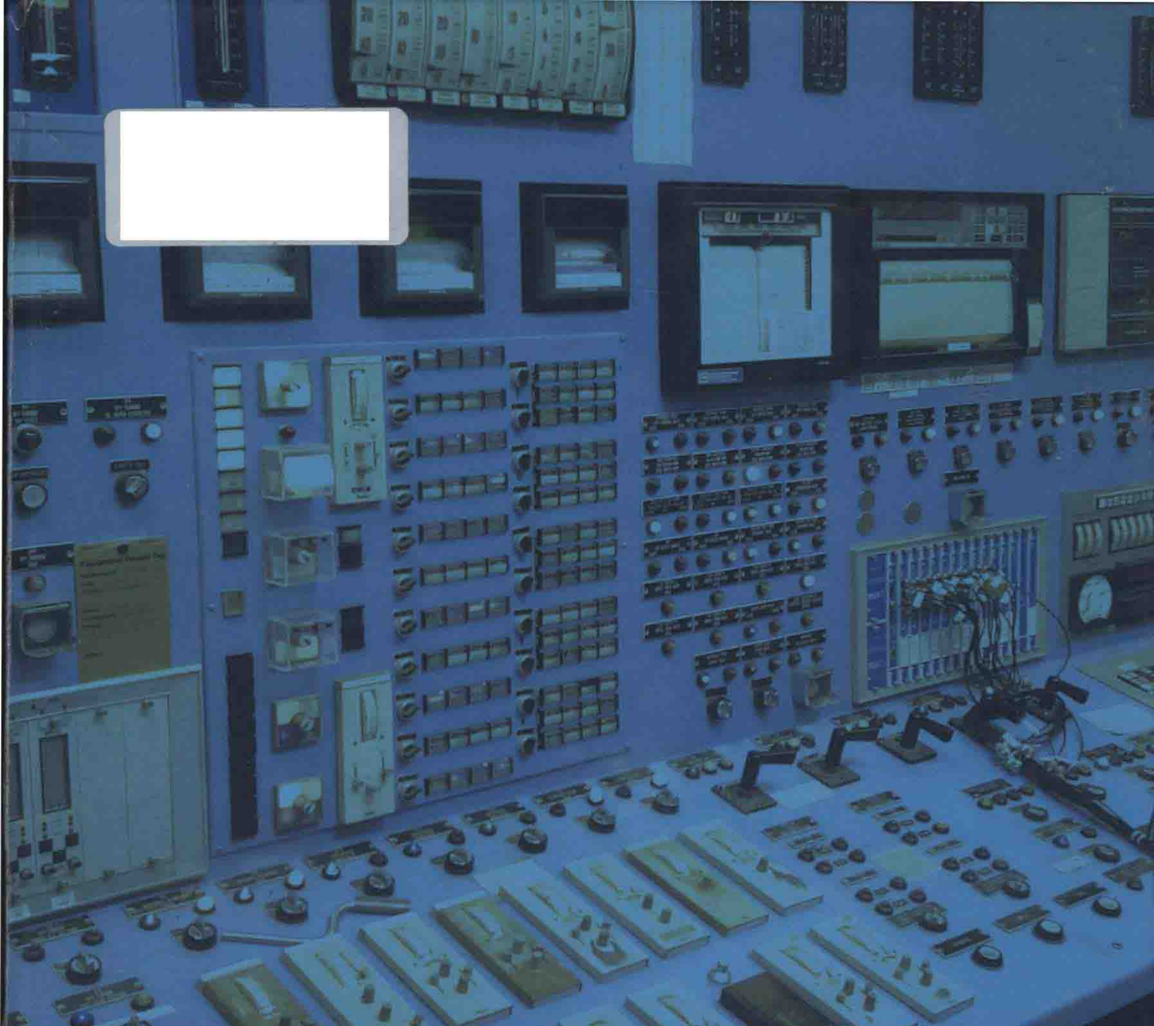

LARGE TURBO-GENERATORS

Malfunctions and Symptoms

Isidor Kerszenbaum
Geoff Klempner

CRC Press
Taylor & Francis Group

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper
Version Date: 20160511

International Standard Book Number-13: 978-1-4987-0702-2 (Hardback)

Library of Congress Cataloging-in-Publication Data

Names: Kerszenbaum, Isidor, author. | Klempner, Geoff, author.
Title: Large turbo-generators : malfunctions and symptoms / authors, Isidor Kerszenbaum and Geoff Klempner.
Description: Boca Raton : Taylor & Francis Group, CRC Press, [2016] | Includes bibliographical references and index.
Identifiers: LCCN 2016006135 | ISBN 9781498707022 (alk. paper)
Subjects: LCSH: Turbogenerators--Maintenance and repair. | System failures (Engineering)
Classification: LCC TK2765 .K47 2016 | DDC 621.31/3--dc23
LC record available at https://lccn.loc.gov/2016006135

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http://www.crcpress.com

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Malfunctions and Symptoms

To our families:

Jackie, Livi, and Yigal Kerszenbaum,

Susan Klempner,

and

to the operators, technicians, and engineers in the power stations around the world who keep the lights on, and the power flowing around the clock, and through adverse conditions for the benefit of everyone.

Preface

It is an indisputable fact that a large electric power system comprising thousands of generators feeding tens of thousands of miles of transmission and distribution lines, through countless transformers, breakers, and myriad associated devices, and controlled with the most sophisticated instruments and computer programs, represent the most complex engineering system in operation ever created.

Not only is the *electric power system* complex, but it is the organism most critical to the support of modern life, as we know it. One of the core components of any electric power system is generation, where the fuel, be it fossil, nuclear, hydraulic, wind, or any other, is converted into electricity. Of the many types of generators associated with these sources of generation, the most widely utilized are the combustion and steam turbine-driven generators, or simply, the turbogenerators.

Although all turbogenerators are distinguished by their cylindrical rotor, there are numerous variants, be it in their age, way of cooling its components, insulation characteristics, materials used in the construction of their key components, excitation arrangement and so on. Some are operated continuously (base load), and in others the load changes daily or several times during the day. The typical generator is designed to operate about 30 years; however, it is not uncommon to have its life extended for two or more decades. Given that over such long periods of time technologies and materials have changed immensely, it is common to see an abundance of diversity in design and construction of these machines. This book covers the following type of turbogenerators:

1. Air-cooled
2. Indirect hydrogen-cooled
3. Directly (inner) hydrogen-cooled (stator and rotor)
4. Directly (inner) water-cooled stators
5. Directly (inner) water-cooled rotors
6. Two poles
7. Four poles

Note: Directly (inner) oil-cooled stators are not specifically discussed herein, but the vast majority of the subjects included in this book also apply to those generators, with the exception of the stator winding oil cooling system.

Turbogenerators are found in generating stations, where operators are responsible for their daily operation, assisted by electricians, mechanics, technicians, and engineers. A vital challenge for the operator is to keep the machine under control for both normal and abnormal transient system conditions. In this, he/she is aided by monitoring and protection instrumentation; nevertheless, it is up to the operator to validate instrumentation behavior and maintain maximum availability of the unit to the grid. In doing so, the operator/technician/engineer is confronted with a large number of machine reactions to normal and abnormal operating conditions. Sometimes, the power plant personnel must troubleshoot a problem quickly to return a generator to service as soon as possible, and in most cases, significant sums of money depend on how fast a generator can be brought back online for the purpose of delivering power to the grid and its customers.

With deregulation of the electric power industry, many small nonutility (so called third party) power producers operate small fleets of generators without the benefit of in-house expertise. To make up for that, they depend heavily on OEMs and independent contractors and consultants. In many instances, large utilities have also seen their expertise dissipate to a large extent due to a refocus of management priorities. All these developments are occurring at the same time that these units are called to operate in more onerous environments such as *two-shifting* and load-following, as guided by *economic dispatch*. All these developments, together with an aging fleet of generators, are placing a significant burden on the operator.

This book is written with the operator and other power plant personnel responsible for the operation of the generators in mind. As mentioned earlier, not every company, much less power plants, retains an individual with the breadth and depth of expertise required for troubleshooting all of its units, which may be very different in their design and construction characteristics. With their expertise over many years, the authors' intent is to facilitate operators' understanding of developing adverse conditions with their generators, their causes, and mechanisms of defense. Hopefully, this knowledge can provide an edge in troubleshooting a problem more effectively and faster than otherwise would be the case while avoiding preventable damage to the unit and loss of production. We anticipate that this book will be not only useful to the operator in the power plant, but also to the design engineer and system operations engineers who may find its information useful from time to time. The authors are aware that although it is impossible to cover in any single book all possible conditions that may be encountered during the operation of a generator, they have strived to include a wealth of information that covers most common situations. And, hopefully, they may afford the reader enough skills to elucidate any other information not covered in this book. Although we have tried to cover each topic as comprehensively as possible, while at the same time keeping it simple and adequate for the purpose on hand, the book should not be seen as a guide to detail troubleshooting, but as an additional tool to facilitate finding the true causes of any given malfunction. In each case in which a real problem is approached, a whole number of very specific issues only relevant to that very unique machine come into light. These can never be anticipated or known and thus fully described in a book. Thus, we recommend using this book as a general reference source, or as a starting point in the interpretation of a developing problem, but the reader should always obtain adequate on-the-spot expertise when dealing with a particular malfunction.

The organization of the material in the book is covered in Chapter 1.

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Caveat Emptor

As with any similar book, caution *must* be exercised by the reader. The general nature of the contents of this book are not intended to serve as specific opinion or advice, similar to those proffered by a consultant well versed on a particular topic trying to solve a specific problem. No two machines are the same, and so no two outcomes may be the same, even if symptoms may appear to be pointing to the same problem. The purpose of this book is to aid in the identification of a malfunction, be it degradation or a failure, based on general knowledge accumulated over many years. It is up to the reader to build up on the book's material and other sources as well as personal experience, and finally on his/her independent judgment to reach an opinion as to the cause of a specific problem on hand, and the different pertinent responses.

Acknowledgments

The contents of a book such as this one are impossible to learn in the classroom. They are the result of personal experience accumulated over many years of working with large turbogenerators, but, for the most, they are the result of the invaluable long-term contribution of coworkers and associates. Each author was motivated and supported during his career by a number of outstanding individuals who had a major influence in their professional development. Attempting to mention all these people would lead to the unintended omission of some.

The authors are indebted to CRC Press for reviewing the proposal for the book and supporting its publication. They also express their sincere gratitude to the technical reviewers of the proposal, Dr. Mohamed El-Sharkawi and Tom Baker, and in particular the technical reviewers of the final draft, Relu Ilie and Nils Nilsson, who not only put long hours into the review of the book, but also provided very helpful insights and comments. The authors also thank the members of the editorial department at CRC Press, and all others involved in the publication of the book for their support in making its publication possible.

Finally, the authors thank their immediate families for the continuous support and encouragement.

List of Acronyms

AUT	auxiliary unit transformer
AVR	automatic voltage regulator
BCB	back of core burning
CEFS	core-end flux shield
CR	control room
CT	current transformer
CTG	combustion turbine generator
DCS	distributed control system
DFR	digital fault recorder
DO	dissolved oxygen
EL-CID	electromagnetic core imperfection detector
EMI	electromagnetic interference
FFC	field flashing circuit
GCM	generator condition/core monitor
GITV	grid-induced torsional vibration
GVPI	global vacuum pressure impregnation
HFG	high-frequency generator
Hipot	high potential test
HV	high voltage
IPB	isophase bus
IR	insulation resistance
LCM	life cycle management
MOT	main output transformer
MV	medium voltage
NDE	nondestructive examination
OEM	original equipment manufacturer
PDA	partial discharge activity
PI	polarization index
PMG	permanent magnet generator
PT	potential transformer
PTFE	polytetrafluoroethylene
RCW	rotor cooling water
RCWS	rotor cooling water system
RF	radio frequency
RFM	rotor flux monitor
RTD	resistance temperature detector
SCADA	supervisory control and data acquisition system
SCW	stator cooling water
SCWS	stator cooling water system
SUT	step-up transformer

TC	thermocouple
TECW	total enclosed water cooled
TST	thermal sensitivity test
UAT	unit auxiliaries transformer (also known as AUT)
UEL	underexcitation limiter
UMP	unbalanced magnetic pull
VDU	visual display unit
VPI	vacuum pressure impregnation
VT	voltage transformer (same as PT)