

Reliable circuit protection – a vital backbone for your machine. Build it in.



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EAT•N

Powering Business Worldwide



Maximizing uptime, productivity and safety with an effective circuit protection strategy.

Manufacturers in all types of industries want high throughput machines with solid performance as much as they ever did. Reduced operating costs and increased safety are also essential. However as machine builders work to meet these demands, they face ever-greater challenges from an increasingly global marketplace. Against tough competition, they must deliver faster and at lower prices while facing shorter product lifecycles and rising costs.

Additionally, end users are progressively trending towards focusing on their core competencies, while outsourcing other issues back to their machine suppliers. Another trend is that, due to higher reliability of technical installations, fewer technicians are available for maintenance or complex operations, while the increasing complexity of the machines installed and technology used requires more expertise and multiple technologies to achieve optimal protection. To mitigate this, machines must be designed to be as simple and safe to operate and maintain as possible.

End users and their suppliers must also ensure full compliance with safety standards as new legislation comes into force and existing regulations evolve. Acceptance of injury or accidents involving operators, due to inadequate machine safety, has sharply reduced and modern legislation reflects this.

Machine builders can gain a competitive edge while improving their customers' profitability by improving their understanding of circuit protection technology. This is an area that's wide-ranging and complex, yet the results of working with a suitable circuit protection specialist can be very rewarding. As well as enhancing safety for operators, the right circuit protection can eliminate or significantly reduce loss of production through nuisance tripping, power blackouts, equipment failure or damage due to let-through of excess electrical energy caused by overload currents, overvoltage or other reasons.

Productivity and uptime is maximized by ensuring that if a fault develops, only the power circuit local to the fault is shut down; the rest of the system continues production without interruption. Correct protection also improves uptime for the affected circuit by interrupting power before it can cause serious and permanent damage. Additionally, many modern circuit protection components provide local or remote indication of their status and can warn of impending problems. This makes pre-emptive maintenance easier and further reduces downtime.

Secondly, a machine, once designed, may need to be reproduced for installation into different customer locations around the world – while being expected to perform to a consistent standard, and

comply with local conditions and legislation. It takes a partner of a certain size to understand these issues, advise on and provide the local variants required.

To better understand how to develop a competitive and effective circuit protection policy, we can start by looking at the power infrastructure a machine builder typically has to provide as part of his delivery to a manufacturing end-user. We can then consider the electrical faults and problems that can occur within this infrastructure and their possible consequences. This information will allow us to discuss the circuit protection components and strategies available to solve these issues.

A machine builder may typically deliver a single machine or set of machines to an end-user for integration into their production line. Equally though, the supply could comprise a full production line or an entire 'packaged factory'. Solutions such as these include a complete power infrastructure, distributing electricity from the main intake, throughout the production area and into each individual machine. For most factory environments, voltage levels will be at 400 or 415 VAC three-phase, stepped down to 220–240 VAC single phase. Additionally, many controllers, sensors and actuators operate on 24 VDC.

However, the success of any circuit protection strategy depends very much on choosing the right partner, for a couple of important reasons. Firstly, circuit breakers, fuses and other devices rarely work best as standalone items. They are usually designed into hierarchical power systems where responsibility for protection is shared among components according to their position in the overall layout. It therefore makes sense to source all these elements from a single partner that can guarantee their efficacy in working together, and can advise on building a balanced solution.

At this point, it's worth making a brief mention of DC power distribution as an alternative to using AC power – for example, distributing power throughout a production line or factory area at, say, 380 VDC rather than 415/240 VAC. Although currently unusual in a factory environment, some awareness of its possibility and implications is helpful. As photovoltaic applications become more popular, DC voltages of this level are beginning to make an appearance. Additionally, some industries and applications including data centres are starting to use DC instead of AC voltage distribution; they are achieving improved energy efficiency by reducing the number of AC/DC conversions across the system. There is also some discussion within the industry about the possibility of using intelligent DC power networks for high-efficiency industrial drive systems.

By contrast, DC power distribution at 24 V has for a long time been widely used in manufacturing environments. It is an established level for distributing power between electronic controllers such as PLCs and the sensors and actuators they are interacting with.

If a higher voltage DC-distribution scheme is used, it does pose special challenges to circuit protection components. AC current limiting circuit breakers can open in as little as two or three ms to minimise the energy let through. As voltages and currents rise, however, this becomes harder to do; use of the zero crossing point becomes an increasingly important factor in the circuit breaker's opening behaviour. Above 1000 VAC it becomes essential. As a DC supply has no such zero crossing, DC circuit breakers must rely entirely on their own capabilities in opening quickly and minimising the energy they pass.

Possible fault conditions and their potential consequences

In practice, most factory circuits and machines will include the cables, switchgear, step-up and -down transformers, induction motors, power electronics such as frequency inverters, local control panels and user interfaces, distribution panels and motor control centres. There will also be PLCs, meters and other controllers, together with their associated sensors and actuators.

The fault conditions that may arise can be broadly classified as over-currents, residual or leakage currents, arcing faults, shock hazard, and surges induced by lightning strikes or neighbouring equipment. All represent a hazard to operator safety as well as a risk of equipment damage.

Over-currents can be caused by harsh environments, general deterioration, damage from accidents or natural causes, excessive expansion or overloading of the distribution system. They can be either overload or short-circuit currents. An overload current exceeds normal operating currents, but is confined to the normal conducting paths through the conductors and other components and loads of the distributed system. A short-circuit current, however, flows outside the normal conducting paths.

An overload, frequently between one and six times the normal current level, is usually caused by a harmless temporary surge that occurs when motors start up or transformers are energised. Since they are of brief duration, any temperature rise is trivial and has no harmful effect on the circuit components; protective devices should not react to them. However, overloading can become continuous if caused by defective motors, worn bearings, overloaded equipment or too many loads connected to one circuit. Such overloads are destructive and must be cut off by protection

equipment. However since they are of relatively low magnitude compared with short-circuit currents, their removal within a few seconds to many minutes will generally prevent equipment damage. If sustained though, overload current causes over-heating of conductors and other components while causing insulation deterioration. This may eventually result in severe damage and short-circuits if not interrupted timely.

Unlike overload currents' modest values, a short-circuit or fault current can be many hundred times larger than normal operating current levels, rising possibly to 50,000 A or more. If not cut off within a few milliseconds, damage and destruction can become rampant, with results including severe insulation damage, melting of conductors, metal vaporisation, ionisation of gases, arcing and fires. Simultaneously, high level short-circuit currents can develop huge magnetic-field stresses. Magnetic forces between bus bars and other conductors can be many kilograms per linear metre; even heavy bracing may not be adequate to prevent warping or distortion beyond repair.

Residual or leakage currents are not as large or energetic as short-circuits, but if a leakage current as low as 30 mA is allowed to flow through a human being for more than a small fraction of a second it can cause cardiac arrest or serious harm. Further injury, in many instances, can be caused if a person falls after receiving a shock. Accordingly, power distribution systems must include residual current device (RCDs) that open when they detect an imbalance between energised line and neutral conductor currents. Any such imbalance normally indicates a short circuit or other electrical anomaly. Apart from electric shock risk, there is also the danger of fire arising from excessive residual currents.

However, machine systems often include frequency converters for variable speed drives, and these also generate operational earth leakage currents. Therefore it is essential that any RCD used reacts adequately to fault currents that are actually dangerous, without 'nuisance tripping' in response to normal drive system earth leakage currents.

An abnormal arc in an electrical system is referred to as an arcing fault. If uncontrolled, it can release sufficient energy to cause extensive equipment damage or serious injury to personnel. Additionally, it can cause widespread harm by igniting a fire. Both serial and parallel arcing events can be caused by insulation faults, breaks in a conductor, loose contacts or damaged conductors within the electrical installation or equipment connected to it.

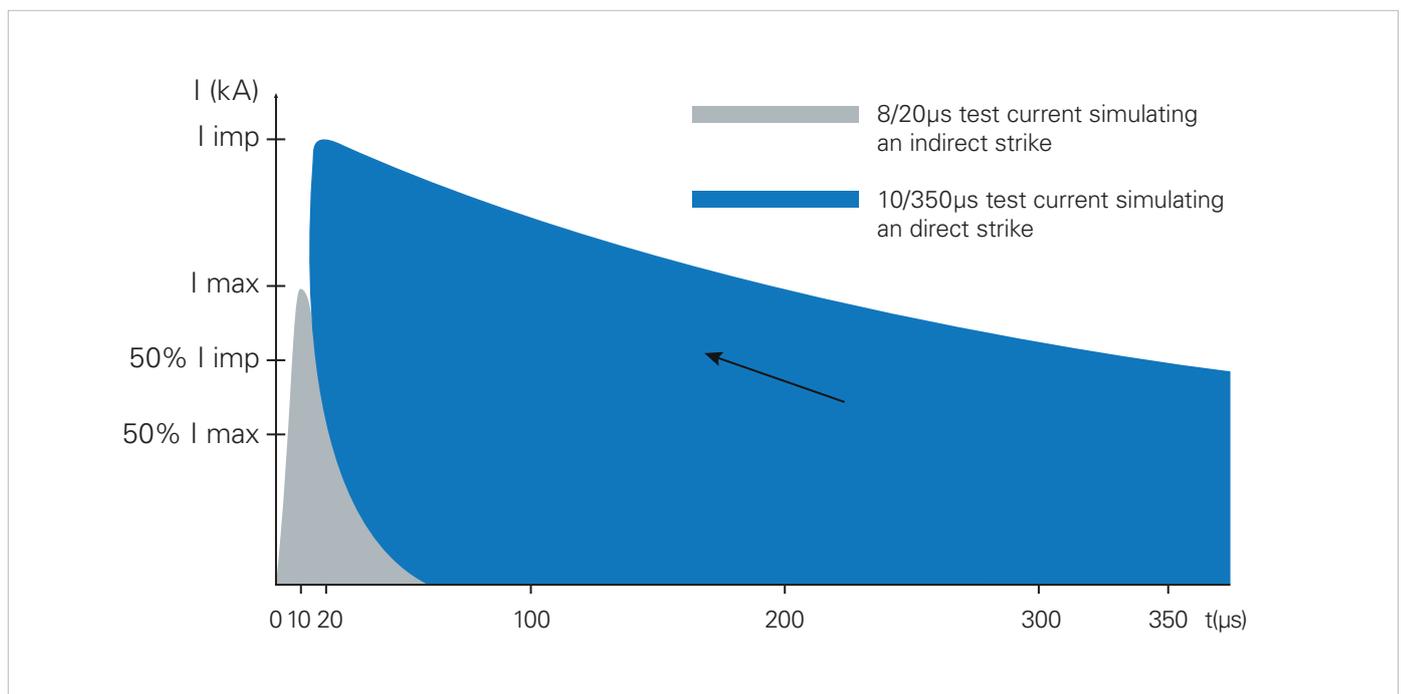


Fig. 1: Surge current caused by lightning strike

Current-Limitation – Component Protection

A non-current-limiting protective device, by permitting a short-circuit current to build up to its full value, can let an immense amount of destructive short-circuit heat and magnetic energy through before opening the circuit.

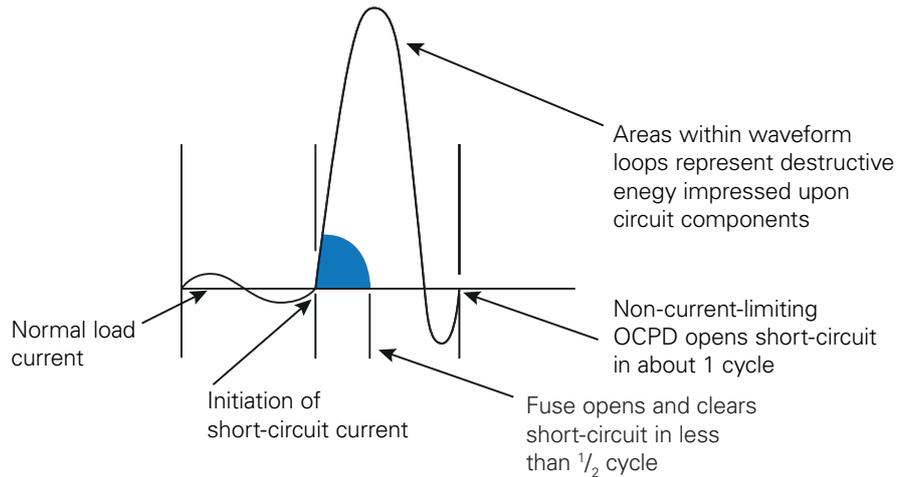
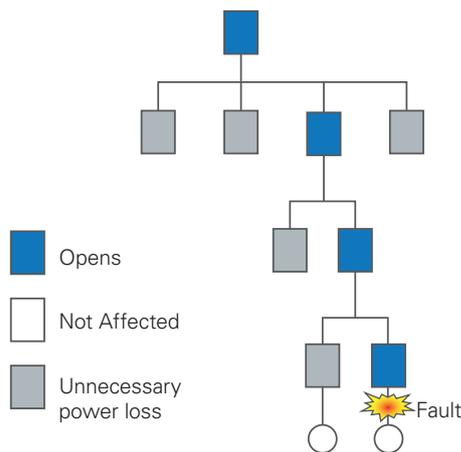


Fig. 2: Showing how current-limiting devices prevent the flow of destructive energy

Selective Coordination: Avoid Blackouts

Without Selective Coordination



With Selective Coordination

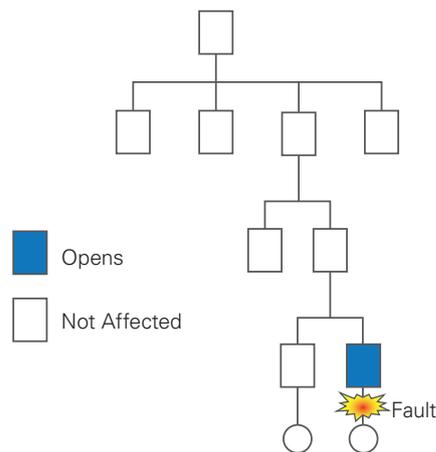


Fig. 3: Using selective co-ordination to minimise power loss and blackouts

Because arcs typically cause neither over-currents nor residual currents, circuit breakers cannot detect them or provide protection. Electrical installations therefore need protection devices that can respond fast to potentially dangerous arc events, without nuisance tripping.

The need for surge protection across the distribution network has grown steadily with the ever-increasing use of microprocessors and other sensitive electronic components used in computers, programmable logic controllers and other commonly used electrical and electronic equipment. Surges can wreak havoc on equipment, causing catastrophic failures, process interruptions and premature ageing leading to failure. Causes can be external events such as lightning or grid switching; however internal items such as fluorescent lighting ballasts, light dimmers, photocopiers, fax machines and variable frequency drives are more frequent catalysts. Fig. 1 shows the profile of a transient overvoltage caused by a lightning strike.

Circuit protection devices

Above, we have seen the problems that can arise in a typical manufacturing electrical distribution system, and their potential for

damage to people and equipment. Now we will look at the various types of circuit protection equipment available, the relative merits of different technologies and products for different protection applications, and how all these devices can complement one another within an overall protection strategy.

Over-current protection

The two fundamental product families that protect against over-current are fuses and circuit breakers. There is some belief that circuit breakers are a more modern replacement for fuses, however this is not the case, especially within manufacturing OEM applications. In fact they have complementary roles, with both often being used within a single system. The key fuse advantage is their fast response; they can open within a quarter cycle of a fault event, compared with the half-cycle or more required by circuit breakers. High fault currents are therefore prevented; this 'current-limiting' ability makes fuses attractive for many applications – particularly those involving power electronics such as insulated-gate bipolar transistors (IGBTs) and other semiconductor devices within power electronics systems. Cable and switchgear specifications can be reduced, saving costs and space, as fuses protect them from carrying excessive fault currents.

Fuse features and parameters are specified by standard IEC 60269: Low-voltage fuses. There are several parts to this standard, where parameters and types of tripping characteristics are specified. These include gG for line protection; gM, aM for motor protection; gR, aR for protection of semiconductors and others.

Fuses have a number of ratings that must be specified to ensure obtaining the best device for an application. Voltage rating is important; it must be at least equal to or greater than the circuit voltage. It determines the ability of a fuse to suppress the internal arcing that occurs after the fuse link melts and an arc is produced. An insufficient voltage rating will impair the fuse's arc suppression capability and it may not clear the fault properly. Every fuse must also have a specific amp rating, which should not exceed the current carrying capacity of its host circuit. Under some circumstances, however, the rating can be greater; for example in motor circuits, dual rated fuses such as 100M125 have similar characteristics to the 125 A gG fuse with 100 A continuous current rating to allow for fusing on cables rated up to 100 A.

A fuse's interrupting rating describes its ability to withstand the destructive energy of short-circuit currents. If a fault current exceeds this rating, the fuse may actually rupture, causing additional damage. Standard IEC fuse links typically have a breaking capacity of 80 kA or 120 kA, while some specialist IEC high speed fuses have 200 kA breaking capacity, which is sufficient for most applications.

Protective devices (fuses, and as we shall see, circuit breakers) can be co-ordinated to prevent power outages or blackouts caused by overcurrent conditions. This co-ordination can be 'selective', meaning that only the fuse nearest the fault opens while larger upstream fuses remain closed. As Fig. 3 shows, the

faulty circuit is isolated while the rest of the system continues operation without downtime. Modern fuses can be simply selectively co-ordinated by maintaining a ratio of approximately 1.6 of fuse-amp ratings between upstream and downstream devices. However, this ratio should only be used as a guide and fuse co-ordination should be done using the time current curves and $i2t$ values for the selective devices. General rules for co-ordination of low voltage devices regarding selectivity and back-up protection in electrical installations are mentioned in several standards, including IEC 60364-1 and IEC 60364-5-53.

Help with fuse selection is often useful, if not essential. The breadth of applications where fuses can be used, together with the depth of choice available is vast. Eaton, for example, catalogues 8500 different fuse types – although this may be an unusually large range.

Circuit breakers, by contrast to fuses, are resettable, in some cases even remotely. For some applications, the ability to reset a circuit breaker from a central location rather than having to send a technician to site provides an overwhelming argument. Circuit breakers also perform better than fuses in circuits with inductive loads such as motors or transformers that draw heavy transient start-up currents. They can more easily be set to open on genuine faults, without 'nuisance tripping' during the inductive transients.

Additionally, circuit breakers have adjustable protection characteristics suitable for many different applications, whereas a fuse with exactly the right parameters must be selected for each individual application. Also circuit breakers provide other functions such as Emergency Stop and mains switching. For example, Eaton's NZM circuit breakers provide the required multiple functions in just one single device. They combine overcurrent protection with highly variable, modular rotary handle solutions

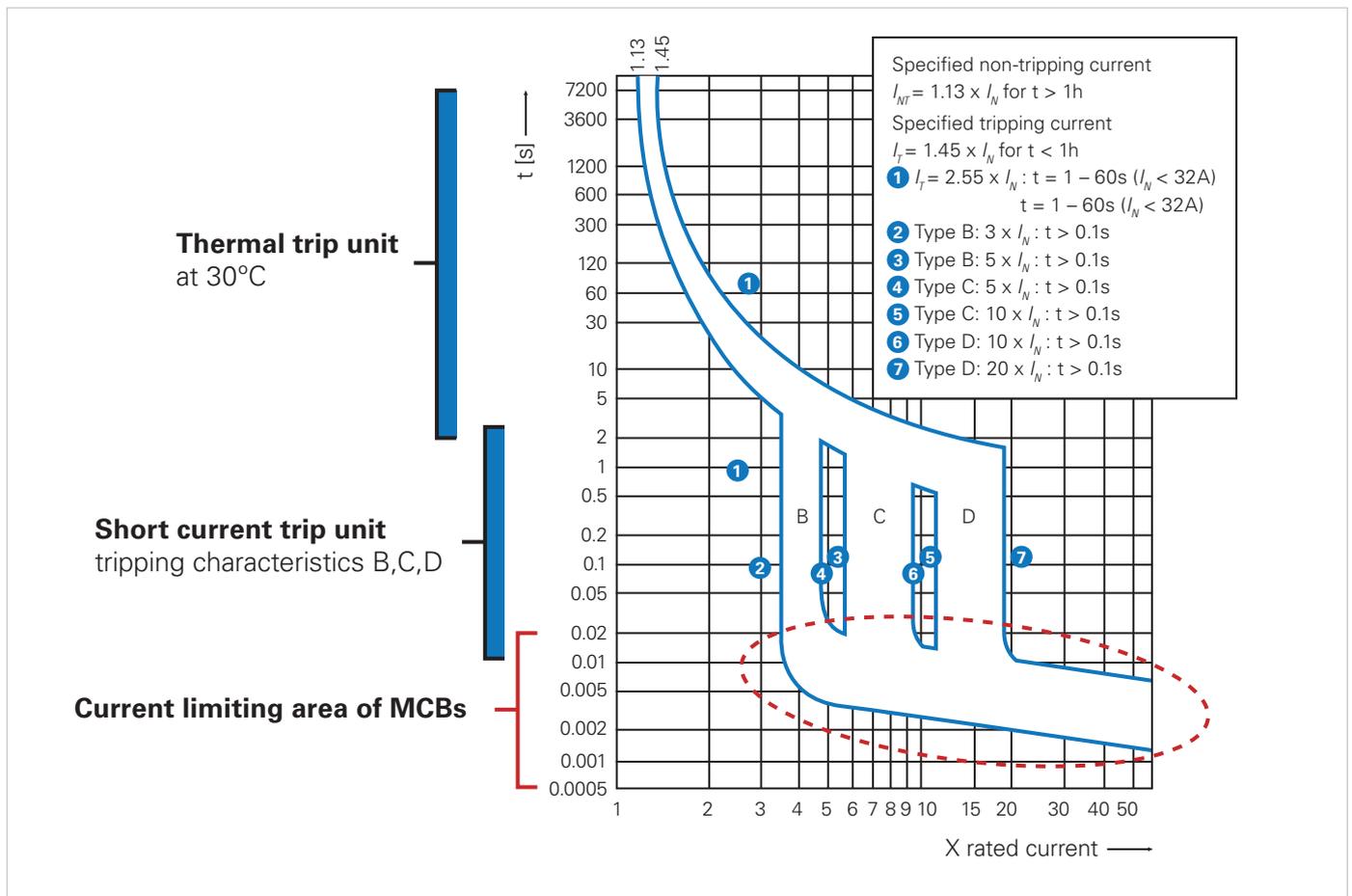


Fig. 4: B, C and D tripping characteristics for miniature circuit breakers

and circuit interruption for emergency-stop application, fitting even the most challenging installation requirements. Rotary handles are adaptable for example with side and rear mounting and thus fitting to most applications. From 24 VDC up to 1000 VAC, emergency stop as well as remote tripping solutions are available. In all cases, the circuit breaker's actuator and auxiliary switches accurately and reliably indicate whether the circuit is opened or close and safeguard the installation during maintenance and use.

Circuit breakers used for over-current protection can be classified broadly by their current-carrying capacity and construction. Miniature Circuit Breakers (MCBs) are specified by standard: IEC/EN 60898 and can be rated up to 125 A. Although mostly found in domestic and similar environments, they are also used within machines as IEC/EN60947-2 devices. IEC/EN 60898 defines MCB tripping characteristics B, C and D; these in turn specify the MCB short circuit current tripping levels. Fig. 4 compares B, C and D tripping characteristics.

Moulded Case Circuit Breakers (MCCBs) and Air Circuit Breakers (ACBs) are widely used by manufacturing OEMs for machine building and other industrial applications. They protect cables and bus bar trunking systems, switchgear and control systems as well as motors, generators and transformers. For optimum protection and economy of operation, their tripping characteristics must be matched as precisely as possible to the individual performance of the equipment to be protected. Economic viability also depends on operation without unnecessary or nuisance tripping.

ACBs are typically rated at currents of 630 A to 6300 A, while MCCBs operate at lower currents. Their construction and performance requirements are specified by IEC/EN 60947-2 of the IEC 60947 standard family: Low voltage switchgear and controlgear.

MCCBs comprise moulded insulating material housing integrated contacts that cannot be replaced or maintained. Frame size determines electrical parameters; however selection depends first on distinguishing between current-limiting and non-current-limiting circuit breakers. Current-limiting types use modern MCCB design in which, if a short circuit occurs, breaking time is reduced to less than half a cycle of the symmetrical prospective short circuit current waveform. This significantly decreases the amount of

energy let through, as energy is a function of current and time that the current flows (I^2T).

Non-current-limiting circuit breakers are designed using larger frame sizes of MCCBs with robust contact systems and interrupt the current at its natural current zero. They have a higher value of short circuit current that they can withstand for a short time. For an even higher ability to withstand short circuit currents for a short time, together with a higher switching capacity, ACBs can be used.

Fig. 5 shows a typical tripping characteristic for a MCCB or ACB circuit breaker. It covers behaviour under both operational and exceptional conditions.

In Fig. 5, Region 1 is the normal operational current range over which the breaker should never trip. Region 2 is the overload range, where the current-dependent thermal (bimetallic) or current-dependent electronic delayed overload release acts. Eaton offers products in which the overload releases are adjustable as highlighted by the yellow arrows in the graph. The tripping curve,

which is designed to match the capability of the equipment being protected, is long for marginally excessive currents and becomes shorter as the overload current increases. For motor protection, electronic load releases allow the position of the curve on the time axis to be offset to handle heavy start-up currents. Users can specify MCCBs such as Eaton's NZM range with trip release types specified for distribution circuits, motor protection with or without overload, selective or generator protection.

If current to the equipment exceeds permissible overload levels, the switching characteristic enters the short-circuit range of Region 3, where the breaker acts to shut the current down as fast as possible. The response time can be adjusted to suit the application; for motors and transformers, protection can be balanced against the need to avoid unwanted tripping due to inrush currents. Some breakers incorporate both non-delayed and time-delayed releases. With careful selection and adjustment of the circuit breaker, nuisance tripping, can be avoided over the complete current range.

If tight, temperature-independent tolerance of the trip point is required, hydraulic-magnetic circuit breakers (HMCCBs) can be used. Their tolerance, at minus 0 % to plus 25 % of the must trip point is considerably more closely controlled than that of fuses or thermal breakers. Nuisance tripping caused by high ambient temperatures in or near the installation is eliminated. Additionally, unlike thermal breakers, these devices can be reset immediately after clearing the fault. They also activate faster at higher temperatures, raising safety margins. Another advantage of HMCCBs is that they carry their full rated current even at elevated temperatures. Derating or other forms of temperature compensation are unnecessary.

HMCCBs are used in applications where temperature fluctuates because of the environment in which the equipment sits, rather than the load, for example, in a control cabinet in an industry with wide temperature variations such as paper mills or metallurgy. The consequence of not using HMCCBs in these applications is that nuisance tripping would occur, for instance, if an MCCB or ACB is set to 10 A it would nuisance trip at 8 A if the temperature reaches 80 °C.

Selectivity has been mentioned above with reference to fuses, but is likewise applied to systems with circuit breakers, or systems with both circuit breakers and fuses – in fact any system where the response of protective devices must be co-ordinated to protect individual circuits while avoiding wider-scale blackouts. For circuit breakers, IEC 60947-2 specifies a set of selectivity definitions:

Over-current selectivity co-ordinates the operating characteristics of two or more devices so that, up to stated limits, only one responds to an over-current.

Backup protection is the over-current co-ordination of two devices in series where the device which is typically on the supply side

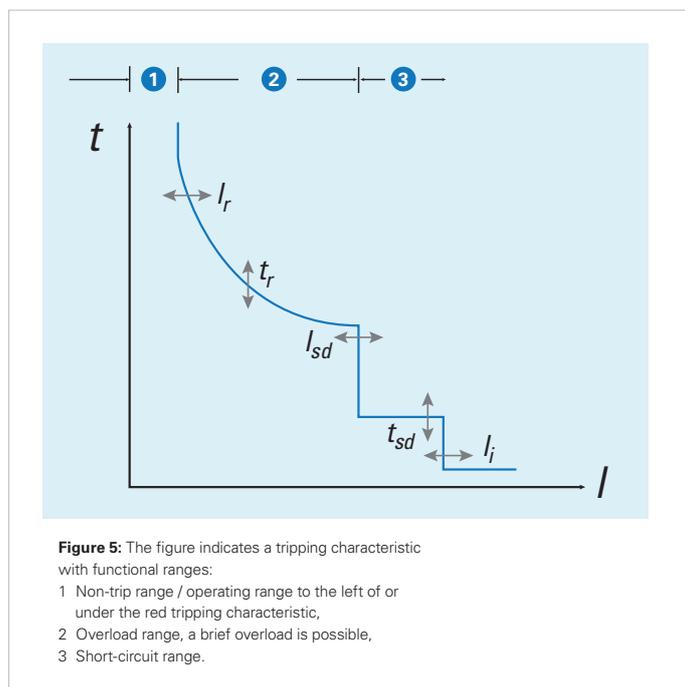


Fig. 5: General tripping characteristic for MCCBs and ACBs

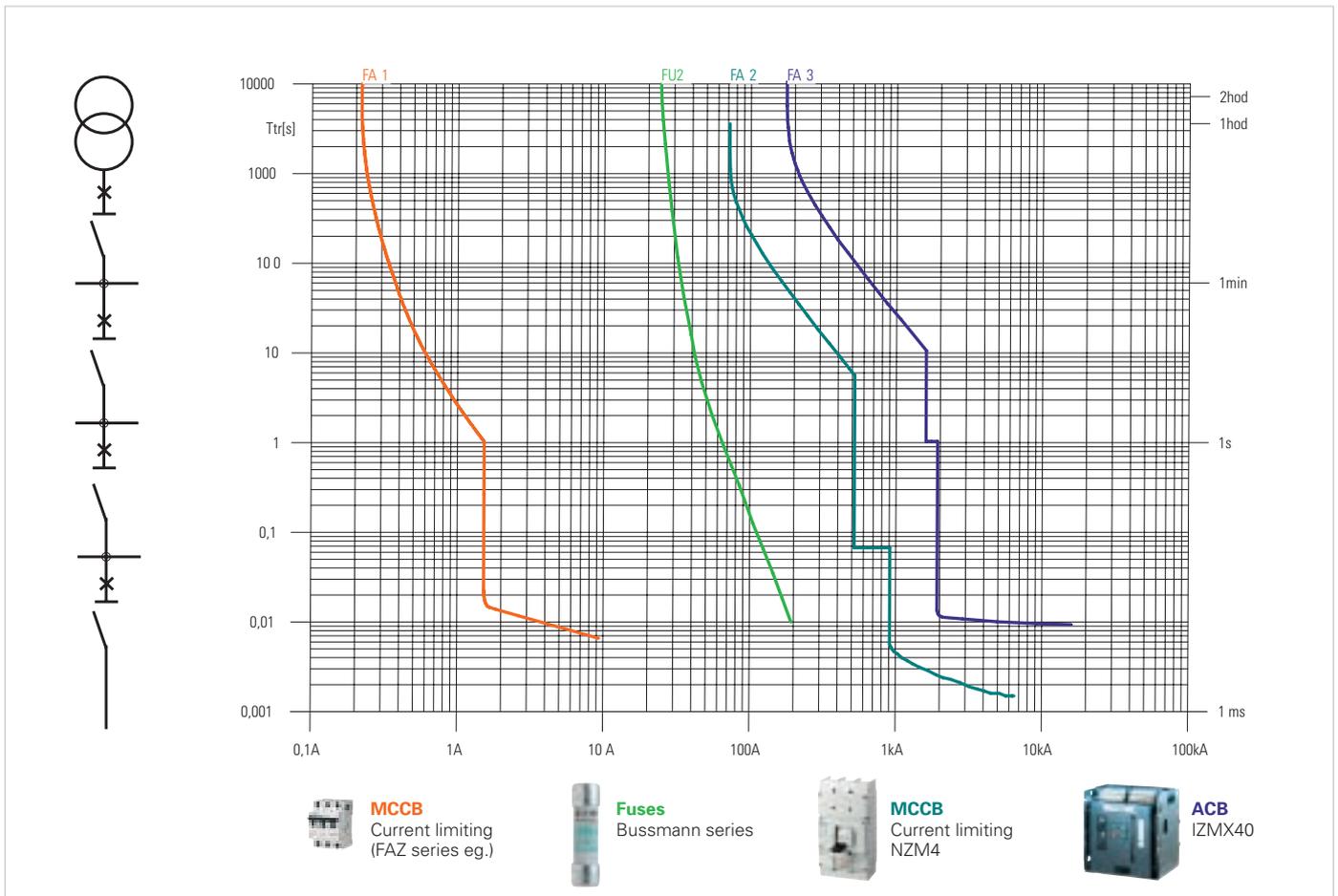


Fig. 6: Evaluating selectivity using software-based graphical representation

affects the over-current protection with or without the assistance of the second device.

Total selectivity concerns two protective devices in series. The load side device effects protection up to its maximum breaking capacity without causing the other device to operate.

Partial selectivity, unlike total selectivity, is where the load side device effects protection up to a given level of over-current without causing the other device to operate.

There is also **time selectivity** in which the device on the upstream or power supply side uses a time delay which permits the downstream devices nearer the fault to trip. Design of time selectivity must allow for the value of short-time withstand currents for the breakers and associated parts of the electrical installation as additional delay can significantly increase the value of let-through energy during a fault.

As different parts of the power distribution system will have different current levels, breakers of different frame sizes are often connected in series through the current path. According to IEC 60947-2 selectivity between them can be verified either by a desk study or by practical testing. Eaton offers supporting software such as xSpider or CurveSelect. xSpider computes actual short circuit currents at the location of the breaker, taking the power grid topology into account; this allows accurate assessment of selectivity. Curve Select allows a simple common representation of different device curves on the same time and current scales to clearly indicate selectivity with very little effort. Fig. 6 shows four different breakers with differing frame sizes, connected in series, and a graphical comparison of their tripping characteristics.

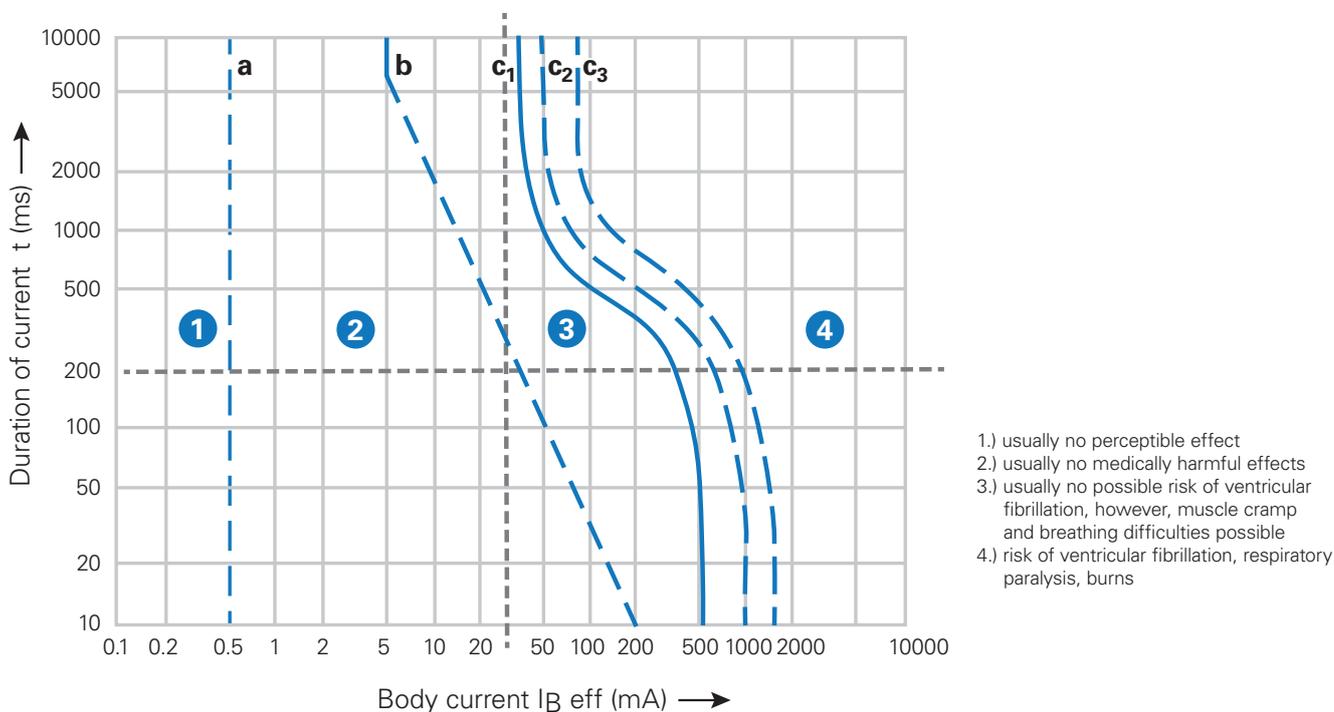
Circuit breakers can include electronic tripping systems; these offer a number of advantages. Firstly, they offer wider ranges



of settings, as well as more settings that can be adjusted. This allows the circuit breaker's protection characteristics to be tuned to those of the application being protected. Other advantages relate to communications and diagnostics. Diagnostics data can be extracted via a USB or communication port to a PC, allowing users to view operations history and analyse possible causes of any faults. Metering is also possible, with generation of power consumption trend graphs for export into Excel files.

As stated at the start of this section, most applications will use both devices in a complementary role. A manufacturing OEM designing power distribution systems will obtain the best results by working with a protection component partner that encompasses both technologies; this will ensure unbiased

Ventricular fibrillation depending on amperage and duration of flow



- 1.) usually no perceptible effect
- 2.) usually no medically harmful effects
- 3.) usually no possible risk of ventricular fibrillation, however, muscle cramp and breathing difficulties possible
- 4.) risk of ventricular fibrillation, respiratory paralysis, burns

Fig. 7: The influence of current on the human body

advice as well as access to both sets of specifications and stock. Unfortunately, one of the anomalies of the way in which the electrical industry has developed is that there are very few partners that advocate, design and manufacture both circuit breaker and fuse technology. Many times the two different technologies have been presented as an either/or solution whereby the very best solutions include both. Eaton has experts across both technologies and decades of experience helping machine builders to develop equipment that best meets their needs.

Residual current protection

Residual or earth leakage currents can arise for many reasons and take many forms. Within the context of machine design, the biggest challenge is to guarantee a safe disconnection of power in case of a fault while maintaining a machine's uptime. Operators and equipment must be protected from danger such as electric shock or fire, while nuisance tripping related to system caused earth leakage currents has to be prevented to guarantee a machine's uptime. The solution is to recognise the different modes of earth leakage current that can occur, and the residual current devices (RCDs) available to manage them.

RCDs offer multiple levels of protection: Most importantly, they offer personal protection if the basic or fault protection fails and a person comes in to direct contact with live part. The effective contact voltage is a serious risk for the human body as shown in Fig. 7 and in the worst case causes cardiac arrest.

The residual currents that may cause problems can appear as AC, pulsating DC, cut half wave, cut half wave currents with a smooth DC component, or smooth DC currents. There are three different RCDs – types AC, A and B – available to respond to these

differing waveforms. Type AC RCDs, mostly found in domestic environments, are sensitive to AC currents (however, it is worth noting the use of Type AC RCDs is not allowed in Germany, Scandinavia, Belgium, Luxemburg, Switzerland or Ireland). Type A devices are similar to Type AC but are also sensitive to pulsating DC currents. Types AC and A must conform to IEC/EN 61008-1.

Machine builders are more concerned with Type B RCDs to meet the protection requirements in machinery equipment's. The challenge for a machine builder is to keep a high system up-time combined with a high protection level for the equipment and the operator wherever the machine is located. Therefore it is essential to consider the compliance with all standards and regulations.

Eaton Type B RCDs are sensitive to all forms of residual current; their tripping curve up to 2 kHz is defined by IEC 62423 and they can detect smooth DC fault currents that can occur in frequency inverter controls. Type B+ RCDs comply with the standard VDE 0664-400 (formerly VVDEV 0664-110) for personal and advanced fire protection up to 20 kHz as required by the Association of German Insurance Companies. Type Bfq has a frequency range adjusted to be insensitive to operational earth leakage currents at higher frequencies. This prevents nuisance tripping errors in industrial plants with powerful frequency inverter controllers while offering personal protection.

Attention must be also paid to the technical compatibility problems between RCDs and electrical drive systems and the possible occurring residual smooth DC currents and high frequency residual currents.

Smooth DC residual currents, such as those caused by rare isolation failures, lead to a pre-magnetization of the transformer in an RCD Type AC or A. As a result, the transformer's ability to



Fig. 8: Digital RCDs have warning LEDs to alert maintenance staff of problems before a blackout occurs

detect changes is reduced and if a sinusoidal AC fault occurs a safe disconnection is no longer guaranteed. However, Type B RCDs cover this failure situation and guarantee the necessary protection.

The frequency components in the residual current must also be taken into account. The following critical frequency components occur in combination with a frequency converter:

- Clock frequency of the frequency converter (typical up to 20 kHz)
- Motor frequency (typical 0 to 50 Hz, max. up to 1 kHz)
- 3rd Harmonic of 50 Hz (150 Hz in three-phase applications)

RCDs Type B, B+ or Bfq with their tripping curves (Type B up to 2 kHz, Type B+ up to 20kHz and Type Bfq up to 50 kHz) are designed for this field of application, while Type AC and A are not. As the RCD is not able to differ between high frequency residual currents and system caused earth leakage currents, the tripping curves are a good compromise to guarantee a high protection level and to maintain a high throughput of the machine. Digital RCDs are now available from Eaton, offering several advantages to machine users. With real-time measurement of

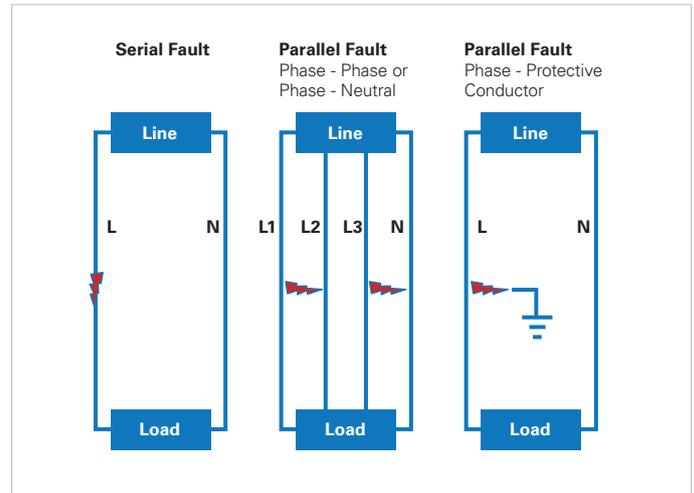


Fig. 9: Different types of arc fault

the residual current, they can provide pre-warnings both locally via LEDs and remotely via potential-free contacts. Faults can be recognized before tripping occurs; this reduces the need for unscheduled maintenance and increases system uptime

Arcing faults

Arcing faults, resulting in particular from insulation faults or loose contacts, are the main cause of damage in electrical installations. As well as any such electrical installation damage, arc faults can easily ignite fires which may have severe impacts on people, plant and buildings. A typical cause for such an arc would be a cable supplying separate components of a machine that is damaged by a fork lifter. Insurance companies estimate that 25% of all fires caused by electrical failure have at one stage been an arc. Arc Fault Detection Devices (AFDD) were initially designed to protect people from fire hazard in residential buildings, but since the technology has proven to be reliable and affordable, they are now becoming increasingly attractive to machine builders.

The detection of an arc is handled by a complex electronic circuitry that senses HF signals on the line. Arcs show a general noise pattern different to other HF noise on a wide HF bandwidth. As soon as an arc is detected, a connected MCB, or better residual current circuit breaker (RCBO) will trip and cut the supply power to the arc.

The most important quality differentiator for an AFDD is a low nuisance tripping, which is a challenge for a manufacturer since there are many HF signals on the line that might be misinterpreted as arcs, for example, switching arcs. A quick and safe detection (and mitigation) of an arc is extensively tested during the approval period.

According to IEC regulations, arc fault protection strategies centre on AFDDs. AFDDs work in partnership with overcurrent protection circuit breakers or RCBOs (a residual current device with additional overcurrent protection function). AFDDs should trip on detection of any arc with an energy of 100 joules or more, with the allowable trip time reducing as the energy of the arc increases. For very high arc currents, AFDDs should detect and trip in less than 120ms. Overall, protection success depends critically on responding fast to minimise arc energy.

IEC member countries have approved international standard IEC 62606 that defines what a fault detection device is, and how to perform standardised AFDD tests. Another standard, IEC 60364, gives the rules for the design, erection and verification of electrical installations protected by AFDDs.

AFDDs are essential even in systems that already have over-current protection. Circuit breakers and RCDs cannot detect arc faults, e.g. due to a loose connection, which typically cause neither overcurrent nor residual currents. IEC 62606 defines the



complementary roles of the various fault protection devices: AFDDs provide protection from serial arcing faults, while AFDDs and MCBs (or RCBOs) together protect from phase-neutral or phase-phase parallel faults. AFDDs together with RCDs provide protection from parallel-phase protective conductor faults.

Surge protection

The largest transient (short-time) electrical energy surges are caused by local lightning strikes. Lower-energy events can be caused by more distant strikes, or by large-scale equipment switching. The size of discharge current generated is influenced by the situation of the building affected; all of a lightning strike's energy must be absorbed by an isolated building, whereas any surrounding structures can share and mitigate the strike energy. Lightning rods matter as well. Although essential for building protection, they actually conduct a lot of energy into the electrical system via the common grounding.

In the past SPDs have been used rarely and they are seldomly missed because the traditional electrical equipment is fairly robust against transient overvoltage. However, machine builders nowadays use more and more electronic equipment which is increasingly sensitive. Therefore installing at least one SPD per distribution cabinet, one per sensitive device and one per sensor line that leaves a building, is becoming standard. Particularly, when you bear in mind, that the cost of SPDs is usually a tiny fraction compared to the damage it helps to prevent.

A common misunderstanding is caused by the technical background of SPDs: overcurrent protection equipment and RCDs trip in case of a failure, however SPDs mostly show no sign of activity. As a result, SPDs are often seen as inactive and therefore needless. It is only after a disaster (such as those caused by lightning), that the value and installation of SPDs are no longer questioned.

IEC 62305-2 defines four lightning protection levels for surge protection devices, with Class I & II relating to a direct strike with an expected lightning discharge of 200 kA, while Classes III & IV relate to direct strikes with discharge currents down to 100 kA. The correct lightning protection level to work to in any given installation depends not only on the expected discharge current, but also on local regulations and tables. The most important consideration in providing surge protection is that surges rise to dangerous levels very quickly, possibly within nanoseconds; this means that fuses and circuit breakers cannot react quickly enough to prevent surge damage. Alternative approaches are therefore necessary to add surge protection to any overcurrent measures already in place. The most widely-used technologies currently are spark gaps and varistors. Both offer very high resistance during normal operation,

yet quickly provide a low-resistance conductance path in the event of a voltage surge. Energy is safely diverted to ground instead of being allowed to flow through the electrical installation.

Each approach offers its own advantages and strengths. Spark gaps typically require some level of activation energy to trigger when voltages exceed 1.5 kV, while offering galvanic isolation with no leakage current during normal operation. They have a long lifetime and provide high conductive capacity. Varistors are very fast, typically becoming conductive above 400 VAC, if rated for 230 V. They are low cost and need no energy to trigger, hence also offering protection from lower energy surges.

Specifying a surge protection device depends on the configuration and the test class required, as well as the device's location within the power distribution network. Different locations such as the main supply feed, distribution boards and devices needing protection need different test classes. Manufacturers such as Eaton offer a wide range of SPDs with many different ratings, using either varistors or spark gaps, or both, internally as appropriate. Note that the machine builder does not have to make an explicit choice between spark gaps, varistors or any other available surge protection technology. Instead, he can focus on the protection levels he needs, while the device manufacturer builds the most appropriate technologies into the products supplied.

Conclusions

In this paper we have seen the electrical problems that can threaten a power system and its users and the possible consequences if no or non-sufficient circuit protection measures are in place to prevent such problems or limit their effects. Accordingly we have reviewed the different circuit technologies and products available to manage the various fault conditions that can arise.

While such fault conditions present a threat, they also create opportunities for machine builders that use the best and most effective circuit protection strategies. Their customers using the systems in their facilities benefit from improved productivity due to reduced downtime. Safety to users is improved while damage to equipment is prevented, or at least localised to the seat of the fault rather than causing larger-scale blackouts. Circuit protection devices can also reduce machine costs through their current-limiting capabilities; these allow reduced-size, lower cost cabling and switchgear to be used in some circumstances.

Maintenance is simplified and made safer by circuit protection equipment that can warn of actual or potential problems remotely.

Set-up for end users is also eliminated or simplified by the availability of circuit breaker devices with pre-configured tripping curves.

However, to gain these advantages for themselves and their customers, manufacturing OEMs must work with circuit protection partners who have the resources essential for success in terms of products, expertise, support and international coverage. Optimal, rationalised and simplified strategies depend on integration and complementary design at all levels. For example arc fault protection devices work in partnership with overcurrent protection circuit breakers and RCDs, while fuses complement circuit breakers in their role. Fuses and circuit breakers also complement one another for protection sharing within selective designs. In addition to this, a large number of specification choices and possibly customisation capability for each product type is essential to efficiently meet the particular requirements of each individual application.

So, circuit protection product providers must cover all the product technologies – fuses, circuit breakers, arc fault and surge protection devices – while offering the width of range, depth of products and expertise to integrate them and support in helping the manufacturing OEM develop the best solution. In reality though, there is often a further challenge – having developed the solution, the manufacturing OEM typically needs to replicate it for installation in widely-distributed locations around the world.

For success at this level of production, the circuit protection component partner must be able to support the OEM locally, wherever in the world his installations are situated. This involves not only support with logistics and component supplies, but also recognition of local legislation and its impact on the products being supplied. As we have seen, all of the products' design is governed by international standards; these are mostly related to the IEC system in Europe, but different legislation applies in other parts of the world.

Overall, though, perhaps the most important benefit of working with a circuit protection partner such as Eaton is the truly balanced advice that they can offer. As they have all the available technologies in their portfolio, they can focus on recommending the best possible solution for a particular machine application,

without bias due to commercial interests or limitations of product availability.

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If you are a machine builder contemplating your next project or upgrade, it is well worth contacting Eaton for ideas and advice. Eaton experts are always available to provide support and help you choose the best protection for your installation in terms of technical specifications, cost-effectiveness and competitive advantage.

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