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Mathematics and Computers in Simulation 63 (2003) 377–391
MATHEMATICS AND COMPUTERS IN SIMULATION
www.elsevier.com/locate/matcom

An accurate model of squirrel cage induction machines under stator faults

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Abstract

A substantial portion of squirrel cage induction motor faults are stator related. An accurate transient model of squirrel cage induction machines under stator faults is presented here. A coupled magnetic circuits approach is used and very few restrictive assumptions are made. All parameters are calculated from the actual geometry and winding layout of the machines rather than from transformed or equivalent variables. The detailed depiction of the procedure needed to implement such an accurate model with simulation results is the subject of this paper.

Keywords: Inductance; Induction machines; Power system faults; Simulation; Squirrel cage motors; Windings

1. Introduction

Rotating electrical machines play a very important role in the world's industry. Among them, the three-phase squirrel cage induction motor is frequently used because of its relatively simple, robust construction and its low price. Besides, there is also a strong industrial demand for reliable and safe operation of rotating machines. Faults and failures of critical electromechanical parts can indeed lead to excessive downtimes and generate costs of millions of dollars in reduced output, emergency maintenance and lost revenues. This is why industry is interested in adopting monitoring and diagnosis techniques to assess and evaluate electrical machines condition. Even if induction machines are known as reliable, they can be submitted to external and internal stresses, and degradation can occur in their electrical and mechanical parts [1]. Stator faults constitute a substantial portion of the faults related to squirrel cage induction motors [2]. These faults (turn-to-turn, coil-to-coil and phase-to-phase short circuits, phase breakdown, ground fault) occur primarily due to the thermal, electrical, mechanical and environmental stresses that the stator windings have to undergo during their life cycle.

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doi:10.1016/S0378-4754(03)00083-1

People who work on monitoring and diagnosis of squirrel cage induction machines often need an accurate model to predict performances and/or to extract faults signatures (on electromagnetic torque, stator currents, mechanical vibrations, etc.). However, model accuracy and computation time represent two opposite criteria. Conventional model obtained with the Park transformation, for instance, is based on restrictive assumptions and does not require lots of computation time. On the contrary, model obtained with the finite elements method is based on minimal assumptions and requires lots of computation time. There is a real need to establish an alternative model which offers a good balance between accuracy and computation time. This is the aim of the present paper where an accurate transient model of squirrel cage induction machines under stator faults is presented. A coupled magnetic circuits approach [3] is used and very few restrictive assumptions are made. Parameters are calculated from the actual geometry and winding layout of the machines rather than from transformed or equivalent variables. The detailed depiction of the procedure needed to implement such an accurate model with simulation results is the subject of this paper.

2. Minimal assumptions

Consider a three-phase squirrel cage induction machine having m stator and n rotor slots. Stator windings are, in a first analysis, viewed as a set of independent stator coils which can be later connected in any fashion to form the stator phases. The rotor cage is viewed as n identical and equally spaced rotor coils (plus one end-ring coil) which can be later connected to form the correct rotor bars/end-rings configuration. The model is based on a coupled magnetic circuits approach and all space harmonics are taken into account without any restrictions concerning general symmetry of the machine. Moreover, the following assumptions are made:

- Permeability of iron is infinite.
- Rotor bars are insulated.
- Skin effect is not taken into account.
- Air-gap is not necessarily smooth.
- Rotor bars skewing is taken into account.

3. “Native” system equations

Notations used in this section are rather classical and self-explanatory; they will not then be deeply explained in detail. It is worth noticing that $[I_s]$ and $[J_r]$ are, respectively, composed of three stator phase currents and of $n + 1$ rotor loop currents as illustrated in Fig. 1; the electromagnetic torque C_{em} is obtained from the magnetic coenergy W_{co}. The following “native” system equations can be written for the three-phase squirrel cage induction machine with n rotor bars:

$$[V_s] = [R_s] \cdot [I_s] + \frac{d[\Phi_s]}{dt} \quad (1)$$

$$[V_r] = [R_r] \cdot [J_r] + \frac{d[\Phi_r]}{dt} \quad (2)$$

$$[\Phi_s] = [L_s] \cdot [I_s] + [M_{sr}] \cdot [J_r] \quad (3)$$