Preface

Monitoring and diagnosing faults in electrical machines is a scientific and economic issue which is motivated by objectives for reliability and serviceability in electrical drives. This concern for continuity of serviceability has been motivating electrotechnical engineers since the first industrial applications of electrical machines. To avoid failures, these engineers used experiment feedback to improve machine construction and to make the said machines more robust. Moreover, they gathered knowledge from the detected faults and developed techniques for "manual diagnosis", following examples seen in mechanics and, above all, car maintenance.

The generalization of power supplies through power electronics from the 1950s to 1960s and onward, and the decisive contribution of microcomputers at the end of the 1970s radically changed the approach to machine maintenance through the introduction of "automated" diagnosis techniques. The development of digital control and an increased power in computer systems have opened up a channel for new techniques of automatic control, integrating new functionalities, such as real-time identification and online adaptation of control algorithms. The supervision function has become a natural and necessary addition to the management of automated systems which are becoming increasingly more sophisticated and complex. Furthermore, the concept of integrating automated fault detection and diagnosis came about at the beginning of the 1980s, as a functionality of supervision systems.

This revolution in machine control has also, unfortunately, resulted in new causes for machine failures. Now, to the classic electrical, mechanical, and thermal faults, we can add failures in power electronics and information systems, as well as new faults caused by Pulse Width Modulation power supplies. Moreover, these failures may have instant destructive consequences which justify early diagnosis, whether this is followed by a somewhat instantaneous switch-off or reconfiguration of the machine's power supply.

From now on, the diagnosis of electrical machines, and more widely electrical drives, must be a fundamental aspect of the design, use, and maintenance of a variable speed system. Such a concern is perfectly justified for high powered equipment where the integrity of an expensive system must be conserved. However, we must not lose sight of the fact that the breakdown of a low powered device may also have considerable economic consequences, following the shutdown of a production line.

As for the implementation of advanced numerical control algorithms, new fault diagnosis techniques have been tested. The introduction of the Fourier analysis for detecting mechanical rolling faults or electrical squirrel-cage rotor faults using vibration and current sensors has been a natural extension of “manual” diagnosis techniques. On the other hand, a preference for artificial intelligence in the initial studies on this area can be explained by the classic approach based on expertise. A third channel that opened up used detection techniques based on mathematical models, such as state observation and identification, was initially developed by the automatic control community.

In order to harmonize their work on fault detection in electrical drives in 1995, the research groups “GDR Electrotechnique” and “GDR Automatique” (Electrical Engineering and Automatic Control) set up joint research on the subject of monitoring and diagnosing induction machines. The main French teams from these two domains, as well as a few teams in the signal processing domain, came together regularly to present their work and to discuss joint approaches. In the same way, the work group “Identification”, operating on the same principle, highlighted themes regarding the identification of continuous systems and the estimation of physical parameters applied to electrical machines. Out of all these exchanges and joint efforts, two essential outcomes emerged: the need for specific modeling of machines in a fault situation, and an interest in identification for early fault detection.

More specifically, the studies by E. Schaeffer (Chapter 2) on modeling short-circuited stator windings are behind this progress in fault detection. This new approach has made it possible to develop macro-models for early fault detection as well as to define more sophisticated models for simulating electrical faults in AC machines. Also, works by J. Faucher and his students[1, 2] opened up the pathway to these simulation techniques, both in addition to or as substitutes for experiments, which are often impossible to perform due to their potential for destruction.

1 V. Devanneaux, Modélisation des machines asynchrones triphasées à cage d’écureuil en vue de la surveillance et du diagnostic, PhD Thesis, INP Toulouse, 2002.

2 A. Abdallah Ali, Modélisation des machines synchrones à aimants permanents pour la simulation de défauts statoriques: application à la traction ferroviaire, PhD Thesis, INP Toulouse, 2005.

With regard to identification, it has been shown that this methodology is suitable for detecting internal faults (short-circuits in stator windings, rotor broken bars), whereas approaches through state observation are better suited to detect external faults, such as sensor or actuator failures. Moreover, the combination of fault modeling/estimation of physical parameters with prior knowledge (of the characteristics of healthy operation) has enabled the development of a complete methodology for diagnosing stator and rotor faults in induction machines. These studies have already been reported in two chapters[3] of another book in the same collection, and will only be partly mentioned in Chapters 2 and 3.

The studies presented in this book come from or have been inspired by this collaboration with the aforementioned research groups. They are dedicated to electrical machine diagnosis and, in a more comprehensive approach, to electrical drives diagnosis. The faults here primarily deal with machines, but also deal with the monitoring of power electronic devices and energy storage in batteries. These faults are largely varied: electrical stator or rotor faults, mechanical faults, thermal faults, inverter faults, and estimation of state of charge. We will also note the range of techniques which are carried out to detect and diagnose these faults. These techniques are usually classified into two categories: those which are based on a model (identification, state observation, model invalidation) and those which are independent of a model (spectral analysis, artificial intelligence methods such as neural networks, fuzzy logic, etc.).

It is useful to remind the readers here that diagnosis comes under the domain of probabilities. Detecting a fault, especially early, must also correspond to a confidence index. Let us also remind the readers that normal operation may also give the same outcome as abnormal operation: thus, an increased resistance estimated by an identification algorithm may also result in rotor heating (normal) as well as bar breakage (abnormal). There is, then, no miracle solution for the problem of monitoring electrical machines, and we must not lose sight of the fact that it is a set of simultaneously acting techniques which make it possible to develop a reliable and robust diagnosis which in turn can help reduce the false alarm rate.

Chapter 1 describes failures affecting electrical machines, in order to know their occurrence and also to analyze their physical causes (either external or internal) such as induced currents in rolling or the repeated action of thermal cycles on conductor insulators. This wide range of main operational faults is followed up by a bibliographical panorama of the most commonly used diagnosis techniques.

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3 Chapter 7, "Parameter estimation for knowledge and diagnosis of electrical machines" and Chapter 8 "Diagnosis of induction machines by parameter estimation", in *Control Methods for Electrical Machines*, edited by René Husson, ISTE Ltd., and John Wiley, 2009.

In Chapter 2, a new modeling of a short-circuited winding is introduced, based on the induced currents in the short-circuited section which produce a disturbing magnetic field in the air gap of the machine. This physical analysis has resulted in a new Park model with short-circuited stator winding, which is then extended to the case of a squirrel-cage rotor. This approach to fault situation modeling has enabled us to define and implement a methodology for detecting and locating stator and rotor failures in the asynchronous machine by parameter estimation, validated by experiments on a laboratory benchmark.

Fault diagnosis through parametric estimation generally comes up against a practical problem: to reach convergence, identification algorithms need persistent excitation in order to disturb the machine's operation point, which indeed goes against regulation objectives. One solution is to use the charge disturbances which result in variable voltages generated by the inverter. Thus, we have a closed-loop identification problem. To this end, Chapter 3 offers an identification methodology, which takes into account the non-linear and multivariable nature of vector control algorithms, within an objective to improve electrical fault diagnosis in asynchronous machines.

Observers play a vital role in the vector control of AC machines, particularly when estimating the flux. To do so, we may use a Luenberger observer, a Kalman filter, or a high-gain observer. In addition to state variables, we can also estimate the parameters which vary with the operation point, such as the rotor resistance, for instance. We can, then, make use of an extended observer. Chapter 4 goes back to the basic theories of this methodology and applies it to a few concrete situations.

Whereas we usually imagine electrical faults in machines, the thermal causes behind these failures often go unnoticed. Thermal monitoring is therefore a vital objective within the framework of a global diagnosis system, as much for estimating the temperatures which are impossible to measure directly, as for fault detection such as the obstruction of a ventilation duct. The extended Kalman filter is perfectly suited to this use. Nonetheless, its correct usage assumes a sound prior knowledge of the different noises which affect the measurements, and a perfect control over the algorithm's parameters of adjustment. Chapter 5 offers a reference methodology applied to temperature estimates, which play an important role in thermal monitoring.

Accumulator batteries also hold a vital position in the electrical or hybrid drive chain of a car. Estimating its state of charge is a fundamental issue for continuity of serviceability and operational safety. Chapter 6 proposes an original, dual function procedure. It is original not only through the use of a technique of invalidating the model identified during an initial phase, but also through using an unconventional model of the battery by fractional calculus. This methodology can also be transposed to machine fault diagnosis, whether it is for modeling squirrel-cage frequency effects or thermal transfers inside the machine, both governed by a diffusion partial differential equation.

Aging and the abnormal use of a rotating machine result in mechanical imbalances and sound and ultrasound vibrations. A well-trained human ear is capable of detecting and locating different types of failures, even in the early stages. Indeed, signal processing techniques are used to automate this monitoring process. The information needed to be processed may be provided by a vibration sensor. However, we prefer the already present line current sensor, which offers more general information regarding the mechanics and electrical operation. The basic tool for spectral analysis is the discrete Fourier transform and its sophistications made possible by the computing power of digital processors. Chapter 7 gives a wide view of the potentials offered by the spectral analysis when applied to mechanical and electrical fault detection of induction machines, using experimental examples.

Artificial neural networks are of high interest to the monitoring of automatic systems. They act as a reference tool for processing problems of classification. Their use for detecting and locating faults in asynchronous machines is perfectly justified, provided that a methodology which is adapted to their properties is implemented. The approach presented in Chapter 8 is based on a residual generation technique using a Park model combined with a Fourier transform algorithm, in order to make a spectral signature of the stator and rotor faults occur. The neural network is responsible for the knowledge and classification of faults using a training database, enabling their detection and location.

Since the generalization of electronic machine control, fault detection in a static converter has become a key element in a global system for monitoring an electrical drive. Conventional approaches through state estimation or identification seem unsuitable for detecting failures which affect the converter. We therefore suggest a set of techniques from the domain of artificial intelligence (neural networks, fuzzy logic) and multivariate statistical methods. Section 9.1 of Chapter 9 offers a number of examples of these applied techniques. However, following the example of electrical and mechanical faults, it is indeed necessary to analyze the failures affecting the electronic components of the converter, and more particularly, failures caused by thermal fatigue. Section 9.2 of Chapter 9 offers a panorama of these failures and outlines a few suggestions for diagnosing them.

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