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Research Paper

Closed loop Direct Torque Control Scheme for an Induction Motor Powered by Five Level Diode Clamped Multi-level Inverter

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Abstract: This article discusses the operating principle and simulation of closed loop control of a three phase induction motor (IM) powered by five level diode clamped multilevel inverter (DCMLI) using direct torque control (DTC) technique. The main purpose of this article is to regulate the torque and speed of an IM and to decrease total harmonic distortion (THD). In this article, a five-level inverter's direct modulation approach with the dc link voltage self-balancing is presented. To reduce capacitor voltage variation, the redundancies of various switch topologies for the creation of intermediate voltages are also used. The use of LC filter results in lower output voltage and current distortion. A multicarrier PWM control technique is used for DCMLI to provide high quality sinusoidal output voltage with decreased harmonics. This can be obtained by employing Sinusoidal Pulse Width Modulation (SPWM) method for speed and torque control. This demonstrates that the recommended method of controlling the motor's speed and torque is effective. The simulation result reveals that DTC for the five-level inverter fed IM drive gives a rapid dynamic response, lower voltage and current THDs, and much less flux and torque distortion. The simulation is carried out in MATLAB Simulink (R2014).

Keywords: Induction Motor Drive, LC Filters, Multilevel Inverter, Neutral Point Converter, Voltage Source Inverter

1 Introduction

WITH the rising need for variable speed applications in the industry, research has been conducted to create various speed control techniques for AC motors to obtain high efficiency, fast dynamic, and precise control. In most DTC motor drives, two-level inverters are used. Multi-level inverters (MLIs) have garnered more study interest as power electronic switches have advanced, and they are now extensively employed in AC motor drives [1].

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The induction motor drive (IMD) based on a voltage source inverter (VSI) has the following disadvantages. THD is extremely high in motor voltage and current. The life of IGBT and motor windings is reduced by high voltage stress (dv/dt).

Because the output of a normal VSI has a high common mode voltage (CMV) and the rotating current passes through the bearing, limiting its life. The high switching frequency of standard VSIs leads in large switching losses, low productivity, and reduced electromagnetic interference (EMI). The above-mentioned difficulties of traditional VSI-based IMD can be suppressed using an MLI. MLI features a better voltage and current shape, as well as a reduced $dv/_{dt}$, a low CMV, and fewer switching losses [2].

More than Two-level diode-clamped inverters have been utilized in high-voltage grid interconnections and variable-speed motor drives. Common-mode voltage cancellation, leakage current reduction and total harmonic distortion become hard to handle using the standard VSI based IMD when a pulse modulation approach is used for dc-link capacitor voltage stabilization [3]. Because dc capacitor voltages are difficult to maintain when active power is exchanged between capacitor banks and loads or utilities, five-level diode clamp converters (DCCs) are still not cost-effective [4]. Since its introduction in 1979, the diode clamped inverter has been employed in steel mill drives, unified power flow controllers, and other applications [5]. The neutral point converter (NPC) is a well-known technology with a wide range of industrial applications. The NPC inverter's remarkable revelation has sparked a flurry of research into alternative MLIs with larger voltage levels, as well as never-ending experiments to manufacture MLI substitutes. In terms of effectiveness, firmness, level of voltages, and other characteristics, MLIs, such as NPC inverters, has lately received a lot of attention [6].

A general multilevel inverter design that can balance each voltage level regardless of inverter control or load parameters is essential for the above said applications [7]. The potential benefits of multiphase drives in electric traction and generating systems have focused the interest of the scientific community in recent years. Multiphase machines outperform three-phase drives in terms of power distribution per phase and overall system dependability, making them suitable when high fault-tolerance is required [8]. Because of their availability, durability, simplicity, reduced maintenance requirements, ease of manufacture, and economic feasibility, induction motors (IM) are widely used in industries for a range of speed control applications. In a variety of high-performance control applications, field-oriented control (FOC) and direct torque control (DTC) approaches are widely utilized for IM drives [9].

For IM drives, DTC is designed as a quick and reliable controller. To alter the torque and flux magnitude concurrently, traditional DTC uses hysteresis controls for flux and torque, as well as rapid switching of inverter voltage vectors. It achieves great control performance at the expense of enormous torque and flux ripples, which cause noise, vibrations, and losses. There have been reports of modern systems that will function with low torque ripple and consistent switching frequency. PWM is utilized to reduce torque ripple in most instances. However, when linear proportional-integral (PI) controllers are employed, control robustness is lost [10].

According to the previous controllers, the IM can be linked directly to the mains or to a scalar controller like the Voltage-Frequency driver. At low speeds, the latter is restricted and has a poor torque response. Vector control approaches (VCT) were introduced to help partially solve IM control difficulties. The FOC is amongst the most well-known VCTs. By working on the stator current phase and quadrature elements, this method regulates the rotor flux and torque separately.. Although FOC designs are frequently simple, their effectiveness is contingent on a thorough understanding of IM parameters and load changes. Furthermore, designing rotor flux observers is challenging when the IM characteristics change with frequency and temperature [11].

The key drawbacks of DTC include excessive torque ripple, a high start-up current, a variable switching frequency, and underperformance during overloading and operating at low speeds. There has been a lot of research presented in the literature to enhance the DTC performance. Refs. [12] and [13] presents changing methodology of the DTC to improve the starting condition and low-speed functioning. Analytically, the effects of hysteresis bands on an IM's DTC are investigated, and the inverter's switching frequency is predicted. Only the flux and torque hysteresis bands may be changed in DTC, and they have an effect on the inverter switching frequency and current. As a result, the inverter switching frequency and current harmonics should be kept to a minimum and the amplitude of the hysteresis band should be determined using acceptable criteria across the operating range. Various prediction techniques are presented to address the above flaws [14-22]. However, these techniques are parameter dependent. The majority of studies presented in the literature focuses on topologies in which all devices have the same voltage rating [23].

Modularity and control simplicity are two advantages of such symmetric multilevel converters. In a hybrid multilevel inverter different types of voltage sources are used. This structure is well suited to electric vehicles (EVs) and hybrid electric vehicles (HEVs) which use batteries, ultra capacitors, or fuel cells [24-27].

In compared to a symmetric multilevel inverter, more unique output voltage levels may be formed with the same number of components by adding and subtracting these voltages [28] to [31]. Output quality can be increased and output filters can be drastically lowered, if not eliminated altogether, with fewer cascaded cells and control complexity. There are two types of speed control techniques used by IM: vector control and scalar control. The IM scalar control implementation is uncomplicated. However, it simply regulates the magnitude and frequency of voltage and frequency. The operation of IM is unstable as a result of significant variations in flux and torque when providing unexpected and severe changes in load. Further, it is ineffective for controlling a huge variety of torques and speeds, because the execution time of a speed observer is high proportional to the control duration. The decrease of the computational burden is crucial for speed motor drives. The controller should be computationally efficient under this condition [32, 33].

In this paper, a direct modulation technique for a five-level diode clamped MLI fed to an induction motor with the dc link voltage self-balancing is presented. For diode clamped multilevel inverters, a multicarrier PWM control approach is employed which provides low harmonics and sinusoidal output voltage of high quality. The redundancies of various switching topologies for the generation of intermediate voltages are employed to limit capacitor voltage fluctuation. When an LC filter is used, the output voltage and current distortions are reduced. A multicarrier SPWM approach is implemented to create high-quality sinusoidal output voltage for speed and torque control of IM. This proves that the suggested approach of controlling the motor's speed and torque is effective for IM applications.

2 Design and Configuration

2.1 Concept of Multilevel Inverter

For better understanding across the text the concept of two-level inverter is discussed in this section. A two-level inverter provides the load with two separate voltages. When a dc voltage V_{dc} is input into a two-level inverter, the outputs are $+\frac{V_{dc}}{2}$ and $-\frac{V_{dc}}{2}$, respectively. These two freshly produced voltages are frequently switched in order to establish an AC voltage. PWM is a common switching technique. Although this technique of producing AC is efficient, it has several disadvantages, such as harmonic distortions in the output voltage and a higher voltage stress $dv/_{dt}$ than a multilayer inverter. This strategy usually works, but in a few situations, it might pose problems, especially when low output voltage distortion is required.

The MLI is a two-level inverter version. This study does not deal with two-level voltage in multilevel inverters; instead, more than two voltage levels are linked to give a smoother stepped output waveform with decreased harmonic disturbances and reduced $dv/_{dt}$. The smoothness of the waveform is related to the voltage levels; as the voltage level increases, the controller circuit and components become more complicated. The waveforms for the two and five level inverters are shown in the Fig 1. From Fig. 1, it is clear that the waveform becomes smoother as the levels are increased.

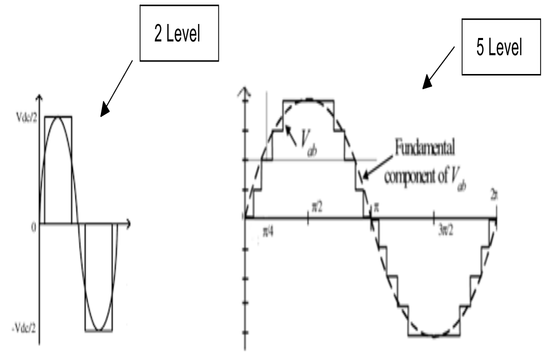


Fig. 1 Line voltages of two level and five level DCMLI.

2.2 Diode Clamped Multilevel Inverters

Clamping diodes are used in diode clamped multilevel inverters, also known as neutral point converters, to lessen the voltage stress on power equipment. As a result, a 'm' level diode clamped inverter requires (*m–1*) input voltage source, (*2m–2*) switching components, and (*m–1*) (*m–2*) diodes. The voltage across each diode and switch is measured V_{dc}. A three-phase, five-level DCMLI is shown in Fig 2.

2.2.1 Design Values

A 5 level diode clamped converter typically has 4 capacitors, 8 switching unit, and 6 clamping diodes. C_{dc1}, C_{dc2}, C_{dc3}, and 4are four capacitors on the DC bus of a three-phase five-level diode clamped converter as shown in Fig 2. The voltage across each capacitor is $\frac{V_{dc}}{4}$. The switches are numbered as follows: S_{a1}, S_{a2}, S_{a3}, S_{a4}, $S_{a1'}$, $S_{a2'}$, $S_{a3'}$, and $S_{a4'}$. Clamping diodes will restrict the voltage stress on each device to one capacitor voltage level of $\frac{V_{dc}}{4}$.

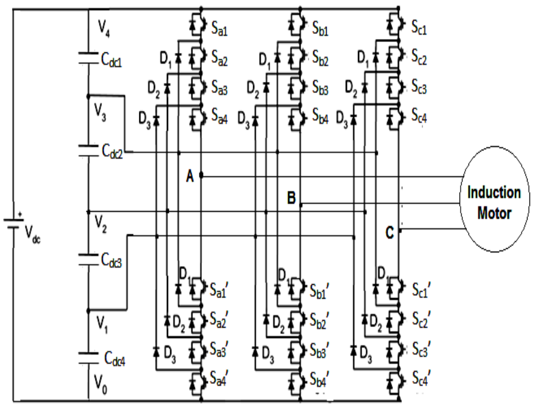


Fig. 2 Five-level DCMLI fed IM.

2.2.2 Working Principle

The following are the steps for synthesizing five stage voltages to obtain staircase output voltage.

1. To get an output voltage $V_0 = V_{dc}$, turn on the higher switches S_{a1}, S_{a2}, S_{a3}, S_{a4}.
2. For a $V_0 = 3\frac{V_{dc}}{4}$ output voltage, turn on the following switches S_{a2}, S_{a3}, S_{a4}, and $S_{a1\prime}$.
3. To get a $V_0 = \frac{V_{dc}}{2}$ output voltage, turn on the following switches S_{a3}, S_{a4} , $S_{a1\prime}$ and $S_{a2\prime}$.
4. For a $V_0 = \frac{V_{dc}}{4}$ output voltage, turn on the following switches S_{a4}, $S_{a1\prime}$, $S_{a2\prime}$, and $S_{a3\prime}$.
5. To produce a $V_0 = 0$ output voltage, turn on the lower switches S$S_{a1\prime}$, $S_{a2\prime}$, $S_{a3\prime}$, and $S_{a4\prime}$.Table 1 shows the voltage level similar switch states.

Table 1 Five level converter voltage levels and corresponding switching states for a-phase.

V_0	S_{a1}	S_{a2}	S_{a3}	S_{a4}	$S_{a1\prime}$	$S_{a2\prime}$	$S_{a3\prime}$	S_{a4}
V_{dc}	1	1	1	1	0	0	0	0
$3\frac{V_{dc}}{4}$	0	1	1	1	1	0	0	0
$\frac{V_{dc}}{2}$	0	0	1	1	1	1	0	0
$\frac{V_{dc}}{4}$	0	0	0	1	1	1	1	0
0	0	0	0	0	1	1	1	1

2.3 Direct Torque Control Method

AC induction motors are controlled by variable frequency drives using one of many control techniques. Scalar control (also known as V/Hz or V/f control) changes the voltage and frequency of the power supplied to the motor in order to keep the ratio between the two constant. This maintains the magnetic field's intensity at a consistent level, ensuring reliable torque output. Scalar control is a basic, low-cost control mechanism; however it does not provide accurate motor speed control. To regulate both motor speed and torque, vector control (also known as field oriented control or FOC) adjusts the magnetizing and torque-producing components of the stator current independently.

DTC is a control method that decouples torque and flux and governs them independently compared to field oriented control. However, because DTC does not use a modulator to control motor torque, torque response is significantly faster. Traditional DTC drives have two significant flaws: very high switching frequencies and large torque ripples. The multilayer inverter fed DTC drives have been demonstrated to be a viable solution to these issues.

The inverter control signals are generated by sinusoidal PWM in the drive control systems described in the literature. DTC is an alternate way of control the motor drive. The torque reference, T_e^*, and the flux magnitude reference, $|\varphi_s|^*$, are derived for a drive with a sinusoidal pulse width technique. The switching table selects the necessary inverter state to create a voltage vector that modifies the flux and torque as needed, and the hysteresis comparators create the appropriate change in flux and torque. The hysteresis comparator in DTC system requires torque, stator flux and rotor speed estimation. This estimation is calculated using the motor currents, a model-based estimator, and motor voltages based on the switching state and the input voltage V_{dc}. The motor model used to compute flux, torque and speed without DTC is complicated and highly reliant on the drive specifications. As a result, the DTC approach is used, which is uncomplicated and does not rely on motor parameter estimates.

3 Proposed System

The DC signal is received by the five-level DCMLI, which creates a low harmonics and sinusoidal output voltage of high quality. The output of the inverter is connected to a motor. The induction motor's speed is utilized as a feedback signal, which is compared to a reference signal before being processed using the sinusoidal PWM approaches. SPWM is a modulation method used to turn a signal into a pulsating waveform.

The switches power loss is reduced using this SPWM technique. For the hysteresis comparators, a computation of stator flux, estimated rotor speed and torque is required by the DTC system. The flux magnitude reference $|\varphi_s|^*$ and the reference torque T_e^* are established. The switch table determines the requisite inverter position to provide a voltage vector, while the hysteresis comparators supply the suitable change in flux and torque.

Finally, it produces a sinusoidal output voltage of good quality with few harmonics. It also controls the induction motor's speed and torque with reduced THDs of voltage and current, as well as less flux and torque distortion.

Figure 3 shows the proposed system block diagram. There are two components to it. A power circuit and a drive circuit. A DC power supply to a five-level DCMLI makes up the power circuit. The driver circuit includes sinusoidal PWM, a torque and flux control block, and a DTC, with the motor linked to the output of the ML inverter.

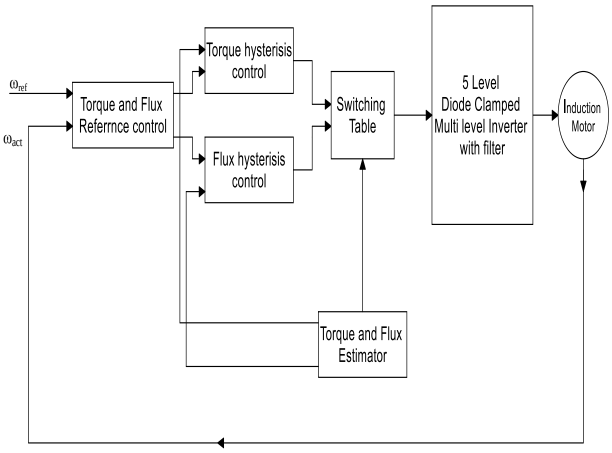


Fig. 3 Block diagram of proposed system.

A five-level diode clamped ML inverter receives the dc signal and generates a high-quality sinusoidal output voltage with few harmonics. ML inverters have been utilized in a wide range of applications due to their high power capacity, low number of harmonics, and low sum of losses. In AC drives, it also optimizes power while minimizing harmonics. As a result, it is a valuable component that has provided a solution to a variety of practical issues that have arisen in the electrical system.

Figure 2 shows a five-level ML inverter circuit. It contains three legs, each with eight switches, for a total of 24 switches to create the three phase output voltage. Each leg generates a single phase voltage, while the three legs together form a three phase output voltage with a 120^o phase shift. The output of a three-phase ML inverter is connected to the IM's input. An IM's rotational speed may be regulated in a variety of ways, including constant V/f, variable frequency, variable voltage, and so on.

In this system, the IM's rotational speed will be controlled using a variable frequency scheme known as DTC. The IM's rotational speed was utilized as feedback, and it was compared to a reference signal before being processed with the sinusoidal PWM technique. SPWM (Sinusoidal Pulse Width Modulation) is a signal modulation method that converts a signal into a pulsating waveform. The major purpose is to control the amount of power delivered to the electrical drives. This SPWM technique reduces the power loss of the switches.

The DTC system's hysteresis comparators need a calculation of stator flux, rotor speed, and torque. These characteristics are determined using the motor currents, a model-based estimator, and the motor voltages based on the switching state and the input voltage V_{dc}. Similar to a sinusoidal pulse width modulator drive, the reference torque T_e^* and flux magnitude reference $|\varphi_s|^*$ are determined.

The switch table determines the inverter condition required to generate a voltage vector, while the hysteresis comparators give the appropriate flux and torque change. Finally, this suggested technique generates a high quality sinusoidal output voltage with decreased harmonics. Further, it controls the speed and torque of the IM with lower THDs of voltage and current with less flux and torque distortion. Finally, a LC filter can be used to reduce the THD of voltage and current further.

4 Design and Execution of Proposed System

In this section, the proposed system is built using a MATLAB Simulink library components and basic simulation models from the library. The proposed simulation schematic for an IM drive is employed using a five-level diode clamped ML inverter circuit with DTC technique is shown in Fig 4. The simulation of five level diode clamped ML inverter comprises of 24 insulated gate bipolar transistor (IGBT) switches, 18 clamping diodes, and 4 capacitors placed in a diode clamped topology.

The gating pulses in the driver circuit for a three-phase ML inverter are generated using the SPWM method. The SPWM simulation circuit for one phase is shown in Fig 5. These gating pulses power this circuit, which comprises of 24 switches of a three-phase inverter.

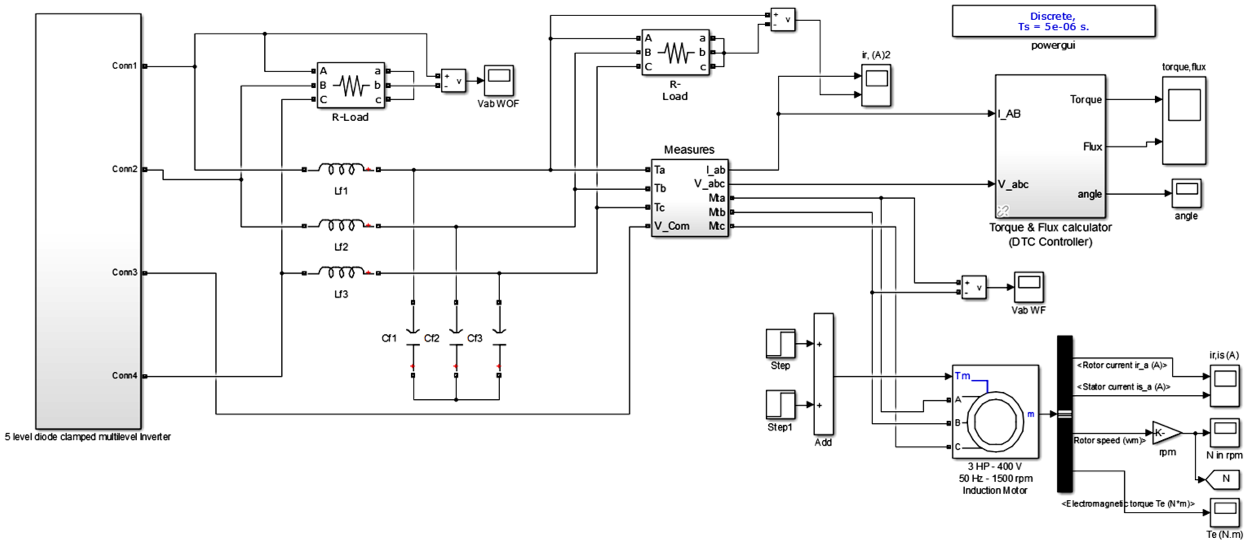


Fig. 4 Proposed simulation design for an IM drives employing the five-level DCMLI circuit with DTC technique.

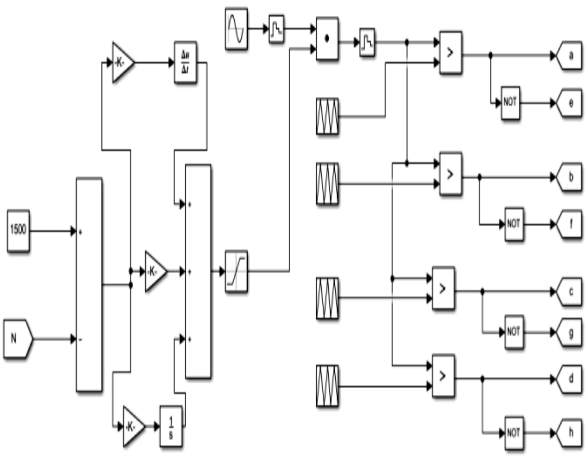


Fig. 5 Sinusoidal Pulse width modulation simulation circuit for one phase.

A sinusoidal pulse is compared to different triangular pulses in this gate circuit, and pulses for the ML inverter can be generated using logic gates. The output of a three-phase ML inverter is connected to the input of an induction motor using variable frequency. As a result, the IM speed and torque can be controlled. Speed and torque may be calculated for different step times using the matching step values.

The output of a three-phase ML inverter is fed into the input of the IM using the DTC technique of variable frequency. Before being processed using the SPWM technique, the speed of IM is taken as feedback and compared to a reference speed of 1500rpm. The motor speed, which is created by combining actual speed and reference speed, establishes the inverter frequency. The reference signals for the closed-loop control of the voltage in terms of pulses for each switch are produced from the frequency f with the help of PID controller. It ensures nearly a constant flux operation up to the reference speed and the operation at a constant terminal voltage above the reference speed. A positive speed error results from increasing the speed by one step. The drive accelerated at a maximum permissible inverter current and producing the maximum available torque until the speed error is reduced. As a result, the rotational speed of the IM drives is controlled.

The Estimation of stator flux and torque, and rotor speed are required by the hysteresis comparators and the speed controller in the direct torque control system. Figure 6 shows the torque and flux calculator simulation circuit, which generates the reference torque T_e and flux magnitude reference $|\Psi_s|$ using a sinusoidal pulse width modulator.

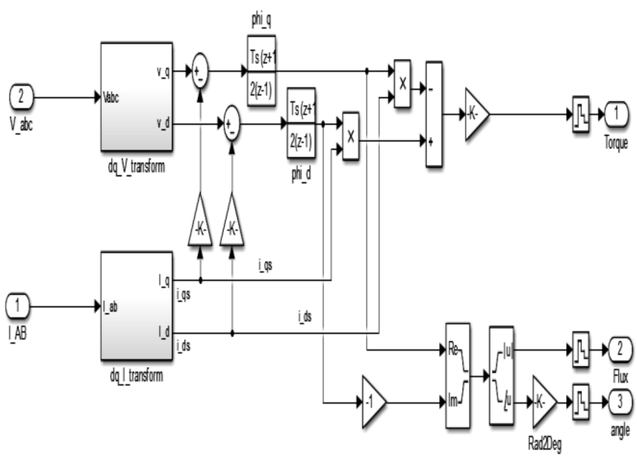


Fig. 6 Torque and flux calculator simulation circuit.

The stator voltage is determined by the DC link voltage Vdc. The switching state (S_a, S_b, and S_c) generated by the switching table, and the stator current. The dq-transformation converts these parameters into coordinates (α, β), which are properly fitted to the DTC method. The estimated values of the electromagnetic torque T_e and the stator flux Ψ_s are then compared to their respective reference values T_e^* and Ψ_s*, the outcome of the comparison provide as the inputs for the hysteresis comparators. Based on the switching state table (Table 1), the proper voltage vector is chosen. The stator flux Ψ_s and the electromagnetic torque T_e are estimated from the following equations:

$$\Psi_s = \int (v_s - R_s i_s) dt \qquad (1)$$

$$T_e = \frac{2}{3} p \, (\Psi_s * i_s) \qquad (2)$$

where,

Ψ_s: Stator flux,

v_s: stator voltage,

R_s: stator resistance,

i_s: stator current,

T_e: electromagnetic torque,

p: pole pairs of the motor.

With the stator flux components in the reference (α, β) are:

$$\Psi_s = \sqrt{\Psi_{s\alpha}^2 + \Psi_{s\beta}^2} \qquad (3)$$

$$\Psi_{s\alpha} = \int (v_{s\alpha} - R_s i_{s\alpha}) dt \qquad (4)$$

$$\Psi_{s\beta} = \int \left(v_{s\beta} - R_s i_{s\beta}\right) dt \qquad (5)$$

The switching table generates the appropriate inverter configuration to produce a voltage vector that modifies the torque and flux as required, while the hysteresis comparators supply sufficient torque and flux change.

4.1 LC Filter Design

As an outcome of switching signals, it has been found that the inverter's output voltage and current have significant harmonic components. Higher harmonics might be filtered out more readily by choosing a higher frequency for the inverter. The *LC* filter is commonly used to remove harmonics from the inverter output.

The following equation is used to compute the value of inductor *L*:

$$L = \frac{V_{rms-p}}{2} * 2.44 * f_{is} * I_{ripple-peak} \qquad (6)$$

where,

L: inductance in mH

V_{rms-p}: RMS phase voltage, Volts

f_{is}: inverter switching frequency, Hz

$I_{ripple-peak}$: ripple peek current, A

The inductor value is chosen such that the ripple peek current in the inductor is kept to a maximum of 15%. Similarly, the following equation is used to compute the value of *C*:

$$C = \frac{1}{(2 * \pi * f_0)} * 2 * L \qquad (7)$$

where,

f_0: cutoff frequency, Hz

C: capacitance, μf

This value of cutoff frequency is 1/6th of the fundamental frequency. The *LC* filter is thus used on the load side, resulting in a filtered output that allows the load to operate smoothly. This reduces the percentage of THD in both voltage and current. The percentage of THD reduction for voltage and current is discussed in the section 5.

5 Results and Discussions

The DTC scheme is used to simulate a five-level DCMLI. Figure 5 shows the proposed simulation diagram for an IM drive. The output of a three-phase ML inverter is fed into the input of the IM using the DTC variable frequency approach. Before using the SPWM approach, the induction motor's speed is utilized as feedback and compared to a reference speed. As a consequence, the IM drives speed is modified.

The following results are obtained for the proposed system. The line voltage waveform of a three phase 5 level diode clamped multi-level converter without filter is shown in Fig 7. Three phase five level waveforms are 1200 phase shifted and connected to an induction motor through the output of three phase ML inverter. The IM is driven by these voltages.

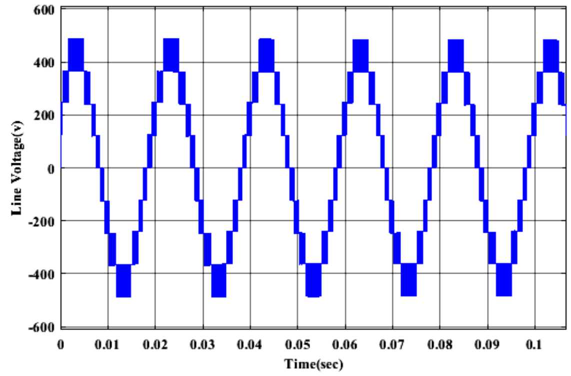


Fig. 7 Line voltage waveform of three phases 5 level DCMLI without filter.

Figure 8 illustrates the waveform of 3 phase 5 level DCMLI line voltage with LC filter which provides a smooth operation for the load.

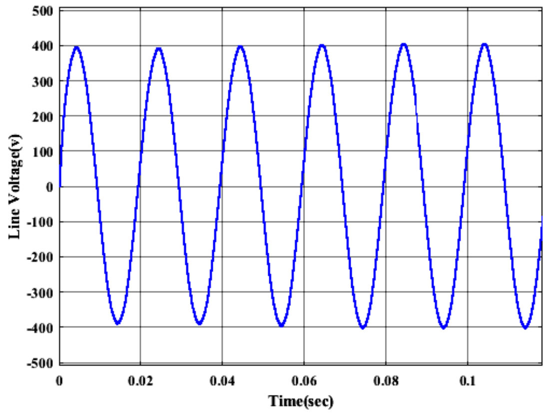


Fig. 8 Line voltage waveform with LC filter for 5-level DCMLI.

Figure 9 shows the rotor current waveform for two phases of five level diode clamped multi-level inverter with LC filter. Fig 10 shows controlled speed curve of induction motor. A frequency of 50 Hz motor is running at maximum speed (below 1500rpm) which requires high starting current as shown in Fig. 10.

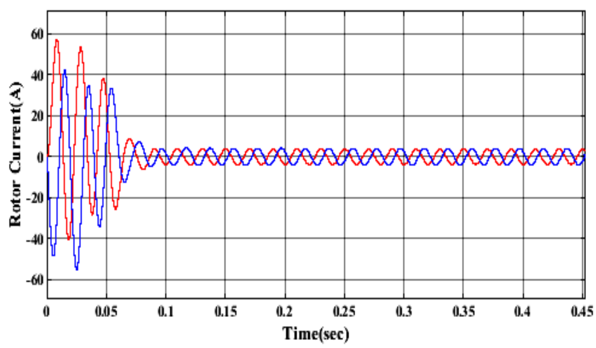


Fig. 9 Rotor current waveform with LC filter for two phases

Figure 11 and Fig. 12 shows controlled torque and controlled flux curve of induction motor. A frequency of 50 Hz motor is running at maximum speed which requires high starting torque as shown in Fig. 11.

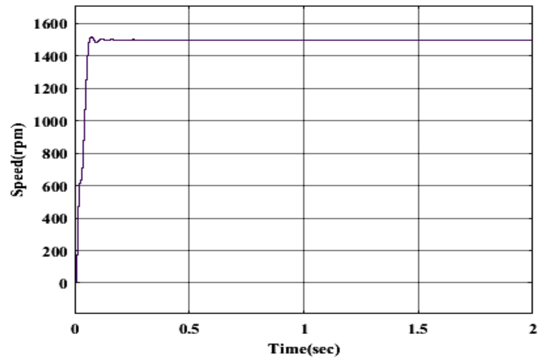


Fig. 10 Controlled speed curve of induction motor.

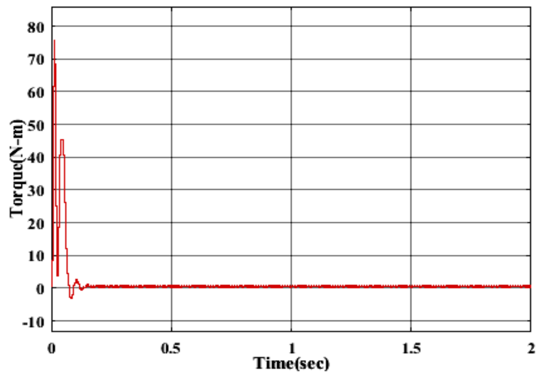


Fig. 11 Controlled torque curve of induction motor.

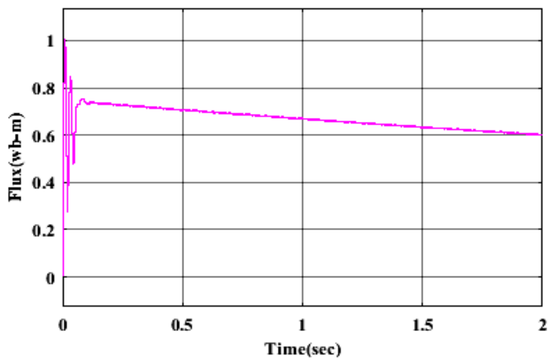


Fig. 12 Controlled flux curve of induction motor.

A sudden change in the reference torque would have an impact on the motor's speed. Figure 13 shows the change of reference torque curve of induction motor. Figure 14 shows the effect of controlled speed curve of induction motor due to change of reference torque. Figure 13 and Figure 14 make it extremely clear that changes to the reference torque will have an impact on the motor's speed. There are 0.5 and 1 second changes to the torque reference. It clears that if the reference torques changes, the speed decreases throughout the same time period.

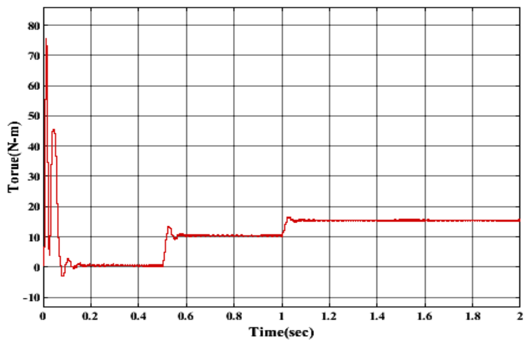


Fig. 13 Change of reference torque curve of induction motor.

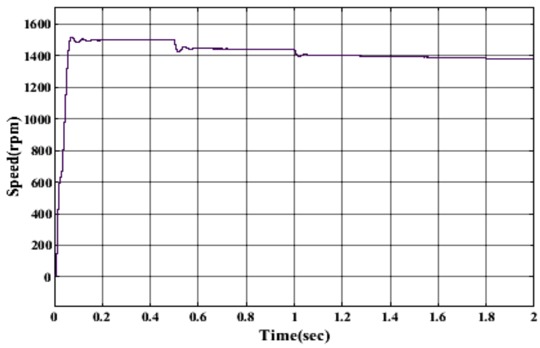


Fig. 14 Effect of controlled speed curve of induction motor due to change of reference torque.

An unexpected disturbance, such as if the inductive filter of one phase failed, will surely have an effect on the performance of the induction motor's torque and speed. This is clearly explained by the waveform mentioned in Fig. 15. The waveform shows that the torque ripple will exceed its controlled range in the occurrence of an unexpected disturbance. Therefore, it will have a direct impact on the motor's speed. As a result, the performance of the system has completely collapsed.

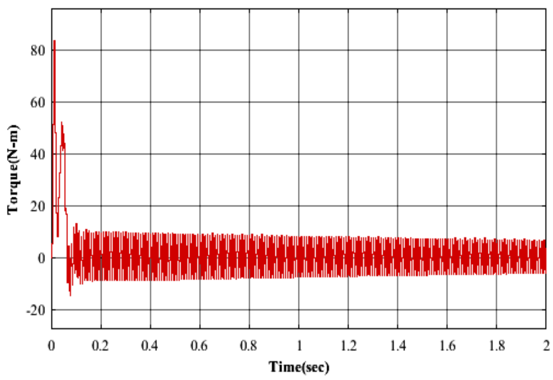


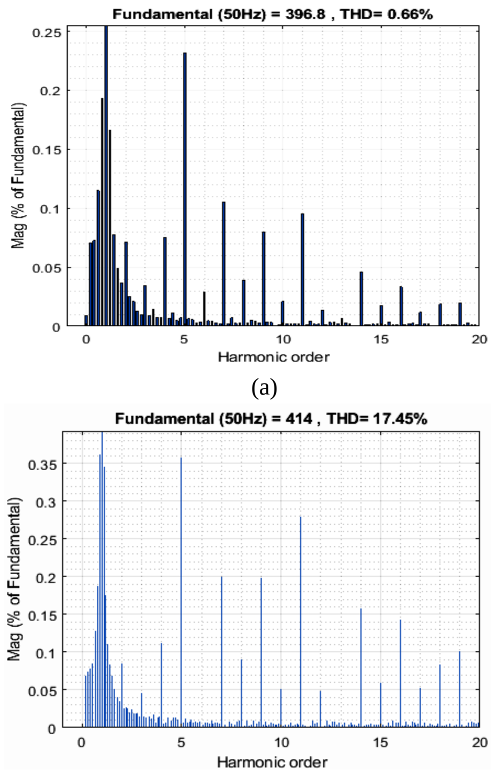
Fig. 15 Torque curve of induction motor due to Effect of sudden disturbance.

The qualitative comparison of percentage THD of line voltage and current between with and without filter of proposed system is given in Table 2. From the Table 2, the THD of line voltage of the proposed system for with and without filter is 0.66% and 17.45% respectively. The percentage THD of line current of the proposed system for with and without filter is 1.20% and 10.46% respectively. For the open loop system, the percentage THD of line voltage and current without filter is 17.61 % and current is 17.68% respectively [34]. When compared to an open loop system, the suggested technique significantly reduces the percentage THD of voltage and current.

Table 2 Qualitative comparison of percentage THD of line voltage and current between with and without filter of proposed system.

Closed loop system performance	Percentage THD	
	Line Voltage	Current
With Filter	0.66	1.20
Without Filter	17.45	10.46

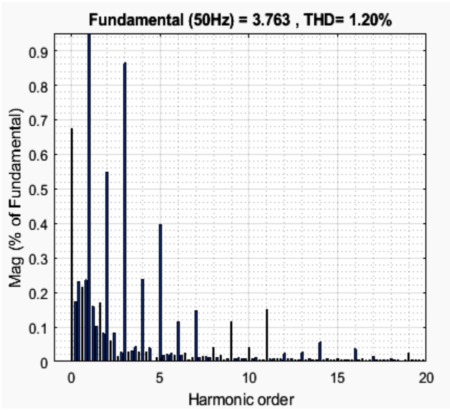
MATLAB's FFT function computes the data's Fourier transform using a quick Fourier transform algorithm. The MATLAB SIMULINK provides a power guide option for acquiring FFT of different signals, which is used to calculate maximum harmonic distortion with reference to fundamental frequency. Figure 16 and Fig. 17 shows the FFT window output of percentage THD for line voltage and current incorporating filter and without filter.



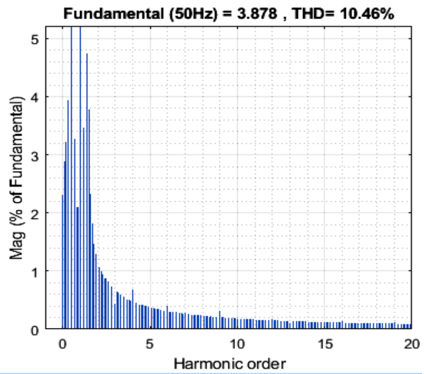
(a)

(b)

Fig. 16 FFT window for percentage of line voltage THD (a) with filter and (b) without filter.



(a)



(b)

Fig. 17 FFT window for percentage of current THD (a) with filter and (b) without filter.

6 Conclusion

A closed loop DTC technique for induction motor applications is presented in this article. A five-level DCMLI supplied by a dc link capacitor voltage feeds this closed loop control. The ML inverter's output may be used to drive an induction motor. To generate gate pulses, the sinusoidal PWM method is used which results in high-quality five-level output voltages with closed loop operation. Variable frequency is used to alter the speed range and torque of an IM. The simulation results showed that DTC for the five-level inverter fed IM drive provides a rapid dynamic response, lower voltage and lower current THDs with reduced flux and torque distortion. The simulation results show that the suggested circuit successfully regulates the motor speed while also improving the motor performance. In addition, it lowers overall harmonic distortion. Water pumps, household appliances, fans and air conditioners, autos, and industrial machineries such as boiler pumps and compressors all employ induction motors with decreased harmonic distortions. This proposed system is applicable for electric vehicles (EVs) and hybrid electric vehicles (HEVs).

Intellectual Property

The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing to publication, with respect to intellectual property.

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S. M. Ahmed: Idea & Conceptualization, Research & Investigation, Project Administration, Software and Simulation. **K. S. Ahmed:** Supervision, Revise & Editing. **Y. M. Shuaib:** Revise & Editing.

Declaration of Competing Interest

The authors hereby confirm that the submitted manuscript is an original work and has not been published so far, is not under consideration for publication by any other journal and will not be submitted to any other journal until the decision will be made by this journal. All authors have approved the manuscript and agree with its submission to "Iranian Journal of Electrical and Electronic Engineering".

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