

# Simulation Based Study of Diode Clamped Multilevel Inverter Using Feedback V/f Strategy

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**Abstract** - This Project focuses on the Simulation based Study of a three phase three-level Diode Clamped Multilevel Inverter (DCMLI), displaying eight switches and combining a closed-loop Voltage-to-Frequency (V/f) feedback strategy for the performance of three-phase squirrel cage induction motors. The Space Vector Pulse Width Modulation (SVPWM) technique is used to analyze the implementation of the system through both simulation and experimental validation, utilizing MOSFETs as the switching devices. The V/f control loop make sure a stable voltage-to-frequency ratio, supporting steady motor operation over different speed ranges. Instantaneously to check data provide essential insights into the system's behavior, aiding in the development of energy-efficient and precise motor control solutions. Key performance parameters, like Total Harmonic Distortion (THD), power factor, dynamic response and efficiency are assessed across various operating conditions. The results of this research contribute to the enhanced implementation of multilevel inverters in industrial motor drive applications.

**Key Words:** Diode Clamped Multilevel Inverter (DCMLI), V/f Closed Loop, SVPWM, Matlab Simulation

## 1.INTRODUCTION

As industrial applications continue to evolve, the demand for motor control systems that are efficient, reliable, and precise is increasing rapidly. Among the various types of power electronic converters, multilevel inverters have become a preferred choice for medium and high-power applications due to their ability to produce high-quality output waveforms, with lower harmonic distortion and reduced switching losses.

This study focuses on the Three-level Diode Clamped Multilevel Inverter (DCMLI) with eight switches, implementing closed-loop Voltage/Frequency (V/f) control for three-phase asynchronous induction motor drives. V/f control has long been a popular choice for industrial motor control due to its simplicity and reliability. By maintaining a constant voltage-to-frequency ratio, this technique ensures proper motor magnetization across various speed ranges, preventing problems such as over-fluxing at low speeds and under-fluxing at high speeds. The use of a closed-loop feedback system further

enhances the stability and dynamic response of the system, improving its performance under different load conditions.

While conventional two-level inverters have been widely used in industrial motor drive systems, they have notable drawbacks, such as high harmonic distortion, electromagnetic interference, common-mode voltage issues, and increased switching stress. Multilevel inverters provide a solution by generating AC output voltages from multiple DC voltage levels, which significantly reduces these limitations. The Three-level DCMLI strikes an optimal balance between performance improvements and system complexity, making it particularly suitable for medium-power motor drive applications.

This research contributes to the development of optimized motor drive systems, focusing on energy efficiency, power quality, and reliability—key concerns in industrial applications. By analyzing the performance of the Three-level DCMLI using closed-loop V/f control and Space Vector modulation, the study offers valuable insights for engineers and system designers in industries such as manufacturing automation, HVAC, water pumping, and renewable energy systems.

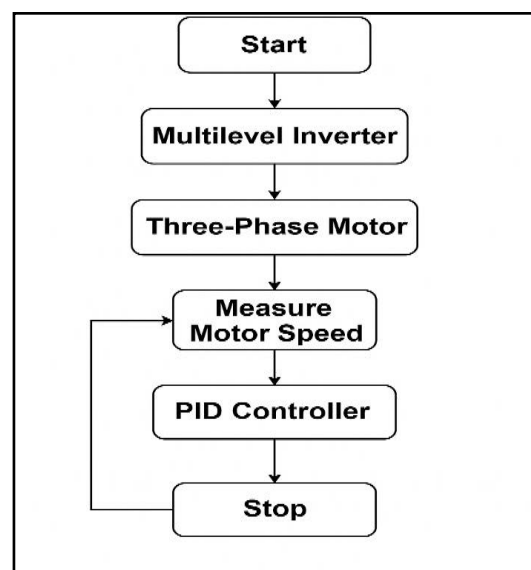


Fig 1 shows the flowchart of system

## 2. DIODE CLAMPED MULTILEVEL INVERTER

A Diode Clamped Multilevel Inverter is a device that changes DC power (like from a battery or solar panel) into AC power, which gives a smoother and better-quality output. It's called diode clamped because it uses diodes to control the voltage levels. These diodes clamp or limit the voltage so that the switches used in the inverter are not damaged by high voltages. This makes the inverter safer and more reliable.

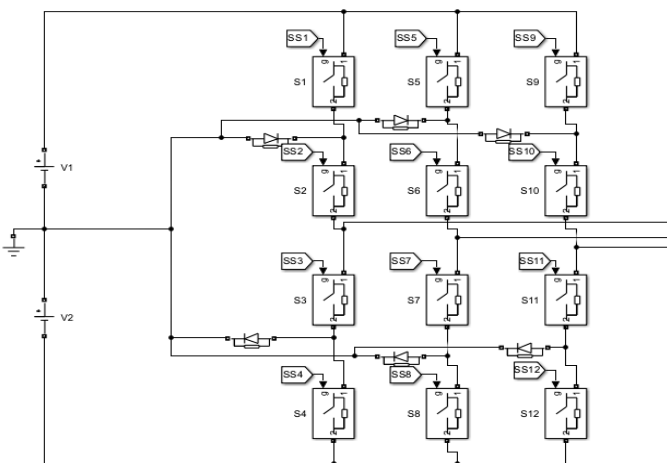


Fig 1. Three level Diode Clamped MLI

Figure 1 illustrates a three-phase, three-level Diode-Clamped Multilevel Inverter (DCMLI), which features three inverter legs linked to a common DC bus. This DC bus voltage is evenly split using a series of capacitors. Each clamping diode in the circuit is designed to withstand a voltage determined by the number of switches above it, scaled by the input DC voltage. In a general  $n$ -level DCMLI structure, each leg includes  $(n-1)$  capacitors and  $(n-2)$  clamping diodes. To operate each leg,  $2(n-1)$  switching devices are required. Specifically, in a three-level system, there are 12 power switches typically denoted as S1, S2, S5, S6, S9, S10, along with their complementary switches S3, S4, S7, S8, S11, and S12. The DC bus employs two capacitors, identified as C1 and C2, while each leg contains two clamping diodes, resulting in a total of six diodes for the entire inverter. These diodes play a critical role in regulating the voltage across each switch, allowing the inverter to generate a stepped AC output waveform as shown in fig2.

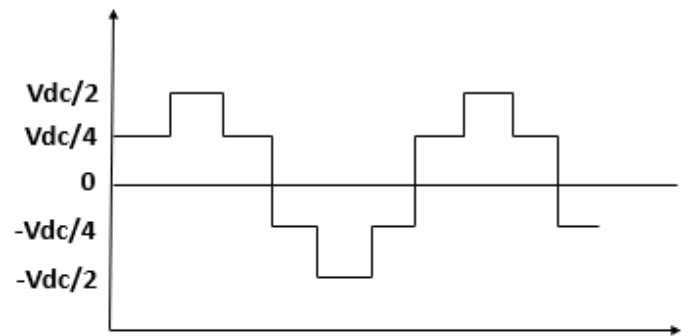


Fig.2 output waveform of 3level diode clamped MLI

### Advantages

- **Better Output Quality**  
The output AC voltage is smoother and closer to a sine wave. This reduces noise and improves performance.
- **Lower Harmonics**  
It produces less unwanted frequencies (called harmonics), which helps protect motors and devices.
- **Reduced Voltage Stress**  
Each switch handles only part of the total voltage, so it lasts longer and is less likely to get damaged.
- **High Efficiency**  
Less heat is produced, so less energy is wasted.
- **Suitable for High Power**  
Ideal for large systems like factories, solar plants, and electric vehicles.
- **Modular Design**  
Easy to expand to more levels for better output.

### Demerits (Disadvantages)

- **More Components Needed**  
Needs many switches, diodes, and capacitors, which makes the design more complex.
- **Difficult to Control**  
More levels mean more control signals and complicated control systems.
- **Unequal Capacitor Voltage Balancing**  
It can be hard to keep the voltage levels equal across all capacitors.
- **Bulky Size**  
Because of the extra parts, the inverter can be larger and heavier.

- High Cost  
More parts and complexity lead to a higher initial cost.

### 3. PWM TECHNIQUE

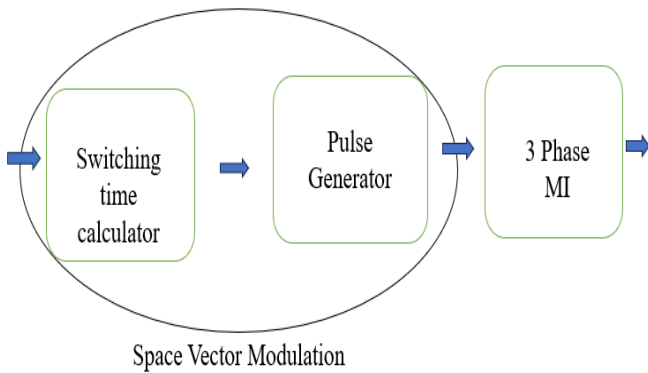


Fig.3 Block diagram of a space vector modulation

This diagram outlines the process of converting a DC input into a balanced three-phase AC output using a method called Space Vector Modulation (SVM) and a three-phase inverter. It involves three main stages: signal generation, modulation, and power conversion shown in fig.3. At this stage, the desired three-phase voltage waveforms are created typically sine waves for each phase A, B, and C. These waveforms represent the target output voltages that the system aims to produce at the end. Space Vector Modulation Block is responsible for converting the reference signals into switching commands for the inverter. Switching Time Calculator block calculates the exact timing for turning on and off the switches in the inverter. It works by comparing the reference voltages to available voltage vectors in the inverter to approximate the desired output. Once the switching times are calculated, Gate Pulse Generator generates gate signals (pulses) for the inverter switches. These signals ensure the power devices operate in the correct sequence to produce the intended output waveform. The inverter is made up of six switches organized into three legs, one for each phase. The output is shaped according to the modulation strategy to closely follow the reference waveforms. After modulation and switching, the inverter outputs three sinusoidal voltages, each 120 degrees apart. These outputs can then be used to drive AC loads like motors or industrial equipment. It efficiently manages switching to deliver smooth, sinusoidal AC power from a DC supply. Fig.4 shows the simulation of SVPWM.

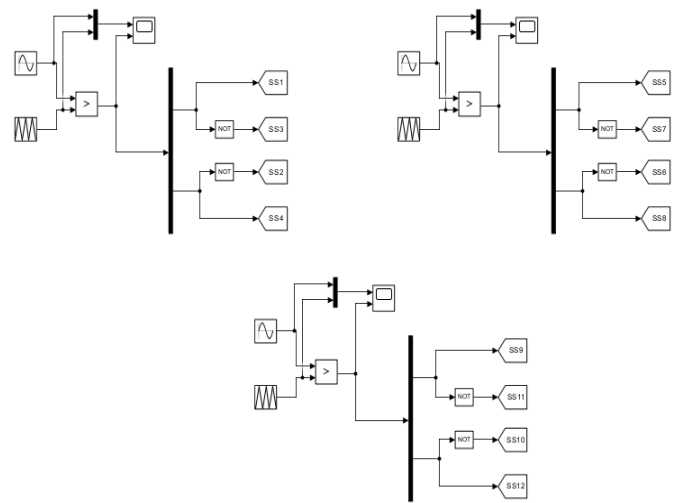


Fig4 Simulation of SVPWM using MATLAB/SIMULINK

This method facilitates the creation of a continuously rotating voltage vector that aligns with the motor control system's performance goals. The main aim of Space Vector Modulation (SVM) is to make sure the generated output accurately follows the reference signal during each pulse-width modulation (PWM) cycle, thereby delivering reliable and high-efficiency motor control.

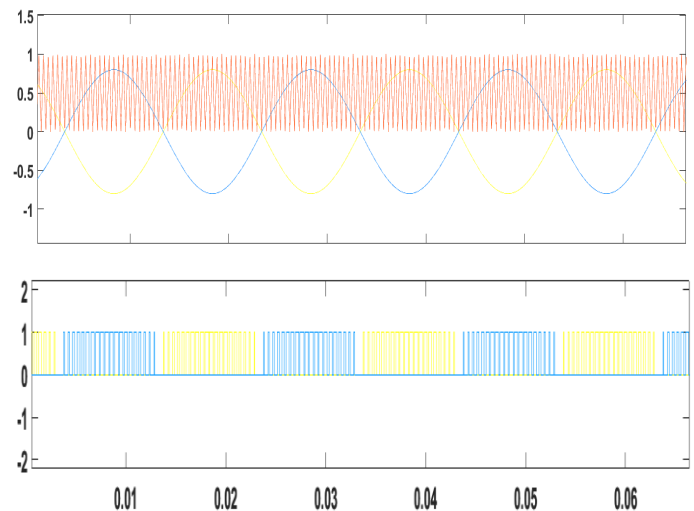


Fig5 Gate pulse generation as a result of comparing the modulation wave and the carrier wave.

### 4. TYPES OF SPEED CONTROL METHOD

Speed control methods for electric motors are broadly classified into two categories: open-loop control (without feedback) and closed-loop control (with feedback).

#### Open Loop V/f Control

This diagram represents a V/f (Voltage/Frequency) control system for an induction motor, specifically in an open-loop configuration. In open loop control, the system

does not use feedback from the motor. A controller set the V/f according to desired speed. The motor follow this input, but there is no correction if the speed changes due to load as shown in fig.6.

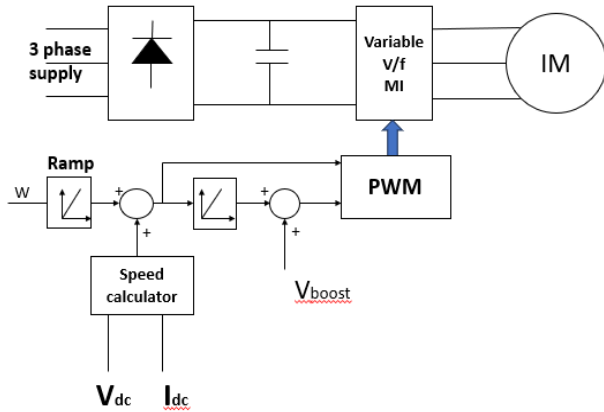


Fig.6 Open Loop V/f Control

### Closed-Loop V/f Control

In a closed-loop voltage/frequency (V/f) control system, the speed and torque of an induction motor are controlled by adjusting the applied voltage and frequency to the motor. 1. The speed of the motor is directly related to the supply frequency. In this control method, the frequency is adjusted according to the desired speed of the motor. The voltage is adjusted in proportion to the frequency to ensure that the voltage-to-frequency ratio remains constant. This prevents saturation in the motor and ensures efficient operation as shown in fig.7.

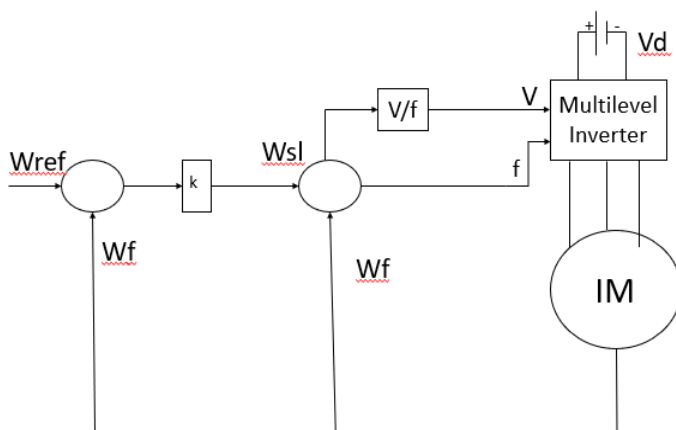


Fig.7 Closed Loop V/f Control

A feedback loop continuously monitors the motor's actual speed, typically using a tachometer or encoder. The feedback is compared with the reference speed, and 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.

### 5. SIMULATION DISCUSSION AND RESULT

Three-level Diode Clamped Multilevel Inverter (DCMLI) with closed loop V/f driving a three-phase squirrel cage induction motor. The system start with an AC power source, rectified to DC using a diode bridge, followed by a filter to provide a stable DC bus. This DC bus 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 by SVM logic to reduce harmonics and improve power quality. 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 as shown in fig.8.

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, and scopes are used to monitor performance in real-time.

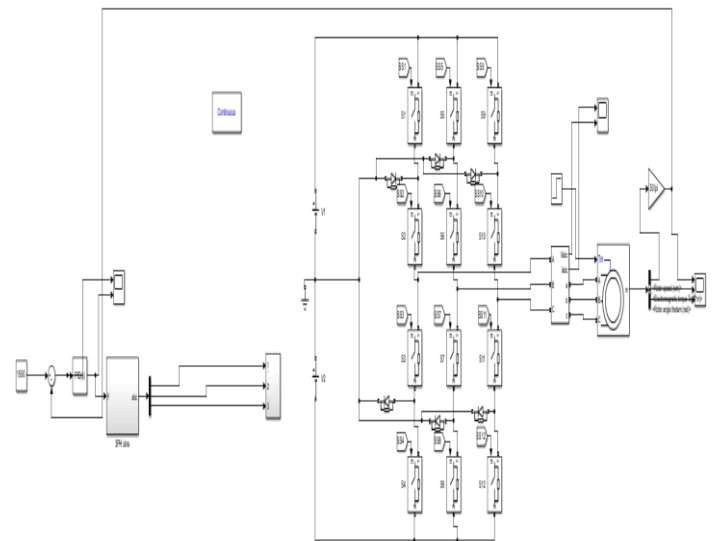


Fig. 8 simulink model using MATLAB/SIMULINK

### Three phase induction motor graph

The graph is given when the motor gives 10HP, 575V, 60Hz,1760RPM speed which illustrates the dynamic performance of an asynchronous motor drive system controlled by a Three-Level Diode Clamped Multilevel Inverter (DCMLI) under closed-loop V/f (voltage/frequency) control. From fig.9 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 ( $T_e$ ) in Newton-meters. Initially, there are significant oscillations, with the torque swinging between approximately  $-11 \text{ N}\cdot\text{m}$  and  $+6 \text{ N}\cdot\text{m}$ . These transients are characteristic of the motor starting process, where it adjusts to overcome inertia and align its magnetic fields.

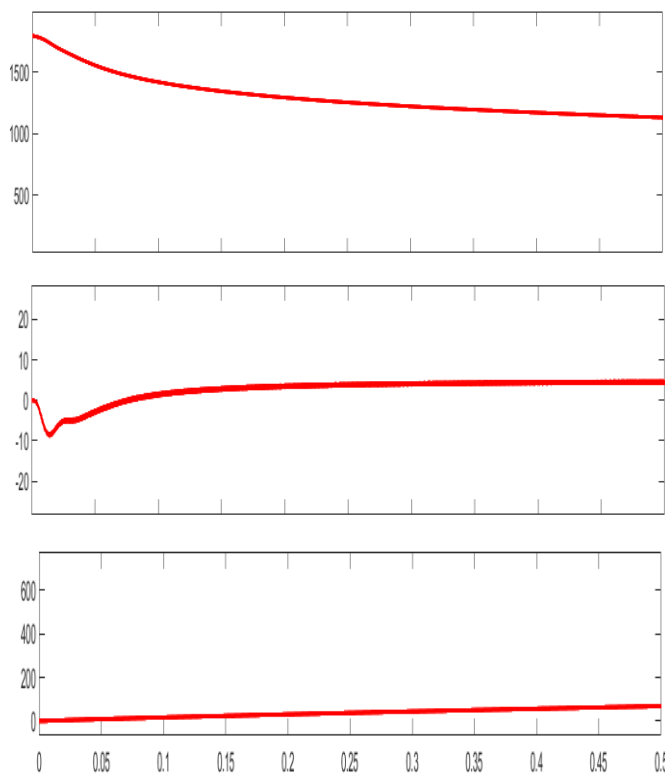


Fig.9 shows The Three Phase Induction Motor a)Rotor Speed b)Electromagnetic Torque c)Rotor Angle

As time progresses, the torque stabilizes around a steady value near  $3 \text{ N}\cdot\text{m}$ , 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 ( $\theta$ ) 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.

**Output voltage and current waveforms comparison**

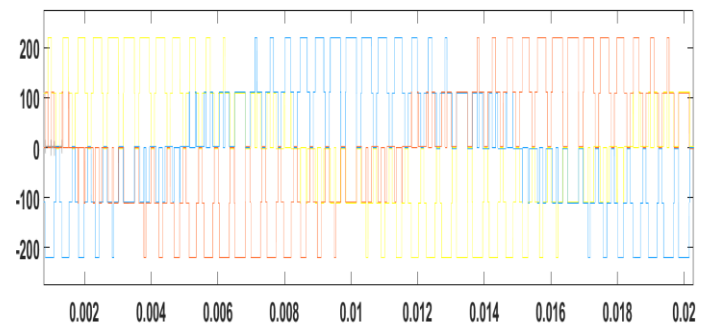


Fig.10 Output voltage from three level diode clamped multilevel inverter

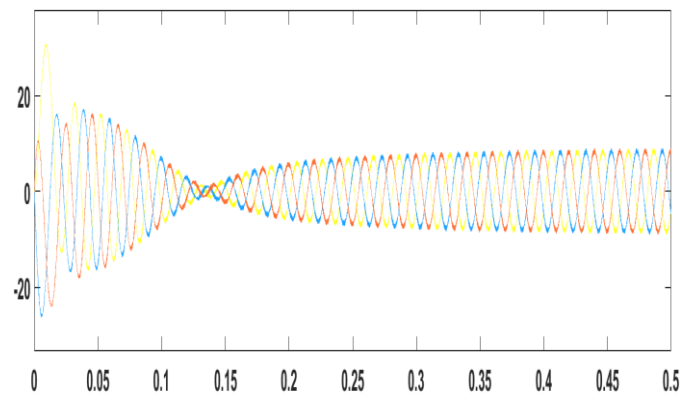


Fig.11 Output Current from three level diode clamped multilevel inverter

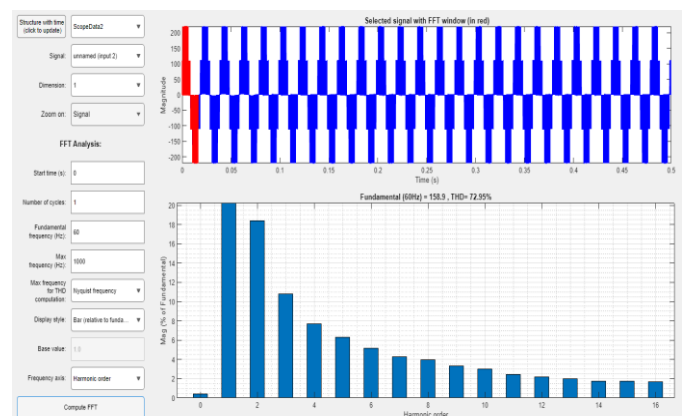


Fig.12 THD for three level diode clamped multilevel inverter voltage output with closed loop

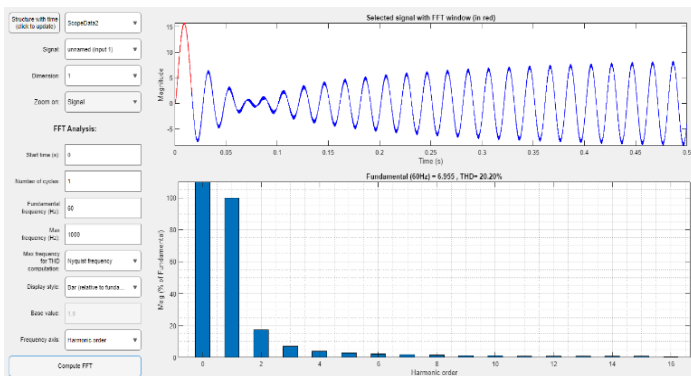


Fig.13 THD for three level diode clamped multilevel inverter current output with closed loop

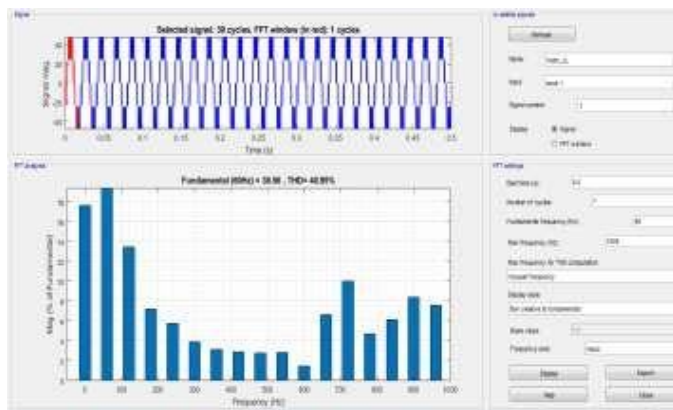


Fig.14 THD for Three level diode clamped multilevel inverter Voltage output with open loop

Output Current from three level diode clamped multilevel inverter From the given fig.10 upper graph shows the 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

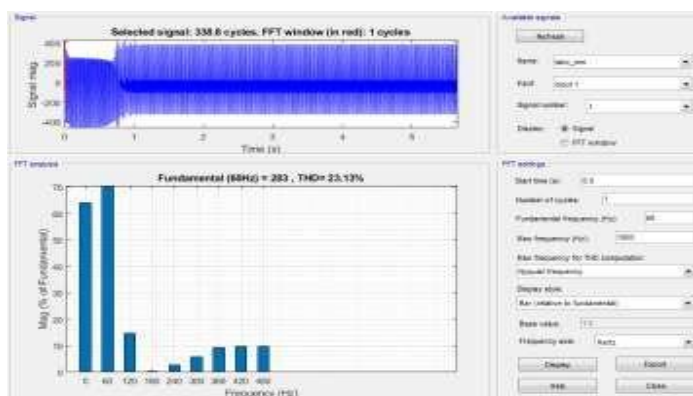


Fig.15 THD for Three level diode clamped multilevel inverter current output with open loop

THD data for three level diode clamped multilevel inverter with closed loop and open loop V/f control

3level DCMI	THD%
Closed loop V/f control	20.20
Open loop V/f control	23.13

Table.1

From the output graph, the inverter voltage waveform fig.10 shows distinct multilevel switching patterns with levels peaking approximately at +220V and -220V verifying the stepped nature of the DCMLI, which minimizes total harmonic distortion (THD). The stator current waveforms in fig.11 for phases R, Y, and B gradually stabilize into balanced sinusoidal curves, with peak values reaching approximately ±8A after initial transients subside around 0.05 seconds.

Fig.12 and Fig.13 shows the THD for three level diode clamped multilevel inverter voltage and current output with closed loop .Fig.14 and Fig.15 shows the THD for three level diode clamped multilevel inverter voltage and current output with open loop. This shows a comparison of Three level diode clamped MI with open and closed loop V/f control. As a result, the Closed loop V/f Control system operates with better power quality, reduced harmonic and effects lower switching losses effects, to supply of voltage and current by motor, which helps it produce smooth torque and to maintain proper speed as compared to Open loopV/f control.

## 7.CONCLUSION

V/f controlled three-phase induction motor using a Diode Clamped Multilevel Inverter DCMLI simulation demonstrates that the multilevel inverter is highly effective in delivering high-quality voltage waveforms to the motor. The voltage waveform clearly shows multiple discrete levels, which confirms the precise control of switching states within the DCMLI topology. The inverter's stepped output reduces harmonic content significantly compared to traditional two-level inverters, as evidenced by the smooth and symmetrical sinusoidal current waveforms observed after initial transient damping. The voltage waveform clearly shows multiple discrete levels, which confirms the precise control of switching states within the DCMLI topology.

The stabilization of current waveforms around ±8A and the multilevel voltage profile peaking at ±220V support the effectiveness of this control strategy in providing dynamic performance and speed control. The motor reaches steady-state operation quickly, showcasing the reliability of V/f control in maintaining a constant ratio between voltage and frequency to make sure steady motor

flux. The combination of diode clamped multilevel inverter with V/f control gives improving Power quality while decreasing electromagnetic interference and mechanical stress on the motor.

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