HIGH VOLTAGE DIRECT CURRENT TRANSMISSION

CO[illegible] SYSTEMS and DC GRIDS

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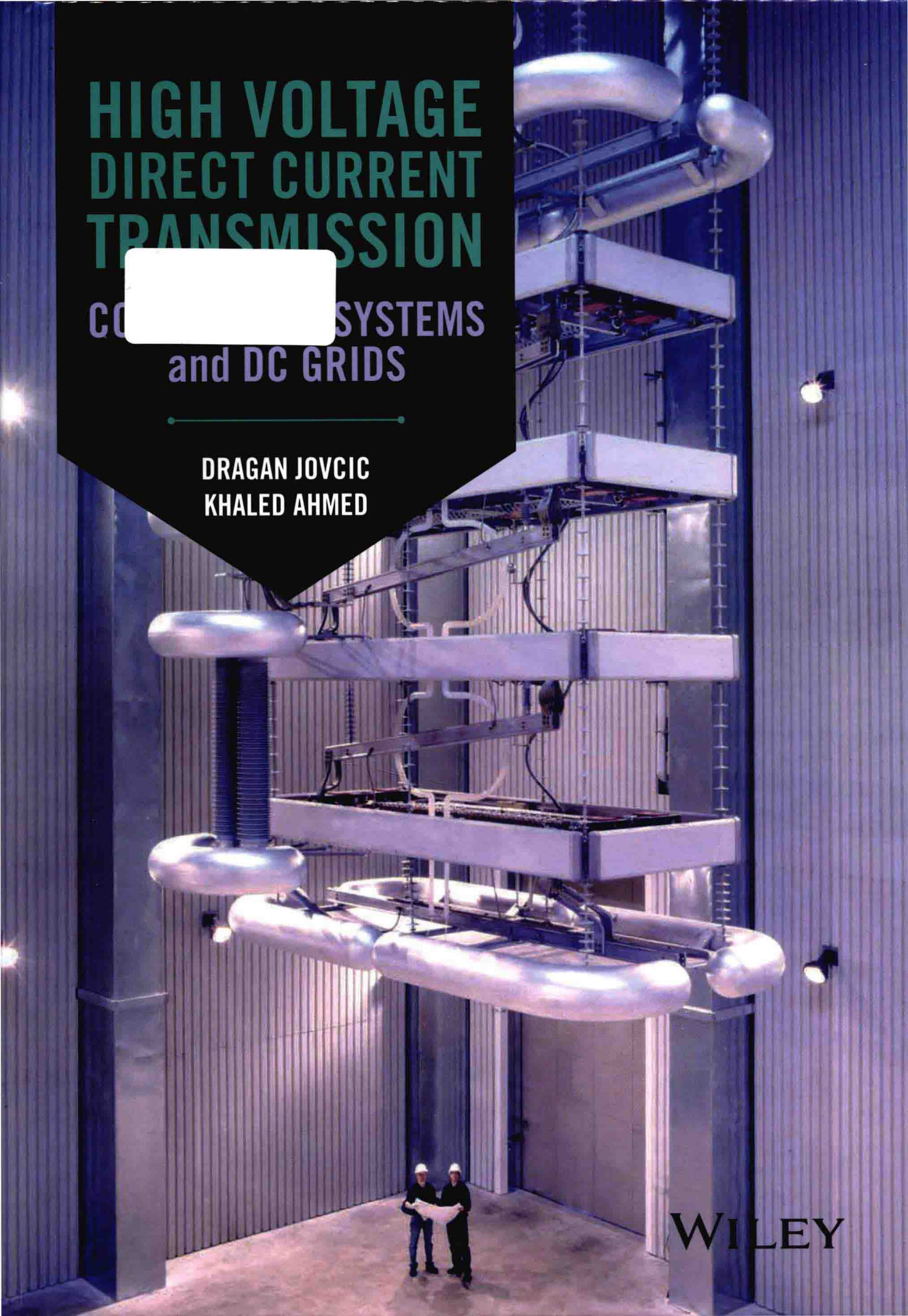

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HIGH-VOLTAGE DIRECT-CURRENT TRANSMISSION

CONVERTERS, SYSTEMS AND DC GRIDS

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This edition first published 2015
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John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

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Library of Congress Cataloging-in-Publication Data

Jovcic, Dragan.
High-voltage direct-current transmission : converters, systems and DC grids / Dragan Jovcic, Khaled Ahmed, School of Engineering, University of Aberdeen, Scotland, UK.
pages cm
Includes bibliographical references and index.
ISBN 978-1-118-84666-7 (cloth)
1. Electric power distribution–Direct current. 2. Electric power distribution–High tension. 3. Electric current converters.
I. Ahmed, Khaled. II. Title.
TK3111.J68 2015
621.319′12–dc23

2015011296

A catalogue record for this book is available from the British Library.

Set in 9.5/11.5pt Times by SPi Global, Pondicherry, India

Printed in Singapore by C.O.S. Printers Pte Ltd

1 2015

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Preface

At the time of writing, there are over 170 high-voltage direct-current (HVDC) links installed worldwide. The largest installations operate at ±800 kV DC voltage and the highest DC current ratings are over 4500 A. Although alternating current was the predominant method for transmitting electrical energy in the twentieth century, HVDC was demonstrated to be the best solution for many specific application areas and the number of installations per year has been constantly increasing at the beginning of twenty-first century. Despite significant converter-station costs, HVDC is techno-economically preferred in general applications for:

- long-distance, large-scale power transfer;
- subsea and long-distance cable-power transmission;
- interconnecting asynchronous AC systems or systems with different frequencies;
- controllable power transfer between different nodes in an electricity market or markets;
- AC grid-stability support, ancillary service provision and resilience to blackouts;
- connecting isolated systems like offshore wind farms or oil platforms.

DC transmission technology was used in many instances in very early power systems but modern HVDC transmission begins with the 1954 Sweden–Gotland installation. This system and all the other HVDCs commissioned until the mid-1970s were based on mercury arc valves. A significant technical advance came with the introduction of solid-state valves (thyristors), although they only support the line-commutated converter (LCC) concept. In the first decade of the twenty-first century there has been very rapid development of fundamentally new technologies and an increasing demand for HVDC technology. The introduction of voltage-source converters (VSCs) requires new valves, which use insulated-gate bipolar transistors (IGBTs) and also new protection and control approaches. The modular multilevel converters have eventually emerged as the most cost effective VSC converter concept, which practically eliminates filtering needs with HVDC and removes voltage limits with VSC valves.

In the second decade of the twenty-first century it has become apparent that DC transmission grids are a technically feasible and viable solution to large-scale energy challenges. The primary application drivers come from initiatives like the North Sea DC grid, Medtech, Desertec, the European overlay super grid and Atlantic Wind. It is accepted that the DC transmission grids must have levels of reliability and technical performance that are similar to or better than an AC transmission system. This level of performance, security and reliability is technically feasible, although, in many aspects, DC grids will be substantially different from traditional AC systems. The development of DC grids brings significant technical advances in HVDC technologies, in particular related to DC circuit breakers (CBs), DC/DC converters and DC protection systems, and substantial further research and development are anticipated.

Nowadays, HVDC and DC grids are associated with green energy, as facilitators of large-scale renewable energy plants. This helps with public acceptance and image, and facilitates further investments in large public projects. HVDC is perceived as the technology that avoids pylons by using long underground cables, further strengthening arguments for future funding decisions.

The timing of this book is therefore in step with an increased interest in HVDC and a projected significant increase in its use.

The book is organized in three parts in order to study all three major HVDC concepts – line commutated HVDC, VSC HVDC and DC grids current research developments. Each part will review theoretical concepts and analyse aspects of technology, interaction with AC grids, modelling, control, faults and protection, with particular emphasis on practical implementation aspects and on reported operational issues.

The technical field of HVDC transmission and DC grids straddles three major traditional electrical engineering disciplines:

- *Power transmission engineering*. The impact of HVDC systems on the connecting AC transmission systems and the national grid is of primary importance. The influence of AC systems on HVDC is also of significance in terms of technical performance, stability, protection and power transfer security in general. Harmonic interaction will be studied in some depth.
- *Power electronics*. Each HVDC link involves at least two AC/DC converters whereas DC grids will have many more, including semiconductor DC CBs and DC/DC converters. These converters have features that are similar to those of traditional low-power converters but many other unique requirements exist to develop valves and converter assemblies capable of sustaining up to 800 kV and perhaps over 4500 A. The protection of valves and converters is very important and is a defining power electronics feature in HVDC.
- *Control engineering*. Modelling and simulation of HVDC is essential for design and operation and several different modelling approaches exist, depending on the model application. In particular, because of the high costs of HVDC testing and the consequences of any design issues, model accuracy and simulation speed play crucial role in the system design. The control systems for HVDC have evolved into very complex technologies, which are always multivariable, nonlinear and with multiple control layers.

The above three technical disciplines will be employed in this book in order to analyse all essential technical aspects of HVDC and DC grids which is aimed to facilitate learning by researchers and engineers who are interested in this field.

The material in this book includes contributions from many HVDC researchers and engineers and it is developed from research projects funded by several research councils and private firms. More importantly, the studies are inspired by and build on previous work by numerous great HVDC engineers.

The authors are particularly grateful to ALSTOM Grid, UK, for providing their comprehensive report, *HVDC: Connecting to the Future,* as well as to SIEMENS, Germany and ABB, Sweden, for their HVDC photographs. We are also indebted to the researchers at the University of Aberdeen Power Systems Group and, in particular, to Dr Weixing Lin, Dr Ali Jamshidifar, Dr Masood Hajian, Dr Huibin Zhang and Dr Lu Zhang for their contributions.

We would like to give our special thanks to SSE, Scotland, and in particular to Andrew Robertson, for their support for the HVDC course at University of Aberdeen, which provided important material for this book.

The authors are also grateful to the following organizations, which supported related research studies at the University of Aberdeen:

- Engineering and Physical Sciences Research Council (EPSRC) UK;
- European Research Council (ERC), FP 7 Ideas Programme;
- Réseau de Transport d'Électricité, (RTE), France.

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Part I

HVDC with Current Source Converters

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