Optimal Control Technique of an Induction Motor

Cheikh Oudaa[1], Ethmane Isselem Arbih Mahmoud[2], Abdel Kader Mahmoud[3] ,Cherif Bilal djamal Eddine[4], Bendiabdellah Azeddine[5]

[1 ,2,3]Unité de Recherche Appliquée aux Energies Renouvelables, Eau et Environnement (URA3E), FST, UNA de Nouakchott, Mauritania
[2]Unité de Recherche en Electromécanique 'UREM', Institut Supérieur d'Enseignement Technologique (ISET), Rosso, Mauritania
[4,5]Diagnostic Group, LDEE laboratory, Electrical Engineering Faculty University of Science and Technology of Oran,Algeria

Article Info

Article history:

Received Jan 11, 2023
Revised May 13, 2023
Accepted Jun 5, 2023

Keywords:

IM
FOC
DTC
DTC-SVM
Inverter

ABSTRACT

The squirrel cage induction motor (IM) has many advantages over other types of electric technique (FOC), classical direct torque control (DTC), and direct torque control with space vector modulation (DTC-SVM) is carried out. The objective of this paper is to decouple the mechanical quantities such as torque and flux in a way similar to the DC motor control. And also, to minimize the torque and flux modulation of the IM. Torque oscillations can cause mechanical resonances and consequently acoustic noise, hence damaging the machine. Reducing the switching frequency significantly minimizes switching losses. The DTC-SVM control technique improves the performance of conventional DTC, which is characterized by low torque and flux modulation as well as a fixed switching frequency. Simulation results in MATLAB show that torque and current ripples are reduced with the improved DTC. DTC-SVM used for the traction control system is easy to implement in digital systems and also allows to move the photovoltaic panels according to the position of maximum sunshine to extract the maximum energy with high efficiency from the system.

Corresponding Author :

Cheikh Oudaa,
Unité de Recherche Appliquée aux Energies Renouvelables, Eau et Environnement (URA3E),
FST, UNA de Nouakchott,
Ksar caraffour cherif, Noukchott, Mauritania.
Email: cheikhoudaa4@gmail.com

1. INTRODUCTION

The squirrel cage induction motor (IM) is the most widely used electromechanical energy converter in various fields such as industry and transport. The advantage of the IM is its high robustness and low cost. Moreover, the growth in the use of variable speed drives has greatly increased their application in various fields [1-3].

Earlier IM control technique is known as File Oriented Control (FOC), its algorithm provides good dynamic torque control and better performance over a wide speed range [4-10]. It performs independent flux and torque control like DC machines[11-15]. The FOC technique, unfortunately requires a lot of mathematical processing. There are other types of control techniques such as Direct Torque Control (DTC). This control technique was proposed in the mid-1980s by Takahashi and Depenbrock. It becomes a concurrent control to conventional control techniques (FOC and Scalar control). The DTC technique is also less sensitive to parametric variations of the machine compared to the FOC technique. Note that the DTC technique has a fast dynamic torque response. In addition, the DTC technique does not require either Park transformation or voltage decoupling blocks. Its control algorithm is simple due to the absence of the pulse width modulation (PWM) strategy. DTC technique has drawbacks, such as sensitivity to stator resistance and the need to obtain stator flux and torque estimates. These drawbacks lead us to seek other solutions. Therefore, the advantages and disadvantages of these two control techniques are demonstrated. Therefore, it is proposed in this paper a contribution based on a better implementation of a DTC-SVM torque control of the IM. To verify the performances of the DTC-SVM technique, a MATLAB simulation of the IM powered by a two-level space vector modulation (SVM) voltage source inverter (VSI) is performed [15-25]. The characteristics of the proposed study are simple to implement, give high dynamic performance compared to FOC and classical DTC control of IM, without complex coordinate transformation, without current regulators, without speed sensors, not depending on parameters of the motors, decreases the current and the ripple torque and imposes constant frequency.

2. IM DYNAMIC MODEL

Note that in a reference system based on the rotating field, the equations of the stator and rotor voltages of the IM are written as follows:

$$\begin{aligned} V_{sd} &= R_s i_{sd} + \frac{d\psi_{sd}}{dt} - w_s \psi_{sq} \\ V_{sq} &= R_s i_{sq} + \frac{d\psi_{sq}}{dt} + w_s \psi_{sd} \\ 0 &= R_r i_{rd} + \frac{d\psi_{rd}}{dt} - w_{sl} \psi_{rq} \\ 0 &= R_r i_{rq} + \frac{d\psi_{rq}}{dt} + w_{sl} \psi_{rd} \end{aligned} \tag{1}$$

Where V_{sd} is stator voltage, R_s, R_r are stator and rotor resistances respectively, $\psi_{sd}, \psi_{sq}, \psi_{rq}, \psi_{rd}$ are stator and rotor flux in dq axis, i_{sd} and i_{sq} are stator current in dq axis , i_{rd} and i_{rq} are rotor current in dq axis, w_s is stator pulsation and w_{sl} is slip pulsation.

Rotor flux vector control is based on the Park dq-axis reference frame orientation, whereby the d-axis is aligned with the flux direction (ψ_r).

3. IM CONTROL TECHNIQUES

In the following, the three types of control models, namely FOC, DTC and DTC-SVM, are introduced and discussed.

3.1. FOC Strategy Model

Principle of FOC

The orientation of the magnetic flux along the direct axis leads to the suppression of its quadrature component:

$$\psi_{rd} = \psi_r \qquad \psi_{rq} = 0 \tag{2}$$

We thus obtain the components of the stator voltages:

$$\begin{aligned} V_{sd} &= R_s i_{sd} + \sigma L_S \frac{d_{isd}}{dt} + \frac{L_m}{L_r}\frac{d\psi_{rd}}{dt} - w_s \sigma L_s i_{sq} \\ V_{sq} &= R_s i_{sq} + \sigma L_S \frac{d_{isq}}{dt} + w_s \frac{L_m}{L_r}\psi_{rd} + w_s \sigma L_s i_{sd} \end{aligned} \tag{3}$$

Where σ is dispersion coefficient, L_S and L_r are stator and rotor inductance and L_m is mutual inductance.

Writing the state equation $\psi_{rq} = 0$ as a system, we find:

$$\begin{aligned} \frac{di_{sd}}{dt} &= -\frac{1}{\sigma L_s}\left(R_s + \frac{R_r L_m{}^2}{L_r{}^2}\right) is_d + w_s is_q + \frac{1}{\sigma L_s}\left(\frac{R_r L_m}{L_r{}^2}\right) + \psi_{rd} + \frac{1}{\sigma L_s} V_{sd} \\ \frac{di_{sq}}{dt} &= +w_s is_d - \frac{1}{\sigma L_s}\left(R_s + \frac{R_r L_m{}^2}{L_r{}^2}\right) is_q - \frac{1}{\sigma L_s}\left(\frac{L_m}{L_r}\right) w \times \psi_{rd} + \frac{1}{\sigma L_s} V_{sq} \\ \frac{d\psi_{rd}}{dt} &= \frac{R_r L_m}{L_r}\, is_d - \frac{R_r}{L_r}\, \psi_{rd} \end{aligned} \tag{4}$$

The expression of the electromagnetic torque is given as:

$$T_e = p\frac{M}{L_r}\,\psi_{rd} i_{sq} \tag{5}$$

Where T_e is the electromagnetic torque, p is the pole pair number.

It can be noticed that this torque expression is similar to the expression of the torque of the DC motor where the flux and torque quantities are decoupled.

3.2. DTC Strategy Model

Figure 1 shows the basic block diagram used to implement the DTC technique for an IM. The principle of DTC is based on the direct application of a command sequence to the voltage inverter switches. This sequence is selected by applying a switching table and two hysteresis regulators. Their task is to control and regulate the electromagnetic torque and the flux of the machine in order to decouple the mechanical quantities.

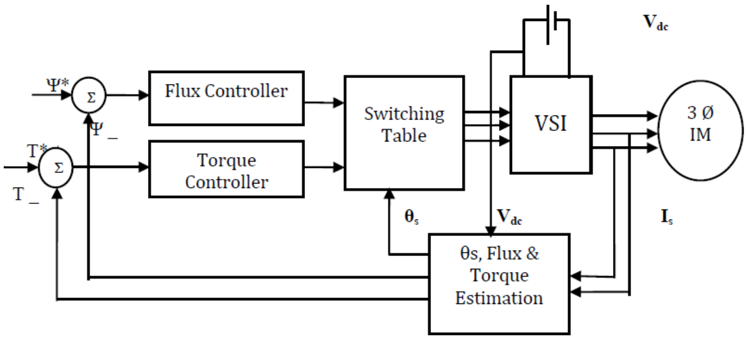

Figure 1. Schematic diagram of the DTC (VSI) applied to the IM

3.2.1 Model for DTC:

$$\frac{dw_s}{dt} = V_s - R_s i_s \tag{6}$$

And

$$\psi_s(t) = \int_0^{T_z}(v_s - R_s i_s)dt + \psi_s(0) \tag{7}$$

Where ψ_s is a flux vector at the instant t = 0

By introducing a non-zero vector in the sampling period Tz, the voltage drop over the stator resistance can be neglected, hence equation (8) can be written as:

$$\psi_s(t) = V_s T_z + \psi_0(0) \tag{8}$$

The relationship between stator voltage and stator flux variation can be determined as follows:

$$\Delta\psi_s = \psi_s(t) - \psi_0(0) = V_s T_z \tag{9}$$

Equation (9) shows that the stator flux can be changed by supplying a stator voltage during a time Tz. The extreme side of the stator flux vector moves in the direction given by the voltage vector and carries out a circular trajectory as depicted by figure 2.

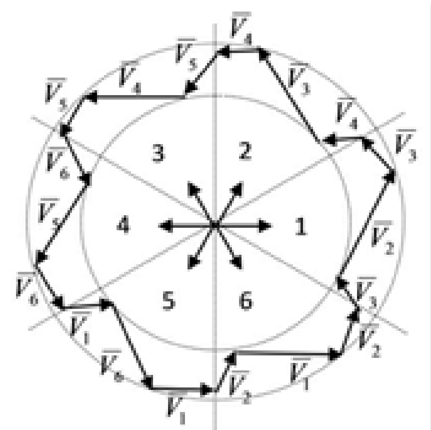

Figure 2. Evolution of the stator flux vector in the complex plane

The estimation of the stator flux is mainly done by integrating the back emf. The stator flux components can be expressed using stator voltages and currents in the stationary reference frame (α, β):

$$\psi_{s\alpha} = \int_0^t (v_{s\alpha} - R_s i_{s\alpha})dt \quad (10)$$

$$\psi_{s\beta} = \int_0^t (v_{s\beta} - R_s i_{s\beta})dt \quad (11)$$

The stator flux angle is determined by:

$$\theta_s = Arctg\left(\frac{\psi_{s\beta}}{\psi_{s\alpha}}\right) \quad (12)$$

The output voltages of the inverter, which are the input voltages of the IM stator, are given by:

$$\begin{aligned} V_{sa} &= \frac{V_{dc}}{3}(2s_a - s_b - s_c) \\ V_{sb} &= \frac{V_{dc}}{3}(2s_b - s_c - s_a) \\ V_{sa} &= \frac{V_{dc}}{3}(2s_c - s_a - s_b) \end{aligned} \quad (13)$$

The electromagnetic torque is estimated from the flux and current information as follows:

$$T_e = p(\psi_{s\alpha} i_{s\beta} - \psi_{s\beta} i_{s\alpha}) \quad (14)$$

3.3. DTC- SVM Strategy Model

Figure 3 shows a conversion chain made of a three phase AC power supply, a three-phase rectifier, a DC link and an IGBT voltage source inverter with a frequency (2 Khz to 16 Khz) to achieve the geometric construction of three AC signals of equal amplitude in given time 120 degrees out of phase with each other and similar in shape to a sinusoidal signal.

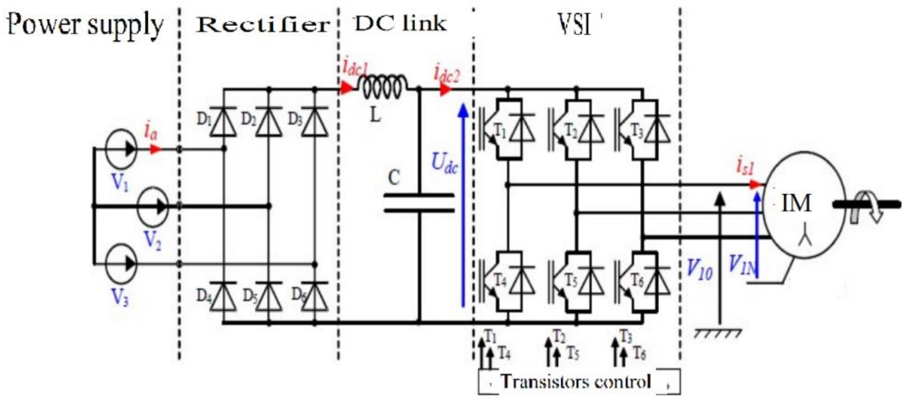

Figure 3. Inverter fed three-phase IM (star connected)

The inverter control is based on the logical values Si with:

$S_i = 1,\ T_i\ is\ on\ and\ \overline{T_i}\ is\ off$
$S_i = 0,\ T_i\ is\ off\ and\ \overline{T_i}\ is\ on$

With $i = a, b, c$

The voltage vector is generated by the following equation

$$V_s = \sqrt{\frac{2}{3}} V_{dc}\left[s_a + s_b e^{i\frac{2\pi}{3}} + s_c e^{i\frac{4\pi}{3}}\right] \quad (15)$$

Where V_{dc} is the DC voltage, s_a, s_b , s_c are switching states.

There are eight possible positions from the state combinations of the switches. Six are active vectors (V1, V2 ... V6) and two vectors are null (V0, V7).

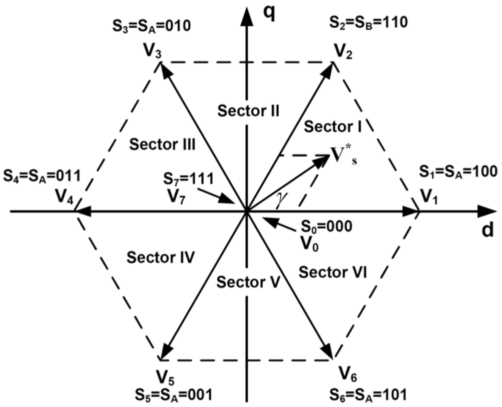

Figure 4. Voltage vectors V_i representation

3.3.1. Architecture Of The Proposed DTC- SVM Technique

The control scheme is formed by seven (07) blocks as given in figure 5 and are listed as follows: PI speed Control, PI torque Control, PI Flux Control, Park Transformation, SVI Inverter, SVM,Torque and flux Estimators[25,29].

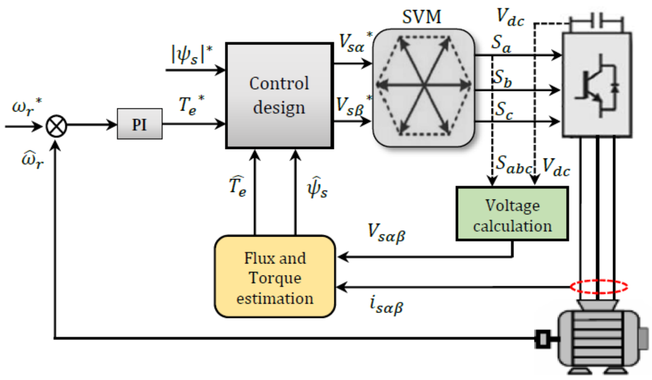

Figure 5. Global structure of the DTC-SVM control technique

3.3.2. SVM Strategy Algorithm

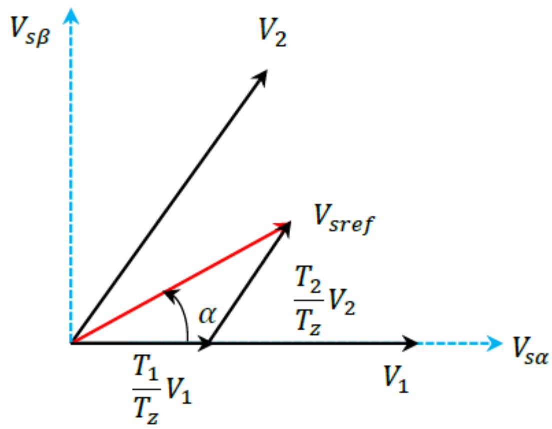

Figure 6. Reference vector as a combination of vectors adjacent to sector 1

$$V_s^* T_z = V_1 T_1 + V_2 T_2 + V_0 T_0 \tag{16}$$
$$T_z = T_1 + T_2 + T_0$$

Where T_1, T_2 and T_0 are the corresponding operating times of the voltage vectors respectively and Tz is the sampling time.

$$T_1 = \frac{T_z}{2V_{dc}}\left(\sqrt{2}\,V_{s\beta}^{\;*} - \sqrt{2}\,V_{s\alpha}^{\;*}\right)$$

$$T_2 = \sqrt{2}\,\frac{T_z}{V_{dc}}V_{s\alpha}^{\;*} \tag{17}$$

The computation of the switching times is given as follows:

$$T_{aon} = \frac{T_z - T_1 - T_2}{2}$$
$$T_{bon} = T_{aon} + T_1 \tag{18}$$
$$T_{con} = T_{bon} + T_2$$

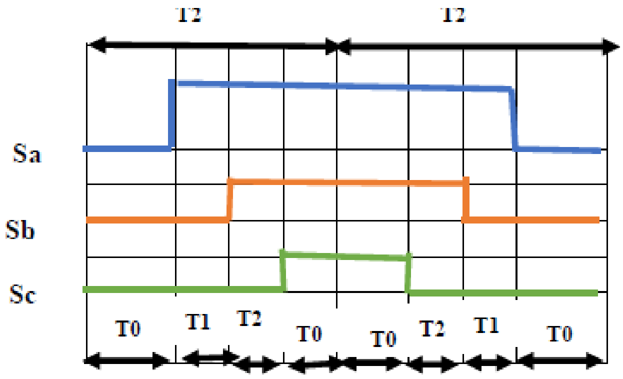

Figure 7. Switching time of sector 1

The following table illustrates the switching times for each sector

Table 1. Switching times for each sector

Sector	1	2	3	4	5	6
Sa	Tbon	Taon	Taon	Tcon	Tbon	Tcon
Sb	Taon	Tcon	Tbon	Tbon	Tcon	Taon
Sc	Tcon	Tbon	Tcon	Taon	Taon	Tbon

4. RESULTS AND DISCUSSION

The motor powered by a two-level VSI and controlled by vector modulation strategy is simulated. The IM has a torque load at time t = 1 s. The simulations are performed using MATLAB Simulink. The simulation results are shown below for the FOC, DTC, and DTC-SVM cases. The parameters of the IM are summarised in Table 2 below.

Table 2. Parameters of the IM

Power supply	380
Coupling	Δ
Rated power	3kW
Nominal current	7A
Rated speed	1440tr/min
Stator resistance	6Ω
Rotor resistance	2.8Ω
Stator cyclic inductance	0.5668Ω
Rotor cyclic inductance	0.5142Ω
Mutual inductance	0.5142Ω
poles pairs number	2
Moment of inertia	0.058kg.m2
Coefficient of viscous friction	0.005 N.m.rad-1.s

4.1. FOC Simulation Results and Discussion

The results of the simulation of the indirect vector control of the IM for the case of a healthy inverter are given in the figure (8,9,10). The vector control is tested with a reference speed of 1500 rpm and a resistive torque of 20 N.m applied after one second (1s).

For 0 < t < 1s: During the transient statee, Figure 8 shows the behavior of the IM for a speed setpoint during an no-load start. It can be seen that the speed curve perfectly follows its set point, without which it is reached very quickly. It is clear that the performances of the speed control loop are satisfactory with an acceptable rise time and even the rejection of disturbances is ensured.

For t > 1s: When applying the disturbance, it can be observed a decrease in the rotor speed, which is an obvious result.

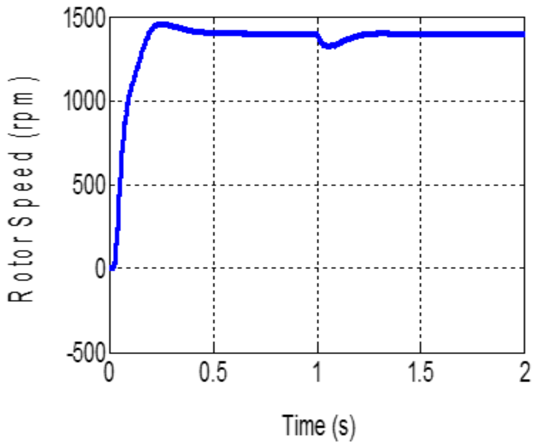

Figure 8. IM rotor speed response

Figure 9 depicts the electromagnetic torque where torque peaks are observed. In transient mode, the torque increases slightly to reach a maximum value of 150 N.m for a response time of 0.2s. If a load is applied at time t = 1s, the torque will be 20 N.m.

For 0 < t < 1s: During the transient state, the torque is strongly pulsating. In the first moments of starting, it presents significant oscillations, which explains the noise generated by the mechanical part. In steady state, the electromagnetic torque practically cancels out.

For t > 1s: In the second step, a resistive torque disturbance, Cr = 20 Nm is applied to the machine shaft (operation under load). The electromagnetic torque stabilizes at the value of the resistive torque with an almost instantaneous response.

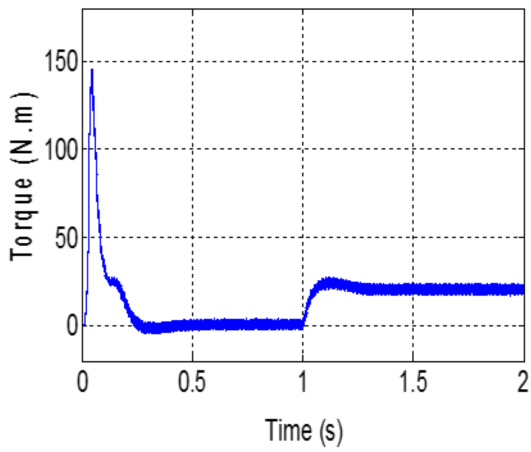

Figure 9. Electromagnetic torque with load application of 20N.m at t=1s

It can be seen in figure 10, that the stator current waveform has some ripples, which has a direct impact on the torque quality. Therefore, the torque is the product of flux and the torque producing current. Motor current increases in proportion to load torque reaching its maximum value, when the rotational speed becomes zero as well.

For 0 < t < 1s :

During the transient regime no-load start-up, we immediately notice the importance of the current which can cause the destruction of the SAM by overheating in the event of excessive repetitions, but which rapidly disappears after a few alternations to give rise to a sinusoidal shape of constant amplitude sinusoidal shape with a constant amplitude.

For t > 1s :

It can also be seen that the stator current changes according to the load applied to the machine shaft.

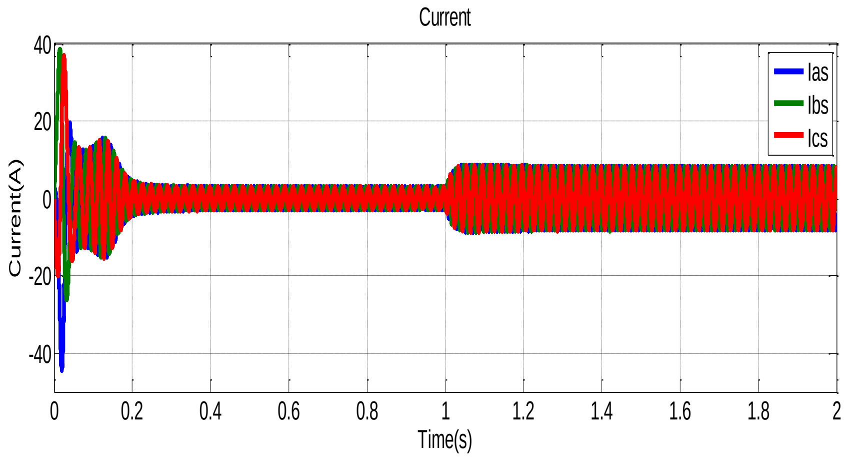

Figure 10. Stator current response

4.2. DTC Simulation Results and Discussion

Figure 11 shows the behaviour of speed, torque, and stator current. It is observed that the rotor speed perfectly follows its set point and reaches a maximum value of 1500 rpm at a response time t = 1.25 s. Peaks of the electromagnetic torque are also observed. During the transient mode, the torque increases slightly to reach a value of 500 N.m and then decreases. For the current response, Ripples are observed at transient mode and the current reaches 2000 A.

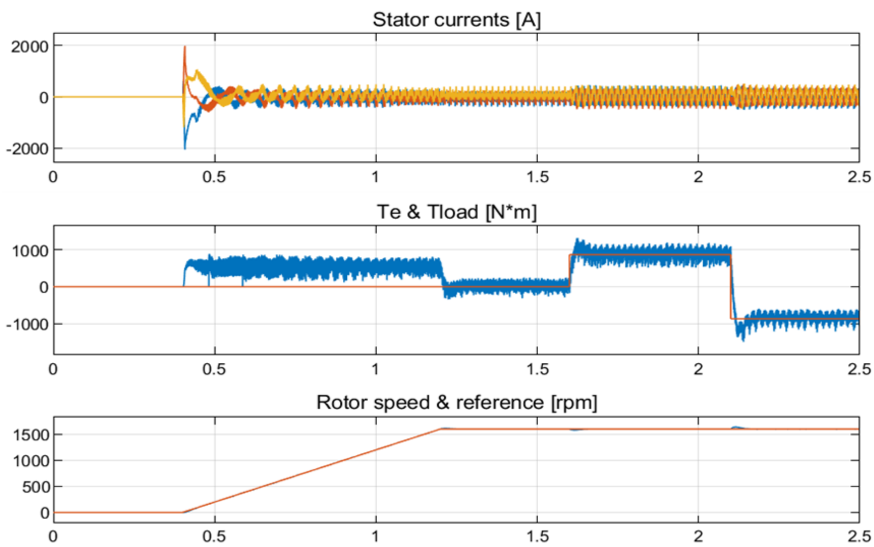

Figure 11. Torque, speed, and current response

4.3. DTC-SVM Simulation Results and Discussion

In figure 12 and 13, it is observed that the rotor speed perfectly follows its set-point and achieves a maximum value of 1000 rpm at a response time t= 0.55 s. We also observed small peaks of the electromagnetic torque. During the transient mode, the torque increases slightly to reach a value of 750 N.m and then decreases. For the response of the current, we observe at the transient mode, the ripples and the current attained 1500 A.

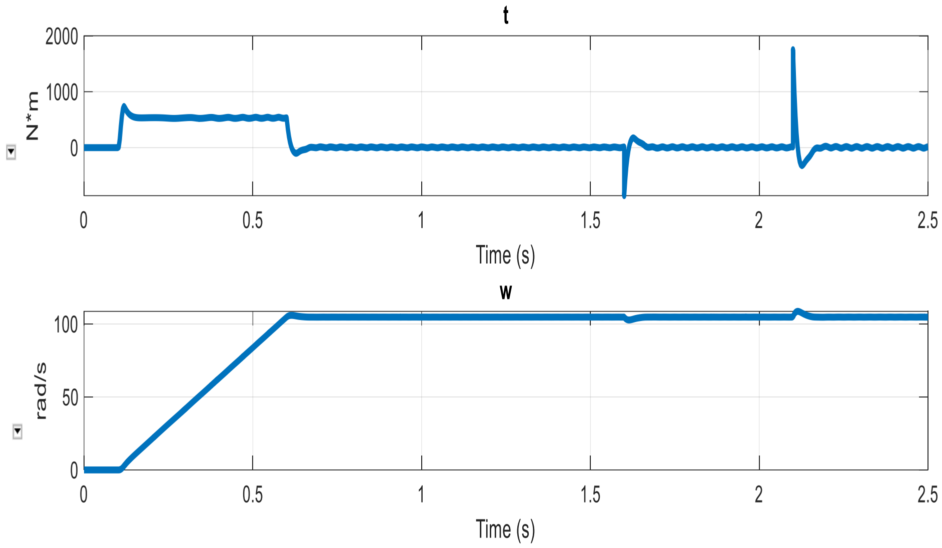

Figure 12. Torque and speed responses

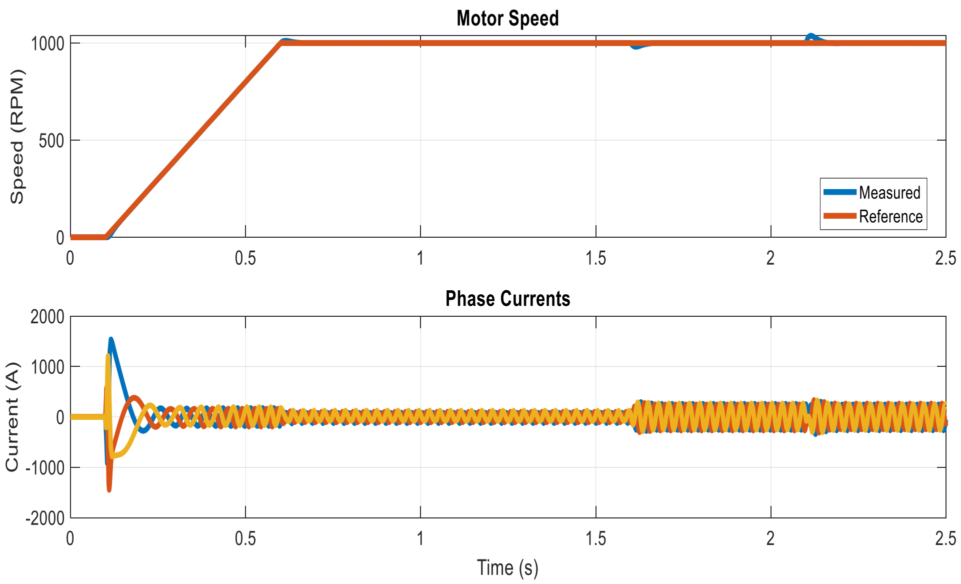

Figure 13. Current and speed responses

5. CONCLUSION

In this paper, a comparison of three different technique, namely, vector-oriented control (FOC), classical direct torque control (DTC) and direct torque control with space vector modulation (DTC-SVM) applied on the motor three-phase induction powered by a two-level inverter is presented. The simulation results obtained show that the DTC- SVM technique is superior to the two others as it corrects the constraints of vector control and DTC control. Moreover, the DTC-SVM is a technique to reduce the ripple. SVM techniques have several advantages that are offering better DC bus utilization, lower torque ripple, lower total harmonic distortion in the AC motor current, lower switching loss, and easier to implement in the digital systems.This technique will apply in our case to the moving of the PV panel according to the position of maximum sunshine to extract a high efficiency from the system and the pumping of water at the level of the rivers using induction motors.

ACKNOWLEDGEMENT

The authors would like to thank the Rosso Higher Institute of Technological Education, Electromechanical Engineering Department, also the Diagnostic Group at the LDEE Laboratory, Department of Electrical Engineering, in Algeria and finally the Laboratory of Research Applied to Renewable Energies, Modern University of Nouakchott, Mauritania.

REFERENCES

[1] H. Abdelfattah1, M. I. Mosaad, M Nagwa and F. Ibrahim.; "Adaptive Neuro-Fuzzy Technique for Speed Control of Six-Step Brushless DC Motor, ", *Indonesian Journal of Electrical Engineering and Informatics (IJEEI*), Vol. 9, No. 2, pp. 302-312, 2021.

[2] P. M. D. Zemgue, R. C. G. N. Ewo and A. T. Boum "Multi-objective Predictive Control of 3L-NPC Inverter Fed Sensorless PMSM Drives for Electrical Car Applications*," Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, Vol. 10, No. 3, pp. 522~533, 2022.

[3] M. H. Basappa. and P. Viswanathan, "ANFIS based Direct Torque Control of PMSM Motor for Speed and Torque Regulation," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, vol. 10, no. 2, pp. 549–558, 2022.

[4] Liu, Tingting, Guojin Chen, and Shigang Li. "Application of vector control technology for PMSM used in electric vehicles." *The Open Automation and Control Systems Journal*,Vol. 6, No. 1 2014.

[5] G. K. Lounas, and M. S. Aspalli, "Direct torque control and dynamic performance of induction motor using fractional order fuzzy logic controller," *International Journal of Electrical and Computer Engineering (IJECE)*, Vol. 13, No. 4, pp. 3805-3816, 2023.

[6] M. Boonpramuk1, S. Tunyasirut, and D. Puangdownreong; "Artificial Intelligence-Based Optimal PID Controller Design for BLDC Motor with Phase Advance ", *Indonesian Journal of Electrical Engineering and Informatics (IJEEI),* Vol. 7, No. 4, pp. 720~733. 2019. ISSN: 2089-3272, DOI: 10.11591/ijeei.v7i4.1372

[7] Q. Al Azze and I. Abdul-Rida Hameed, " Reducing torque ripple of induction motor control via direct torque control", *International Journal of Electrical and Computer Engineering (IJECE)* ,Vol. 13, No. 2, pp. 1379-1386, 2023.

[8] M. D. Raman, C. E. Jaber, V. K. Srinivasan and B. Chokkalingam,"Development of performance characterization in VSI fed induction motor drives using random PWM", *International Journal of Power Electronics and Drive Systems (IJPEDS),* Vol. 13, No. 3, pp. 1469~1477. 2023.

[9] S. M. Ali1, M. S. Kalavathi, Mtibaa, A. and M.F. Mimouni, "Analysis of coupled and decoupled PWM techniques for induction motor drive ", *Indonesian Journal of Electrical Engineering and Informatics (IJEEI),*Vol. 7, No. 1, pp. 95~104, 2019. ISSN: 2089-3272, DOI: 10.11591/ijeei.v7i1.529.

[10] A.C. Subrata et al., "Review on Adjustable Speed Drive Techniques of Matrix Converter Fed Three-Phase Induction Machine," *in of the 5th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI* 2018), 2018.

[11] I. Boukhechem, A. Boukadoum, L. Boukelkoul, and H. E. Medouce, "Sensorless Predictive direct power control PDP-SVM for PWM Converter under Different Input Voltage Condition," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI),* Vol. 8, No. 1, pp. 33~44, 2020. ISSN: 2089-3272, doi: 10.11591/ijeei. v8i1

[12] L. Heru Pratomo "A New Topology of a Single-Phase Five-Level Inverter," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI),* Vol. 8, No. 3, pp. 447~456, 2020. ISSN: 2089-3272, doi: 10.11591/ijeei.v8i3.1766

[13] S. Vashishtha, and K.R. Rekha, "A Survey: Space Vector PWM (SVPWM) in 3φ Voltage Source Inverter (VSI), " *International Journal of Electrical and Computer Engineering (IJECE),* vol. 8, no. 1, pp. 11-18, 2018.

[14] A, Nikolic, "Direct Torque Control Strategy Based on Constant Switching Frequency Applied in Current Source Inverter Fed Induction Motor Drive," *International Journal on Energy Conversion (IRECON),* Vol. 6,No 1, pp. 30-37.2018, doi: https://doi.org/10.15866/irecon.v6i1.15546

[15] H. F. E. Soliman et al., "Direct Torque Control of a Three Phase Induction Motor Using a Hybrid PI/Fuzzy Controller," *Industry Applications Conference, 2007*. 42ndIAS Annual Meeting Conference Record of the 2007 IEEE, New Orleans, LA, pp. 1681-1685, 2007

[16] E. S. Sergaki, "Motor flux minimization controller basedon fuzzy logic control for DTC AC drives," XIX *International Conference on Electrical Machines (ICEM),* pp. 1-6, Sep. 2010.

[17] B. Basakdaim, "Transient Behaviour of Three Phase Induction Motor Under Supply Interruption of One Phase During Starting ", *Indian Institute of Technology, Kharagpour 721302, 27-29, 2002.*

[18] M. Hagiwara, K. Nishimura, and H. Akagi, "A medium-voltage motor drive with a modular multilevel PWM inverter," *IEEE Trans. Power Electron*., vol. 25, no. 7, pp. 1786–1799, 2010.

[19] Mesloub, Hayette, R. Boumaaraf, Mohamed Toufik Benchouia, Amar Goléa, Noureddine Goléa, and K. Srairi. "Comparative study of conventional DTC and DTC_SVM based control of PMSM motor—Simulation and experimental results." *Mathematics and Computers in Simulation*, Vol. 16, no. 7, pp. 296-307, 2020

[20] Abosh, Atheer H., Zi-Qiang Zhu, and Yuan Ren. "Cascaded direct torque control of unbalanced PMSM with low torque and flux ripples*." IEEE Transactions on Power Electronics*, Vol. 33, No. 2, pp. 1740-1749, 2017.

[21] Navardi, Mohammad Javad, Jafar Milimonfared, and Heidar Ali Talebi. "Torque and flux ripples minimization of permanent magnet synchronous motor by a predictive-based hybrid direct torque control." *IEEE Journal of emerging and selected topics in power electronics*, Vol. 6, No. 4, pp. 1662-1670, 2018

[22] Zhong, Zaimin, Junming You, and Shuihua Zhou. "Torque Ripple Reduction of DTC Based on an Analytical Model of PMSM." *World Electric Vehicle Journal*, Vol. 11, No. 1, pp. 1-28, 2020.

[23] Zhang, Zheng, and Xinghua Liu. "A duty ratio control strategy to reduce both torque and flux ripples of DTC for permanent magnet synchronous machines." *IEEE Access*, Vol. 7, pp.11820-11828, 2019.

[24] H. F. Rashag, S. P. Koh, A. N. Abdalla, and N. M. L. Tan , "Modified Direct Torque Control using Algorithm Control of Stator Flux Estimation and Space Vector Modulation Based on Fuzzy Logic Control for Achieving High Performance from Induction Motors," *Journal of Power Electronics*, Vol. 13, No. 3, pp. 1-12, 2013.

[25] S. Saravanan, and K. Geetha B., "Direct Torque Control Of Induction Motor Drives – A Study," *Australian Journal of Basic and Applied Sciences*, vol. 8, No. 1, pp. 213-221, 2014.
[26] C. Dinaaran, " Modeling and simulation of speed control of induction motor by space vector modulation technique using voltage inverter," *Journal of Electrical Engineering*, pp. 1-9, 2015.
[27] M. Malla and S. K. Gudey, "A Novel space vector modulated DTC scheme of induction motor drive with a single PI controller for electric vehicles," Journal of Energy Systems, Vol. 6, No. 3, pp. 436-450, 2022.
[28] N.Ouanjli,A.Derouich and A.El ghzizal., "Modern improvement techniques of direct torque control for induction motor drives - a review," *Protection and Control of Modern Power Systems*, pp. 1-12, Vol. 4, No 11, 2019.
[29] E. Ozkop, et al., "Direct Torque Control of Induction Motor Using Space Vector Modulation (SVM-DTC)," *Power System Conference, 2008. MEPCON 2008*. 12th International Middle-East, pp. 368-372, 2008.

BIOGRAPHY OF AUTHORS

Cheikh Oudaa was born in El Mina, Noukchott, Mauritania, in 1990. He received his Master degrees from the University of Sciences and Technology of Oran, (USTO-MB), Algeria in 2018. He is currently working for his Ph.D degree at UNA, Mauritania. His research interests include Power Conversion and Electric Machines and Drives and Tolerance.

Ethmane Isselem Arbih was born in Tidjikja, Mauritania, in 1966.He received Master of Sciences degree in electrical systems and networks from Ukraina-Vinnitsa state university in 1994. and his PhD degree in electrical engineering from the Technical University of Mohammad V (UM5R) in Morocco, in 2019. Currently is a lecturer assistant at the High Technological Educational Institute of Rosso country. His current research interests include Electric Network, Power Systems and Energy Efficiency and automatic control. Author of five (5) manuscripts, two (2) conferences and two books.

Abdel Kader Mahmoud was born in Aleg, Mauritania in 1960. He received his Master degree of Sciences in power stations in 1988 and his PhD degree in electrical engineering from the Technical University of Tashkent in Uzbekistan, in 1991. Then he received his second doctorate degree in renewable energy from the University of Cheikh anta Diop (UCAD), Dakar, Senegal, in 2008. Currently he is in charge of the Applied Research Laboratory of Renewable Energy (LRAER). He is the author and co-author of more than 30 scientific papers.

Azeddine Bendiabdellah, IEEE Member, Algeria. He received his Bachelor Engineering degree with honors and his Ph.D degree from the University of Sheffield, England, in 1980, and 1985 respectively. He is currently Professor lecturer and researcher in Electrical Engineering Faculty and the Director of the Electrical Drives Development Laboratory (LDEE) at the University of Sciences and Technology of Oran, (USTO-MB) Algeria. His research interests include: Electrical machines and Drives Modelling and Analysis, Electrical machines and Drives Control and Converters as well as Electrical machines and drives Faults Diagnosis and Tolerance.