7TH INTERNATIONAL CONFERENCE ON ELECTROMECHANICAL AND POWER SYSTEMS
October 8-9, 2009 - Iaşi, Romania

COMPARISON BETWEEN TWO DOUBLE STATOR SYNCHRONOUS MACHINE SUPPLYING STRATEGIES

Nazih MOUBAYED and Mouafac BERNARD

Faculty of Engineering – Lebanese University – Lebanon, nmoubayed@ieee.org

Abstract **– In high power applications, power division methods for AC high power converters and machines are used. The rated power of the elementary converters and/or machines becomes lower when the number of converters and/or machines increases. Therefore, power switches with high switching frequency can be used. Then, the current and torque ripples would have theoretically lower amplitude. Tow strategies in supplying a double stator synchronous machine, which is an application of power division, are studied in this paper. In the first strategy, two independent voltage source inverters supply this machine. In the second strategy, one five legs voltage source inverter is used to supply this machine. A comparison between these two power supply strategies is finally discussed.**

Keywords: *Multi-converters, multi-leg converter, double stator machine, power division.*

1. INTRODUCTION

Electrical propulsion in embarked applications like ships and aircraft requires high power machines with variable speed drives. In this field, AC machines are increasingly used. These machines can be supplied by GTO Voltage-Source Inverter (VSI). The disadvantage is the low commutation frequency of the GTO and consequently the important current and torque ripples. In order to reduce these ripples, it is necessary to use high commutation frequency semi-conductor devices [1],[2]. Several solutions based on power division can be envisaged [3].
Actually, in high power applications, association of multi-converters with multi-machines is developed. For economic reasons, these electric systems may share some resources in the energizing chain which imply some couplings between the various components [4]. Taking into account these couplings, the system passes by a global approach of the set of the electric components connected to a same supplying source. The global system is defined then by the denomination 'Multi-converter Multi-machine System (MMS)' [2],[4]. It is composed of coupled subsystems which are going to interact between them.
This paper treats the case of a Double Stator Synchronous Machine (DSSM) supplied by two independent VSI or by one five legs VSI. This paper is organized as follows. Section 2 is devoted to review the modelling of the DSSM. Section 3 presents the simulation results when this machine is supplied by two independent VSI. In the fourth section, the functioning of a five legs VSI connected to a DSSM is given.
In section 5, a comparison between these two types of power supply strategies is discussed. Finally, conclusions are given in section 6.

2. DOUBLE STATOR SYNCHRONOUS MACHINE

The studied machine is composed of two stars; each one is formed of three Y connected windings. These stars can be shifted from each other by an electrical angle equal to γ (Fig. 1). The rotor contains permanent magnets [5].

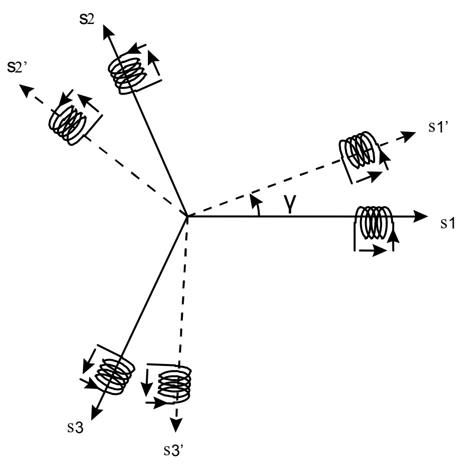

Fig. 1 - Double stator of the studied machine.

To simplify this study, it should be supposed that:

- The used machine is not saturated,
- Iron and all types of losses are neglected,
- The inductances of the machine are constant,
- The coils distributions are sinusoidal.

For the studied machine:
i_k and i'_k are the currents flowing the k and k' phases of the two stators, with k = 1, 2 or 3,
v_k and v'_k are the voltage across the k and k' phases of the two stators,
e_k and e'_k are the emf of the k and k' phases of the two three phase windings, these emf are supposed to be sinusoidal,
p is the number of pair of poles,
l_s is the coil inductance,
r is the winding resistance,
m.cos ξ is the mutual inductance between two windings delayed by an electric angle of ξ. The coefficient m is positive, [$m_{11'} = m.\cos(\gamma)$].

The expressions of the voltage v_k and v'_k are:

$$\begin{cases} v_k = r.i_k + \dfrac{d\phi_k}{dt} + e_k \\ v'_k = r.i'_k + \dfrac{d\phi'_k}{dt} + e'_k \end{cases} \quad (1)$$

where ϕ_k and ϕ'_k are the generated flux in k and k' phases:

$$\begin{cases} \phi_k = (ls + \dfrac{m}{2}).i_k + \dfrac{3.m}{2}.\cos(\gamma).i'_k \\ \qquad - \dfrac{m.\sqrt{3}}{2}.\sin(\gamma).[i'_{k+1} - i'_{k+2}] \\ \phi'_k = (ls + \dfrac{m}{2}).i'_k + \dfrac{3.m}{2}.\cos(\gamma).i_k \\ \qquad + \dfrac{m.\sqrt{3}}{2}.\sin(\gamma).[i_{k+1} - i_{k+2}] \end{cases} \quad (2)$$

The electromotive force e_k and e'_k take the form:

$$\begin{cases} e_k = E.\sqrt{2}.\sin\left(\omega t - (k-1).\dfrac{2\pi}{3}\right) \\ e'_k = E.\sqrt{2}.\sin\left(\omega t - (k-1).\dfrac{2\pi}{3} - \gamma\right) \end{cases} \quad (3)$$

where ω is the electric speed.

The torque expression of the studied machine is:

$$\Gamma = \frac{p}{\omega}.\left[\sum_{k=1}^{3}(e_k.i_k + e'_k.i'_k)\right] \quad (4)$$

3. DSSM SUPPLIED BY TWO INDEPENDENT PWM VSI

As mentioned in the above section, the DSSM is composed of two star windings. These stars can be shifted from each other by an electrical angle equal to γ. Each star is supplied by its own PWM VSI (Fig. 2).

Fig. 3 and Fig. 4 show the influence of the shifted angle on the current wave form. In fact, if the two stars are shifted (Fig. 4), current ripples appear and can be dangerous for the two inverters and for the machine. These ripples, which appear only on the currents, do not affect the machine torque (Fig. 5 and Fig. 6).

The power division by using multi-star machines supplied by independent PWM VSI can not be applied except if the magnetic coupling between stars is weak [6],[7]. Or in other case, the applied voltages to the homologous phases of the star windings should be instantaneously the same (inverters should be controlled by master-slave control strategy), and the star windings should not be shifted [8],[9].

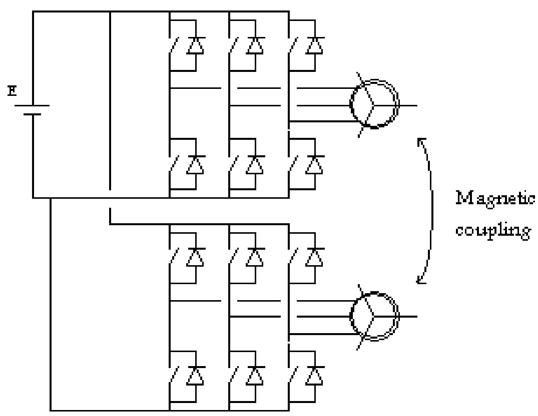

Fig. 2 - DSSM supplied by two independent VSI.

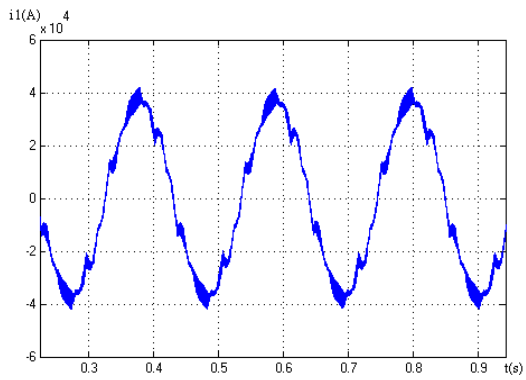

Fig. 3 - Machine first phase current of the first star windings for non shifted stars.

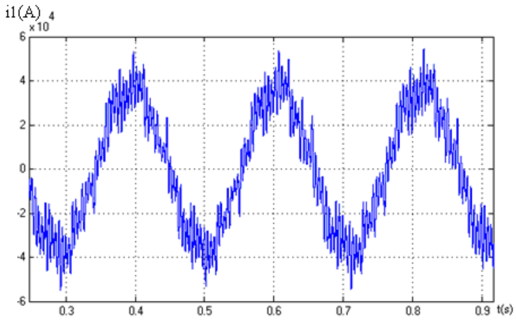

Fig. 4 - Machine first phase current of the first star windings for stars shifted by 30 degrees.

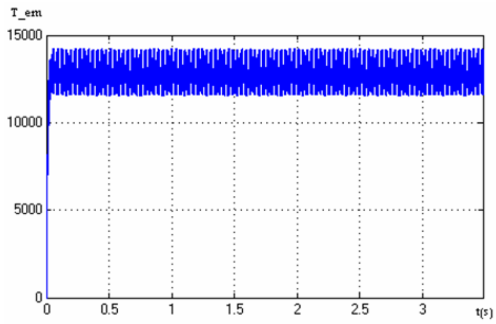

Fig. 5 - Machine torque for non shifted stars.

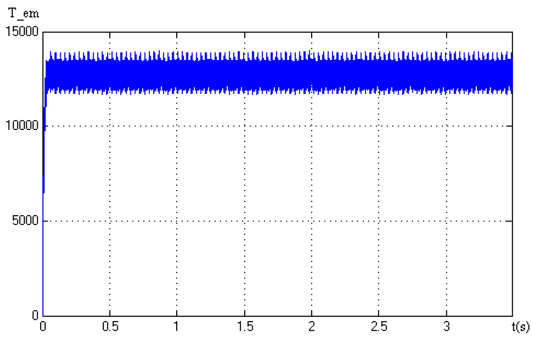

Fig. 6 - Machine torque for stars shifted by 30 degrees.

4. DSSM SUPPLIED BY A FIVE LEGS VSI

An example of electrical and magnetic couplings is presented in figure 7. This system is composed of one double stator synchronous permanent magnets machine (magnetic coupling) supplied by a five legs VSI (electric coupling) [4],[9].

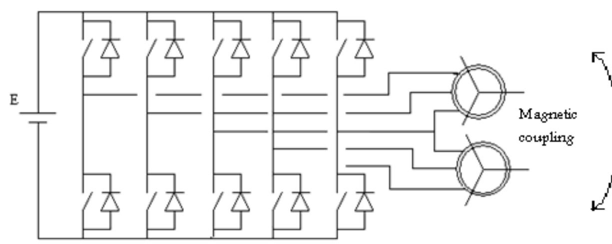

Fig. 7 - DSSM supplied by a five leg VSI.

As the two stars are not shifted, the currents wave forms are ripples free (Fig. 8). In this figure, the two stars are supposed to have different rated currents. The inverter common leg should contain components of high power rating compared to those placed in the other legs (Fig. 9). The developed motor torque of the studied machine is presented in figure 10.

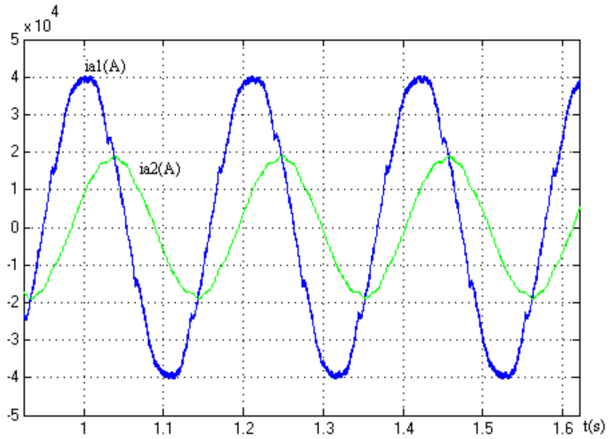

Fig. 8 - First phase currents in star 1 and star 2.

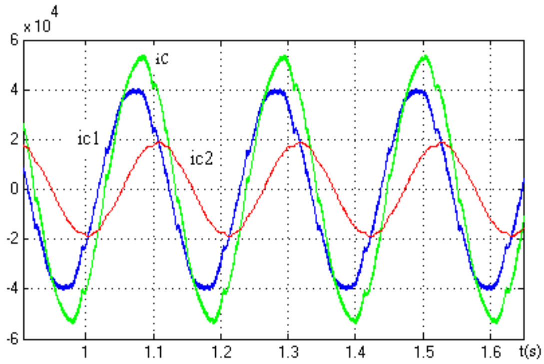

Fig. 9 - The third phase and the common leg currents.

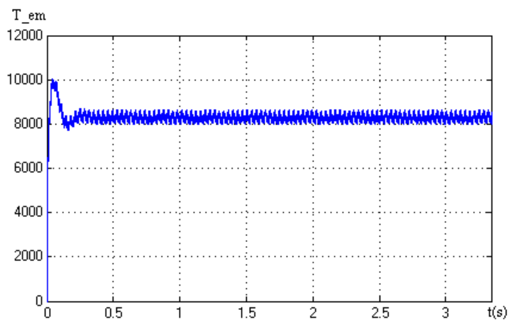

Fig. 10 - Machine torque.

5. COMPARISON BETWEEN TWO THREE PHASE VSI AND ONE FIVE LEG VSI

As presented in the previous sections, the two independent three phase VSI contain components of same power ratings. The number of these controlled components is equal to six per inverter. This means that it is necessary to use twelve controlled components to supply the studied DSSM. By using the five legs VSI, the number of the controlled components is equal to ten. Two components, which are placed in the common leg, should be of high power rating compared to those of the other components.

By applying a current controller to the DSSM supplied by two independent VSI, the current and the torque waveforms are illustrated in figure 11 and 12.

The current and torque waveforms for a current control applied to the five legs VSI supplying the DSSM are presented in figure 13 and figure 14.

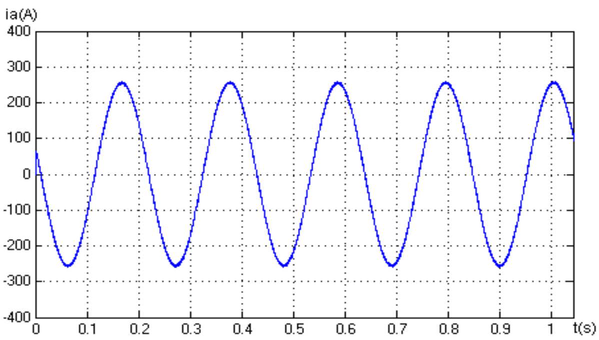

Fig. 11 - Phase current of the DSSM after control – 1st strategy.

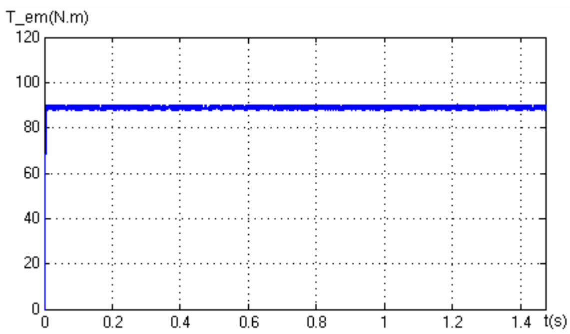

Fig. 12 - Machine torque after control - 1[st] strategy.

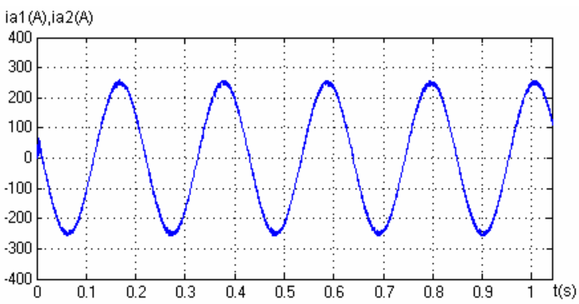

Fig. 13 - Phase current of the DSSM after control – 2[nd] strategy.

By using the current control, the two strategies in supplying the DSSM give approximately the same current and torque waveforms.

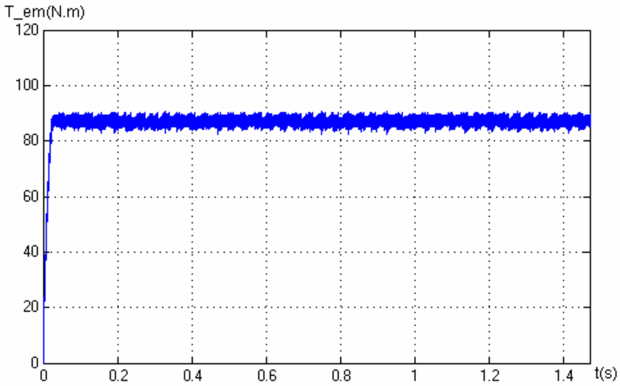

Fig. 14 - Machine torque after control - 2[nd] strategy.

For these two strategies, some problem occurs if one transistor for example is damaged or opened after 1.1 second of normal functioning. For this, the torque ripples that appear in figure 16, where the DSSM is supplied by the five legs VSI, are more significant than those in figure 15, where the DSSM is supplied by the two independent VSI.

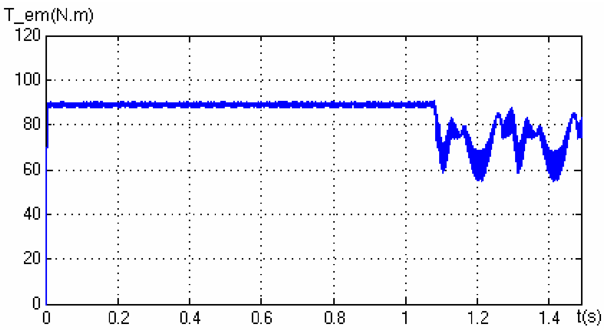

Fig. 15 - One open transistor at 1.1 second – 1[st] strategy.

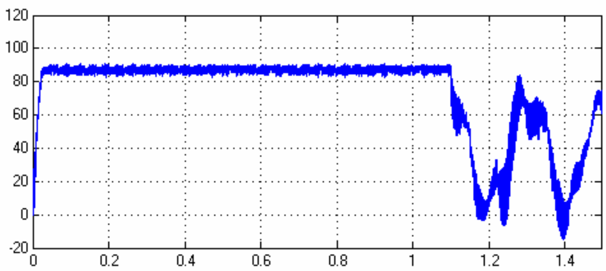

Fig. 16 - One open transistor at 1.1 second – 2[nd] strategy.

5. CONCLUSION

In this paper, power division in high power application is discussed. The treated example was the case of a double stator synchronous machine supplied firstly by two independent voltage source inverters and secondly by one five legs voltage source inverter. In the first strategy, the two independent VSI needs two more controlled components than those used in the five legs VSI. In the second strategy, the common leg controlled components should have high rated power than the other components used in this converter or those used in the two independent VSI of the first strategy. In addition, if one controlled component is damaged and opened, the torque behaviour is more critical if the five legs VSI is used to supply the studied machine than the two independent VSI. For these reasons, it is preferred to supply a DSSM by two independent VSI.

References

[1] N. Moubayed, *Alimentation par onduleurs de tension des machines multi- étoiles*, PhD. from INPL, Nancy, France, 1999.

[2] A. Bouscayrol, B. Davat, B. De Fornel, P. Escane, B. Francois, J.P. Hautier, F. Meibody-Tabar, N. Moubayed, J. Pierquin, M. Pietrzak-David and H. Razik, *Formalisme pour la caractérisation des systèmes Multi-machines Multi-convertisseurs*, SDSE'00, Sûreté et Disponibilité des Systèmes Electrotechniques, Villeurbanne – France, pp. 86-91, 2000.

[3] R. Zaiter and N. Moubayed, *Study of the functioning of Multi-converter Multi-machine system*, 1st Electrical Engineering Conference, 22-25 June 2007, Aleppo, Syria, pp. 1-10.

[4] A. Bouscayrol, B. Francois, P. Delarue and J. Nijranen, *Control Implementation of a five-leg ac-ac converter to supply a three-phase induction machine*, IEEE Transactions on Power Electronics, Vol. 20, NO. 1, pp. 107-115, 2005.

[5] N. Moubayed, F. Meibody-Tabar and B. Davat, *Alimentation par deux onduleurs de tension d'une machine synchrone double étoile*, Revue Internationale de Génie Electrique, vol. 1, n° 4, pp. 457-470, 1998.

[6] A. El Ali and N. Moubayed, *Segmentation de puissance dans les ensembles convertisseurs – machines*, EPE 2006, 4th International Conference on Electrical and Power Engineering, IASI – Rumania, Volume A, pp. 15-20, 2006.

[7] N. Moubayed, F. Meibody-Tabar and B. Davat, *Study and simulation of magnetically coupled multi stator induction machine supplied by independent three phase voltage-source inverters*, ELECTR-IMACS'99, 6th International Conference on Modeling and simulation of electric machines, converters and systems, Portugal, vol. 1, pp. 59-64, 1999.

[8] N. Moubayed, F. Meibody-Tabar B. Davat and I. Rasonarivo, *Conditions of safely supplying of DSIM by two PWM VSI*, EPE'99, 8th European Conference on Power Electronics and Applications, Lausanne - Suisse, pp. 1-7, 1999.

[9] R. Zaiter and N. Moubayed, *Control methods of multi-converter multi-machine systems*, JIMEC6 2007, The sixth Jordanian International Mechanical Engineering Conference, 22-24 October 2007, Amman – Jordan.