Inventronics Circuit Breakers

An overview of circuit breakers, LED Driver input and inrush current, and how to load a circuit breaker with Inventronics LED Drivers.

INVENTRONICS

DRIVING THE LIGHTING REVOLUTION

Contents

Introduction

A circuit breaker is a safety switch designed to automatically disrupt the current flow in an electrical circuit during fault conditions. The function is similar to a fuse, but a circuit breaker has a switch allowing for reuse after each detected fault condition; whereas, a fuse must be replaced. This protects users and other equipment if a circuit is overloaded or encounters a short, consequently preventing shock, fire, and site-wide damaged equipment.

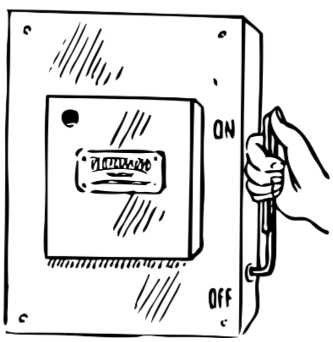

Figure 1: Industrial Switchgear

When a fault condition is detected, the circuit breaker will "trip", meaning that the circuit is opened and the corresponding circuit breaker lever will automatically switch from the ON position to the OFF position. Typically, this will require manually flipping the lever back to the ON position as depicted in Figure 1.

The styles of circuit breakers vary as greatly as the applications they are designed to operate in. This includes circuits that handle individual household appliances, to circuits that handle large industrial switchgear, to even high voltage circuits that feed power to an entire city.

Electrical services distribute power and typically allocate up to 100A or 200A per household. A small electrical panel comprised of several 15A or 20A breakers is then used to properly distribute this power throughout the house.

Offices, factories, and other business facilities are allocated more power as their power consumption needs are much greater than a single household. This power is distributed similarly, but on a larger scale via several different electrical panels throughout the facility.

Circuit breakers have four main types: thermal, thermal-magnetic, magnetic, and high performance. This overview will focus on circuit breakers as they relate to LED lighting, where *Mini Circuit Breakers*, or MCBs, are used. With this, lighting predominantly uses thermal-magnetic MCBs as there exists both high inrush current as well as a potential for faults over time. When possible, it is recommended that lighting be placed on isolated circuits (without any other type of loads) to prevent accumulative damage caused by transients on the input lines.

What Trips a Thermal-Magnetic MCB?

A thermal-magnetic MCB can be tripped either thermally or magnetically. If the current flowing through the MCB is great enough to generate more heat than the device is rated for, the MCB will thermally trip. Alternatively, if the peak inrush current that instantaneously flows through the device is exceeded, the MCB will magnetically trip. With this, the LED driver maximum rated input current and the inrush current are both important specifications to understand for proper MCB loading and selection.

LED Driver Input Current

Every Inventronics LED driver has a maximum specified input current written on the label of the driver and specified in the datasheet. Using the EUG-096S350DT for example, the label is shown in Figure 2 and the datasheet specification is shown in Figure 3. Notice that the maximum input current is different between the product label and the datasheet specification. The product label input current is assigned based upon the testing measured by the safety agency. The datasheet defines a current slightly higher than what is shown on the product label as this includes added margin for tolerance between production units and is the value referenced for warranty.

Input current is defined as the amount of current that the LED driver draws from the power source (typically AC mains) under normal, steady-state operation. The load and the input current are directly related, meaning that as the load decreases, the input current will also decrease. With this, the maximum input current is measured when the driver is fully loaded.

Also notice that the lower the input voltage, the higher the input current will be. With this, the worst-case input current conditions are full-load at the minimum rated input voltage. The amount of current and power drawn in a specific fixture can be easily measured when using a power meter.

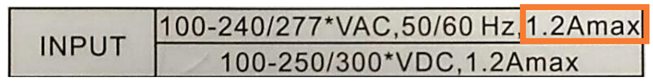

Figure 2: Maximum Input Current on Product Label

Input AC Current	1.32 A	Measured at full load and 100 Vac input.
	0.60 A	Measured at full load and 220 Vac input.

Figure 3: Maximum Input Current in Datasheet

LED Driver Inrush Current

The current pulse, or inrush current, is the instantaneous current drawn when the LED driver is first powered ON. This is caused by the charging of capacitors on the input side of the driver. This instantaneous charging will draw a peak current several magnitudes greater than the steady-state current. Obtaining this specification is less straight forward than the input current, but it is an equally important specification to understand. The inrush current is not shown on the product label, but it is defined in the datasheet which also includes the inrush current waveform. These waveforms are comprised of the peak amplitude and a time duration as shown in Figure 4.

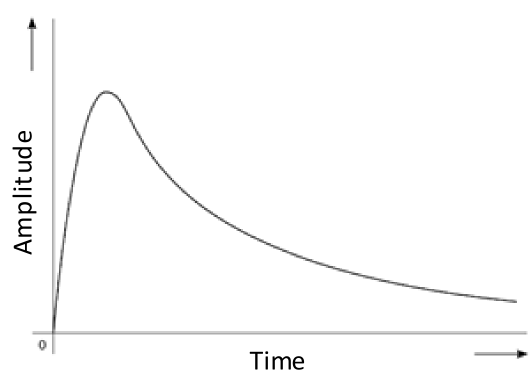

Figure 4: General Inrush Current Waveform

Inrush Current Factors

The peak current and duration depends on many factors, such as temperature, load, input voltage, and when the driver is turned on relative to the input signal.

Many of our designs include an NTC thermistor to limit the peak inrush current without compromising efficiency. This means that at cold-start, the resistance will be high and the current will be limited. However, if starting when the system is already warm, the resistance will be lowered and the driver will pull more inrush current. Note: this is why efficiency is measured after the system has warmed.

Similar to input current, the inrush current will also decrease as the load decreases. Inrush current will be maximized with a full load.

As the input voltage increases, the peak inrush current also increases. This also holds true when considering the ON timing relative to the input AC signal as shown in Figure 5. Inrush current will be greatest when turned ON at the peak of the input sine wave and will be most minimized when turned ON at the zero-crossing point of the sine wave.

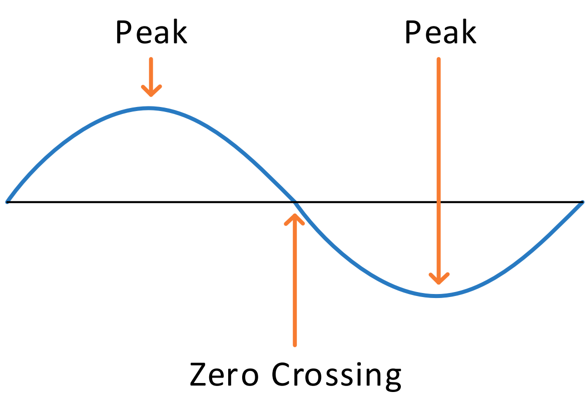

Figure 5: Sine Wave Peak and Zero Crossing

Example Showing How Input Voltage Influences Inrush Current

The EUG-096S350DT inrush was captured with a 100Vac input shown in Figure 6 and a 220Vac input shown in Figure 7, where all other conditions are the same. The 100Vac input has a peak current of 30A and a duration of 400µs vs the 220Vac input with a peak current of 53.5A and a duration of 760µs.

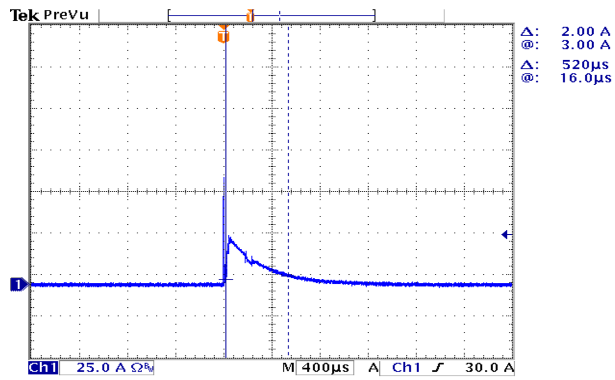

Figure 6: Inrush Waveform of 100Vac input voltage

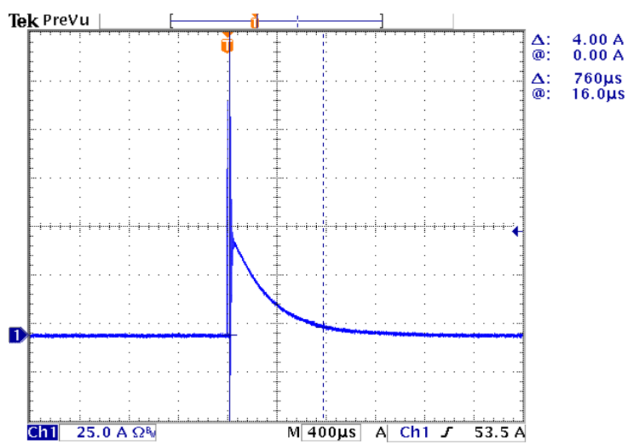

Figure 7: Inrush Waveform of 220Vac input voltage

Example Showing How Temperature Influences Inrush Current

The EBD-240S105DV inrush waveform was captured at 25°C shown in Figure 8 and at 75°C shown in Figure 9, where all other conditions are the same. The 25°C waveform has a peak current of 69.2A and a duration of 1.77ms vs the 75°C waveform with a peak current of 100A and a duration of 1.39ms.

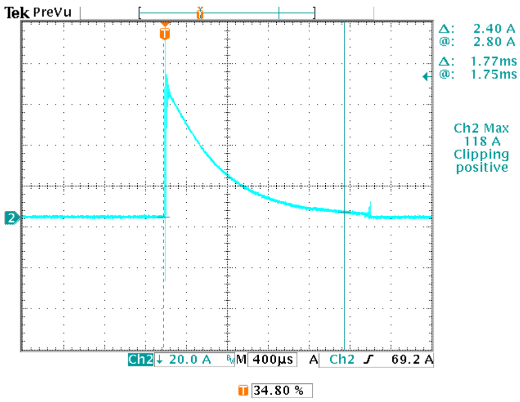

Figure 8: Inrush Waveform at 25℃

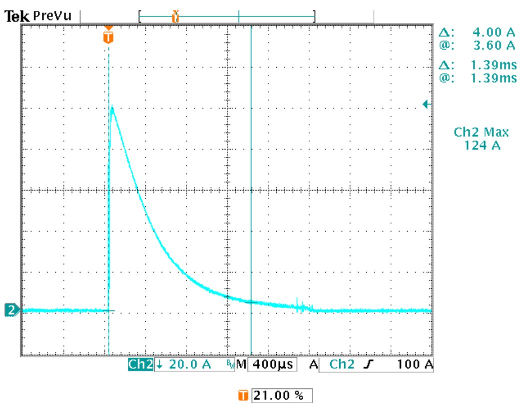

Figure 9: Inrush Waveform at 75℃

With many factors involved, Inventronics provides a single representative waveform that may be used as a reference. These waveforms are captured at 25℃ with maximum load. The input voltage used is 220Vac for universal input drivers and is 480Vac for high input drivers. As other factors may need to be considered in each unique site installation, this waveform is to serve as a reference only.

Inrush Current Waveform

All Inventronics waveforms and calculations are based on the driver model with the worst-case inrush current for the full family of drivers defined in the datasheet. Inventronics simulates turning the driver ON at the peak of the AC input as shown earlier in Figure 5 by using a charged bank of capacitors to serve as the source of power. An oscilloscope and current probe are used to capture the inrush current as the circuit is energized.

Tip

If a current probe is not available, the same test setup may be used, but with a small resistor (≤ 0.1Ω) added in series with the LED driver. The I^2t calculation described in the next section is the same, except the voltage must also be divided by the resistance in order to obtain the inrush current value. Figure 10 shows this waveform measuring voltage rather than current.

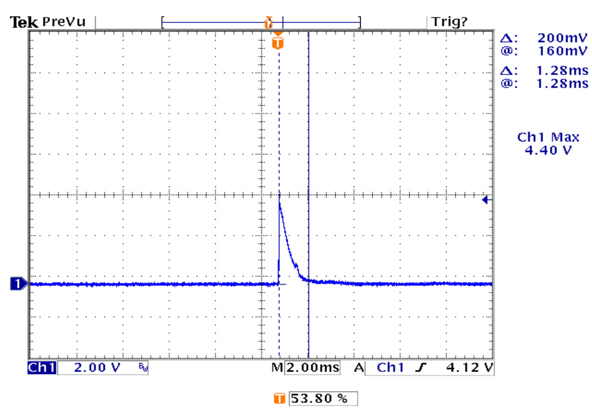

Figure 10: Inrush Voltage Waveform

This overview will only provide waveforms and examples measuring current as this is most commonly used.

Inrush Calculation

The total energy contained in a current pulse depends on the waveform's shape, peak current, and duration. Table 1 presents several common inrush waveforms with their corresponding calculations. These calculations serve well as a general method for defining the approximate total energy in the current pulse. Inventronics uses the 4th equation to derive the inrush I^2t specification, where time (t) is defined as the duration between 10% to 10% of the peak current.

Table 1: Common Inrush Waveforms and Corresponding Calculation

	Waveform	Calculation
1.	Ip, t	$I^2t = I_p^2 t$
2.	Ip, Ia, t	$I^2t = \frac{1}{3}\left(I_p^2 + I_p I_a + I_a^2\right)\cdot t$
3.	Ip, t	$I^2t = \left(\frac{1}{3}\right) I_p^2 t$
4.	Ip, t	$I^2t = \left(\frac{1}{2}\right) I_p^2 t$
5.	Ip, t OR t	$I^2t = \left(\frac{1}{5}\right) I_p^2$

In addition to this general calculation, Inventronics adds a multiplier of 2 for LED drivers that are < 60W and adds a multiplier of 1.5 for LED drivers > 60W. The I^2t value is not used for other calculations, but can be used as a tool of comparison with other LED drivers measured the same way.

Derive Datasheet I^2t Value for Drivers < 60W

Drivers < 60W add a multiplier of 2 to the Inrush Current I^2t datasheet specification. Using the EBS-040SxxxBTE for example, the datasheet shares the waveform found below in Figure 11.

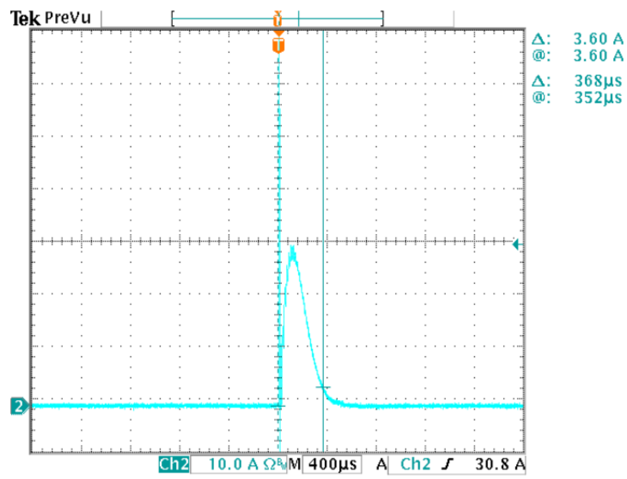

Figure 11: EBS-040SxxxBTE Inrush Waveform

This shows that the peak current is 30.8A (notice that the transient peak is ignored). The time duration is 368µs.

$$I^2t\left(\frac{1}{2}\right) = inrush\ current$$

$$\frac{30.8^2 x\ 0.000368}{2} = 0.175A^2s$$

Max inrush current = 0.175 x 2= 0.349A^2s

Inrush Current(I^2t)	0.35 A^2s	At 220Vac input, 25°C Cold Start, Duration =368 µs, 10%Ipk-10%Ipk. See Inrush Current Waveform for the details.

Figure 12: EBS-040SxxxBTE I^2t Datasheet Specification

Derive Datasheet I^2t Value for Drivers > 60W

Drivers > 60W add a multiplier of 1.5 to the Inrush Current I^2t datasheet specification. Using the EUG-096S350DT for example, the datasheet shares the waveform found below in Figure 13.

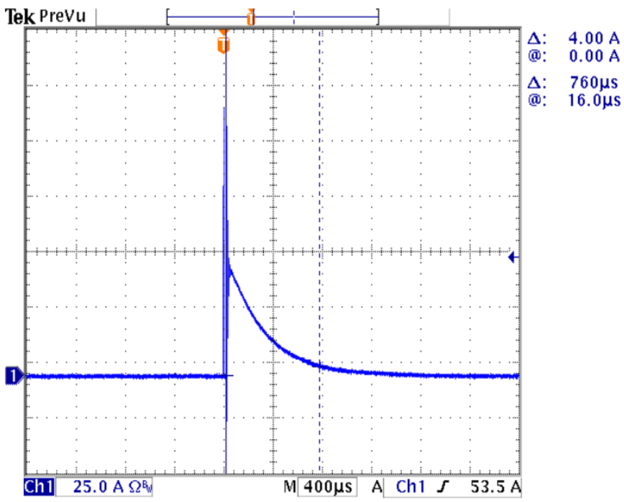

Figure 13: EUG-096S350DT Inrush Waveform

This shows that the peak current is 53.5A (notice that the transient peak is ignored). The time duration is 760µs.

$$I^2t(\frac{1}{2}) = inrush\ current$$

$$\frac{53.3^2x\ 0.00076}{2} = 1.1A^2s$$

Max inrush current = 1.5 x 1.1=1.65A^2s

Inrush Current(I^2t)	1.65 A^2s	At 220Vac input, 25℃ cold start, duration=760 µs, 10%Ipk-10%Ipk. See Inrush Current Waveform for the details.

Figure 14: EUG-096S350DT I^2t Datasheet Specification

MCB Standards and Regulations

The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees. International Standard IEC 60898-1 and European Standard EN 60898-1 define the rated current as the maximum amount of current that the MCB is designed to carry continuously (at an ambient air temperature of 30 °C). This rated current is referred to as I_n.

MCB Ampere Ratings

The typical ampere ratings are 6A, 8A, 10A, 13A, 16A, 20A, 25A, 32A, 40A, 50A, 63A, 80A, 100A and 125A; however, the MCB will not include the unit symbol “A”. Instead, the ampere rating is preceded by a letter "B", "C" or "D" that indicates the breaker type. This letter corresponds to the magnitude of I_n that the MCB can handle instantaneously without tripping. The ranges of magnitude for each type are shown in Table 2:

Table 2: MCB Type Instantaneous Tripping Current Ranges

Type	Range
B	Above 3 I_n up to and including 5 I_n
C	Above 5 I_n up to and including 10 I_n
D	Above 10 I_n up to and including 20 I_n [a]

For example, this means that a C20 MCB will have an instantaneous tripping current range of 100A to 200A. Table 3 shows other examples of the minimum tripping current for reference.

Table 3: Minimum Instantaneous Tripping Current

MCB Type	B16	C16	D16	B20	C20	D20
Instantaneous Tripping Current	48A	80A	160A	60A	100A	200A

Note

The instantaneous tripping current is the *minimum* amount of current that can cause the MCB to trip typically in less than 100ms.

MCB Tripping Characteristics

When using a thermal-magnetic MCB, both the magnitude of current and the duration of this current determine when the MCB will trip. This relationship between I_n and the tripping (action) time will be provided by the MCB manufacturer in the datasheet and will be similar to Figure 15 which shows simplified tripping curves for Type B, Type C and Type D MCBs. The boxed area represents the instantaneous tripping region that was previously described.

The blue curve represents the rated current at defined time durations. The steady-state rated current is expressed as "1" on the x-axis and is the maximum current the device can handle indefinitely without tripping. The greater the current, the more quickly the device will trip. Table 4 was generated from these curves and shows that the MCB can withstand 2 times the rated current for 850ms without tripping for a type C MCB. Alternatively, the same MCB can withstand 3 times the rated current for only 130ms before tripping.

Table 4: MCB Type Tripping Times Per Magnitude of In

Type	Tripping Time (ms)					
	2In	3In	5In	6In	10In	20In
B	> 400	< 100	< 100	/	/	/
C	> 850	> 130	< 100	< 100	< 100	/
D	> 1200	> 1600	> 130	> 120	< 100	< 100

If operating within the instantaneous tripping range for less than 100ms the device may or may not trip. With this tolerance, the minimum instantaneous tripping current is used to avoid nuisance tripping.

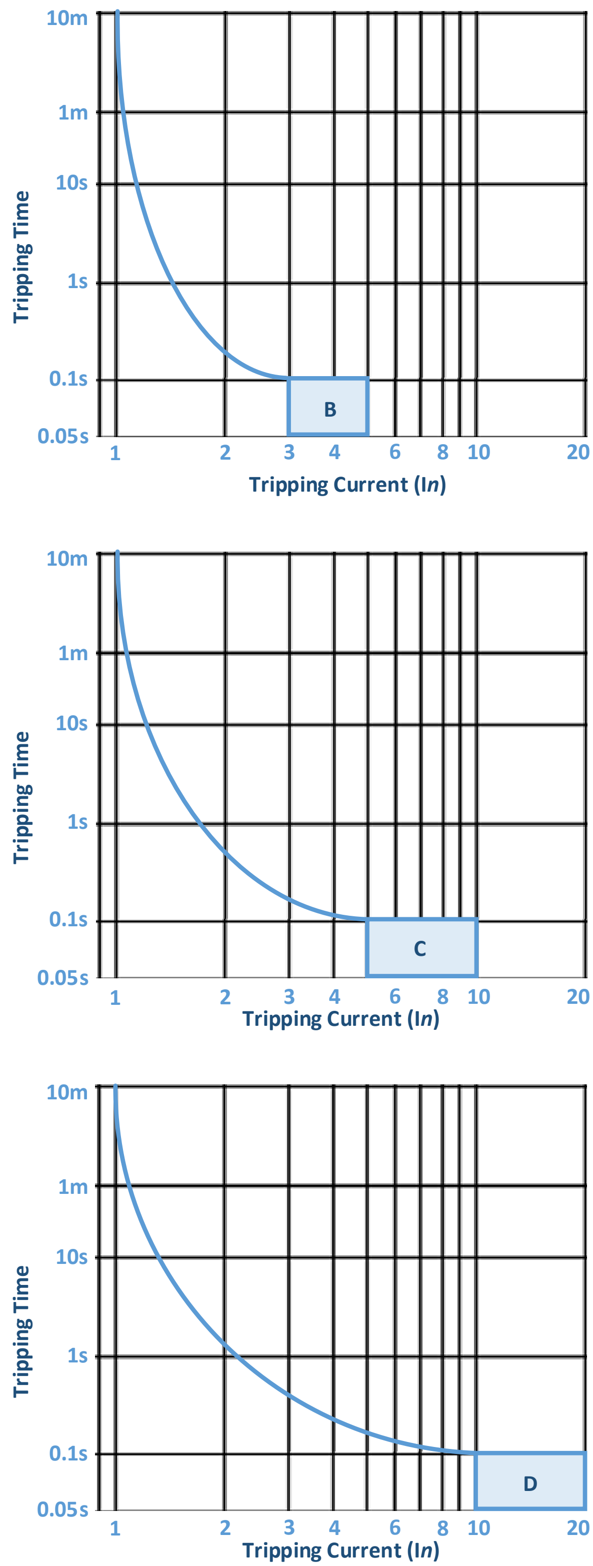

Figure 15: MCB Type B, C, and D Tripping Curves for

Considering Inrush Duration < 50ms

Notice that the curves in Figure 15 only go down to 50ms and end at the maximum instantaneous tripping range. Many MCB datasheets will not define performance below 50ms as they are thought to be unable to react to such short bursts of energy. Additionally, introducing inrush over the maximum specified instantaneous tripping range for any period over 50ms is operating the MCB out of specification. However, compared to traditional applications, LED lighting has significantly higher peak inrush currents at significantly shorter durations.

Some MCBs do actually respond to this burst of energy, even though it is not defined in the datasheet. Due to this nuisance tripping, some manufacturers have started making circuit breakers specifically designed for lighting. For circuit breakers that do not have information for less than 50ms, Figure 16 may be referenced which provides a proof factor based upon the duration of the waveform. The shorter the waveform, the more peak current the MCB can handle.

For example, if the duration of the inrush waveform is 520us, the maximum instantaneous tripping limit is increased by a multiplier of 5. If the duration of the inrush waveform is 800us, the maximum instantaneous tripping limit is increased by a multiplier of 3.

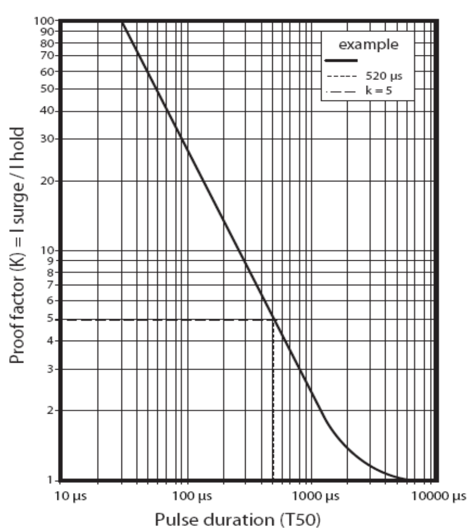

Figure 16: Proof Factor for Instantaneous Tripping Current (source ABB)

"How Many LED Drivers Can I Use Per MCB?"

To understand the maximum number of drivers that may be connected to a single MCB, two calculations are needed. One calculation reviews the nominal input current of the driver compared to the allowed rated input current of the MCB. The other calculation reviews the inrush current of the driver compared to the allowed instantaneous current of the MCB.

Whichever calculation yields fewer drivers is the number that should be used to avoid nuisance tripping. To simplify the calculation, input current and inrush current are considered additive.

Calculation Reviewing the Nominal Input Current Limitation

The input current calculation includes a derating percentage (D%) multiplied by the rated current (Imcb) of the MCB and divided by the maximum input current for the driver (Id). The calculation follows:

$$D\%\ x\ \frac{Imcb}{Id} = Max\ Number\ of Drivers\ to\ MCB$$

The derating percentage helps to prevent nuisance tripping and varies by type due to their typical sensitivity:

B type: 60%
C type: 70%
D type: 80%

For example, if using a C16 MCB and a driver with a maximum input current of 500mA, the calculation would be:

$$70\%\ x\ \frac{16}{0.5} = 22.4\ Drivers\ to\ MCB$$

Calculation Reviewing the Inrush Current Limitation

The inrush current calculation includes the rated current (In), the MCB type's minimum instantaneous tripping multiplier (Itrip), and a proof factor (K) to help account for high peak, short duration inrush currents.

$$In\ x\ Itrip\ x\ K = Max\ Allowed\ Inrush\ Current$$

Recall that Table 2 shows the minimum *Itrip* for each type is:

B type: 3
C type: 5
D type: 10

A proof factor for short durations, may be published in the MCB datasheet, but for general calculations Inventronics references Figure 16.

For example, for a C16 MCB and an inrush current waveform with a duration of 800µs, the maximum allowed inrush current is calculated:

$$16\ x\ 5\ x\ 3 = 240A$$

This value (Irmax) is then divided by the peak amplitude of the inrush waveform (Ipeak).

$$\frac{Irmax}{Ipeak} = Max\ Number\ of\ Drivers\ to\ MCB$$

If the driver had an inrush peak of 50A, the calculation would be:

$$\frac{240A}{50A} = 4.8\ Drivers\ to\ MCB$$

Comparing Calculations

To avoid nuisance tripping, the worst-case calculation must be chosen. This includes rounding decimals down and choosing the lower quantity between the input current and inrush current calculations.

For example, the input current allows for 22.4 drivers, which is rounded down to 22. The inrush current allows for 4.8 drivers, which is rounded down to 4. Comparing the two, the system is limited by the inrush current and can have a maximum of 4 drivers loaded per MCB without nuisance triggering.

Increase Number of Drivers per MCB When Limited by Input Current

If a system is limited by nominal input current, increasing the MCB's rated current will allow for more drivers to be loaded onto a single MCB. Using the previous example, changing from a C16 MCB to a C20 MCB would support the nominal input current of 6 more drivers for a total of 28 drivers per MCB.

Increase Number of Drivers per MCB When Limited by Inrush Current

If the system is limited by inrush current, increasing the MCB's rated current, changing the MCB type, and offsetting the drivers' ON time will allow for more drivers to be loaded onto a single MCB. Using the previous example:

Change MCB Rating

Changing from a C16 MCB to a C20 MCB, would support 2 more drivers for a total of 6 drivers per MCB.

Change MCB Type

Changing from a Type C MCB to a Type D MCB, would support 5 more drivers for a total of 9 drivers per MCB.

Offset When LED Drivers Power ON

Offsetting when the drivers are powered ON will minimize the inrush current by dividing the total energy into smaller current pulses. Using the same example, the C16 MCB can handle an instantaneous peak of 240A before tripping. The drivers have a peak of 50A, so the MCB can handle 4 drivers turned on at the same time for a peak of 200A. If 5 drivers were turned on at the same time, it would exceed the minimum instantaneous tripping current and may cause nuisance tripping. In this example, 20 LED drivers would have a steady-state input current of 10A. If a 6^{th} group of 4 led drivers were added, this would yield a steady-state input current of 12A and would exceed the derated load value for a C16 MCB of 11.4A.

With this, the system can support up to 5 groups of 4 LED drivers before it hits the nominal input current limitation. A simplified visual representation is shown in Figure 17 where the blue pulse signifies all 20 drivers powered on at the same time which would trip the MCB. The orange pulses signify 20 drivers each powered on separately in group of 4 which would not trip the MCB. The green line indicates the nominal input current which is 10A for both systems after inrush current has stabilized.

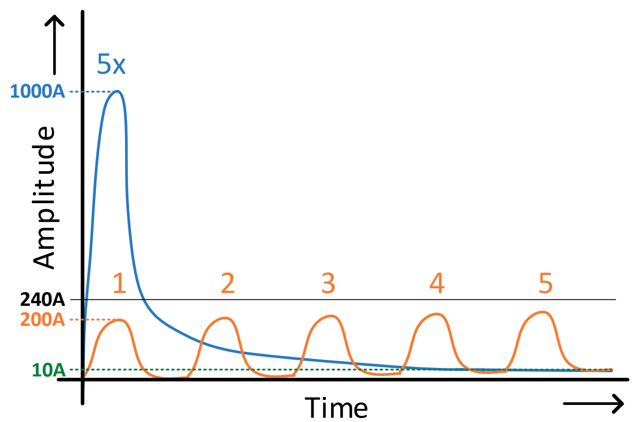

Figure 17: Offsetting Driver ON Time

Summary

Circuit breakers serve as a safety mechanism to prevent excess current flow under fault conditions. They are sensitive to the input current and inrush current of LED drivers which can increase or decrease depending on environmental conditions. If loaded too heavily, nuisance tripping may occur where the breaker disrupts power when no fault condition exists. The number of drivers that may be loaded on a single circuit breaker while avoiding nuisance tripping can be calculated by considering environmental conditions and using the driver's input and inrush current.

For the most accurate calculation, the input and inrush currents may be measured under the worst-case environmental conditions for the luminaire. For general calculations, the information provided in the datasheet may be used.

Note

The *General MCB Load Recommendation* is another resource which provides a quick reference on how to load an MCB for Inventronics product families. This resource provides the recommended maximum number of drivers to start with and is based upon general calculations using the defined input and inrush current. The calculation uses an inrush duration (t) defined by 50%-50% peak. Due to the application, tolerance, and MCB sensitivity, it may be found that the number of drivers should be reduced or that more drivers can actually be placed on the MCB without tripping. With this, testing is always recommended.

Disclaimer

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