusoidal current waveforms that emerge once the initial transients settle. The voltage output, characterized by multiple distinct levels, demonstrates the accurate switching control inherent in the DCMLI structure. This reduction in harmonic content leads to decreased system losses, reduced torque pulsations, and longer motor lifespan, making the setup well-suited for demanding industrial environments.Furthermore, the motor reaches steady-state operation rapidly, underlining the reliability of V/f control in maintaining a consistent voltage-to-frequency ratio to preserve constant magnetic flux. The current waveforms stabilize around ±10A, and the voltage waveform peaks near ±200V, indicating effective dynamic response and speed regulation. In summary, the integration of DCMLI with V/f control delivers a dependable and energy-efficient drive solution, enhancing power quality while minimizing electromagnetic interference and mechanical wear.

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