1. Introduction

Fault current is usually caused by a failure in wiring or other equipment (perhaps due to accident or abuse), resulting in a breakdown or bridging of the electrical insulation. This occurs typically, though not always, at terminations. Fault currents are generally much larger than either load currents or overload currents, and may cause serious damage to wiring or equipment unless appropriate protection is provided. General information on fault current can be found in Topic F13-13.

The fundamental principle of protection against fault current is stated in Regulation 130-05-01, the appropriate text of which is reproduced as follows:

‘Conductors, and any other parts likely to carry a fault current, shall be capable of carrying that current without attaining an excessive temperature ...’

Protection against fault current is provided by using protective devices as explained in this topic. In most cases, both fault current protection and overload protection are provided by a single overcurrent protective device (item 7.2 refers).
2. Types of fault current

There are two types of fault current: short-circuit current and earth fault current, as referred to in the following definitions from Part 2 of BS 7671:

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

'Earth fault current. A fault current which flows to earth.'

Examples of phase-to-phase short-circuit current and earth fault current are shown in figures 1 and 2, respectively. Both figures are based on a TN-C-S system.
The symbols used in Figures 1 and 2 have the following meanings:

- E is the main earthing terminal
- $I_f$ is the fault current.
- L1, L2 and L3 are the phase terminals at the origin of the installation.
- N is the neutral terminal at the origin of the installation.
- $Z_1$, $Z_2$ and $Z_3$ are the source impedances of the supply.
- $Z_N$ is the impedance of the supply source neutral conductor.

A more detailed explanation of both short-circuit and earth fault conditions is given in Topic F13-13.

3. Fault current protective devices

Fault current may cause overheating, arcing, fire and even explosion, resulting in injury to persons and damage to property. To reduce the risks of such injury or damage occurring, BS 7671 requires fault protective devices to be provided. The basic requirement is stated in Regulation 434-01-01, which is reproduced as follows:

**Regulation 434-01-01:**

A protective device shall be provided in a circuit to break any fault current flowing in conductors of that same circuit before such current causes danger due to thermal or mechanical effects produced in those conductors or the associated connections.

The nominal current of such a protective device may be greater than the current-carrying capacity of the conductor being protected.

In addition, Regulation 533-03-01 requires the application of the regulations in Chapter 43 to take into account minimum and maximum fault current conditions, when selecting a device or devices for the protection of wiring against fault current.

The types of device that may be used for protection against fault current are covered in the topics listed in item 7.4 and in Topic F13-1.

4. Position of devices for fault current protection

Regulation Group 473-02 covers the positioning of devices for fault current protection. Regulation 473-02-01 requires a fault current protective device to be placed at the point where a reduction occurs in the value of current-carrying capacity of the conductors, as shown in Fig 3. Generally, the reduction in the current-carrying capacity is
due to a reduction in the cross-sectional area of the circuit conductor(s), but it may also be
due to a change in the method of installation, cable grouping, type of cable or conductor,
or environmental conditions (eg ambient temperature)

Protection device placed at a point where a reduction in current-carrying capacity of conductors occurs

Regulations 473-02-02 and 473-02-03 permit a fault current protective device to be placed
at a position other than that specified in Regulation 473-02-01, under certain
conditions. Further information is given in Topic F13-29.

5. Omission of devices for fault current protection
Regulation 473-02-04 states that a device for fault current protection may be omitted in
certain circumstances. Omission of devices for fault current protection is dealt with

6. Determination of prospective fault current
Regulations 313-01-01 and 434-02-01 of BS 7671 require the prospective fault current to be
determined at the origin and other relevant points of an installation under both short-circuit
and earth fault conditions. The determination may be made by calculation or enquiry, as
explained in other topics in Section F13 of the Technical Manual, or by measurement, as
explained in the NICEIC book Inspection, testing and certification.

7. Characteristics of a fault current protective device
The characteristics of fault current protective devices are detailed in Regulation
Group 434-03.

7.1 Breaking capacity rating
With one exception, which discussed in the next paragraph, Regulation 434-03-01
required the breaking capacity rating* of each device for protection against fault
current to be not less than the prospective short-circuit current or earth fault current
(whichever is the greater) at the point at which the device is installed.

* Sometimes called the ‘short-circuit’ capacity.
A lower breaking capacity rating is permitted where so-called ‘back-up’ protection is provided. Back-up protection is where another protective device (or devices), having the necessary breaking capacity, is installed on the supply side, and the characteristics of the two protective devices are co-ordinated. The co-ordination is required to be such that the energy let-through ($I^2t$) of the devices does not exceed that which can be withstood, without damage, by the device or devices on the load side. Where back-up protection is required for a fault current protective device, the manufacturer of the device will normally provide information on the selection of suitable devices for back-up protection.

**Note.** For overcurrent protective devices incorporated in a consumer unit complying with BS EN 60439-3: 1991 Corrigendum April 1994, or with BS 5486 Part 13, the breaking capacity rating may be taken as 16 000 A. This rating is however conditional upon the consumer unit being protected by a type II fuse to BS 1361 rated at not more than 100 A, or any other short-circuit protective device having the same let-through energy ($I^2t$) and cut-off current.

**7.2 Where an overload protective device is to provide fault current protection**

In most cases, both fault current protection and overload protection are provided by a single overcurrent protective device, such as a fuse to BS 88, BS 1361 or BS 3036, or a circuit-breaker to BS EN 60898 or BS EN 60947-2.

Where this is the case, Regulation 434-03-02 indicates that, with certain exceptions†, it may be assumed that the requirements of the Regulations are satisfied as regards fault current protection of the live conductors on the load side of the protective device, providing both of the following conditions are met:

(i) the device provides overload protection of the conductors in accordance with Section 433 (overload current protection is dealt with in Topic O69-5), and

(ii) the device has a rated breaking capacity rating of not less than the value of the prospective earth fault current or prospective short-circuit current (whichever is the greater) at its point of installation.

The validity of the assumption of Regulation 434-03-02 must be checked, where there is doubt, for conductors in parallel and for certain types of circuit-breaker, eg non-current-limiting types.

Where the assumption of Regulation 434-03-02 cannot be made, a calculation must be carried out in accordance with Regulation 434-03-03, as explained in item 7.3.

† That is, where required by Regulation 434-03-03 (where a protective device is provided for fault current protection only) or Regulation 473-02-05 (fault current protection of conductors in parallel).
7.3 Calculation of maximum permissible fault clearance time

Regulation 434-03-03 requires that where a protective device is provided for fault current protection only, the clearance time of the device under both short-circuit and earth fault conditions must not result in the admissible limiting temperature of any live conductors being exceeded. The time $t$, in which a given fault current will raise the live conductors from the highest permissible operating temperature in normal duty to the limiting temperature can, as an approximation, be calculated using equation (1)$^\dagger$:

$$ t = \frac{k S I^2}{2} $$

Where:

- $t$ is the duration of the short-circuit, in seconds
- $S$ is the conductor cross-sectional area in mm$^2$
- $I$ is the value of fault current in amperes, expressed for a.c. as the rms value, due account being taken of the current limiting effect of the circuit impedances
- $k$ is a factor, depending on conductor material, insulation material and the initial and final conductor temperatures

Therefore, as an approximation, for a fault current $I$, the fault current protective device is required to disconnect the faulty circuit in $t$ seconds or less, in order to prevent damage to conductors or their insulation.

As a worked example, consider the load side conductors protected by fault current protective device 'A', in Fig 4.

Position of fault current protective device 'A' for the worked example

In this worked example, it is supposed that the load side live conductors are 6 mm$^2$ copper and have thermosetting insulation, and that the prospective fault current in the load side conductors is 400 A. (Note: For the types of overcurrent protective device

$^\dagger$ Equation (1) is valid for disconnection times up to 5 seconds
considered in BS 7671, it is normally the minimum value of prospective fault current (ie that at the most remote part of the circuit and when the conductors are at their maximum permitted normal operating temperature) which is the most onerous from the point of view of protection of conductors against fault current.)

What is the maximum permissible fault clearance time (t) that will protect the load side conductors against energy let-through damage?

\[ S = 6 \quad \text{for the 6 mm}^2 \text{ live conductors} \]
\[ I = 400 \text{ A} \quad \text{from the prospective fault current information provided} \]
\[ k = 143 \quad \text{from Table 43A of BS 7671 for the live conductors} \]

Substituting these values into equation (1) gives the following:

\[ t = \frac{k^2S^2}{I^2} = \frac{143^2 \times 6^2}{400^2} = 4.6 \text{ s} \]

The time, \( t = 4.6 \) seconds, is the maximum time for which the live conductors of the circuit can withstand the given fault current, before damage is expected to occur to the conductors or the associated connections.

Suppose that, from the time/current characteristics of fault current protective device A, it is found that a fault current of 400 A will cause the protective device to operate in 0.3 seconds. This means that the live conductors will be protected against damage from the given fault current.

Similar calculations should be repeated for the prospective earth fault current.

For very short durations (less than 0.1 s) where asymmetry of the current is important and for current limiting devices, the value of \( k^2S^2 \) for the cable needs to be greater than the value of let-through energy \( (I^2t) \) of the device, as given by the manufacturer of the device; that is to say, equation (1) is rearranged as \( k^2S^2 \geq I^2t \) (Regulation 434-03-03 refers).

Asymmetry of fault current is important when evaluating the capabilities of overcurrent devices located near to generation (eg alternators) or transmission equipment (eg transformers). Transformer windings have negligible resistance compared to their inductive reactance. The asymmetrical fault current from a transformer is the sum of the discharge of the d.c. current from the stored energy in the transformer and the transformed a.c. current. The d.c. current is a maximum if the fault occurs when the a.c. phase voltage across the transformer’s output terminals

\[ \text{¶ If the initial temperature of the conductor was lower than the value given in Table 43A (such as if the conductors where intended to carry a current less than their normal current-carrying capacity), then an alternative value of } k \text{ may have been used (while also taking into account the ambient temperature). See Topic K1-1 for further information.} \]
passes through zero. This may give rise to an asymmetrical peak fault current of up to approximately 2.5 times the symmetrical rms short-circuit current. The d.c. component will generally fall rapidly to about 30% of its initial value after 2.5 cycles. Current and voltage waveforms for a fault current occurring close to a low impedance inductive source of supply, such as a distribution transformer or alternator (at an instant of voltage passing through zero) are illustrated in Topic C81-21.

The method of calculation described in this item (ie based on equation (1)) is based on the assumption that the heat due to the fault current is retained inside the conductor for the duration of the fault (ie adiabatic heating). In practice, there is some heat transfer into adjacent materials, such as the cable’s insulation, during the fault. There may be occasions where a calculation with greater accuracy is required (for instance, where the results are marginal and the cable size is large and the difference in cost between one size and another is high). In such cases, a calculation may be made in accordance with the method given in BS 7454 – Method for calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects.

7.4 Further information
Information about the characteristics of particular devices which are used for fault current protection is given in the following topics:

- Circuit-breakers
  - For household and similar installations to BS EN 60898, Topic C81-13
  - Miniature, to BS 3871, Topic C81-19
  - Moulded-case (MCCB), to BS EN 60947-2, Topic C81-21
- Fuses
  - Cartridge, high breaking capacity (HBC) to BS 88 and BS 1361, Topic C33-5
  - Rewireable (semi-enclosed) to BS 3036, Topic F133-17

8. Fault current protection of conductors in parallel
Regulation 473-02-05 states the requirements for fault current protection of conductors in parallel. Fault current protection of conductors in parallel is dealt with in Topic P5-5.

9. Co-ordination of overload current and fault current protection
Regulation 435-01-01 requires that where separate devices are used for protection against fault current and overload current, the characteristics of the devices are co-ordinated. The purpose of this requirement is to ensure that the energy let-through by the fault current protective device does not exceed that which can be withstood without damage by the overload current protective device.
Typical positioning of co-ordinated fault current and overload current protective devices for load side conductors

The general case of the positioning of fault current and overload current devices (that have been correctly co-ordinated) to protect the load side conductors is shown in Fig 5.

The case of the motor starter overload device shown in Fig 6 is different. In this example the motor is protected by the motor starter’s overload protective device, which is in turn protected against fault current by the HBC cartridge fuses in the switch-fuse.

For a circuit incorporating a motor starter Regulation 435-01-01 permits the type of co-ordination described in BS EN 60947-4-1, subject to seeking advice from the manufacturer of the motor starter.

Typical positioning of co-ordinated fault current and overload current protective devices for a motor

In the event of a short-circuit or earth fault in the motor or the wiring between the motor starter and motor, a fault current may arise which could damage the motor starter. However, the fault current protective device (the HBC fuse in the switch-fuse in Fig 6) will limit the damage to the starter to the level compatible with the degree of co-ordination selected.
Topics referred to in this text:

C33-5 CARTRIDGE FUSES: High breaking capacity (BS 88, BS 1361)
C81-13 CIRCUIT-BREAKERS: For household and similar installations (BS EN 60898)
C81-19 CIRCUIT-BREAKERS: Miniature, conforming to BS 3871
C81-21 CIRCUIT-BREAKERS: Moulded-case (MCCB), general
F13-1 FAULT CURRENT: Devices for protection against
F13-9 FAULT CURRENT: Omission of protection
F13-29 FAULT CURRENT: Protection against, position of protective devices
F133-17 FUSES: Rewireable (semi-enclosed)
K1-1 K VALUES, EVALUATION OF: General
O69-5 OVERLOAD CURRENT: Protection against
P5-5 PARALLEL CONDUCTORS: Fault current, protection against

Topics not referred to in this text, which are related and may be of interest:

D61-1 DISCRIMINATION: General

BS 7671 (Requirements for electrical installations)

Some of the most important requirements are found in:

Protection against overcurrent 130-04
Protection against fault current 130-05
Nature of supply Section 313
Protection against overcurrent Chapter 43
Protection against overcurrent Section 473
Overcurrent protective devices Section 533