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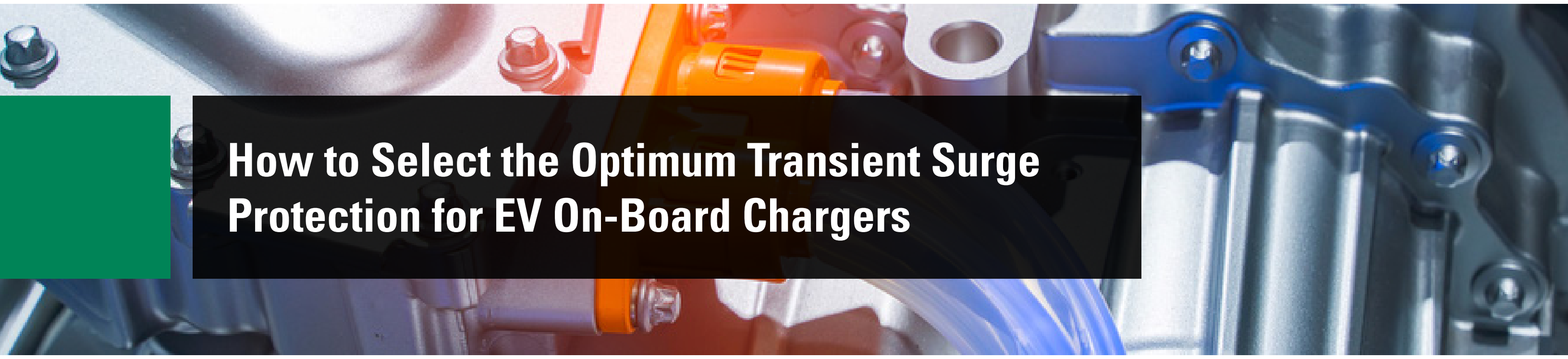
Application **Note**



How to Select the Optimum Transient Surge Protection for EV On-Board Chargers

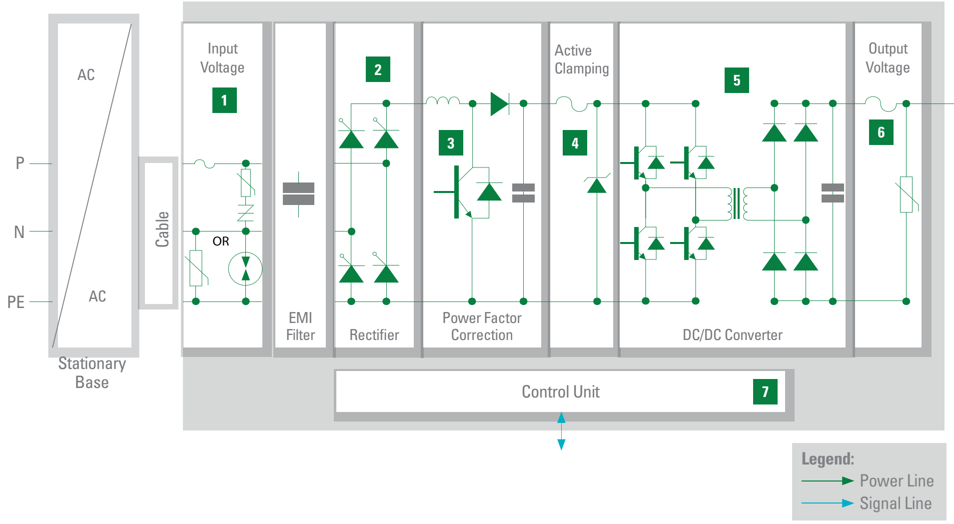
The automotive environment is one of the most severe environments for electronics. Today's vehicle designs proliferate with sensitive electronics, including electronic controls, infotainment systems, sensing systems, battery packs, battery management systems, electric vehicle powertrains, and on-board chargers. In addition to the heat, voltage transients, and electromagnetic interference (EMI) in the automotive environment, the on-board charger must interface with the AC power grid, requiring protection from AC line disturbances for reliable operation.

Manufacturers of protection components offer multiple components for protecting electronic circuits. Due to the connection to the grid, safeguarding the on-board chargers from voltage surges with unique components is essential.

Littelfuse solutions focus on advanced overcurrent and overvoltage protection technologies, including MOV (Metal Oxide Varistor), TVS (Transient Voltage Suppressor), GDT (Gas Discharge Tube), and SIDACtor® protection thyristor components. The challenge for the design engineer is optimizing the component selection and determining the best combination of several technologies to reach the best fit in performance and price.

A unique solution combines a SIDACtor and a Varistor (SMD or THT), reaching a low clamping voltage under a high surge pulse. The SIDACtor plus an MOV (SIDACtor+MOV) combination enables automotive design engineers to optimize the selection and, therefore, the cost of the power semiconductors in the design. These parts are needed to convert the AC voltage into the DC voltage to charge the vehicle's on-board battery.

Figure 1. On-Board Charger block diagram



	Technology	Series
1	Fuse	526, 527, 10EV, 20EV
	Metal Oxide Varistor (MOV)	AUMOV, SM10
	GDT	CG2, CG3
	SIDACtor	Pxxx0FNL, Pxxx0SD, Pxxx0S3N, Pxxx0S3N-A
2	Thyristor	S8016xA
3	Gate Driver	IXD 6xxSI, IX434ONE
4	TVS Diode	TPSMB, SZ1SMB, SZP6SMB
5	Gate Driver	IXD 6xxSI, IX434ONE
	TVS Diode	TPSMB, SZ1SMB, SZP6SMB
	Diode Array	AQ4022
6	Fuse	526, 10EV, 20EV
	Metal Oxide Varistor (MOV)	AUMOV, SM10
	TVS Diode	TPSMB, SZ1SMB, SZP6SMB
7	Diode Array	AQ24CANA

The On-Board Charger (OBC) is at risk during EV charging due to exposure to overvoltage events that may occur on the power grid. The design must protect the power semiconductors from overvoltage transients because voltages above their maximum limits can damage them. To extend the EV's reliability and lifetime, automotive engineers must address increasing surge current requirements and lower maximum clamping voltage in their designs.

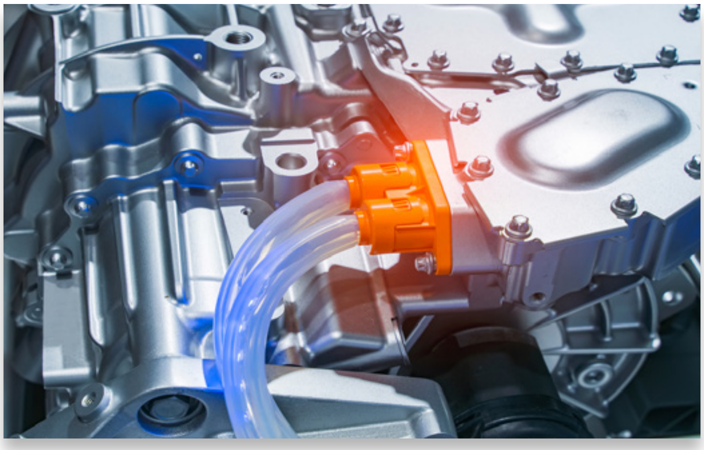
Figure 1 shows the circuit blocks requiring protection components and blocks that can employ high-efficiency components. The table to the right lists the recommended component technologies.

The potential surge pulses for the OBC come from indirect lightning strikes, load switching, and failure in the system. If you imagine the power of a direct lightning strike of 100 kA, a high surge current requirement in the specification is understandable. Other possible root causes for a surge pulse are abrupt load switching and faults in the power system.

Example sources of transient voltage surges include the following:

- Switching of capacitive loads (capacitor banks, set up of new connections)
- Switching of low voltage systems and resonant circuits
- Short circuits resulting from construction, traffic accidents, or storms
- Triggered fuses and overvoltage protection.

The coupling of the surge pulses is capacitive on parallel cables, inductive on conductor loops, and emission in the near field. The transient surge occurs basically over cable (on power, data, or signal lines), and it can be symmetrical (line to line) or asymmetrical (line to ground). If you must solve the problem in the application, it is crucial to know the source of coupling and propagation.



The IEC 61000-4-5 is the relevant standard for surge immunity. Table 1 lists maximum surge voltages up to 4 kV. The 2 Ω generator resistance results in a 2 kA surge pulse.

Table 1. IEC 61000-4-5 peak voltage and peak current withstand ratings

Open-circuit peak voltage +/-10% at the generator output	Short-circuit peak current +/- 10% at generator output
0,5 kV	0,25 kA
1 kV	0,5 kA
2 kV	1,0 kA
4 kV	2,0 kA

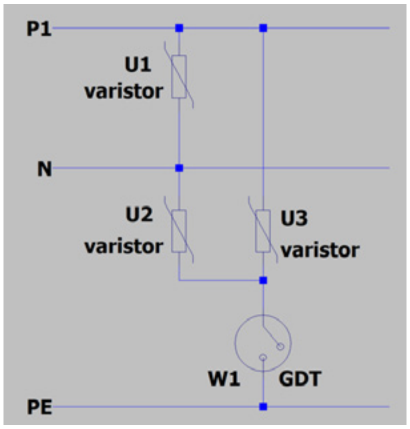
The IEEE C62.41.2-2002 standard specifies a 6 kV/3 kA surge rating. Today, most power grid-related AC power circuits are designed to resist the IEEE surge requirement.

Table 2. IEEE C62.41.2-2002 Standard 1.2/50 µs-8/20 µs, expected voltages and current surges.

Location Category	Peak values		Effective impedance (Ω)
	Voltage (kV)	Current (kA)	
A	6	0.5	12
B	6	3	2

According to the 6 kV/3 kA surge, many designers use 14 mm MOVs in the AC primary side circuit.

Figure 2. Recommended circuit configuration for differential and common mode transient voltage circuit protection using MOVs and a gas discharge tube.



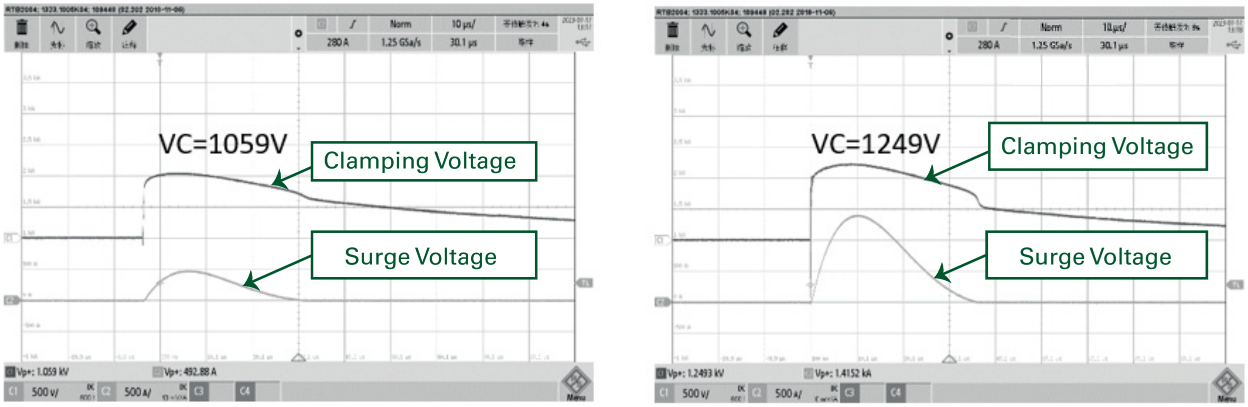
A 20 mm MOV is preferred for better reliability and protection. The 20 mm MOV can typically handle 45 pulses of 6 k / 3 kA surge current, which is much more robust than the 14 mm MOV. The 14 mm disc can only handle around 14 surges over its lifetime.

Performance comparison of voltage transient protection components

The following description compares an MOV's transient voltage protection performance with a combination of an MOV and a SIDACtor protection thyristor. Figure 3 shows the clamping performance of a 14 mm MOV when struck with a 2 kV and a 4 kV surge. The MOV has a maximum operating voltage of 385 VAC$_{RMS}$. The clamping voltages are more than 1000 V, which puts a high stress level on the power semiconductors.

MOV Transient Voltage Performance

Figure 3. Clamping performance of the Littelfuse V14P385AUTO MOV under 2 kV and 4 kV surges. The clamping voltage exceeds 1000 V.



V14P385AUTO clamping voltage at 2 kV 1.2/50 µs = 1059 V

V14P385AUTO clamping voltage at 4 kV 1.2/50 µs = 1249 V

The following description compares an MOV's transient voltage protection performance with a combination of an MOV and a SIDACtor protection thyristor. Figure 3 shows the clamping performance of a 14 mm MOV when struck with a 2 kV and a 4 kV surge. The MOV has a maximum operating voltage of 385 VAC_{RMS}. The clamping voltages are more than 1000 V, which puts a high stress level on the power semiconductors.

Parameters for selecting an MOV include the following:

- **Rated Operating Voltage** - The maximum continuous voltage of the circuit to be protected,
- **Ambient Temperature** - The temperature in the area surrounding the MOV. This will be used to determine if thermal derating is needed.
- **Transient Voltage Waveform** - This defines the transient pulse, including peak voltage, duration, and transient source impedance. It is typically provided in a Standard (e.g., IEC 61000-4-5).
- **Quantity of Transient Voltage Pulses -** Defined by the Standard, this is the number of pulses that the components must survive, and that the MOV will need to absorb
- **Peak Pulse Current -** The transient voltage pulse and the generator's internal resistance provide the peak current.
- **Mounting requirements of MOV (straight, bent leads or SMD).**

The requirement to meet the 6 kV / 3 kA waveform drives MOV selection. The typical lifetime requirement is 10 pulses.

Here is an example selection determination:

Level 1 Charger - 120 VAC, single-phase circuit: The expected ambient temperature is 100 °C.

Step one is to determine the minimum voltage rating of the MOV. The rule of thumb is to add 25% to the nominal AC line voltage to account for an imperfect power service: 120 VAC x 1.25 = 150 VAC. This is the minimum suggested voltage rating. The maximum peak surge current must be above 3 kA.

Repetitive Surge Capability must meet the standard requirements. The peak surge current and the energy rating must be reduced based on the temperature derating chart. The high potential capacity depends on the coating selection. Using a GDT helps the protection configuration achieve the leakage requirements of the High Potential test, which an MOV cannot meet alone.

MOV and SIDACtor Transient Voltage Performance

Figure 4. Combination SIDACtor and MOV for protection from voltage transients occurring between line and neutral

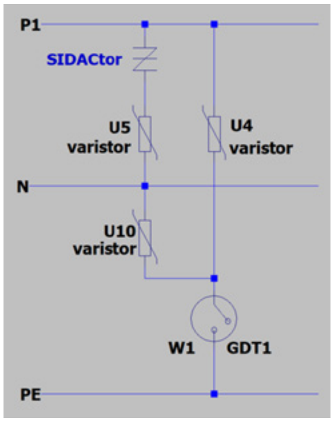


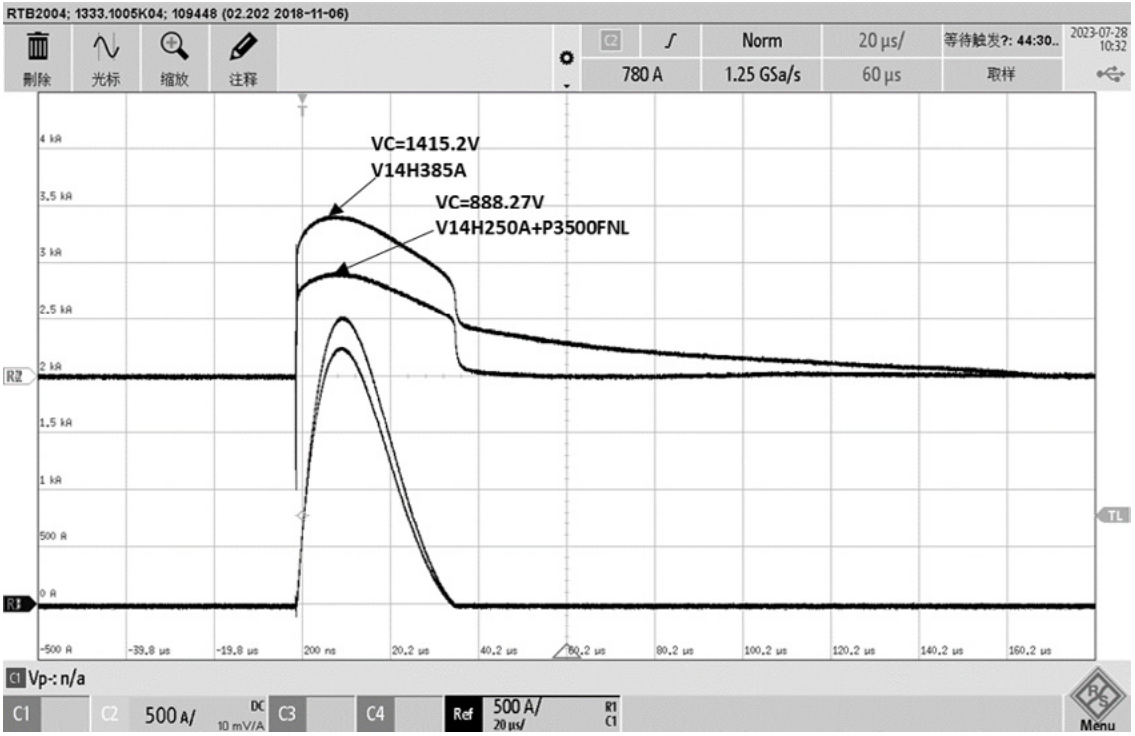
Table 3. Clamping voltage of a Littelfuse V14H385A MOV compared with a Littelfuse P3800FNL SIDACtor and a V14H250A MOV under different surge voltage.

Surge Voltage	V14H385A Clamping Voltage	P3800FNL+V14H250A Clamping Voltage	Delta
2 kV	1059 V	727 V	352 V
4 kV	1240 V	859 V	381 V
6 kV	1415 V	888 V	527 V

The new approach with SIDACtor+MOV has several advantages. The primary advantage is that for a 6 KV / 3 KA surge, the clamping voltage is under 1000 V as indicated in Table 3.

Figure 5 illustrates the voltage vs time response of the MOV and SIDACtor+MOV combination, again showing that the SIDACtor+MOV combination has a lower clamping voltage.

Figure 5. Plots showing the response of the MOV and the MOV-SIDACtor combination to a 6 kV surge



An MOV alone will show degeneration after multiple surges. The leakage current increases with the number of surges the MOV must absorb. Also, the breakdown voltage is expected to fall with an increasing number of surge strikes. The rising leakage and the clamping voltage change show the MOV parameters' drift. The designer must select a larger disc size to avoid this situation with an MOV. This approach will impact the cost and consume critical PC board space. However, their performance is more stable with a SIDACtor+MOV combination, and the SIDACtor extends the MOV lifetime.

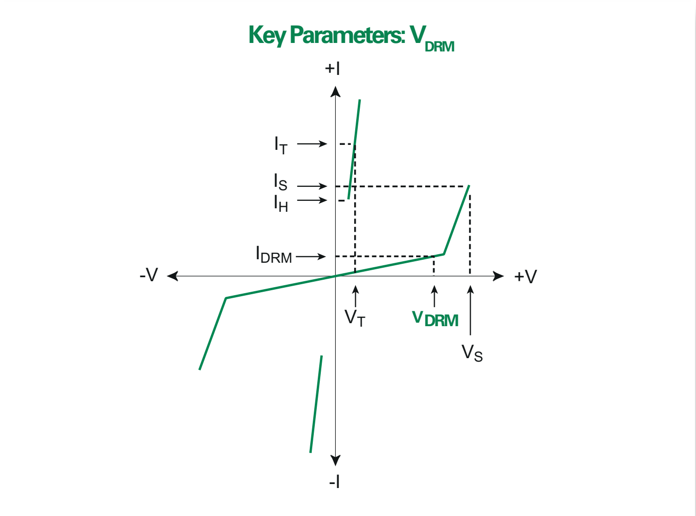
The superior solution for transient surge protection – SIDACtor+MOV

While a designer will consider an MOV for voltage transient protection of downstream circuitry, Littelfuse can offer the designer a superior solution with its SIDACtor protection thyristor placed in series with an MOV. The SIDACtor+MOV combination has a lower clamping voltage to reduce semiconductor stress. In addition, the combination has a much lower leakage current and a breakdown voltage that degrades much less with increasing transient strikes. Using a SIDACtor+MOV combination for transient surge protection will result in a more reliable, robust on-board charger.

Appendix I. Introduction to a SIDACtor

A SIDACtor is a PNPN semiconductor. It is a thyristor device without a gate. SIDACtor devices are crowbar devices. Once triggered, it shorts out the protected line, redirecting the energy away from the semiconductor. Upon exceeding its peak off-state voltage (V_{DRM}), a SIDACtor will clamp a transient voltage to within the device's switching voltage (VS) rating. A SIDACtor turns off when the current is under the hold current (IH). This is the case if the voltage drops below the MOV breakdown voltage.

Figure 6. SIDACtor V-I characteristics

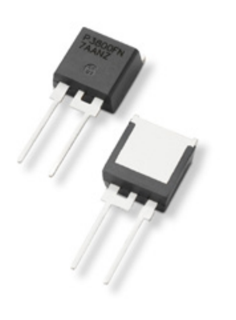


Advantages of a SIDACtor include:

- No degradation over multiple surge strikes
- Low on-state voltage allows a much lower clamping voltage when combined with an MOV
- Withstanding higher surge currents compared to TVS diodes
- Available in a leaded or an SMD Package.

SIDACtor package options:


Pxxx0S3N, DO-214AB
Pxxx0S3N-A (auto. grade) DO-214AB


Pxxx0FNL, TO-262M


Pxxx0ME, T0-218

Appendix II. Conclusion of MOV vs. SIDACtor+MOV

MOVs are clamping devices. The SIDACtor is a crowbar device. Under the same load, we can see the difference in clamping voltage. The SIDACtor+MOV approach is a good compromise between performance and pricing. Adding a SIDACtor in series to an MOV enables the selection of an MOV with a lower clamp voltage to achieve an overall lower circuit clamping voltage. The combination circuit has a lower drop of breakdown voltage and an insignificant change in leakage current with increasing transient strikes than an MOV alone. There will be less leakage, particularly under high temperatures, compared to an MOV alone when using this approach. There will not be a drift of the leakage current over the component's lifetime. Furthermore, the combination benefits extended MOV life because the SIDACtor limits the leakage current. A SIDACtor does not wear out and has better reliability over time and multiple surge strikes.

Appendix III. High Power SIDACtor+MOV for OBC protection part selection list

Table 4. MOV+SIDACtor product selection reference list

MOV	Part Number	Max Continuous Voltage		Varistor Voltage at 1mA	Maximum Clamping Voltage	Max Peak Current (8 x 20µs 1 pulse)
		Vrms	Vdc		Vc	Itm
AUMOV® Series	V14H250AUTO	250	320	390±10%	650	6500
	V20H250AUTO	250	320	390±10%	650	10000
	V14H320AUTO	320	420	510±10%	650	6500
	V20H320AUTO	320	420	510±10%	650	10000
	V14H385AUTO	385	505	620±10%	1025	6500
	V20H385AUTO	385	505	620±10%	1025	10000
	V14H420AUTO	420	560	680±10%	1120	6500
	V20H420AUTO	420	560	680±10%	1120	10000
	V14H460AUTO	460	615	750±10%	1240	6500
	V20H460AUTO	460	615	750±10%	1240	10000
SM10 Series	V250SM10	250	320	390±10%	650	5000
	V320SM10	320	420	510±10%	840	5000
	V350SM10	350	460	560±10%	930	5000
	V385SM10	385	505	620±10%	1025	5000
	V420SM10	420	560	680±10%	1120	5000
	V460SM10	460	615	750±10%	1240	5000

SIDACtor	Part Number	V_{DRM}	V_S	IH	I_{PP}
			@100 V/µs	mA min	A min
Pxxx0FNL Series	P1900FNLTP	155	220	50	3000
	P2300FNLTP	180	260	50	3000
	P2600FNLTP	220	300	50	3000
	P3500FNLTP	320	400	50	3000
	P3800FNLTP	350	430	50	3000
Pxxx0S3N-A Series	P1900S3NLRP-A	155	220	50	3000
	P2300S3NLRP-A	180	260	50	3000
	P2600S3NLRP-A	220	300	50	3000
	P3500S3NLRP-A	320	400	50	3000
	P3800S3NLRP-A	350	430	50	3000

Note: For more details about how to pick the MOV and SIDACtor parts working together, please contact the Littelfuse sales.