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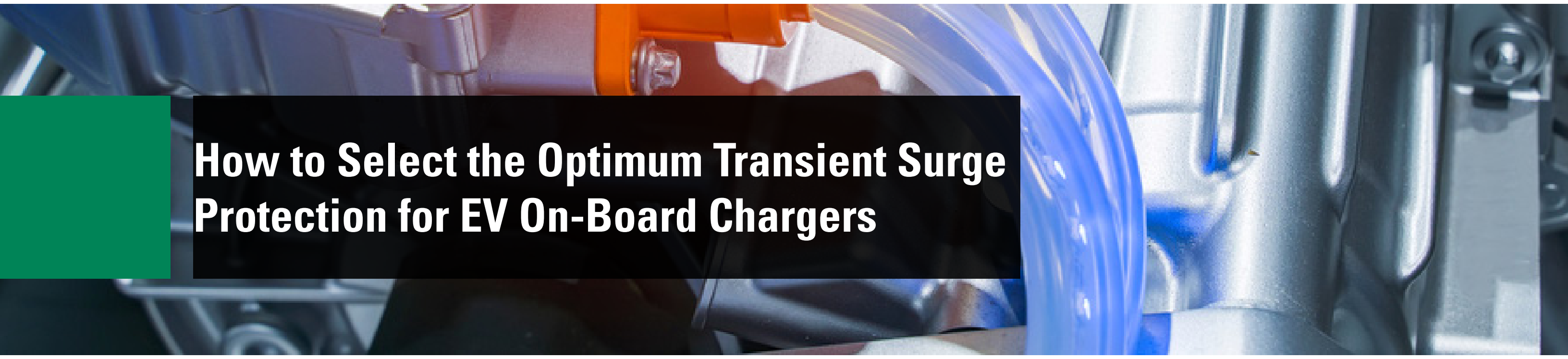
Application **Note**



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

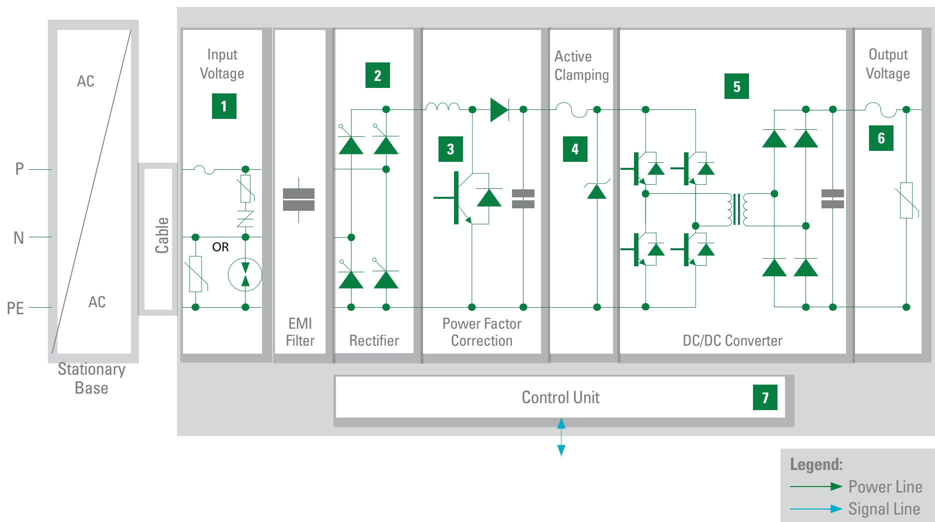
The automotive environment is one of the most severe environments for electronics. Today's vehicle designs proliferate with sensitive electronics, including electronic controls, infotainment systems, sensing systems, battery packs, battery management systems, electric vehicle powertrains, and on-board 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 Charger 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® device and a Varistor (SMD or THT), reaching a low clamping voltage under a high surge pulse. The SIDACtor plus a 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
	Metal Oxide Varistor (MOV)	AUMOV, SM10
	GDT	CG2, CG3
	SIDACtor	Pxxx0FNL, Pxxx0S3N-A (6 kW/3 kA), Pxxx0S3G-A (4 kW/2 kA)
2	Thyristor	S8016xA
3	Gate Driver	IXD 6xxSI, IX4340NE
4	TVS Diode	TP5.0SMDJ
5	Gate Driver	IXD 6xxSI, IX434ONE
	TVS Diode	TPSMB, SZ1SMB, SZP6SMB
	Diode Array	AQ4022
6	Fuse	526, 828 30EV1K, 25EV1K
	Metal Oxide Varistor (MOV)	AUMOV, SM10
	TVS Diode	TPSMB, SZ1SMB, SZP6SMB
7	Diode Array	AQ24COM-02

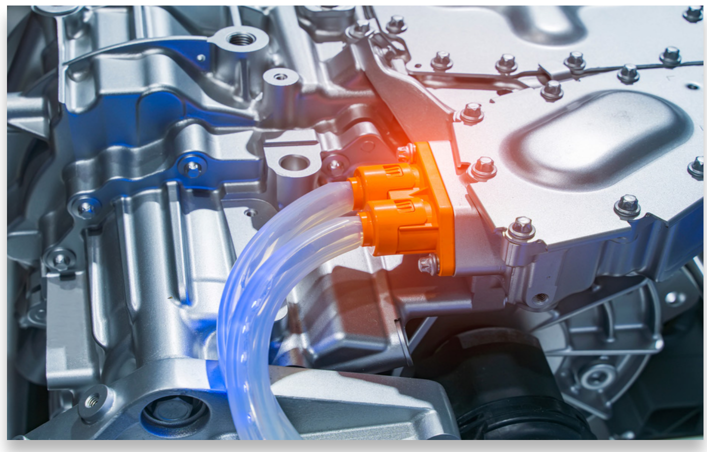
The On-Board Charger (OBC) is at risk during EV charging due to exposure to overvoltage events that may occur on the power grid. The design must protect the power semiconductors from overvoltage transients because voltages above their maximum limits can damage them. To extend the EV's reliability and 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 over cable (on power, data, or signal lines) and can be symmetrical (line to line) or asymmetrical (line to ground). Knowing the source of coupling and propagation is crucial if you must solve the problem in the application.

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

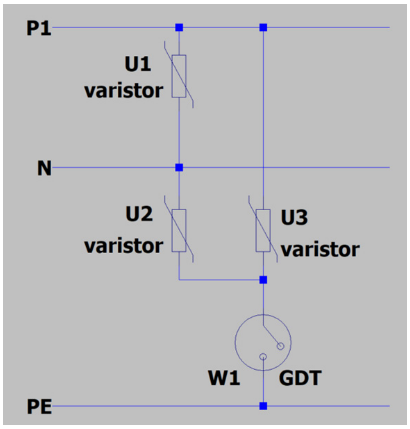
The IEEE C62.41.2-2002 standard specifies a 6 kV/3 kA surge rating. Today, most power grid-related AC power circuits are designed to resist the IEEE surge requirement.

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.



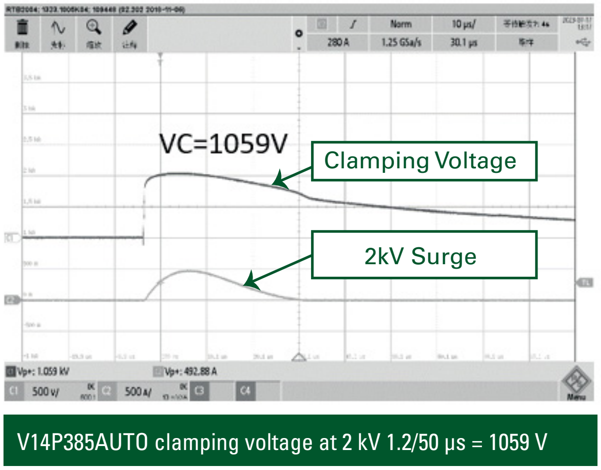
A 20 mm MOV is preferred for better reliability and protection. It can typically handle 45 pulses of 6 k / 3 kA surge current, which is much more robust than the 14 mm MOV. The 14 mm disc can only handle around 14 surges over its lifetime.

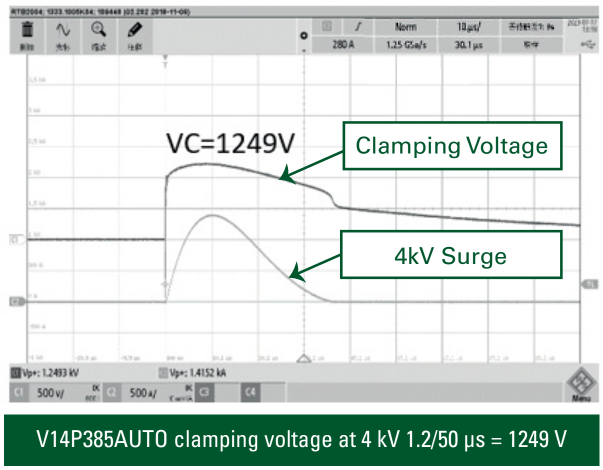
Performance comparison of overvoltage protection components

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.





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:

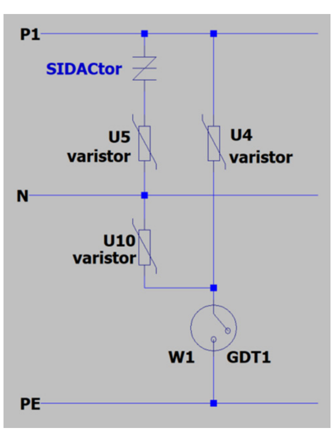
Level 1 Charger - 120 VAC, single-phase circuit: The expected ambient temperature is 100 °C.

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

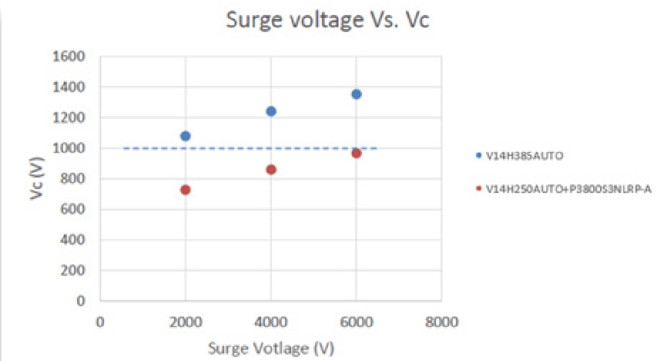
Figure 4. Combination SIDACtor and MOV for protection from voltage transients occurring between the line and neutral



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.

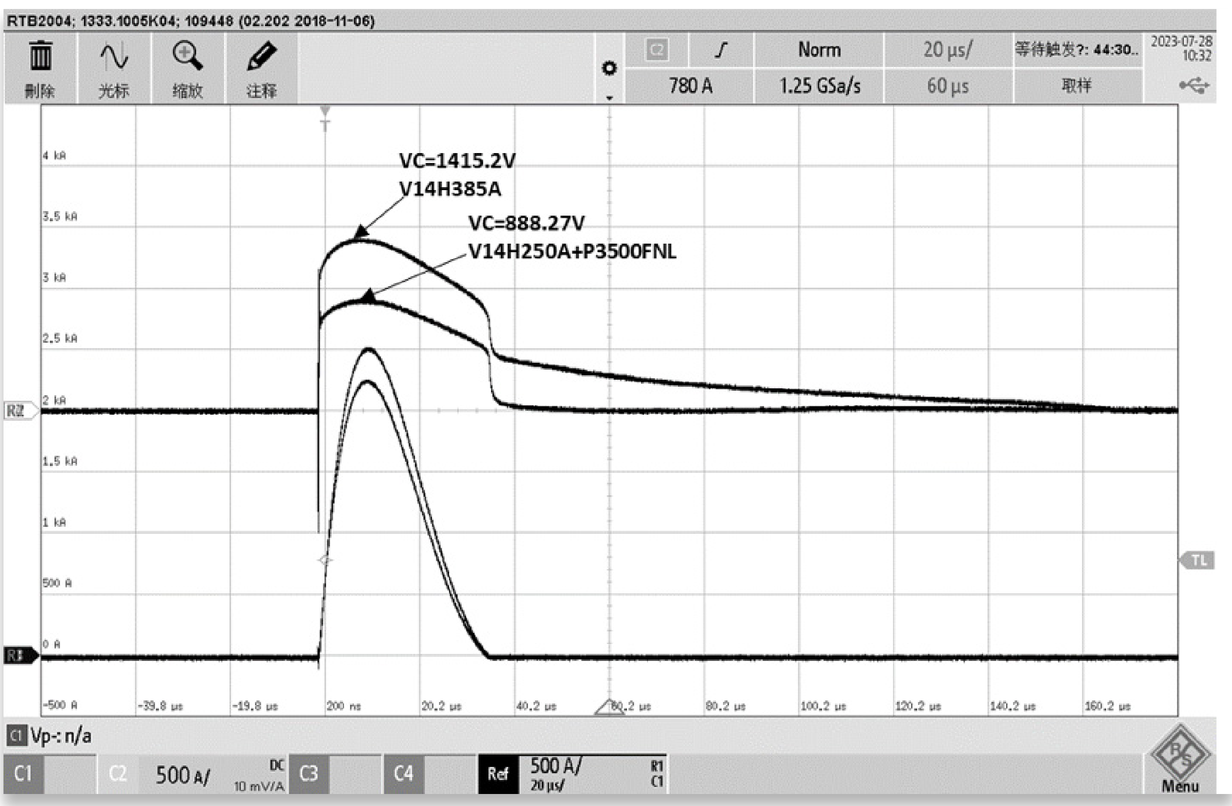
Figure 5 illustrates the voltage vs time response of the MOV and SIDACtor+MOV combination, again showing that the SIDACtor+MOV combination has a lower clamping voltage.

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



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

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

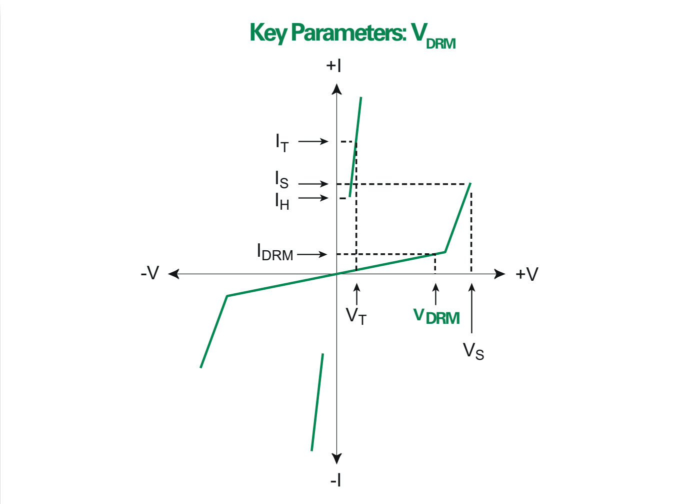


A MOV alone will show degeneration after multiple surges. The leakage current increases with the number of surges the MOV must absorb. Also, the breakdown voltage is expected to fall with an increasing number of surge strikes. The rising leakage and the clamping voltage change show the MOV parameters' 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, the performance is more stable with a SIDACtor+MOV combination, and the SIDACtor+MOV will extend MOV lifetime under static state.

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 (V_S) rating. A SIDACtor turns off when the current is under the hold current (IH). This is the case in the series connection of MOV + SIDACtor, 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 Key Parameters:

V_{DRM}

- The maximum voltage that can be applied to the SIDACtor device without triggering the device into conduction

V_S

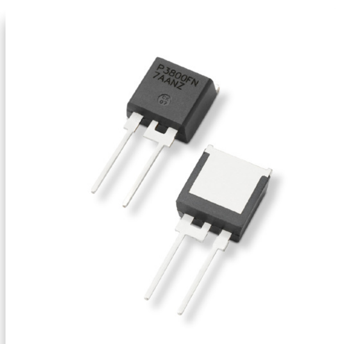
- V_S is the peak voltage that will appear across the SIDACtor device during its transition into the crowbar state.

I_H

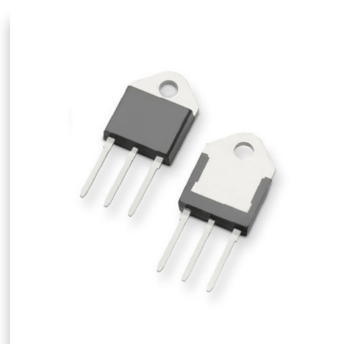
- Once the SIDACtor device is in the crowbar state, the current through it must go below the holding current for the device to reset into its off state.

SIDACtor package options:

Pxxx0S3N, DO-214AB
Pxxx0S3N-A (auto. grade) DO-214AB
Pxxx0S3G-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. 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. How to select MOV in the solution of MOV+SIDACtor

We selected the MOV with the lowest rated voltage possible to reduce the clamping voltage. If the MOV's rated voltage exceeds the system's AC rms voltage, we must verify its follow-on AC current.

If a surge happens, the SIDACtor will turn on and keep conducting. In the worst-case scenario, the MOV alone must endure the sine wave's upper shadow portion.

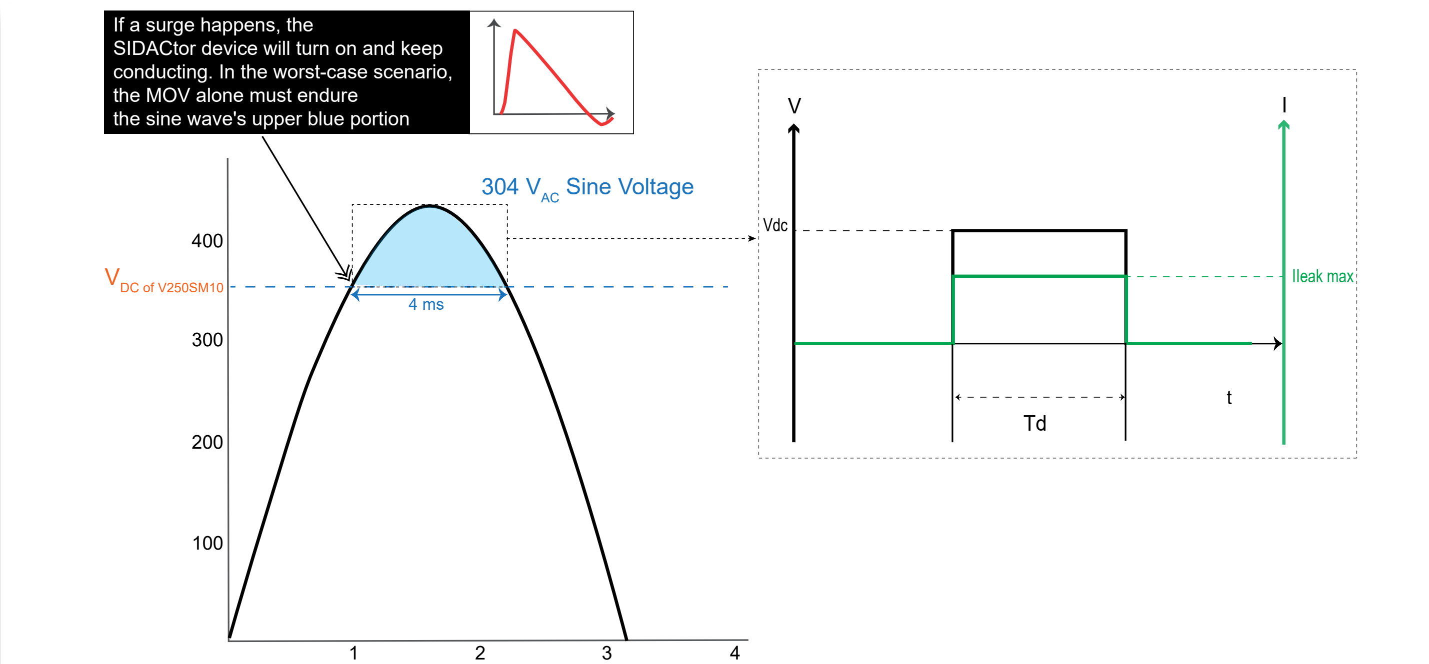
V14H250AUTO has a max. continuous voltage of 320 Vdc. The grid voltage for this example calculation is set to Vrms = 304 V. The value is dependent on the region and the expected voltage tolerances. To calculate the duration time of the shadow waveform we conduct the following:

Frequence 50 Hz => Period = 20 ms => ½ period = 10 ms ; Vrms = 304 V => Vpeak = Vrms * $\sqrt{2}$ = 304 V * $\sqrt{2}$ = 430 V

Duration time: td = (90°- arcsin (Vdc / Vpeak)) * 2 / 180° * ½ period

td = (90°- arcsin (320V / 430V)) * 2 / 180° * 10 ms = 3.92 ms ≈ 4 ms

We can use a rectangular waveform with td time to simulate the shadow waveform. After conducting the test on the MOV,, we get an **I_leak_max = 5.0 A at Vrms = 304 V.**

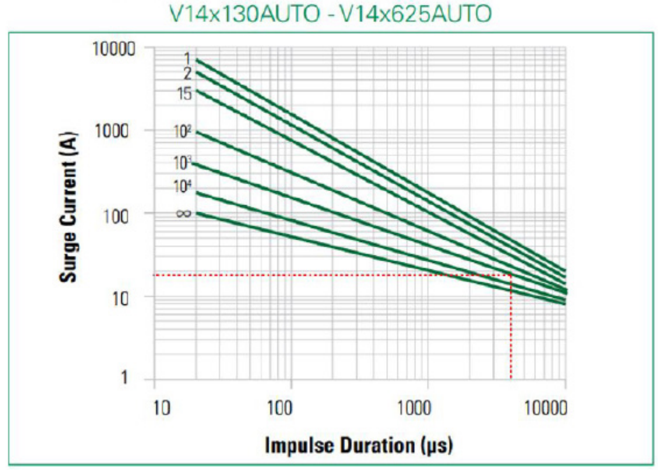


Looking up the figure of Repetitive Surge Capability for 14 mm Parts, we get the surge current I_surge at td and different times.

For 1000 surges, we get an I_surge of 18 A which is larger than I_leak_max = 5.0 A. Therefore, we can assess this MOV is reliable

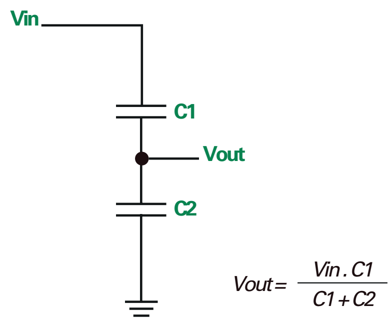
Repetitive Surge Capability for 14mm Parts

V14x130AUTO - V14x625AUTO



Appendix IX. How to select SIDACTOR in the solution of MOV+SIDACTOR

We need to consider the voltage distribution resulting from the differences in capacitance on AC lines with MOV (Metal Oxide Varistor) and SIDACtor devices. The SIDACtor's V_{DRM} must exceed the circuit's maximum operating voltage. When using an MOV and a SIDACtor, the voltage division between them must be calculated. The capacitance for the V14H250AUTO is typically 490 pF. The lowest P3800S3GLRP-A's capacitance is 150 pF, which is considered the worst case compared to the MOV capacitance.



P3800S3GLRP-A => $V_{SIDACTOR}$ = 490 pF ;

V14H250AUTO => C_{MOV} = 150 pF

Vrms = 304 V => Vpeak = Vrms * √2 = 304 V * √2 = 430 V

The voltage on the SIDACtor is calculated as follows:

$V_{SIDACTOR}$ = Vpeak * C_{MOV} / (C_{MOV} + $C_{SIDACTOR}$)

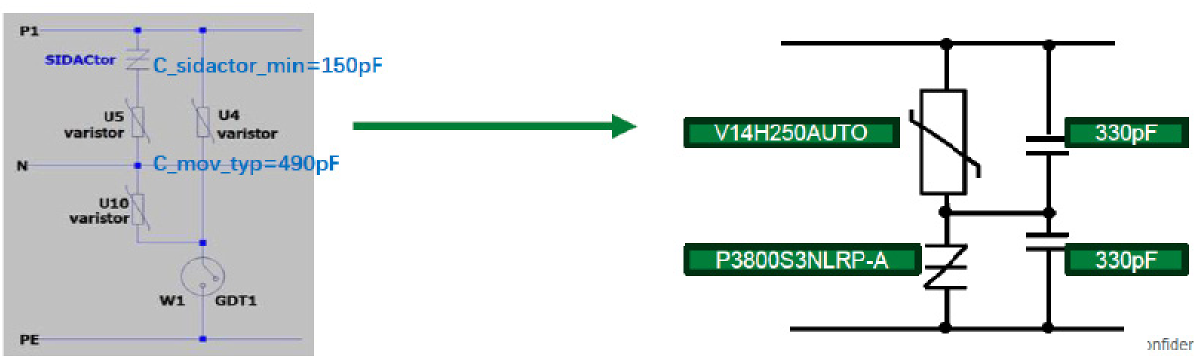
= 430 V * 490 pF / (490 pF +150 pF) = **329 V**

The V_{DRM} of the SIDACtor must exceed the maximum operating voltage of the circuit.

The V_{DRM} of P3800S3GLRP-A is 350 V. To add a safety margin, we have to account for a V_{DRM} variation of +/—20 %.

V350Vdc * 80 % = **280 V$_{dc}$** < $V_{SIDACTOR}$ =**329 V** => The calculated V_{DRM} is lower than the Voltage on the SIDACtor.

This cannot meet the requirement.



The SIDACtor will be turned on at the peak voltage Vs = 430 Vpeak. We must ensure the SIDACTOR can't switch on during the normal operating voltage range. Therefore, we have to balance the voltage by paralleling additional capacitors. After adding 330 pF capacitors, we can recalculate the SIDACtor's voltage.

$V_{SIDACTOR}$

= Vpeak * (C_{MOV} + C1) / (C_{MOV} + $C_{SIDACTOR}$ + C1 + C2)

= 430Vpeak *(490 pF + 330 pF) / (490 pF + 150 pF + 330 pF + 330 pF)

= **271 V**

The SIDACtor P3800S3GLRP-A has a V_{DRM} 350 V

V_{DRM} = 350 Vdc * 80 % = 280 Vdc > 271 V => The calculated V_{DRM} is higher than the Voltage on the SIDACtor.

P3800S3GLRP-A meets the requirements.

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

Table 4. MOV+SIDACtor product selection reference list

MOV	Part Number
AUMOV® Series	V14H250AUTO
	V20H250AUTO
	V14H320AUTO
	V20H320AUTO
	V14H385AUTO
	V20H385AUTO
	V14H420AUTO
	V20H420AUTO
	V14H460AUTO
	V20H460AUTO
SM10 Series	V250SM10
	V320SM10
	V350SM10
	V385SM10
	V420SM10
	V460SM10

SIDACtor	Part Number
Pxxx0FNL Series	P1900FNLTP
	P2300FNLTP
	P2600FNLTP
	P3500FNLTP
	P3800FNLTP
Pxxx0S3N-A Series	P0640S3NLRP-A
	P0720S3NLRP-A
	P0900S3NLRP-A
	P1100S3NLRP-A
	P1300S3NLRP-A
	P1500S3NLRP-A
	P1900S3NLRP-A
	P2300S3NLRP-A
	P2600S3NLRP-A
	P3500S3NLRP-A
	P3800S3NLRP-A
Pxxx0S3G-A Series	P2600S3GLRP-A
	P3100S3GLRP-A
	P3500S3GLRP-A
	P3800S3GLRP-A

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. A SIDACtor+MOV combination for transient surge protection will result in a more reliable, robust On-Board Charger.