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STUDY OF ASSOCIATION OF DUAL STATOR WINDING INDUCTION MACHINE WITH MULTI LEVEL INVERTER

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ABSTRACT

The present paper gives a quantitative analysis of an dual winding induction machine supplied by multi level inverters, with taking account an arbitrary displacement between the two three-phase windings sets. The effect of the inverter level on the motor voltage and current total harmonic distortion is performed. The investigation is particularly extended to the steady state electromagnetic torque, where a significant reduction of the oscillations rate is obtained if such multi level inverters are used. All simulation results are achieved by means of Matlab/Simulink software.The effect of the multi level inverter appears in courant voltage and the torque verified using a relative torque ripple rate.

KEYWORDS: Dual winding stator induction machine (DSIM), multi-level inverter, PWM, regulation performance.

INTRODUCTION

The multi-phases AC machines drive plays a very important role in industrial applications. The performances requested from these machines are constantly increasing from the point of view of the dynamics speed and of the waveform quality of the delivered torque. The progress achieved in the domain of the power electronics permitted to construct some static converters at variable frequency which has led to the effective speed drive of the multi-phase induction machine. For high powers, the use of the dual stator winding induction machines (DS-WIM) associated static inverters especially finds its application in the electric traction and the motorisation at variable speed of the embarked systems [1-2].

The voltage source inverter fed multi-phase induction machine drive systems have many advantages such as a rugged and low cost rotor structure, capability of high waveform fidelity with PWM operation, reasonably high performance [3]. When increasing power, problems arise both in the voltage inverter that the machine. The static switches of the voltage inverter must switch high currents and it is often necessary to place several structures in parallel. Given power, reducing switching currents through the voltage increase. The inverter voltage PWM technique imposes high voltage gradients, thus causing accelerated aging of insulating, [4-5].

In addition to enhancing the power rating, a multi-phase system also has the merit of high reliability at the system level. In particular, with loss of one or more of stator winding excitation sets, a multi-phase induction machine can continue to be operated with an asymmetrical winding structure and unbalanced excitation [6-8].

The potential benefits of a multiphase induction machine drive result from the 30° displacement angle between the two three-phase sets of a six-phase machine, leading to elimination of all the air-gap harmonics of order Consequently, all the rotor copper losses produced by these harmonics as well as all the torque harmonics of the order are eliminated. Large multiphase machines for ship propulsion have already been prototyped industrially, and are currently undergoing commercial evaluation [9], [10].

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The development of the high power components allowed the passage of the voltage supply of these machines with two voltage source inverters (VSI) and their use makes it possible to segment the power which improves commutation of these power components. Moreover, in low and average power, the feeding of this machines is generally assured by two-level inverters, however, for the high power, these machines supply often requires multilevel inverters [11-14]

This paper is mainly organized into six sections beginning with an introduction and ending with a conclusion. The second section includes the mathematical models of the double stator induction machine for displacement between the two three-phase windings sets and the third is devoted to derivation of mixed model .The fourth describes the quantitative analysis of a DSIM fed by an NPC type inverter with different voltage levels and the fifth section is for the simulation results obtained.

MODELING OF THE DUL STATOR ASYNCHRONOUS MACHINE

A dual stator induction machine has two systems in the stator windings of three phase shifted them to an electrical angle α (in this model we take α = 30 °) and a wound rotor or squirrel cage either. To simplify the study, we consider the electrical circuits of the rotor as equivalent to a winding three-phase short –circuit.
With the usual assumptions, transient operations a six phase induction machine is generally analyzed in a synchronous reference frame by the following electric equations of stator 1, stator 2 and rotor.

$$\left[V_{abc,s1}\right]=\left[R_{s1}\right].\left[I_{abc,s1}\right]+\frac{d}{dt}\left[\lambda_{abc,s1}\right] \quad (1)$$

$$\left[V_{abc,s2}\right]=\left[R_{s2}\right].\left[I_{abc,s1}\right]+\frac{d}{dt}\left[\lambda_{abc,s2}\right] \quad (2)$$

$$\left[V_{abc,r}\right]=\left[R_{r}\right].\left[I_{abc,r}\right]+\frac{d}{dt}\left[\lambda_{abc,r}\right] \quad (3)$$

The model is based on Park transformation of a three phase system of axes (a, b, c) a two-phase equivalent system of axes (d, q) creating the same magneto motive force. During the application of the d-q transformation and making the necessary manipulations, the equations (1), (2), (3) in d-q
Become:

$$V_{ds1}=R_{s1}i_{ds1}+\frac{d\lambda_{ds1}}{dt}-w_a\lambda_{qs1} \quad (4)$$

$$V_{qs1}=R_{s1}i_{qs1}+\frac{d\lambda_{qs1}}{dt}+w_a\lambda_{ds1} \quad (5)$$

$$V_{ds2}=R_{s2}i_{ds2}+\frac{d\lambda_{ds2}}{dt}-w_a\lambda_{qs2} \quad (6)$$

$$V_{qs2}=R_{s2}i_{qs2}+\frac{d\lambda_{qs2}}{dt}+w_a\lambda_{ds2} \quad (7)$$

$$0=R_r i_{dr}+\frac{d\lambda_{dr}}{dt}-(w_a-w)\lambda_{qr} \quad (8)$$

$$0=R_r i_{qr}+\frac{d\lambda_{qr}}{dt}+(w_a-w)\lambda_{dr} \quad (9)$$

Where:

$$\lambda_{ds1}=L_s i_{ds1}+L_{ps}i_{ds2}+Mi_{dr} \quad (10)$$

$$\lambda_{qs1}=L_s i_{qs1}+L_{ps}i_{qs2}+Mi_{qr} \quad (11)$$

$$\lambda_{ds2} = L_{ps} i_{ds1} + L_s i_{ds2} + M i_{dr} \qquad (12)$$
$$\lambda_{qs2} = L_{ps} i_{qs1} + L_s i_{qs2} + M i_{qr} \qquad (13)$$

And

$$\lambda_{dr} = L_r i_{dr} + M i_{ds1} + M i_{ds2} \qquad (14)$$
$$\lambda_{qr} = L_r i_{qr} + M i_{qs1} + M i_{qs2} \qquad (15)$$

With

w : Speed of rotation of the coordinate (d,q) relative to the rotor.

w_a : Speed of rotation of the coordinate (d, q) relative to the stator 1.

$L_s = L_{s1} = L_{s2} = l_{s1} + L_{sm} + L_m$: The cyclic inductance of the stator.

$L_r = l_r + L_m$: The cyclic inductance of the rotor.

$L_{ps} = l_{sm} + L_m$: The cyclic mutual inductance between stator1, stator2.

L_m : Mutual inductance between stator1, stator 2 and the rotor.

L_{sm} : Mutual leakage inductance between stator1, stator2.

l_{s1}, l_{s2} : Stator leakage inductance.

l_r : Rotor leakage inductance.

The electromagnetic torque can be expressed by:

$$C_{em} = n_p \frac{M}{L_r}\left[(i_{qs1} + i_{qs2})\lambda_{dr} - (i_{ds1} + i_{ds2})\lambda_{qr}\right] \qquad (16)$$

The analytical d- model has been developed in a general reference frame and can be used to analyze the behavior of induction machine in any reference frame.

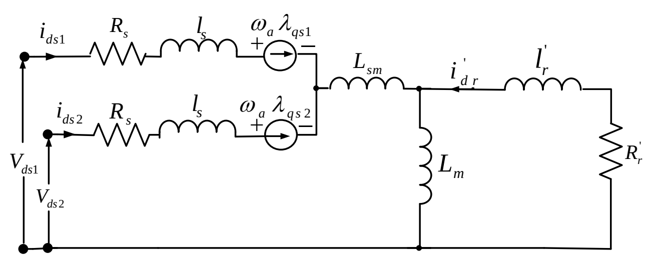

Fig1: d-axis equivalent circuit of a DSIM in arbitrary reference frame.

These equations suggest the equivalent circuit as shown in Fig.1. The common mutual leakage inductance represents the fact that the two sets of stator windings occupy the same slots and are, therefore, mutually coupled by a component of leakage flux [6],[8].

RESULTS AND DISCUSSION

A typical and relatively known transient are investigated here in order to prove the validity of the existing models as well as the influence of offset alpha between stator.

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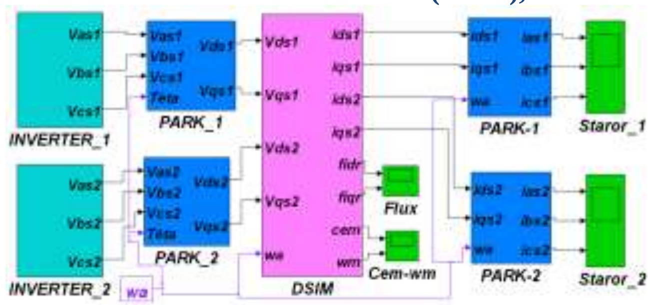


Fig.2: Bloc diagram of simulation performed by "Matlab-Simulink".

The folowing figures show that the alpha can influence the performance of the machine such as torque, speed, and flux.

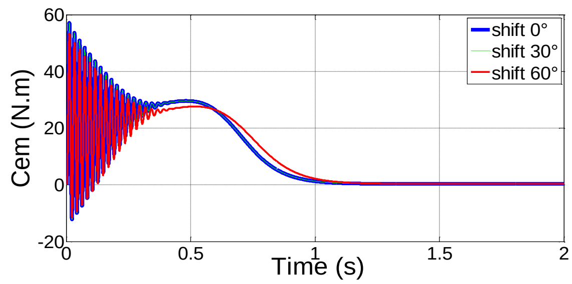


Fig.3: Characteristic of the electromagnetic torque.

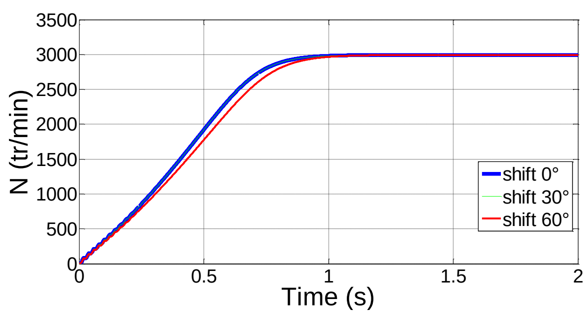


Fig.4: Rotor speed evolution during the starting.

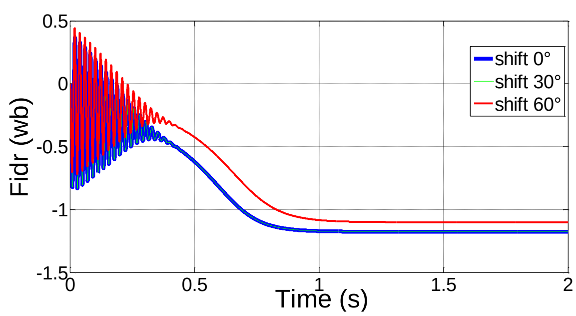


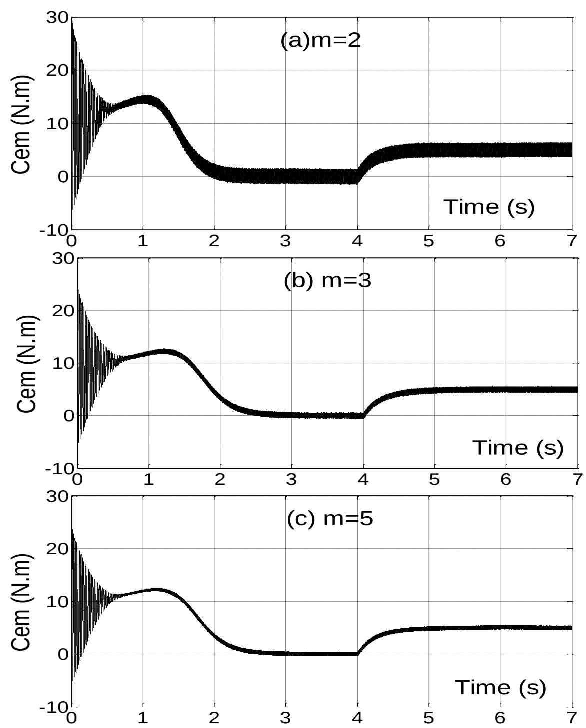
Fig.5: Characteristic of direct rotor flux λ_{dr}

According to the figures presented above, there's a delay steady state establishment with (α=0°) and (α=30°), for all characteristics, compared to (For α=60°), table1.

Table I : Effect Of An Angular Offset On The Operating Characteristics Of The Dsim

	For α=0°	For α=30°	For α=60°
Peak torque	57.1 N.m	55 N.m	53 N.m
Rated torque	29.8 N.m	29.5 N.m	27.5 N.m
Time of stabilization torque	1 s	1s	1.1 s
Time of speed stabilization	0.9 s	0.9s	1s

During the starting, figure (6) show that the electromagnetic torque is oscillating in the first moments. The transient torque may reach a peak of almost 24 Nm. From t = 4 s, a load torque of 5 Nm is applied.
Besides, the influence of the waveform of the supply voltage on the rotor torque is especially noticeable during the steady state operation.
In fact, it is clearly observable in figure (6) the electromagnetic torque ripple in steady state decreases gradually and progressively as the number of levels of the inverter increases. According to the results found there that when the level of the inverter voltage is m=2 to m = 7 the output voltage approaches more and more perfect sinusoidal form.



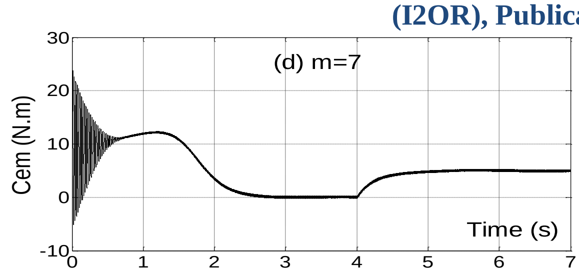


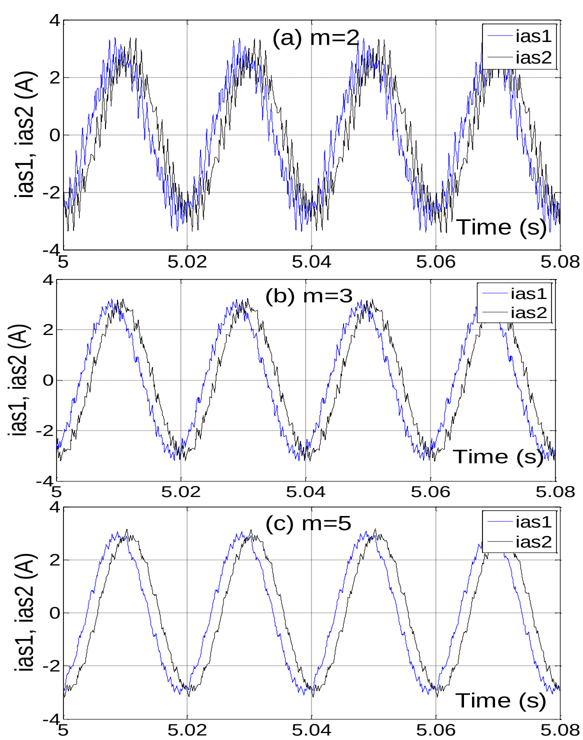
Fig.6: Electromagnetic torque for m=2, 3, 5, 7.

In fact, the previous figure clearly illustrates that the torque ripple during steady state period decreases gradually and progressively as the inverter number of levels increases. Relative results are resumed in Table II.

Table II: Relative Torque Ripple Rate As Function Of The Inverter Levels Number

Levels number	Relative torque ripple rate in %
$m=2$	45.2%
$m=3$	10.52%
$m=5$	5.1%
$m=7$	4.96%

The influence of the waveform of the supply voltage appears at the level of electromagnetic torque in steady state and has no influence on the shape of the characteristic speed of rotation.



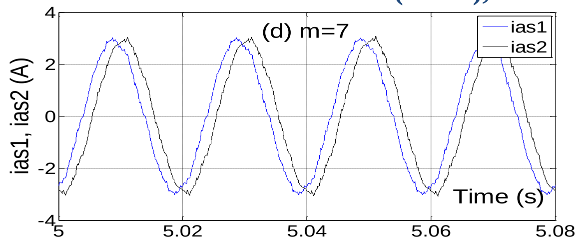


Fig. 7: Phase current waveform at a steady state for Cr=5N.m and for m=2, 3, 5, 7.

Special interest was focused on the waveforms of the stator current (fig.7) as well as the oscillations rate of the electromagnetic torque as functions of the inverter level amount. Consequently, when a DSIM is fed by a multilevel inverter, it would be not necessary to go beyond 5 levels to get suitable current, voltage and torque waves.

CONCLUSION

The modeling of a dual winding stator induction machine (DWSIM) supported by a multi level inverter was analyzed. A simulation study was performed to show consequent improvements in the machine electrical and mechanical wave forms. Special interest was focused on the form of the stator current and the oscillations rate of the electromagnetic torque as functions of the inverter level amount. Consequently, when an DWSIM is fed by an multilevel inverter, it would be not necessary to go beyond 7 levels to get suitable current, voltage and torque waves.

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