SVM TECHNIQUE BASED ON DTC SENSORLESS CONTROL OPTIMIZED BY ANN APPLIED TO A DOUBLE STATOR ASYNCHRONOUS MACHINE FED BY THREE-LEVEL SIX-PHASE INVERTER

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ABSTRACT

The present paper is focused on Direct Torque Control (DTC) Speed Sensorless of a double stator asynchronous machine (DSAM) fed by three-level six-phase inverter. The inverter switches control is based on Space Vector Modulation technique optimized by Artificial Neuronal Network (SVM-ANN). Compared to the conventional DTC technique, voltage vectors selection table is replaced by space vector modulation technique to realize a DTC-SVM speed sensorless control. Moreover, to validate the proposed control technique several tests were conducted by computer simulations. The obtained results have showed high speed performances and a reduction in torque and flux fluctuations compared to other techniques (DTC and DTC-SVM) when the proposed DTC-SVM-ANN control technique is applied to control a double stator asynchronous machine fed by a three-level six-phase inverter.

Keywords

Direct Torque Control, Multilevel inverter, Space Vector Modulation, Artificial Neuronal Network.

1. INTRODUCTION

A simplified model of a double stator asynchronous machine presents many advantages such as robustness, reliability and improved performances compared to the model of conventional machine. Since, it enables the reduction of electromechanical torque ripples and improves power factor [1-2]. In addition, in the case of any problem, this machine will continue to operate without difficulties.

The use of multilevel inverters has been increased in recent decades; these types of topologies were widely applied in many high voltage and high power systems, due to the high quality of output waveforms, low switching losses and electromagnetic compatibility in the high-voltage capacitors [3-6].

Improving the output voltage waveform of this type of inverters is a great issue in the field of electrical engineering. The main objective of this work is to improve the quality of the output voltage waveform and to overcome the problems associated with two-level inverters.

There are several control techniques using pulse width modulation, such as sinusoidal modulation, hysteresis modulation, [7], DTC [2, 8, 9] and space vector modulation [5, 9, 10]. Space vector modulation introduced by [11] is the most efficient and the most used technique. However, with the increase in the level of six-phase inverter, this type of modulation is becoming more and more complicated, because of the increased number of possible positions of the output voltage vector. This is to approximate the output voltage vector of six-phase inverter to three-level by a combination of vectors limiting the sector containing this voltage vector. This method may cause sudden changes in the output voltage, due to the passage of reference voltage vector from one sector to another during its rotation in three dimensions complex plane. These sudden changes are the main cause of harmonic content increase.

In addition, with this typical method, the computation of inverter states sequences is required at each sampling period and periods where each sequence must be applied (such as two-level SVM) [6]. This causes a significant increase in computation time in the case of three or more inverter levels. In order to improve the performance in terms of computing time, the artificial neural networks have better properties in terms of speed and learning. Therefore, in this work the Artificial Neural Networks (ANN) technique is used in order to imitate the SVM controller to generate the control signals of six-phase three-level inverter.

In this paper, an increased level of voltage with SVM-ANN control technique is added to the concept of Direct Torque Control DTC of a double stator induction machine without speed sensor. This extension of level concerns the generation of voltage vector applied to double-stator asynchronous machine according to the number of voltage levels generated by six-phase inverter [12]. This new approach of direct torque control can highly improve the performance of double stator induction motor supplied by three-level six-phase inverter with NPC structure. Recently, DTC algorithms optimization based on three-level NPC inverter were widely studied and reported [5]. Thus, in this work, an approach of control technique based on vector modulation and Artificial Neural Networks called SVM-DTC-ANN sensorless speed is proposed. The switching table of the conventional system is replaced by a set of ANN-SVM system. The speed is estimated by MRAS (model reference adaptive system) technique.

The rest of the paper is organized as follows:
In sections 2 and 3, the mathematical model of double stator asynchronous machine in (α-β) frame and as state equations is reported. In section 4, the basic principle, the control objectives, and the general structure of direct torque control of double stator induction motor are defined. In section 5, the proposed

DTC-SVM technique is developed and explained. In section 6, the estimation principle of adaptive estimation of the speed with reference model (MRAS) is presented. In section 7, the DTC-SVM control system Based on Artificial Neural Networks is developed. In section 8, the validation of the proposed technique by computer simulation is conducted and the obtained results are discussed and analyzed. In section 9, the robustness of this control technique is tested on speed variations and the performances are evaluated. Finally, the concluding remarks and observations are given in section 10.

2. MATHEMATICAL MODEL OF DOUBLE STATOR ASYNCHRONOUS MACHINE IN THE (α-β) Frame

After applying the Park transformation to rotor variables, the machine final model is obtained in rotor referential, and is expressed by the following equations:

$$\begin{cases} \bar{v}_s = r_s \bar{i}_s + P\bar{\varphi}_s \\ 0 = r_r \bar{i}_r + P\bar{\varphi}_r - j\omega_r \bar{\varphi}_r \\ \bar{\varphi}_s = L_s \bar{i}_s + L_m \bar{i}_r \\ \bar{\varphi}_s = L_m \bar{i}_s + L_r \bar{i}_r \\ \Gamma_{em} = \frac{1}{2} P\left(\varphi_{\alpha s} i_{\beta s} - \varphi_{\beta s} i_{\alpha s}\right) \end{cases} \quad (1)$$

And,

$$\begin{cases} \bar{v}_s = v_{\alpha s} + j v_{\beta s} \\ \bar{i}_s = i_{\alpha s} + j i_{\beta s} \\ \bar{i}_r = i_{\alpha r} + j i_{\beta r} \\ \bar{\varphi}_s = \varphi_{\alpha s} + j\varphi_{\beta s} \\ \bar{\varphi}_r = \varphi_{\alpha r} + j\varphi_{\beta r} \end{cases} \quad (2)$$

3. MATHEMATICAL MODEL OF DOUBLE STATOR ASYNCHRONOUS MACHINE AS STATE EQUATIONS

The state representation expresses the model of the machine as follows:

$$\begin{cases} \dot{X} = AX + BU \\ y = CX + DU \end{cases} \quad \text{With: } \begin{cases} X \text{ State vector} \\ U \text{ Input vector} \\ Y \text{ Output vector} \end{cases}$$

The voltages $U = \left[V_{\alpha s1} \quad V_{\alpha s2} \quad V_{\beta s1} \quad V_{\beta s2}\right]^T$ are chosen as control variables, currents and stator fluxes $U = \left[\varphi_{\alpha s1} \quad \varphi_{\alpha s2} \quad \varphi_{\beta s1} \quad \varphi_{\beta s2} \quad i_{\alpha s1} \quad i_{\alpha s2} \quad i_{\beta s1} \quad i_{\beta s2}\right]^T$ as state variables.

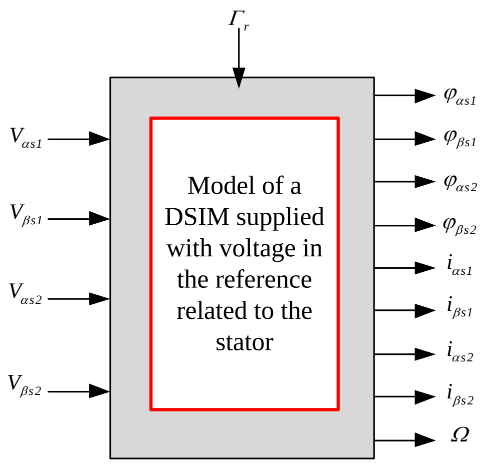

Figure1. Model DSASM in the (α-β) frame

After, matrix computation, the following system is obtained:

$$\dot{X} = AX + BU$$

with:

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & -r_{s1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -r_{s2} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -r_{s2} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -r_{s2} \\ r_r h_1 & -r_r h_2 & \omega L h_1 & -\omega L h_2 & -a & -b & -w & 0 \\ -r_r h_2 & r_r h_1 & -\omega L h_2 & \omega L h_1 & -c & -d & 0 & -\omega \\ -\omega L h_1 & \omega L h_2 & r_r h_1 & -r_r h_2 & \omega & 0 & -a & -b \\ \omega L h_2 & -\omega L h_1 & -r_r h_2 & r_r h_1 & 0 & \omega & -c & -d \end{bmatrix}$$

(3)

$$B = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ Lh_1 & -Lh_2 & 0 & 0 \\ -Lh_2 & Lh_1 & 0 & 0 \\ 0 & 0 & Lh_1 & -Lh_2 \\ 0 & 0 & -Lh_2 & Lh_1 \end{bmatrix}$$

(4)

With:

$$y = \left[l_m\left(l_r + l_{s1}\right) + l_r l_{s1}\right].\left[l_m\left(l_r + l_{s2}\right) + l_r.l_{s2}\right] - l_m^2.l_r^2$$

$$L = l_r + l_m$$

$$h_1 = \frac{l_m.\left(l_r + l_{s1}\right) + l_r l_{s2}}{y} \qquad h_1' = \frac{l_m.\left(l_r + l_{s1}\right) + l_r l_{s1}}{y}$$

$$h_2 = \frac{l_m l_r}{y} \qquad h_3 = \left[r_r\left(l_m + l_{s1}\right) + r_{s1}\left(l_m + l_{s1}\right)\right]$$

$$h_3 = \left[r_r\left(l_m + l_{s2}\right) + r_{s2}\left(l_m + l_{s2}\right)\right]$$

$$a = \left[h_3 h_1 - r_r l_m h_2\right] \qquad b = \left[r_r l_m h_2 - h_2 h_4\right]$$

$$c = \left[r_r l_m h_1 - h_2 h_3\right] \qquad d = \left[h_2 h_1 - r_r l_m h_2\right]$$

It is observed that the study of this type of motor is not easy, because harmonic effects are very important. These harmonics can be classified into several groups, depending on their order and the angle (γ) between the two stators. For a conventional machine with γ = π / 6, the harmonic group of order k = 12n ± 1 (n = 1, 2, 3, ...) and the harmonic group of order k = 6n ± 1 (n = 1,3, 5, ...) have different equivalent circuits, only the first group involved in the conversion of electromechanical energy. The arrangement of coils reduces harmonics greatly by increasing the coupling between the two stators and torque, sixth harmonic is removed [12- 13].

4. GENERAL STRUCTURE OF DIRECT TORQUE CONTROL OF DOUBLE STATOR INDUCTION MOTOR

In its basic principle, the direct torque control is a method based on the switching tables with hysteresis torque and stator flux. Using this method, the inverter switching number are minimized, torque/stator fluxes decoupling, inverter control without PWM generator, open loop parameters estimation in the referential related to the stator and control is provided without mechanical sensor [12-13].

4.1. Voltage vector of the three-level six-phase inverter

Fig.2 shows the circuit of a six-phase three-level diode clamped inverter and the switching states of each leg of the inverter. Each leg is composed from two upper and lower switches with anti-parallel diodes. Two series DC-link capacitors split the DC-bus voltage in half, and six clamping diodes confine the voltage across the switches within the voltage of the capacitors. Each leg of the inverter can have three possible switching states; *2*, *1* or *0*. When upper switches *Sij1* and *Sij2* are turned ON, switching state is 2 [3-4]. When the switches *Sij3* and *Sij4* are turned ON, switching state is 0. When the switches *Sij2* and *Sij3* are turned ON, switching state is 1. So there exist 27 type of switching states in three phase three-level inverter.

$N_{a1,b1,c1}$ $N_{a2,b2,c2}$ the neutrals of stator 1 and stator 2 respectively and O is the neutral point of the source. Phase voltages are composed from:

$$\begin{cases} v_{as1} = v_{a1n1} + v_{a1o} + v_{on1} \\ v_{bs1} = v_{b1n1} + v_{b1o} + v_{on1} \\ v_{cs1} = v_{c1n1} + v_{c1o} + v_{on1} \end{cases}$$
$$\begin{cases} v_{as2} = v_{a2n2} + v_{a2o} + v_{on2} \\ v_{bs2} = v_{b2n2} + v_{b2o} + v_{on2} \\ v_{cs3} = v_{c1n3} + v_{c3o} + v_{on2} \end{cases} \quad (5)$$

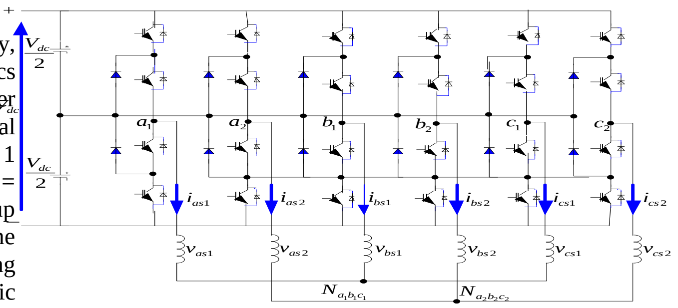

Figure 2. Operating scheme of six-phase voltage inverter feeding a double stator asynchronous machine

The mathematical model of the three-level inverter is represented by the following matrix:

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \cdot \begin{bmatrix} S_{a1}S_{a2} - S_{a3}S_{a4} \\ S_{b1}S_{b2} - S_{b3}S_{b4} \\ S_{c1}S_{c2} - S_{c3}S_{c4} \end{bmatrix} \frac{V_{dc}}{2}$$
(6)

Each arm of the inverter has three switching conditions shown in Table 1.

V_A, V_B and V_C : phase to neutral voltages

S_{ij} : Switching state

V_{dc} : dc voltage

Table.1. Switching states of three-level inverter

Switching states	S_1	S_2	S_3	S_4	V_{KN}
$S_n = 1 = P$	1	1	0	0	U_{dc}
$S_n = 0 = O$	0	1	1	0	$\frac{U_{dc}}{2}$
$S_n = -1 = N$	0	0	1	1	0

The space vector diagram of a three-level inverter is showed in Fig.3. The 27 switching states of three-level inverter correspond to 19 different space vectors. Based on their magnitude, the space vectors are divided into four groups, these vectors have different effects on neutral point voltage variations [5-6].

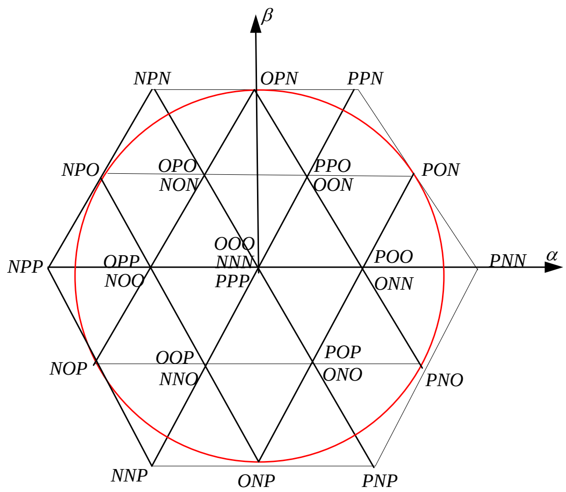

Figure 3. Space vector diagram, showing switching states of first three-level clamped diode inverter

- ZVV group, zero voltage vectors V_0 .

-SVV group, small voltage vectors (V_1 ,V_4 , V_7 , V_{10} , V_{13} , V_{16})

- MVV group, average voltage vectors (V_3 , V_6 , V_9 , V_{15} , V_{18})

-LVV group, large voltage vectors (V_2 , V_5 , V_9 , V_{11} , V_{14} , V_{17})

Zero vectors has three switching states, small vectors have two states (USVV, LSVV), average and large vectors have only one switching state example voltage vector V_2 corresponds to PNN state. Voltage vectors associated to switching states are summarized in Table 2.

Table.2. Voltage vectors associated to switching states

Voltage vector	Symbols
ZVV	$(PPP);(OOO);(NNN)$
MVV	$(POP);(OPN);(NPO)$; $(NOP);(ONP);(PNO)$
LVV	$(PNN);(PPN);(NPN)$; $(NPP);(NNP);(PNP)$
USVV	$(POO);(PPO);(OPO)$; $(OPP);(OOP);(POP)$
LSVV	$(ONN);(OON);(NON)$; $(NOO);(NNO);(ONO)$

Logic variables associated to the latter are [3]:

$$\begin{cases} S_{a1} = 1, S_{a2} = 1, S_{a3} = 0, S_{a4} = 0 \\ S_{b1} = 0, S_{b2} = 0, S_{b3} = 1, S_{b4} = 1 \\ S_{c1} = 0, S_{c2} = 0, S_{c3} = 1, S_{c4} = 1 \end{cases}$$

In regard to the control, this converter topology offers the following advantages:

- The number of degrees of freedom is high compared to two-level inverter,
- Reduced output current ripple
- Remarkable property of hexagons fitting, concept of two- level three-phase cell.

Thus, inverter- DSASM connection matrix [C] is deduced, giving voltages across the machine according to the inverter output voltages.

$$\begin{cases} v_{as1} = v_{a1n1} = v_{a1o} + v_{on1} \\ v_{bs1} = v_{b1n1} = v_{b1o} + v_{on1} \\ v_{cs1} = v_{c1n1} = v_{c1o} + v_{on1} \end{cases} \quad (7)$$

$$\begin{bmatrix} v_{as1} \\ v_{bs1} \\ v_{as2} \\ v_{bs2} \\ v_{as3} \\ v_{bs3} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 & 0 & 0 & 0 \\ -1 & 2 & -1 & 0 & 0 & 0 \\ -1 & -1 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2 & -1 & -1 \\ 0 & 0 & 0 & -1 & 2 & -1 \\ 0 & 0 & 0 & -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} v_{a1o} \\ v_{b1o} \\ v_{a2o} \\ v_{b2o} \\ v_{a3o} \\ v_{b3o} \end{bmatrix} \quad (8)$$

$$[V_s] = [C][V_{ond}]$$
(9)

$$[V_{ond}] = V_{dc}[S] = V_{dc}[S_{a1}\, S_{b1}\, S_{c1}\, S_{a2}\, S_{b2}\, S_{c2}]$$
(10)

[S], is the vector giving switching states (1: ON; 0: OFF)

4.2. Flux control strategy

In this paper, a study and an investigation of a control structure where DSASM is fed separately by two three-level voltage inverters and individual flux control φ_{s1} and φ_{s2} is conducted [2, 14]. The control is performed by applying the voltage vectors generated by each inverter. Under machine normal operation conditions, the components α-β of φ_{s2} are ahead compared to those of φ_{s1} an angle of π / 6, as shown in Fig.4.

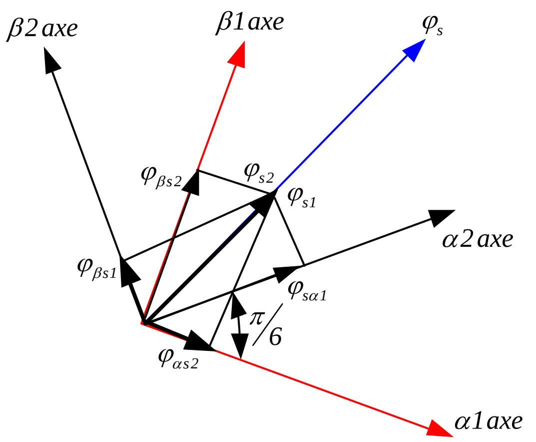

Figure 4. Different fluxes description

In this method and in the case of three-level voltage inverters, the vector diagram of the second inverter is delayed by π/6 with respect to that of the inverter 1 [3,13]. The electromagnetic torque is calculated from the estimated flux and current measurement. The total torque developed by the machine can be determined by an algebraic sum (Eq. 13). In this method the stator flux is estimated by the model described above in open loop. Thus, these modules are given by the following equations:

$$|\varphi_{s1}| = \sqrt{\varphi_{\alpha 1s}^2 + \varphi_{\beta 1s}^2}, \qquad |\varphi_{s2}| = \sqrt{\varphi_{\alpha 2s}^2 + \varphi_{\beta 2s}^2}$$
(11)

$$\begin{cases}\Gamma_{em1} = P\left(\varphi_{\alpha 1s} i_{\beta 1s} - \varphi_{\beta 1s} i_{\alpha 1s}\right) \\ \Gamma_{em2} = P\left(\varphi_{\alpha 2s} i_{\beta 2s} - \varphi_{\beta 2s} i_{\alpha 2s}\right)\end{cases}$$
(12)

$$\Gamma_{em} = \Gamma_{em1} + \Gamma_{em2} \tag{13}$$

The machine behaves as two equivalent machines to which DTC technique is applied. Note that, the application of conventional (Takahashi) DTC approach to different types of special electric machines is reported in the literature [3, 13, 15, 16]

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5. DTC-SVM OF DOUBLE STATOR ASYNCHRONOUS MACHINE (DSASM)

In this new DTC-SVM control strategy, d-q coordinates of reference voltage vector can be directly computed from the state regulators of torque and flux [14, 9]. The expression of voltage coordinates is as follows:

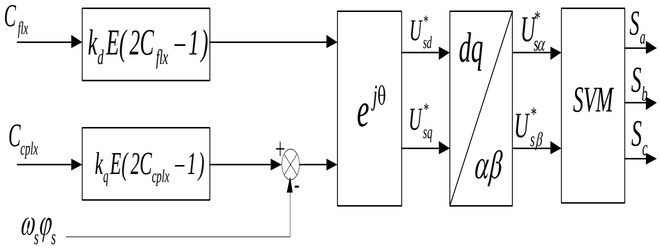


Figure 5. Reference voltage vector principle

Where, *Ccplx* and *Cflx are ON-OFF* binary results of the torque and flux with $Ccplx$, $Cflx \in \{0,1\}$.

K_d *and* K_q Coefficients appearing at the interval [0,1]. When ω_s corresponds to the derivative of the estimated stator flux vector position. The equations of the stator in the *d-q* frame are as follows [7]:

$$\begin{cases}U_{sd} = R_s I_{sd} + \varphi_{sd} \\ U_{sq} = R_s I_{sq} + \varphi_{sq}\end{cases}$$
(14)

Where, θ_s, φ_{sq}; the returning electromagnetic fields and $\varphi_{sd} = \varphi_s$ in this frame.

6. ADAPTIVE ESTIMATION OF THE SPEED WITH REFERENCE MODEL (MRAS)

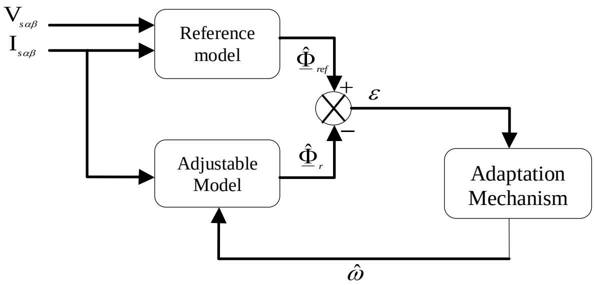


Figure 6. Estimation of asynchronous machine speed by MRAS technique

The estimation principle using this method is based on the comparison of the values obtained in two different ways, by a computation which does not depend on the speed (reference model) and by a computation that depends on speed (adaptive model). This method developed by Schauder [17], is known as Model Reference Adaptive System (MRAS).

Fig.7. Shows the overall control structure, all the blocks have been studied previously and the two stators are fed separately by two inverters controlled by the DTC-SVM technique by estimating the stator flux and the developed torque in the machine [16-17]. The individual flux modules φ_{s1} and φ_{s2} are considered equal to half the resultant flux module φ_{sref}.

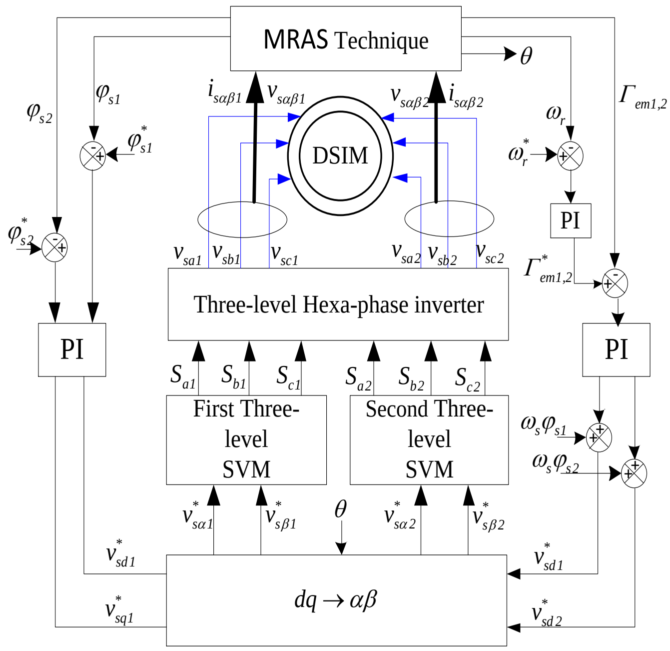


Figure 7. General structure of direct control of flux and torque of double stator asynchronous machine with SVM

7. DTC-SVM BASED ON ARTIFICIAL NEURAL NETWORKS

Control system based on neural network of a double stator asynchronous machine supplied through a three-level six-phase inverter controlled by DTC-SVM employed in this work is designed from a MLPNN (multilayer-Layer Perception Neural network) [5, 18, 19]. This network enables to imitate SVM controller generating control signals of the inverter supplying double stator asynchronous machine. The network adopted architecture consists on a MLP of three layers: input layer representing V_α, V_β input voltages of SVM bloc, a hidden layer composed from **m** neurons, and an output layer representing control signals of three-level six-phase inverter upper half bridge switches S_{a1}, S_{b1}, ….. S_{c1}. Hidden layer neurons number can be chosen by conducting many learning tests, in this case 14 neurons are used with a sigmoid function.

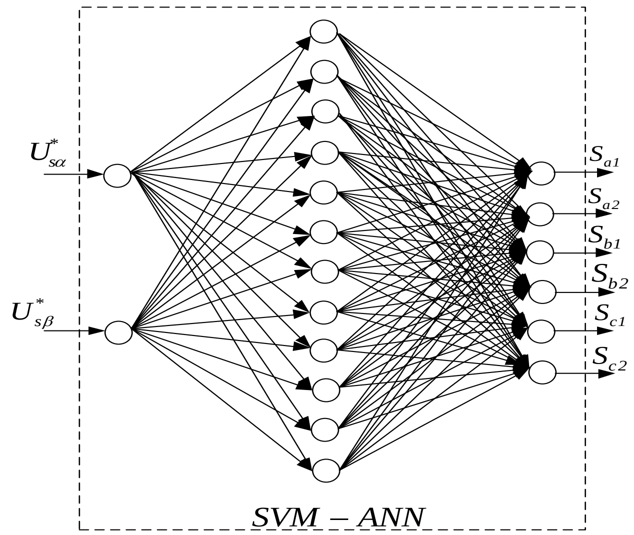


Figure 8. Artificial Neural Network structure for three-level DTC-SVM-ANN control of the speed sensorless of double stator asynchronous machine

This network learning is realized with retro-propagation (Levenberg-Marquarrdt) algorithm 1500 learning examples (off-line) obtained by simulation. This method is recommended when using Mean Square Error performance function. However, output layer neurons use linear function. Fig.8 illustrates bloc diagram scheme of ANN controller used to optimize SVM technique.

8. RESULTS AND DISCUSSION

To validate the proposed technique, computer simulations were conducted in Matlab simulink environment using parameters presented in table 3. The tests are carried out by applying DTC, DTC-SVM, and SVM optimized by ANN (DTC-SVM-ANN) to a double stator asynchronous machine supplied through a three-level six-phase inverter. The obtained results are illustrated in the figures shown below.

Table.3. Simulation parameters

Parameters	Values
DC inverter input voltage	514 V divided into two equal parts represented by two capacitors
Switching frequency f_s	7 kHz
Sampling period T_e	10 µs

Fig. 9 shows the switching signals of the upper switches in the first phase using three control switches of three-level six-phase inverter. It can be noted from Fig. 10 that switching losses are reduced when using the proposed DTC-SVM-ANN control technique.

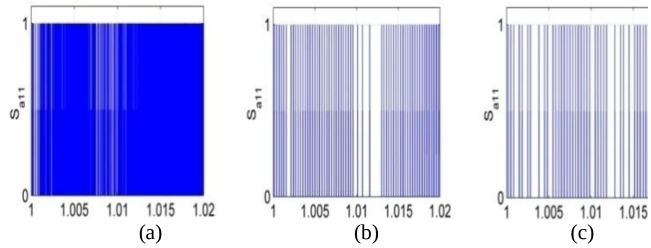


Figure 9. Switching pulses (a) DTC, (b) DTC-SVM, (c) SVM optimized by ANN (DTC-SVM-ANN)

Fig.10 a, b and c show the shape of output voltage waveforms V_{sa1} and V_{sb1} when a) DTC, b) SVM and c) SVM-ANN techniques are used to control three-level six-phase inverter respectively. It is observed that the output voltage when SVM and SVM-ANN are applied is blocked at a constant level when the output current has a maximum value. As it has been explained previously, this control strategy enables to reach two main objectives. The first objective, the arm does not balance at specific intervals (discontinuous modulation), consequently the number of commutation events is reduced. The second objective is the commutation events are produced when the output current is not at its maximum value; consequently, inverter switching losses are reduced to a minimum value.

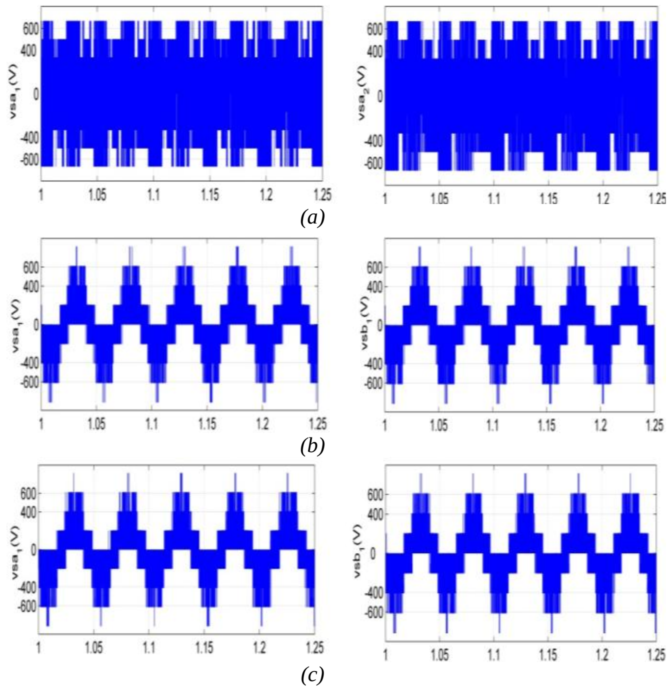
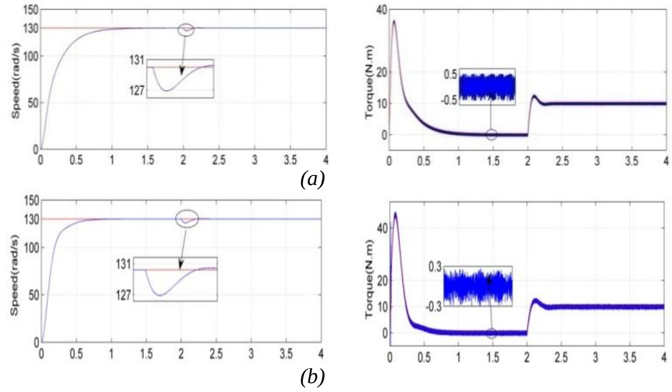
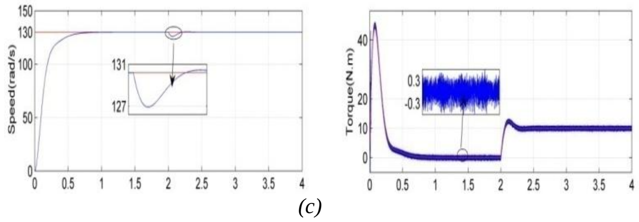


Figure 10. Output voltage of the first phase: (a) DTC, (b) DTC-SVM, and (c) SVM optimized by ANN (DTC-SVM-ANN)

Fig.11 (a), (b) and (c) shows the speed and the torque when applying : (a) DTC, (b) Space Vector Modulation technique (DTC-SVM), and (c) Space Vector Modulation technique optimized by Artificial Neuronal Network (SVM-ANN) controlling the switches of three-level six-phase inverter respectively, for a reference speed of 130 rad/s. It is observed that, the transient, time response and steady state ripples are reduced with DTC-SVM and DTC-SVM-ANN control techniques.

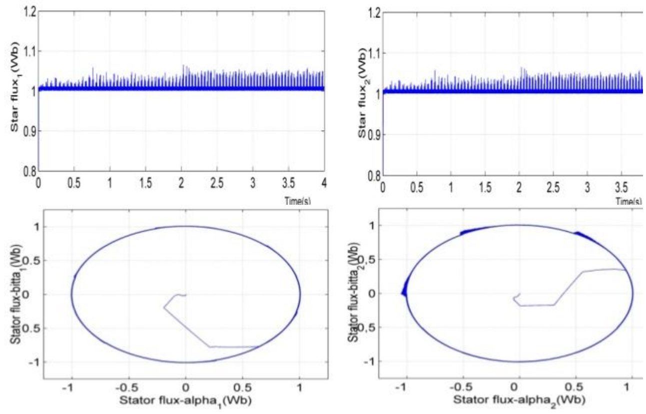




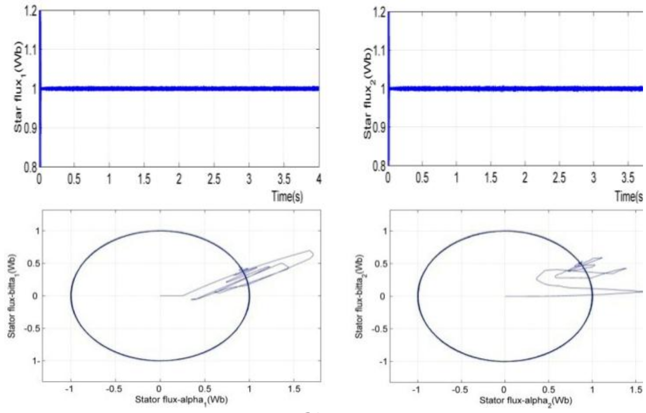
(c)

Figure 11. Torque and speed curves applying: (a) DTC, (b) DTC-SVM, (c) SVM optimized by ANN (DTC-SVM-ANN)

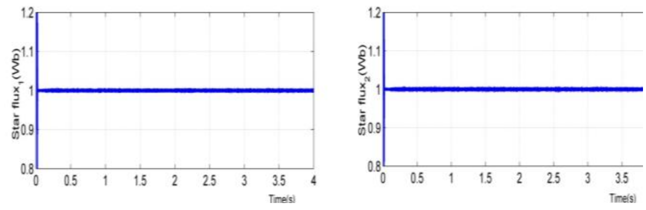
Fig. 12 (a), (b) and (c) show the stator flux time response and stator circular flux for: (a) DTC, (b) Space Vector Modulation technique (DTC-SVM), and (c) Space Vector Modulation technique optimized by Artificial Neuronal Network (DTC-SVM-ANN). The conventional DTC uses a constant flux command of 1 W_b with high ripple, whereas SVM and SVM-ANN reduces the flux ripple to a considerable lower amount. The smoother flux trajectory for the proposed technique confirms the ripple reduction in torque, flux, stator current and speed time response.

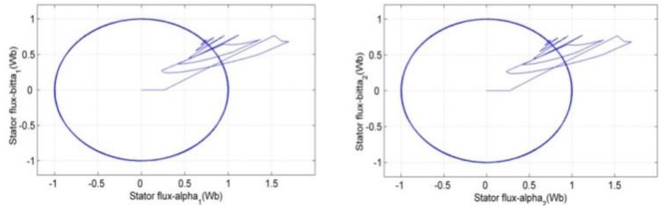


(a)



(b)





(c)

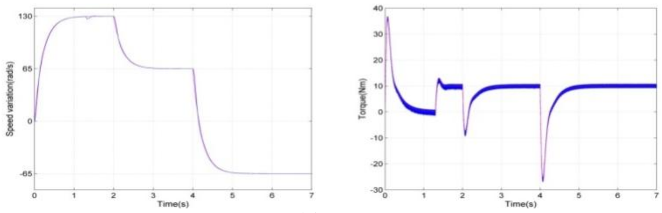
Figure 12. Stator fluxes circular trajectory when applying: (a) DTC, (b) DTC-SVM, and (c) SVM optimized by ANN (DTC-SVM-ANN)

9. ROBUST CONTROL OF SPEED VARIATION

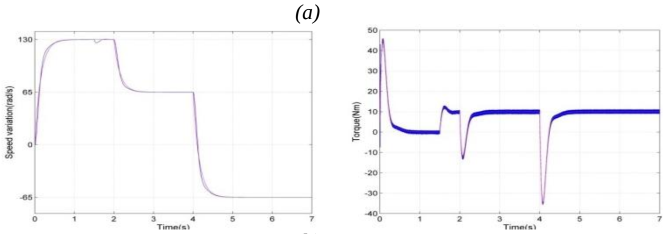
Three control algorithms (DTC, DTC-SVM, and SVM optimized by ANN (DTC-SVM-ANN)) are applied in order to verify the robustness of these three control techniques for comparison. Several tests were conducted under speed variation (the speed is varied at t=2 and 4s).

Several tests were conducted under speed variation (the speed is varied at t=2 and 4s). Fig.13 (a), (b) and (c) show the speed variation for the values: (Ωref = 130, 65 and -65 rad/s), with the load of 10 N.m applied at t=1.5s for: (a) DTC, (b) Space Vector Modulation technique (DTC-SVM), and (c) Space Vector Modulation technique optimized by Artificial Neuronal Network (DTC-SVM-ANN).

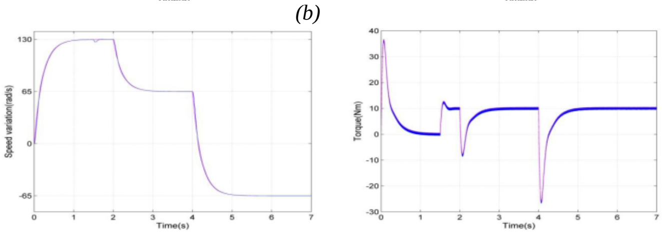
The results have showed that this variation has led to a variation in the flux and the torque. The system response is positive and the speed follows its reference value while the torque returns to its reference value with insignificant error.



(a)



(b)



(c)

Figure 13. Robust controls for a speed variation (a) DTC, (b) DTC-SVM, and (c) SVM optimized by ANN (DTC-SVM-ANN)

10. CONCLUSION

In the present paper, the analysis and the implementation of Direct Torque Control (DTC) speed sensorless control of double stator asynchronous machine fed by three-level six-phase inverter has been discussed and analyzed. The proposed control strategy is based on Space Vector Modulation technique optimized by Artificial Neuronal Network (DTC-SVM-ANN) controlling the switches of three-level six-phase inverter.
In this work an increased level of voltage with SVM-ANN control technique is added to the theory and the concept of Direct Torque Control (DTC). This control strategy has showed a significant reduction in torque, flux and stator current ripples as well as speed time response.

It can be concluded that a double stator asynchronous machine fed by three-level six-phase inverter operates with high performances when the proposed DTC-SVM-ANN control technique is applied. In addition this technique can be used to improve the effectiveness, the reliability and the control of industrial double stator asynchronous machines.

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