Issue: November 2016

Surges and Transients Can't Read Specifications! How to Protect Power Supplies Against Real-World Threats*

by Kevin Parmenter, Excelsys Technologies and Todd Phillips, Littelfuse, Chicago, Ill.

**For best viewing, select "Fit to width" and use the page down key to advance the slides.*

There are numerous standards and specifications in the industry regarding electrical overstress.

Global Safety & Surge Immunity Standards:

There are so many!!

	United States	Europe S. America	Japan	Taiwan	China	Korea
Surge Immunity (Combo wave) 1.2×50µs Voc/ 8×20µs Isc Integrated LED light bulbs (E27 Base Europe/ E26 Base USA) (LED retrofit lamps and indoor commercial)	Energy Star (Based on IEEE C62.41.2) Ring wave 2.5kV 100kHz Class A	IEC/EN 61547 IEC/ EN 61000-4-5 500V/250A 1kV/500A	JIS C 61000-4-5 (Based on IEC/EN 61000-4-5) 500V/250A 1kV/500A	CNS 14676-5 (Based on IEC/EN 61000-4-5) 500V/250A 1kV/500A	GB/T 18595 (Based on IEC/EN 61547) 500V/250A 1kV/500A	K61547 (Based on IEC/EN 61547) 500V/250A 1kV/500A
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Safety	UL 8750, UL 1310, UL 1993, UL 1598	IEC/EN 62560 bulb IEC/EN 60598 Luminaire IEC/EN 61347 driver IEC/EN 62031 LED array/module	DENAN standards JEL 801	CNS standards	GB24819-2009/ IEC62031 LED Module for general lighting-safety	KS standards

SAFETY:
Short circuit / overload protection is required by most global standards

SURGE:
Tolerance to transient overvoltage events may be optional, but is **CRITICAL** for functionality and reliability

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Unfortunately, transients and surges cannot read!

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In the real world, transients and surges often exceed the test specifications and damage the power supply.

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SURGE:
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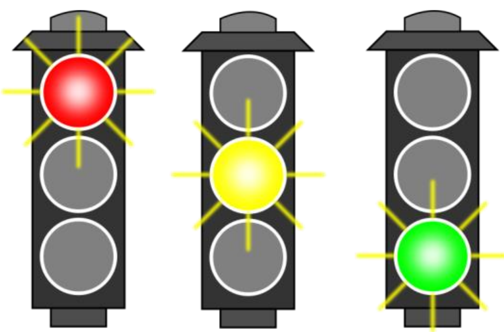
However, the specifications and circuit protection techniques used to protect against surges and transients in outdoor LED lighting are extremely robust, yet highly cost effective.



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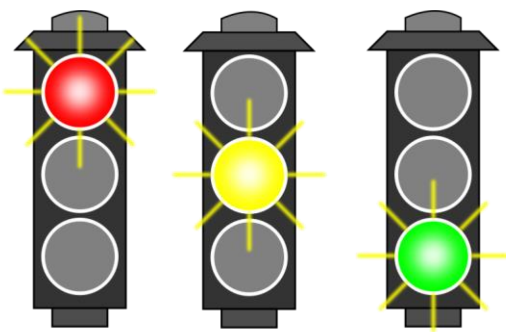
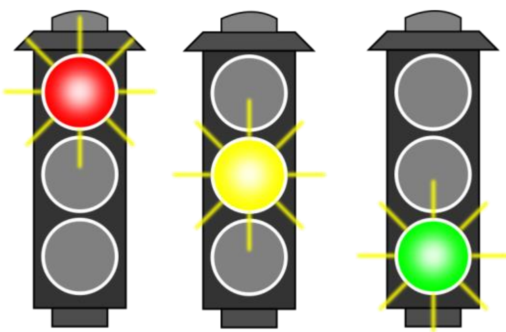


Therefore the circuit protection techniques applied in LED power supplies are well suited for use in other industrial power supply applications.

However, the specifications and circuit protection techniques used to protect against surges and transients in outdoor LED lighting are extremely robust, yet highly cost effective.



Using these techniques will still permit you to meet the required specifications in your application.

This presentation discusses the following topics:

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I. Why use circuit protection techniques developed for LED power supplies?

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II. Global safety and surge immunity standards in the lighting field.

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I. Why use circuit protection techniques developed for LED power supplies?

II. Global safety and surge immunity standards in the lighting field.

III. Use of MOVs for surge protection.

Part I

Why use circuit protection techniques developed for LED power supplies?

LED power supplies provide a good starting point for developing surge and transient protection for all types of power supplies because…

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- An LED power supply is functionally similar to other power supplies—the main difference is the load.

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- An LED power supply is functionally similar to other power supplies—the main difference is the load.
- Circuit protection techniques developed for LED lighting will work in almost any application.

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- Circuit protection components developed for LED lighting are inexpensive.
  - LED lighting applications such as streetlights are high volume.
  - Customers in this field "beat down" prices on all components.

Circuit protection techniques developed for LED lighting will work in almost any application because…

- Circuit protection components designed for LED lighting are available with short lead times on delivery.

Circuit protection techniques developed for LED lighting will work in almost any application because…

- Circuit protection components designed for LED lighting are available with short lead times on delivery.
  (Someone always has stock of the components because they are needed for the lighting market in a moment's notice.)

Circuit protection techniques developed for LED lighting will work in almost any application because…

- Circuit protection components offer quality and reliability.

Circuit protection techniques developed for LED lighting will work in almost any application because…

- Circuit protection components offer quality and reliability. The volumes and cost of a service call in lighting drive the quality so high that the likelihood of customers receiving a bad component is very low.

Circuit protection techniques developed for LED lighting will work in almost any application because…

- Of standards and robustness.

Circuit protection techniques developed for LED lighting will work in almost any application because…

- Of standards and robustness. The LED lighting applications see lightning strikes and environmental extremes in excess of what power supplies will see in most other applications.

Circuit protection techniques developed for LED lighting will work in almost any application because…

- Of standards and robustness. For example, if the circuit protection components will withstand the abuse of a streetlight with surges, transients, temperature variations, rain, moisture, etc. , they will be robust enough for many other power supply applications.

Part II

Global safety and surge immunity standards in the lighting field.

Global safety and surge immunity standards—there are so many!

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For safety, short circuit or overload protection is required by most global standards.

Global safety and surge immunity standards.

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For surge protection, tolerance to transient overvoltage events may be optional, but is critical for functionality and reliability.

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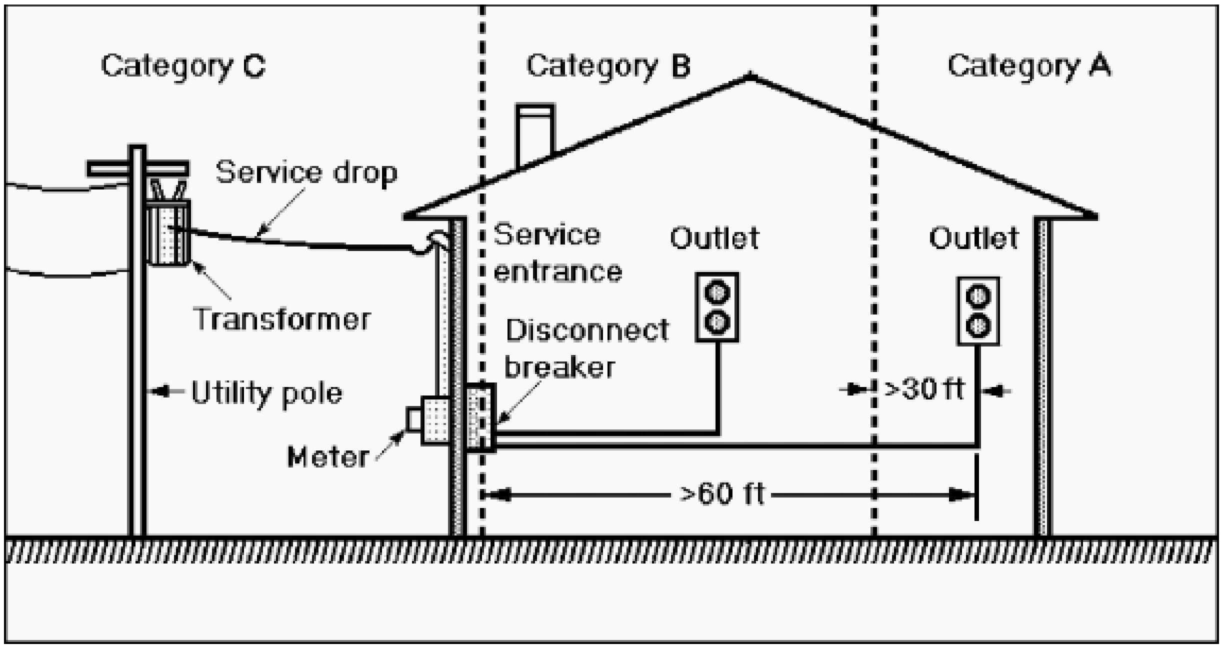
IEEE C62.41.1 defines three surge environments.



IEEE C62.41.1 qualifies products that will be connected to the ac mains for immunity to transients and surges.

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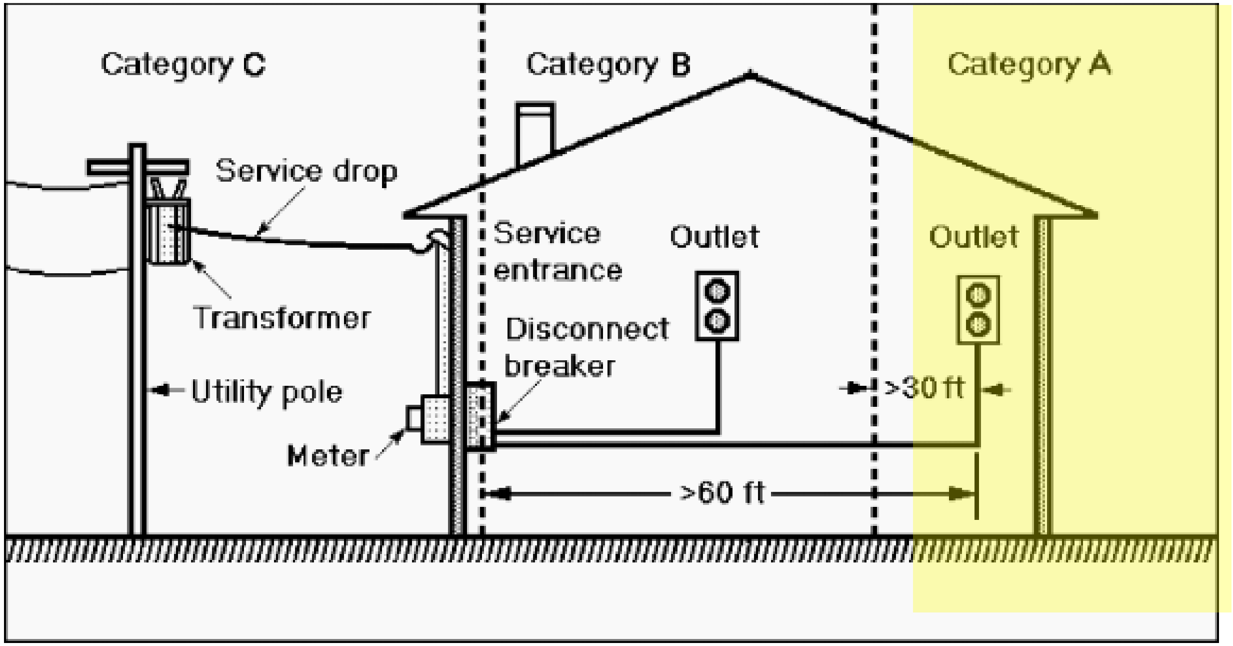

Category A refers to parts of the installation at some distance from the service entrance.

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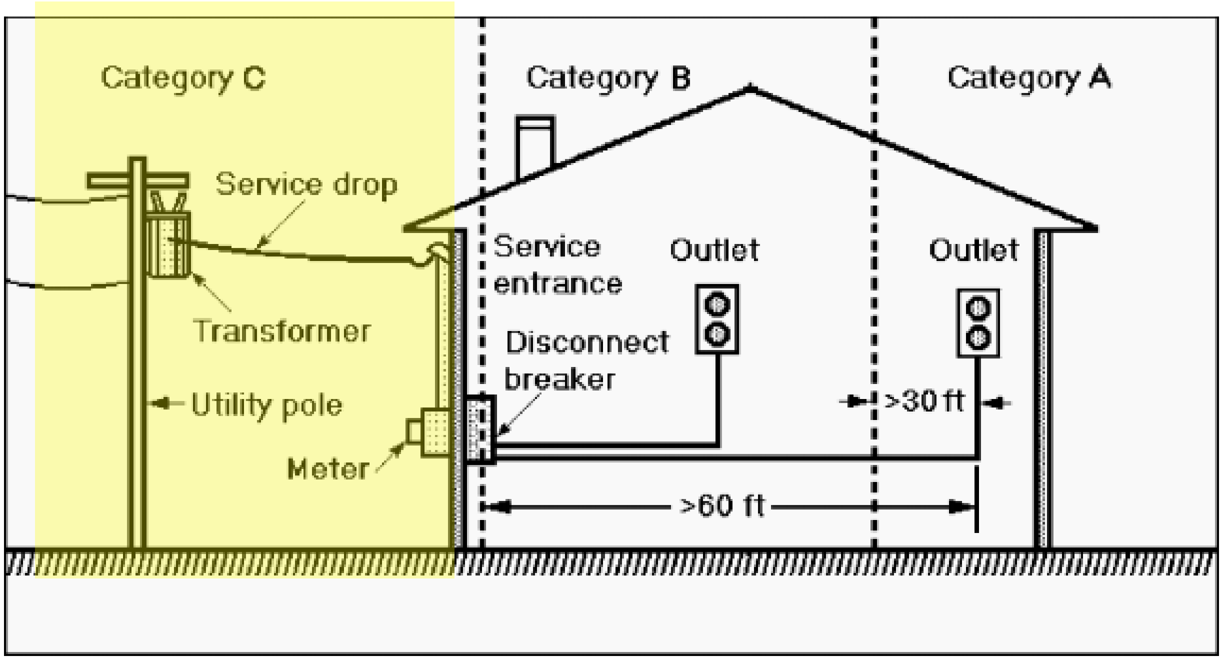
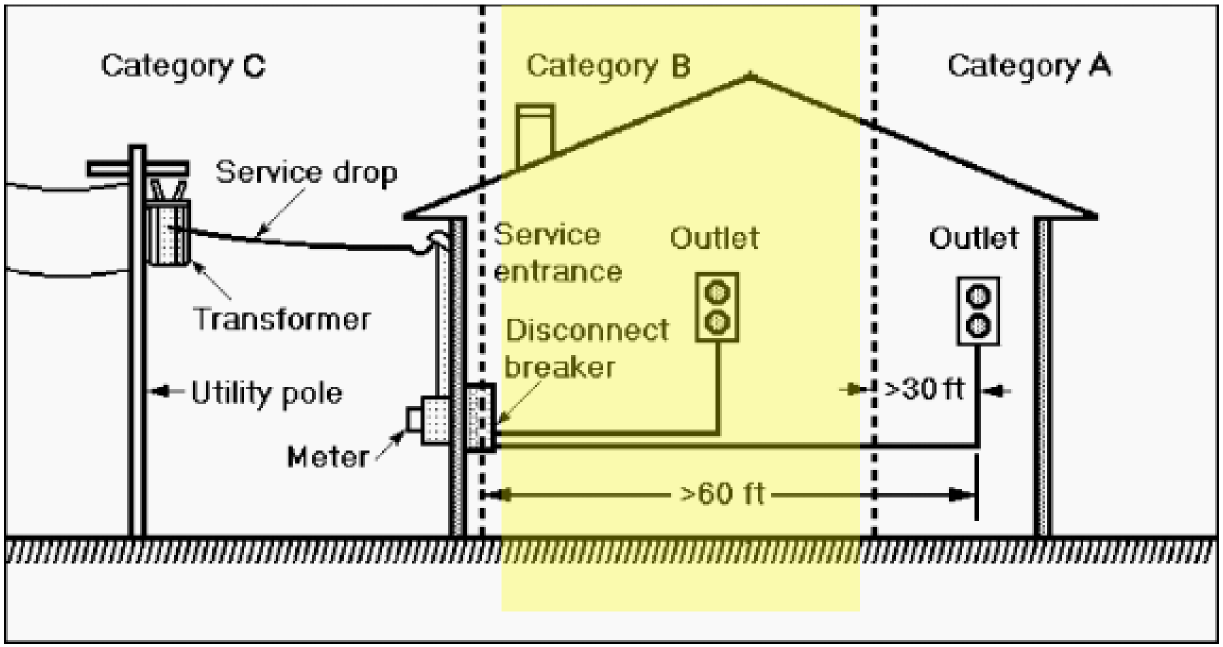


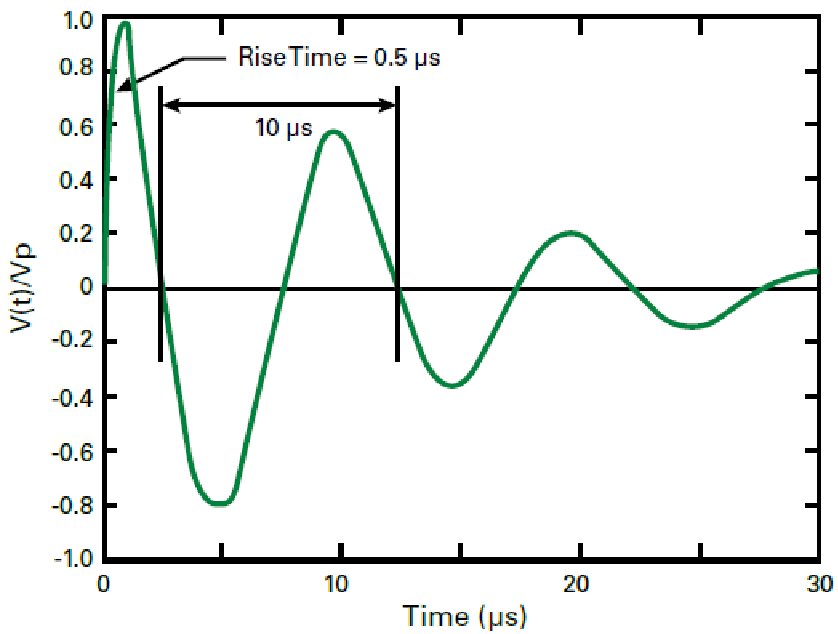
Category C refers to external parts of the structure, extending some distance into the building.

IEEE C62.41.1 defines three surge environments.



Category B refers to parts of the installation between Cat A and Cat C.

Energy Star specifies surge testing per IEEE C62.41.1-2002 (USA).



The 100 kHz Ring Wave (voltage and current)

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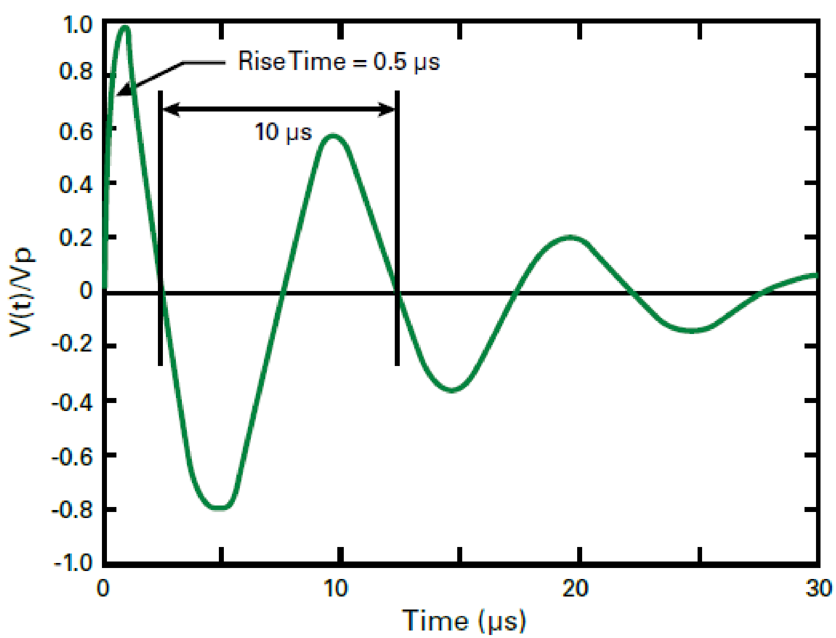

The 100 kHz Ring Wave (voltage and current)

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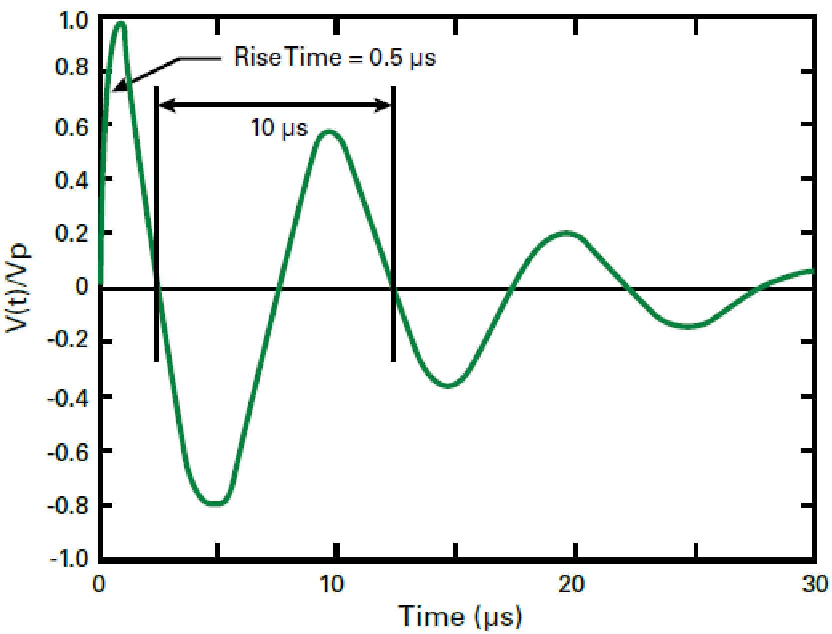

The 100 kHz Ring Wave (voltage and current)

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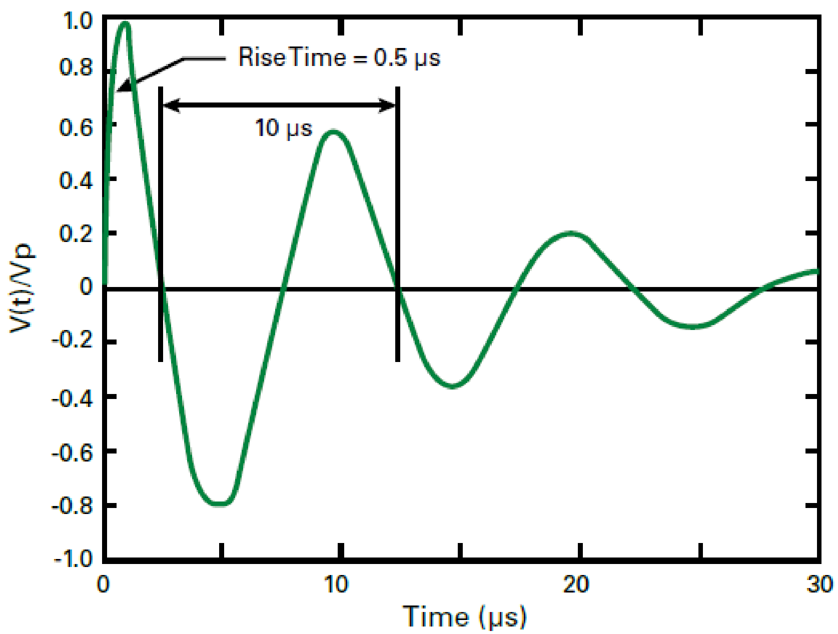
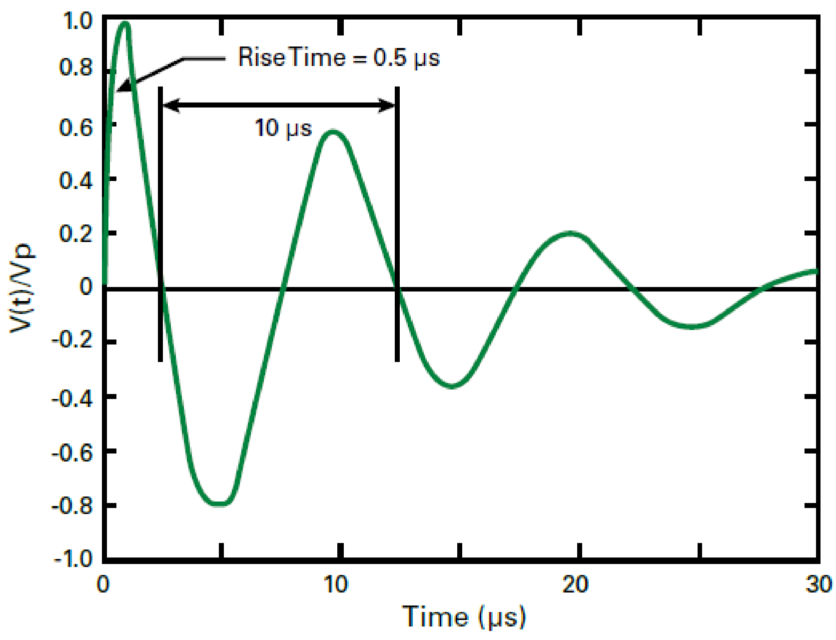
Energy Star specifies surge testing per IEEE C62.41.1-2002 (USA).



The 100 kHz Ring Wave (voltage and current)

- Test level is 2.5 kV/83 A, line-to-Line (class A operation.)

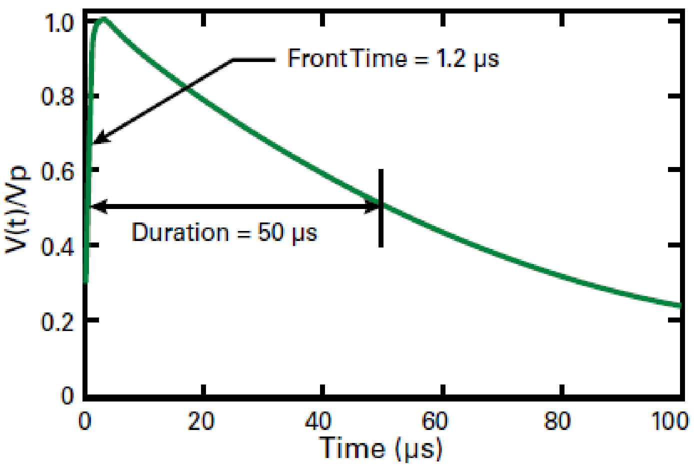
Energy Star specifies surge testing per IEEE C62.41.1-2002 (USA).



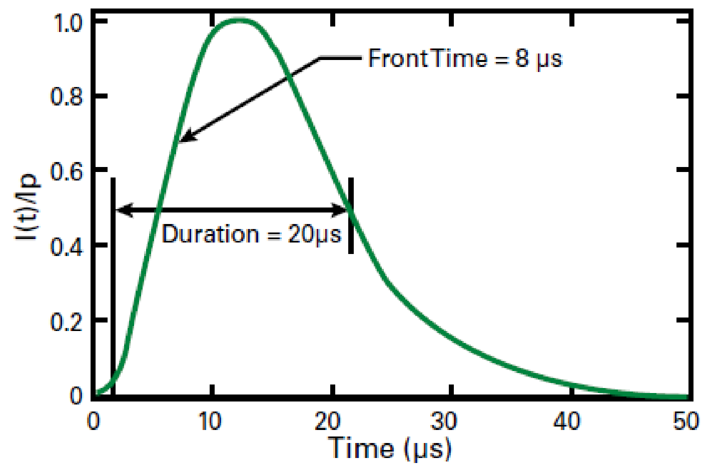
The 100 kHz Ring Wave (voltage and current)

- Number of surges is 7 strikes in common mode and 7 in differential mode, 1 minute between each strike.

IEC 61000-4-5 (Global) specifies transient surge testing.



Combination Wave open-circuit voltage



Combination Wave short-circuit current

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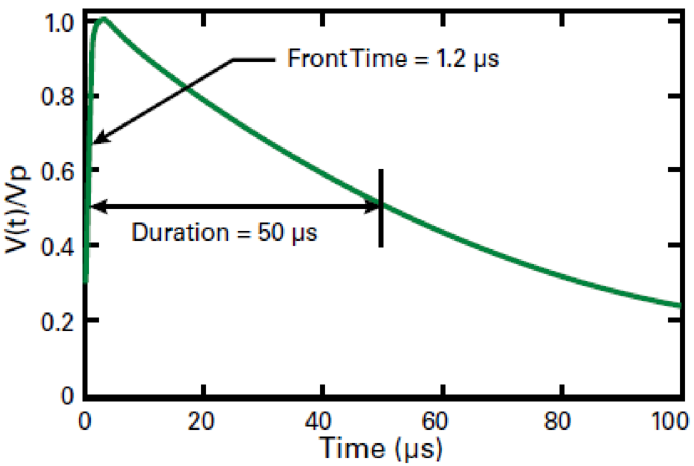

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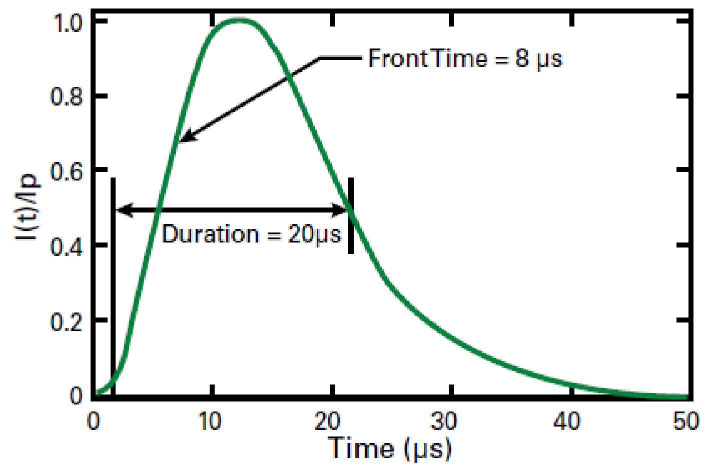

Combination Wave short-circuit current

The test waveform is a combination waveform—1.2 x 50-µs voltage plus 8 x 20-µs current.

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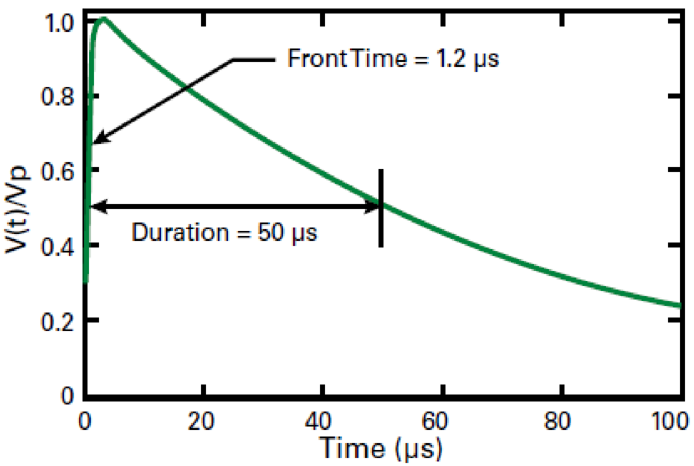

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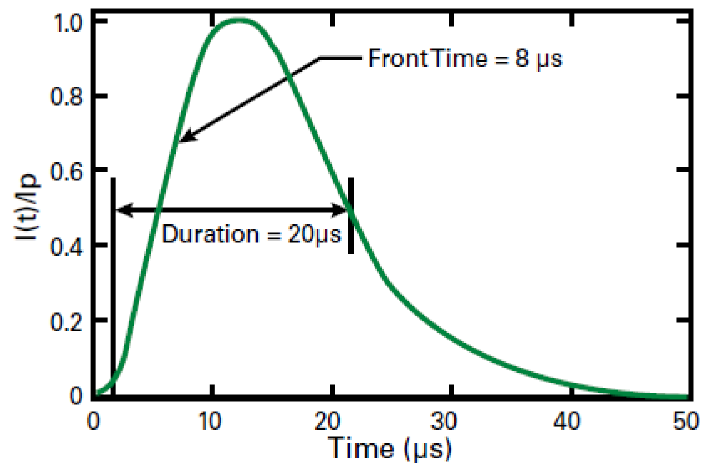
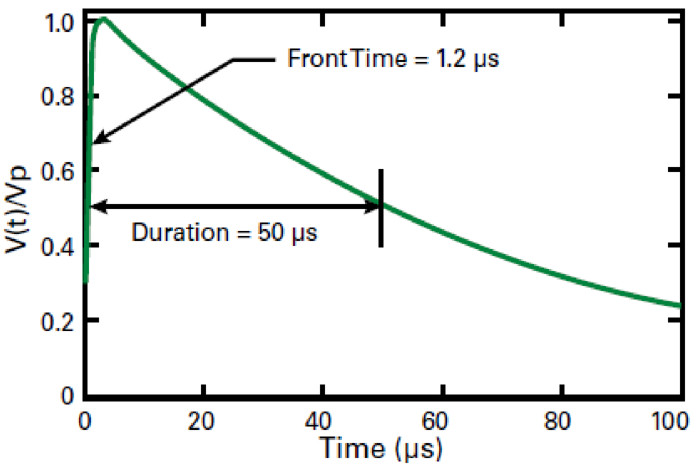


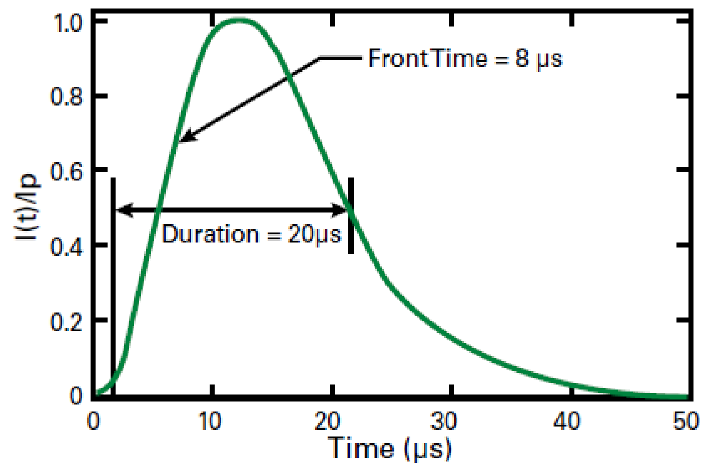
Combination Wave short-circuit current

- For self-ballast lamps < 25W use 500-V/250-A test (installation class 2).

IEC 61000-4-5 (Global) specifies transient surge testing.



Combination Wave open-circuit voltage



Combination Wave short-circuit current

IEC

- For self-ballast lamps < 25W. Apply 500 V L-L with 2-Ω source impedance & 1 kV L-G with 12 Ω.

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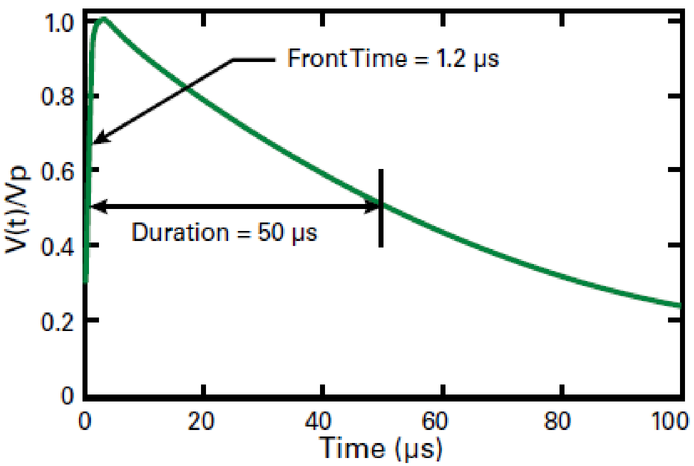
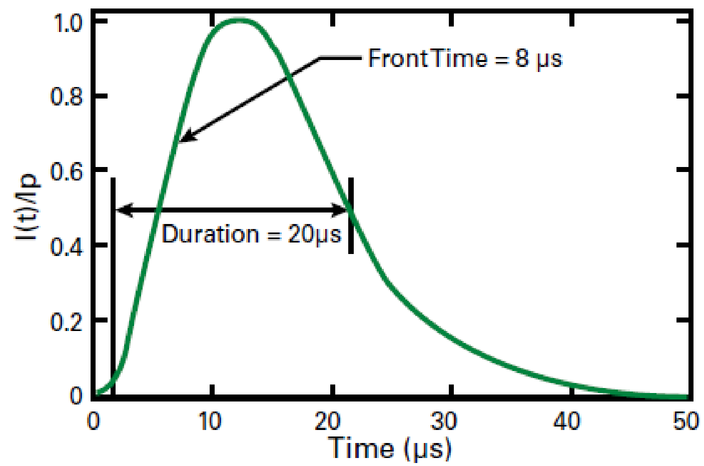
IEC 61000-4-5 (Global) specifies transient surge testing.



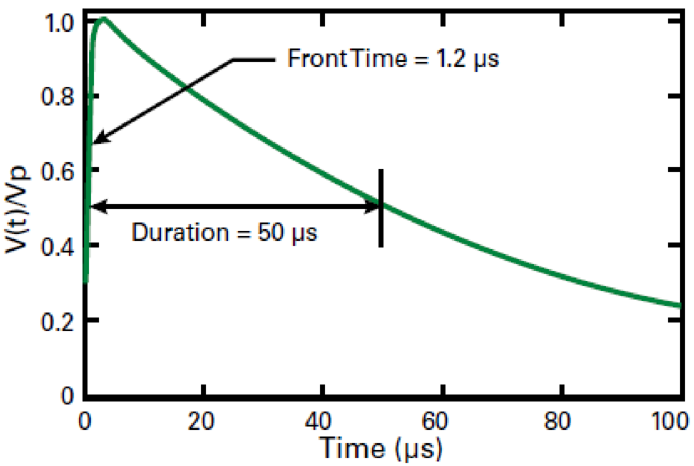
Combination Wave open-circuit voltage



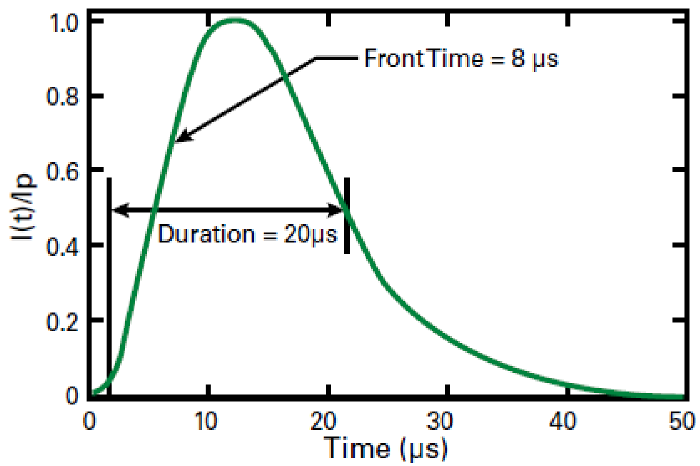
Combination Wave short-circuit current

- For self-ballast lamps > 25 W use 1000-V/500-A test.

IEC 61000-4-5 (Global) specifies transient surge testing.



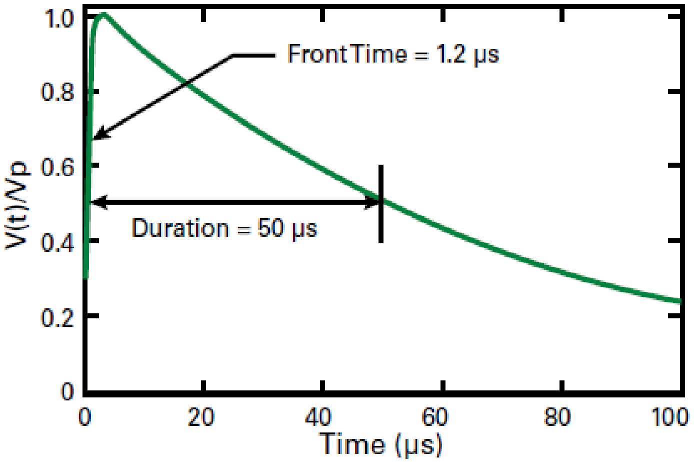
Combination Wave open-circuit voltage



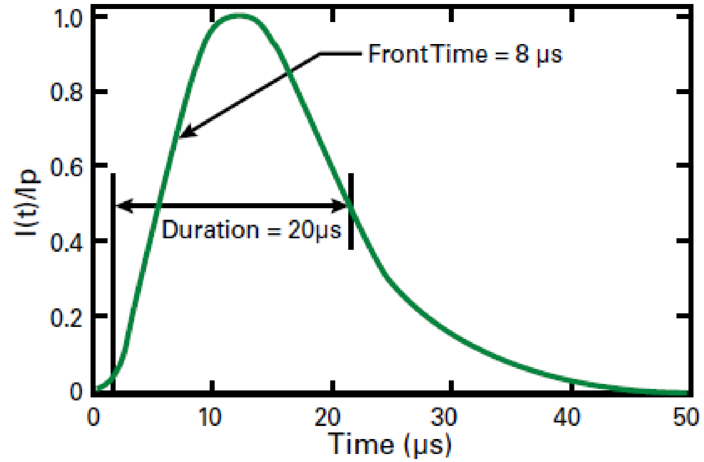
Combination Wave short-circuit current

- For self-ballast lamps > 25 W. Apply 1 kV L-L with 2-Ω source impedance & 2 kV L-G with 12 Ω.

IEC 61000-4-5 (Global) specifies transient surge testing.



Combination Wave open-circuit voltage



Combination Wave short-circuit current

- Number of surges required is 40 strikes, 5+ and 5- at phase angles of 0°, 90°, 180°, and 270° with 1 min. intervals between each strike.

Transient surge threats—the problem.

- Lightning strikes are traveling electrostatic discharges, usually coming from clouds to the ground with a magnitude of millions of volts.

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Transient surge threats—the problem.

- Lightning strikes are traveling electrostatic discharges, usually coming from clouds to the ground with a magnitude of millions of volts.
- Surges up to thousands of volts are applied to copper wires carrying induced current from lightning strikes occurring up to a few miles away.
- These ***indirect strikes usually occur in exposed outdoor wires,*** transmitting surges to devices like streetlights or traffic lights.

Transient surge threats—the problem.

- A **surge protection module (SPM)**, at the upstream of the circuitry, is directly facing surge interference coming from the power line. It diverts or absorbs surge energy, ***minimizing surge threats to downstream devices*** like the ac-dc power supply.

Transient surge threats—the problem.

- A surge protection module (SPM), at the upstream of the circuitry, is directly facing surge interference coming from the power line. It diverts or absorbs surge energy, minimizing surge threats to downstream devices like the ac-dc power supply.

Note: In this presentation, a surge protection module is also referred to as a surge protection device or SPD.

Part III

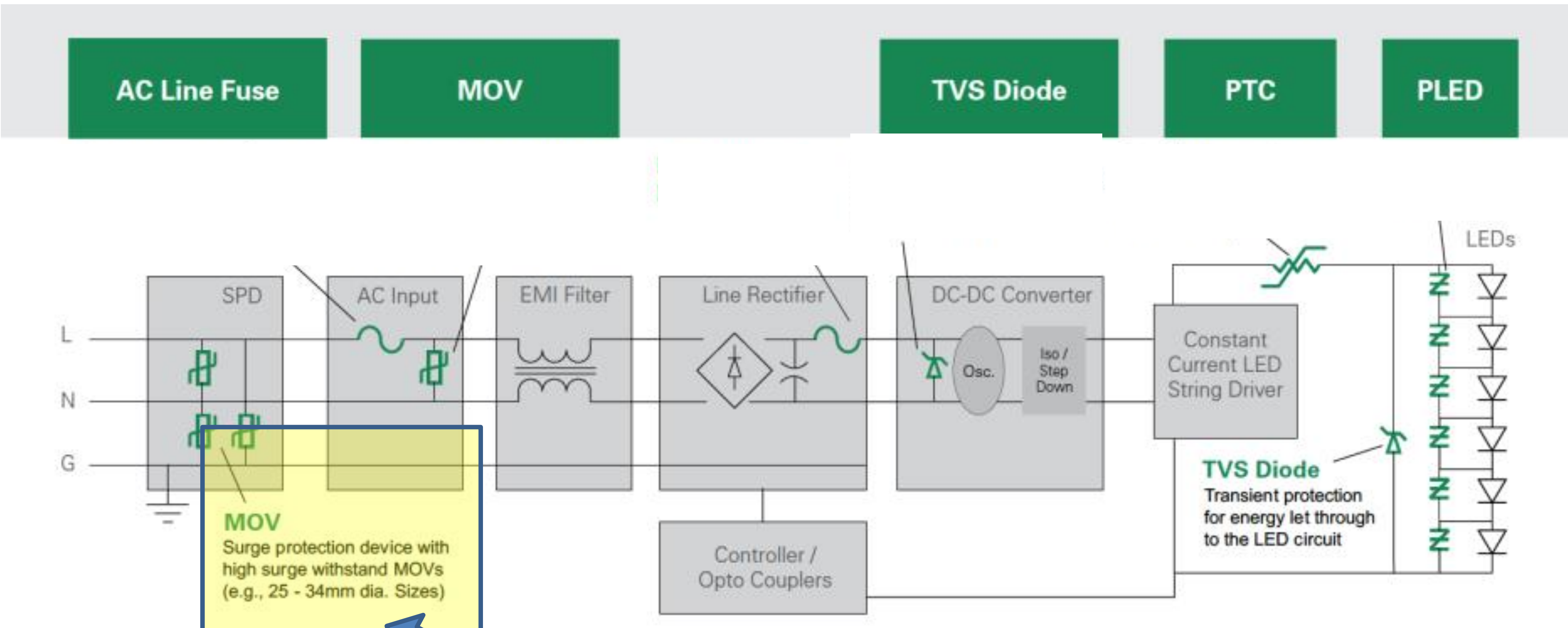
Use of MOVs for surge protection.

Part III

Use of MOVs for surge protection.

We start by looking at the LED luminaire.

The LED luminaire assembly contains multiple protection devices.



SPD module also known as a surge arrestor.

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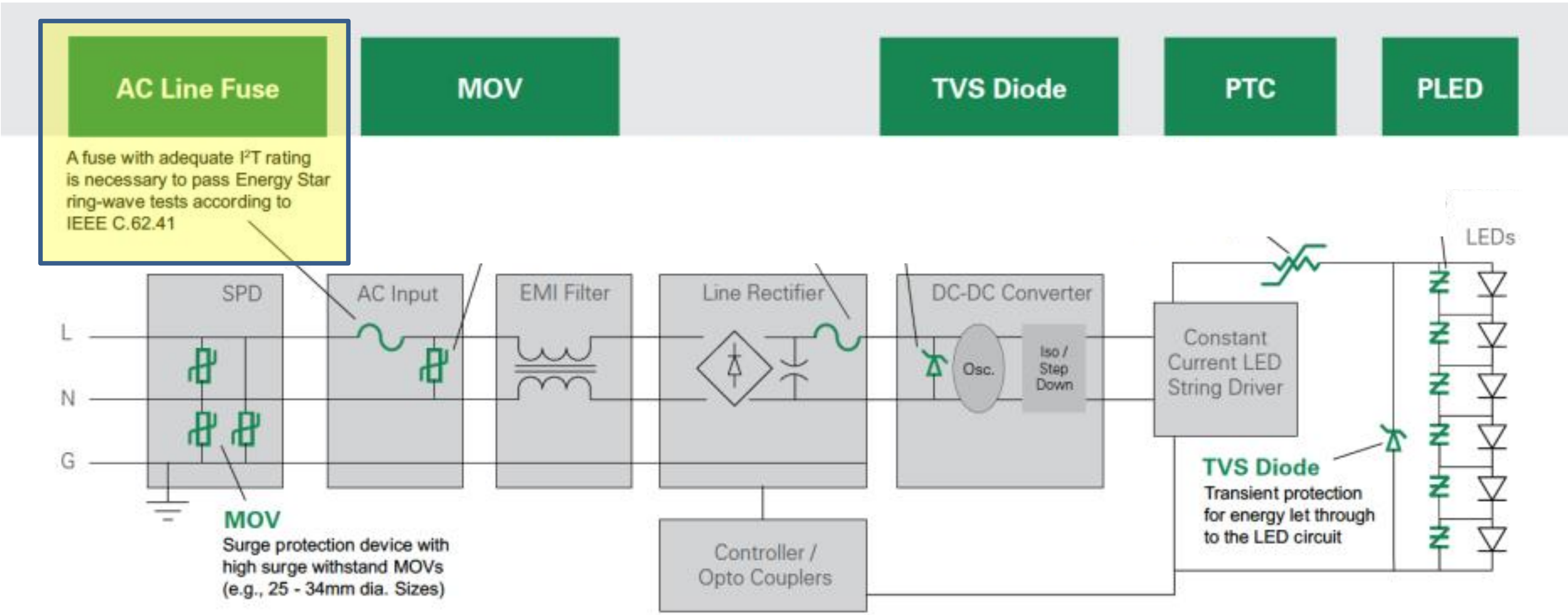
The LED luminaire assembly contains multiple protection devices.



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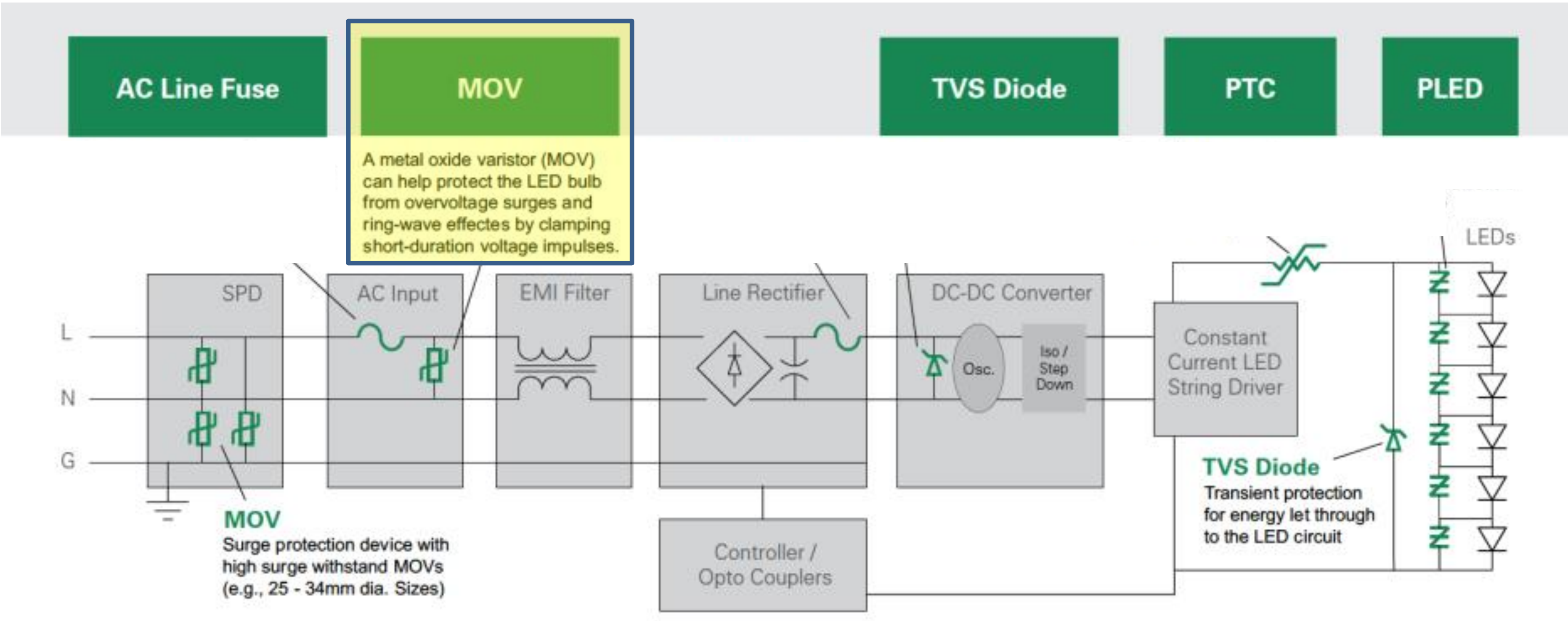

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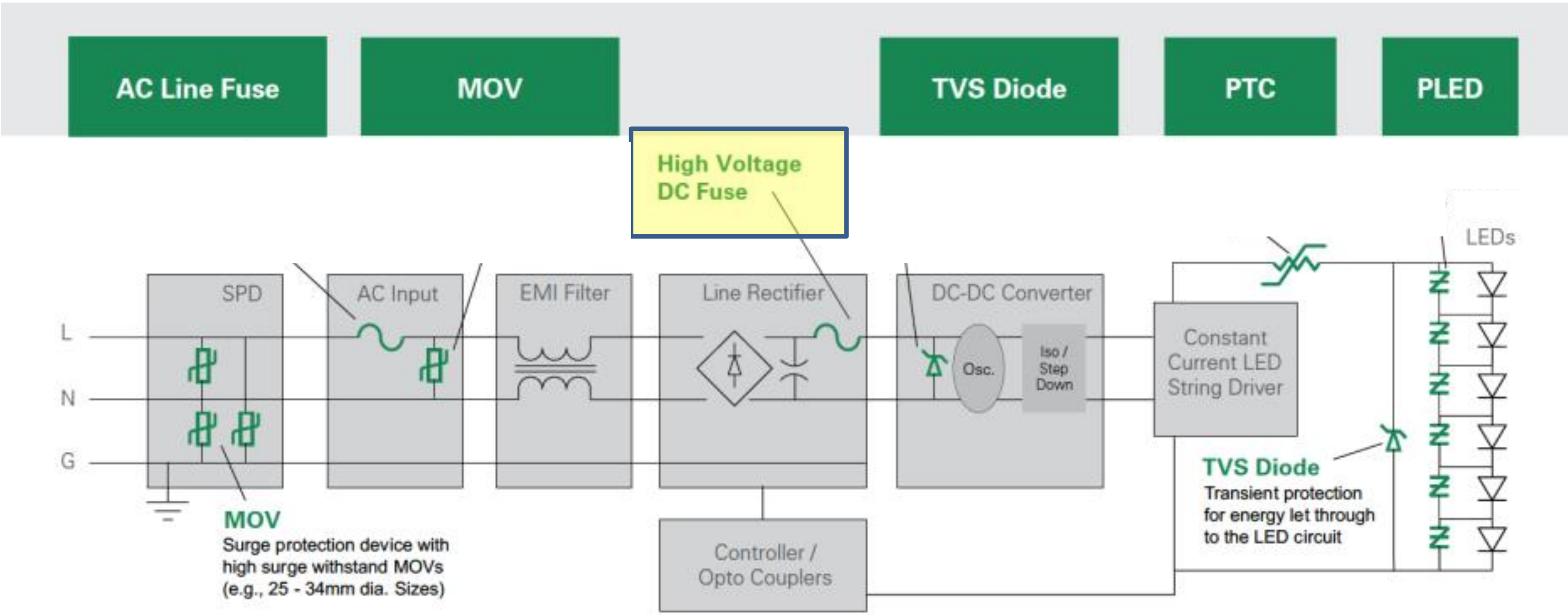

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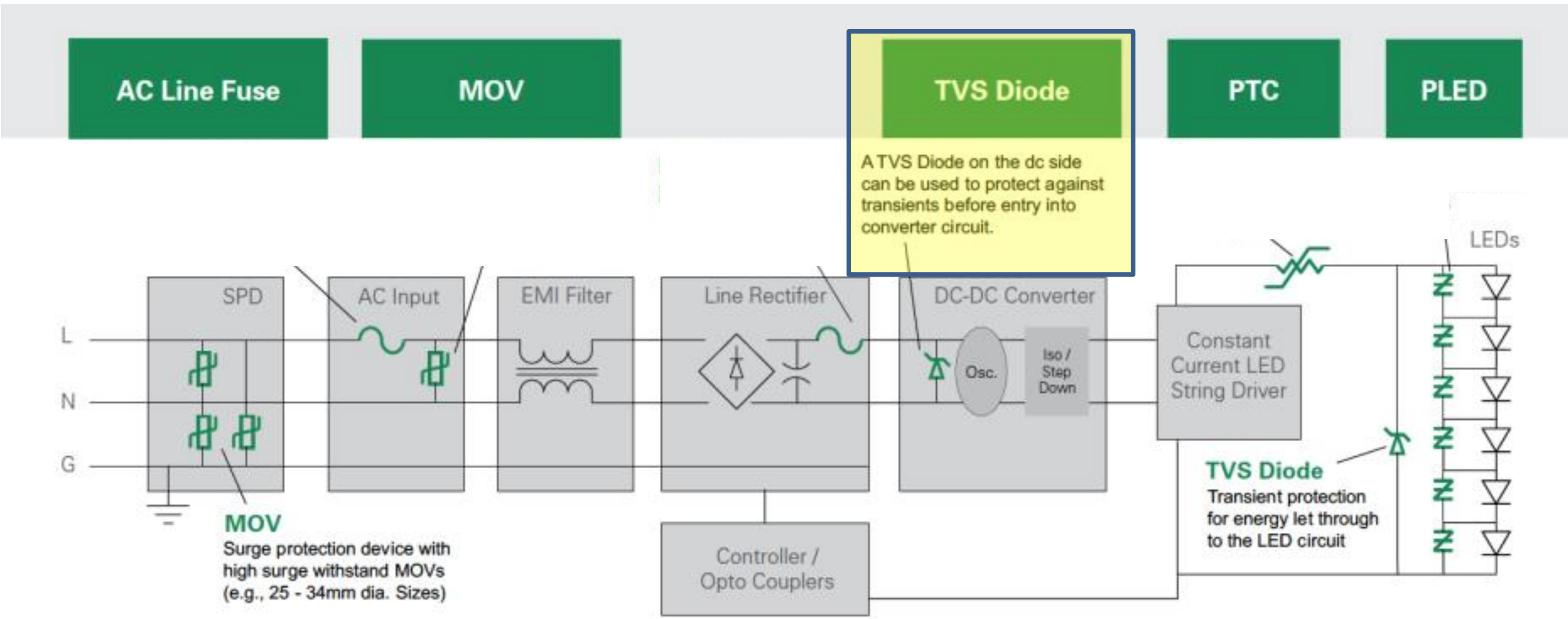
Protection components and systems: The LED luminaire assembly contains multiple protection devices.



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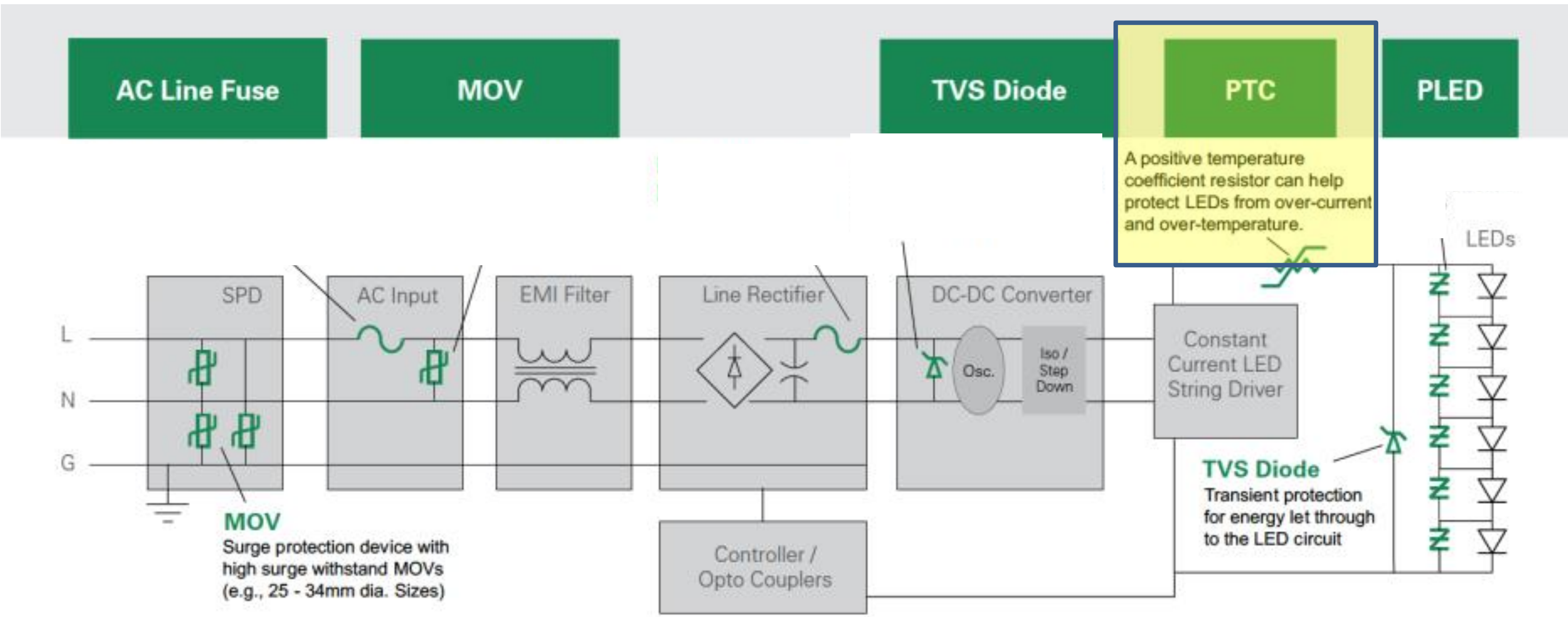
The LED luminaire assembly contains multiple protection devices.



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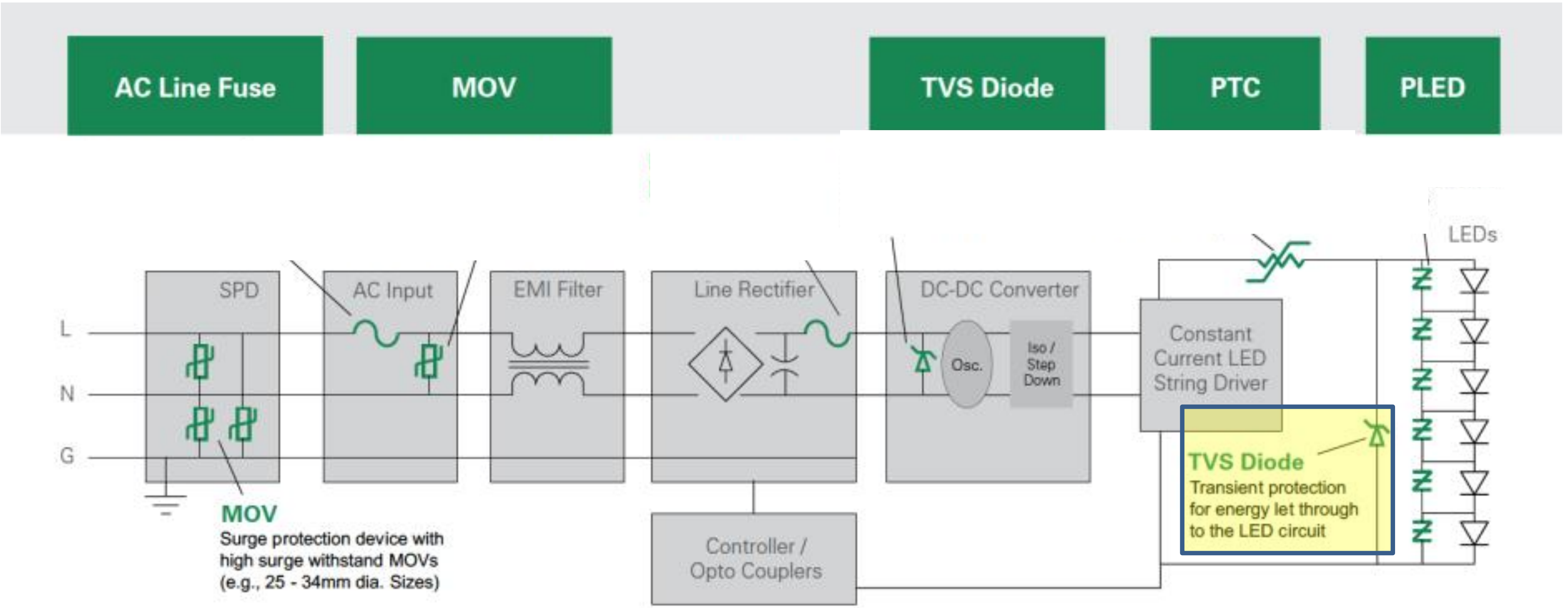

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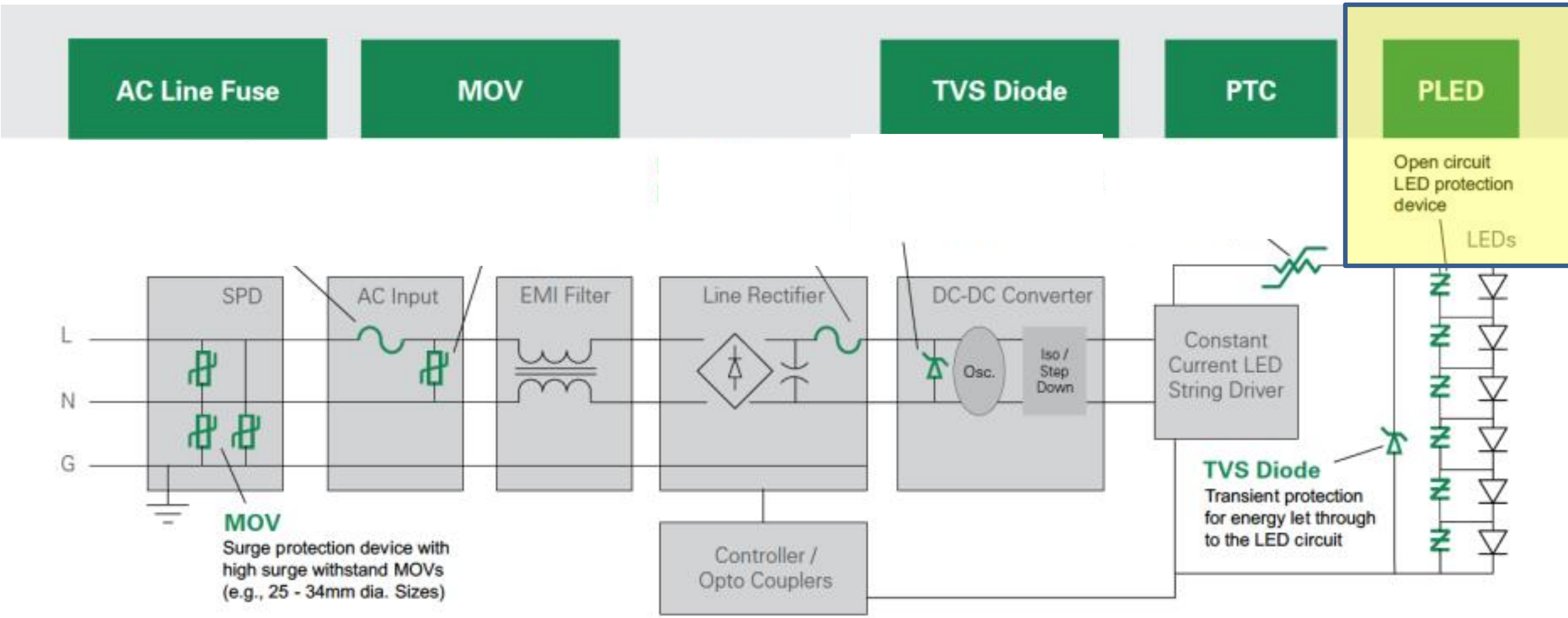

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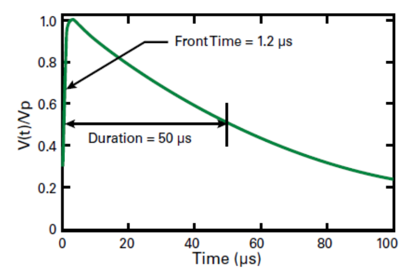
The U.S. Department of Energy specifies these surge testing requirements for high exposure levels.

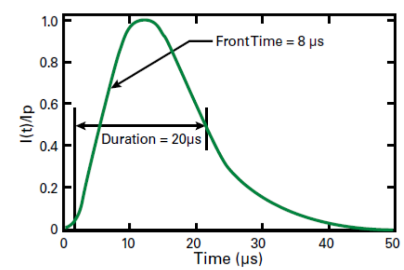
Parameter	Test Level/ Configuration
1.2/50µs Open Circuit Voltage Peak	Low: 6 kV. High: 10kV*
8/20µs Short Circuit Current Peak	Low: 3 kA. High: 10kA
Coupling Modes	L1 toPE, L2 to PE, L1 to 72
Polarity and Phase Angle	Positive at 90° and Negative at 270°
Test Strikes	5 for each Coupling Mode and Polarity/Phase Angle combination
Time Between Strikes	1 minute
Total Number of Strikes	= 5 strikes × 3 coupling modes × 2 polarity/phase angles = 30 total strikes

*This is a MINIMUM requirement. Note that for most combination wave generators, which have a source impedance of 2Ω, the generator charging voltage will need to be raised above the specified level (to somewhere in the vicinity of 20kV) to obtain the specified current peak.

1.2 x 50-µs open circuit voltage and 8 x 20-µs short circuit current combination waveform.



Combination Wave open-circuit voltage



Combination Wave short-circuit current

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This is our guideline for choosing surge protection devices for the LED luminaire's power supply.

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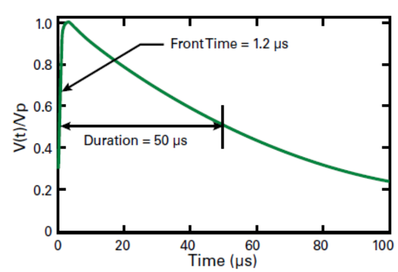
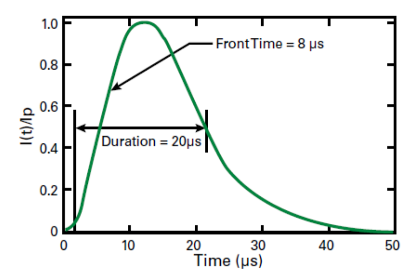


Combination Wave open-circuit voltage



Combination Wave short-circuit current

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Note the high test voltage and current required, which may push the test equipment to its limits.

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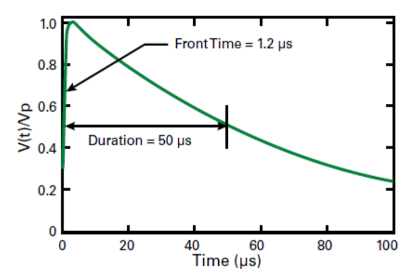

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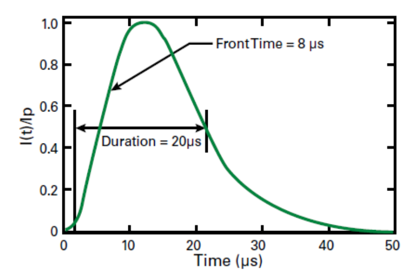
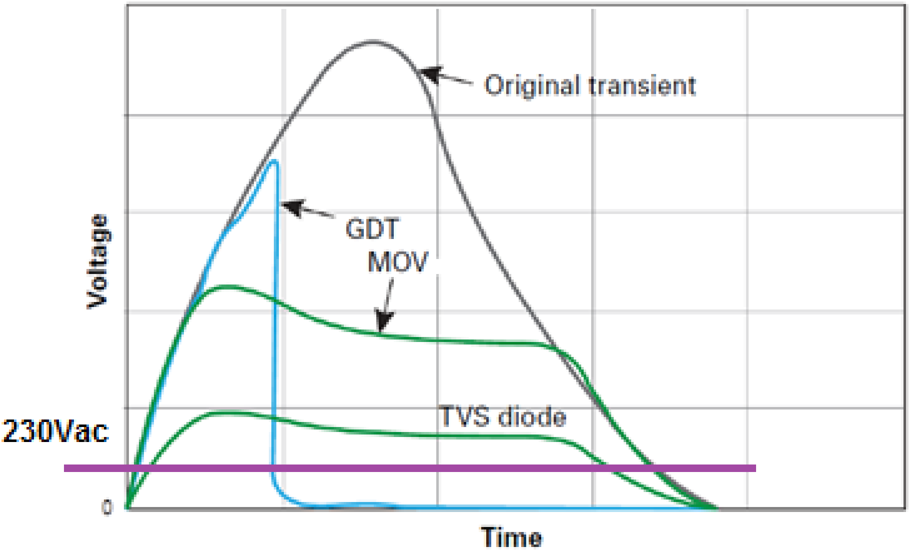


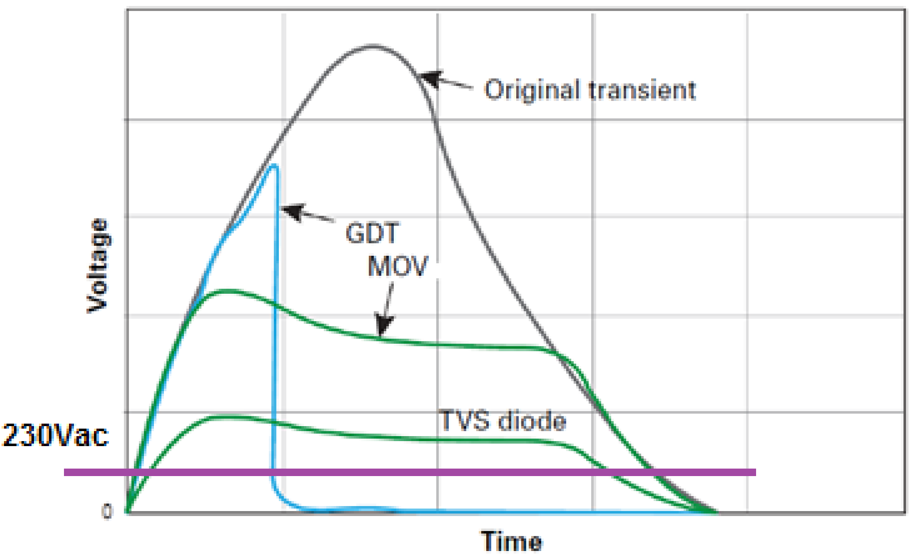
Combination Wave short-circuit current

Protecting against surges: Why Use MOVs?



- The TVS diode is the best device as its lowest clamping but it’s also the costliest.

Protecting against surges: Why Use MOVs?



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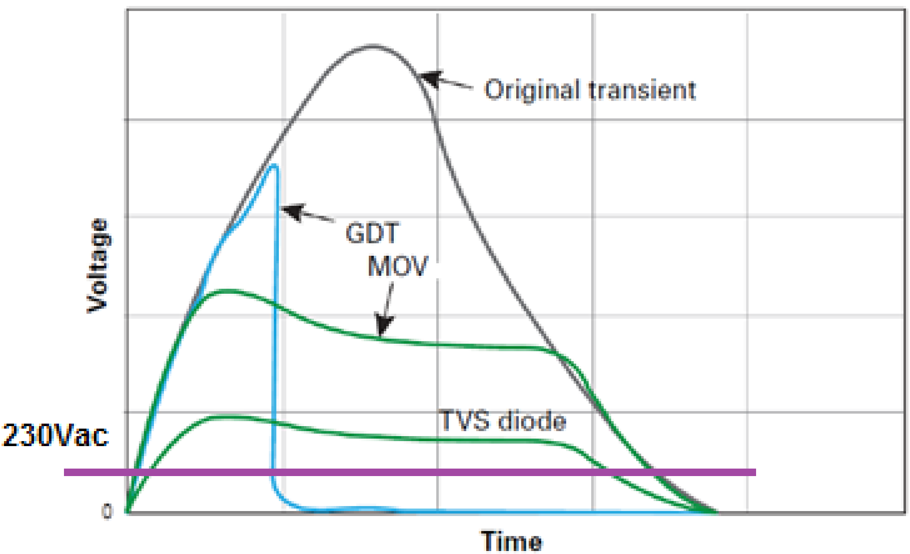

- The TVS diode is the best device as its lowest clamping but it's also the costliest.
- The MOV is the most suitable, offering the highest protection at the lowest cost.
- But every good thing has a limitation: MOVs have limited lifetimes and need protection at the end of life.

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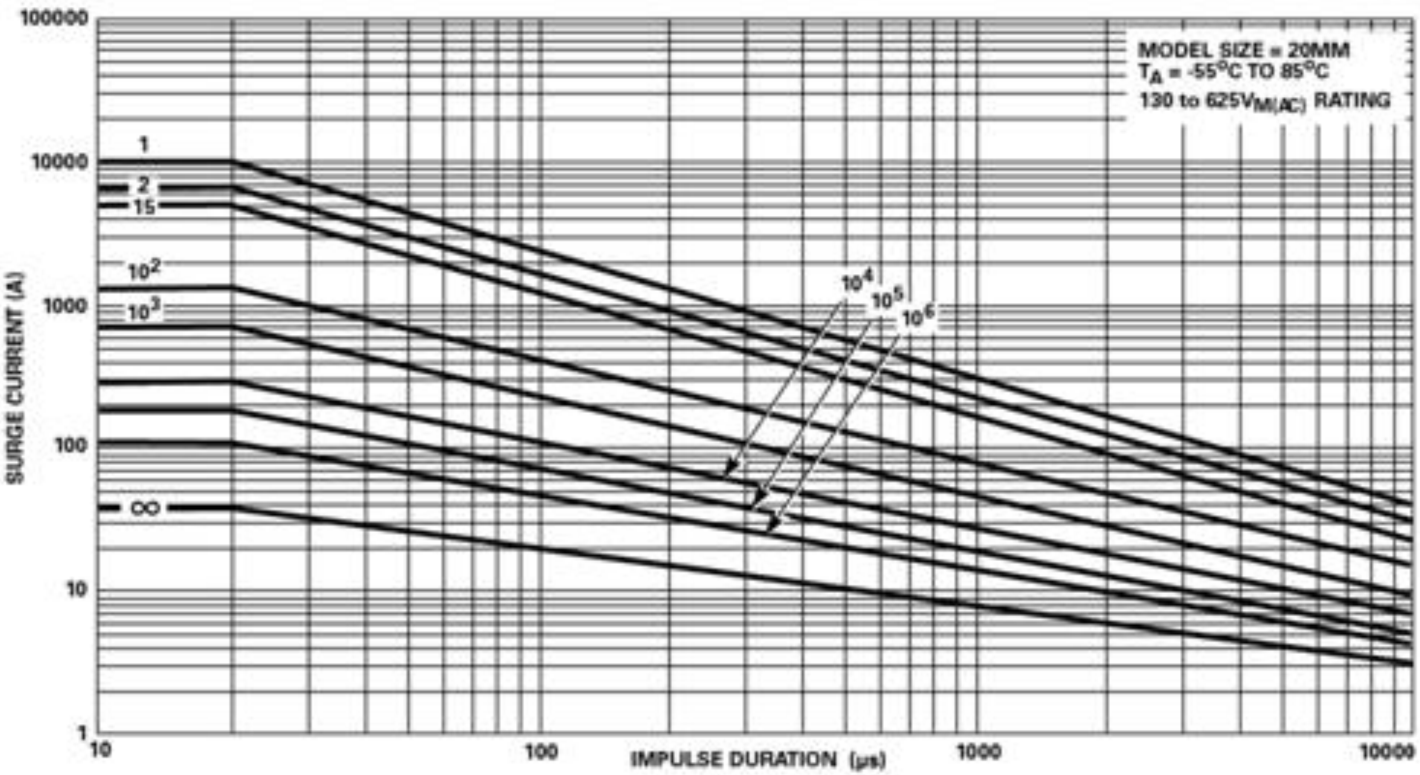
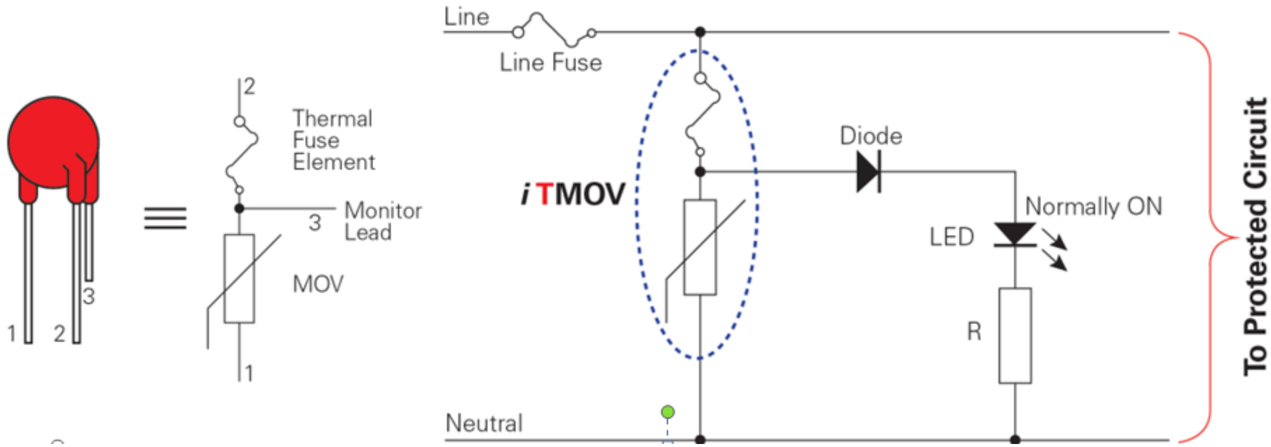
Protecting against surges: Why Use MOVs?



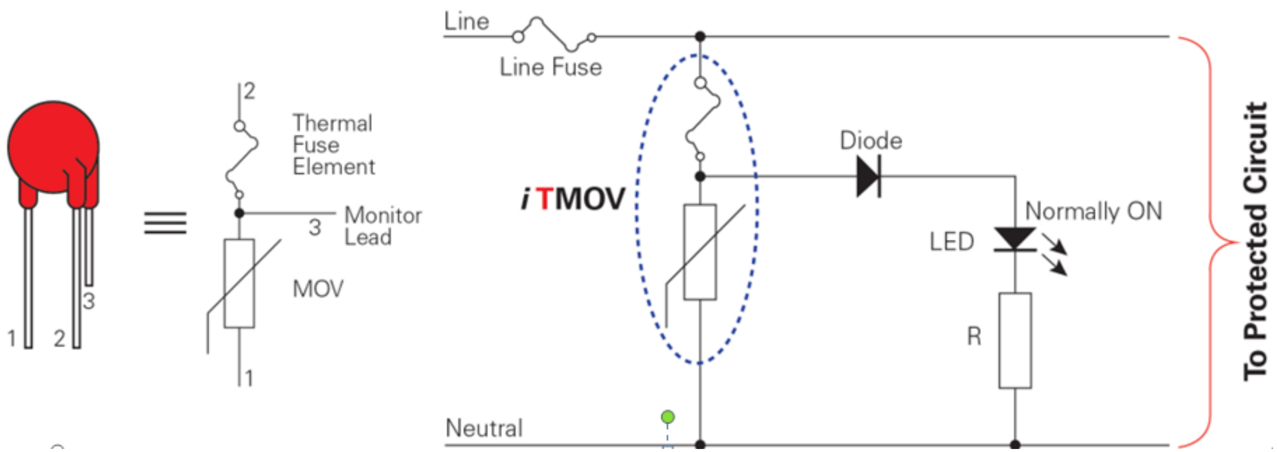
MOV life is dependent on the surges it suppresses.

Protecting against surges: Why Use MOVs?



- A **TMOV** has an integrated thermal fuse.

Protecting against surges: Why Use MOVs?



- A TMOV has an integrated thermal fuse.
- This ensures the MOV is disconnected from the supply when it reaches end of life.

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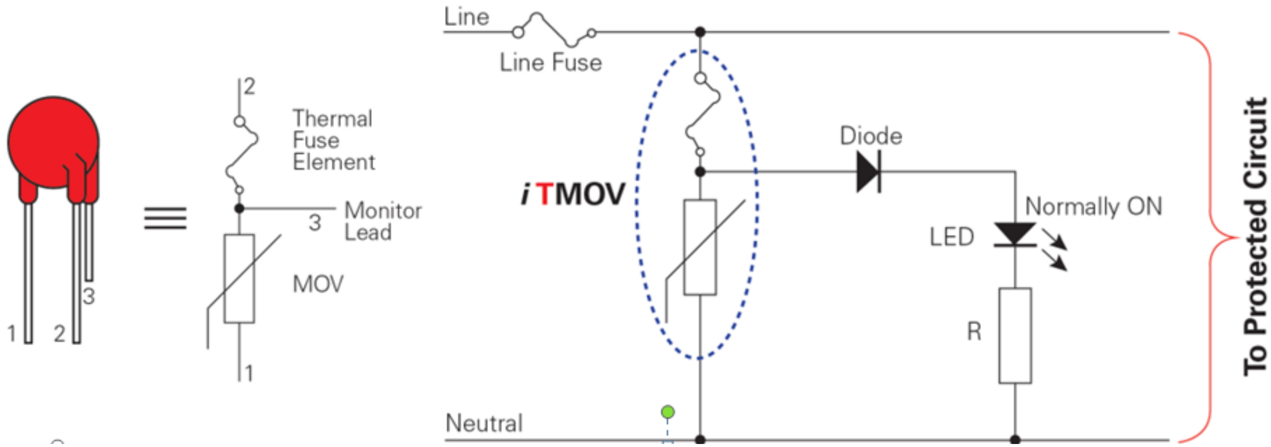
Protecting against surges: Why Use MOVs?



- The TMOV has integrated thermal fuse.
- This ensures the MOV is disconnected from the supply when it reaches end of life.
- An iTMOV can also give indication of end of life.

Thermal protection of varistors is needed to protect against the continuous overvoltage threat.

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- Metal oxide varistors (MOVs) are commonly used to suppress transients in surge protection modules.

Thermal protection of varistors is needed to protect against the continuous overvoltage threat.

- MOVs can also be subjected **to continuous abnormal overvoltage** conditions rather than short duration transients.

Thermal protection of varistors is needed to protect against the continuous overvoltage threat.

- Continuous abnormal overvoltage faults are usually caused by **poor power grid quality** or **loss of neutral-to-ground connection in power transformer wiring.**

Thermal protection of varistors is needed to protect against the continuous overvoltage threat.

- The abnormal conditions may last for minutes, even hours.

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Thermal protection of varistors is needed to protect against the continuous overvoltage threat.

- If an MOV is subjected to a sustained abnormal overvoltage, the MOV may go into thermal runaway, resulting in **overheating, smoke, and potentially fire**.

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- In many cases, it requires surge protection module makers to include a **thermal disconnect** for an MOV.

Thermal protection of varistors is needed to protect against the continuous overvoltage threat.

- In many cases, it requires surge protection module makers to include a thermal disconnect for an MOV.
- That thermal disconnect has traditionally been a thermal fuse or thermal cut-off (TCO) device. It disconnects the MOV from the power line when **overtemperature** is detected.

Abnormal overvoltage can be caused by a loss of neutral.

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Common reasons for the loss of the neutral-ground connection are:

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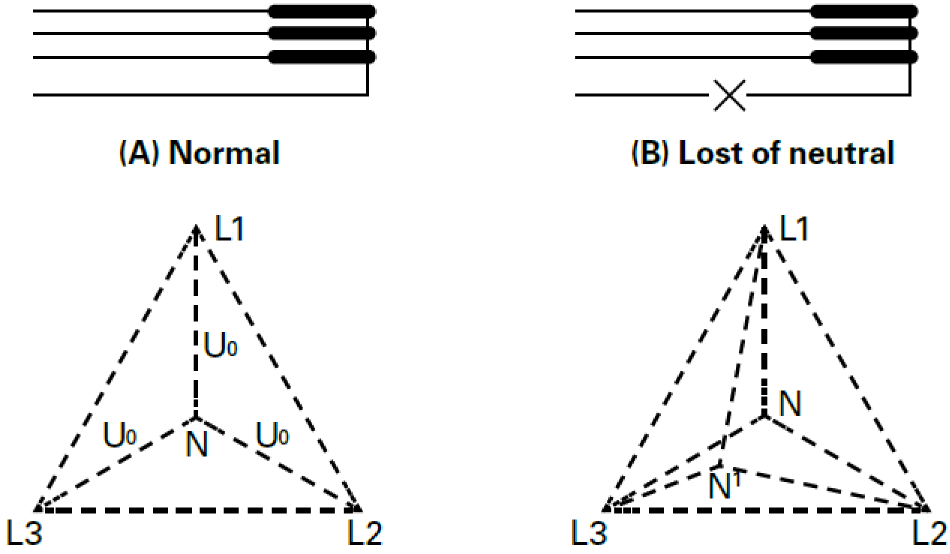
Common reasons for the loss of the neutral-ground connection are:

- Wrong equipment like connector failure or transformer malfunction
- Human error such as improper installations or connectors used, accidental line contacts
- Natural reasons like rain or thunderstorms.

Abnormal overvoltage can be caused by a loss of neutral.

– **Loss of Secondary Neutral.** A broken neutral shifts its potential away and may cause a 1.73× (√3) over-voltage at Line-to-Neutral in the worst case.



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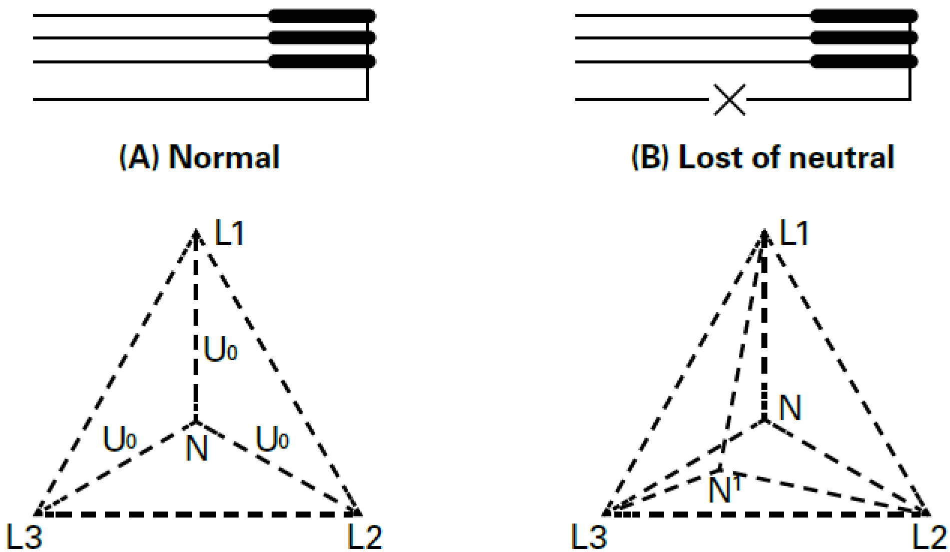

- This can result in sustained overvoltage, which can affect the SPD & driver, MOVs can fail and cause smoke, outgassing and eventually fire.

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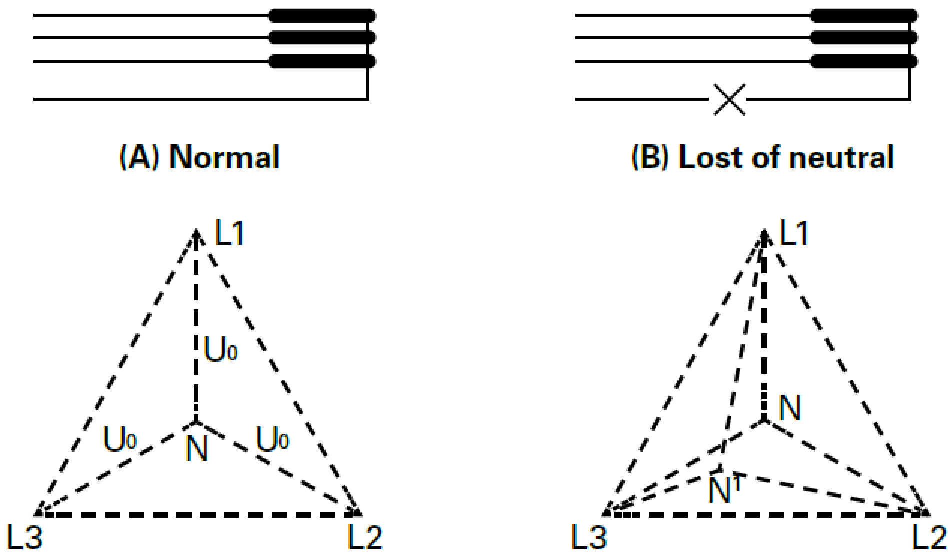

•UL1449 & IEC61643-11 specify that the SPD should have protection against this fault for which thermally protected MOVs are used.

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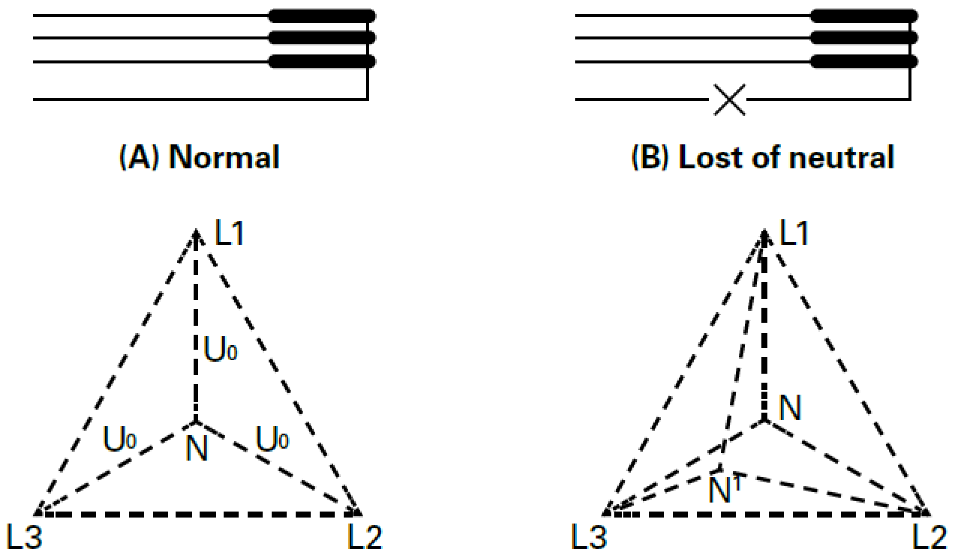

- Poor installation & infrastructure result in frequent problems, so driver & SPD should withstand continuous overvoltage.

MOV end-of-life failures are really hot!

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A simple experiment with three 150-V MOVs demonstrates this problem.

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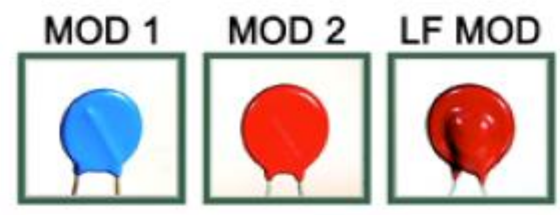
We tested:



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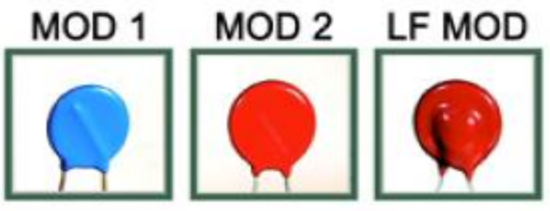
We tested:

- A Littelfuse thermally protected MOV (TMOV) (shown on the right)



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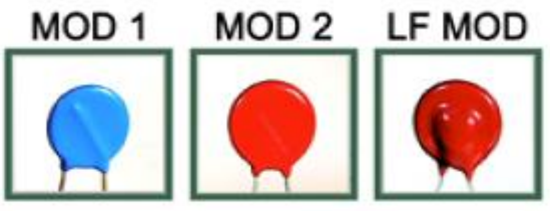

We tested:

- A Littelfuse thermally protected MOV (TMOV) (shown on the right)
- A standard MOV (in the middle)

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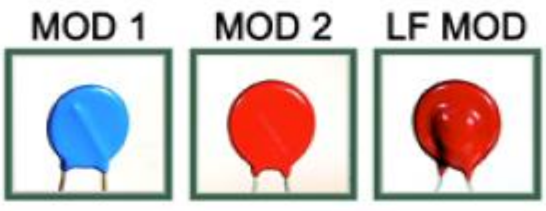
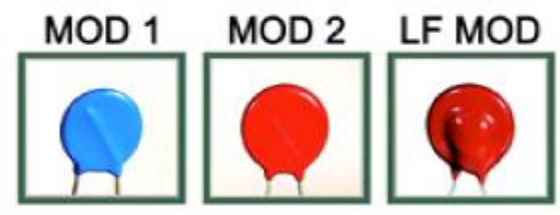


We tested:

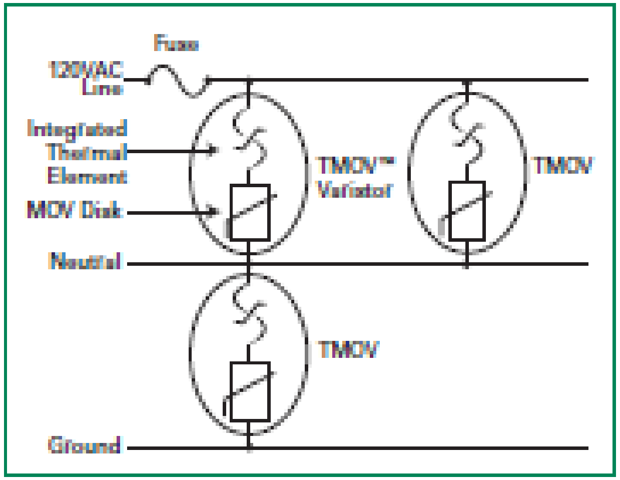
- A Littelfuse thermally protected MOV (TMOV) (shown on the right)
- A standard MOV (in the middle)
- A competitor's standard MOV (on the left.)

MOV end-of-life failures are really hot!

A simple experiment with three 150-V MOVs demonstrates this problem.



A 250-V 10-A fault was applied, simulating an end-of-life condition.



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MOV end-of-life failures are really hot!

A simple experiment with three 150-V MOVs demonstrates this problem.

Click on this video to watch the demo.

Or use the link shown.

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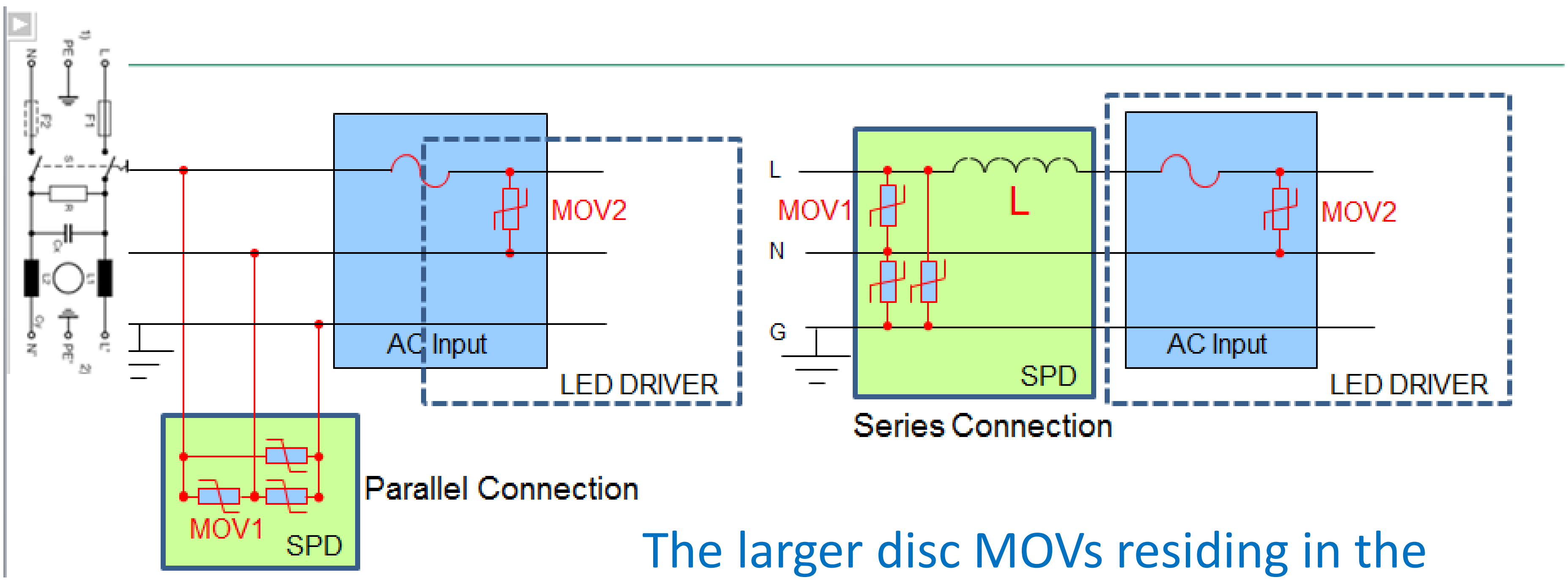
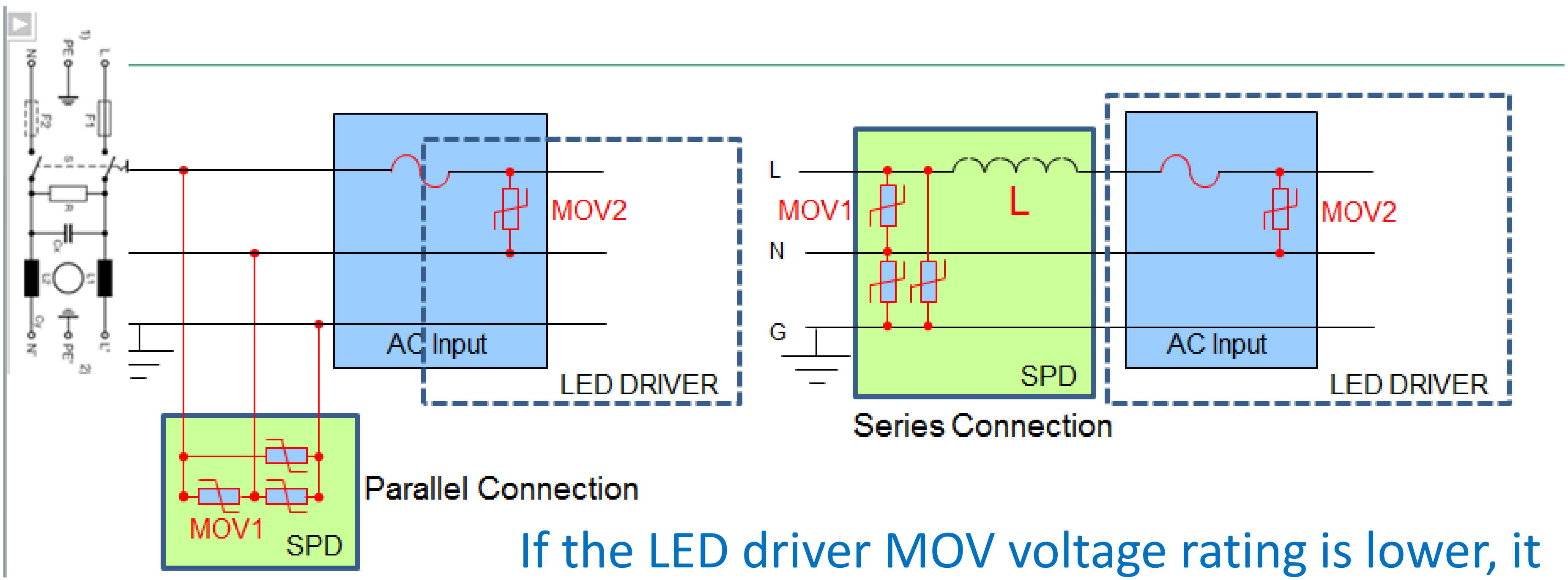
vimeo.com/111156290

Use the power supply filter to your advantage: Coordinate the MOVs in SPD with those in the power supply.



The larger disc MOVs residing in the surge protection module (SPD) should clamp before the smaller MOV used in the power supply.

Use the power supply filter to your advantage: Coordinate the MOVs in SPD with those in the power supply.



If the LED driver MOV voltage rating is lower, it will take the brunt of the transient since it will likely turn on first. That could result in a catastrophic event.

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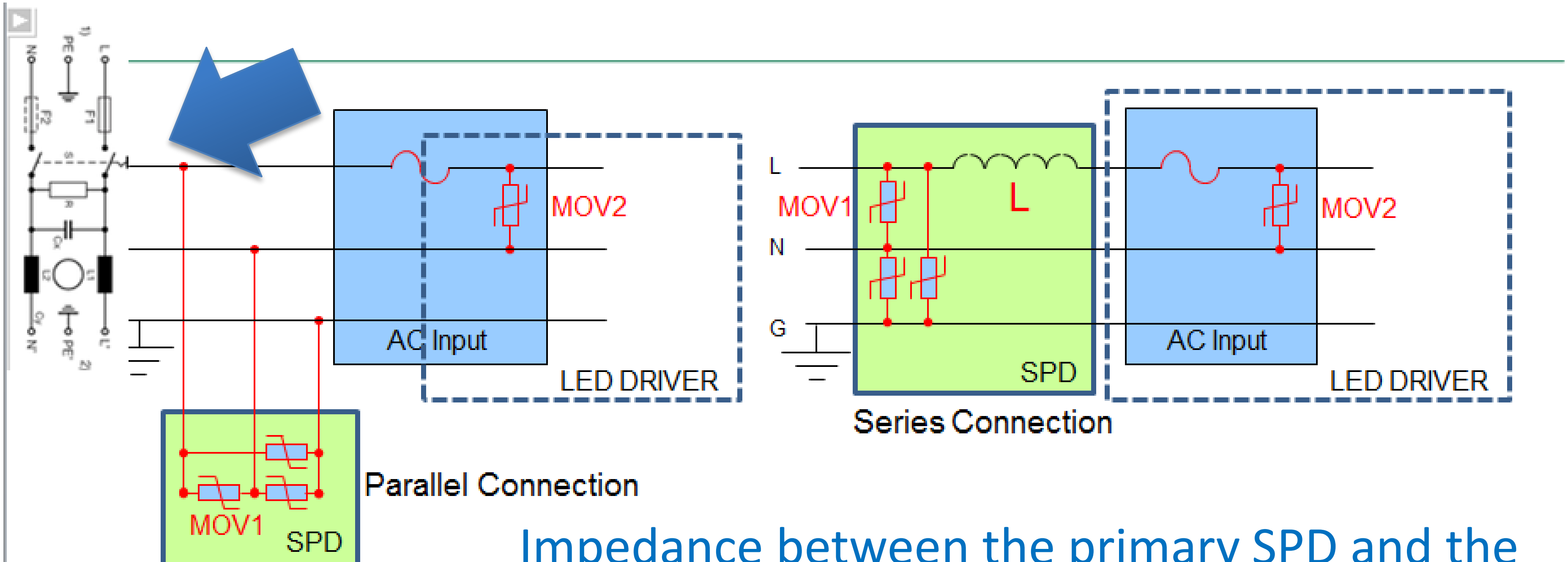
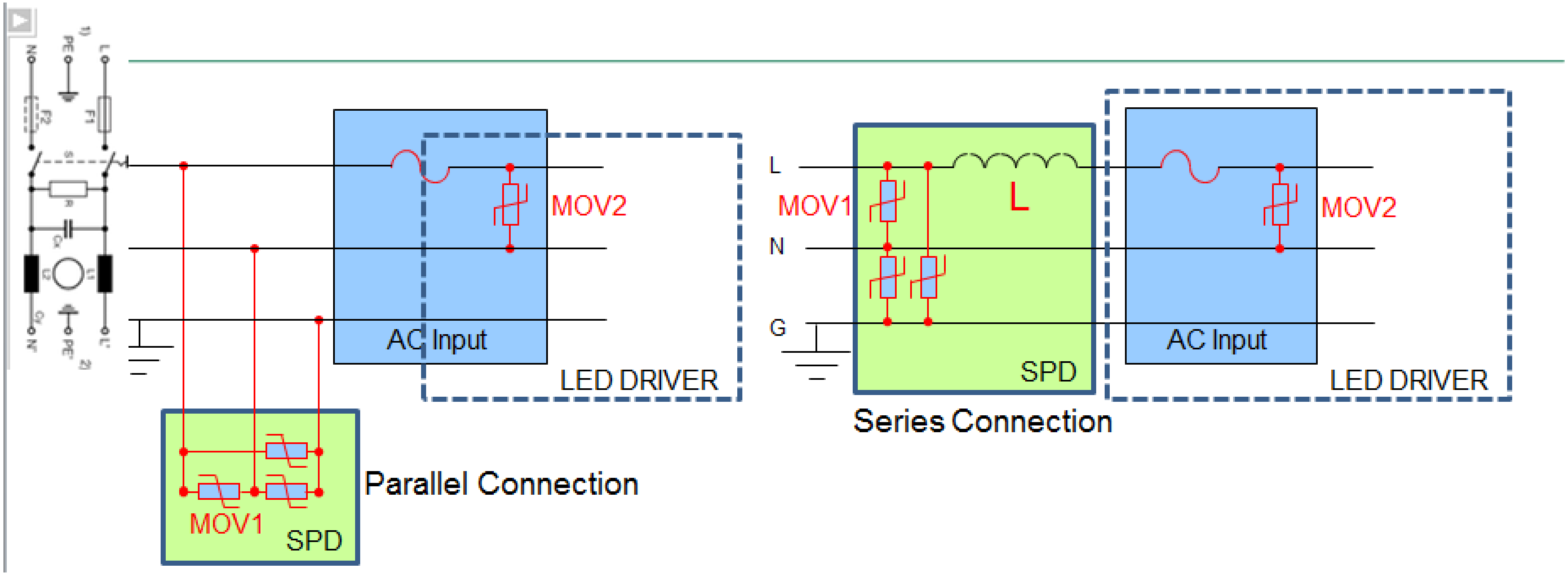
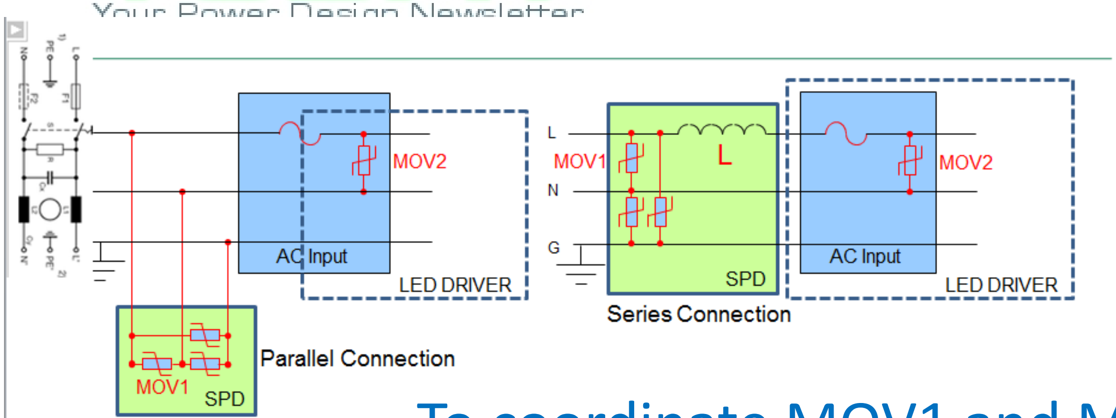
Use the power supply filter to your advantage: Coordinate the MOVs in SPD with those in the power supply.



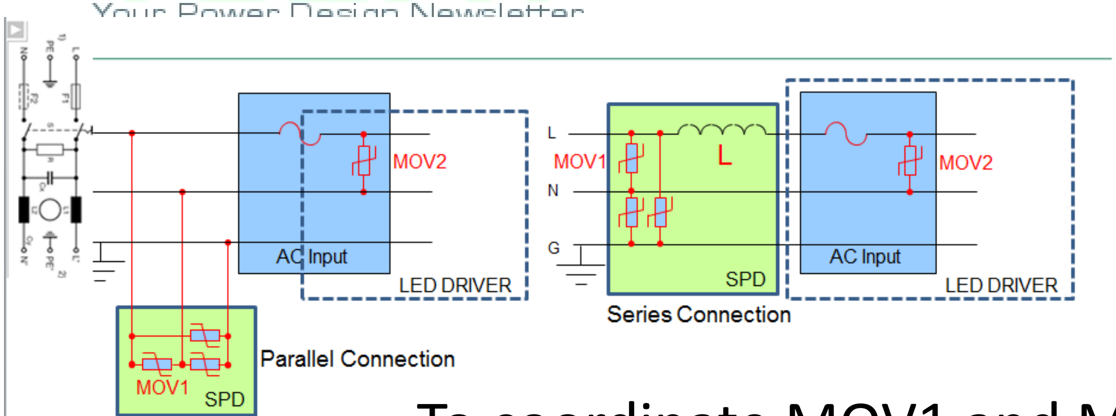
Impedance between the primary SPD and the driver will help in ensuring proper coordination. Use the EMI filter to perform this!



Engineers must account for enough line impedance to direct a majority of the surge current through the primary MOV (MOV1 above) and limit the surge current through the secondary MOV (MOV2 above) to a level within its surge rating.



To coordinate MOV1 and MOV2 so that most of surge current/energy flows through MOV1, do the following:



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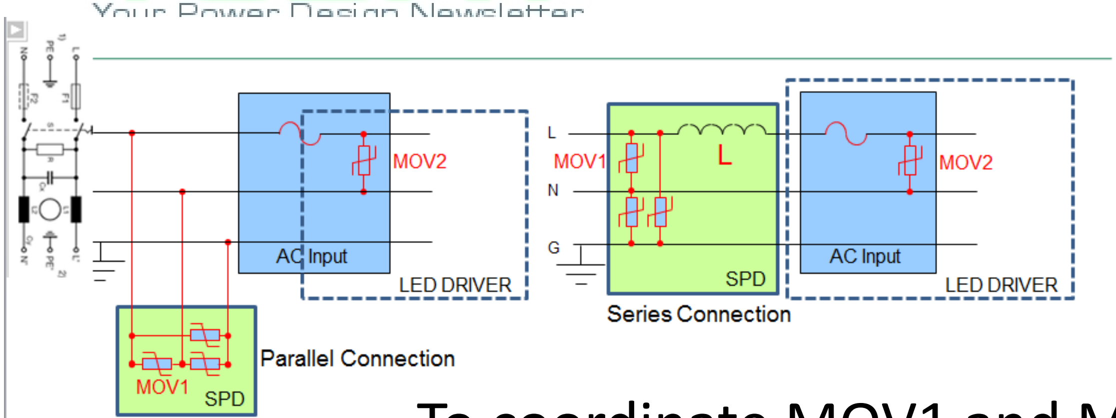

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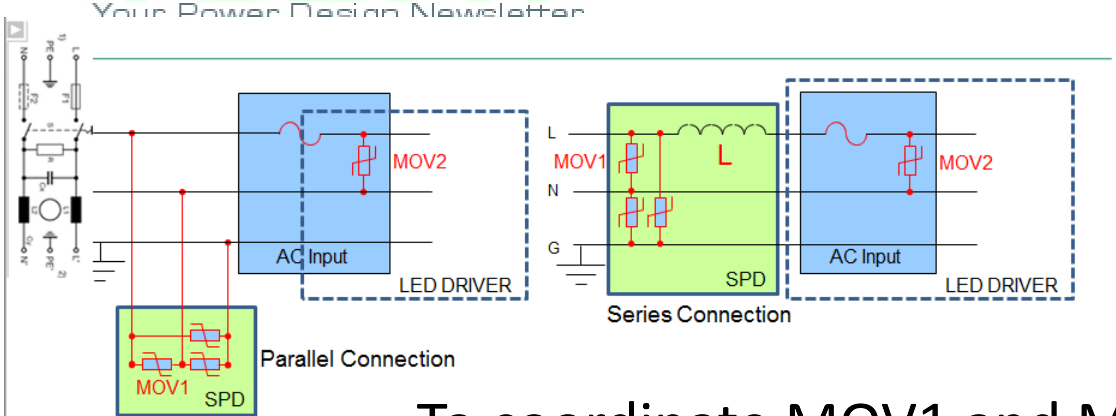
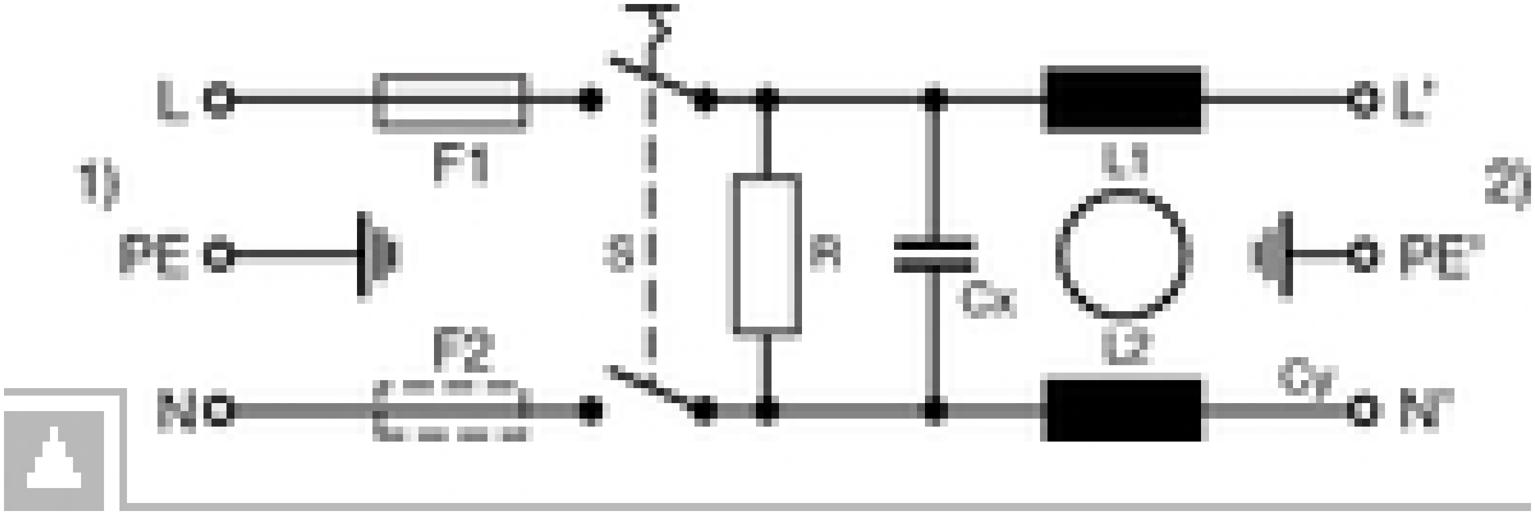
1. Select MOVs with V_M(MOV1) ≦ V_M(MOV2) where V_M = max. cont. operating voltage.
2. Select MOVs with V_C(MOV1) ≦ V_C(MOV2) where V_C = max. clamping voltage.



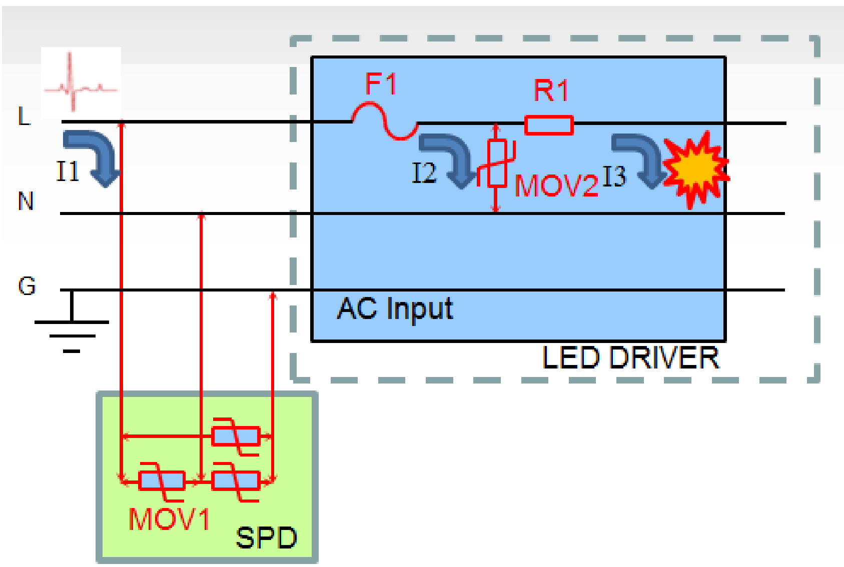
To coordinate MOV1 and MOV2 so that most of surge current/energy flows through MOV1, do the following:

1. Select MOVs with $V_M(MOV1) \leqq V_M(MOV2)$ where V_M = max. cont. operating voltage.
2. Select MOVs with $V_C(MOV1) \leqq V_C(MOV2)$ where V_C = max. clamping voltage.
3. Inductance L may be added in series connected SPD. Increasing L will result in better coordination as MOV1 will absorb higher surge energy. $VMOV1 = VMOV2 + L * di/dt$

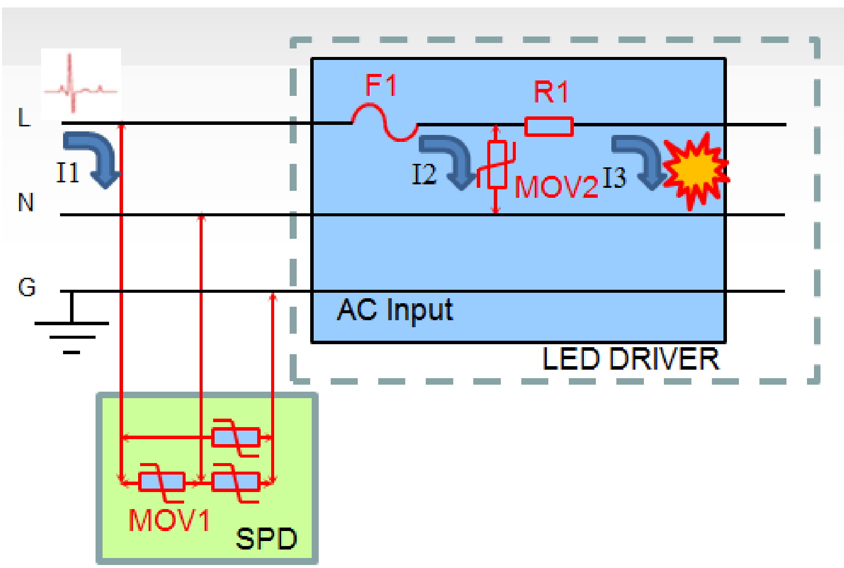
Note that the filter's series impedance with the SPD helps clamp transients.



Residual energy passes through the SPD.

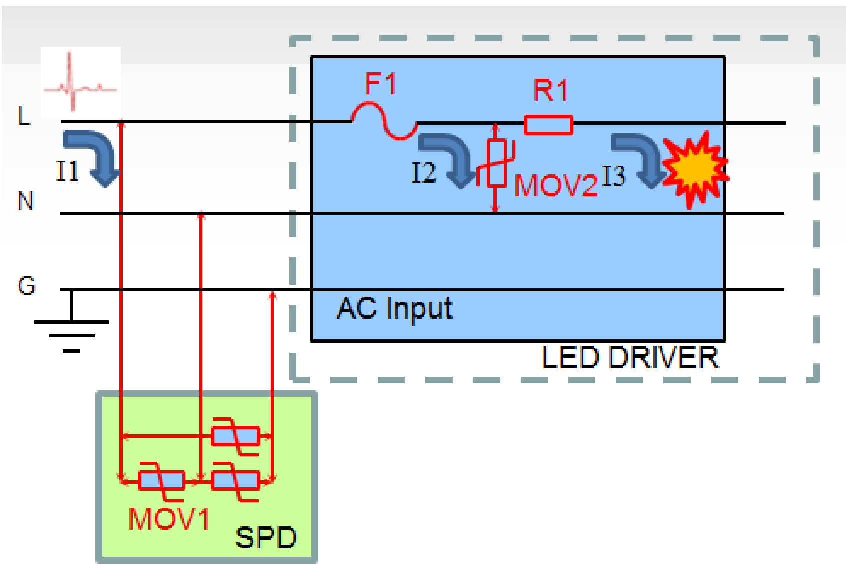


Residual energy passes through the SPD.



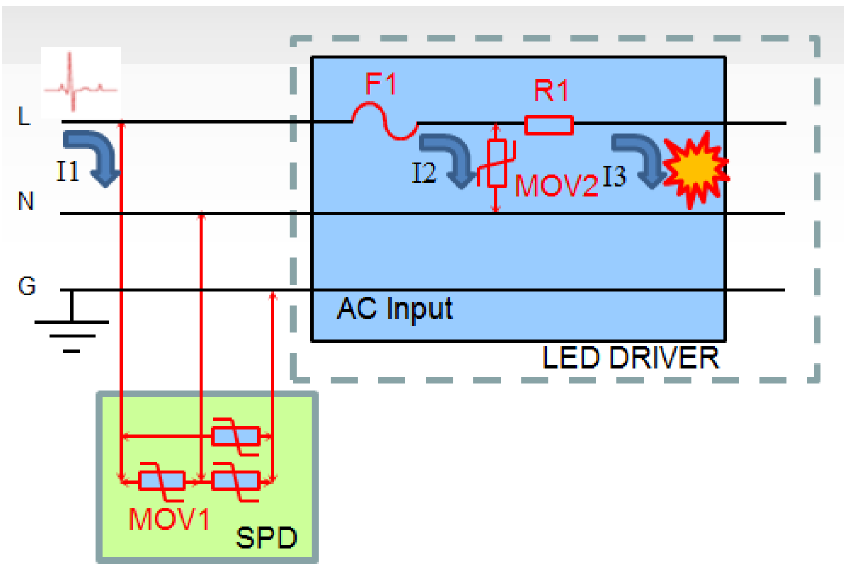
The surge protection module (SPD) absorbs most of the surge energy; however, there is still residual energy going into power supply and causing damage to the components inside.

Residual energy passes through the SPD.



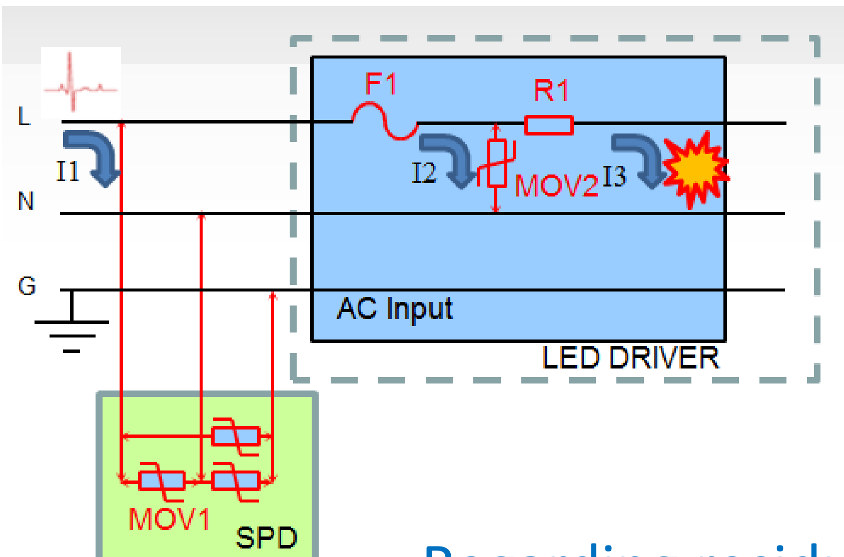
To minimize the damage, the power supply should coordinate with the surge protection module so that less energy enters the application.

Residual energy passes through the SPD.



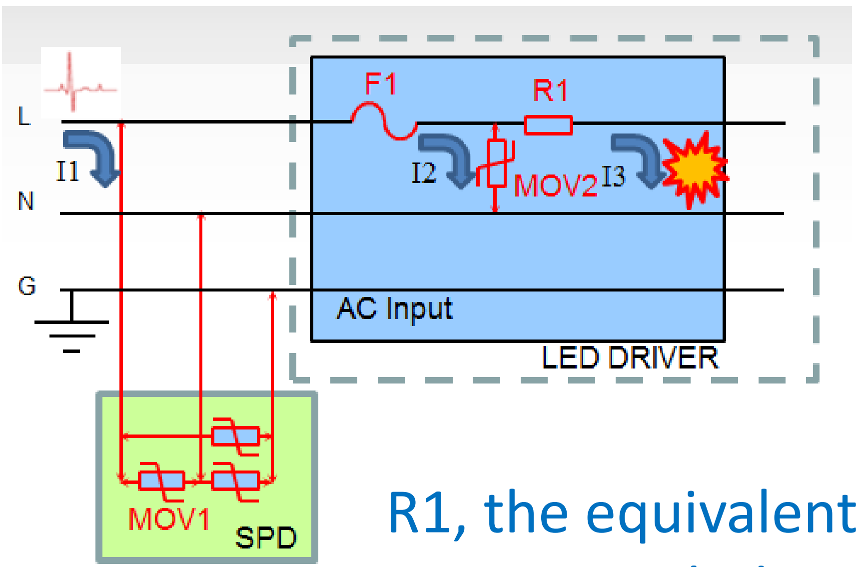
The residual voltage is determined by MOV1, so a varistor with fast-response-time and low clamping voltage is preferred.

Residual energy passes through the SPD.



Regarding residual current, it is suggested that MOV2 have a higher clamping voltage than MOV1 to maximize I1 and minimize I2 so that fuse F1 is not damaged by residual current.

Residual energy passes through the SPD.



R1, the equivalent resistance of the primary circuitry including NTC, EMI filter, rectifier, PFC, transformer, transistor, etc., could be adjusted higher if necessary to minimize I3 and component damage in the primary circuitry.

For more information, see the LSP10240 series product page.

About The Authors

Kevin Parmenter has over 20 years of experience in the electronics and semiconductor industries. Kevin is currently vice president of applications engineering in the U.S.A. for Excelsys Technologies. Previously, Kevin has served as director of Advanced Technical Marketing for Digital Power Products at Exar, and led global product applications engineering and new product definition for Freescale Semiconductors AMPD - Analog, Mixed Signal and Power Division based in Tempe, Arizona.

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About The Author

Prior to that, Kevin worked for Fairchild Semiconductor in the Americas as senior director of field applications engineering and held various technical and management positions with increasing responsibility at ON Semiconductor and in the Motorola Semiconductor Products Sector. Kevin also led an applications engineering team for the start-up Primarion where he worked on high-speed electro-optical communications and digital power supply semiconductors.

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Kevin serves on the board of directors of the PSMA (Power Sources Manufacturers Association) and was the general chair of APEC 2009 (the IEEE Applied Power Electronics Conference.) Kevin also has design engineering experience in medical and military electronics. He holds a BSEE and BS in Business Administration, is a member of the IEEE, and holds an Amateur Extra class FCC license (call sign KG5Q) as well as an FCC Commercial Radiotelephone License.

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Kevin is a special contributor to How2Power.com who frequently writes technical articles on power supply topics and reports on numerous conferences and tradeshows.

See Kevin's other articles in How2Power Today.

About The Authors

Todd Phillips is a strategic marketing manager for the electronics business unit; focusing on the LED, Datacenter and Mobile markets. He joined Littelfuse as a sales engineer in 2006 for the industrial POWR-GARD business unit. Then, Todd joined the electronics business unit in 2011 as a regional sales manager.

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Todd's current responsibilities include development of marketing collateral material, management of marketing activities for new product launches and performing market studies and feasibility analyses for new product ideas. He received his BSEE from Milwaukee School of Engineering. Todd can be reached at tphillips@littelfuse.com.