Computer Relaying for Power Systems

Second Edition

Arun G. Phadke
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WILEY

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COMPUTER RELAYING FOR POWER SYSTEMS

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COMPUTER RELAYING FOR POWER SYSTEMS

About the authors

Dr. Arun G. Phadke worked in the Electric Utility industry for 13 years before joining Virginia Tech 1982. He became the American Electric Power Professor of Electrical Engineering in 1985 and held this title until 2000 when he was recognized as a University Distinguished Professor. He became University Distinguished Professor Emeritus in 2003, and continues as a Research Faculty member of the Electrical and Computer Engineering Department of Virginia Tech. Dr. Phadke was elected a Fellow of IEEE in 1980. He was elected to the National Academy of Engineering in 1993. He was Editor in Chief of Transactions of IEEE on Power Delivery. He became the Chairman of the Power System Relaying Committee of IEEE in 1999–2000. Dr. Phadke received the Herman Halperin award of IEEE in 2000. Dr. Phadke has also been very active in CIGRE. He has been a member of the Executive Committee of the US National Committee of CIGRE, and was the Chairman of their Technical Committee. He was previously the Vice President of USNC-CIGRE and served as Secretary/Treasurer. In 2002 he was elected a 'Distinguished Member of CIGRE' by the Governing Board of CIGRE. Dr. Phadke was active in CIGRE SC34 for several years, and was the Chairman of some of their working groups. In 1999 Dr. Phadke joined colleagues from Europe and Far East in founding the International Institute for Critical Infrastructures (CRIS). He was the first President of CRIS from 1999–2002, and currently serves on its Governing Board. Dr. Phadke received the 'Docteur Honoris Causa' from *Institute National Polytechnic de Grenoble (INPG)* in 2006. Dr. Phadke received the 'Karapetoff Award' from the HKN Society, and the 'Benjamin Franklin Medal' for Electrical Engineering in 2008.

Dr. James S. Thorp is the Hugh P. and Ethel C. Kelley Professor of Electrical and Computer Engineering and Department Head of the Bradley Department of Electrical and Computer Engineering at Virginia Tech. He was the Charles N. Mellowes Professor in Engineering at Cornell University from 1994–2004. He obtained the B.E.E. in 1959 and the Ph. D. in 1962 from Cornell University and was the Director of the Cornell School of Electrical and Computer Engineering from 1994 to 2001, a Faculty Intern, American Electric Power Service Corporation in 1976–77 and an Overseas Fellow, Churchill College, Cambridge University in 1988. He has consulted for Mehta Tech Inc., Basler Electric, RFL Dowty Industries, American Electric Power Service Corporation, and General Electric. He was an Alfred P. Sloan Foundation National Scholar and was elected a Fellow of the IEEE in 1989 and a Member of the National Academy of Engineering in 1996. He received the 2001 Power Engineering Society Career Service award, the 2006 IEEE Outstanding Power Engineering Educator Award, and shared the 2007 Benjamin Franklin Medal with A.G. Phadke.

Preface to the first edition

The concept of using digital computers for relaying originated some 25 years ago. Since then the field has grown rapidly. Computers have undergone a significant change – they have become more powerful, cheaper, and sturdier. Today computer relays are preferred for economic as well as technical reasons. These advances in computer hardware have been accompanied by analytical developments in the field of relaying. Through the participation of researchers at Universities and industrial organizations, the theory of power system protection has been placed on a mathematical basis. It is noted that, in most cases, the mathematical investigations have confirmed the fact that traditional relay designs have been optimum or near-optimum solutions to the relaying problem. This is reassuring: the theory and practice of relaying have been reaffirmed simultaneously.

An account of these developments is scattered throughout the technical literature: Proceedings of various conferences, Transactions of Engineering Societies, and technical publications of various equipment manufacturers. This book is our attempt to present a coherent account of the field of computer relaying. We have been doing active research in this area – much of it in close collaboration with each other – since the mid 1970's. We have tried to present a balanced view of all the developments in the field, although it may seem that, at times, we have given a fuller account of areas in which we ourselves have made contributions. For this bias – if it is perceived as such by the reader – we seek his indulgence.

The book is intended for graduate students in electric power engineering, for researchers in the field, or for anyone who wishes to understand this new development in the role of a potential user or manufacturer of computer relays. In teaching a course from this book, we recommend following the order of the material in the book. If a course on traditional protection is a pre-requisite to this course, Chapter 2 may be omitted. The mathematical basis for relaying is contained in Chapter 3, and is intended for those who are not in an academic environment at present. The material is essential for gaining an understanding of the reason *why* a relaying algorithm works as it does, although *how* an algorithm works – i.e. its procedural structure – can be understood without a thorough knowledge of the mathematics. A reader with such a limited objective may skip the mathematical background, and go directly to the sections of immediate interest to him.

Our long association with the American Electric Power Service Corporation (AEP) has been the single most important element in sustaining our interest in Computer Relaying. The atmosphere in the old Computer Applications Department in AEP under Tony Gabrielle was particularly well suited for innovative engineering. He was responsible for starting us on this subject, and for giving much needed support when practical results seemed to be far into the future. Also present at AEP was Stan Horowitz, our colleague and teacher, without whose help we would have lost touch with the reality of relaying as a practical engineering enterprise. Stan Horowitz, Eric Udren, and Peter McLaren read through the manuscript and offered many constructive comments. We are grateful for their help. The responsibility for the book, and for any remaining errors, is of course our own.

We continue to derive great pleasure from working in this field. It is our hope that, with this book, we may share this enjoyment with the reader.

Arun G. Phadke
Blacksburg

James S. Thorp
Ithaca
1988

Preface to the second edition

The first edition of this book was published in 1988. The intervening two decades have seen wide-spread acceptance of computer relays by power engineers throughout the world. In fact, in many countries computer relays are the protective devices of choice, and one would be hard pressed to find electromechanical or electronic relays with comparable capabilities. Clearly economics of relay manufacture have played a major role in making this possible, and the improved performance, self-checking capabilities, and access to relay settings over communication lines have been the principal features of this technology which have brought about their acceptance on such a wide scale.

It has been recognized by most relay designers – and is also the belief of the authors – that the principles of protection have essentially remained as established by experience gained over the last century. Computer relays provide essentially the same capabilities as traditional relays in a more efficient manner. Having said this, it is also recognized that changes in protection principles have taken place, solely because of the capabilities of the computers and the available communication facilities. Thus adaptive relaying could not be realized without this new technology. Adaptive relaying, along with the new field of wide area measurements (which originated in the field of computer relaying) forms a significant part of the present edition of our book.

A study of published research papers on relaying will show that researchers continue to investigate the application of newer analytical techniques to the field of relaying. We have included an account of several such techniques in this edition, but it must be stated that most of these techniques have not seen their implementation in practical relay designs. Perhaps this confirms the authors' belief that the principles of protection are essentially dictated by power system phenomena, and the long established techniques of protection system design are very sound and close to being optimum. The newer analytical techniques which are being investigated offer very minor improvements at best, and it remains questionable as to when or for which applications we will see a clear benefit of these newer analytical techniques.

Our book remains a research text and reference work. As such the problem set at the end of each chapter is often a statement of research idea. Some problems are quite complex, and each problem leaves room for individual interpretation and development. We therefore offer no solutions to these problems and leave their resolution to the individual initiative of the reader. We are of course interested in receiving any comments that the users of our book care to make.

The authors have participated with pleasure in project "111", a Key Research Project of the North China Electric Power University since its inception in 2008 under the direction of Professor Yang Qixun. In addition to promoting research in many aspects of computer relaying in which the authors continue to participate, the facilities provided in Beijing under the auspices of this project for the authors have facilitated the timely completion of this Second Edition of our book.

We continue to derive great pleasure from working in this field. It is our hope that, with the second edition of this book, we may share this enjoyment with the reader.

Arun G. Phadke
Blacksburg

James S. Thorp
Blacksburg
2009

Glossary of acronyms

A/D	Analog to Digital
ADC	Analog to Digital Converter
ANN	Artificial Neural Network
ANSI	American National Standards Institute
CIGRE	International Council on Large Electric Systems
CT	Current Transformer
CVT	Capacitive Voltage Transformer
DFT	Discrete Fourier Transform
EHV	Extra High Voltage
EMI	Electromagnetic Interference
EMTP	Electromagnetic Transients Program
EPRI	Electric Power Research Institute
EPROM	Erasable Programmable Read Only Memory
FFT	Fast Fourier Transform
GPS	Global Positioning System
I/O	Input Output
IEC	International Electrotechnical Commission
IEEE	Institute of Electronic and Electrical Engineers
MOV	Metal Oxide Varistors
MUX	Multiplexer
NAVSTAR	NAVSTAR is not an acronym. It represents GPS described above.
PDC	Phasor Data Concentrator
PMU	Phasor Measurement Unit
PROM	Programmable Read Only Memory
PT	Potential Transformer
RAM	Random Access Memory
RAS	Remedial Action Scheme

ROM	Read Only Memory
S/H	Sample and Hold
SCDFT	Symmetrical Component Discrete Fourier Transform
SIPS	System Integrity Protection Scheme
SWC	Surge Withstand Capability
WAMS	Wide Area Measurement System
WAMPACS	Wide Area Measurement, Protection and Control System
WLS	Weighted Least Squares

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