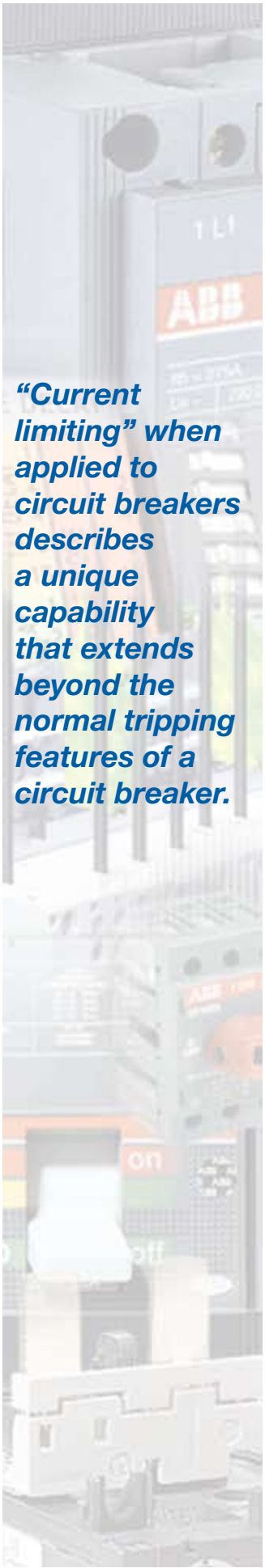
Current Limiting MCCB's*

* Current Limiting Molded Case Circuit Breakers



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Some of today's high performance molded case circuit breakers have had the qualifier *"current limiting"* added to their description in recent years. Current generation design technology has resulted in these products offering customer solutions based on additional features and benefits beyond traditional overcurrent protection capabilities. This paper will discuss the design, construction and application of current limiting molded case circuit breakers.

Current limiting overcurrent protective devices have been available in the marketplace for many years. The age old competition between fuses and circuit breakers has reached a new level with the introduction of these fast acting, high performing current limiting circuit breakers.

Current limiting fuse applications require compromises by the end user, especially in 3-phase applications. It is not unusual for at least one of the three fuses in the circuit not to open during an overcurrent event. This could create a single phasing situation on the system which could result in equipment damage, especially in motor applications.

To assure that all three phases are open prior to inspection, maintenance or fuse replacement, the switching device in which the fuses are installed must either be manually opened or have supplemental means to automatically open the switch, which is common only above 800 amperes. Although these switches always include safety interlocking to assure that the clips or clamps are de-energized, local codes may still require that service technicians wear protective clothing during this replacement process.

Market dynamics have encouraged other current limiting solutions. This has led to the demand for circuit breaker-based current limiting devices in recent years. We will examine what *"current limiting"* means in the context of circuit breaker applications, what technical design hurdles were overcome, and discuss numerous benefits of circuit breaker-based solutions.

'Current Limiting' Defined

"Current limiting" when applied to circuit breakers describes a unique capability that extends beyond the normal tripping features of a circuit breaker. Although all circuit breakers could be said to limit current by opening during an overload or fault current condition, 'current limiting' circuit breakers are special versions that provide additional protection. This current limiting protection is provided typically beyond the calibration of the instantaneous trip system that would typically respond to fault current. But first, we need to fully understand the need for current limitation in electrical systems and how the standards define current limiting.

During a fault current event, usually referred to as a short circuit, one or more of the electrical conductors make accidental contact with ground or an adjacent phase. This can be compared to a broken water main. The electric current in the circuit, like the water in the pipe, wants to take the shortest path out. At that moment when there is a phase to phase or phase to ground failure, all of the electric current available rushes to that short circuit pushed by the system voltage, much like the pressurized water in that main rushes to the area of the break. Unlike our water main example, however, engineers have designed fast-acting protective devices to minimize the damage that can occur during a short circuit. These circuit breakers operate very rapidly to limit the short circuit current flow before it reaches a level that damages electrical conductors in the equipment, as well as the downstream load.

The standard for molded case circuit breakers, **UL 489** (and its current twin, **IEC 60947-2**), defines a current limiting circuit breaker as ***'one that does not employ a fusible element and, when operating within its current-limiting range, limits the let-through I^2t to a value less than the I^2t of***

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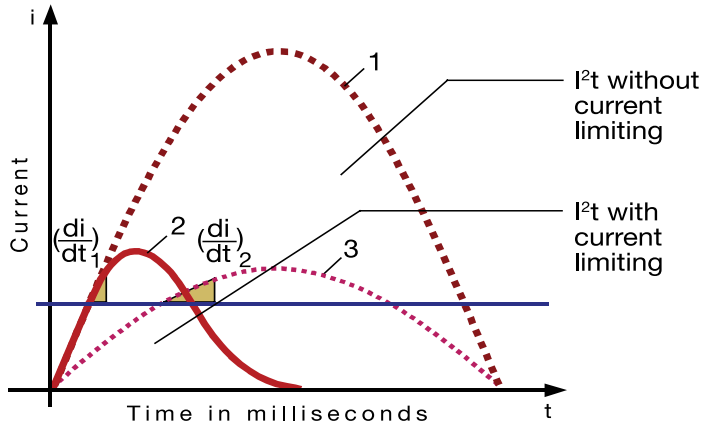
a 1/2-cycle wave of the symmetrical prospective current.' [1] Furthermore, I^2t is defined as ***'an expression related to the circuit energy as a result of current flow. With respect to circuit breakers, the I^2t is expressed for the current flow between the initiation of the fault current and the clearing of the circuit.'*** [2] Expressed graphically, the energy in the circuit, I^2t, is represented as the area under the curve.

For a circuit breaker to be current limiting, it must interrupt the short circuit energy in one half cycle or less. It should be noted that an electrical short that lasts just three cycles adds six times the energy of one lasting just one-half cycle. In 60 Hz systems, half cycle

Figure 1



tripping means that the circuit breaker must sense the short circuit current, trigger the tripping mechanism, part the electrical contacts, and interrupt the subsequent arc in no more than 8.3 milliseconds. However, this interruption is performed only when the short circuit current is in the current limiting range of the trip device. This range is typically above the 10X to 15X instantaneous trip element calibration in these high-end molded case circuit breakers (MCCBs). To perform these functions at the speeds required to be current limiting requires fast acting current sensing, a special mechanism, customized electrical contacts, and unique arc chute construction. We will examine these features in the next section.

'Current Limiting' Design Features

Current limiting capability has been made possible in part due to advancements in molding compounds for MCCBs. Because modern insulating materials tolerate high temperatures, withstand significant mechanical stress, and provide higher dielectric integrity, circuit breaker designers have been able to exploit these features in their designs. Although the newer plastics enabled the creation of these breakers, many other design elements had to converge to create the complete package.

In earlier generations of circuit breakers, the electrical contact assemblies, including the moving insulated parts that isolated them, were hefty designs that had to be set in motion to open the circuit. These designs do not allow the high speed movement that true current limiting capability requires. Engineers have developed designs that maintain the continuous current capability of previous designs, while decreasing the mass of the various current carrying parts. They have also positioned internal current carrying parts so that current is flowing in parallel but opposite directions, thus creating a repulsive electromagnetic force which acts upon the movable contact arm, causing the contacts to separate rapidly. This reverse current flow is another design feature that differentiates a conventional molded case circuit breaker from a circuit breaker with current limiting performance.

In the current limiting **ABB Tmax** design, the arcing contacts close immediately as the main contacts part, transferring the energy to the arcing contacts. At the moment of arcing contact separation, there is an instantaneous formation of a voltage arc from the contacts

[1] *from UL 489, paragraph 2.25, April 25, 2002*

[2] *from UL 489, paragraph 2.50, April 25, 2002*

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ABB Tmax Series Circuit Breakers

Tmax T2 **Tmax T4** **Tmax T5**

The ABB molded case current limiting circuit breakers contain and dissipate ionized gases within the case of the circuit breaker.

as they part. Specially shaped arcing contacts pull the arc up rapidly into the arc chute plates. The general shape of the main contacts, arcing contacts and the area adjacent to the contacts contribute to a magnetic effect that encourages the arc to move in the direction of the arcing chute plates.

As the current carrying parts were downsized, operating mechanisms were simplified to allow rapid operation. Coupled with the repulsive electromagnetic force generated by the contacts themselves, contact parting takes place early enough in the current half cycle to allow full arc extinction in the arc chutes.

Perhaps the hardest working part of the current limiting molded case circuit breaker, the arc chutes, have also been optimized for current limitation. Featuring designs similar to conventional arc chutes, the arc chute has multiple parallel steel plates. Note, however, that the steel arc chute plates inside the arc chute are electrically separated from one another. During the initiation of the high energy arc, an electrical potential is generated between each of the arc chute plates. This arc chute voltage opposes the electrical system voltage driving the short circuit current. This further acts to elongate and snuff out the arc in the general proximity of the arc chute plates. To further stretch the arc, alternate plates differ in general shape so that the arc is forced to 'zigzag' from plate to plate. This segmentation of the arc allows it to be rapidly extinguished. Hot ionized gases are by-products as the high energy arc is created. These gases must have a path of escape through the arc chute and its baffles. If these ionized gases happen to contact grounded steel components adjacent to the arc chute inside or above the circuit breaker, they will create a path to ground for the arc. At that point, control of the arc is lost and significant damage can result. It is for this reason, The **ABB** molded case current limiting circuit breakers contain and dissipate ionized gases within the case of the circuit breaker.

There is one final component that provides a key role in current limiting molded case circuit breaker performance, the trip system. Current limiting molded case circuit breaker trip systems fall into two categories: electro-mechanical and electronic. Traditional electro-mechanical trip systems use a magnetic trip assembly, which acts as a simple solenoid when a magnetic field is created in

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the breaker due to high current flow. This triggers immediate circuit breaker opening.

Electronic trip systems have allowed extremely fast recognition of high fault current events, surpassing electro-mechanical trip systems for speed. Using current sensors in each phase of a three pole circuit breaker, electronic trip systems derive both their control power and current magnitude from these sensors. Employing a microprocessor with embedded software, electronic trip systems monitor the current magnitude for overload, short circuit and high energy trip conditions. It is the third condition, high energy trips, that provide the current limiting performance. With the ability to sense the rate-of-rise of the current, *di/dt* as it is called; electronic trip systems allow end users to customize the current limiting performance of the circuit breaker according to fault current rate-of-rise.

In **Figure 1**, two trip currents are shown; curve 1 is a high energy fault current, curve 3 is a lower level fault current. For the circuit breaker to respond within the first half cycle, the rate-of-rise, di/dt_1 is calculated. This is compared to the programming of the trip system; if the rate-of-rise meets the current limiting trip criteria, the circuit breaker flux shifter is energized to trip the opening mechanism.

The other fault condition, signified by curve 3 would not meet the criteria for high speed instantaneous tripping; its rate-of-rise di/dt_2 is much lower. Curve 2 represents the 'let-through' current allowed by the current limiting circuit breaker prior to complete interruption. Obviously the I^2t, the area under that curve, is much less than that of curve 1. The potential damage that could have resulted in downstream devices served by a current limiting circuit breaker is, therefore, significantly reduced. That capability plays a key role in the short circuit current ratings of industrial control panels.

Current Limiting Circuit Breakers and Short Circuit Current Ratings

Resulting from revisions in the 2005 **National Fire Protection Association (NFPA)** 70, better known as the **National Electrical Code**, industrial control panels are now required to have a short circuit current rating (SCCR) appear on their nameplate. Article 409 was added to the NEC to focus on safe design, application, and inspection of industrial control panels. Rising out of concern for the misapplication of industrial control panels, the NEC requires that consideration be given for short circuit current rating of the entire assembly—circuit breaker, contactor, overload relay, and terminal blocks. The short circuit current rating, by definition is the maximum RMS symmetrical current that the industrial control panel (ICP) can withstand for a minimum of three ac cycles (50 milliseconds) or until a circuit breaker clears this circuit. In other words, the SCCR represents the maximum short circuit current level that the ICP can safely withstand without compromising safety of the building or personnel. To assist design engineers, *UL 508A, Supplement SB*, was issued to define the process for determining the SCCR of an ICP. With regard to current limiting circuit breakers, *508A supplement SB4.3.2* states that "for branch circuit breakers …. marked current limiting in the feeder circuit, the short circuit current rating on the line side of the circuit breaker shall be …..(a) the short circuit current rating of the feeder circuit breaker when all of the components in the branch circuit have a short circuit current rating not less than the published peak let-through current of the circuit breaker…".

The SCCR of the ICP is not to be confused with interrupting ratings—these ratings are associated with overcurrent protective devices, like circuit breakers. A circuit breaker interrupts a short circuit at its rated interrupting rating. Although a circuit breaker is included in the ICP, the SCCR of the ICP is usually not the interrupting rating of that circuit breaker. Other devices with lower short circuit current ratings inside the ICP will tend to lower the

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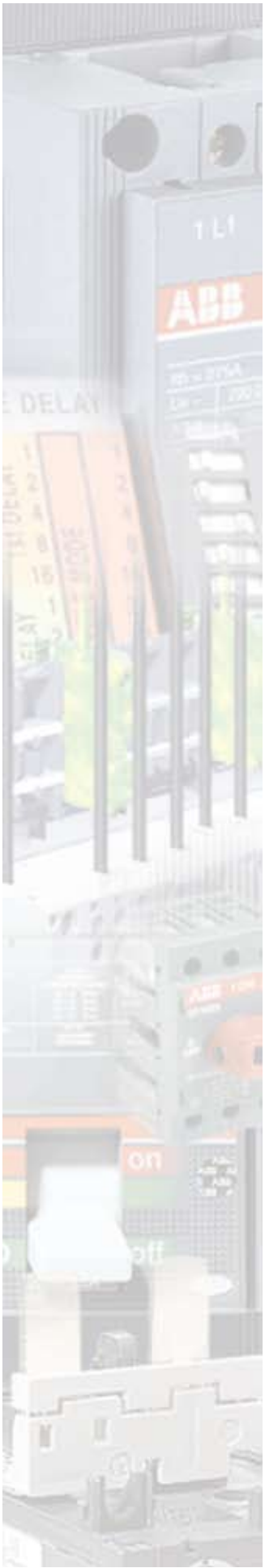

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Figure 2

Circuit Breaker Type	Circuit Breaker Range	10 kA		50 kA		100 kA	
		Let Through Energy (I^2t [10^6 A^2s])	Let Through Peak (I_p 10^3)	Let Through Energy (I^2t [10^6 A^2s])	Let Through Peak (I_p 10^3)	Let Through Energy (I^2t [10^6 A^2s])	Let Through Peak (I_p 10^3)
480 V							
T2 Thermal Magnetic Trip	15	0.21	8.7	0.31	15	—	—
	30	0.26	13	0.40	17	—	—
	50	0.26	11	0.45	21	—	—
	100	0.31	11	0.49	21	—	—
T2 Electronic Trip	100	0.30	11	0.48	21	—	—
T4	250	0.54	16	1.30	35	1.5	41
T5	600	1.30	16	2.40	41	2.4	48
600 V							
T4	250	0.52	14	1.30	30	1.4	37
T5	600	1.00	16	2.70	36	3.0	43

short circuit current rating of the overall assembly. But the proper application of current limiting molded case circuit breakers, like the **ABB Tmax** line, reduces the let-through energy to these vulnerable components. These current limiting circuit breakers, therefore, allow higher short circuit current ratings to be posted on industrial control panels.

This concept can best be illustrated using an **ABB MCCB Combination Starter** example. As shown by the values in **Tables 1** and **2** above, the combination kA rating improves from 22kA to 50kA when a current limiting device is applied in place of a standard breaker.

In **Table 2**, the peak let through current, IP, and the clearing, I^2t, are shown for various **ABB Tmax** circuit breakers at selected interrupting ratings.

When determining the SCCR of an industrial control panel that has a **Tmax** circuit breaker installed, **Table 1** provides a quick reference for circuits with prospective short circuit currents of 10kA, 50kA or 100KA.

In this example, when the components of the industrial control panel meet the criteria outlined in *UL 508A, SB4.3.2* above, then that panel will have the short circuit current rating of the feeder.

In Summary

To achieve the half cycle interruption required to be truly current limiting, the current limiting circuit breaker will have the following design features:

- Special main and arcing contacts that part quickly and transfer arc energy to the arc chute effectively
- Instantaneous development of arc voltage that opposes the system voltage driving the short circuit current.
- Arc chamber design that controls the arc, dissipates and exhausts the ionized gases, and contains the spray of molten material from the arcing contacts
- Fast acting instantaneous sensing and trip system

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Achieving true current limitation in MCCBs is the combination of specialized internal circuit breaker components all configured to sense and interrupt a rapidly rising short circuit current in the first quarter cycle so that interruption is complete within the first half-cycle. The benefits of current limitation have a significant economic impact. For downstream equipment that cannot withstand the effects of the full short circuit current, damage will occur in conductors and the equipment being fed. By designing systems with current limiting protection in the system, this costly damage can be minimized.

Current limiting breakers in new power systems have another beneficial attribute. Because they can limit current to the downstream components, in some cases equipment designers are able to re-size their downstream components. In addition, compared to the equipment costs of fused low voltage circuit breakers, modern current limiting circuit breaker avoid up-front costs as well as maintenance and surveillance costs for the future.

Although current limiting circuit breakers have many clear benefits, they are not able to completely limit the arc flash to the point that unprotected individuals would not be at risk. Even when limiting the current and energy to a much smaller 'let-through,' that let through is still capable of exposing personnel to a significant number or calories per square centimeter. Service personnel must still plan to wear layers of PPE when performing service on live equipment. Unlike fused equipment that must necessarily be serviced through the open door of its enclosure, circuit breaker-based current limiting devices can be reset and re-closed with the door closed, after the original short circuit condition has been cleared.

Arc flash detection relays like **ABB's Arc Guard** or **REA101** relays provide a rapid response to the light flash; main circuit breakers connected to these relays can trip much faster than their usual current sensing components can provide. Use of current limiting relays, in addition to these arc flash detection relays, provide comprehensive arc flash mitigation.

Current limiting molded case circuit breakers should be part of any comprehensive power distribution system or control panel design.

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