

Preface

Thanks to the technology developments and the recent advances in control theory, it is possible to implement new controllers to a large number of Alternative Current (AC) machines. These controllers are more robust with respect to uncertainties, and more efficient under a wide range of operation conditions in very useful applications. One the most attractive applications of the electrical machines is for transport: vehicle traction that is currently in important development.

The control of AC machines is a challenging problem which has attracted attention thanks to its several applications. For instance, the control problem of the induction motor has recently attracted attention due to its complexity: the induction motor is a nonlinear multi-variable system. Classically, the measurable outputs are the stator currents and voltages. The rotor speed measurement is not always available because of the high costs of sensors, their weakness, or noise sensitivity (the performance at low speed can be poor). Furthermore, the rotor speed is a function of the stator currents and rotor fluxes. The rotor fluxes measurement is not an easy task: it is necessary to introduce sensors in the motor which is expensive and physically complicated to install. When the rotor speed cannot directly be computed from these variables, its control becomes more difficult. On the other hand, the load torque and some parameters like the rotor resistance are usually unknown or inaccurately known and, moreover, time varying. Then, the mathematical models of the AC machines contain parametric uncertainties. Regarding the permanent magnetic synchronous motors, the position and rotor speed knowledge require sensors. However, the introduction of more sensors in the machine implies more complexity and the possibility to introduce failures in the machine. This fact weakens the motor robustness and increases the system cost. The rotor resistance is a time varying parameter depending on the motor temperature. Generally, other parameters (inductance and inertia for instance) are not well known with a sufficient precision. All these elements introduce uncertainties in the model used to design the control, so the control of the machines becomes more complex and its action less efficient.

Clearly, to achieve high-performance objectives, the design of robust controllers requires suitable models describing the dynamical behavior of the machines.

For AC machines, the models are nonlinear and multi-variable (multi-state variables, multi-outputs to track, and multi-control inputs). Moreover, in practice, all the state variables are not measurable, which implies that the implementation of the controller is to be limited. To overcome this difficulty, observation theory provides a solution to reconstruct the unmeasurable state by using observer. Moreover, when the AC machine operates at low speed, some important difficulties appear owing to the loss of the observability property. This property is very important for the estimation of the system state and thus is a preliminary step in the observer design.

Sensorless control of electrical machines implies the new and interesting challenging problem of eliminating the mechanical sensors. The solution to this problem has focused the attention recently in the control community. For this reason, the robust sensorless control of electrical machines is considered as an open problem. To solve this problem, first, it is necessary to study the observability property of these machines. It is well known that the observability of nonlinear systems can depend on the input. In the sensorless case of electrical machines and from the measurement of the inputs (stator voltages) and measured outputs (stator currents), this property could be lost. This situation complicates the reconstruction of the system state. Several concepts and results are introduced in this book as tools to verify if a system is observable or under which conditions it is observable. For that purpose, a precise analysis is necessary for AC machines.

If the system is observable then the design of an observer can begin: it is known that for nonlinear systems there is no general observable form for which an observer can be constructed. Nevertheless, there exist conditions for which a nonlinear system can be exactly transformed into another one so that it is possible to design an observer. The classes of nonlinear system for which an observer can be designed, include: (1) “Luenberger type” (i.e., linear plus a nonlinear output injection), (2) “triangular form” type, or (3) “extended Kalman like” type, like state affine observers or adaptive state affine observers. Furthermore, in terms of convergence, these observers can be divided into two classes: one based on asymptotic methods and the other with finite-time convergence. Recently, the observer design for AC machines is one of the most studied topics in electrical machines research.

The control of the induction motor and synchronous motors have important developments thanks to the advances in power electronics, signal processing, and the progress in computer technology allowing the implementation of sophisticated control strategies. Among the classical control techniques to drive electrical machines, we can find the field-oriented control, or those based on state space representation such as feedback linearization, which have been used in many applications. However, these controllers have shown some limitations in practice.

Recently, the sensorless control problem of AC electrical machines has been intensively addressed and significant contributions have been published to give a solution to this problem. Several observer–controller schemes have been proposed, where conditions are obtained to guarantee the closed-loop stability of the system.

This book presents the basic fundamentals of electrical machines with an emphasis on the permanent magnet synchronous motor and on the induction motor, as well as their mathematical models in different frames and state space

representation. After the observability of these AC machines is analyzed, an important contribution is the machines nonlinear observer design. Furthermore, robust control designs based on the backstepping technique and on the sliding mode control are presented. The combination of the observer and controller designs is analyzed and implemented on industrial benchmarks and their results are discussed.

It is clear that the objective of the book is to provide a framework that subsumes significant developments on observer and controller designs for AC electric machines. More precisely, the purpose of the book is to present robust AC machine control designs based on backstepping techniques and sliding mode controls that are combined with nonlinear observers based on either asymptotic or finite-time convergence designs. These observer–controller schemes are evaluated on significant industrial benchmarks with digital simulations and experimental results, showing their performance.

The book is intended to be a reference for practicing engineers, students, and academics, interested in knowing the most recent significant developments on observer design and robust nonlinear sensor or sensorless control techniques applied to AC electrical machines.

Acknowledgments

We are grateful to the colleagues and students who contributed to the writing of this book; Ph.D. students: Malek Ghanes, Dramane Traore, Marwa Ezzat, Mohamed Assad Hamida; Setup engineer: Robert Boisliveau; Professors Franck Plestan and Luc Loron. We also thank the Facultad de Ingeniería Mecánica y Eléctrica, Universidad Autónoma de Nuevo León and École Centrale de Nantes. Finally, we thank Ciencia Basica Grant No. 105799 CONACYT-Mexico, IREENA and IRCCyN Laboratories, the Research management of École Centrale de Nantes and the Centrale Initiative Fondation for their support.

Nantes, France
Monterrey, Mexico
November 2014

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Sensorless AC Electric Motor Control

Robust Advanced Design Techniques and Applications

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2015, XVIII, 244 p. 84 illus., 82 illus. in color., Hardcover

ISBN: 978-3-319-14585-3