Bidirectional protective devices

By: **Michael Peace CEng MIET MCIBSE**

With the advent of alternative supplies such as solar photovoltaic (PV) and energy storage systems, power flows in both directions and bidirectional power flow is something that needs to be considered with respect to certain protective devices.

This article looks at the selection and erection of protective devices for other sources, such as PV and electrical energy storage systems, as highlighted in the recently published BEAMA bulletin *Connection of unidirectional and bidirectional protective devices*.

What is a unidirectional protective device?

Unidirectional protective devices are marked to indicate the line and load terminals and are designed to work when the power can only flow in one direction, i.e., from supply to load. It is vital to observe the connection details.

Single-module sized residual current breakers with over-current protection (RCBOs) have been available for several decades and utilize electronic circuits to provide residual current protection. These compact RCBOs contain electronic components and are typically unidirectional. Arc fault detection devices (AFDDs) are also typically unidirectional.

The product standard for RCBOs states that if it is necessary to distinguish between the supply and load terminals, they shall be clearly marked, for example, by line and load placed near the corresponding terminals or by arrows indicating the direction of power flow. Therefore, if a device is marked line, load, with arrows etc, it is indicating that it is necessary to distinguish between the supply and the load terminals. Not all compact RCBOs are unidirectional. Some RCBOs employ technology/solutions that ensure that the RCBO is not damaged when supplied in either direction and these are bidirectional.

What is a bidirectional protective device?

A protective device that does not have markings to indicate line and load terminals is a bidirectional device, where power flow in either direction will not cause damage.

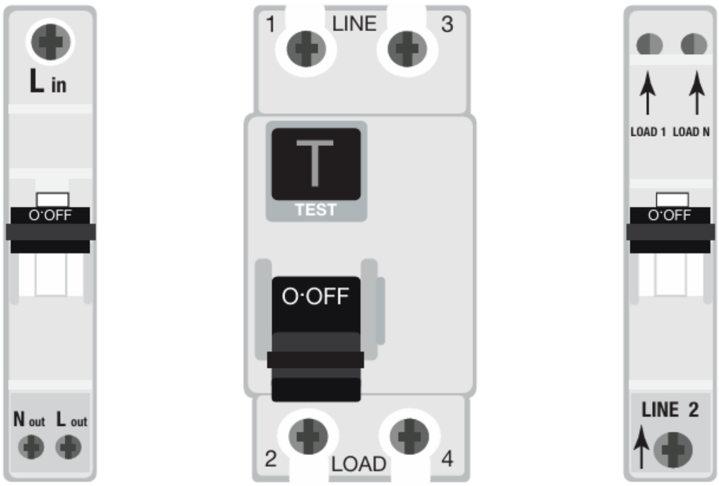
The 'typical' residual current circuit-breaker (RCCB) is an electromechanical device, however, electronic RCCBs also exist. RCCBs for consumer units are in the form of a two module-sized device. These devices are not usually marked in and out, and therefore are bidirectional. In some cases, RCCBs are marked to indicate the terminals to which the neutral or line should be connected.

Single-phase RCBOs are available in a single module, known as 'compact', and two module sizes. Two module RCBOs are not usually marked as with circuit-breakers (CBs), and thus are also bidirectional.

How are unidirectional protective devices marked?

Where required, protective devices such as CBs, RCCBs, RCBOs and AFDDs feature a marking on the device to distinguish between the supply and load terminals. This can be marked in a number of ways such as, line and load, in and out, or by using directional arrows to indicate the power flow. The connection details are shown in Figure 1.

Figure 1 Protective device connection details



Can unidirectional protective devices be used for other sources, such as PV systems?

In addition to Section 712 of BS 7671:2018+A2:2022, PV systems are also covered in Part 8 of BS 7671:2018+A2:2022 which covers prosumer's electrical installations (PEI). Regulation 826.1.2.2 states current flow and polarity should be taken into account. As with all electrical equipment, it is important to take account of manufacturer's instructions, Regulation 134.1.1 and 510.3 of BS 7671:2018+A2:2022 refers.

Where an additional source in parallel to the low voltage (LV) electrical supply is present, such as a PV generator in, the installer is faced with a dilemma. The issue is that it is not possible to follow the line and load convention where two supplies are present.

Unidirectional protective devices should not be used for such power sources as the power flow could be in either direction. Applying a power source to the load terminals of a unidirectional RCCB/AFDD will, under certain circumstances, result in damage to the electronics, rendering the residual current protection inoperable.

Doesn't the inverter shut down automatically in the event of a short circuit or loss of mains?

The power electronic converter system (PECS), or more commonly known as the inverter, is designed to shut down, very quickly, typically milliseconds, in the event of a fault or loss of supply. The maximum trip time for loss of mains for modern PV inverters, according to EREC G98, is up to 0.5 seconds, however, some older PV inverters may have a trip time of up to 2.5 seconds.

The concern highlighted by BEAMA is that a voltage present on the outgoing terminals of the protective device, either due to the device operating in the event of an earth fault or by use of the functional test button, could cause irreparable damage.

Are residual current devices (RCDs) required for PV systems?

RCDs are not required for PV systems per se, but they may be required for other reasons, such as fault protection in TT systems or for additional protection where the AC PV inverter supply cable is buried in a wall.

The majority of PV systems are likely to be retrofit, where the cable used for the AC PV inverter supply circuit is installed surface mounted using steel wire armoured (SWA) cable. Therefore, RCD protection would not be required for additional protection in this case.

Some manufacturers discourage the use of RCDs for inverters due to leakage currents. Where possible, it is best to design it out and provide other methods of protection where required.

Where RCDs are required for generators intended to be used in parallel with the distribution network, it is important to ensure they are bidirectional.

How does this affect existing installations?

When considering existing installations, such as when carrying out an electrical installation condition report (EICR), it is important to keep things in perspective. If the electronic circuit within a RCBO was damaged by voltage on the outgoing terminals, the thermal/magnetic part of the device would still operate, providing overload and short-circuit protection.

For TT systems, RCDs are installed to provide fault protection for the protective measure with automatic disconnection of supply (ADS). Failure of the RCD could be a serious safety issue and would require urgent remedial action.

In a situation where an RCD has been installed for additional protection, such as for cables buried in a wall, if the RCD were to fail, it would be a no more dangerous situation than an electrical installation from BS 7671:1992, the Sixteenth Edition of the IEE Wiring Regulations, when additional protection was not included in the standard at that point.

It's important to remember that the requirements of the latest version of BS 7671 are not retrospective. The Electrical Safety First (ESF) Best Practice Guide (BPG) 4 guidance states that a recommendation for improvement is appropriate for the absence of an RCD for cables buried in a wall. However, the inspector must make an engineering judgement based on the situation.

The guidance in the BEAMA *Technical Bulletin* is that "proportionate action" is required and it is recommended to contact the protective device manufacturer, seeking their advice as to the correct course of action.

Other considerations for RCD selection for generators

It can be easy to think only of Section 712 when considering PV systems. It sometimes gets overlooked that PV systems are in fact generators, which are covered in Section 551 of BS 7671:2018+A2:2022, and it is important to remember that the general requirements also apply.

Regulation 551.7.1 of BS 7671:2018+A2:2022 provides requirements where a generating set may operate in parallel with the distribution network, such as a PV system. It states that where an RCD is providing additional protection in accordance with Regulation 415.1 for a circuit connecting the generator set to the installation, the RCD shall disconnect all live conductors, including the neutral conductor. This can be in the form of a double-pole or single-pole with switched neutral protective device. It is important to check as some compact RCBOs are only available as single-pole devices. This requirement has been included in BS 7671:2008.

It is important to select the correct type of RCD according to DC residual current to prevent the RCD being blinded. Regulation 712.531.3.5.1 of BS 7671:2018+A2:2022 provides requirements for RCDs for solar photovoltaic (PV) power supply systems. It states that where an RCD is used for protection of the PV AC supply circuit, the RCD shall be of Type B according to BS EN 62423 or BS EN 60947-2, unless the inverter or installation provides at least simple separation between the AC and DC side or the inverter does not require a Type B RCD as stated by the manufacturer, based on their instructions.

Summary

Bidirectional power flow of generators or energy storage systems must be considered when selecting protective devices. Unidirectional protective devices are not suitable for other sources, such as PV and battery storage systems.

There is no requirement for RCDs for PV systems as such, however, this is dependent upon the installation characteristics. To avoid unwanted tripping due to leakage currents, design the circuit in such a way that RCD protection is not required.

Where RCDs are required for PV systems, they must switch all live conductors, including the neutral. It is important to select the correct type of RCD according to the expected level of DC residual current to prevent blinding, where a Type B would be most suitable. It is important to take account of manufacturer's instructions.

The product standard for RCBOs states that if it is necessary to distinguish between the supply and load terminals, they shall be clearly marked for example, by line and load placed near the corresponding terminals or by arrows indicating the direction of power flow. It is important to check with the manufacturer of the protective devices to confirm their suitability for bidirectional power flow.

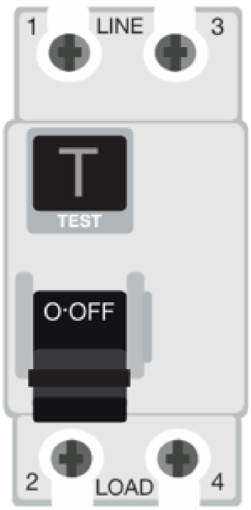
Acknowledgments

I would like to thank the following individuals for their contributions to this article:

- BEAMA
- Frank Bertie (NAPIT)
- Neil Bridgeman (RIA)
- Mark Coles (IET)
- Darren Crannis (ECA)
- Jon Elliot (Certsure)
- Leon Markwell (IET)
- Craig O'Neill (IET)
- Gary Parker (ECA)
- SELECT

Further reading

[BEAMA Technical Bulletin - Connection of Unidirectional and Bidirectional Protective Devices]



Mythbuster #10 “Event distribution boards with socket-outlets are not permitted for use on construction sites.”

By: **James Eade**

This myth stemmed from a query from a colleague and, having discussed it with a distribution board manufacturer, it appears it is not an unusual issue. The concern is that distribution boards which are fitted with connectors (exampled in Figure 1) are not as suitable for use in a typical construction environment, unlike typical steel framed boards to which incoming and outgoing circuits are manually terminated (as illustrated in Figure 2).

Figure 1 Distribution board fitted with plug and socket connectors

Figure 2 Rewireable metal-cased distribution unit

Many rental companies are moving over to preassembled extension leads and distribution boards as the equipment can be reused time and again without waste. It also saves time on-site, allowing functional systems to be erected and commissioned quickly using pre-terminated and pre-tested equipment.

There are three standards of relevance for this application. Firstly, BS 7671 *Requirements for Electrical Installations* has, in addition to the general rules, additional requirements for construction and demolition sites in Section 704. The second standard is BS EN 61439 *Low-voltage switchgear and controlgear assemblies* and particularly Part 4 of that standard, BS EN 61439-4 *Low-voltage switchgear and controlgear assemblies. Particular requirements for assemblies for construction sites (ACS)*. The final one is BS 7375 *Distribution of electricity on construction and demolition sites. Code of practice.*

As always, it pays to start at the beginning to trace the requirements. Part 1 of BS 7671 (Scope, Object and Fundamental Principles) requires the designer to consider the environmental conditions to which the electrical installation will be subjected to (Regulation 132.5.1) and equipment should be selected, taking into consideration the conditions of the installation (Regulation 133.3), and to ensure that equipment complies with appropriate standards (Regulation 133.1).

Moving through BS 7671, Regulations 511 and 512.2 reinforce the requirements for compliance with standards and equipment selection according to external influences respectively. Notably, Regulation 512.2.2 does state that:

If the equipment does not, by its construction, have the characteristics relevant to the external influences of the location, it may nevertheless be used on condition that it is provided with appropriate additional protection in the erection of the installation.

These requirements are expanded on in Section 704. In respect of Regulation 511, Regulation 704.511.1 details which standards as follows:

All assemblies on construction and demolition sites for the distribution of electricity shall be in compliance with the requirements of BS EN 61439-4. Plugs and socket-outlets with a rated current of 16 A up to 125 A shall comply with the requirements of BS EN 60309-2. Plugs and socket-outlets with a rated current exceeding 125 A up to 800 A and where interchangeability is not required shall comply with BS EN 60309-1.

Regulation 704.512.2 expands on the types of environmental factors to which equipment may be subject as follows:

Consideration shall be given to the risk of damage to electrical equipment by corrosive substances, movement of structures and vehicles, wear and tear, tension, flexing, impact, abrasion, severing and ingress of liquids or solids.

Note that Regulation 704.511.1 refers to BS EN 60309-2 connectors (‘Commando’ or ‘Ceeform’ types) which is of course a characteristic of the distribution boards shown in Figure 1. Regulation group 704.522.8 goes on to state requirements for cable, noting that H07-RNF types should be used for low voltage supplies which are commonly used with BS EN 60309 connectors in this application. The common single-pole connectors used for supplies over 125 A (often referred to by the brand name ‘powerlock’) are also catered for in Regulation 704.511.1.

With these requirements in mind, it can be seen that BS 7671 does not preclude the use of such distribution boards if they comply with BS EN 61439-4 and where connections are made by plug and socket, that the connections use BS EN 60309-2 connectors as depicted in Figure 1.

In respect of compliance with standards, distribution boards should be manufactured to BS EN 61439-1 and additional specific requirements for assemblies for construction sites (ACS) are given in BS EN 61439-4. This has requirements for service conditions such as ambient air temperatures, humidity and pollution levels. Part 4 also has specific requirements for labelling, handles, accessible parts and terminals for external conductors. Notably, this has requirements for terminals for external conductors, stating “All connections shall be rewireable or shall be socket-outlets.”

Assuming the distribution unit is constructed to comply with Part 1 of BS EN 61439, suitably IP rated and complies with the additional mechanical, impact and corrosion requirements of Part 4, there are no particular requirements that would preclude the use of the distribution boards exampled in Figure 1.

Finally, there is the Code of Practice for *Distribution of electricity on construction and demolition sites*, BS 7375. The current version is dated 2010 and is in need of revision in places, not least to review the out-of-date references. As well as general requirements for robustness, it does state inter alia that:

Distribution equipment in site installations should embody the following features: a) flexibility in application for repeated use on contract work, i.e. to allow easy substitution of components for specific duty as might be required from site to site; b) suitability for transport and storage.

The distribution boards examples in Figure 1 fulfill both these requirements admirably. They have long been in used in events and entertainment where such portability and robustness are key factors as they are often used in different locations on a daily basis and in quite arduous conditions.

Assuming a distribution board complies with BS EN 61439, there is no reason why it cannot be used on construction sites whether fitted with connectors or other terminations. Even if the mechanical or IP rating requirements cannot be complied with, BS 7671 does allow for additional measures to be put in place to achieve an equivalent level of protection.

IET Guide to Temporary Power Systems – an update

By: **James Eade**

The IET's *Guide to Temporary Power Systems* is undergoing a long-awaited update. Much has changed since the first edition published in 2012, not just in respect of the British Standards BS 7671 and BS 7909, but also with the temporary power industry in general. Perhaps the most significant progression has been in renewable energy; the revised guide has a section on battery storage which is increasingly common in events, construction and similar. With the draft guide now out for public review, it has seen a raft of changes and this article gives an overview of what the more significant ones are.

The use of transportable battery systems allows hybridization of generator packages which is important in the move to Stage V emissions compliant diesel engines. Running such generators on low loads often results in unexpected shut-downs as the exhaust temperatures do not get hot enough for the emissions filters to work effectively; hybridizing a system with energy storage allows the generator to work hard for shorter durations, bringing the exhaust temperature up and alleviating the problem. As the generator will usually operate in parallel with the battery unit, it is important to consider earthing arrangements and the effects of circulating currents.

Along with these issues, the updated guide looks at the considerations around energy storage capacities as well as how battery units can integrate into generation systems, such as working in a simple hybrid mode or as a mini-grid with other generators operating in a load-on-demand configuration, for example.

On the subject of generators, generator control and operation has been updated and now includes guidance on parallel operation of sets, leading power factors and the stability of generator sets powering capacitive loads, such as switched-mode power supplies, as commonly found in most modern equipment and lighting. The (often vexed) question over generator earthing – or lack of – has been significantly revised to take into account the previous work published in the IET's *Practitioner's Guide to Temporary Power*. Importantly, the requirements for effective electrodes are explained along with the typical failure modes experienced with temporary systems, demonstrating the relationship between the protection installed on the generator output and the value of the electrode resistance achieved on site. This section reflects the latest best practice which has yet to be reflected in relevant standards.

Another section to receive a makeover is mobile and transportable units, which range from temporary site huts and office cabins through to complex broadcast vehicles. In general, the requirements relating to equipment selection detailed in Part 717 of BS 7671 are quite straightforward, but the design is sometimes less so. There are diagrams in Part 717 which give examples of how the supply and earthing arrangements to a unit may be configured, but understanding the benefits and drawbacks of each can be a challenge. These are all explained in the revised section, in particular the benefits of transformer-based designs with respect to mitigating shock risks in the event of supply neutral (PEN) conductor failure where units are connected to the public distribution.

Protective earthing has been revised to provide more guidance on determining extraneous-conductive-parts and the appropriate requirements for protective bonding. In a similar vein, the need to join electrical environments is often necessary where multiple supplies are operating in proximity to each other. This has been considered in more detail (including fault current paths), building on the guidance in BS 7909.

Supply resilience is increasingly important in installations as well as with temporary systems. The section on uninterruptible power supplies has been updated and now includes information on the hazards associated with neutral switching on UPS inputs for example, as well as looking at how inverters behave when faults occur on the output, which can vary between designs. Supply resilience in the event of emergencies is important for events where there may be large numbers of the public present. Systems may have to be kept operational for crowd control purposes and this is very important for outdoor events where the thunderstorms roll in. The guide has a completely revised section on management of the temporary systems when lightning is forecast, taking into account recent industry guidance on the subject.

While these are headline changes, there are of course a significant number of updates arising from the revisions to BS 7671 and BS 7909. The former has undergone a range of changes since the first edition of the book, with salient topics including cables in escape routes, the use of Arc Fault Detection Devices, Surge Protective Devices and the application of 30 mA RCDs on socket-outlets rated at 32 A or less. BS 7909:2023 has also seen a major revision, the last being in 2011. Many of the changes reflect those in BS 7671, whereas others relate to generator operation, earthing and renewables, for example, which are explored in more detail in this guide.

While the underlying theme of the book is temporary power for events, the advice and guidance on temporary power, generally from generators to cable selection and design methodologies, will be useful and appropriate for many other sectors using temporary electrical systems. This is reflected in the revised title for the book: *Guide to Temporary Electrical Systems*.

The draft has been released for public review – to read and send in comments, visit the DPC page here.