Control of a Seven-phase Axial Flux Machine Designed for Fault Operation

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Abstract – This paper deals with control in fault operation of a seven-phase Permanent Magnet Synchronous Machine supplied by a seven-leg Voltage Source Inverter (VSI). Using a Multi-Machine description, a seven-phase machine which presents a special ability to be controlled with only five phases supplied has been designed. The machine is presented and experimental results are provided when two phases are opened. In a first case of no change of classical control, high torque ripples are observed. In a second case, a specific control deduced from the Multi-Machine modelling is suggested for reducing torque ripples.

I. INTRODUCTION

Multiphase machines suffer from an apparent higher number of switching devices than three-phase ones. Nevertheless, in high power applications such as electrical ships [1] or low voltage/high current applications such as on-board traction systems [2]-[3], this drawback is not so obvious: the use of high current devices implies high heat dissipation capabilities especially with high frequencies. In these cases parallel converters or parallel/series device associations are often used.

Moreover, when reliability is required such as in aircraft [4], in marine applications [5], multiphase drives [6] must be considered as an alternative to three-phase multi-level converter drives whose reconfiguration in safety mode is not obvious.

Contrary to three-phase wye-connected machines, the loss of one phase is not critical for seven-phase machines. However, torque ripples appear with usual vector control of the machine [5]-[7]. The magnitude of the ripples depends on the interaction between the non-symmetrical system of currents and the symmetrical system of electromotive forces (EMF). In [8], new references of the currents are determined and corresponding currents are obtained using to hysteresis controllers in stator frame. However in this case the carrier frequency of the Pulse Width Modulation (PWM) VSI is not constant which is damaging for electromagnetic compatibility. In [7], two models are used. The first one is dedicated to normal operation. A second model is defined for fault operation using a new transformation. In this case, the control of currents is then achieved in a new synchronous frame with Proportional Integral (PI) controllers which have constant references in steady states. The errors are then equal to zero. However, the change of synchronous frame depends on the kind of fault.

In this paper, the same model is used for normal and fault operations. Thus the same control structure is used in both operation modes using PI controllers in the synchronous frame. Such a fault operation control is possible because the machine has been specifically designed.

This control strategy is deduced from a Multi-Machine Multi-Converter modelling of the seven-phase machine supplied by seven-leg VSI [9]. In this modelling method, the seven-phase machine can be considered as a set of three (dq) fictitious machines. Mathematically, this approach is close to multi-reference frame one [10] but highlights physical couplings which have to be taken into account by the control. The mathematical basis of the two approaches, introduced for six-phase machines [11], is the same: the existence of subspaces associated with the eigenvalues of stator inductance matrix.

From the suggested model, constraints on the control but also on the machine are deduced. A seven-phase NN TORUS machine has been made using analytical and 3D-Finite Element Methods [12]-[13]. Experimental results of the implemented control are provided when two phases are not supplied. Using the same PI controllers as in normal operation it is shown that torque ripples can be weak if reference currents are adapted. At last, reduction of torque

Fig. 1. Multi-Machine Energetics Macroscopic Representation of the seven-phase machine
ripples is obtained using a specific control deduced from the Multi-Machine model.

VI. CONCLUSION

In this paper the tolerance to a fault operation has been validated for a seven-phase machine. These results have been obtained by using a specific design of the machine. One interest with this machine is that neither the structure of the control nor the PI-controllers have to be changed between the normal and fault operations. A modification of the current references in a fictitious machine M2 has only to be calculated to reduce drastically the torque ripples which appear when two phases are opened. In this machine M3 the references are not constant but it is no a matter since the EMF is equal to zero. For the two others machines the references remain constant. In this paper, a particular case has been chosen (phase A and B opened) but the approach can be extended when one phase or two other phases are opened. However, as the EMF of the M3 machine is not equal to zero the extension to more than two phases opened is not so easy.

VII. REFERENCES


Appendix: Synoptic of Energetic Macroscopic Representation

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