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Combined Vector and Direct Controls Based on Five-Level Inverter for High Performance of IM Drive

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Abstract: The goal of this study was to figure out how to regulate an induction motor in a hybrid electric vehicle. Conventional combined vector and direct control induction motors take advantage of the advantages of vector control and direct torque control. It is also a method that avoids some of the difficulties in implementing both of the two control methods. However, for this method of control, the statoric current has a great wealth of harmonic components which, unfortunately, results in a strong undulation of the torque regardless of the region speed. To solve this problem, a five-level neutral point clamped inverter was used. Through multilevel inverter operation, the voltage is closer to the sine wave. The speed and torque are then successfully controlled with a lower level of ripple in the torque response which improves system performance. The analysis of this study was verified with simulation in the MATLAB/Simulink interface. The simulation results demonstrate the high performance of this control strategy.

Keywords: vector control; direct torque control; combined vector and direct controls; five-level NPC inverter; hybrid electric vehicle; induction motor; torque ripple attenuation

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1. Introduction

The major equipment utilized for electromechanical converters worldwide is the induction motor. It is used in most production sectors and contributes to about two-thirds of electrical production in industrial applications [1]. This effort is part of a project to develop a hybrid electric vehicle. The most important advantages of an induction motor are: Its construction is quite simple in nature which does not only contain brushes but also slip rings and commutators. Furthermore, for a hybrid electric vehicle, the induction motor appears to be the ideal option.

Its cost is quite low compared to DC motors with the disadvantages of the brush commutator as well as corrosion and the need for servicing. Therefore, closed-loop induction motors are particularly used for speed-controlled applications [2]. The development of microprocessors and power engineering has led to the implementation of novel techniques for precise control of torque and speed of induction machines [3].

There are generally two types of controls for induction motors. First, there is vector control (VC). In VC, the decoupling of torque and flux control can be guaranteed which makes it possible to control the induction motor linearly like a separately excited DC motor [4]. However, the rotor's torque and flux are regulated by the stator current decoupled from the d and q axes.

The second alternative command is direct torque control (DTC) [5], which is made up of a pair of hysteresis comparators, a couple of torque and flux calculators, a look-up table, and a voltage source converter [6]. The main interest in DTC is based on certain advantages compared to conventional vector drives, such as the control without the use of current loops, the transmission does not require coordinate conversion between the stationary and

synchronous loops, and the use of a pulse-width modulator (PWM) is not necessary [7]. However, this type of drive usually poses major problems, such as the need to estimate the flux and torque and then vary the switching frequency. The literature on this variation is extensive, and several techniques are suggested to decrease the impact of this variety [8].

The objectives of combining the performance of vector control and direct torque control are speed and accuracy which resulted in a new control method that has already been defined and proposed in [9–12] under the name of combined vector control and direct torque control (VC-DTC). The combination of these two systems consists of replacing the PI controllers with PWM (pulse width and modulation) and hysteresis signals provided by the switch table. However, this transmission has some disadvantages, including heavy torque ripple and current distortion. To overcome this problem, [13] introduced a fuzzy controller in this drive to minimize torque ripple.

More recently, due to the demand for high and medium power applications in utilities and the industry, the demand for voltage source inverters (VSIs) has risen sharply. For a two-stage inverter, the harmonic reduction of the output current is mainly achieved by increasing the commutation frequency. However, for more powerful applications, the switching frequency of the power device must be reduced to less than 1 KHz because of increased switching losses and the DC bus voltage level [14]. Thus, for the reduction of harmonics and the high voltage level of the DC link, multilevel inverters are an interesting choice for medium- and high-power applications [15]. The cascaded H-bridge inverter [16], neutral point clamped [17], and the flying capacitor [18] are currently the most widely used and developed topologies. The neutral point clamped inverter, also known as the multi-stage converter, was particularly used in the case of very high power in order to reduce output harmonics in voltage, current, and commutation losses [19]. An optimized efficiency modulation strategy for a three-stage NPC inverter is proposed in [20] which takes into account the NP potential balance and the reduction of switching losses. A control technique for decreasing the common-mode voltage (CMV) in the three-phase inverter with five levels of active neutral point lockout (5L-ANPC) is proposed in [21], using only the 55 voltage vectors selected from the 125 that generate low CMV values.

This paper's main contribution is the proposition of a new combined vector control and direct torque control by incorporating a five-level inverter. The obtained simulation results prove the efficiency of the suggested scheme so as to optimize the choice of the voltage space vector, followed by a successful control of torque and speed with a lower ripple level in response to torque and current. To achieve this research objective, the document is organized into seven main sections. This section discusses the context and importance of the proposed work. Section 2 presents the mathematical model of the induction engine. The five-level NPC inverter model is discussed in Section 3. Section 4 presents vector and direct torque control strategies. Section 5 presents the proposed control system and its basic idea. The effectiveness of the proposed system, as demonstrated in MATLAB/Simulink, is presented in Section 6. Finally, conclusions are presented in Section 7.

2. Mathematical Model of Induction Motor

In an equilibrium situation, it is possible to express the three-phase stator voltage of an induction motor as follows:

$$\begin{cases} V_a = \sqrt{2}.V_{rms}.\sin(\omega t) \\ V_b = \sqrt{2}.V_{rms}.\sin(\omega t - \frac{2\pi}{3}) \\ V_c = \sqrt{2}.V_{rms}.\sin(\omega t + \frac{2\pi}{3}) \end{cases} \quad (1)$$

Using the following equation, these voltages are converted into the reference frame with synchronous two-phase rotation of the dqo axis.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{2}}{3} & -\frac{\sqrt{2}}{3} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (2)$$

Therefore, the dq axis tensions are:

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \quad (3)$$

The stator and rotor voltage equation of induction motor written in (d, q) reference frame are given by the following equations:

$$\begin{cases} V_{sd} = R_s \cdot i_{sd} + \frac{d\phi_{sd}}{dt} - \omega_s \cdot \phi_{sq} \\ V_{sq} = R_s \cdot i_{sq} + \frac{d\phi_{sq}}{dt} + \omega_s \cdot \phi_{sd} \end{cases} \quad (4)$$

$$\begin{cases} V_{rd} = R_r \cdot i_{rd} + \frac{d\phi_{rd}}{dt} - \omega_s \cdot \phi_{rq} \\ V_{rq} = R_r \cdot i_{rq} + \frac{d\phi_{rq}}{dt} + \omega_s \cdot \phi_{rd} \end{cases} \quad (5)$$

where (V_{sd}, V_{sq}) and (V_{rd}, V_{rq}) are, respectively, the (d, q) stator and rotor axis voltage. (i_{sd}, i_{sq}) are the (d, q) axis stator current. (i_{rd}, i_{rq}) are the (d, q) axis rotor current. ω_s and ω_r represent, respectively, the reference frame and the slip speed. (ϕ_{sd}, ϕ_{sq}) and (ϕ_{rd}, ϕ_{rq}) are the (d, q) axis stator and rotor fluxes and can be expressed by the expression:

$$\begin{cases} \phi_{sd} = L_s \cdot i_{sd} + L_m \cdot i_{rd} \\ \phi_{sq} = L_s \cdot i_{sq} + L_m \cdot i_{rq} \end{cases} \quad (6)$$

$$\begin{cases} \phi_{rd} = L_m \cdot i_{sd} + L_r \cdot i_{rd} \\ \phi_{rq} = L_m \cdot i_{sq} + L_r \cdot i_{rq} \end{cases} \quad (7)$$

where L_s and L_r represent, respectively, stator and rotor inductance, and L_m is the magnetizing inductance.

An IM's dynamic mechanical model is defined as follows [11]:

$$T_e - T_L = J_m \cdot \frac{d\omega_r}{dt} + F_r \cdot \omega_r \quad (8)$$

where J_m is the total inertia, F_r is the friction coefficient, T_L describes the load torque, and T_e is the electromagnetic torque that is defined by:

$$T_e = p \cdot \frac{L_m}{L_r} \cdot (i_{sq} \cdot \phi_{rd} - i_{sd} \cdot \phi_{rq}) \quad (9)$$

where p is the number of pole pairs.

3. Five-Level Neutral Point Clamped Inverter

Currently, five-stage inverters are very popular for the majority of inverter applications, including machine controls and power factor controllers. They have the advantage of reducing the harmonic content and reducing the rated voltage or current of the semiconductors [22,23]. Figure 1 presents the topology of a five-stage inverter circuit based on the eight main switches. The three phases of the inverter share a common DC bus, which is further subdivided by four capacitors.

The function F_{ij} interprets the open or closed state of each switch such as [22]:

$$F_{ij} = \begin{cases} 0 & \text{if } T_{ij} \text{ is OFF} \\ 1 & \text{if } T_{ij} \text{ is ON} \end{cases} \quad (10)$$

Figure 1. Five-level diode clamped voltage source inverter.

In reference to the neutral point (n) of the DC bus voltage, the voltages of the output phases are [22]:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} F_{11} & F_{21} & F_{31} & F_{41} & F_{51} \\ F_{12} & F_{22} & F_{32} & F_{42} & F_{52} \\ F_{13} & F_{23} & F_{33} & F_{43} & F_{53} \end{bmatrix} \begin{bmatrix} E/2 \\ E/4 \\ 0 \\ -E/4 \\ -E/2 \end{bmatrix} \quad (11)$$

Each inverter branch can have five different switching states: $E/2$, $E/4$, 0 , $-E/2$, and $-E/4$, respectively. Figure 2 shows the spatial voltage vectors of a five-level inverter for all switching states. The output space vector is determined by the combination of the three branches' switching states. The output terminals a, b, and c of the 401 transistor, for example, have potentials of $E/2$, 0 , and $E/4$, respectively. The three-level inverter contains $5^3 = 125$ switching states, as indicated in the diagram, since each branch has five types of switching states. Because certain switching states are redundant and form the same space vector, the output voltage vector can only take 61 distinct locations in the figure [24].

Figure 2. Space vector diagram of five-level inverter.

4. Principles of Vector and Direct Torque Control

4.1. Vector Control

Mathematically, the command consists in establishing all the transformations to go from a system with a structural double non-linearity to a linear system that ensures the independence between the creation of the flow and the production of the couple as in a separate excitation DC machine [24]. The vector control (VC) technique applied to the induction motor is to adjust the flow by one current component and the torque by the other component. To do this, you must choose an axis system (d, q). Figure 3 shows the VC scheme:

Figure 3. Vector control scheme.

The application of the VC allows one to obtain:

$$\begin{cases} \phi_{rq} = 0 \\ \phi_{rd} = \phi_r \end{cases} \quad (12)$$

Under these conditions, we have:

$$\begin{cases} V_{sd} = L_s \cdot \frac{d i_{sd}}{dt} \cdot \sigma + R \cdot i_{sd} - \sigma \cdot L_s \cdot \omega_s \cdot i_{sq} - \frac{L_m}{L_r} \cdot R \cdot \phi_r \\ V_{sq} = L_s \cdot \frac{d i_{sq}}{dt} \cdot \sigma + R \cdot i_{sq} + \sigma \cdot L_s \cdot \omega_s \cdot i_{sd} + \frac{L_m}{L_r} \cdot \omega \cdot \phi_r \end{cases} \quad (13)$$

When implementing the decoupling method, the tension equations become:

$$\begin{cases} V_{sd} = V_{sdref} - e_{sd} = L_s \cdot \frac{d i_{sd}}{dt} \cdot \sigma + R \cdot i_{sd} \\ V_{sq} = V_{sqref} - e_{sq} = L_s \cdot \frac{d i_{sq}}{dt} \cdot \sigma + R \cdot i_{sq} \end{cases} \quad (14)$$

where:

$$\begin{aligned} \sigma &= \left(1 - \frac{L_m^2}{L_s \cdot L_r} \right) \\ R &= R_s + R_r \cdot \left(\frac{L_m}{L_r} \right)^2 \\ e_{sd} &= \sigma \cdot L_s \cdot \omega_s \cdot i_{sq} + \frac{L_m}{L_r} \cdot R \cdot \phi_r \\ e_{sq} &= \sigma \cdot L_s \cdot \omega_s \cdot i_{sd} - \frac{L_m}{L_r} \cdot \omega \cdot \phi_r \end{aligned}$$

4.2. Direct Torque Control

The principle of direct torque control (DTC) consists in maintaining the statoric flow in a range. The synoptic scheme of the DTC command is shown in Figure 4 [25,26]. The DTC control of an induction motor is based on the direct determination of the sequence of controls applied to the voltage inverter switches. This strategy is generally based on the use of hysteresis comparators whose role is to control the amplitudes of the statoric flux and the electromagnetic torque.

Figure 4. Direct torque control scheme.

According to the stator and rotor voltage formulas, the stator voltages are obtained:

$$\begin{cases} V_s = R_s \cdot i_s + \frac{d\phi_s}{dt} \\ V_r = R_r \cdot i_r + \frac{d\phi_r}{dt} - j \cdot \phi_r \cdot \omega \end{cases} \quad (15)$$

Therefore, the statoric flux can be calculated by:

$$\phi_s = \sqrt{\phi_{sd}^2 + \phi_{sq}^2} \quad (16)$$

where:

$$\begin{cases} \phi_{sd} = \int_0^t (V_{sd} - R_s \cdot i_{sd}) dt \\ \phi_{sq} = \int_0^t (V_{sq} - R_s \cdot i_{sq}) dt \end{cases} \quad (17)$$

The estimated torque and current equations are then obtained:

$$T_e = \frac{3}{2} \cdot p \cdot (\phi_{sd} \cdot i_{sq} - \phi_{sq} \cdot i_{sd}) \quad (18)$$

$$i_s = \frac{1}{\sigma} \cdot \frac{\phi_r}{L_r} - \frac{1}{\sigma} \cdot \frac{\phi_s \cdot L_m}{L_r \cdot L_s} \quad (19)$$

Substituting (19) in (18) yields:

$$T_e = \frac{3}{2} \cdot p \cdot \frac{\phi_s \cdot L_m \cdot \phi_r}{L_r \cdot L_s \cdot \sigma} \cdot \sin(\theta) \quad (20)$$

where θ the stator flux angle.

The derivative of (20) corresponds to the following result:

$$\frac{dT_e}{dt} = \frac{3}{2} \cdot p \cdot \frac{\phi_s \cdot L_m \cdot \phi_r}{L_r \cdot L_s \cdot \sigma} \cdot \frac{d\theta}{dt} \cdot \sin(\theta) \quad (21)$$

To ensure direct control of the stator flux and electromagnetic torque of the inverter-driven induction motor, a switching panel must be developed which best implements the possibilities of the inverter. Tables 1 and 2 represent, respectively, the switching tables for the two-level and five-level inverters with an NPC structure. They are based on the choice

of the statoric voltage vector applied to increase or decrease the statoric flux module and the value of the electromagnetic torque.

Table 1. Switching table of two-level inverter.

		Sector					
C_{flx}	C_{cpl}	1	2	3	4	5	6
1	+1	2	3	4	5	6	1
	0	7	0	7	0	7	0
	−1	6	1	2	3	4	5
−1	+1	3	4	5	6	1	2
	0	0	7	0	7	0	7
	−1	5	6	1	2	3	4

Table 2. Switching table of five-level inverter.

		Sector											
C_{fl}	C_{cp}	1	2	3	4	5	6	7	8	9	10	11	12
+1	+4	107	101	109	102	111	103	113	104	115	105	117	100
	+3	76	64	78	65	80	66	82	67	84	68	86	63
	+2	118	27	119	28	120	29	121	30	122	31	123	26
	+1	44	2	45	3	46	4	47	5	48	6	49	1
	0	zero vector											
	−1	49	1	44	2	45	3	46	4	47	5	48	6
	−2	123	26	118	27	119	28	120	29	121	30	122	31
	−3	68	85	63	75	64	77	65	79	66	81	67	83
	−4	105	116	100	106	101	108	102	110	103	112	104	114
0	+4	109	102	11	103	113	104	115	105	117	100	107	101
	+3	78	65	80	66	82	67	84	68	86	63	76	64
	+2	119	28	120	29	121	30	122	31	123	26	118	27
	+1	45	3	46	4	47	5	48	6	49	1	44	2
	0	zero vector											
	−1	48	6	49	1	44	2	45	3	46	4	47	5
	−2	122	31	123	26	118	27	119	28	120	29	121	30
	−3	67	83	68	85	63	75	64	77	65	79	66	81
	−4	104	114	105	116	100	106	101	108	102	110	103	112
−1	+4	102	110	103	112	104	114	105	116	100	106	101	108
	+3	65	79	66	81	67	83	68	85	63	75	64	77
	+2	28	120	29	121	30	122	31	123	26	118	27	119
	+1	3	46	4	47	5	48	6	49	1	44	2	45
	0	zero vector											
	−1	5	48	6	49	1	44	2	45	3	46	4	47
	−2	30	122	31	123	26	118	27	119	28	120	29	121
	−3	67	83	68	85	63	75	64	77	65	79	66	81
	−4	104	114	105	116	100	106	101	108	102	110	103	112

5. Improved Combined Vector Control and Direct Torque Control Strategy

In this part, a correspondence between the VC and the DTC is presented. It is also proven that the VC and DTC have a common basis despite their differences in implementation [9,10]. Section 4 shows that the rotor flow and electromagnetic torque are approximately the following systems:

$$\begin{cases} \phi_r = \Lambda_d \cdot i_{sd} \\ T_e = \Lambda_q \cdot i_{sq} \end{cases} \Rightarrow \begin{cases} \phi_r \propto i_{sd} \\ T_e \propto i_{sq} \end{cases} \Rightarrow \begin{cases} \Delta\phi_r \propto \Delta i_{sd} \\ \Delta T_e \propto \Delta i_{sq} \end{cases} \quad (22)$$

where Λ_d and Λ_q rely on the parameters of the induction motor.

According to the DTC command, $T_e \Delta\phi_s$ is broken down into two elements: the first is the radial component $\Delta\phi_f$ which contributes to the control of the level of the statoric flux, and the second element is the tangential component $\Delta\phi_t$ which controls the angle of rotation of the flux [13].

The variation of the electromagnetic torque can then be expressed as [11]:

$$\Delta T_e = K \cdot \phi_r ((\phi_s + \Delta\phi_t) \cdot \sin(\alpha + \Delta\alpha) - \phi_s \cdot \sin(\alpha)) \quad (23)$$

Using a good approximation:

$$\sin(\alpha + \Delta\alpha) = \sin(\alpha) + \cos(\alpha) \cdot \frac{\Delta\phi_t}{\phi_s} \quad (24)$$

Substituting (24) into (15) provides:

$$\Delta T_e = K \cdot \phi_s \cdot \Delta\phi_t \cdot \cos(\alpha) \quad (25)$$

Thus:

$$\Delta T_e \propto \Delta\phi_t \quad (26)$$

Figure 5 clearly shows that the variation in the amplitude of the statoric flux is:

$$\Delta\phi_s = \Delta\phi_t \quad (27)$$

Figure 5. Flux linkage vector variation.

Equation (24), in relation to (24), gives:

$$\Delta\phi_r = \Delta\phi_t \quad (28)$$

Referring to (22), (26), and (28), the radial component of the DTC flux is proportional to the direct axis component of the statoric current in VC, and the tangential component of the DTC flux is proportional to the quadrature component of the statoric current vector in VC.

$$\begin{cases} \Delta\phi_f = \Delta_{sd} \\ \Delta\phi_t = \Delta_{sq} \end{cases} \quad (29)$$

Figure 6 shows a block diagram of a combined vector control and direct torque control strategy controlled induction motor drive.

Figure 6. Combined vector control and direct torque control scheme.

6. Simulation Results

To evaluate the validity and the performance of the system, a numerical simulation model for an induction motor in Figure 6 was developed and modulated under MATLAB/Simulink®. The THD analysis is an effective parameter that must be considered in order to prove the efficiency of the multilevel inverter integration. For this, we studied the harmonic rate of the current I_{sd} and the ΔI_{sd} , the variation between I_{sdmax} and I_{sdmin} and I_{sqmax} and I_{sqmin} .

The results of the currents, voltage waveforms, and THD analysis are discussed in this section. The simulation parameters are those presented in the table in the Appendix A.

6.1. Variable Torque

As shown in Figures 7–11, the responses of torque, stator current components, and stator phase current increase from 6 to -6 , at $t = 2$ s.

Figure 7. Output voltage of the inverter: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 8. Torque response: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 9. Stator current: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 10. Isq components: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 11. Isd components: (a) conventional inverter; (b) five-level inverter.

As the five-level inverter can provide a voltage closer to the sine than the two-level inverter as shown in Figure 7, the torque inverter has been considerably reduced as shown in Figure 8. On the other hand, when using a five-level inverter in a combined VC-DTC structure, it is noted that the distortion of the statoric current and statoric phase current

component has been considerably reduced, as shown in Figures 9–11. Figure 12 illustrates the FFT analysis of the current I_{sd} and the fundamental harmonic THD, where the THD analysis demonstrates that the THD voltage of the five-level inverter is much lower than the conventional inverter. Table 3 represents the ΔI_{sd} and ΔI_{sq} for the two-level and five-level inverters with an NPC structure. This good low THD result of the five levels and the ΔI_{sd} and ΔI_{sq} demonstrate the efficiency of the multilevel inverter.

Figure 12. FFT analysis of the I_{sd} and the fundamental harmonic THD: (a) conventional inverter; (b) five-level inverter.

Table 3. ΔI_{sd} and ΔI_{sq} of two- and five-level inverters.

	Conventional Inverter	Five-Level Inverter
ΔI_{sd}	3.23	1.43
ΔI_{sq}	1	0.4

6.2. High Speed

To further evaluate the combined VC-DTC proposal, a closed-loop speed control was applied to the drive. The results obtained with the conventional combined VC-DTC are also presented for the sake of comparison. As shown in Figure 13, the speed of the drive increases from 70 to 40 and, finally, drops to 10 rad/s, at $t = 4$ and 7 s, respectively. Figures 14–18 represent the results. Table 4 represents a comparison between the ΔI_{sd} and ΔI_{sq} for the two-level and five-level inverters.

Figure 13. Speed response: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 14. Torque response: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 15. Stator current: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 16. Isq components: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 17. Isd components: (a) conventional inverter; (b) five-level inverter.

Figure 18. FFT analysis of the I_{sd} and the fundamental harmonic THD: (a) conventional inverter; (b) five-level inverter.

Table 4. ΔI_{sd} and ΔI_{sq} of two- and five-level inverters.

	Conventional Inverter	Five-Level Inverter
ΔI_{sd}	3.6	0.4
ΔI_{sq}	1	0.5

6.3. Reverse Speed

As shown in the Figures 19–24 and Table 5, the five-level inverter offers high performance compared to the conventional inverter which applies to minimizing the ripple of the stator torque and current. Reverse speed always remains a critical point in the majority of applications; thus, to verify the efficiency of the proposed drive, the induction motor was submitted to a negative reference speed to demonstrate the good results obtained in this case.

Figure 19. Speed response: (a) conventional inverter; (b) five-level inverter.

Figure 20. Torque response: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 21. Stator current: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 22. Isq components: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 23. Isd components: (a) conventional inverter; (b) five-level inverter.

(a)

(b)

Figure 24. FFT analysis of the Isd and the fundamental harmonic THD: (a) conventional inverter; (b) five-level inverter.

Table 5. ΔI_{sd} and ΔI_{sq} of two- and five-level inverters.

	Conventional Inverter	Five-Level Inverter
ΔI_{sd}	3.33	0.7
ΔI_{sq}	1.1	0.37

7. Conclusions

The article presents induction motor control using conventional combined vector control and direct torque control. However, this command causes disadvantages such as a great wealth of harmonic components of the statoric current and the torque. In order to improve the performance of the induction motor, a five-stage inverter to reduce torque ripple was introduced in this system. This article analyzes and compares the operation and efficiency of the control with a five-level inverter compared to the two-level inverter. Tests of simulation of the control by variation of the speed are presented. The results obtained show that the control VC-DTC five levels are very efficient. This demonstrates the effectiveness of the proposed strategy. The experimental data are required to verify the accuracy of the findings from our suggested study. As a further step, we will conduct experiments to compare the outcomes we obtained.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Induction motor data: rated power $p = 1$ kw, rated speed $n = 1425$ rpm, rated voltage $V = 220$ V, stator resistance $R_s = 6.8 \Omega$, rotor resistance $R_r = 5.43 \Omega$, stator inductance $L_s = 0.3973$ H, rotor inductance $L_r = 0.3558$ H, mutual inductance $L_m = 0.3558$ H, moment of inertia $J = 0.02$ Kg·m², and number of pole pairs $p = 2$.

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