ECA

Electrical Installation Calculations for Compliance with BS 7671:2008

FOURTH EDITION

MARK COATES | BRIAN JENKINS

WILEY

Electrical Installation Calculations: for Compliance with BS 7671:2008

Fourth Edition

Mark Coates

ERA Technology trading as Cobham Technical Services, UK

Brian Jenkins

formerly IEE, UK

ECA

Representing the best in electrical engineering and building services

WILEY

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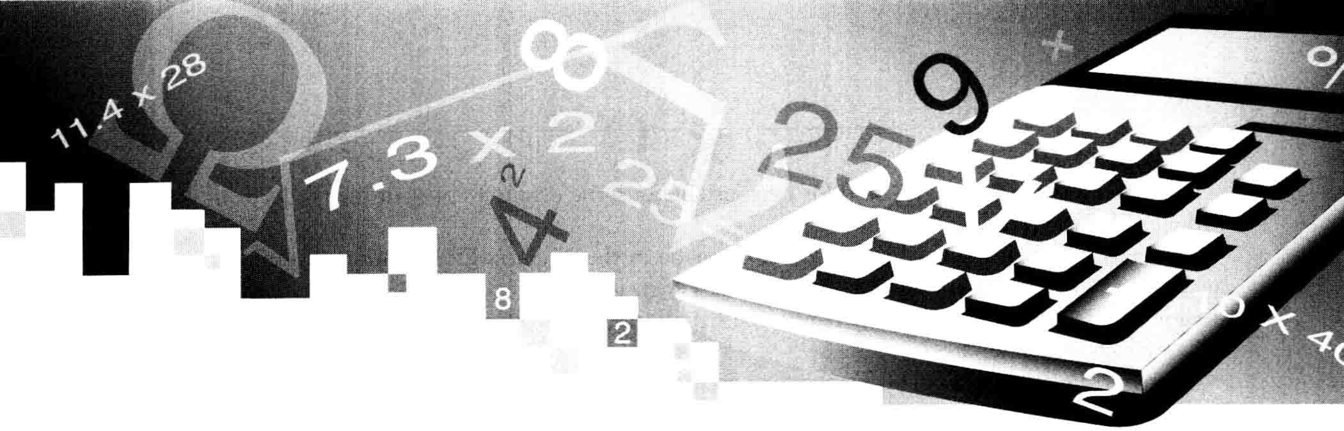
About the authors

Mark Coates BEng collaborated with Brian in developing the First Edition and has since been responsible for revising the subsequent editions. He joined ERA Technology Ltd (now trading as Cobham Technical Services) in July 1983 and is currently a Cable Engineering Consultant. He gained a degree in Mechanical Engineering from Sheffield University (UK) in 1977 and he worked for a chemical and textile company until 1983. Since joining ERA, he has primarily worked on projects to determine cable current ratings both experimentally and by theoretical methods. In addition to the usual cable rating problems, this work has included development of rating methods for mixed groups of cable, cables on winch drums and sub-sea umbilicals. Other projects have included assessments of new cable designs, the mechanical performance of cables and joints, failure analysis of LV, MV and HV transmission and distribution equipment, and life prediction tests for HV cables. He is a member of the UK IEE/BSI Committee concerned with electrical installations, and attends BSI and IEC meetings. He is the convenor of IEC TC20 WG19, the specialist IEC working group responsible for maintaining and updating the International Standards on steady state, cyclic and short-circuit ratings of power cables.

Brian Jenkins BSc, CEng, FIEE had many years' industrial experience before working as a Principal Technical Officer at the British Standards Institution. He then joined the Institution of Electrical Engineers as a Senior Technical Officer. Brian passed away in 2007.



Preface

The publication of BS 7671 and its predecessors, the 15th and 16th Editions of the IEE Wiring Regulations, led to a number of guides and handbooks being published by organizations involved in the electrical contracting industry. These included the publication, by the Institution of Engineering and Technology, of an On-site Guide and a number of Guidance Notes as well as several books by independent authors and a considerable number of articles and papers in the technical press. It also led to numerous instructional courses, seminars and conferences.

It was thought that there was little else one could write about concerning the Wiring Regulations, but after talking to a number of engineers in the electrical installation contracting industry, Brian Jenkins gained the strong impression that there was one need that had not really been satisfied. The need was for a book that made considerable use of worked examples with the absolute minimum discussion of the associated theoretical aspects. In other words, a book which used such examples to show how one carried out the calculations involved in circuit design for compliance with BS 7671.

Whilst Brian designed the book to be primarily of interest and help to those in the smaller companies in the electrical installation contracting industry, we believe the student and the plant engineer will also find it of interest.

BS 7671 offers certain options. For example, when calculating voltage drop either an approximate method or a more accurate one can be used and we have attempted to show where the latter could be used to advantage. This, we believe, will make the book of interest to a wider circle.

BS 7671 does not refer to 'touch voltages' as such, these being the 'voltages between simultaneously accessible exposed and extraneous conductive parts' that may lead to a risk of electric shock in the event of an earth fault. It had long been Brian's opinion that a fuller understanding of the touch voltage concept would assist many in the electrical contracting industry to more fully understand the requirements for automatic disconnection. For this reason we hope that the Appendix will prove to be of interest.

Since the First Edition of this book there have been a number of amendments to the Requirement for Electrical Installations. Some of the changes introduced by the amendments affect the examples given in this book. The most important changes have been the change to the nominal voltage from 240/415 V to 230/400 V, the change to the assumed temperature of conductors under fault conditions and the inclusion of current-carrying capacities for buried cables. New work has also been done to clarify the effectiveness of supplementary circuit protective conductors connected in parallel with the armour of SWA cables. This Fourth Edition is intended to keep *Electrical Installation Calculations* up to date with the latest version of BS 7671. Examples using semi-enclosed fuses have, mainly for legacy, been retained and updated to BS 7671: 2008; although it is recognized that these devices would not generally be used for new installations, the examples present the reader with the rudiments of the principles of calculations.

There is one final point which needs to be made in this Preface. Examination of some of the answers may suggest to the reader that there is a high intrinsic degree of accuracy in installation design calculations. This obviously cannot be true because, for example, estimated circuit lengths will be rather approximate.

Many of the answers have been given to a greater number of significant figures than is necessary in practice merely to assist the reader should he, or she, wish to check through the examples.

Mark Coates

Acknowledgements

Brian Jenkins acknowledged the initial encouragement and subsequent assistance given by M.J. Dyer when he was Director of Technical Services of the Electrical Contractors' Association and by C.P. Webber BTech, CEng, MIEE, the present Head of Technical Services of that Association.

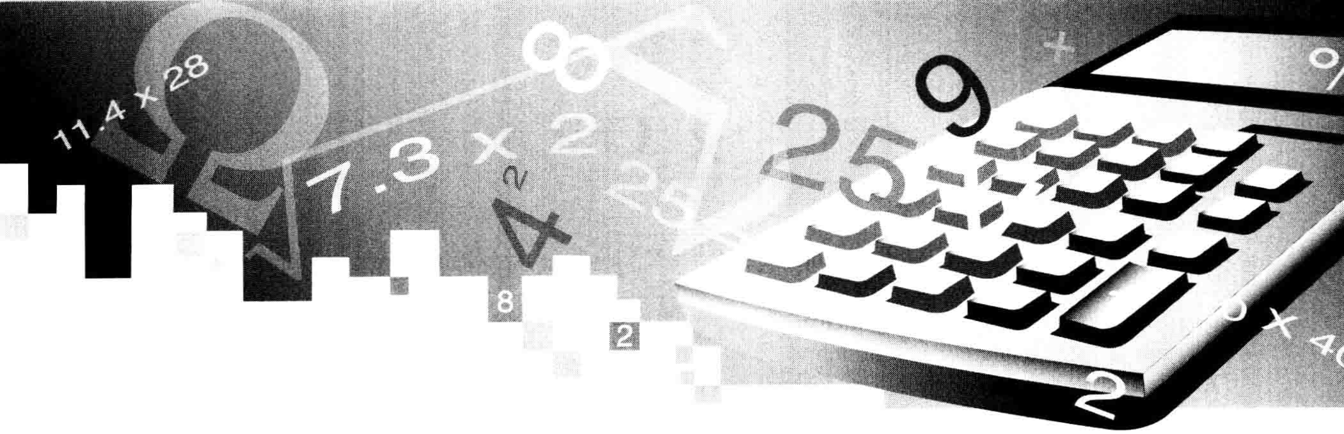
He also wished to acknowledge the considerable assistance given by a number of friends who kindly agreed to read his drafts and who offered useful suggestions. In this respect he particularly wished to thank:

F.W. Price, CEng, MIEE
J. Rickwood, BSc (Eng), CEng, FIEE
G. Stokes, BSc, CEng, MIEE, FCIBSE, MISOH
J.F. Wilson, MBE, AMIEE

Brian Jenkins passed away in 2007 having enjoyed his retirement in the North of England where his interests moved from writing on electrical matters to researching local history.

Finally, thanks are due to the Institution of Engineering and Technology for its permission to reproduce a number of the definitions from BS 7671 and to the International Electrotechnical Commission for their permission to reproduce the touch voltage curves shown in the Appendix.

In the compilation of this Fourth Edition Mark Coates wishes to acknowledge the help of Eur Ing Darrell Locke, of the Electrical Contractors' Association, for his assistance as an advisor and critic.



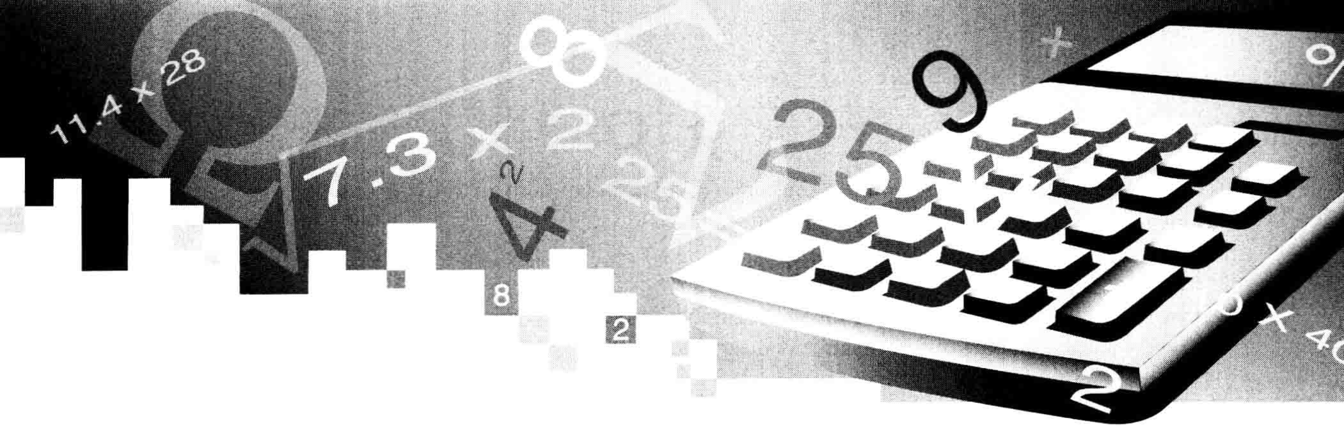
Symbols

The symbols used in this book are generally aligned with those used in BS 7671 together with some additional symbols which have been found necessary.

Symbols used infrequently are defined where they occur in the text.

C_a correction factor for ambient temperature
C_b correction factor for the depth of burial of a buried cable or duct
C_c overload correction factor for buried cables or cables in buried ducts
C_d correction factor for type of overcurrent protective device
$C_d = 1$ for HBC fuses and mcbs
$C_d = 0.725$ for semi-enclosed fuses
Note: C_c and C_d are combined in BS 7671:2008 as C_c but they are, in fact, two separate factors
C_g correction factor for grouping
C_i correction factor for conductors embedded in thermal insulation
C_r correction factor for grouping of ring circuits
C_s correction factor for the thermal resistivity of the soil surrounding a buried cable or duct
I_b design current of circuit, A
$I_{\Delta n}$ rated residual operating current of an RCD, mA or A
I_{ef} earth fault current, A
I_n nominal current of protective device, A
I_{sc} short circuit current, A
I_t required tabulated current-carrying capacity, A
I_{ta} actual tabulated current-carrying capacity, A
I_x current used as a basis for calculating the required current-carrying capacity of the live conductors, A
I_z effective current-carrying capacity, A
l circuit route length, m
S conductor cross-sectional area, mm^2
t_a actual or expected ambient temperature, °C
t_o maximum permitted conductor temperature under overload conditions, °C
t_p maximum permitted normal operating conductor temperature, °C
t_r reference ambient temperature, °C – (t_r in BS 7671 is 30°C)
t_1 actual conductor operating temperature, °C
U_n nominal voltage, V

U_o nominal voltage to Earth, V
U_p nominal phase voltage, V
Z_1 impedance of live conductor, ohms, $= \sqrt{(R_1^2 + X_1^2)}$ where R_1 is its resistance component and X_1 is its reactance component
Z_2 impedance of protective conductor, ohms, $= \sqrt{(R_2^2 + X_2^2)}$ where R_2 is its resistance component and X_2 is its reactance component
Z_E that part of the earth fault loop impedance which is external to the installation, ohms
Z_{pn} phase to neutral impedance, ohms
Z_s earth fault loop impedance, ohms



Definitions

The following definitions are of terms which appear in this book and have been aligned, generally without modification, with the definitions in BS 7671:2008.

Ambient temperature

The temperature of the air or other medium where the equipment is to be used.

Basic protection

Protection against electric shock under fault-free conditions.

Note: For low voltage installations, systems and equipment, basic protection generally corresponds to protection against direct contact, that is 'contact of persons or livestock with live parts'.

Bonding conductor

A protective conductor providing equipotential bonding.

Bunched

Cables are said to be bunched when two or more are contained within a single conduit, duct, ducting, or trunking or, if not enclosed, are not separated from each other by a specified distance.

Circuit protective conductor (cpc)

A protective conductor connecting exposed conductive parts of equipment to the main earthing terminal.

Current-carrying capacity of a conductor

The maximum current which can be carried by a conductor under specified conditions without its steady state temperature exceeding a specified value.

Design current (of a circuit)

The magnitude of the current (rms value for a.c.) to be carried by the circuit in normal service.

Direct contact

Contact of persons or livestock with live parts. Deleted in BS 7671:2008, see Basic protection

Distribution circuit

A circuit supplying a distribution board or switchgear.

A distribution circuit may also connect the origin of an installation to an outlying building or separate installation, when it is sometimes called a sub-main.

Earth fault current

An overcurrent resulting from a fault of negligible impedance between a line conductor and an exposed-conductive-part or a protective conductor.

Earth fault loop impedance

The impedance of the earth fault current loop starting and ending at the point of earth fault. This impedance is denoted by Z_s.
The earth fault loop comprises the following, starting at the point of fault:

- the circuit protective conductor;
- the consumer's earthing terminal and earthing conductor;
- for TN systems, the metallic return path;
- for TT and IT systems, the earth return path;
- the path through the earthed neutral point of the transformer;
- the transformer winding;
- the line conductor from the transformer to the point of fault.

Earth leakage current

Deleted in BS 7671:2008. See Protective conductor current. A current which flows to earth, or to extraneous-conductive-parts, in a circuit which is electrically sound. This current may have a capacitive component including that resulting from the deliberate use of capacitors.

Earthing

Connection of the exposed-conductive-parts of an installation to the main earthing terminal of that installation.

Earthing conductor

A protective conductor connecting the main earthing terminal of an installation to an earth electrode or to other means of earthing.

Equipotential bonding

Deleted in BS 7671. Previously 'Electrical connection maintaining various exposed-conductive-parts and extraneous-conductive-parts at substantially the same potential.'

Exposed-conductive-part

A conductive part of equipment which can be touched and which is not normally live, but which may become live when basic insulation fails.

External influence

Any influence external to an electrical installation which affects the design and safe operation of that installation.

Extraneous-conductive-part
A conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation.

Fault current
A current resulting from a fault.

Fault protection
Protection against electric shock under single-fault conditions.
Note: For low voltage installations, systems and equipment, fault protection generally corresponds to protection against indirect contact, mainly with regard to failure of basic insulation. Indirect contact is 'contact of persons or livestock with exposed-conductive-parts which have become live under fault conditions'.

Final circuit
A circuit connected directly to current-using equipment, or to a socket-outlet or socket-outlets, or other outlet points for the connection of such equipment.

Indirect contact
Deleted in BS 7671:2008. See Fault protection.

Live part
A conductor or conductive part intended to be energized in normal use, including a neutral conductor but, by convention, not a PEN conductor.

Main earthing terminal
The terminal or bar provided for the connection of protective conductors, including protective bonding conductors, and conductors for functional earthing if any, to the means of earthing.

Origin of an installation
The position at which electrical energy is delivered to an electrical installation.

Overcurrent
A current exceeding the rated value. For conductors the rated value is the current-carrying capacity.

Overload current
An overcurrent occurring in a circuit which is electrically sound.

PEN conductor
A conductor combining the functions of both protective conductor and neutral conductor.

Protective conductor
A conductor used for some measures of protection against electric shock and intended for connecting together any of the following parts:

- exposed-conductive-parts
- extraneous-conductive-parts
- the main earthing terminal
- earth electrode(s)
- the earthed point of the source, or an artificial neutral.

Protective conductor current

Electric current appearing in a protective conductor, such as leakage current or electric current resulting from an insulation fault.

Residual current

The algebraic sum of the currents flowing in the live conductors of a circuit at a point in the electrical installation.

Residual current device (RCD)

A mechanical switching device or association of devices intended to cause the opening of the contacts when the residual current attains a given value under specified conditions.

Residual operating current

Residual current which causes the RCD to operate under specified conditions.

Ring final circuit

A final circuit arranged in the form of a ring and connected to a single point of supply.

Short circuit current

An overcurrent resulting from a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions.

System

An electrical system consisting of a single source, or multiple sources running in parallel, of electrical energy and an installation. For certain purposes (of the Wiring Regulations), types of system are identified as follows, depending upon the relationship of the source, and of exposed-conductive-parts of the installation, to Earth:

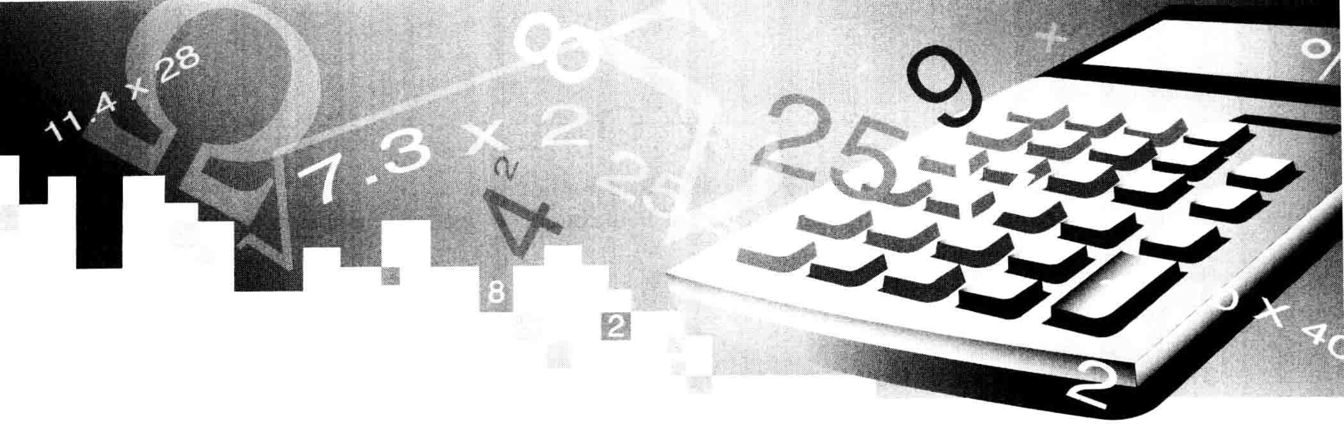
- *TN system,* a system having one or more points of the source of energy directly earthed, the exposed-conductive-parts of the installation being connected to that point by protective conductors.
- *TN–C system,* in which neutral and protective functions are combined in a single conductor throughout the system.
- *TN–S system,* having separate neutral and protective conductors throughout the system.
- *TN–C–S system,* in which neutral and protective functions are combined in a single conductor in part of the system.
- *TT system,* a system having one point of the source of energy directly earthed, the exposed-conductive-parts of the installation being connected to earth electrodes electrically independent of the earth electrodes of the source.
- *IT system,* a system having no direct connection between live parts and earth, the exposed-conductive-parts of the electrical installation being earthed.

Voltage, nominal

Voltage by which an installation (or part of an installation) is designated. The following ranges of nominal voltage (rms values for a.c.) are defined:

- *Extra-low.* Normally not exceeding 50 V a.c. or 120 V ripple free d.c., whether between conductors or to earth.
- *Low.* Normally exceeding extra-low voltage but not exceeding 1000 V a.c. or 1500 V d.c. between conductors, or 600 V a.c. or 900 V d.c. between conductors and earth.
- *High.* Normally exceeding low voltage.

The actual voltage of the installation may differ from the nominal value by a quantity within normal tolerances.



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