# Electrical Power System Protection

## 2nd Edition

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Kluwer Academic Publishers

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Figure 4.26 is reproduced from BS 142: Section 3.2: 1990 with the permission of BSI. Complete copies of the standard can be obtained by post from BSI sales, Linford Wood, Milton Keynes, MK14 6LE.

# Preface to the second edition

The death of Professor Arthur Wright in the summer of 1996 deprived me of a friend and a colleague whose judgement and experience shaped this book. I pay tribute to his contributions to protection and electrical engineering education.

In the five years since the first edition appeared, many developments have taken place and it is now necessary to update the book. The use of digital communications and advanced signal processing techniques is now widespread and several fully numeric relays are available from manufacturers. Two new Chapters 13 and 14 have been added to introduce readers to these concepts and associated techniques. Artificial intelligence is making its impact in all engineering applications and power system protection is no exception. Expert systems, fuzzy logic, artificial neural networks, adaptive and integrated protection, synchronized measurements using the global positioning system, genetic algorithms, flexible a.c. transmission systems, are some of the techniques considered in connection with protection. Although many of these techniques have not yet found major application in protection, it is nevertheless essential for the educated protection engineer to have a basic understanding of the underlying principles and methodology so that he, or she, can evaluate their suitability for new relaying problems and applications. Chapter 15 was therefore added to guide readers through this developing area. I have also added some new material in other chapters to reflect changes over the past years. The emphasis remains the same as for the first edition and this is the presentation of the fundamentals of protection illustrated by examples of current engineering practice.

I wish to thank Professor Shi Shiwen of the Southeast University, Nanjing, China, for pointing out several errors in the first edition, and my colleague Miss Ana Vuković for assisting me in the preparation of this edition.

Christos Christopoulos

# Preface to the first edition

Several books have been produced over the years about the protective equipment which is incorporated in electrical power systems and manufacturers continually produce detailed literature describing their products. Recognizing this situation and accepting that it is no longer possible in a single volume to provide a complete coverage of the protective equipment now available and the many factors which have to be considered when it is being developed and applied, we have concentrated on basic principles and given examples of modern relays and schemes in this work.

Chapter 1 deals with electric fuses, which were the earliest protective devices. The chapter begins with a historical introduction, as do all the chapters, and then information is provided on the construction and behaviour of fuses and finally the factors which must be taken into account when they are to be applied to circuits are examined.

Chapters 2 and 3 deal respectively with conventional current and voltage transformers and modern transducers. In each case, details are given of the constructions and behaviours of theses devices, which play important roles in supplying protective equipment.

Chapter 4 deals with relays which have constant operating times and those which have inverse time/current characteristics. After tracing their development, modern relays are described and then the factors which must be considered when applying them are considered in some detail.

The principles of current-differential schemes are set out in Chapter 5 and the causes of the imbalances which can arise in them when protected units are healthy are examined. The biasing features provided to enable satisfactory performance to be obtained are outlined.

The later chapters are devoted to the protection of the main components of the networks, namely transformers, busbars, rotating machines and transmission and distribution lines and cables. The presentation is similar to that in the earlier chapters. In each case information is provided about the construction and behaviour of the plant being protected and then the appropriate protective schemes, including current-differential, phase comparison, distance and travelling wave, are described and examined.

Appendices dealing with per-unit quantities, symmetrical components and other modal quantities are included.

We express our appreciation of the assistance given to us by Dr D.W.P. Thomas during the preparation of this book and during research into travelling-wave protective schemes. We also wish to thank Miss S E Hollingsworth for typing the manuscript.

We hope that this book will prove of value to those involved in the study, development, production and application of protective equipment and that they will enjoy working in a challenging field in which new problems continuously arise.

Arthur Wright and
Christos Christopoulos

# List of symbols

| | |
|---|---|
| $A$ | cross-sectional area ($m^2$) |
| $B$ | magnetic flux density (T) |
| $C$ | capacitance (F) |
| $e$ | instantaneous e.m.f. (V) |
| $E$ | r.m.s. or constant e.m.f. (V) |
| $i$ | instantaneous current (A) |
| $I$ | r.m.s. or constant current (A) |
| $L$ | inductance (H) |
| $M$ | mutual inductance (H) |
| $N$ | turns in a winding |
| $R$ | resistance (Ω) |
| $t$ | time (s) |
| $v$ | instantaneous voltage (V) |
| $V$ | r.m.s. or constant voltage (V) |
| $\varphi$ | magnetic flux (Wb) or phase angle |
| $\mu$ | permeability of magnetic material (Wb/Am) |

SUFFIXES

| | |
|---|---|
| a, b, c | phases of three-phase system |
| p | primary circuit or winding |
| pk | peak value of alternating current or voltage |
| s | secondary circuit or winding |
| t | tertiary circuit or winding |
| 1, 2, 0 | positive, negative and zero-sequence quantities |

# Contents