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Review

A review of induction motor fault modeling

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ABSTRACT

Induction motors are susceptible to various types of electrical and mechanical faults that can lead to unexpected motor failure and consequently unscheduled down time. Since it is not economically feasible to physically study machine failure, a number of detailed computer models have been developed. These are able to adequately represent the physical phenomena associated with the failure modes and associated changes in measured parameters. This paper provides a review of the mathematical models that have been used to study induction motors under faulty conditions. The models are categorized as multiple coupled circuit models, *dq* models, magnetic equivalent circuit models and finite element models. A general description of each type of model is given along with advantages and disadvantages in their ability to model different types of faults.

Contents

1. Introduction

Induction motors are widely used in industrial applications. Their popularity is largely due to their simplicity, ruggedness and low cost of construction; easy maintenance; high power efficiency and high reliability. These do not preclude them, however, from electrical or mechanical failures. Thorsen [1] provides an very useful survey of machine failures from industry using different categorizations including, inter alia: machine size, enclosure type, protection scheme, age, running hours, maintenance regime, number of poles, etc. He identifies initiators, contributors and underlying causes for stator and bearing faults which together account for over 75% of all failures. These faults lead to unexpected motor failure and consequently production shutdown and

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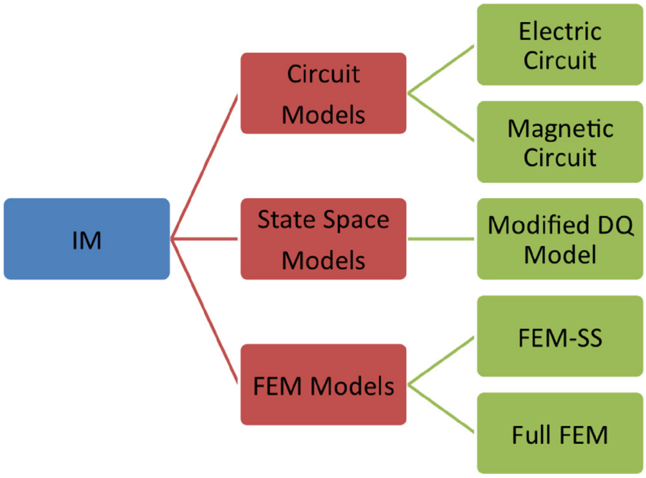

Fig. 1. Breakdown of induction motor fault models.

financial loss. As such, condition monitoring of induction motors is highly important. There are many published condition monitoring techniques. Some which have traditionally been used in industry include: motor current signature analysis (MCSA), electromagnetic torque analysis, noise and vibration monitoring, acoustic noise measurements and partial discharge [2]. The basis of any reliable condition monitoring technique is an understanding of the electric, magnetic and mechanical behavior of the machine in healthy-state and under fault conditions [3]. The design and verification of these techniques typically involve the use of elaborate mathematical models that allow for thorough computer simulation, the prediction of motor performances and the identification of fault signatures [2–5]. Models of motor operation under healthy and faulty conditions are useful for investigating the operational characteristics of faulty motors without destructive testing [6].

The modeling of an induction machine can be broken down into three broad categories as illustrated in Fig. 1

The categories can be further classified as multiple-coupled circuit (MCC) models, modified d-q models, magnetic equivalent circuit (MEC) models, and finite-element method (FEM) models. The aim of this paper is to present a review of these four types of fault models. For each type of model, the model description, parameter estimation, faults modeled, model size and computational intensiveness are covered. A number of summary tables are presented at the end for convenient referencing of models to pertinent works.

2. Multiple coupled circuit models

2.1. General description

The multiple-coupled circuit model was first proposed in [7] for the analysis of concentrated winding induction machines in adjustable speed drive applications. A detailed description of the procedure necessary to implement this model and simulation results of the completed model was subsequently presented in [10]. This transient model is developed by considering the stator and rotor of a squirrel cage induction motor to comprise multiple inductive circuits which are coupled together. The motor is considered to have m stator circuits and n rotor bars. The rotor cage is treated as n identical and equally spaced loops. Each loop comprises two rotor bars plus the connecting portions of the end-rings between them as shown in Fig. 2 [8].

As evident from Fig. 2, an RL circuit model is adopted. The capacitance between turns and windings are usually ignored due to the relatively low frequencies being studied. Once the parameters are known the loop currents can be solved for using standard circuit analysis techniques.

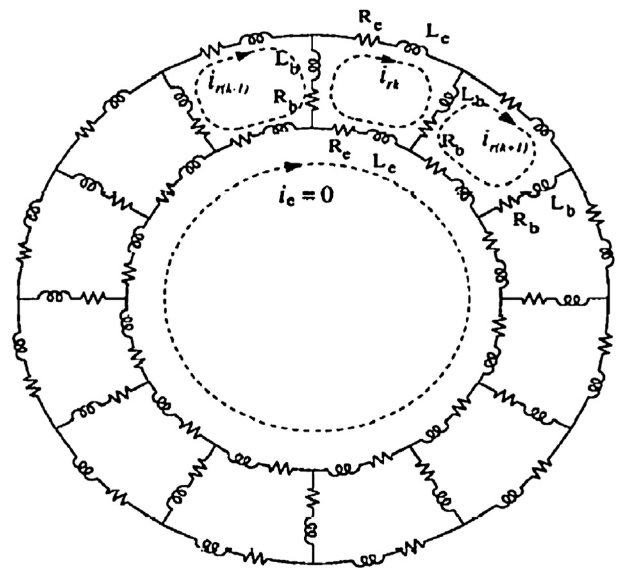

Fig. 2. Multiple coupled circuit topology [8].

2.2. Faults modeled

The MCC method is perhaps the most robust circuit type model and has been used to model a large number of stator and rotor faults including: rotor bar and end ring cracks, stator open and short circuits, static and dynamic eccentricity and even corrosion [6]. Table 1 provides a list of references for commonly reported faults.

2.3. Parameter estimation

As with any model, accurate determination of the circuit parameters for the coupled circuit model is naturally of critical importance. Typically resistance is estimated by examining the dimensions of the conducting paths. Cracked bars or otherwise damaged rotor bars can then be modeled by simply adjusting the model resistances without changing the structure.

The inductance, by contrast, is not as simple a matter. Inductance matrices are typically calculated using the winding function method. This method accounts for all the space harmonics in the machine. However, it also assumes symmetry of the machine, negligible saturation and eddy currents. The model, is not suitable for the modeling of eccentricities since the assumption of symmetry does not hold and although it was initially also applied to these cases, the resulting inductance matrices were non-symmetric, which are not physically meaningful. This led to the development of the modified winding function approach. In this method, the air-gap constant

Table 1
References for faults studied with MCC.

Fault	References
Broken rotor bar	[5,6,9,8,10–16]
End ring	[9,10,12,14,15]
Stator open circuit	[9,10,17]
Stator short circuit	[9,8,17–19]
Static eccentricity	[20–23]
Dynamic eccentricity	[24,21–23]
Corroded rotor bar	[6]
Bearing/race defect	[25]