Innovative control techniques of power converters for industrial automation

by

Marco Liserre

Dissertation submitted to the Politecnico di Bari
in partial fulfilment of the requirements for the degree of
Doctor of Philosophy in Electrotechnical Engineering

Politecnico di Bari, Italy
Department of Electrotechnic and Electronic
December, 2001

Preface

This thesis is submitted to the Politecnico di Bari, in partial fulfilment of the requirements for the PhD degree in Electrotechnical Engineering with Curriculum in Electrical Machines and Drives. The research has been conducted at Department of Electrotechnic and Electronic of the Politecnico di Bari.

The project has been followed by Professor Antonio Dell'Aquila. I would like to thank him, Professor Pericle Zanchetta and all the Research Group of Converters, Machines and Electric Drives for their support and their comments to my work.

The Italian MURST and the European Social Fund have funded the major part of the research leading to this thesis.

From October 2000 I spent one year at the Institute of Energy Technology of Aalborg University, DK, where I visited the Professor Frede Blaabjerg and I collaborated also with External Professor Paul Thøgersen and Doctor Steffan Hansen of Danfoss Drives. It was a great scientific and human experience and I am sincerely thankful to them and to all the staff of IET. In particular I wish to thank, Mr Florin Lungeanu of Danfoss Low Power, Mr Gert Andersen and Mr John Godsk Nielsen of IET for their friendship and for the helpful discussions on my and their research topics.

From the beginning of my PhD thesis I carried out a collaboration with the Professor Nicola Rotondale, Professor Carlo Cecati and Professor Antonio Ometto, of Department of Electrical Engineering of University of L'Aquila. This collaboration gave a big contribution to the development of my PhD work.

A special thank goes to Professor Carlo Cecati for his friendship, his technical advice and for his help in reviewing the first three chapters of this thesis.

Finally the patience of my family and my friends was indispensable to preserve the balance in my life.

Abstract

The research documented in this PhD thesis refers to the innovative control techniques for the Three-phase Voltage Source Converter in three applications: a current controlled inverter feeding an induction motor; an active rectifier used as grid interface stage and a three-wire active filter compensating highly distorted currents. The use of the VSC in applications characterised by such a wide range of voltage and current waveforms is due to the availability of advanced design and control techniques.

The VSC allows the conversion of energy from a dc source to an ac one and viceversa. The standard configuration of this converter employees six power devices with turn-off and bidirectional current capabilities. Two of these switching devices in series form a leg across a dc bus with a dc capacitor. The common point is connected to one of the ac phases through a mainly inductive impedance. The dc voltage across the capacitor is used to generate an ac voltage through the complementary switching of the devices of each leg. The control of the switching can be made through the modulation of the width of the devices on/off state on a period (Pulse Width Modulation).

Through the control of the ac voltage it is possible to get the ac current control. Then through the ac current control, the dc bus level could be regulated in relation with the device connected on the dc bus.

The design and control of the VSC in the three chosen applications are introduced in *Chapter 1* of this thesis. In all the applications the digital control techniques both of the dc voltage and of the ac current have been tested. They can be classified as follows: linear such as PI-based or dead beat-based, non-linear and fuzzy logic-based. The first group allows an exact study of the dynamic and stability of the system needed especially when an ac LCL-filter is used. The second one allows fast and easy controls needed in low cost commercial drives. As for the third group, the fuzzy logic is based on the use of particular sets which allow an element, differently from what happens in traditional logic, to partially belong to more than one of them, as described in the *Chapter 2*. Fuzzy logic offers the possibility to design a non-linear controller on the basis of the knowledge of many non-well defined relations among the variables of the system, and suitable of optimal performances in several working conditions. The fuzzy logic based controls presented in this thesis are particularly relevant to the design criteria.

In *Chapter 3* the current loop, the inner loop of the Field Oriented Control of the induction motor drive is investigated. The inverter's current control is responsible of the harmonic content and of the reference tracking of the stator currents. A good control allows a high efficiency of the converter and an optimal operation of the torque and speed loops.

The current control is crucial also in the active rectifier field studied in *Chapter 4*. The active rectifiers are designed to obtain sinusoidal ac currents, unity power factor and controllable dc voltage. One of the limits of the active rectifier is due to the cost, thus it arises the industrial interest for sensorless applications. Another limitation is due to the harmonic pollution caused by the switching, that can disturb other EMI sensitive equipment on the grid. One of the most interesting solutions is the use of a LCL-filter on the ac side. This needs a step-by-step procedure for the filter design, the selection of the passive or active damping and the verification of the system’s dynamic and stability.

An interesting alternative to the use of the active rectifiers is the use of active filters. The most used type is the shunt configuration described in *Chapter 5*. Its control could be a high demanding task especially if highly distorted currents have to be compensated. Moreover the polluting currents depend on the considered non-linear load thus it is proposed the use of virtual instrumentation for analysis and simulation of load oriented compensation solutions. Moreover also a fuzzy control could offer the possibility to track sudden slope changes due to highly distorted currents.

In conclusion the use of a simple and reliable conversion structure such as the VSC needs advanced design and control criteria to be used in many applications characterised by different goals. This PhD thesis exploits the digital control in the Z-domain and the fuzzy logic to face problems related to stability, dynamic and compensation of the system non-linearities.

Table of contents

If you want the PhD thesis

“Innovative control techniques of power converters for industrial automation”

please write to liserre@ieee.org