Abstract

The majority of specifications produced today for circuit breakers are often inadequate for the application intended. Either too little information is provided (in comparison to other building services disciplines) or the text has been recycled for a large number of years.

Over the past few decades the low voltage installation has become increasingly more challenging for Moulded Case Circuit Breakers (MCCBs). Increased fault levels, higher harmonics levels, changing legislation and demand for maximum uptime have substantially altered the requirements of this important protective device.

The objective of this paper is to update the professional electrical engineer on the safe application of low voltage MCCB technology. In doing so we will examine thoroughly protection disciplines, isolation principles and future trends for MCCBs.
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10.0 References and Acknowledgement
1.0 Introduction

The specification for circuit breakers is often the poor relation in comparison to other building service disciplines when it comes to the written detail. Several pages, indeed chapters may be written on other electrical disciplines of lighting, lift systems, Heating Ventilation and Air Conditioning (HVAC), Uninterruptible Power Supplies (UPS), Building Management Systems (BMS) and the switchboard itself. However the specification for the MCCB is often limited, outdated and usually a hybrid of other circuit breakers such as Miniature Circuit Breakers (MCB) and Air Circuit Breakers (ACB).

2.0 Where are MCCBs used?

A normal low voltage installation for an industrial or commercial application would consist of an ACB incomer connecting the low voltage side of the distribution transformer to the main switchboard. The area known as final distribution would consist of MCBs feeding the loads directly.

The area in between is normally where an MCCB would be located within the distribution network. The protective device in this area could also be a fuse switch but the comparison of pro and cons of fuses versus MCCB (albeit an interesting debate) is not within the scope of this paper.

Figure 1. Typical low voltage system
3.0 What is an MCCB?

The formal definition from the British Standard for circuit breakers BS EN 60 947-2 is as follows:

“a mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit condition such as those of short circuits.”

The key words here to note are *switch*, *make*, *carry* and *break*.

An MCCB is there to protect both plant and personnel from serious damage resulting from an overcurrent. It must also provide isolation facilities to ensure maintenance can be carried out safely and in line with current legislation.

Most manufacturers offer MCCBs with ratings anywhere from 12A to 2500A (but it is possible for the frame size to be even higher and lower than this.) The minimum frame rating is typically 125A and 90% of the UK volume of MCCBs is up to 800A or 1000A. Although MCCBs are available at ratings higher than this, the majority of specifiers use ACBs at these levels and above to ensure higher selectivity and maintainability.

The MCCB is so called as this housing of the contacts structure are contained within a moulded base and finished with a moulded lid.

The main elements of a MCCB are the contacts, arc chamber, tripping unit, trip mechanism and toggle.

![Figure 2 Cross section of an MCCB](image)
The functions of the main MCCB elements are shown below:

**Contacts**
Fixed and opening contacts ensure rapid opening under overcurrent condition. The contacts are made from copper but with silver tungsten tips to increase conductivity and electrical endurance.

**Arc chamber**
The arc chamber consists of many ‘splitter plates’ which help extinguish the low voltage arc. The magnetic field of the overcurrent helps direct the arc away quickly from the contact tips and into the arc chamber where overall surface length and impedance is increased to help extinguish the arc and clear the overcurrent.

**Tripping Unit**
The tripping unit can either be thermal magnetic or microprocessor type. This instructs the trip mechanism on how quickly it should take to operate and is usually has adjustable in settings.

**Tripping mechanism and toggle**
The tripping mechanism releases the energy within the mechanism to quickly open the contacts. The toggle should be directly connected to the contacts to indicate the true position of the contacts.

**4.0 What are the Standards for MCCBs?**

The British Standards that refer to circuit breakers are identical to the IEC standard and are as follows:

**BS EN 60 947-1 General Rules**
**BS EN 60 947-2 Circuit Breakers**
**BS EN 60 947-3 Switch Disconnectors**

The above publications contain the *minimum standards* for safety, which all MCCB manufacturers must meet. As an MCCB is an important safety device it is good practice to design the MCCB beyond the standard where possible. Other standards that are sometimes referred in MCCB specifications are:

**BS EN 60204-1**
Safety of machinery. Electrical equipment of machines. General requirements.

**BS:7671**
Requirements for Electrical Installation (IEE Wiring Regulations 17th Edition).
These standards will be referred to later in this paper. The main MCCB ratings and specification items detailed in the IEC 947 series of standards are shown below:

- Rated Current (In)
- Ultimate Breaking Capacity (Icu)
- Service Breaking Capacity (Ics)
- Short time withstand (Icw)
- Rated Making Capacity (Icm)
- Rated Operational Voltage (Ue)
- Rated Insulation Voltage (Ui)
- Rated Impulse Voltage (Uimp)

All of the above are important in determining the MCCB specification. However, as a minimum, the specifications should at least refer to those associated with the main definition of an MCCB. That is to carry current (In), to break current (Icu) and to make current (Icm) at a specified voltage level (Ue). We shall now look at each one in turn.

### 4.1 Rated Current (In)

This is the maximum value of current that the MCCB can carry indefinitely at an ambient temperature, without exceeding the specified temperature limits of the current carrying parts. The maximum temperature rise that is permitted on the MCCB terminals when carrying full load current is $70^\circ$C according to BS EN60947-2. However, some other standards for MCCBs such as the American ANSI or Japanese JIS specify a much lower temperature rise limit of $60^\circ$C.

This temperature difference can influence the derating of an MCCB when installed in a switchboard. This is important as all circuit breakers are rated in free air to establish a common reference point. Once in an enclosure the derating characteristics can influence the current carrying capacity.

In hotter climates such as the Middle and Far East it is common for specifications to ask for all MCCBs to be rated at $50^\circ$C, to ensure their performance is adequate for the environment intended.

### 4.2 Breaking Capacity (Icu)

This is the highest short circuit current the MCCB is capable of breaking without being damaged. The value is always quoted as symmetrical (sym.) root mean square (rms)
An industry standard fault level of 50kA sym. rms is a fairly typical breaking capacity for an MCCB when fed from a 2MVA, 415v distribution transformer. Other typical fault levels for MCCB tend to be 25, 36, 50, 65, 80, 100 kA depending on the type of installation.

Fault levels are increasing all the time and the supply of large transformers up to 4MVA(100 kA at 415v), have dramatically increased due to the huge power and cooling requirements, of power hungry installations such as data centres. With high current limiting MCCBs it is possible to achieve fault levels up to 200kA at 415V (a fuse is usually limited to 80 kA). However this tends to be used only in marine installations where several generators are operating in parallel at the same time.

This Icu is also referred to as the **ultimate breaking capacity** and is evaluated by performing a breaking test at the maximum three phase fault level, then re-closing back onto the same fault magnitude and breaking a second time. This is also referred to as O-CO test (open, close –open). This test replicates two full 3 phase ‘bolted’ short circuits at the MCCB terminals which in practice only really occurs during a test condition. The vast majority of faults tend to be towards the load end and the conductor impedance would substantially reduce the fault level. It’s also more likely to be a single phase rather than a three phase thereby reducing the fault further.

After the Icu breaking test the MCCB must still be able to carry load current, pass a dielectric test and operate within tripping tolerance bands. This value is used within 90% of UK electrical installations to determines the breaking capacity of an MCCB.

A more onerous rating is the **Ics breaking capacity** value also referred to as the service breaking capacity. This is a three short circuit rating represented as O-CO-CO. Ics is usually applied more to incoming circuit breakers such as ACBs where the proximity of the circuit breaker is close to the supply source. However, it is also applied to MCCBs in higher risk applications such as oil/gas installations and offshore.

Some specifications call unnecessarily for the Ics value to be 100% of the Icu. If an Ics rating is required then this should be based on the system fault level. Most manufacturers can offer both Icu and Ics ratings but the Ics rating can sometimes be at higher cost, depending on the rating.

**4.3 Short Time Withstand (Icw)**

This is the ability of an MCCB to withstand the thermal and electrodynamic effects of a short circuit for a specified period of time. For MCCBs up to 2500A, this is 12(In) or 5kA, whichever is greater. Above 2500A the Icw should be 30 kA. (The preferred time value ranges from 100msec to 1second).
A common mistake, in an MCCB specification is to ask for an Icw of 50 kA for 1 second. This is a specification for an ACB or the busbar within a switchboard. An MCCB would not be able to offer this withstand value.

Associated with the Icw are two categories of MCCBs:

**i. Category A**
This is for MCCBs with no intentional time delay and are therefore not specifically intended for high selectivity applications, which tend to be a thermal magnetic MCCB. These MCCBs would **not** have a Icw rating.

**ii. Category B**
These MCCBs have a time delay which makes them more suited to applications that demand higher selectivity. The majority (but not all) of microprocessor MCCBs have a short time withstand Icw rating.

For example a 1250A MCCB may have an Icw of 15ka rms for 300msec

### 4.4 Rated Making Capacity (Icm)

The rated making capacity is an important but sometimes relatively underused item in the specification of an MCCB.
This is the highest short circuit current the MCCB is capable of closing onto without being damaged. The value is always quoted as asymmetrical (asym) peak.

When logically thought through this is an important safety parameter of the MCCB. The chances of an operator, being in close proximity to a switchboard, during an MCCB breaking operation is very, very remote.

However the chances are much increased for an operator being present during a making operation(unless remotely controlled ) as they must physically be holding the MCCB toggle or operating handle to close the MCCB after say a routine maintenance schedule. If an operator attempted to close an MCCB onto a short circuit and the making capacity was inadequate, then serious and perhaps fatal consequences could be the result.

The standard BS EN 60947-2 sets out to provide minimum levels of safety. Within the standard there is table which provides guidelines for ratios of breaking capacities to making capacities which is shown as the multiplication factor ‘n’ in the table below.

<table>
<thead>
<tr>
<th>Short circuit (I), kA r.m.s</th>
<th>Power Factor (cos $\phi$)</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$4.5 &lt; I \leq 6$</td>
<td>0.7</td>
<td>1.5</td>
</tr>
<tr>
<td>$6 &lt; I \leq 10$</td>
<td>0.5</td>
<td>1.7</td>
</tr>
<tr>
<td>$10 &lt; I \leq 20$</td>
<td>0.3</td>
<td>2.0</td>
</tr>
<tr>
<td>$20 &lt; I \leq 50$</td>
<td>0.25</td>
<td>2.1</td>
</tr>
<tr>
<td>$50 &lt; I$</td>
<td>0.2</td>
<td>2.2</td>
</tr>
</tbody>
</table>

*Figure 3. Table from BS EN60-947-2 showing factor ‘n’*
Example, An MCCB rated with a 50 kA sym rms breaking capacity (Icu) would require to have a minimum making capacity of 105 kA sym peak (50 x 2.1 = 105)

As shown in the above table the factor ‘n’ is proportional to the short circuit power factor(not to be confused with load power factor). The lower the short circuit power factor(sometimes also shown as reactance to resistance ratio X/R) the higher the DC offset component and the higher the asymmetrical peak value.

Similar to the temperature rise issues the American and Japanese standard authorities demand more onerous electrical parameters in relation to short circuit power factors for a given fault level.

For example at a 50 kA fault level the BS/IEC recommendation is an assigned short circuit power factor of 0.25 but ANSI/JIS would suggest a lower value of 0.2. This means any MCCB meeting these standards would have to have a higher making capacity by default.

The value of an MCCB making capacity is more important today than in previous years as backup generation facilities on mission critical facilities like data centres, telecommunication and hospitals is increased to maximise uptime of the installation. This is important as the supply characteristics (X/R) of a transformer fed installation are quite different to a generator or rotary UPS supply source. This can result in very larger peak asymmetrical short circuit (Iasym) currents, to which the MCCB must be able to safely make onto,

\[ I_{sym} \]
\[ I_{asym} \]
\[ DC \]

*Figure 4. Asymmetrical short circuit current peak*

A common example could be three parallel generators rated at 1.6MVA/415V, which has a combined fault current output of 80 kA sym rms but a peak asymmetrical output of 204 kA.
This represents an ‘n’ ratio of 2.55 which is well above what the BS standard for MCCBs refers to.
If a standard 80 kA sym rms MCCB was to be installed it would probably only have a making capacity of 176 kA asym peak. (The standard specifies an ‘n’ of 2.2 as a factor for 80 kA).

If this MCCB attempted to close onto the combined fault output of the generators it would be disastrous for the installation.
In this example all MCCBs would have to be selected primarily on their making capacity to ensure that the MCCB was capable of closing onto the potential value of a short circuit

Provided the building design software, accommodates short circuit studies fed from sources such as generators/DRUPS , then this would be highlighted and the MCCB selection would need to be driven by making capacity first and breaking capacity second.

4.5 Rated Operational Voltage (Ue)

The rated operational voltage is the voltage at which the MCCB has been designed to operate in normal conditions.
The assigned breaking (Icu) and making capacities (Icm) are always set at a specified operational voltage (Ue).
BS EN60 947-2 cover voltages up to 1000V AC rms but the main voltage levels tend to be 380,400,415,440,525 and 690V

Example is 50 kA sym rms at 415V AC rms

The actual voltage the MCCB is tested at is the ‘recovery voltage’ which is the voltage present immediately following a short circuit. This is expressed as a percentage of the operational voltage. In the MCCB BS standard this is at 105%.

In the above example the voltage used in the actual test would be 435V (=415 x 1.05)
Again in the American and Japanese standards the recovery voltage is set at 110% so an MCCB influenced by these standard would be tested at 456V (=415 x 1.10)

Other reference voltages mentioned in the standard are as follows:

**Rated Insulation Voltage (Ui)**
This is the voltage referred to, when conducting dielectric tests and checking creepage distances. A typical MCCB would be rated for 800 V AC rms

**Rated Impulse Voltage (Uimp)**
This is the maximum voltage the MCCB can withstand without failure
A typical MCCB would be rated for 8 kV AC
5.0 Protection

One the primary functions of an MCCB is to protect conductors from the potentially damaging effects of overcurrent. Overcurrents are generally categorised as being either an overload (In to 10In) or a short circuit(10In to 50In+). Chapter 43 of the 17th Edition of IEE Wiring Regulations provides guidance when selecting a protective device to provide overcurrent protection. The following regulations summarise the criteria for selecting an MCCB in relation to overload and short circuit protection.

**Protection against overload**

Regulation 433.1.1

\[ I_b \leq I_n \leq I_z \]

\[ I_2 \leq 1.45 \times I_z \]

- \( I_b = \) Design current or full load current
- \( I_n = \) MCCB nominal current rating
- \( I_z = \) Conductor current rating
- \( I_2 = \) Current causing operation of MCCB

**Protection against short circuit**

Regulation 434.5.2

\[ t \leq \frac{k^2 s^2}{I^2} \]

- \( t = \) duration (secs)
- \( s = \) cable cross section (mm$^2$)
- \( I = \) effective short circuit current (Amps)
- \( k = \) a factor taking into account various criteria of the conductor e.g. for a p.v.c. insulated copper conductor \( k = 115 \)

*Figure 5.Extract from 17th edition on MCCB overcurrent protection*

On the subject of overload protection there is also a Regulation in BS7671 that states

"Every circuit shall be designed so that a small overload of a long duration is unlikely to occur"

This regulation(433.1.1) suggests that it is good design practice, to select a protective device that does not thermally stress the conductor where possible. The table below is a comparison of \( I_2 \), the current causing operation of several protective devices. It is worth noting that a typical MCCB would start to operate at 115% (In) whereas a traditional BS 88 fuse would allow a 144% overload to flow indefinitely. For more details on the pre-trip alarm option see section 5.2(microprocessor based MCCBs)
To offer effective protection against overcurrents it is a normal requirement for the MCCB to have adjustable overload and short circuit protection. The type of MCCB thermal magnetic or microprocessor will have different levels of adjustability.

5.1 Thermal Magnetic MCCBs

On a thermal magnetic MCCB the overload protection is performed by the deflection of a bimetallic strip engaging with the trip bar of the MCCB. The higher the overload, the more heat ($I^2R$) produced resulting in a quicker operating time.

This ‘thermal’ part of the time current characteristic is shown with current magnitude being inversely proportional to the operating time.

A typical interrupting time is 20 seconds for an overload magnitude of 600% ($I_n$) (as shown by the inverse part of the curve in figure 7).
Figure 7. Thermal magnetic MCCB characteristics with adjustable settings

The short circuit part is carried out by the ‘magnetic operation’. In this type of MCCB the short circuit would create a strong magnetic force that would engage a moving magnetic core to operate the trip bar very quickly. For low short circuits the total clearing time (opening and arcing time) could be approximately 20msec. However most modern MCCBs all exhibit current limiting properties. This utilises the magnetic force of the short circuit to rapidly assist the opening of the contacts. In other words the higher the short circuit the quicker the opening time. The typical clearing time of an MCCB interrupting at its maximum fault current, could be anywhere from 2 to 5 msec. This part of the curve is shown by the definite/instantaneous characteristics in the figure above.

Adjustability of a thermal magnetic MCCB is important to ensure optimum protection of the system. Most modern MCCBs have a thermal adjustment of 63% to 100% of its nominal rating (In.)

Example
A 125A (frame size) MCCB fitted with a 63A(In) trip unit can have its rated current(Ir) set anywhere from 63A(100%In) to 40A(63%In).

This flexibility allows for last minute changes during commissioning where MCCB ratings may have changed due to the alteration of the cable schedule. Adjustable short circuit protection can sometimes be even more important to ensure optimum performance. When switching inductive (motors) or capacitive (power factor correction) loads, it is important to ensure the magnetic trip value (at minimum tolerance) is above the inrush current that these loads could draw. Failure to do this could result in the ‘nuisance’ tripping of the MCCB during switch on. See figure 8 for more details.
Alternatively you may have an installation with a long cable run where the small short circuit level at the end of the cable could result in non compliance with tripping times of the wiring regulations BS7671.
The regulations (411.4.5) relating to earth loop impedance (Ze) require the protective device to operate within 5 seconds for fixed equipment. If Ze is too high the MCCB may take too long to operate for a low short circuit such as an earth fault.
The designer can get round this by increasing the cable size of the circuit protective conductor (CPC) but this would incur extra cost to the client.

If the specification ensures MCCBs with adjustable magnetic/short circuit trips are used then by simply decreasing the instantaneous trip setting then compliance with the regulations can be achieved ‘without’ over-sizing the cable.
There are many electrical engineers, who believe they have to use microprocessor based MCCBs to have adjustable overload and short circuit settings. This is incorrect.
While microprocessor based MCCBs offer a wider range of adjustments and options there is a cost penalty attached to this.

A practical compromise would be for the specification, to advocate the use of thermal magnetic MCCBs up to 400A and use microprocessor based MCCBs above this.

5.2 Microprocessor MCCBs

This type of MCCB has evolved much over the last twenty to thirty years. The initial design was based on using analogue electronics to replace the thermal magnetic trip mechanism. Each phase would have an integral current transformer to reduce the current signal to a level where basic comparators would check the current magnitude against
preset conditions. These were set using external potentiometers which would change the current setting by adding/subtracting resistance into the circuit. Early designs sometimes used an external supply source to supply energy to the tripping coil but this was soon replaced by an integral capacitive element which eliminated the need for this.

The increase in harmonics (see section 6.0) highlighted problems with these types of MCCBs as the vast majority were modelled on peak detection circuitry. Analogue electronic MCCBs would look only at peak value of the waveform and basically divide this by square root of two, to determine the rms value. This could often lead to under or over protection of the conductor. The transition to digital electronics with microprocessor based circuitry helped overcome most of these issues.

Microprocessor MCCBs tend to have a much wider adjustment than its thermal magnetic counterpart with a typical range being 40 to 100% of (In). In addition several parts of the time current characteristics can be adjusted independently of each other depending on the type of MCCB. Most microprocessor MCCBs have at least three parts to the time current characteristic curve. These are sometimes referred to as ‘LSI’ curves.

i. Long Time Delay (LTD). This provides overload protection
ii. Short Time Delay (STD). This provides a time delayed protection for smaller short circuits and assists with selectivity
iii. Instantaneous Trip (Inst). This has no intentional time delay and is responsible for fast tripping of the MCCB on medium to high short circuit levels.

![Microprocessor MCCB characteristics with adjustable settings](image-url)

*Figure 9. Microprocessor MCCB characteristics with adjustable settings*
This degree of curve flexibility can greatly assist with selectivity (where the downstream MCCB should trip before the upstream MCCB).

In addition to this microprocessor MCCBs are available with the following protection options:

i. **Pre-Trip Alarm (PTA).**
   This detects small overloads and the setting is usually fixed at ‘80% of In’ on basic relays and adjustable in the region of ‘70 to 100% of In’ for more advanced relays. This option can provide an important early warning of an impending overload condition. If the microprocessor MCCB came with this option an LED would give local indication of this and a volt free contact would also be provided. This contact could be used to signal load shedding on non-critical load or for additional generation to be provided from a standby generator.

ii. **Ground Fault Trip (GFT)**
   Single phase faults are far more common than three phase faults. Early detection of a low magnitude single phase fault to earth can minimise damage to the electrical installation. Microprocessor MCCBs can usually offer this as an option where the ground trip current is fixed at ‘20% of In’ on economical relays and adjustable from 10 to 40% on the higher spec options.

iii. **Fault Type Indication (FTI)**
   Microprocessor MCCBs can indicate the type of fault that has occurred such as overload, short circuit or earth fault. This can be via a simple LED and volt free contact to more sophisticated types with integral LCD displays (see section 8 for further detail).

6.0 Effects of Harmonics on MCCB protection

Harmonic voltages and currents have substantially increased within low voltage distribution over the past twenty years. The increased use of non linear loads such as variable speed drives, uninterruptible power supplies and computer loads have significantly altered the traditional AC waveform.

Electrical designs carried out today, take this into account when calculating transformer and conductor sizes. There are many techniques that can be adopted to reduce the harmonic level as much as possible. These range from active filters to isolating transformers. The difficult problem is trying to predict the client harmonic load profile five, ten and twenty years from now.
The important criteria for an MCCB is to always respond to the true root mean square (rms) value of the load current as this is what contributes towards the heating effect of the conductor.

Thermal Magnetic MCCBs are excellent for this as the basic bimetallic strip (responsible for overload protection) will always respond to the true rms value of the load current. The heat produced is directly positional to $I^2R$ so a thermal magnetic MCCB will read the true rms value up to the infinite harmonic.

As mentioned earlier, basic electronic MCCBs responded to the ‘peak value’ of the waveform which resulted in the term ‘nuisance tripping’ being associated with some MCCBs. The more modern microprocessor based MCCB utilizes different techniques to read to the true rms value of the load current. One technique is to use a “sampling and integrating” technique. A sampling interval of 0.5msec would enable an MCCB to read up to an including the 19$^{th}$ harmonic based on ‘Shannon’s sampling’ theorem.

![Sampling the harmonic waveform](image)

*Figure 10. Sampling the harmonic waveform*

The BS standard for MCCBs (BS EN 60947-2) gives guidelines in ‘appendix F’ for MCCBs that state to offer ‘true rms’ value of load current measurement. The minimum frequency to offer a true rms microprocessor MCCB according to the standard is 350Hz, which is only the 7$^{th}$ harmonic on a 50Hz supply.

Whilst this will capture a large majority of harmonics it could still under or over protect the conductor if higher harmonic levels were present. Important triple N harmonics (those that are odd and divisible by 3) such as the 9$^{th}$ and 15$^{th}$ harmonic could be missed.
6.1 Neutral Currents

Electrical installations designed twenty years ago were normally designed using half rated neutral conductors. Back then most small to medium enterprises had one personal computer, today they may have several hundred. Single phase power supplies are one of the culprits responsible for harmonic currents.

The problem with triple N harmonics is that due to the phase angle they arithmetically combine in the neutral conductor. For example L1, L2 and L3 may have say 15% 3rd harmonic current in each phase but these would combine in the neutral conductor. This means that traditionally balanced 3phase system with minimal neutral current flowing has now changed where the neutral conductor can now carry as much current as the phases. This requires the designer to consider overload protection for the neutral conductor.

This phenomena has now been recognised in the new 17th Edition of IEE wiring regulations (BS7671) which contains a new appendix 11(Effects of Harmonics) to help provide guidelines for the system designer. It draws attention to the Triple N harmonics and suggests neutral pole protection should be considered where high harmonic distortion can exist.

Most manufactures can provide this as an option on four pole MCCBs. The UK Copper Development Association (CDA) regularly carries out seminars on harmonics and their effects. They have suggested that due to the growth in harmonics engineers may even need to consider neutral conductors at 150% or even 200% of phase conductors. Some manufactures have responded to this growing trend by developing 200% protected rated neutral MCCBs and ACBs.
7.0 Isolation and Indication

A very important function of an MCCB is to provide the user the facility to isolate an electrical supply so that maintenance work could be carried out on the relevant part of the installation. There are two main parts to this. One is the isolation function itself the other is indication to the user that the contacts have reached the correct isolating distance.

For an MCCB to be suitable as an isolating device and be labelled as such it must meet the requirements for a ‘disconnector ‘ as described by BS EN 60 947-3. This consists of three basic tests:

i. Measurement of Earth Leakage Current
A new MCCB must not exceed 0.5mA per pole. For an MCCB that has experienced two full short circuits (Icu) the maximum permitted is 6 mA

ii. Impulse Voltage test (Uimp) of 8kV
This is applied across the open contacts to ensure sufficient contact gap

iii. Mechanical Strength
This is sometimes referred to as a welded contact test. It basically consists of holding the contact closed and applying a force of three times the normal force(3F) to the handle for 10 seconds. During this period the toggle must not indicate open and no padlocking facility should be able to be connected.

Once these tests have been complete it can be labelled with isolator symbol (Figure 12)

Figure 12.Isolation mark on MCCB label
7.1 Electrical Safety Council -Isolation

Within the UK there are many sources of guidelines/regulations for isolation of MCCBs. These include The 17th Edition of Wiring Regulations and also the Electrical Safety Council.

The latter provides a best practice guide called “Guidance on safe isolation procedures for low voltage installations” which is also applicable to MCCBs.

This guide emphasises that isolation should be made on the main incoming MCCB or switch disconnecter on the switchboard or distribution board. The point of isolation should use a recognised lock system, with the main key or combination held by the person carrying out the work. In the case of multiple operators working on one device or circuit a multi lock hasp should be used. The device should only be used in combination with an adaptor approved by the manufacturer of the isolating device.

With regards to isolation of individual circuits on distribution boards this best practice guide states the following:

“Some distribution boards are manufactured with “Slider switches” to disconnect the circuit from the live side of the circuit breaker. These devices should not be used as a means of isolation for circuits, as they do not meet the requirements for isolation and the wrong switch could easily be operated on completion of the work”

“The practice of placing insulating tape over a circuit breaker to prevent inadvertent switch on is not a safe means of isolation”

![Figure 13. Electrical Safety Council view on Isolation](image)
This is further supported by the fact that any manufacturer who offers manually dependant off load slider switch type devices have printed recommendations to fully isolate the incoming MCCB or switch disconnecter prior to carrying out any maintenance, in essence rendering the ‘slider switch’ useless.

The new 17th edition of the IEE wiring regulation for the first time makes reference to BS EN 60204-1 (Safety of machinery. Electrical equipment of machines. General requirements).

Regulation 537.4.1 states that “where equipment is within the scope of BS EN 60204 the requirements for emergency switching of that standard applies”

This standard gives guideline on “Measures to minimise risk in the event of failure” and “Recommendation for the use of switches having direct opening action”.

It suggests it is good practice to have a direct mechanical link from the toggle to the main contacts. Some operating springs can become weak or even fail. In this case they should not be relied upon for manual opening in an emergency switching condition. Figure 14 below shows a cross section of the MCCB with direct opening action.

Several MCCB manufactures have now incorporated these guidelines for direct opening action into the main mechanism of the MCCB, to provide an enhanced safety function which is beyond the traditional requirements of isolation.
8.0 Present and Future trends

The MCCB continues to evolve in pace with other emerging technologies. Today’s modern MCCBs are smaller and lighter than previous generations. However the demands for increased fault levels, temperature performances, enhanced safety and reliability continues to drive the developments of this important protective device.

8.1 Earth Leakage Protection

The recently published 17th Edition of IEE Wiring regulations place greater demands on the use of earth leakage protection and residual current monitoring devices.

It is a fact that the majority of electrical fires are due to an undetected earth leakage condition around the magnitude of 300 mA or greater. (Regulation 532 refers to “Limit consequence of fault current from point of view of fire risk”)

The traditional method to achieve earth leakage protection on an MCCB would be use a separate earth leakage relay (ELR) and current transformer (CT). Another method was to add an earth leakage block (ELB) to the load side of the MCCB. Both these systems require additional panel space and the ELB can sometimes affect the MCCB temperature performance and cannot be a retrofitted solution.

Several manufacturers can now offer MCCBs with integral earth leakage protection in the same footprint as the MCCB. These are also referred to as Circuit Breakers with Residual protection (CBR).

Figure 15. CBR is an MCCB with integral earth leakage protection
The standard covering this application for Circuit Breakers with Residual protection (CBR) is BS EN60 947-2 Appendix B.

It is also possible to have an ‘earth leakage alarm’ facility which can be set to give an early warning of a potentially dangerous situation rather than a trip function. Many end users are showing a preference for the alarm facility rather than have a critical load trip for an earth leakage condition.

8.2 Integral Measurement Functions and Communication

New microprocessor MCCBs are being developed by several manufacturers that are now fitted with integral LCD displays. Protection and metering used to be treated as separate disciplines within low voltage design. However with advances in electronics many protection relays are now available with on board measuring facilities. The trend started with medium voltage protection relays then evolved to low voltage ACBs about 15 to 20 years ago. Being that bit bigger, it was easier to incorporate both functions on to the ACB. The MCCB presented more of a challenge due to space limitations but these have now been overcome.

The integral LCD monitor can display all the electrical parameters that you would expect to be available on a traditional panel with multi-meters. These include phase currents (including neutral and ground) and voltage, power, energy, maximum demand, harmonic analysis etc. An example of such an MCCB is shown in figure 16.

Figure 16. MCCB with integral monitoring facilities
The added value this solution can provide is that the integral display can offer additional functions beyond what a traditional multi-meter ever could. These include the following:

i Fault Diagnosis
This can show type of fault that has occurred (overload, short circuit or earth fault) and the magnitude and tripping time of the MCCB. This can help achieve faster fault diagnosis and contribute towards reducing downtime. Fault data can be stored and can be compared to previous trips. Similar to a multi-meter all available information can be transmitted to the Energy Management System (EMS) where further analysis of trends and log history can be viewed.

ii Built in Test (B.I.T)Functions
The microprocessor type MCCB can have all its time current characteristics verified by using an external testing device. This would inject currents and allow the tripping time to be read from a display. This is an advantage over thermal magnetic MCCBs that would require a primary injection test for this measurement check. However, even easier is to use an in built test facility that allows this function to be carried out without the need for a separate test device. The user can select if they wish the MCCB to trip or alarm only during such a test.

iii Programmable time current characteristics
Some applications may require the MCCB to ‘change’ its time current characteristic depending on either the load or supply. An example of this could be where a changeover from mains to standby generation/UPS has occurred. The upstream device may have a different rating or time/current curves in this standby mode. To continue to achieve optimum selectivity and protection the downstream device may require to change its settings to accommodate this. This can be done automatically and the new settings can viewed on the local LCD display.

8.3 Condition Based Maintenance facilities

The modern microprocessor MCCBs can provide more information after a fault event. However many end users would of course prefer to know about an issue in advance that may cause downtime within their facility.
In section 8.1 one technique that can be used on the lower rated thermal magnetic MCCBs is earth leakage monitoring.

From an overload protection point of view one of the drawbacks with a microprocessor MCCBs is that they respond to current and not heat.
Some of the most common problems associated with MCCBs tend to be associated with temperature. If an over temperature issue is not detected and corrected this could potentially be a future fire hazard over a long period of time.

Common over temperature problems include

i. **Loose connections**
The terminal bolts that connect the conductor to the MCCB need to be at a certain torque to achieve good conductivity. If these are not tightened correctly or become loose due to vibration from a machine (ie. generator) this could result in their terminal temperature exceeding its design parameters.

ii. **Inadequate ventilation**
The trend these days is to increase packing density of switchboards. Some panels have natural ventilation others have forced ventilation. The Ingress Protection (IP) rating of the switchboard can also be an indicator of how much ventilation is available. Whatever the ventilation facility, if this was to become blocked (dust in louvers) or a fan fail then again this could lead to over temperature issues.

iii. **Contact erosion**
Modern MCCBs are built for high electrical endurance and reliability. A modern 100A MCCB can switch the full load current (100A at 415V) up to 30,000 times. Most MCCBs would never see this kind of switching arrangement. However if the MCCB is unfortunate to have switched several lower short circuits or is daily switching a high inductive or capacitive loads then contact erosion is possible. This increased contact resistance would also result in higher temperatures at the MCCB terminals.

*Figure 17.A 1250A circuit breaker fire damaged from an over-temperature situation*
As a microprocessor MCCB responds to current and not heat, all of the above conditions would not seen by the MCCB as a possible problem. In some severe cases the MCCB may be less than 50% loaded but any one of the above conditions (particularly item 1 or 3) could result in a dangerous terminal temperature. Figure 17 is a real life example of such an incident. The loose terminal connection in the top middle phase resulted in an increased temperature which over a period of time exceeded the limitations of the moulded material. The result was a fire within the switchboard which resulted in 6 weeks lost production time due to this major incident.

An advantage of a thermal magnetic MCCB is that it would ‘self protect’ in all of the above conditions due to the nature of detecting overloads. Thermal imaging is a very useful technique which can greatly assist in detection of hot spots. However this is a one time event and does not provide 24/7 coverage.

MCCB manufacturers are responding to this by offering an option of thermistors that would fit onto the line and load terminals of the MCCB. A basic LED indication facility could show green for healthy, amber to indicate maintenance should now be planned and red to indicate an immediate problem. A volt free contact would then be used to signal the EMS system. The next development of this would then to communicate real time temperature measurements of all phase.

9.0 Conclusion

The MCCB is much more than a basic switch within the low voltage distribution network. It is an important safety device whose main purpose is to protect the conductors within the installation. As such it demands more than a paragraph in the electrical specification document to ensure it can adequately support the application for which it is intended.

A detailed knowledge of the circuit breaker standards it not too important so long as the specifying engineers has an understanding of the basic requirements of the MCCB. That is to carry (In), break (Icu) and make current (Icm) safely.

The standards are there to determine minimum levels of safety for the MCCB. The specifying engineer needs to decide if the nature of the installation requires higher margins of safety. This could be relevant to breaking/making capacities or temperature/harmonic requirements within the system.

The recently published 17th edition of IEE wiring regulations also provides additional guidance on the topics of overcurrent protection, isolation and harmonics.
Ensuring that the MCCB has a basic adjustment of overload and short circuit protection will enable the protective device to be more flexible. This does not mean that we always need to use microprocessor MCCBs as the basic thermal magnetic MCCB still has a number of advantages such as cost, temperature response, harmonic measurement and DC application.

Developments of MCCBs will continue to add value to the protection of the low voltage network. Recent trends in earth leakage protection, measurement facilities and condition based maintenance options will provide design engineers new options to enhance their clients system to maximise uptime.

In closing, it is important that state that where detailed MCCB specifications exist, it is important to make sure that they are up to date with current legislation and are ‘truly’ generic in nature. Several of the leading MCCB manufacturers can offer appraisals on circuit breaker specification documents to ensure full compliance and ‘openness’.
10. References and Acknowledgement

1. IEC Low –voltage and controlgear standards  
   BS EN 60 947-1 General Rules  
   BS EN 60 947-2 Circuit Breakers  
   BS EN 60 947-3 Switch Disconnectors

2. BS EN 60204-1  
   Safety of machinery. Electrical equipment of machines. General requirements

3. BS:7671  2008  
   Requirements for Electrical Installation  (IEE Wiring Regulations 17th Edition)

4. Electrical Safety Council  
   Best Practice -Guidance on safe isolation procedures for low voltage installations

5. Terasaki Electric-TemBreak2 MCCB Catalogue  
   Reference 07-161EU