The European Physical Journal- Applied Physics, Vol 22 n°3, 2003, pp207-221

Vectorial formalism for analysis and design of polyphase synchronous machines

E. Semail[1] — A. Bouscayrol[2] , and J.-P. Hautier[1]

L2EP, Laboratoire d'Électrotechnique et d'Électronique de Puissance de Lille
[1]L2EP, Laboratoire d'Électrotechnique et d'Électronique de Puissance de Lille ENSAM, 8 bd Louis XIV, 59046 LILLE cedex
[2]L2EP, Laboratoire d'Électrotechnique et d'Électronique de Puissance de Lille Université de Lille 1, Bât. P2, F-59655 Villeneuve d'Ascq cedex
http://www.univ-lille1.fr/l2ep/ — eric.semail@lille.ensam.fr

Received: 19 September 2002 / Received in final form: 27 February 2003 / Accepted: 14 March 2003
Published online (Vol 22 n°3 2003) EDP Sciences

Abstract. A vectorial formalism for analysis and design of polyphase synchronous machines without reluctance and saturation effects is described. We prove the equivalence of such a machine with a set of magnetically independent machines, which are electrically and mechanically coupled. Specific problems of polyphase machines can thus be favorably analyzed with this concept. Rules of conception and constraints on electric supply can be deduced. Moreover the vectorial approach, which generalizes the complex phasor method, can also be used to control n-leg Voltage Source Inverters. This methodology is applied to 3-phase and 6-phase synchronous machines.

PACS. 84.30.Jc Power Electronics, power supply circuits, 84.50+d Electric motors

1 Introduction

The transmission of electric energy by 3-phase networks has led to the development of 3-phase electric machines to ensure electromechanical conversion. These machines have taken benefits of the rise of Digital Signal Processors (DSP) and power semiconductors. In association with power electronics, these 3-phase machines have improved their performances particularly in the field of variable speed drives. Nevertheless, when the power has to be increased, problems appear as much in the inverter as in the machine. The power switches have to commute voltages and currents of higher magnitudes. The partition of the power between numerous phases can be a solution of the problem [25], [43]. Moreover, this kind of structure improves the reliability of the electromechanical conversion [23],[34]. Polyphase machines have been thus industrially developed [30],[16]. The double-star machines with a 30° electric phase-shift between the two stars are the most used [4],[15].
The polyphase machines have firstly been supplied by Pulse Amplitude Modulation Current Source Inverter (PAM CSI) [15],[4]. In this case, a machine with q 3-phase stars can be considered as the association of q 3-phase machines mechanically coupled on a same shaft. Each 3-phase machine is associated with one of the q stars. This decomposition is possible in spite of the magnetic coupling between the stars, because of a property of the PAM CSI: when there is commutation of a current in a star, the currents in the other stars are constant. Then, there is no interaction between the stars through mutual inductances. They can be considered as magnetically independent.
Nowadays, a Pulse Width Modulation Voltage Source Inverter (PWM VSI) is chosen because of its better dynamic performances. However this voltage supply requires a much more precise modeling of the polyphase machines [48],[33]. The equivalence of a polyphase machine to a set of more simple machines is no more obvious as in the PAM CSI supply. The proposed vectorial approach enables us to show that, with some conditions, it is possible to find an equivalent set of fictitious electric machines. These equivalent machines, called Multimachine system, are mechanically coupled on the same shaft and electrically coupled. The analysis of the fictitious machines gives information for the design of polyphase machines and VSI control [24],[32].

2 Drawbacks of standard methods

To study transient or unbalanced states of 3-phase electric machines, different methods have been developed. Matricial and complex phasor methods are the most used. Each one of these two approaches defines a 2-phase fictitious machine, which is mathematically equivalent to the real machine. We examine in this section if it is possible to extend the use of these methods to the study of polyphase machines in transient states.

2.1 Complex Phasor Method (Space Vector Theory)

This method consists of working in a complex plane [35],[28]. Consequently, the machine must have a 2-dimensional mathematical model. In this case, the various equations can be summarized by only one equation with complex variables. Thus, it is possible to represent this equation in a complex plane. The same concepts have also been developed for steady state: phasor diagrams of A.C. machines [1]. Consequently, the same graphical rules of construction as those developed for steady state can be used in transient states.