Sizing Guidelines

An excerpt from the POWR-*SPEED*® Fuses Application Guide

SECTION 4.0

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For more insights, download the full POWR-SPEED Fuses Application Guide at **Littelfuse.com/powr-speed-application-guide**

The proper selection of high-speed fuses involves greater understanding and consideration of its product specifications such as rated voltage, rated current, interrupting rating, and melting and total clearing I^2t ratings, and then sizing them appropriately to various application conditions.

This document, which is excerpted from the POWR-SPEED Fuses Application Guide, discusses the general industrial guidelines for sizing high-speed fuse specifications based on these influencing application conditions. Download complete, 52-page POWR-SPEED Fuses Application Guide at Littelfuse.com/powr-speed-application-guide for an in-depth look at high-speed fuse protection.

4.1 Rated Voltage

Rated voltage of a fuse is the maximum ac or dc voltage at which the fuse is designed to operate. Fuses may be rated for ac only, dc only, or both ac and dc. A fuse's voltage rating must equal or exceed the application voltage where the fuse will be installed.

The ac voltage rating on the fuse label is the maximum open circuit rms voltage for which the fuse can be safely applied. But it's also important to note that fuses used in dc circuits must be specifically rated for dc applications. The dc voltage rating on the fuse label is the maximum dc voltage where the fuse can be safely applied.

In some instances, and with certain limitations, an ac only rated fuse could be used on dc circuits. Please consult Littelfuse Technical Services to understand the safe dc voltage rating for applying such fuses. Most common application conditions that affect the rated voltage sizing of high-speed fuses are operating frequency, regenerative loads and adopted agency standards.

4.1.1 Effect of Operating Frequency (E_f)

The ac voltage rating of a fuse is determined by testing at a frequency between 45 Hz and 62 Hz per UL and IEC standards. Typically, application frequencies (up to 1 kHz) do not affect the performance of a fuse. However, at lower frequencies (below 45 Hz), the circuit tends to perform more like a dc circuit which can significantly affect the fuse's ability to safely clear a fault current. In such an application, a fuse with a rated ac voltage higher than the application ac voltage would be recommended.

To determine the minimum rated ac voltage of a fuse at low frequency applications, the appropriate frequency correction factor (E_f) (see **Figure 24** below) should be factored to the application ac voltage to determine the proper fuse voltage rating.

The minimum rated ac voltage of a fuse can be determined by:

$$E_n \geq \frac{E}{E_f}$$

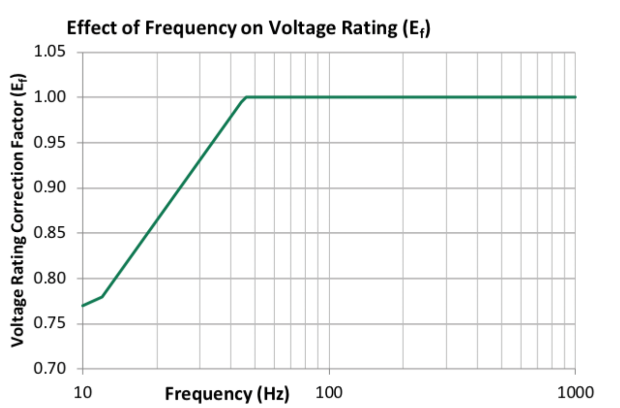

Figure 24. Frequency correction factor curve

Example:

Application Voltage Rating (E) = 480 V ac

Application Frequency = 30 Hz

Frequency Correction Factor (E_f) = 0.9

Minimum Fuse AC Voltage $\mathbf{E_n} \geq \frac{\mathbf{E}}{\mathbf{E_f}} \geq \frac{480 \text{ V ac}}{0.9} \geq 533 \text{ V ac}$

And thus, the recommendation would be to use a 550 V ac or 600 V ac rated fuse.

4.1.2 Effect of Time Constant (E_{fc})

The ability of a dc rated high-speed fuse to safely interrupt dc overcurrents is influenced by the dc time constant (also known as the L/R ratio) of the circuit. In dc circuits, the inductance to resistance (L/R) ratio defines the rate of rise of fault current (di/dt). The dc circuit time constant is generally expressed in milliseconds (ms) and is the time it takes for the dc circuit to reach 63% of its final value.

The longer the time constant of the circuit, the more the burden on the fuse to safely interrupt the fault current. Littelfuse high-speed fuses are tested in circuits with time constant (L/R) no less than 10ms per the UL and IEC standards. When used in circuits with a time constant exceeding 10ms, high-speed fuses require additional rated voltage de-rating. Contact Littelfuse Technical Services for such applications.

4.1.3 Effect of Regenerative Loads (E_{reg})

When fuses are used in a regenerative power converter application where the mechanical energy of the motor and/or connected load is returned to the ac power source during braking, there is a chance of commutation fault. This is the worst-case fault in this circuit. During this fault, the application source ac voltage is superimposed upon the converter output dc voltage causing a sudden increase in system voltage. This affects the fuse's ability to safely clear the fault.

For a high-speed fuse to safely clear a commutation fault in a regenerative load application, a safety factor (E_{reg}) of 1.8 is applied to the application voltage rating (E) to determine the minimum rated voltage of the high-speed fuse (E_n).

$\mathbf{E_n = E \times E_{reg}}$ or $\mathbf{E_n = E \times 1.8}$

For non-regenerative loads, the safety factor $\mathbf{E_{reg} = 1.0}$

4.1.4 Effect of Complying Fuse Standard

High-speed fuses offered by Littelfuse are compliant to either UL, IEC, or in many cases, both standards depending on the fuse style. North American round body style fuses are compliant to the UL 248-13 standard and rated voltage testing is performed at 100 % of the ac voltage of the fuse.

In comparison, square body style fuses are tested to both IEC 60269-4 and UL 248-13 standards. Per the IEC standard, rated voltage testing is performed at 110 % of the ac voltage of the fuse, to factor in any application overload conditions.

When applying North American round body style fuses in an IEC application, an additional safety factor of 0.9 should be factored to the application voltage to determine the rated voltage of the fuse.

Minimum high-speed fuse rated voltage: $\mathbf{E_n = \frac{E}{0.9}}$

So in summary, the rated voltage of a fuse is determined using the formula:

$$E_n = \frac{E \times E_{reg}}{E_f}$$

For North American style fuses used in IEC applications, the rated ac voltage of a fuse is determined by:

$$E_n = \frac{E \times E_{reg}}{0.9 \times E_f}$$

Where:

E = Application voltage rating

$\mathbf{E_{reg}}$ = Regenerative load safety factor

$\mathbf{E_f}$ = Frequency correction factor

4.2 Rated Current

The rated current of a high-speed fuse is defined as the continuous ac rms current (and the dc steady-state current, when rated for ac and dc) that the fuse is designed to carry under specified conditions defined by the complying standard (UL and IEC).

The rated current printed on the fuse label is determined based on testing performed at standard test conditions.

- **Ac Circuit Conditions:** Frequency range from 45 Hz to 62 Hz with an ambient temperature 20 °C ± 5 °C.
- **Dc Circuit Conditions:** A time constant (L/R) of 10ms or less with an ambient temperature of 20 °C ± 5 °C.

Typically, fuses are not always applied at standard test conditions. As a result, the sizing (or selecting) of the fuse's rated current is dependent on various application factors and conditions.

4.2.1 Sizing of the High-Speed Fuse Rated Current

The following steps explain how to size a high-speed fuse for various applications.

Step 1: Determine the Normal Full-Load Current of the Fuses

Depending on the location of the fuse in the power conversion circuitry (ac side or dc side), the load current through the fuse varies. In most cases this normal load current is generally available from the application design engineer.

For applications where normal full load current is not readily available, the value can be determined by calculating the rms current (ac side fusing) or the steady-state current (dc side fusing).

In power conversion applications, the challenge is determining this ac rms current and dc steady-state current (often stated as dc average current) due to the pulsating nature of the rectifier output current.

Figure 25 shows the relationship between ac rms current and dc average current for a single-phase unfiltered full-wave rectifier circuit.

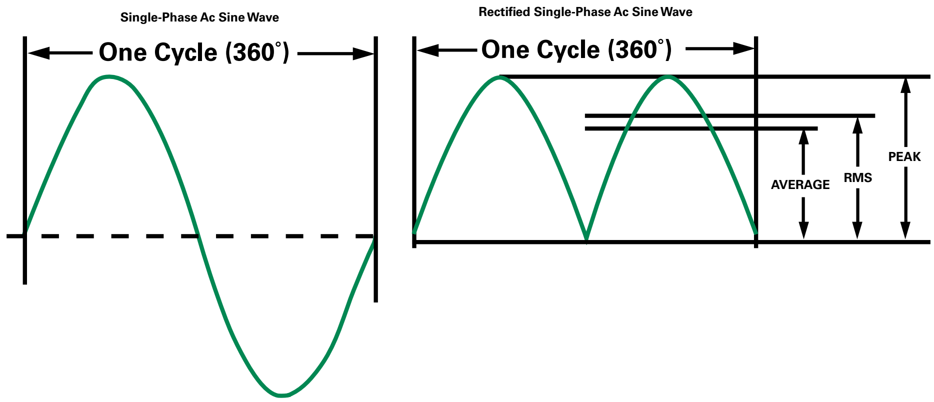

Figure 25. Relationship between ac rms current and dc average current for a single-phase unfiltered full-wave rectifier circuit.

Where,
I_{PEAK} = Peak Current

I_{AVG} = Dc Average (Output) Current

I_{RMS} = Ac RMS Current

$I_{AVG} = 0.636 \times I_{PEAK}$

Or

$I_{PEAK} = I_{AVG} / 0.636$

$I_{RMS} = 0.707 \times I_{PEAK}$

By substituting I_{PEAK} in the above equation,

$I_{RMS} = (0.707 / 0.636) \times I_{AVG}$

Ac Side Normal Full-load Current (I_{AL}): $\mathbf{I_{RMS} = 1.11 \times I_{AVG}}$

Or

Dc Side Normal Full-load Current (I_{AL}): $\mathbf{I_{AVG} = 0.9 \times I_{RMS}}$

The average dc current through the fuse is 90 % of the ac rms current (see **Figure 25**). Fuses located in the ac side of the circuit will see an rms current 1.11 times that of the dc average output current.

When multiple semiconductors (such as full-wave, parallel, three-phase, or similar circuits) along with multiple fuses are used in a circuit, current through each fuse depends on the location of the fuse in the circuit.

The examples below represent a few common rectifier circuit options with possible fuse placement locations shown along with the ac rms current running through the fuse (as calculated at 100 % dc steady-state load current).

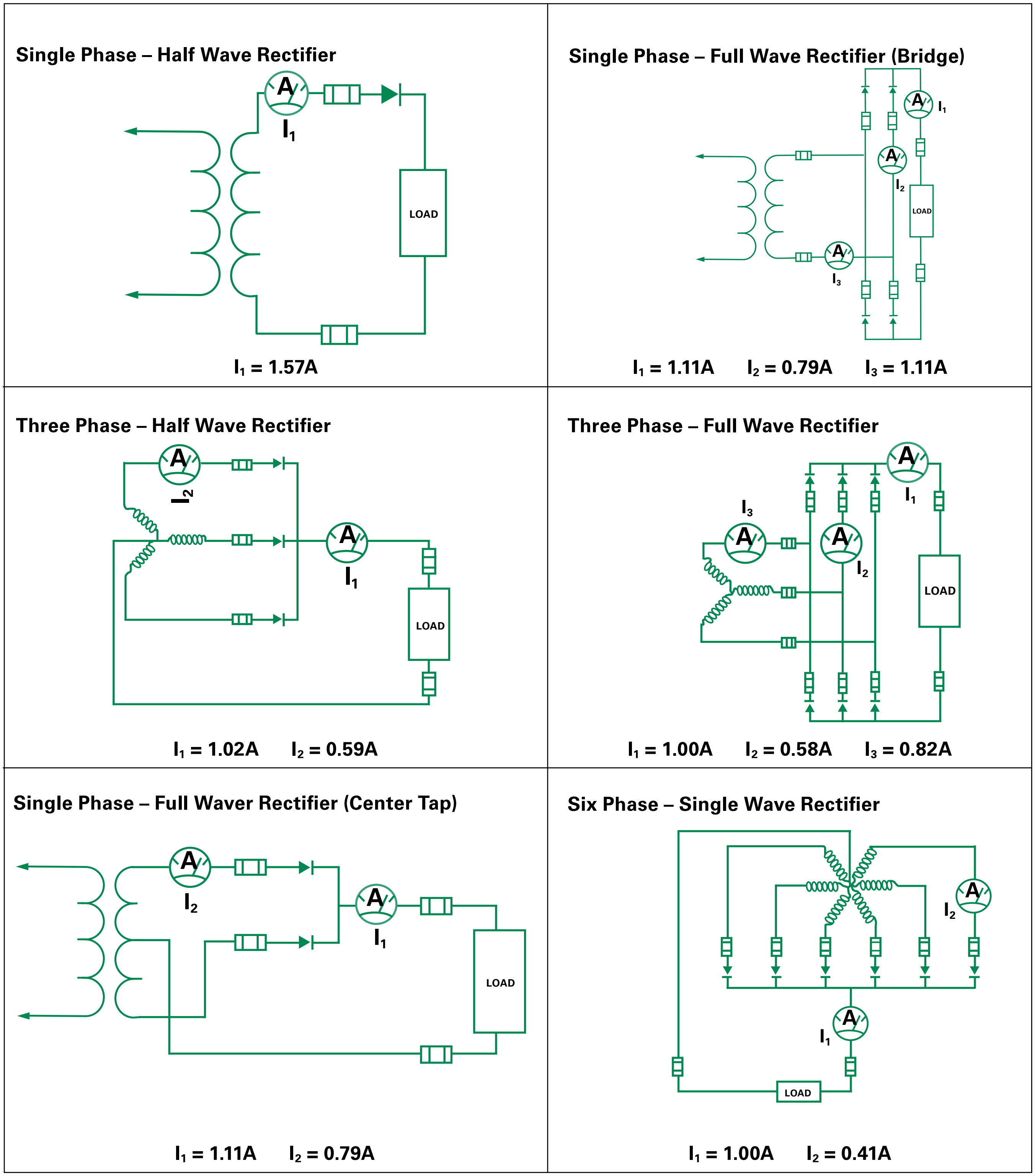

Figure 26. Typical rectifier circuits and locations of high-speed fuses in the circuitry

When the current through the fuse is constant and continues for one hour or more, then the calculated normal load current is similar to the ac rms current or the dc steady state current per the illustrations above.

However, for applications involving varying load current, especially when subjected to inrush current or cyclic current (regular-repeating identical current cycles), the normal load current through the fuse is obtained by calculating the rms current of one duty cycle, known as adjusted normal load current.

Figure 27 is a representation of a typical varying load cycle. The adjusted normal load current for this varying load cycles is provided by the formula,

$$I_{AL} = \sqrt{\frac{I_1^{\,2} t_1 + I_2^{\,2} t_2 + \cdots \ldots \ldots + I_n^{\,2} t_n}{T}}$$

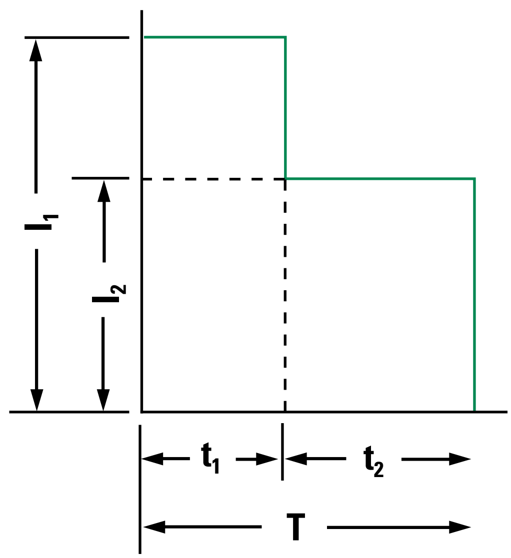

Figure 27. Varying load current (cyclic current)

Where,

I_1, I_2...I_n: Varying RMS load currents (amperes)
t_1, t_2...t_n: Corresponding current cycle duration (seconds)
T: Total duration of one varying load current cycle (Including any OFF period)

Example:

Determine the adjusted normal load current for the cyclic current shown in **Figure 28**.

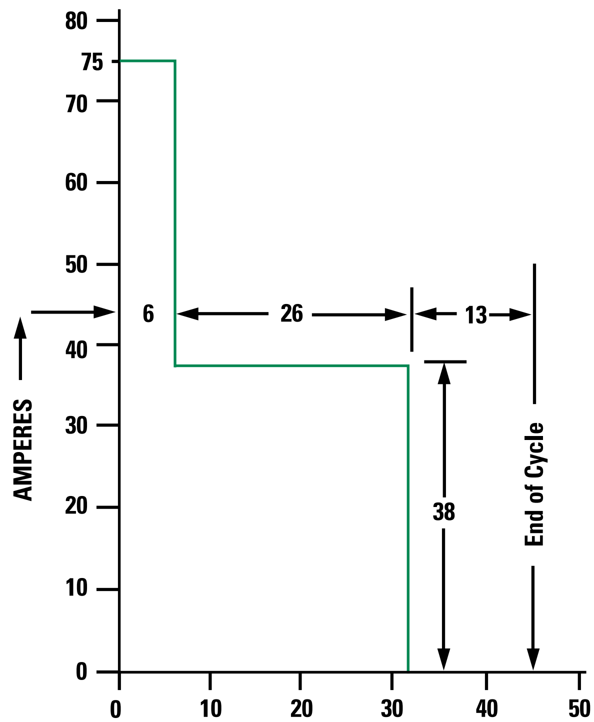

Figure 28. A cyclic current.

Where,

I_1: 75A

t_1: 6 Seconds

I_2: 38A

t_2: 26 Seconds

I_3: 0A

t_3: 13 Seconds

Total Time (T): 45 Seconds

$$I_{AL} = \sqrt{\frac{(I_1^2 * t_1) + (I_2^2 * t_2) + (I_3^2 * t_3)}{T}}$$

$$I_{AL} = \sqrt{\frac{(75^2 * 6) + (38^2 * 26) + (0^2 * 13)}{45}}$$

$$I_{AL} = 40A$$

For irregular current cycles, the adjusted load current must be calculated for a period of one hour, during which the largest effective surge current would occur.

Depending on the magnitude and duration of the surge current, the calculated adjusted normal load current (I_{AL}) may be substantially less than the surges in the system.

Other common scenarios observed in power semiconductor applications would involve having multiple power semiconductor devices connected in parallel (as shown in **Figure 29**). In this scenario called a multi-parallel connection, each device is protected by an individual high-speed fuse in each arm/leg of the power conversion circuit.

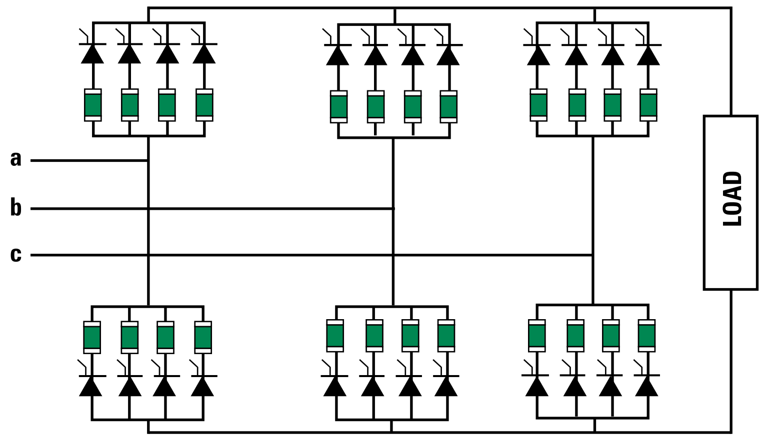

Figure 29. Multi-parallel connection in a rectifier circuit

In such situations, the load current through each arm/leg is shared between all parallel paths. Though load current sharing is typically not equal, as up to 20% of uneven sharing is allowed. Continuous operation of this multi-parallel circuitry with one less parallel path (due to fuse operation on an internal fault) is also possible. Thus, when determining the load current through the fuse in such multi-parallel circuits, both these conditions should be considered.

The normal load current (I_{AL}) through each fuse in a multi-parallel connection circuitry is determined by:

$$I_{AL} = \frac{I_{AL\,(LEG)}}{\left\{\frac{N}{(1+S)}\right\} - 1}$$

Where,

$I_{AL(Leg)}$ = Total rms current in each arm/leg

N = Total number of parallel path in each arm/leg

S = Load current sharing factor (0 %-20 %)

The rated current of the high-speed fuse being selected can be determined by applying re-rating factors (computed in Step 2 below) to the normal load current (I_{AL}) determined from this section.

Step 2: How to determine the appropriate current rating of a high-speed fuse

As thermally sensitive devices, there are various application parameters that affect a fuse's operation (melting). This, in turn, affects the overall current carrying capacity (rated current) of a fuse. The following are the application parameters and their corresponding correction factors that need to be considered while sizing a high-speed fuse.

The rated current of a high-speed fuse can be determined using the following formula:

$$I_N = \frac{I_{AL}}{F_{AT} * F_{FC} * F_{WR} * F_{HZ} * F_{SS} * F_{AL}}$$

Where,

I_{AL} = Adjusted normal full-load current

I_N = Rated current of high-speed fuse for the application

F_{AT} = Ambient temperature correction factor

F_{FC} = Forced cooling correction factor

F_{WR} = Wiring connection factor

F_{SS} = Switching correction factor

F_{AL} = Altitude correction factor

2a: Ambient Temperature Fuses are affected by the air temperature immediately surrounding it (ambient temperature) during its operation. Typically, high-speed fuses are tested at standard test conditions of 20 °C ± 5 °C and can be applied at a wide operation temperature range of -50 °C to +125 °C. When fuses are operated at ambient temperatures outside their standard testing range, the appropriate ambient temperature correction factor needs to be computed and factored to properly select the fuse rating. The ambient temperature correction factor (F_{AT}) is determined by the formula

$$F_{AT} = \sqrt{\frac{125 - T_a}{125 - T_{std}}}$$

Where,

T_a = Application ambient temperature

T_{std} = Standard testing ambient temperature

Example:

Determine the ambient temperature correction factor for a fuse installed at a 55 °C ambient temperature condition?

Per formula, it is calculated to be:

$$F_{AT} = \sqrt{\frac{125-T_a}{125-T_{std}}} = \sqrt{\frac{125-55}{125-25}} = \sqrt{\frac{70}{100}} = \sqrt{0.7}$$

F_{AT} = 0.84

2b: Forced Cooling: Due to their switching properties, power semiconductor devices typically produce large amounts of heat during normal operating conditions. When the heat produced exceeds their safe operating temperature limits, the devices will become inoperable.

Forced air cooling and liquid cooling are the two heat sinking methods commonly practiced in such applications. Fuses that are used to protect such devices are also subjected to such heat sinking methods and can directly affect (increase) the current carrying capacity of the high-speed fuse.

The curve shown in **Figure 30** determines the Forced (Air) Correction Factor (F_{FC}) to be used when sizing the rated current of a high-speed fuse.

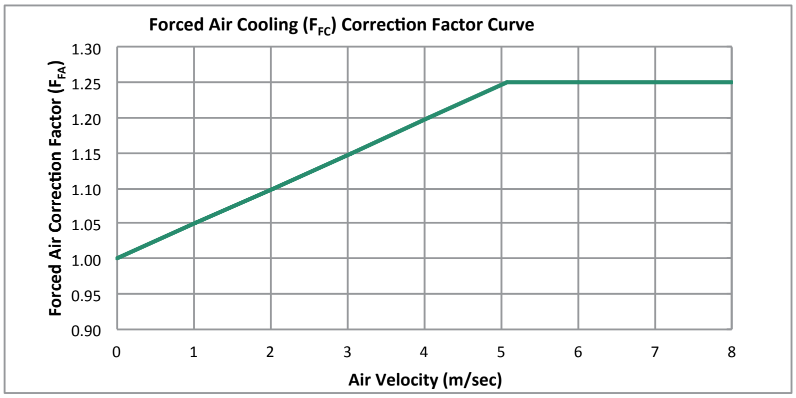

Figure 30. Forced (air) cooling correction factor (F_{FC}) curve

Example:

Determine the forced air cooling correction factor for a fuse installed at an application with an air velocity of 4 m/sec.

Per the forced air correction curve:

An average current density and reference values (100 %)

For an air velocity of 4m/sec, F_{FC} = 1.20

For applications with a liquid cooled bus-bar system (which may be used along with forced air cooling), the forced cooling correction factor of F_{FC} = 1.25 can be considered when sizing a high-speed fuse's rated current.

2c: Conductor Size (Wiring Connection Factor): High-speed fuses are connected to a system by means of copper conductors in the form of cable or bus-bar termination. The main purpose of the termination is to conduct power, but they also serve as a heat sinking device to remove heat from the fuse terminals and allowing it to operate efficiently.

Conductor size is critical for alignment between the fuse specification and the wiring/busbar specification. Lack of consideration may lead to nuisance opening of the fuse.

The cross-section size of the conductor significantly impacts the current carrying capacity of a high-speed fuse. The rated current of a high-speed fuse is determined based on testing with recommended conductor sizes outlined in international standards. When applying these fuses in the field, any reduction in conductor size would require appropriate de-rating of the fuse rated current. In other words, fuse current ratings should be determined based on the cross-section size of the conductor.

Per IEC 60269-4 Standard Section 8.3.1, the current density of the copper conductor used shall be between 1.0 A/mm² (minimum) to 1.6 A/mm² (Maximum) and vary with the rated current of the fuse. For ease of calculation, 1.3 A/mm² is considered as the reference value (100 %) for the conductor sizes. Based on this reference value and the application conductor size, the wiring correction factor (F_{WR}) for the application is determined from the curve showing in **Figure 31** and factored in accordingly while sizing the rated current of high-speed fuses.

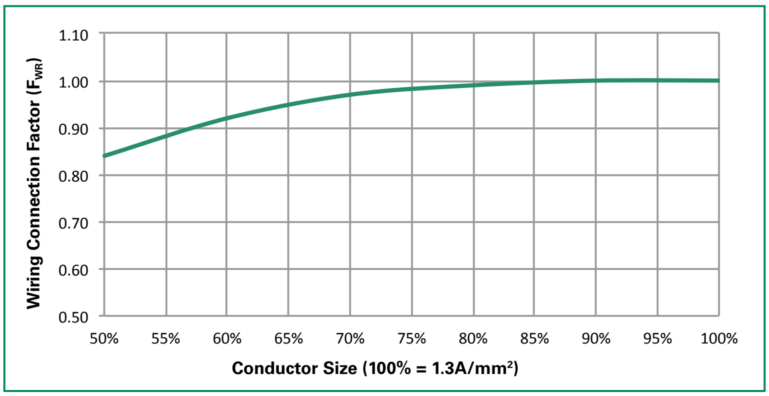

Figure 31. Wiring connection factor (F_{WR}) curve

Example:

Determine the wiring connection factor for an application with a 400 A load current using copper conductor with a cross-section of 185 mm².

Load current: 400 A

Conductor size used in application: 185 mm²

Copper current density per IEC standard: 1.3 A/mm²

Recommended conductor size for 400 A (per IEC standard): $\frac{400\ \text{A}}{1.3\ \text{A/mm}^2} = 308\ \text{mm}^2$

Based on the IEC recommended conductor size determined above, the application conductor size used is about **60 %** of the recommended size.

Applying the 60 % value determined in the wiring connection factor curve, the wiring connection factor for the application is, $\mathbf{F_{WR} = 0.92}$

2d: Frequency: High-speed fuses have one or more fusible elements connected in a parallel configuration within their fuse body. When these fuses are subjected to high frequencies, and due to the electromagnetic property of AC power, the flow of current through the fuse is constrained to the outer layers of the fusible element, known as skin and proximity effect. This phenomenon causes unbalanced sharing of current between fusible elements resulting in increased heat, which significantly reduces the current carrying capacity of a fuse and could result in premature operation of a fuse.

High frequency affects fuse current rating.

Applications with a frequency above 10 kHz are considered as very high frequency applications and require increased attention when sizing high-speed fuses. Consult Littelfuse Technical Services for such applications.

The curve shown in **Figure 32** determines the frequency correction factor (F_{HZ}) to take into consideration when sizing the high-speed fuse rated current.

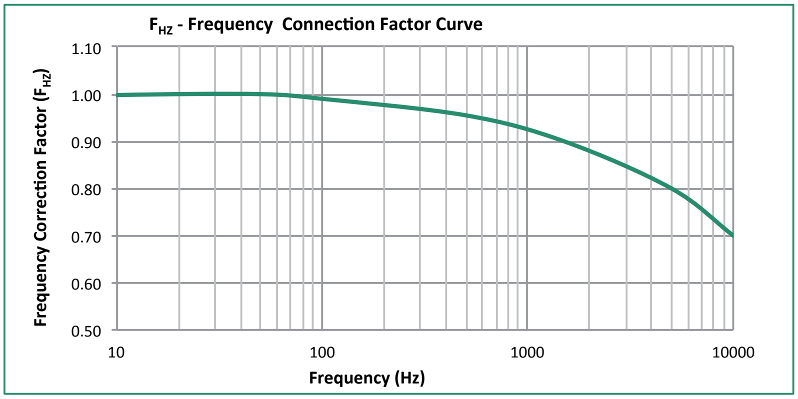

Figure 32. Frequency Correction Factor (F_{HZ}) Curve

Example:

Determine the frequency correction factor for an application with application frequency of 500 Hz.

Application frequency: 500 HZ

From the frequency correction factor curve shown in **Figure 32**, the corresponding frequency correction factor for the application is $\mathbf{F_{HZ} = 0.96}$

2e: Switching and Surges: In general, all electrical equipment is subjected to start-stop operations. The frequency of start (ON) and stop (OFF) operation and the associated surge in current during switching determines the aging effect on high-speed fuses.

An ON-OFF operation induces heating and cooling effects on fuse elements. The higher the number of switching operations, the greater the impact on the fuse current carrying capacity over a period of time.

The switching correction factor table below provides the recommended switching de-rating factors (F_{SS}) to be considered for any frequent switching applications.

Table 1. Switching Correction Factor (F_{ss}) Table

Switching Correction Factor (Fss) Table	
Frequency of Switching	**Switching Correction Factor (Fss)**
Less than 12 stops per year	1.00
More than one stop per month	0.95
More than two stops per week	0.90
More than one stop per day	0.85
Several stops per day	0.80

2f: Altitude: Increase in altitude above 2000 m mean sea level (MSL) causes reduction in heat dissipation due to convection and radiation within fuse elements.

A general industry practice of 0.5 % de-rating in component current rating for every 100 m above 2000 m mean sea level should be applied while calculating the high-speed fuse rated current.

Altitude correction factor is given by the term $\mathbf{F_{AL} = (1-((h-2000)/100)*0.005)}$ where 'h' is the application altitude.

Example

What is the altitude correction factor to be used for installation applied at 3500m above sea level?

Application Altitude (h): 3500 m

Altitude Correction Factor Formula:

$F_{AL} = (1-((h-2000)/100)*0.005)$

$F_{AL} = (1-((3500-2000)/100)*0.005)$

$F_{AL} = (1-(0.075))$

$F_{AL} = 0.925$

Altitude Correction Factor $F_{AL} = 0.925$

Rated Current of the High-Speed Fuse: In summary, the rated current of a high-speed fuse can be determined using the following formula:

Where,

I_{AL} = Adjusted normal full-load current

I_N = Rated current of high-speed fuse for the application

F_{AT} = Ambient temperature correction factor

F_{FC} = Forced cooling correction factor

F_{WR} = Wiring connection factor

F_{SS} = Switching correction factor

F_{AL} = Altitude correction factor

$$I_N = \frac{I_{AL}}{F_{AT} * F_{FC} * F_{WR} * F_{HZ} * F_{SS} * F_{AL}}$$

Example:

Determine the suitable Littelfuse POWR-*SPEED* North American round body fuse for a rectifier application with the following system details:

Ac system voltage = 600 V

Frequency = 60 Hz

Ambient temperature (T_a) = 65 °C

Forced air cooling = 3 m/s

Load current = 100 A

Available short-circuit fault current = 35 kA

Load condition = 15 stops per day

Overload condition = 200 % for 10 sec for every 3 minutes

Thyristor I^2t withstand rating = 20,000 A^2s

Rated Voltage of the Fuse (E_N):

$$E_N = \frac{E}{0.9}$$

$$E_N = \frac{600}{0.9}$$

$$E_N = 667\text{ V} \sim 700\text{ V ac}$$

Load Current:

$$I_{AL} = \sqrt{\frac{I_1{}^2 t_1 + I_2{}^2 t_2}{T}}$$

$$= \sqrt{\frac{(100^2 * 180) + (200^2 * 10)}{190}}$$

$$I_{AL} = 107.6$$

Ambient Temperature Correction Factor:

$$F_{AT} = \sqrt{\frac{125 - 65}{125 - 25}}$$

$$F_{AT} = 0.775$$

Forced Cooling Correction Factor

Forced Air Cooling: 3 m/s

Based on Forced Cooling Correction Factor Graph,

$F_{FC} = 1.15$

Switching Correction Factor

Number of Stops per Day: 15

Based on Switching Correction Factor Table

$F_{SS} = 0.8$

Rated current of the fuse (I_N)

$$I_N = \frac{I_{AL}}{F_{AT} * F_{FC} * F_{SS}}$$

$$I_N = \frac{107.6}{0.775 * 1.15 * 0.8}$$

$$I_N = \frac{107.6}{0.713}$$

$$I_N = 150.9 \sim 150\text{A}$$

Upon calculating the rated current including all of the factors involved, POWR-*SPEED* fuse part number L70QS150.V rated for 150 A, 700 V ac/dc, and 200 kA I.R. could be considered for this application. This fuse has a total clearing I^2t value of 13,650 A^2s at 700 V ac which, is less than the thyristor device withstand rating of 20,000 A^2s, and meets the voltage and current rating requirements of the application and thus can be recommended.

4.3 Interrupting Rating

Interrupting rating is defined as the RMS maximum fault current a fuse can clear without any visible deformity. Interrupting rating for high-speed fuses and other industrial fuses are typically expressed in kiloampere (kA).

Interrupting Rating of Fuse Selected > Available Fault Current

Interrupting rating of the fuse selected should be greater than the application's available fault current to provide adequate protection.

4.4 Total Clearing I^2t Value (Withstand Energy)

Total clearing I^2t value is the maximum let-through energy when tested at rated voltage (published in datasheet table). Total clearing I^2t value for a reduced application voltage can be found using total clearing I^2t correction factor chart (refer to Section 3.8.3).

Total clearing I^2t value < Semiconductor Device Fusing I^2t Value

Total clearing I^2t value of the fuse should be less than the semiconductor device's withstand rating or fusing I^2t value (expressed in A^2s).

4.5 Peak Arc-Voltage

Voltage that appears across the fuse element during its operation is referred as arc-voltage. It is higher than the fuse rated voltage (about twice). Peak arc-voltage for a fuse, appears when tested at its rated voltage. To calculate the arc-voltage for a fuse for voltage ratings lesser than its rated voltage – Use the peak arc-voltage correction factor chart in datasheet (Refer to Section 3.8.4.).

Fuse Peak Arc-Voltage < Semiconductor Peak Inverse Voltage (PIV)

Peak arc-voltage calculated should be less than the peak inverse voltage (PIV) of the semiconductor device used.

DISCLAIMER

The purpose of this Technical Applications Guide is to promote a better understanding of high-speed fuses, power semiconductor devices and their common application details within circuit design. These high-speed fuses being considered are current sensitive devices designed to serve as the intentional weak link in the electrical circuit. Their function is to provide protection of power semiconductor components, or of complete circuits, by reliably operating under current overload conditions.

Application guidelines and product data mentioned in this guide is intended for technical reference only. Fuse parameters and application concepts should be well understood to properly select a fuse for a given application. Application testing is strongly recommended and should be used to verify fuse performance in the circuit/application.

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