Complex Dynamic Models of Multi-phase Permanent Magnet Synchronous Motors

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Abstract: In the paper two power-invariant real and complex state space transformations for modeling multi-phase electrical machines in a compact and general form are proposed. In particular the paper deals with the modeling of multi-phase permanent magnet synchronous machines with an arbitrary number of phases and an arbitrary shape of the rotor flux. The dynamic model of the motor is obtained using a Lagrangian approach and in the frame of the Power-Oriented Graphs technique. The obtained models are equivalent from a mathematical point of view and can be directly implemented in Simulink. The complex transformed model is quite compact and uses a reduced order state vector. Some simulation results end the paper.

Keywords: Dynamic Modeling, Multi-phase synchronous motor, Power-Oriented Graphs, State space transformation.

1. INTRODUCTION

In the literature many coordinate transformations have been proposed in order to write the dynamic equations of synchronous electric motors in a proper form. The transformations typically used are the Park, the Clarke and Fortescue transformations, see Clarke (1950), Park (1929) and Fortescue (1918), respectively. Usually these transformations are exploited for three-phase machines, see Paap (2000), but they can be extended to the case of multi-phase machines, where the number of phases is greater than three. The extended Park and Clarke transformations are based on a real matrix (see Parsa and Toliyat (2005) and Kestelyn et al. (2002)), the Fortescue transformation is based on a complex matrix which contains complex vectors and their complex conjugate (see White and Woodson (1959)) while in the space vector approach (see Grandi et al. (2006)) only one half of the Fortescue matrix is considered (i.e. without the complex conjugate part). Unfortunately, all these transformations are not power invariant, i.e., after the transformations the power flows cannot be expressed as the simple product of the transformed conjugate power variables, but always a correction coefficient must be used.

In this paper two power invariant state-space transformations (one real and one complex) for modeling multi-phase synchronous machines are proposed. They are suitable for machines with an arbitrary odd number of stator phases and for an arbitrary shape of the rotor flux. Using the proposed transformations one obtains the dynamics of the system written in a very simple and compact form, without the need of considering a set of separate fictitious 2-phase machines as it is usually done in the literature (see, for example, Semnai et al. (2004)).

In this paper the dynamic model of multi-phase synchronous motors, usually obtained by means of classical mathematical methods is obtained using a Lagrangian approach (see Zanasi and Grossi (2008)) in the frame of the Power-Oriented Graphs (POG) technique. This graphical modeling technique shows the power flows within the system, allows to write the state space equations of the system in a very compact form with a vectorial notation and provides a dynamic model that can be directly implemented in Simulink.

The paper is organized as follows. Sec. 2 introduces the main features of POG technique. Sec. 3 shows the details of the POG dynamic model of the multi-phase synchronous motors, introduces the two proposed state space transformations and shows the obtained transformed systems. Some simulation results are presented in Sec. 4 and conclusions are given in Sec. 5.

2. POWER-ORIENTED GRAPHS BASIC PRINCIPLES

The Power-Oriented Graphs technique, see Zanasi (1991) and Zanasi (2010), is an energy-based technique suitable for modeling physical systems. The POG are block diagrams combined with a particular modular structure essentially based on the use of the two blocks shown in Fig. 1.a and Fig. 1.b: the elaboration block (e.b.) stores and/or dissipates energy (i.e. springs, masses, dampers, capacities, inductances, resistances, etc.), the connection block (c.b.) redistributes the power within the system.

Figure 1. POG basic blocks: a) elaboration block; b) connection block.