Direct Torque Control of Double Star permanent magnet Synchronous Machine

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Abstract—**In order to increase the availability of the embarked actuators one solution is to equip them with double-star machines. To increase their compactness the permanent magnet synchronous machines (PMSM) are usually preferred.**

This study describes the control of double star PMSM, using Direct Torque Control (DTC). The implementation of the DTC applied to a double star synchronous machine is validated with simulated results. In this paper a method for modeling and simulation of synchronous motor drives using MALAB/SIMULINK.

***Index Terms*—direct torque control (DTC), Double star synchronous Machine (DSPMSM), and inverter.**

I. INTRODUCTION

Since, years 80, double armature synchronous machine DSSM supplied by power electronic converter are widely used for marine applications [1], [4], [6]. Due to their compactness and no power losses in the rotor synchronous machines permanent magnet (PMSM) are increasingly used in embedded systems. In number of applications, such as actuators used in the field of aeronautics or cars [13], [14].

Nowadays, the actual development of power electronics devices allows supplying DSSM by PWM inverter [5], [7]. In the other hand, the vector control technique [8], [9] allows improving performances of this speed drive.

The difficulty to control the DS-PMSM supplied by strong coupling is due to the strong magnetic coupling between.

II. ELECTRICAL DRIVE SCHEME

The electrical drive considered with this study is shown in figure (1). It is composed of double star synchronous machine supplied of two inverters.

III. MODEL OF DOUBLE STAR SYNCHRONOUS MACHINE

A. Description

As every rotating electrical machine, the double star permanent magnet synchronous machine is composed of a stator and rotor. As shown in figure (2), the stator is a two three-phase windings, so called star, shifted up by an angle $\gamma = 30^0$.

B. Assumptions

The study presented in this paper is based upon he following assumptions:

- The two stars are identical shifted up an angle.
- The rotor us non-salient.
- The three windings of each star are shifted by $\theta = 120^0$.
- The magnetomotrice forces in the air-gap have a sinusoidal repartition;
- The saturation of the iron in the machine is neglected.

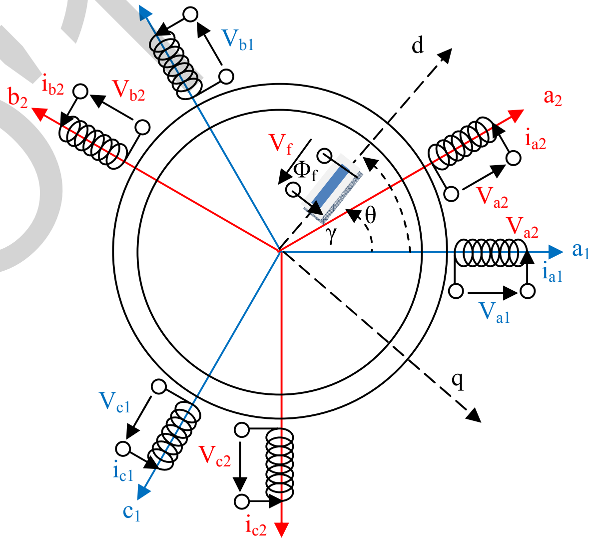


Fig.2 Electrical windings double star permanent magnet synchronous machine

C. Electrical equations with (α.β) frames

By applying the Concordia transformation to each star, the (α, β) model of double star permanent magnet synchronous machine is obtained [11], [12]. Thus, the machine windings can be substituted by an equivalent scheme in the (α, β) frame as shown in figure (3):

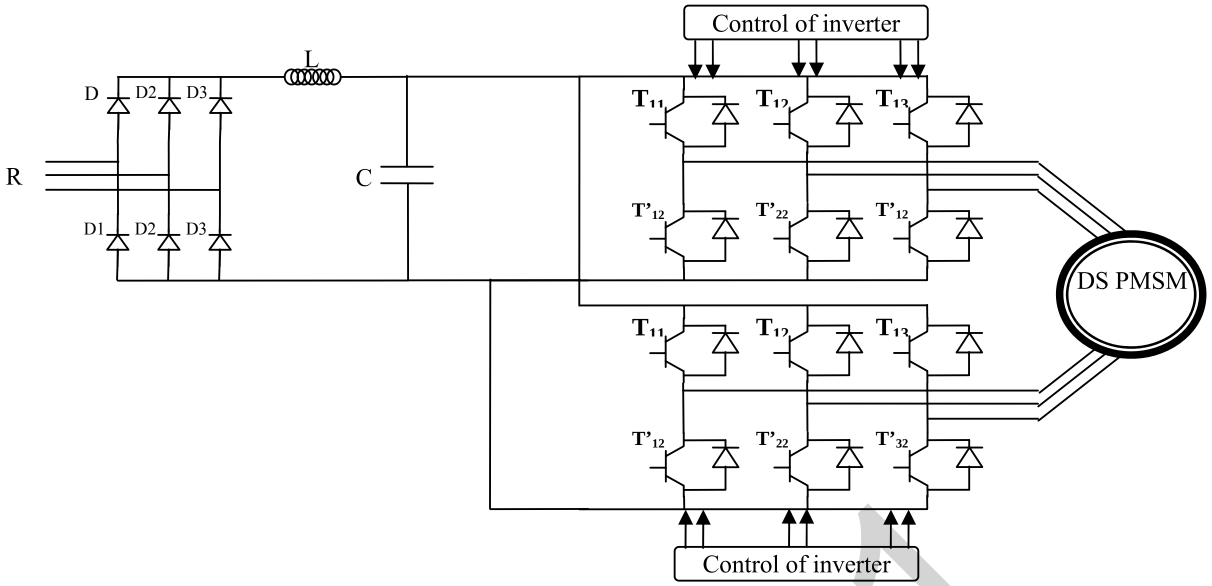


Fig.1 Electrical drive scheme

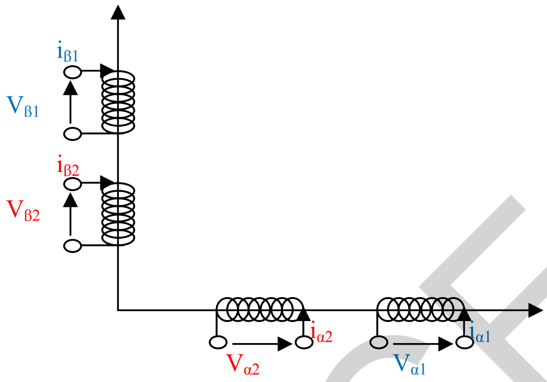


Fig.3 Representation of fictitious coils diphasic in (α, β) frame

The electrical equation in (α, β) frame:

$$V_{\alpha 1} = R \cdot i_{\alpha 1} + \frac{d\varphi_{\alpha 1}}{dt} \quad (1)$$

$$V_{\beta 1} = R \cdot i_{\beta 1} + \frac{d\varphi_{\beta 1}}{dt} \quad (2)$$

$$V_{\alpha 2} = R \cdot i_{\alpha 2} + \frac{d\varphi_{\alpha 2}}{dt} \quad (3)$$

$$V_{\beta 2} = R \cdot i_{\beta 2} + \frac{d\varphi_{\beta 2}}{dt} \quad (4)$$

The flux equation

$$\varphi_{\alpha 1} = L \cdot i_{\alpha 1} + M_{mag} \cdot i_{\alpha 2} + \varphi_f \cdot \cos\theta \quad (5)$$

$$\varphi_{\beta 1} = L \cdot i_{\beta 1} + M_{mag} \cdot i_{\beta 2} + \varphi_f \cdot \sin\theta \quad (6)$$

$$\varphi_{\alpha 2} = L \cdot i_{\alpha 2} + M_{mag} \cdot i_{\alpha 1} + \varphi_f \cdot \cos\theta \quad (7)$$

$$\varphi_{\beta 2} = L \cdot i_{\beta 2} + M_{mag} \cdot i_{\beta 1} + \varphi_f \cdot \sin\theta \quad (8)$$

Electromagnetic torque

$$C_{em} = \frac{p}{\omega}\left[\left(e_{\alpha 1} \cdot i_{\alpha 1} + e_{\beta 1} \cdot i_{\beta 1}\right) + \left(e_{\alpha 2} \cdot i_{\alpha 2} + e_{\beta 2} \cdot i_{\beta 2}\right)\right] \quad (9)$$

$$C_{fr} = f_r \Omega \quad (10)$$

In double star machine

$$e_{\alpha\beta} = e_{\alpha 1} \text{ et } e_{\beta 2} \quad (10)$$

$$\begin{bmatrix} e_{\alpha 1} \\ e_{\beta 1} \end{bmatrix} = \begin{bmatrix} e_{\alpha 2} \\ e_{\beta 2} \end{bmatrix} = \varphi_f \cdot \quad (11)$$

IV. DIRECT TORQUE CONTROL PRINCIPLE

The direct torque control of a double star permanent magnet synchronous machine is based on the direct determination of the sequence control used to switch a voltage inverter.

This choice is usually based on use of hysteresis comparators whose function is to control the system state, namely the amplitude of stator flux and electromagnetic torque. A Voltage Inverter delivers twelve distinct positions (figure 4) in the plan phase.

DTC in single inverter utilizes the (2^3=8) eight possible stator voltage vectors, two of which are zero vectors, to control the stator flux and torque to follow the reference values within the hysteresis bands. The voltage space vector of a three-phase system is given by:

$$V_s = V_\alpha + jV_\beta = k_T\left(V_{an} + a \cdot V_{bn} + a^2 \cdot V_{cn}\right) \quad (12)$$

$$V_s = \begin{cases} \sqrt{\frac{2}{3}} \cdot U_0 \cdot e^{j\frac{(k-1)\pi}{3}} & \text{pour } k = 1,\ldots,6 \\ 0 & \text{pour } k = 0,7 \end{cases} \quad (13)$$

The control sequences of the two inverters is done in a way that will have the voltage vectors at the exit of the second inverter offset by an angle of 30^0, the vectors of voltage at the output of first inverter figure 1.

$$V_s = \sqrt{\frac{2}{3}}\, U_d (S_1 + a S_2 + a^2 S_3 + (S'_1 + a S'_2 + a^2 S'_3) e^{j\gamma})$$
(14)

This angle shift between the two stars of the machines, which is equal π/6.

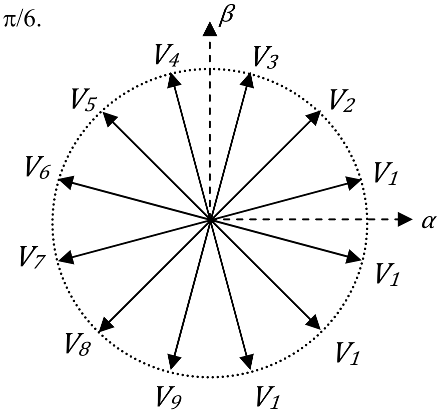


Fig. 4 Voltage space vector

U_d

A combinatorial analysis of switch states of the two inverters gives ($2^6 = 64$) switching modes, ie 64 different vectors V_S possible. Hence there are sixty four possible combinations for controlling the switches of the two inverters. Table I.

We will therefore among the sixty-four sequences, twelve active sequences. These vectors define twelve voltage at the output of both inverters V_{Si} (i=1,2, ..,12), and four sequences (S_i=000000, 000111, 111000, 111111) are sequences of freewheeling and define four zero voltage vectors. The truth table for the active sequences can be summarized in the following table:

The order by the DTC of DSSM can be represented by figure 5.

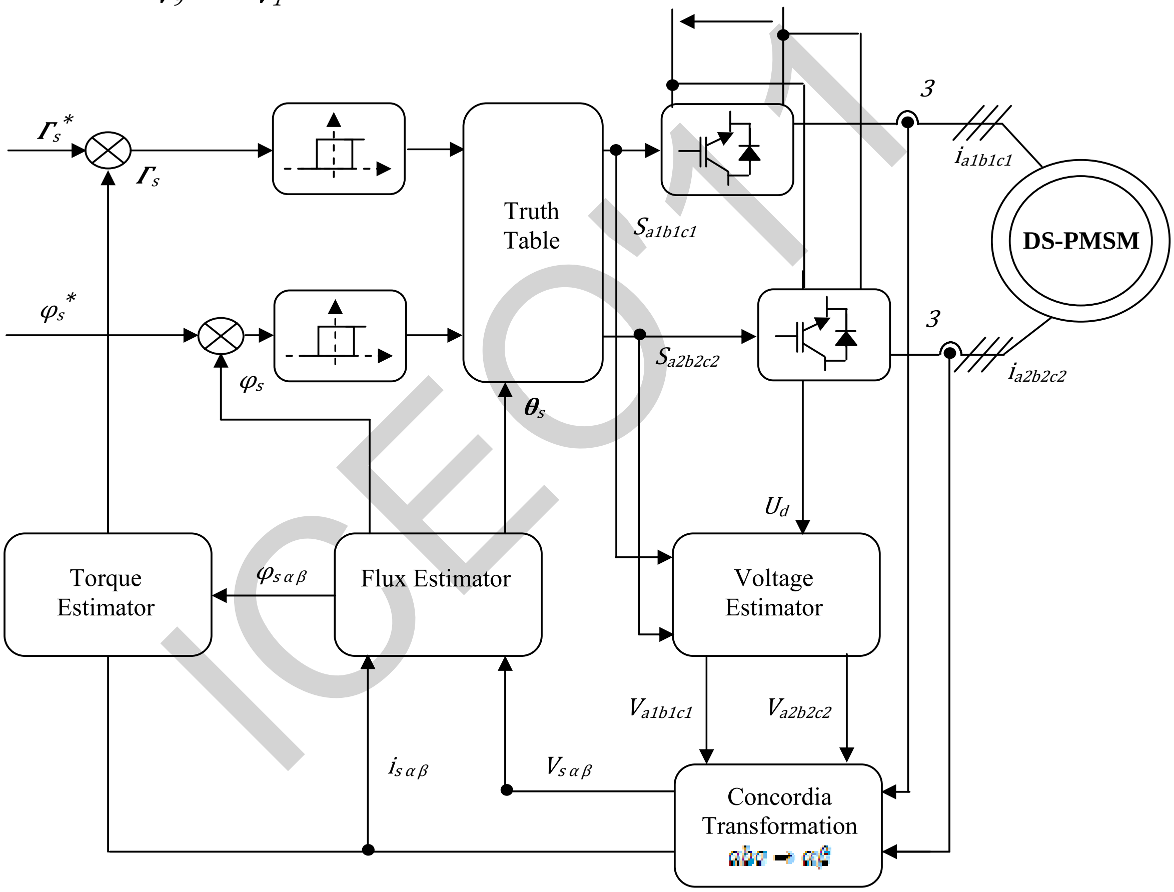
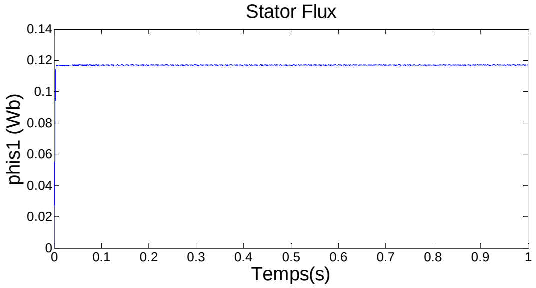


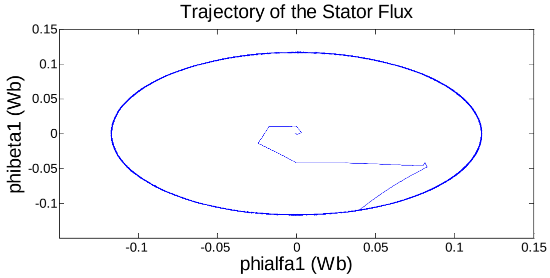
Fig. 5 Direct torque control of DSPMSM

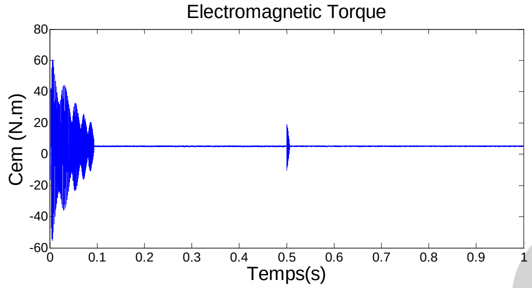
V. NUMERICAL SIMULATION RESULTS

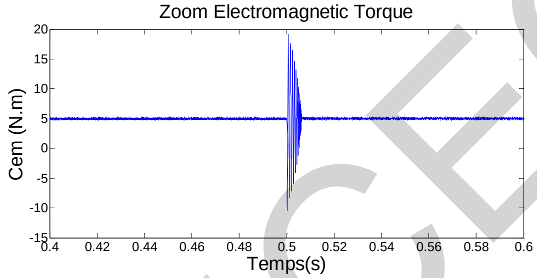
The paper describes a MATLAB SIMULINK that provides facilities for investigation of algorithms for solving direct torque control problems of double star synchronous machine.

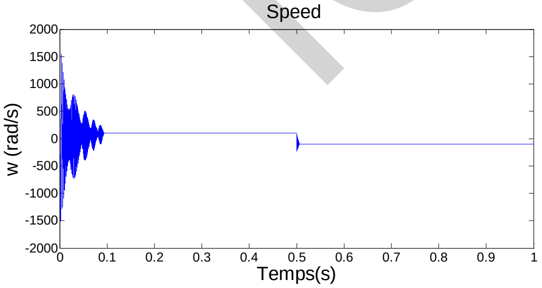
B. Parameters for the Double Star Synchronous machine:
Motor details: 5kW, 3phase, 50Hz, 1 pole, 200v,
$R_s = 2.35\ \Omega$, $L_d = 0.1961$ H, $M_d = 0.185$ H,
$L_q = 0.1105$ H, $M_q = 0.1005$ H, $\gamma = 30^0$,
$J = 0.005 N.m^2/s$, $M_{fd} = 1.518$ H, $i_f = 1$ A,
$f_r = 0.001$ N.s / rad.

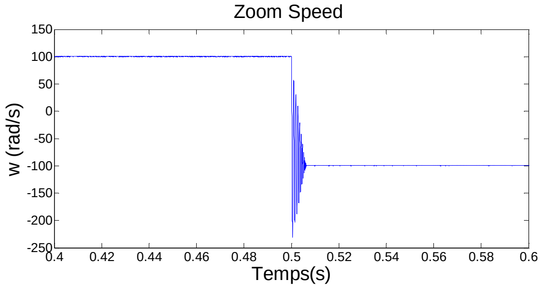












VI. CONCLUSION

In this paper, we presented the direct control of the torque of the synchronous double star machine supplied by two voltage inverters at two levels.

This study presents a control strategy for a double stator the permanent magnet synchronous machine based on the direct control torque (DTC) using an PI regulator. The simulation results show that the DTC is an excellent solution for general-purpose DSSM double star synchronous machine drives. In very wide power range.

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