Performance appraisal study of direct torque control (DTC) besed two and three-levels inverter in asynchronous machine

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Abstract - In this paper a comparative study direct torque control (DTC) alimented by two-level and three-level inverter in induction machine. The comparison it depends on several criteria: dynamic performance, decoupling, current and torque ripples and comparison of these at speed and load values, calculate the percentage of total harmonic distortion (THD), etc..., direct torque control application is in a closed speed loop. Load and speed are at nominal values the goal of this work is provide the best dynamic response the proposed approach is validated through tested on MATLAB/Simulink.

Keywords : switchinge table; direct torque control; total harmonic distortion; inverter, asynchronous machine.

I. INTRODUCTION

In industry, the continuity of service of an asynchronous machine requires degrees of operational reliability and reliability. For this reason, the asynchronous machine requires robust elements to avoid falling into faults. Modern controlled systems technology requires more precise and continuous control of speed, torque and position, while ensuring the highest possible level of stability, speed and efficiency. Frequently used electrical machines in large factories require precise control of speed or torque, so the only machine that is safe to use at work is the direct current motor. Especially due to the high weight and short life, the DC motor was abandoned over time and the machine was gradually developed by asynchronous machine is a powerful and well-known device that allows for increased energy efficiency and production yield [1].

The Direct Torque Control (DTC) technology it has more using industrial applications in asynchronous machine used two level and three-phase inverter with hysteresis controller because of some advantages: simplicity, low dependency on the motor parameters, good dynamic torque response and these techniques have achieved great success in the areas of control and identification of nonlinear systems [2, 3].

In recent years, interest in searching for a simpler, more robust, high-performance control system has increased, and a new vector control system called direct torque control (DTC) has been developed through direct control flux and torque and enter hysteresis controllers for flux and torque control loops this control has become understandable and uncomplicated [4]. Some researchers presented studies of effective solutions to develop this control. In it has proposed the design and construction of a power to direct torque control by using the control technique is implemented on the DSP board based on TMS320LF2407A which allows a great flexibility in the control, quite large execution speed and applied the voltage source inverter adapted is a six phase is composed of 12 IGBT connected in antiparallel with 12 fast diodes [5].

While he presented et al. [6] is study of a conventional direct torque of three phase induction motors through improve the transient response of the conventional DTC by proposing a novel design of its switching table by space vector theory was implemented to derive a mathematical model of a three- phase induction motor. whilst [7] proposes a DTC technique of open end-winding under ITSC fault with stator resistance compensator based on model reference adaptive system by estimation scheme is to improve the DTC performance under fault condition.

Several techniques for observe such as, fuzzy logic control, and artificial neural network have been presented for minimize the torque ripple, stator flux ripple and Total Harmonic Distortion value of stator current where to get better performance of the motor controlled to using DTC, by two-level inverter [8, 9]. Whereas [10] used new Artificial Neural Network controllers by compensation conventional IP and switching table by using Artificial Neural Network controllers in the Direct Torque Control of doubly fed induction motor where induction motor has been optimized performance compared to conventional IP and switching table rules.

In this paper is organized as follows: Section 1: introduces model asynchronous machine three-phase, Section 2: describes the concept tow-level and three-level (NPC) inverter modeling. Section 3: the direct torque control principle. Finally, we present the obtained results and verification of asynchronous machine behavior using tow-level and three-level Inverter.

II. MACHINE MODELING

A dynamic model of the MAS is the subject of control, must be known to understand and develop the vector control, such a model can be obtained by means of the two-axis theory of electrical machines. The machine model equations in general state-all-flux expressed in axes rotational reference (α,β) given as follows [11]:

$$\begin{cases} V_{s\alpha} = R_s i_{s\alpha} + \dfrac{d}{dt}\phi_{s\alpha} \\ V_{s\beta} = R_s i_{s\beta} + \dfrac{d}{dt}\phi_{s\beta} \\ V_{r\alpha} = 0 = R_r i_{ra} + \dfrac{d}{dt}\phi_{r\alpha} + \omega_{r\beta} \\ V_{r\beta} = 0 = R_r i_{r\beta} + \dfrac{d}{dt}\phi_{r\alpha} + \omega_{r\beta}\alpha \end{cases} \quad (1)$$

$$\begin{cases} \phi_{s\alpha} = L_s i_{s\alpha} + M i_{r\alpha} \\ \phi_{s\beta} = L_s i_{s\beta} + M i_{r\alpha} \\ \phi_{r\alpha} = L_r i_{r\alpha} + M i_{s\alpha} \\ \phi_{r\alpha} = L_r i_{r\beta} + M i_{s\beta} \end{cases} \quad (2)$$

The electromagnetic torque is given by:

$$C_e = \frac{3}{2} p\left(\phi_{s\alpha} i_{s\beta} - \phi_{s\beta} i_{s\alpha}\right) \quad (3)$$

Where $V_{s\alpha}$, $V_{s\beta}$, are the stator voltages components;
$i_{s\alpha}$, $i_{s\beta}$, are the stator currents components; $V_{r\alpha}$ and $V_{r\beta}$ are the rotor voltages components; $i_{s\alpha}$ and $i_{s\beta}$ are the rotor currents components; $\Phi_{s\alpha}$, $\Phi_{s\beta}$, are the stator flux components; $\Phi_{r\alpha}$ and $\Phi_{r\beta}$ are the rotor flux components; R_s and R_r are respectively the stator and rotor resistance; and M cyclic mutual inductance between stator and rotor; ωr is the rotor electrical angular speed.

III. CONCEPT TOW-LEVEL AND THREE-LEVEL NPC INVERTER MODELING

The concept two and three-level NPC inverter consists in utilizing an array of series switching devices by synthesizing the staircase voltage from several levels of DC capacitor voltages. Some of the most generally attractive features are that they can generate an output voltage with very low distortion, generate a smaller common-mode voltage and operate at a lower switching frequency compared to traditional two-level inverters [12, 13]. A three-level diode-clamped inverter is shown in Fig.1.

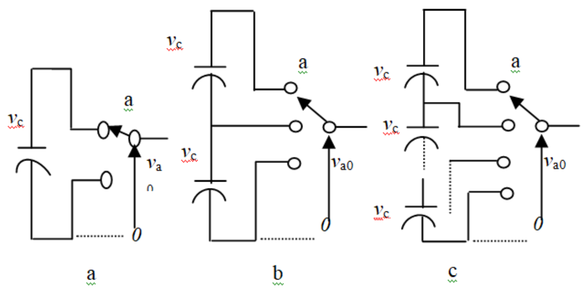

Fig. 1. One phase leg of an inverter with (a) two levels, (b) three levels, and (c) n levels.

The three-level NPC comprises two capacitors connected in series on the continuous side with three arms. Each arm, represented in Fig.2, the dc-bus voltage is split into three levels by two series-connected bulk capacitors. The middle point n of the two capacitors can be defined as the neutral point. The output voltage va0 for example has three states: Vdc, Vdc/2, consists of four switches and two diodes connecting to each neutral point [14].

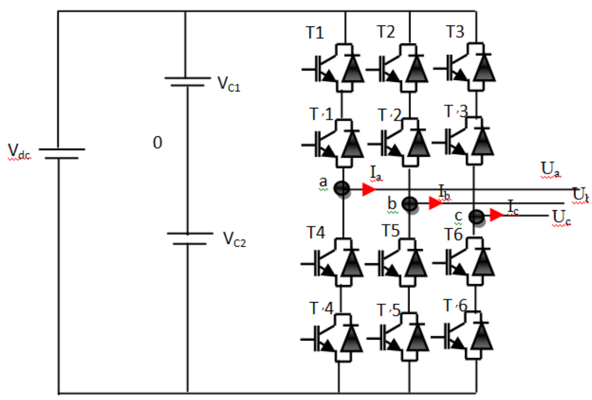

Fig. 2. Two-level inverter.

The inverter is made up of three arms each with two bidirectional switches and fully controllable when opening and closing. In this work we used IGBTs placed in antiparallel with diodes to ensure the bidirectional flow of current. The general structure of a two-level voltage inverter is shown in Fig. 3.

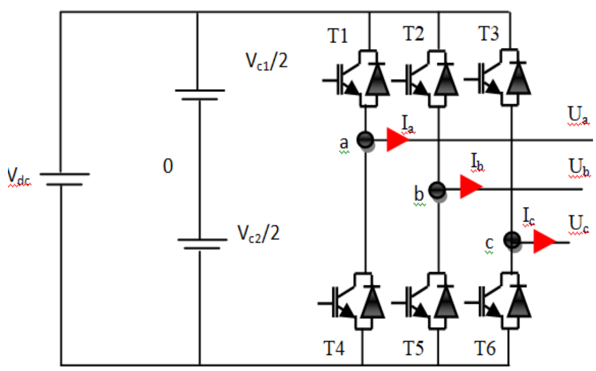

Fig. 3. Three-level NPC inverter.

The inverter two level has the following equation as a mathematical model :

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \qquad (4)$$

Where

$$\begin{cases} V_{an} = \frac{1}{3}\left(V_{ab} - V_{ca}\right) = \frac{1}{3}\left[2V_{a0} - V_{b0} - V_{c0}\right] \\ V_{bn} = \frac{1}{3}\left(V_{bc} - V_{ab}\right) = \frac{1}{3}\left[2V_{b0} - V_{a0} - V_{c0}\right] \\ V_{cn} = \frac{1}{3}\left(V_{ca} - V_{bc}\right) = \frac{1}{3}\left[2V_{c0} - V_{a0} - V_{b0}\right] \end{cases} \qquad (5)$$

And we define the logical connection functions by Sij such that:

$$V_{i0} = V_{dc}\left(S_i - \frac{1}{2}\right) \qquad (6)$$

As for the inverter three level, it is given as follows:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{b0} \\ Vc0 \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} F_a^2 - F_a^0 \\ F_b^2 - F_b^0 \\ F_c^2 - F_c^0 \end{bmatrix} \qquad (7)$$

Where

$$\begin{cases} V_{ab} = V_{a0} - V_{b0} = \left(V_{c1}F_a^2 - V_{c2}F_a^0\right) - \left(V_{c1}F_b^2 - V_{c2}F_b^0\right) \\ V_{bc} = V_{b0} - V_{c0} = \left(V_{c1}F_b^2 - V_{c2}F_b^0\right) - \left(V_{c1}F_c^2 - V_{c2}F_c^0\right) \\ V_{ca} = V_{c0} - V_{a0} = \left(V_{c1}F_c^2 - V_{c2}F_c^0\right) - \left(V_{c1}F_a^2 - V_{c2}F_a^0\right) \end{cases} \qquad (8)$$

Connection functions are expressed using Switches as follows:

$$\begin{cases} F_x^2 = S_{x1}S_{x2} \\ F_x^1 = \overline{S}_{x1}S_{x2} \\ F_x^0 = \overline{S}_{x1}\overline{S}_{x2} \end{cases} \qquad (9)$$

And

$$S_{(i+2)} = \overline{S}_{xj} = 1 - S_{xi} \qquad (10)$$

With i=1, 2, 3,4: arm x switch number.

IV. DIRECT TORQUE CONTROL PRINCIPLE WITH TWO AD THREE-LEVEL INVERTER

The Direct torque control of the asynchronous machine is based on the application of the various voltage vectors of the inverter, which are controlled by two variables are the rotor flux and the electromagnetic torque by hysteresis regulators. The power converter is a conventional voltage inverter. This work uses a DTC scheme for an asynchronous motor fed by two and three-level inverter is shown in Fig.4. These values are directly estimated from stator voltages determined with the constant voltage V_{dc} and the Boolean switching controls (S_a, S_b, S_c). The estimated values of the torque and the stator flux are compared respectively with their estimated reference values C_{em} and Φ_s the comparison results from the inputs of the hysteresis cycle comparators. The commanded electromagnetic torque is delivered from the PI speed controller [15, 16]. The components of the stator voltage vector $V_{S\alpha}$, $V_{S\beta}$ and the stator flux vector $\phi_{s\alpha}$, $\phi_{s\beta}$ in Concordia reference are given by Eq.11

$$\begin{cases} \phi_{s\alpha} = \int_0^t (V_{s\alpha} - R_s i_{s\alpha})dt \\ \phi_{s\beta} = \int_0^t (V_{s\beta} - R_s i_{s\beta})dt \end{cases} \quad (11)$$

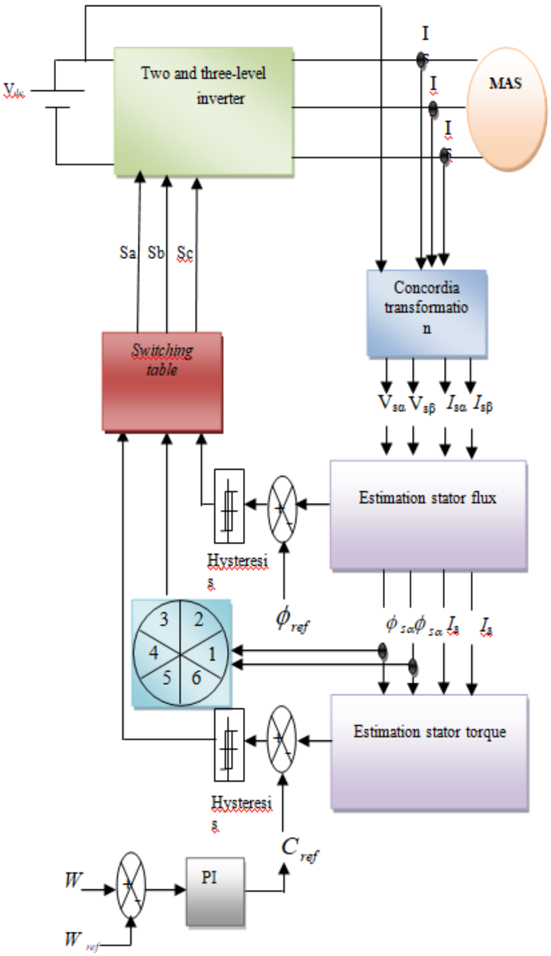

Fig. 4. Bloc diagram of the basic DTC.

The module of the stator flux and its position are given by Eq.(12)

$$\begin{cases} \phi_s = \sqrt{\phi_{s\alpha}^2 + \phi_{s\beta}^2} \\ \theta_s = arctg \dfrac{\phi_{s\beta}}{\phi_{s\alpha}} \end{cases} \quad (12)$$

The electromagnetic torque is expressed in terms of the components of the stator flux vector and the stator current vector as:

$$C_e = \frac{3}{2} p(\phi_{s\alpha} i_{s\beta} - \phi_{s\beta} i_{s\alpha}) \quad (13)$$

V. TORQUE AND FLUX HYSTERESIS CONTROLLER

Its goal is to maintain the end of the vector Φs in a circular ring as shown in Fig.5. The output of the corrector must indicate the direction of evolution of the module of Φs, in order to select the corresponding voltage vector. For this, a simple two-level hysteresis corrector is perfectly suited, and also allows very good dynamic performance to be obtained.

Indeed, if we introduce the difference $\Delta\Phi$s, between the reference flow Φref and the estimated flow Φest in a two-level hysteresis comparator (corrector), this generates at its output the value (C_{flx}= +1) for increase the flow and (C_{flx}=0) to reduce it; this also makes it possible to obtain very good dynamic performance of the flow [17].

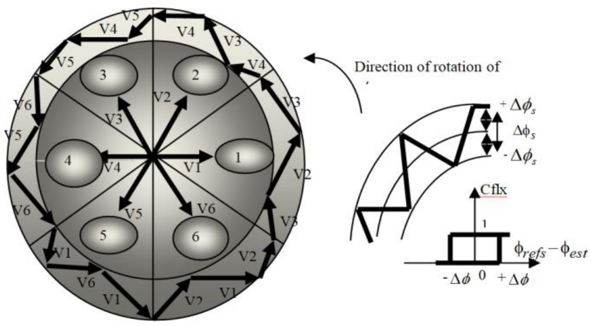

Fig. 5. Controller of the stator flux.

The three-level hysteresis corrector (-1, 0, 1) allows the motor to be controlled in both directions of rotation, either for positive or negative torque, such that (Ccpl) represents the output state of the comparator and ΔC the limit of the hysteresis band as shown in Fig. 6. This choice of increasing the number of levels is proposed in order to minimize the average switching frequency of the switches, because the dynamics of the torque is generally faster than that of the flow. In addition, this corrector allows a rapid decrease in torque, in fact, to reduce its value, in addition to zero vectors (stopping the rotation of Φs).

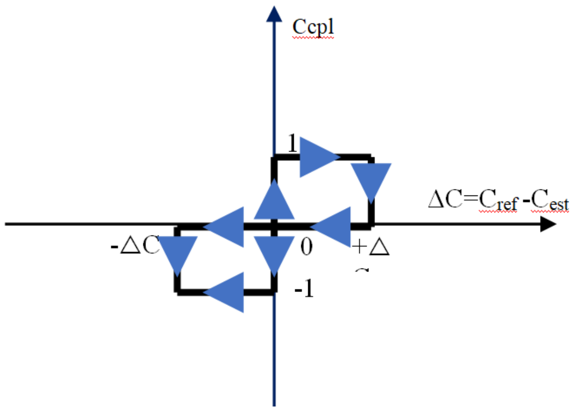

Fig. 6. Three levels hysteresis torque control.

VI. SWITCHING TABLE

The switching table 1 is generated according to the state of the variables (cflx) and (ccpl) and the flow position Φ_s. Selection of the appropriate voltage vector is depented on the control. In the classical DTC method, the level is divided for the six sectors. For the stator flux vector in sector 1 Fig.7, the voltage vectors V1, V2, V6 can be chosen to increase flux vector magnitude.

TABLE 1. SWITCHING TABLE FOR 6 SECTORS.

Sector		1	2	3	4	5	6
Cflx= 1	ccpl =1	V_2	V_3	V_4	V_5	V_6	V_1
	ccpl =0	V_7	V_0	V_7	V_0	V_7	V_0
	ccpl =-1	V_6	V_1	V_2	V_3	V_4	V_5
cflx=0	ccpl =1	V_3	V_4	V_5	V_6	V_1	V_2
	ccpl =0	V_7	V_0	V_7	V_0	V_7	V_0
	ccpl =-1	V_5	V_6	V_1	V_2	V_3	V_4

On the other hand, a decrease in the magnitude of the flow vector can be obtained by choosing V_3, V_4, V_5. By applying one of the zero vectors V0 or V7 will reduce the electromagnetic torque, and stator flux vector ψs is essentially unchanged [18]. The switching strategy is illustrated in table.1.

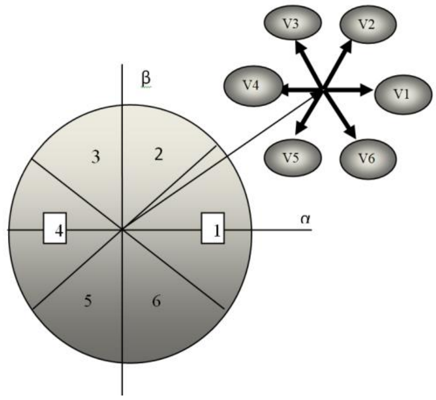

Fig. 7. Voltage vectors for the stator flux vector in sector 1.

VII. SIMULATION RESULTS

The presented simulations of direct torque control of the MAS powered by two two-level and three-level voltage inverters are carried out, with speed adjustment by a PI regulator. The simulation of the machine applied under the following conditions: The hysteresis band of the torque comparator and flux comparator, Φsref=1.2 Wb.

The control performance was tested using the following operating modes. To test the behavior of the asynchronous machine using the following operating modes: empty start and then application of the load, reversal of the direction of rotation we visualize on the rotation speed, the electromagnetic torque, the stator current I_{sa}, the trajectory of the stator flux, stator flux, THD.

After the simulation, the results obtained are effective, as the results showed that, at time t = 1 s is applied the value of load torque of 7 N.m in the presence of DTC control fed by the two and three-level inverter, where the speed increase linearly with time until the point of stability then it remains stable at the desired value (100 rad/s) this means the response speed is almost the same and when using speed reversal of rotation It gradually decreases until stabilizes at zero, a lower torque and flux ripple for the three-level contrary to what we observed two-level inverter during speed reversal.

The electromagnetic torque responds with negligible influence on the speed as it decreases and increases until it is stabilized, the flow trajectory is represented in circular form, and the stator current also responds to variations in torque as well as changes in speed, but it remains full of harmonics in two and two-level inverter, the stator flux follows its reference value (1.2 Wb) with appreciable speed the stator flow in the complex plane (α, β), describes an almost circular trajectory, to follow a circle of radius 1.2 Wb and

It is observed that current distortion ratio the stator current THD is higher in the two level inverter , but it becomes lower in the three level inverter as shown in the table 2.

TABLE 2. THD % FOR STATOR CURRENT IN CASE TWO AND THREE-LEVEL AND SPEED REVERSAL

	2-Level	3-Level	2-Level speed reversal	3-Level speed reversal
isa (THD %)	47.31	43.56	51.86	50.82

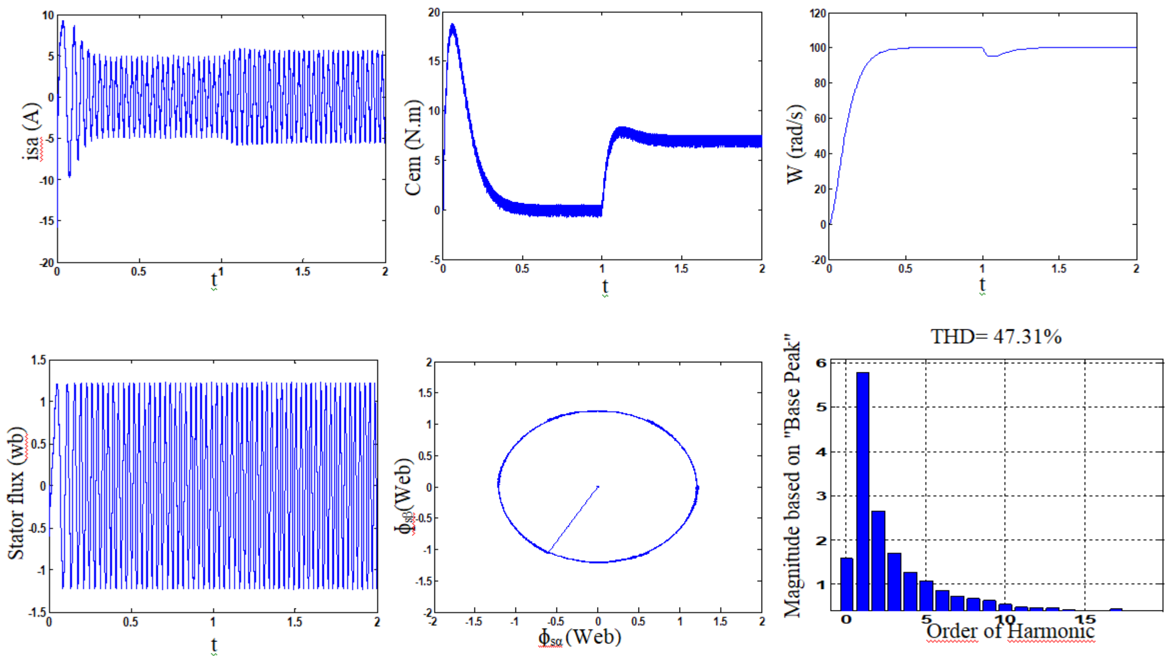

Fig. 8. Electrical and mechanical quantities of DTC control by two-level inverter.

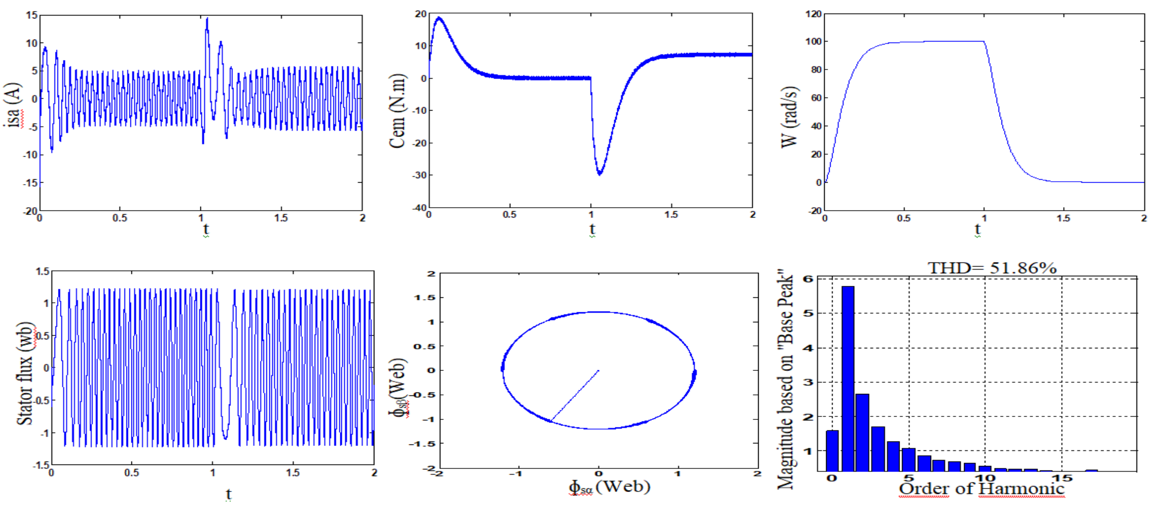

Fig. 9. Electrical and mechanical quantities of DTC control by two-level inverter with change in direction of rotation

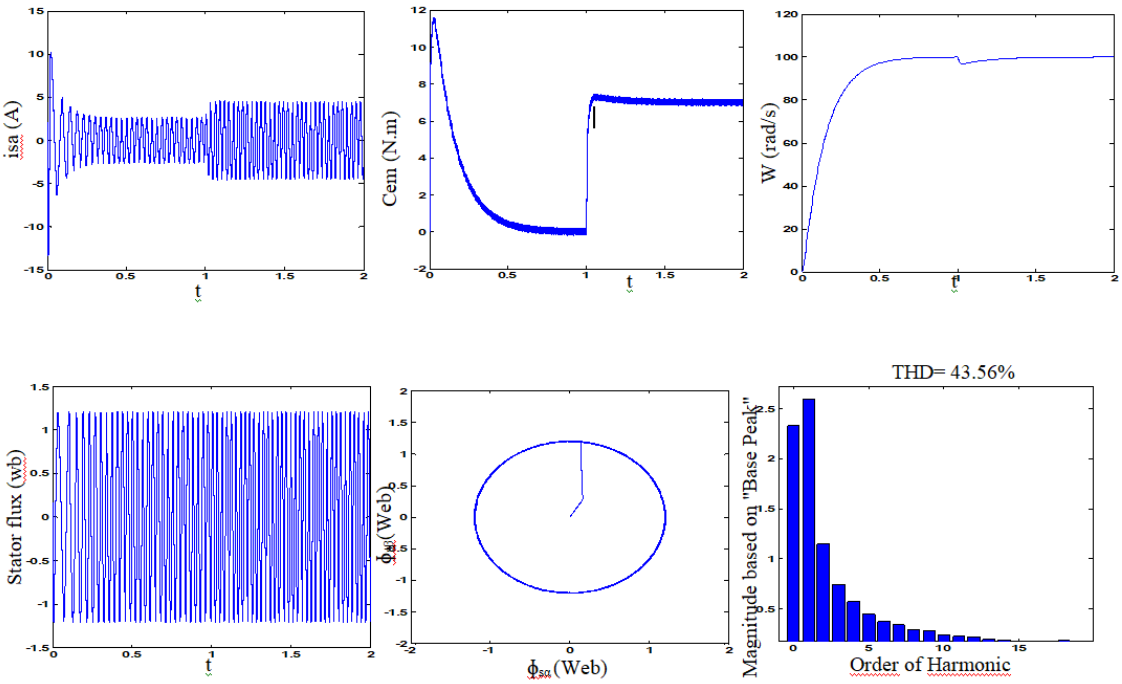

Fig. 10. Electrical and mechanical quantities of DTC control by two-level inverter.

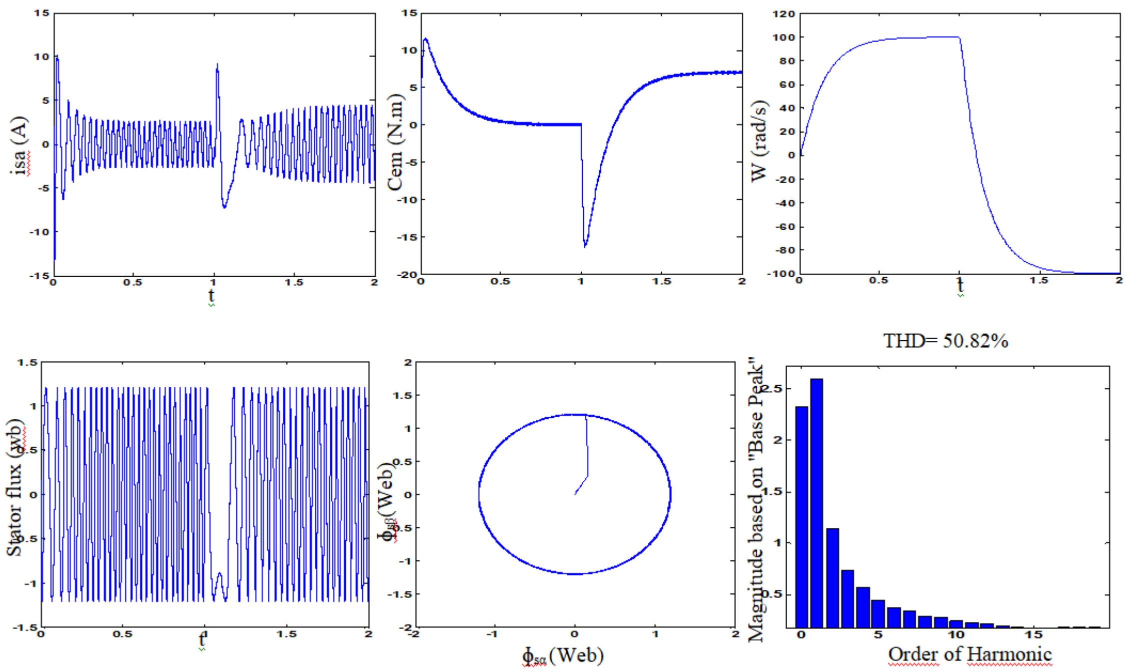

Fig. 11. Electrical and mechanical quantities of DTC control by two-level inverter with change in direction of rotation

VIII. CONCLUSION

In this paper, the performance of two and three-level inverter in an asynchronous machine using direct torque control (DTC) was demonstrated. The use of such a technique will reduce ripples and harmonics in current and torque. The majority of controls used are based on classic PI regulators. The torque and flux ripples, and stator-current gives oscillations because of the presence of hysteresis regulators which have a variable switching frequency, the stator current

THD is noticed to be higher in the proposed system in case two level inverter, while it becomes lower in case three level inverter. The simulation results allowed us provides a very interesting solution to the problems of robustness and dynamics. In short, this technique provides a concrete solution to the problems encountered in other AC motor control techniques.

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TABLE 4. APPENDIX FOR PARAMETERS OF MAS.

Symbol	*Definition*	*Value*	
Pn	output power	1.1	kW
Vs	stator voltage per phase	220	V
Fs	stator frequency	50	Hz
p	poles pair number	1	
Rs	stator resistance	4.80	Ω
Rr	rotor resistance	3.79	Ω
Ls	Stator inductance	0.269	H
Lr	rotor inductance	0.269	H
M	Inductance Mutuelle	0.265	H
J	moment of inertia	0.0054	kg m2