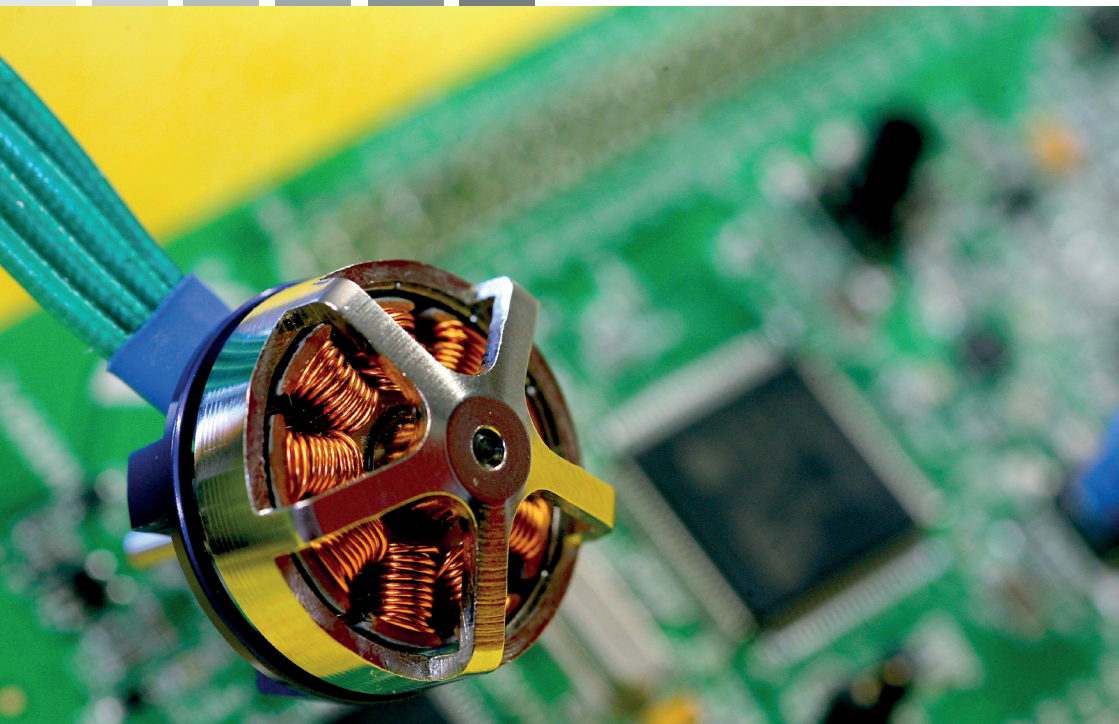
Direct Flux Control – A sensorless technique for star-connected synchronous machines

An analytic approach

Emanuele Grasso



Direct Flux Control - A sensorless technique for star-connected synchronous machines

An analytic approach

Emanuele Grasso

Habilitation thesis, Saarland University
Day of the scientific presentation and colloquium: 07 September 2021

Berichte aus der Steuerungs- und Regelungstechnik

Emanuele Grasso

Direct Flux Control – A sensorless technique for star-connected synchronous machines

An analytic approach

Shaker Verlag
Düren 2021

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Saarbrücken, Univ., Habil.-Schr., 2021

Printed in Germany.

ISBN 978-3-8440-8266-1
ISSN 0945-1005

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren
Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9
Internet: www.shaker.de • e-mail: info@shaker.de

“In physics the truth is rarely perfectly clear, and that is certainly universally the case in human affairs. Hence, what is not surrounded by uncertainty cannot be the truth”.

Richard Feynman

Acknowledgement

This work developed during my time as a scientific researcher at the Laboratory of Actuation Technology of the Saarland University and it could have not been realized without the guide, supervision and support of Prof. Matthias Nienhaus. To him goes all my gratitude. He is also the author of the cover picture of this book and, also for this, a special thanks. I thank also all my colleagues at the LAT department for providing a creative, engaging and unified working environment. In particular, I thank Dr.-Ing. Niklas König, with whom I had the chance to share most of my scientific production in the last years, for his continuous and passionate dedication to provide always interesting discussions. I want to thank also my colleagues Stefano Fabbri and Riccardo Mandriota for their constant availability as well as Klaus Schuhmacher and Stephan Kleen for their interesting and insightful suggestions and ideas.

I also want to acknowledge the support I received from my colleagues abroad, in particular Dr.-Ing. Marco Palmieri and Prof. Francesco Cupertino from the Polytechnic of Bari. Thanks to them, I have had the chance to find new research paths and this work reflects in part the scientific cooperation that we have established over the past few years. I would like to thank Prof. Francesco Grasso from the University of Florence, who gave me the chance to bring my work to his institution where I found fertile ground for widening my research perspectives.

Finally, I want to thank my parents Vincenzo and Angela that, notwithstanding the physical distance, have always been very close to me and supported me with their affection and love.

To my sister Isabella and her three daughters, Irene, Noemi and Giulia.

Abstract

Synchronous machines have found wide application in a variety of technological fields, ranging from domestic to industrial, to transportation. In particular, Permanent Magnet Synchronous Machines, PMSMs, are the most common typology thanks to their higher power density and simpler construction. Hence, they have attracted scientific attention with the aim of optimizing their design and control strategies and, also, techniques for sensorless operation have received particular focus. In fact, eliminating the need for mechanical sensors skews in the advantage of using such machines due to the consequent reduction of space and cost of the driving system. Many techniques for the estimation of the electrical rotor position from electrical measurements have been proposed, either relying on the exploitation of the back-EMF voltage or on machine anisotropies. This work lies in this research field and proposes to offer a mathematical description of the so-called Direct Flux Control (DFC) sensorless technique. This technique, differently from the majority of other proposed approaches, exploits machine anisotropies by measuring the zero-sequence voltage of the machine, i.e. requiring measurements of the star-point voltage. After offering a mathematical derivation of the DFC technique for generic synchronous machines first and for PMSMs later, an experimental investigation is presented and results are commented. Finally, hints for further research works opened by investigations on the DFC technique are proposed.

Kurzzusammenfassung

Synchronmaschinen haben eine breite Anwendung in einer Vielzahl von technologischen Bereichen gefunden, die vom Haushalt über die Industrie bis hin zum Transportwesen reichen. Insbesondere Permanentmagnet-erregte Synchronmaschinen (PMSMs) sind dank ihrer hohen Leistungsdichte und der einfachen Konstruktion die am häufigsten verwendete Topologie. Daher haben sie wissenschaftliche Aufmerksamkeit auf sich gezogen mit dem Ziel, ihr Design und ihre Regelungsstrategien zu optimieren. Insbesondere Techniken für den sensorlosen Betrieb haben Aufmerksamkeit erhalten. So ist der Wegfall mechanischer Sensoren aufgrund der daraus resultierenden Platz- und Kostenreduzierung des Antriebssystems von Vorteil für den Einsatz solcher Maschinen. Eine Vielzahl an Techniken zur Schätzung der elektrischen Rotorposition aus elektrischen Messungen wurden in der Literatur vorgeschlagen, die entweder auf der Ausnutzung der rückinduzierten Spannung oder auf Maschinenanisotropien basieren. Die vorliegende Arbeit liegt in diesem Forschungsbereich und fokussiert sich auf eine mathematische Beschreibung einer sensorlosen Technik namens Direct Flux Control (DFC). Diese Technik wertet, anders als die meisten anderen vorgeschlagenen Ansätze, die Anisotropien der Maschine aus, indem sie die Nullsystemspannung der Maschine misst, d.h. sie erfordert Messungen der Sternpunktspannung. Nach einer mathematische Herleitung des DFC-Verfahrens, zunächst für allgemeine Synchronmaschinen und später für PMSMs, wird eine durchgeführte experimentelle Untersuchung vorgestellt und die Ergebnisse werden kommentiert. Abschließend werden Hinweise für weitere Forschungsarbeiten vorgeschlagen, die sich aus den Untersuchungen zur DFC-Technik ergeben.

Contents