White Paper **WP012012EN**

Single and double break MCCB performance revisited

Background

The MCCB market today is characterized by a huge number of products and a growing emphasis on smart operation and maintenance (O&M) features. Faced with such a huge diversity of products and innovations, it can be surprising to remember that fundamentally there are just two basic MCCB design approaches. Each MCCB product represents a variation on either a single or double break design, which raises the inevitable question—which is better?

This topic has been the subject of extensive research over past years, with MCCB manufacturers and researchers seeking to clarify the merits and drawbacks of each design and the effects on applications. This subject continues to divide experts and consumers within the market. Each design principle has its supporters and opponents, and the global market displays regional preferences for single or double break designs.

However, performance tests between different MCCB products both in research and industry provide no strong basis for supporting one design principle over the other. Firstly, any performance trends observed for each design are specific to the fault current scenario. Secondly, individual products vary around the basic design with revisions to enhance strengths and overcome constraints on the technical level. On a more practical level, each design poses different considerations for purchase and installation.

A better question to ask, then, is which MCCB is best for me?

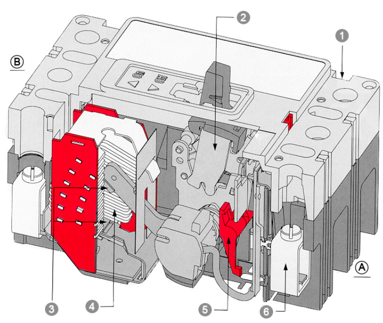
To support a more informed basis for considering the products available in each category today, this paper provides a technical review of single and double break MCCB design principles and the potential impact on device performance.

Component breakdown of single and double break MCCBs

Though individual MCCB designs vary, all devices share five core components:

1. Operating mechanism
2. Contacts, which close at the break point or points
3. Arc interruption chamber
4. Trip units, which trigger mechanism opening during short circuit and overload events
5. Molded case or frame

Of these core components the operating mechanism, arc extinguishers, and contacts differ most significantly between the two designs. The following sections provide a brief function description of each component.



Cross section of a single break MCCB

A. Load side
B. Line side
1. Molded case (frame)
2. Operating mechanism
3. Contacts
4. Arc extinguishers
5. Trip bar
6. Terminal connectors

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Operating mechanism

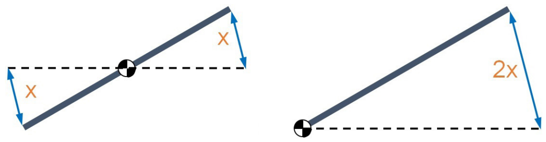
The operating mechanism applies the force needed to open the breaker's contacts or hold them closed. The operating mechanism force must be sufficient to change the contact arm position in an interruption event and also to load the spring for the moveable contact arm to maintain contact pressure. During a short circuit or an overload event, the trip unit unlatches the operating mechanism, causing it to open the breaker by separating the contacts (or keep them separated once they blow open) to stop the flow of current.

In single break designs, the mechanism operates on a single rotational path, controlling the position of one movable contact arm and the contact at its end. In double break designs, the mechanism operates two pairs of contacts simultaneously.

Contact structure

As discussed, single break designs feature a single pair of contacts, while double break designs feature two pairs of contacts which separate simultaneously in series since they share the same movable conductor.

Double break mechanisms generate two arcs in series and when combined these two arcs are usually comparable in length to the arc of the single break.



Double break design

Single break design

Typically, a single break design features a flexible wire component or a conductive pivot joint to attach the movable conductors to the trip unit conductors. This allows for continuous current flow to the contact during opening. In a double break design, the flexible component is not required since both sets of moveable contacts are attached to the same conductor.

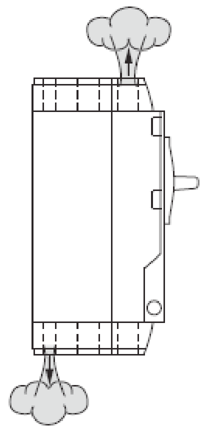
Arc interruption chamber

The arc interruption chamber contains the arc extinguisher, which is responsible for confining, quenching, splitting and extinguishing the arc generated during an interruption event.

During an interruption event, there is a very fast rise of arc chamber pressure, which must be vented to maintain a safe internal chamber pressure and to ensure the breaker case does not rupture. The heat generated by the hot gasses and plasma is sufficient to partially vaporize components in the arc interruption chamber. Gassing inserts can be used to help insulate and protect other components from damage inside the chamber, as well as to provide outgassing to help cool the arc. The inserts are made of thermoplastic or thermoset materials that outgas strongly when exposed to an arc. The outgassing not only quenches the arc, but also generates dynamic gas flow that drives the arc into the arc extinguisher.

In the arc chute, the arc is dispersed when channeled through a stack of arc plates. The plates are aligned and designed to create a magnetic force which drives the arc into the plates and guides it along the chute. Some breaker designs may also incorporate slot motors, which help increase the repulsion force on the moveable conductor to achieve faster contact separation and maximum gap. When incorporated, the slot motor will also increase the propulsion of the arc through the extinguisher by creating a magnetic field, which provides directional force at the point of opening.

Single break MCCBs contain a single arc extinguisher in each pole at the line side of the molded case, and all vents face a single direction. Double break MCCBs house two identical arc extinguishers in each pole, and typically feature two sets of vents at both the line side and the load side of the casing.



Double blow-out direction of standard double break design

Typical performance characteristics of single and double break models

Like all circuit breakers, the primary function of MCCBs is to interrupt the flow of current in the electrical system during fault and overload conditions, as well as to provide galvanic isolation to the downstream components. In addition to fault current interruption, there are another two performance features of circuit breakers that need to be considered.

One feature is how well the breaker minimizes let-through energy to the downstream electrical components during an interruption event. If the let-through energy is too high there is a risk of damaging wiring and other devices within the circuit.

The second feature is how efficiently the breaker disperses the arc energy. Arc generation is a result of interrupting high levels of fault current and a challenge that MCCB designs must address. Arc energy must be dispersed appropriately to avoid serious damage to the device and components, which could either render it unsuitable for further use or even damage other downstream components in the system.

Ultimately, there are as many ways of addressing these needs as there are individual MCCB designs. Nevertheless, there are areas in which double and single break designs exhibit broadly different performance trends:

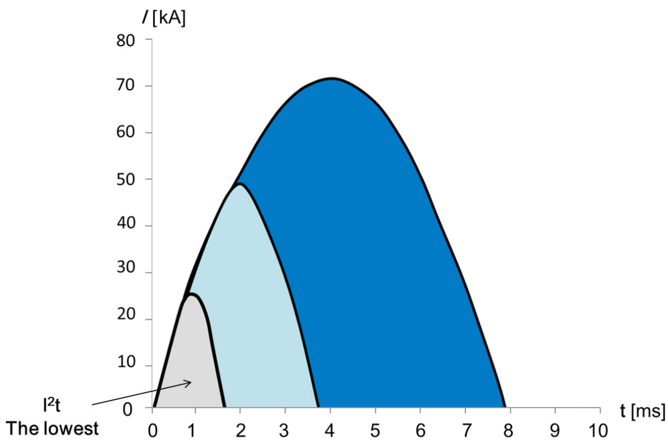
- Current limiting performance and let-through energy during high fault levels
- Current interruption ability and let-through at low-level fault currents
- Thermal performance under normal current conditions

The remainder of this section defines current limiting performance in more detail.

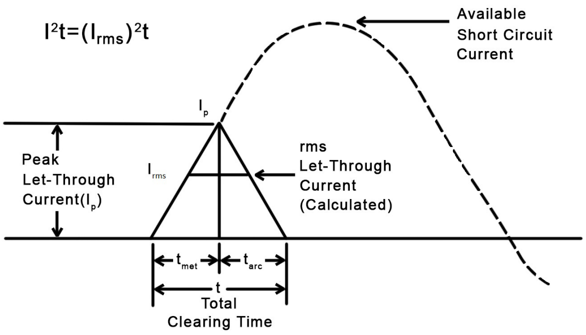
Factors affecting current limiting performance

Let-through energy is expressed in terms of I^2t, where I is the root mean square of the fluctuating current level during the break event (I_{rms}) and t is the total time of current flow.

In typical interruption events, such as those represented by the curves below, I^2t is correlated with the peak current values experienced during the interruption process. Therefore, lower peak currents will correspond to lower let-through energy values with comparable clearing times.



I^2t curves at varying peak current levels



I^2t calculated from I_{rms}

Tests also indicate a strong inverse correlation between peak arc voltage and peak current, such that higher arc voltages generated by breakers usually correspond to lower let-through current values.

There are still some exceptions to this trend to note, including that a relatively low peak voltage can still achieve low peak current values provided that the voltage rises at a faster rate. Several factors affect the rate of rise to peak voltage, but the most important is the opening speed.

It is also important to note that a faster contact opening achieving a low peak current does not always guarantee lower let-through energy. The other variable in I^2t is the clearing time, which is the total time from fault initiation until zero current. This time depends on the breaker's ability to remain fully open during an interruption event, which can be significantly affected by the fault current level.

A breaker's ability to open and remain fully open is influenced by three forces which can act upon its contacts. These three forces come from the mechanism springs, contact springs, and the magnetic repulsion forces between the conductors, which is often referred to as the "blow open force". The magnetic force is created by the high current flowing in the conductors, and forces the contacts to separate as the repulsion force overcomes the contact spring force. If the blow-open force is not sufficient to counteract the contact spring force during the entire fault condition, there is a risk of the breaker partially or fully reclosing after opening and allowing the fault current to continue to flow.

For double break MCCBs, consistency is an additional factor affecting opening and closing. Ensuring all poles open simultaneously requires precise manufacturing and this can be further influenced by uneven wear and degradation of the contacts over time.

Finally, tests also suggest a link between higher arc chamber pressures and effective current limiting performance, since higher pressure often corresponds to a higher peak arc voltage. However, excessive pressure threatens the structural integrity of the breaker case.

Performance trends at high-level fault current

Current limiting performance

The double break design principle offers a theoretical advantage at high-level fault currents with respect to current limiting capability, due to its potential for increased opening speeds and initial generation of higher arc voltage via two arcs. A combination of the second pair of contacts, smaller contact gap and shorter opening distance of a double break MCCB's moveable contact arm enables the contacts to open and reach their maximum gap quickly.

Single break designs typically have greater inertia and larger contact gaps than double break designs, and therefore may open more slowly. To improve current limiting performance and achieve lower let-through values, manufacturers rely on various supplementary design features that increase the speed of the mechanism and the magnitude of the conductor repulsion, to rival performance levels of double break designs. Eaton's products employ many such technologies.

Managing arc energy

Arc events create intense heat and pressure inside of the breaker arc chamber, requiring a mechanism for controlling this energy and evacuating it from the chamber. Higher pressure and hot gas build-up corresponds to increased levels of degradation of chamber walls and other materials. The high pressure also presents a greater risk of case rupture or structural damage if no design precautions are taken.

MCCBs that have small arc chamber volumes and high gassing wall materials tend to see higher pressure build-up during arc interruption events. This is due to a combination of the voltage and hot gas in a smaller space. The pressure generally increases with higher fault current levels as well as voltage levels (e.g. 400 V, 480 V, 600 V and 690 V).

Small-volume, modular arc chambers are an implicit feature of most double break designs. This, combined with higher arc energy and outgassing inserts, means the issues associated with high pressure are more commonly observed in double break MCCBs. However, there are also a number of single break MCCBs that employ isolated small-volume arc chambers and face similar issues.

These issues must be considered in terms of a breaker's interruption rating. For example, they may place restrictions on the maximum current level that the breaker can safely interrupt, affecting the end application. Meanwhile, to comply with IEC and UL product standards, an MCCB must demonstrate that there is no risk of case rupture for the full performance range of the device.

Performance trends at low level fault current

Current limiting performance

At low level fault currents, a phenomenon has been observed in tests whereby breaker contacts partially or even fully re-close temporarily during interruption events. Re-closing is a consequence of the blow-open force causing the contacts in a breaker to separate. As the current level drops, the contacts will reclose due to the AC waveform, but as the current level rises again, the contacts will blow open another time. This phenomenon repeats until the trip unit signals the breaker to open or the fault escalates into something larger.

When re-closure occurs, the current rises a second time, having already begun to descend from the peak current value reached shortly after opening. The time taken to fully interrupt the fault current is longer; accordingly, the time during which fault current is exposed to the downstream system is extended. This phenomenon can therefore lead to substantially higher let-through values (I^2t) relative to the peak current level (although they are still lower than those observed during high fault current interruptions).

In tests, this phenomenon occurs more regularly in double break designs. The main reason why single break designs rarely exhibit this phenomenon is that they tend to have a cam surface incorporated into the moving conductor assembly, which locks the movable contact arm open after the contacts are magnetically separated due to the high current levels. The cam surface prevents the breaker from re-closing during a short circuit event before the trip unit has initiated the tripping signal to the mechanism.

Double break MCCBs that incorporate the cam feature also exist, but it is not typical among double break designs. For most double break MCCBs, the absence of the cam combined with the difficulty of ensuring consistent opening and closing between all poles renders them more susceptible to reclosing under low fault currents.

Managing arc energy

The contact re-closure phenomenon also poses challenges on how to ensure device integrity and durability. Each time a contact opens under load it creates an arc. The generation of an arc on a contact will cause erosion to the contact and degradation of the surface. The higher the current levels experienced during contact separation, the higher the level of erosion and damage to the contacts. Every blow open and re-closure operation will cause contact erosion. Erosion is a factor in contact resistance, which contributes to watt loss and thermal issues under normal current conditions.

In the worst-case scenario, a pair of contacts could weld together when they reclose due to the molten pool of contact surface that is created from the arcing operation, creating an unbreakable circuit state.

The possibility of re-closure cannot be completely averted by any MCCB design. This is because there will always be a critical current level which is sufficient to cause the contacts to blow open, but insufficient to latch them in the open position. However, properly designed breakers will re-close only once at most during an interruption event, and will trip on the second half cycle.

Thermal performance in normal current conditions

There are many sources of resistance in a circuit breaker, including the contacts, shunts and their associated welding spots as well as conducting joints. Most of these do not apply to double break designs, meaning there are less heat-generating points in the device. However, the contacts are one of the hottest points in a circuit breaker, each set of contacts creating resistance due to their imperfect surface connection. Contacts are therefore responsible for a significant amount of the total heat generation of an MCCB.

It is also important to note that throughout the life of the product the contact resistance will increase due to erosion of the contacts during load breaking and fault interruption and also due to changes in the surface conditions from various contaminants. It follows that a double break design will in principle generate roughly double the contact resistance of a single break design.

Contact resistance does not necessarily pose an issue under normal current load conditions as long as the contacts are in good condition and are held tightly shut with proper contact force from the operating mechanism. However, the mating surfaces of the contacts are susceptible to erosion during arc events which will increase the resistance of the contact joint. The increased resistance will create additional power loss in the circuit and increase heat generation in the circuit breaker.

In addition to having an extra point of resistance, the problem of resistance in double break designs is further complicated in the following two ways by its rotational mechanics:

- Firstly, the operating mechanism in a double break design needs to generate a much higher mechanical force to ensure proper contact force in both pairs of contacts at the same time. Any variation in closure between the two pairs of contacts will cause the contacts to wear unevenly, creating additional contact resistance.
- Secondly, as discussed, blow-open force can cause MCCBs to prematurely open and then reclose before the trip unit has initiated an interruption during certain interruption scenarios. Blow-open events create additional contact resistance due to increased erosion from the repeated making and breaking of the contacts. This is a greater issue for double break devices, which face blow open events more often than single break devices.

If the mechanical force in the operating mechanism cannot provide enough force to keep the contact resistance low and prevent the contacts from separating at low-level currents, the continued degradation of the contacts, due to repeated reclosing events, will cause the contact resistance to rise to a level high enough to lead to thermal runaway. Thermal runaway is a condition where the breaker is unable to reach a steady thermal state condition and the temperature in the breaker continues to rise until failure. This condition thus limits the breaker's applicability to the system it is designed to protect with its high breaking speed.

In brief, current fluctuations which are not high enough to trip the double break MCCB's opening mechanism tend to cause partial opening of the contacts, compounding the problem of contact resistance which its design principle introduces. Single break designs tend not to suffer from the same inconsistent contact closure and uneven wear because they only have one set of contacts.

Increased contact resistance causes power loss and excessive heat which can damage the breaker over time, a challenge to manufacturers to design MCCBs that comply with maximum temperature ratings specified in breaker standards.

Practical considerations

In addition to performance considerations, consumers also face practical considerations on installing single and double break models.

Blow-out direction

When installing an MCCB, a clearance zone is required next to the vents to ensure that there is no current transfer to grounded components from the blow-out of hot gas and plasma during short circuit events. Clearance is required at one end of a single break MCCB and typically at both ends of a double break design.

A single blow-out direction and clearance zone allows for more flexible and compact installation. For this reason, double break MCCB manufacturers occasionally also achieve a single blow-out direction through specially designed arc interruption chambers.

Case size

In addition to the bi-directional blowout, double break MCCBs generally require larger molded cases to accommodate the extra set of contacts and modular arc chambers, thus consuming more installation space. This poses no disadvantage when there is ample space at the facility, and sometimes manufacturers take advantage of the extra space to house additional components. However, if space is limited at the facility, single break MCCBs generally allow for higher installation density.

Conclusion

Neither the single nor the double break design principle has demonstrated any performance advantage that applies across all application scenarios. Products based on either design, when certified to industrial product standards (UL489 and IEC60947-2), are thoroughly capable of fulfilling the application requirements up to their maximum ratings.

Both designs offer relative advantages or limitations under specific fault current conditions in principle—but neither design is fixed. Products can and do depart with the trends typical of one design or the other, evidenced by double break devices with a single blow-out direction and single break devices with enhanced opening speeds.

Therefore, the intended application of the device should be considered against the relative merits and drawbacks of the design principle when consumers choose between single or double breakers. Special consideration should also be given to the room for elaboration upon the basic design—and how much cost innovations will add to the products.

"Advances in technology on both single and double break molded-case circuit breakers have rendered the traditional beliefs about the strengths and weaknesses of the designs to be obsolete. In order to create a safe and efficient power distribution system, a designer must not rely on traditional convention, but instead examine the actual performance of the breaker to determine if it meets their requirements."

– Wilbert de Vries PhD, VP Technology, APAC, Eaton

Where both single and double break designs can meet rating requirements for a given system, further consideration should be given to the cost-effectiveness of each option and factors such as thermal performance over its life cycle, especially where installation structures already exist for one design.

In an evolving world economy with increasingly diverse uses of electrical systems, the availability of both single and double break MCCB designs should enable consumers to make choices tailored to their application needs. With a sound technical understanding of their strengths and drawbacks, the global market should display a more diversified adoption of single and double break MCCBs in the years to come.

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Robert W Mueller, Chief Engineer Low Voltage Components and Power Test Labs Manager, Eaton

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Note: Names are ordered in alphabetic sequence.

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