Smart Grid Surge Protection – Matt Wakeham, WG Chair
IEEE PES/SPDC WG 3.6.13

The following issues will be addressed in this presentation:

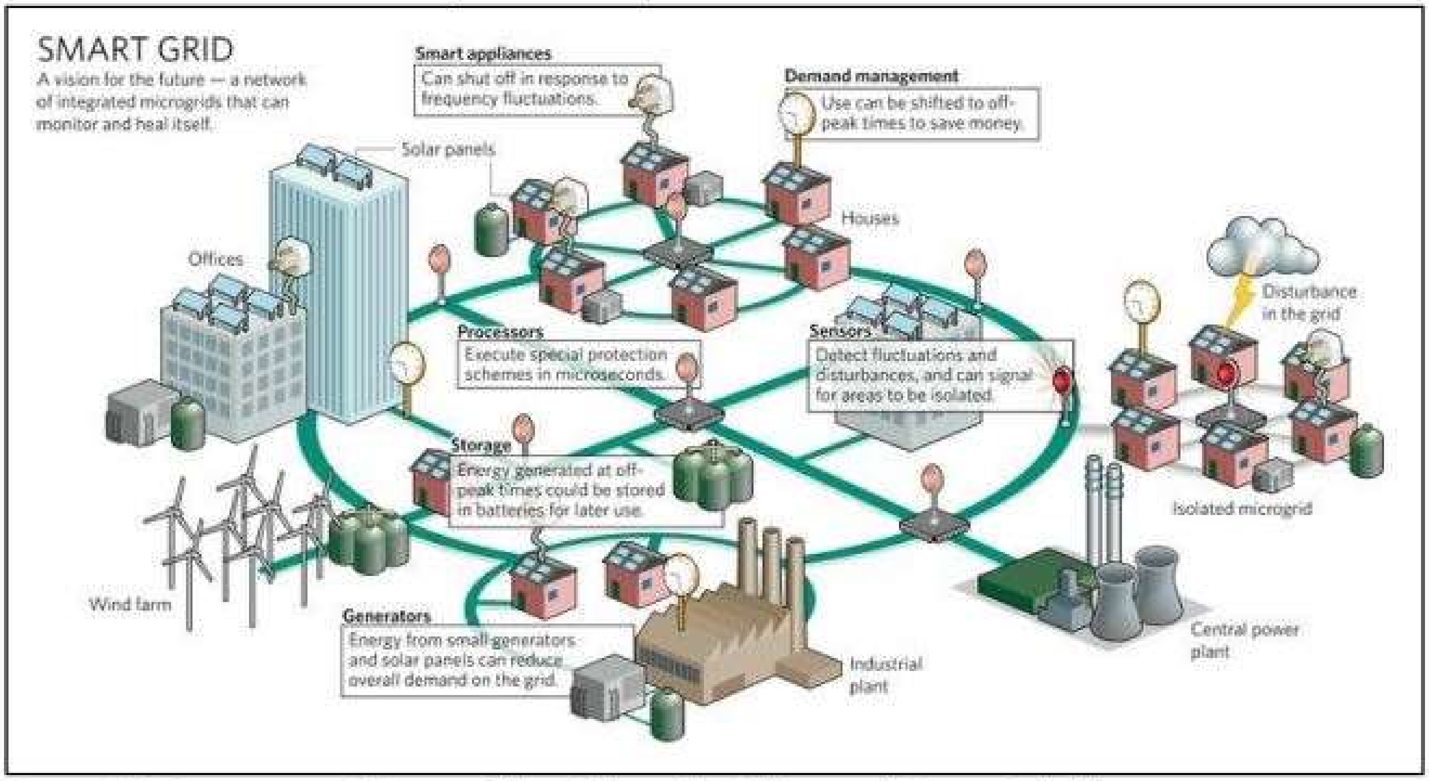
The Smart Grid is an all encompassing term in today's power distribution industry. The threat of equipment disruption and damage from transient surges is very real and can have dire consequences on the delivery of electricity to residential, commercial and industrial users.

This session will discuss the origins of how surges occur and the methods to mitigate these transients from sensitive electronic equipment.

The discussion will overview IEEE standards for surge protection, as well as applicable safety standards. IEEE PC62.220 is presently under development, the working group draft standard for smart grid surge protection will be discussed which includes the scope of power and communications surge protection.

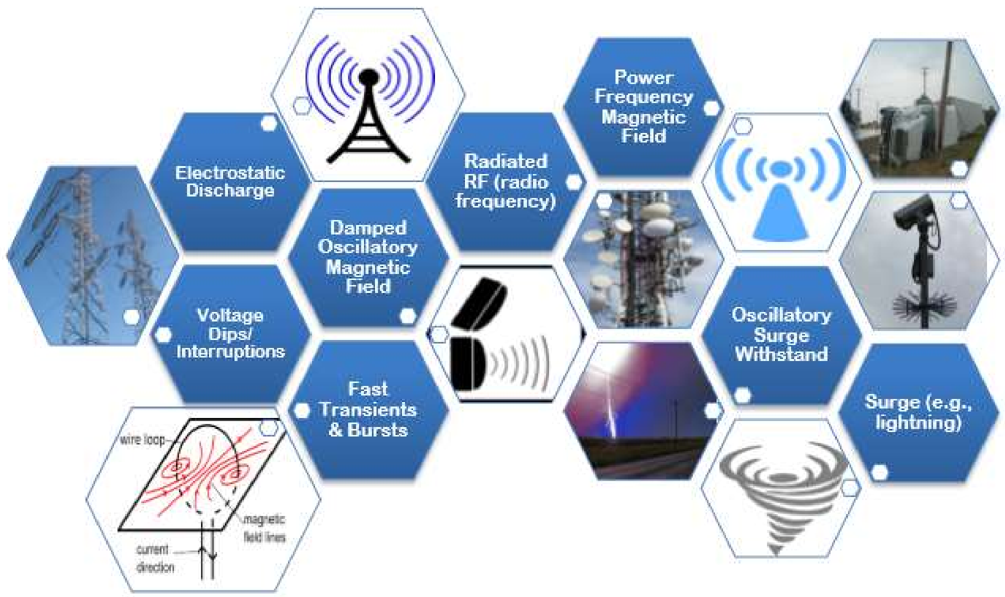
Agenda

- Origin of Surges
- Surge Protection Basics
- SPD Standards Overview
- IEEE SPD Standards
- Safety Standards
- Q & A



Source: U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability

Evaluation of the Electromagnetic Phenomena Issues on Smart Grid Reliability



Smart Grid Electromagnetic Environment

Smart Electric Power Alliance

Where surges originate

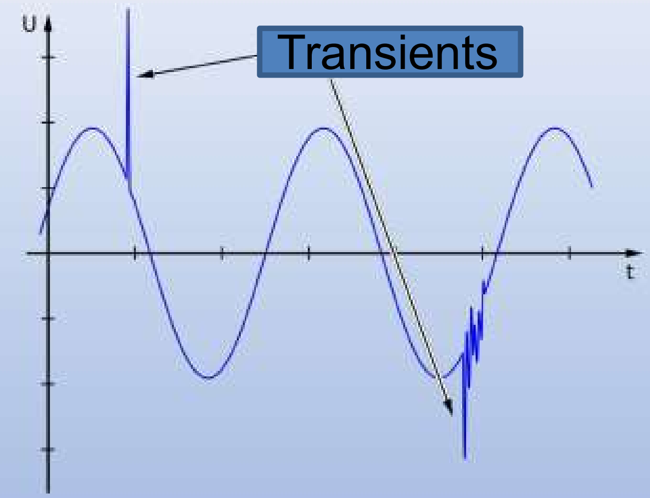
80% - Internal Disturbances

- Load switching
- Variable frequency drives
- Lighting and air handlers

20% - External Disturbances

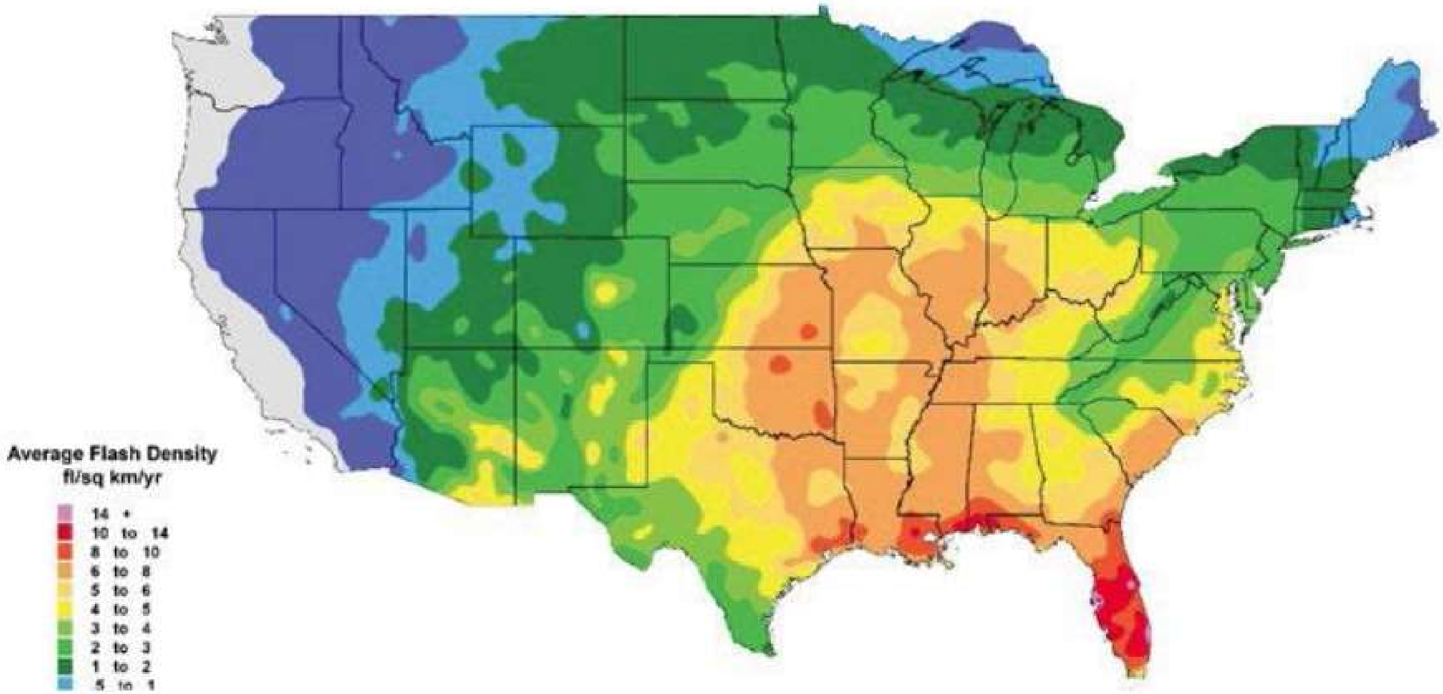
- Utility load switching
  - Smart grid
- Lightning strikes
  - Cloud to cloud
  - Cloud to ground
  - Cloud to man-made object

- Surges are Caused By:
  - Lightning Strikes
  - Switching of Inductive Loads
  - Sudden Changes in Load
  - Power System Faults
- Characterized By Short Rise Time, Long Decay Time
- Typically Results in Equipment Damage

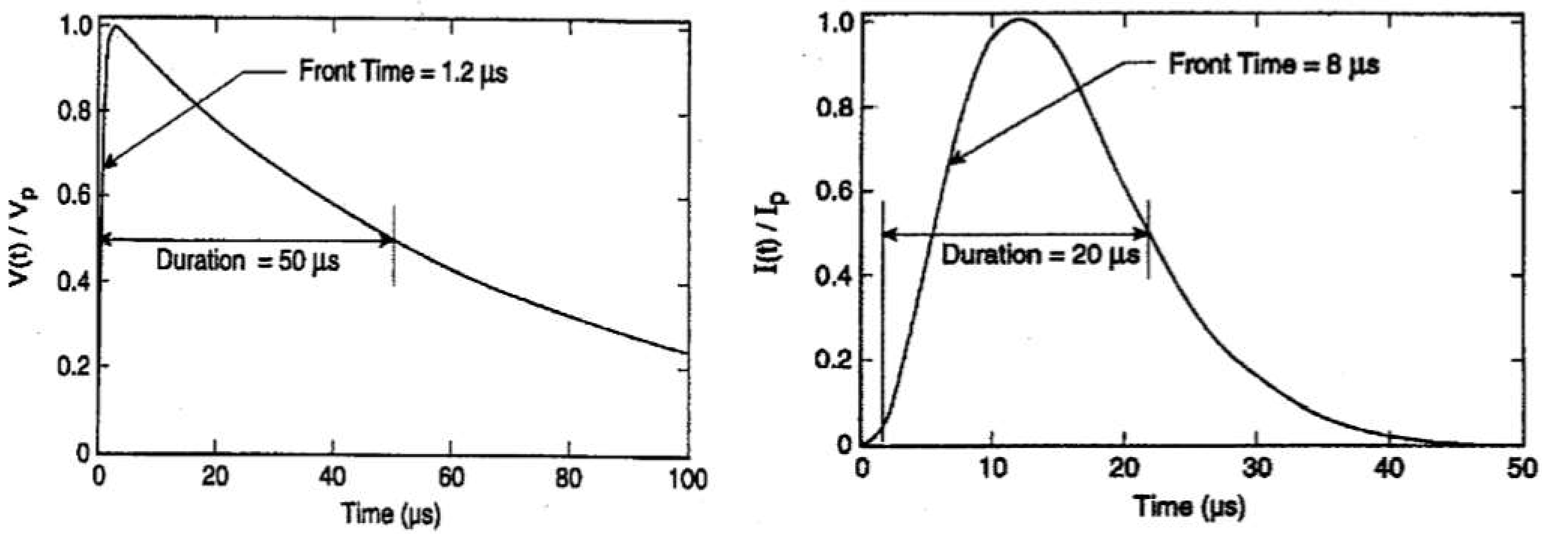


Vaisala's National Lightning Detection Network® (NLDN®)

Cloud-to-Ground Lightning Incidence in the Continental U.S. (1997 - 2012)



Lightning Induced Surges – Impulse Transients

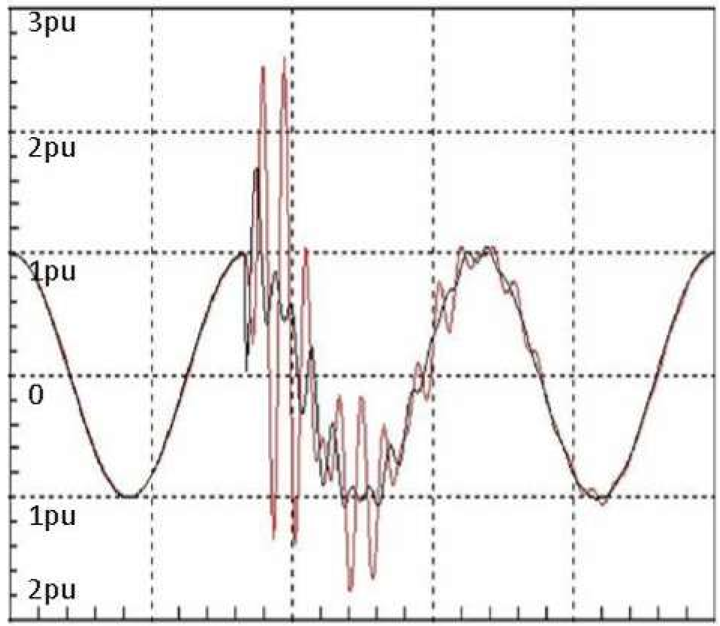


Represented by a combination of voltage and current waveforms (combination wave)

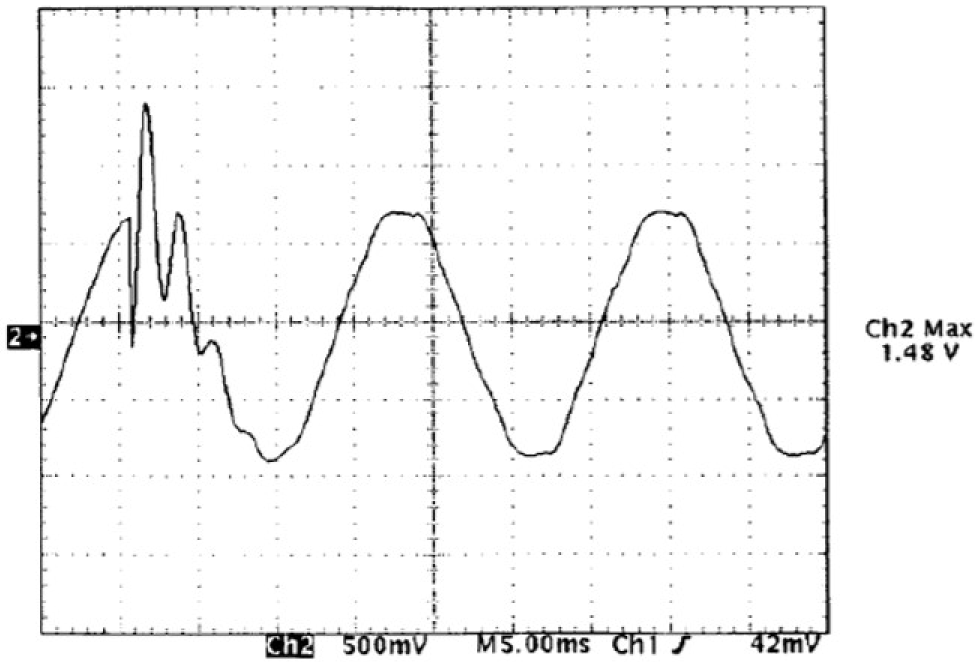
Switching Surges

- Frequency 350 Hz to 1000 kHz
- Often represented by 100 kHz
- Amplitudes typically range from a 2-3 times the operating voltage to 6,000 volts or higher
- Occur regularly and frequently – in some cases multiple times per cycle

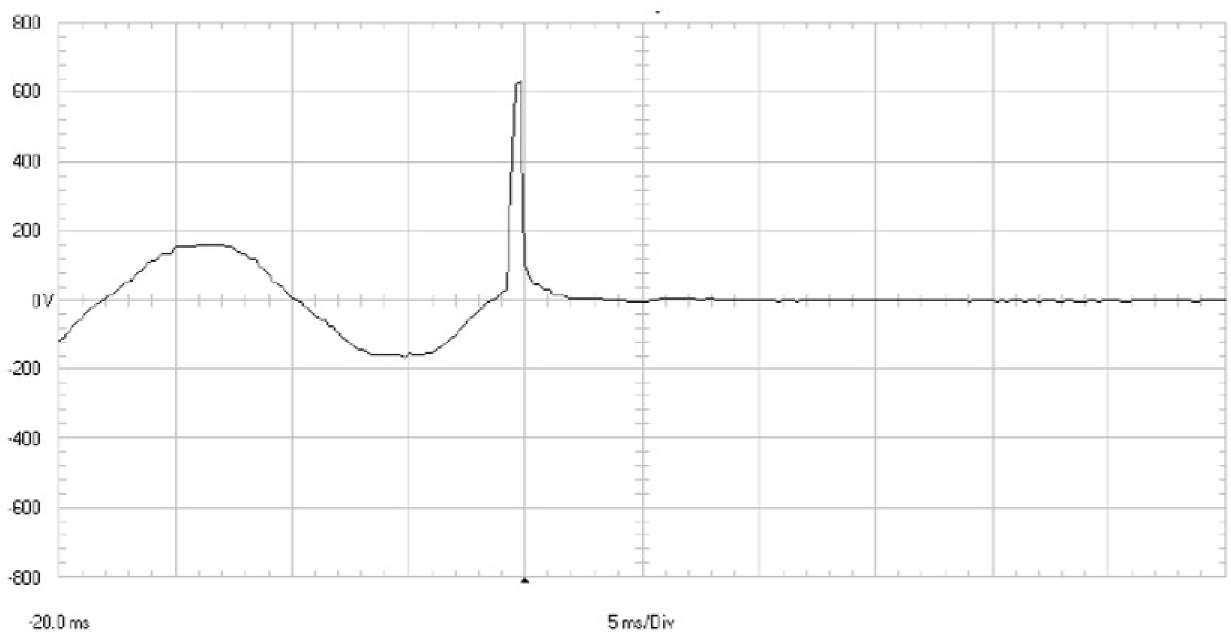
Surge Origins – Contactor, Relay, Breaker Operation



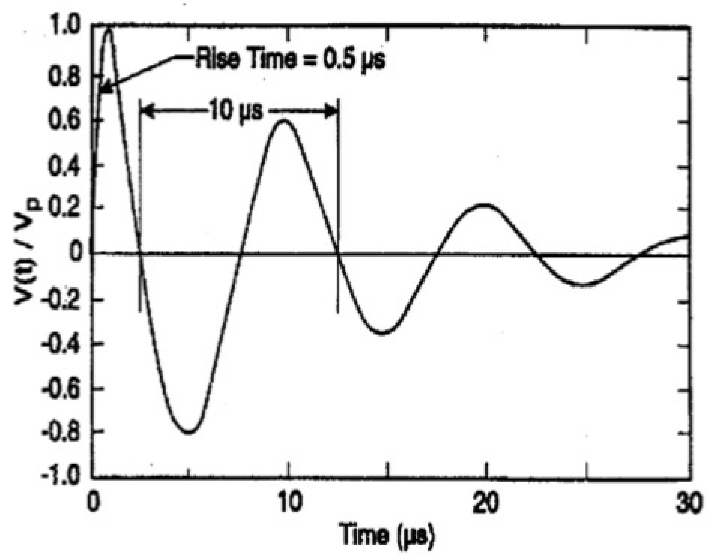
Surge Origins – Capacitor Bank Switching



Surge Origins – Discharge of Inductive Loads



Switching Surges – Ringing/Oscillatory Transients



Represented by a voltage waveform

EFT Burst

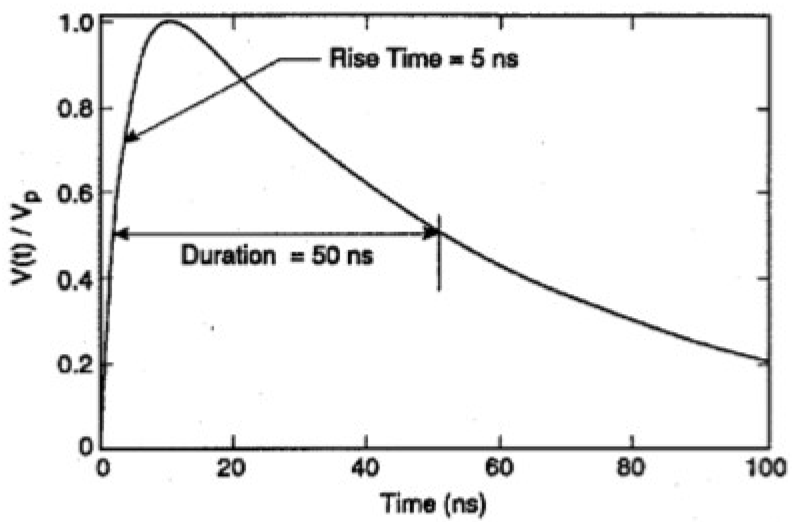
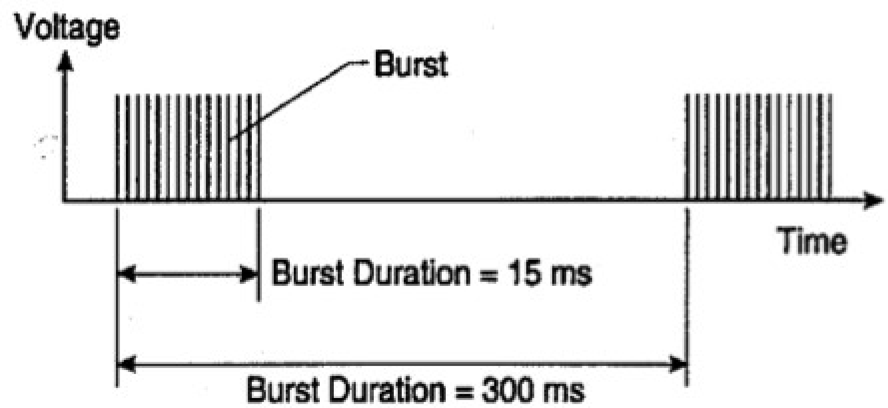


Figure 7—Waveform of the EFT pulse



Test severity	Peak voltage (Open circuit)
Low	1 kV
Medium	2 kV
High	3 kV
X	By agreement

re: IEC 61000-4-4; EN 50121-4, IEEE C62.41.2; IEEE C62.45

Coupling of Electrical Surges

- Occurs when energy from lightning or switching surges is transferred (coupled) to another system
- Impacts control, communication, data and other systems
- Inductive and capacitive coupling

Coupling of Electrical Surges

- Through multi-service/multi-port loads or even some SPDs
- Often damaging to cabling, connectors or interface of low voltage systems
- From power systems to low voltage systems
- From low voltage systems to power systems

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Coupling of Electrical Surges

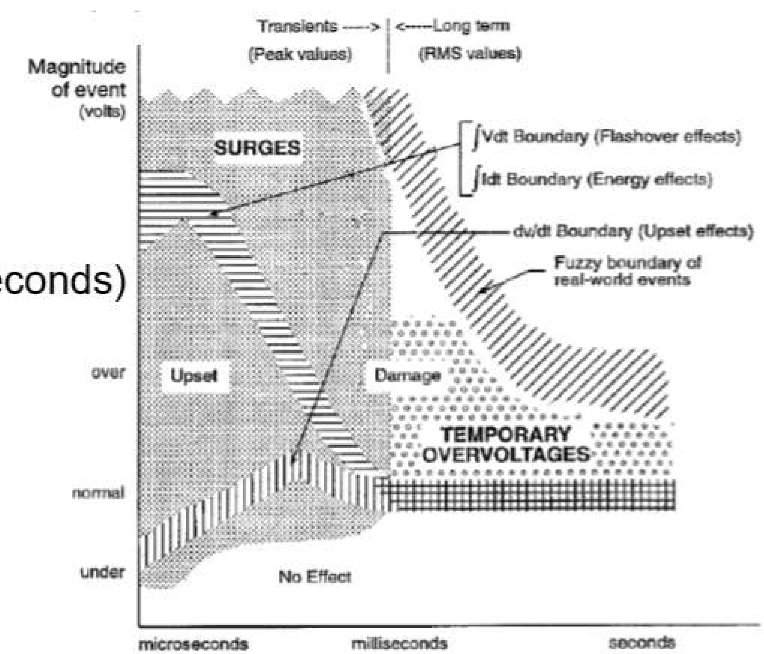
- Due to coupling, failures of components due to surges can be misinterpreted
- A failed component on the communications side does not necessarily mean the surge originated from that point
- The failed component may have simply provided a low impedance path for the surge when coupled to that system

Magnitude vs. Duration
(volts vs. kilovolts/kiloamps)
(microseconds vs. milliseconds vs. seconds)

Damage vs. Upset vs. No Effect

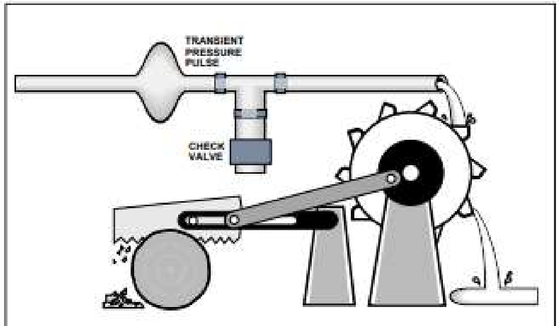
Surges vs. Temporary Overvoltages

(From C62.41.2)

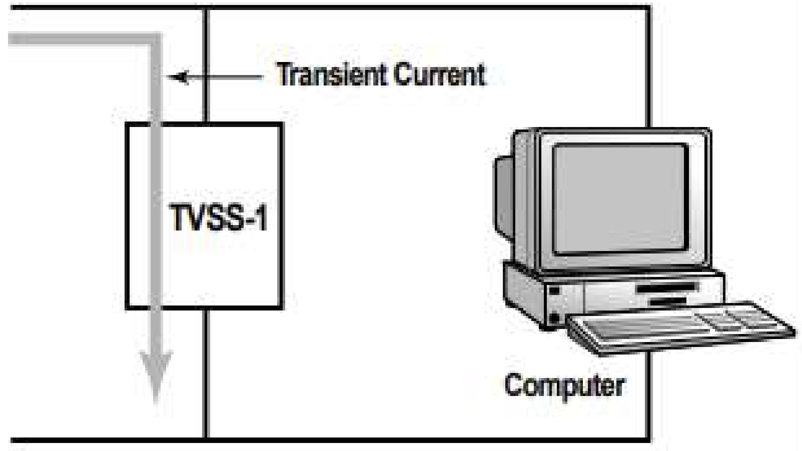


Surge 101

The SPD creates a path of least resistance when a transient surge is present and diverts the surge away from sensitive electronic equipment ….



"The Water Wheel"



SPD Shunt Path For Transients

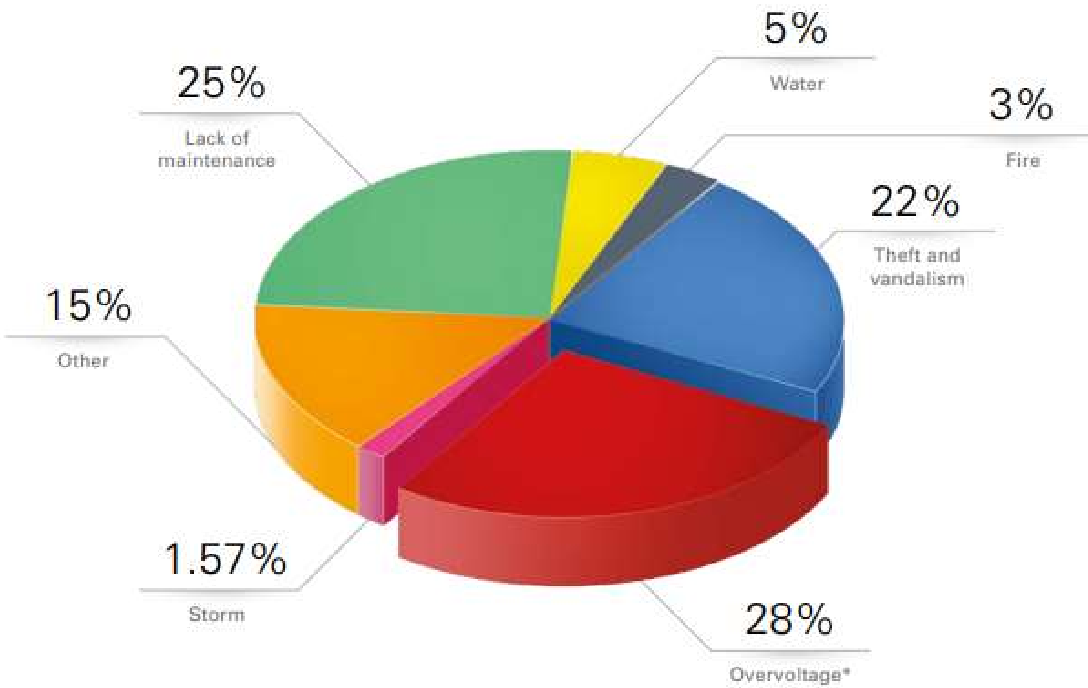
Surge Basics

- Surge – A surge is a transient voltage or current with a duration of a few microseconds.
- Surge arrester – A protective device for limiting surge voltages by discharging or bypassing surge current, and it also prevents continued flow of follow current while remaining capable of repeating these functions. Ref. IEEE 100.
- Surge-protective device (SPD) – Is the generic term used to cover both Surge Arresters (including secondary surge arresters) and Transient Voltage Surge Suppressors (TVSS) devices. An SPD is a non-linear protective device for limiting surge voltages on equipment by discharging, bypassing, or diverting surge current; it prevents continued flow of follow current and is capable of repeating these functions as specified.
- MOV = Metal-Oxide Varistor; under normal operating conditions the device is a very, very high impedance (essentially an Open Circuit) connected in parallel across 2 conductors.
- TPMOV = Thermally-Protected MOV is an MOV with integral fusing which will anticipate a catastrophic failure due to sustained over-voltage (ie: TOV or loss of neutral) or thermal runaway due to low-impedance degradation of the component.

The Surge Threat

A study by a major insurance company illustrates the problem.

- Over 7700 items of industrial electronics were evaluated.
- The most significant cause of premature failure was surge overvoltage.
- In fact surge damage contributed to 28% of failures.



*Lightning discharge and switching operations

Consequences of Surges

1. Disruptions in computer signals and processors
2. Degrade component junctions causing "random" delayed failure
3. Damage to electrical components

The 3 D's ….

There are three main types of effects that transients have on your electronic equipment:

Disruptive effects:
These effects are usually encountered when a transient enters the equipment by inductive coupling. The energy source for this inductive coupling can act on the data output lines that integrate an electronic installation. The electronic components then try to process the transient as a valid logic command. The result is system lock-up, malfunction, erroneous output, lost or corrupted files, and a variety of other undesirable effects.

Dissipative effects:
These effects are associated with repeated stresses to IC components. The materials used to fabricate IC's can only withstand a certain number of repeated energy level surges. After long-term degradation, the device fails to operate properly. The failure is due to the cumulative build-up of transient-created stresses which result in arc-overs, shorts, open circuits, or semiconductor junction failures within the IC.

Destructive effects:

These effects include all conditions where transients with high levels of energy cause equipment to fail instantaneously. Very often, there is actual physical damage apparent, like burnt PC boards or melting of electronic components.

Destructive effects can occur when noise pulses are too fast for power supply regulator circuits to respond by limiting transient voltage to acceptable levels. Also, transients on the power line may subject electronic components to overwhelming voltage levels. For example, components like rectifier diodes can fail immediately when their Peak Inverse Voltage (PIV) rating is exceeded. PIV diode ratings in a well-designed computer can be in the 1 kV – 1.5 kV range. Transients on AC lines can easily exceed 1.5 kV.

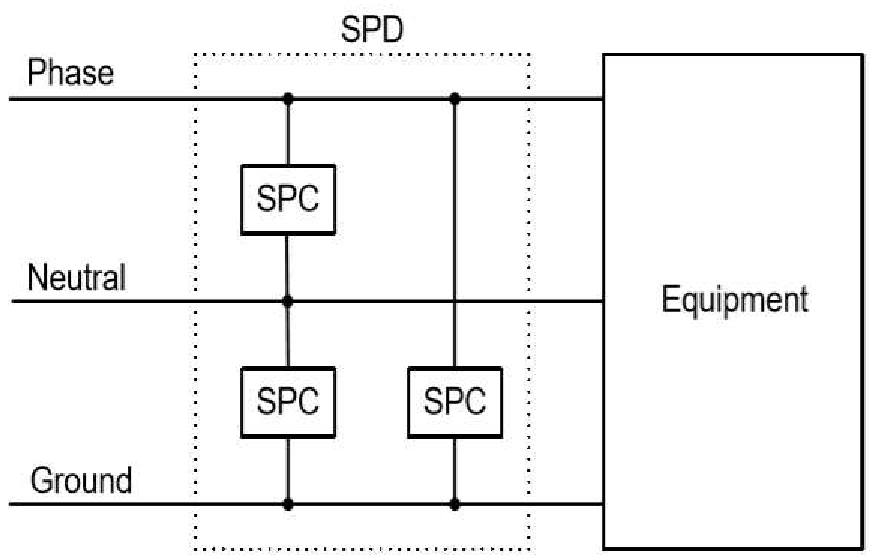
What are the Symptoms of Surge Damage?

There are several possible symptoms to look for to determine whether surges are affecting your office or business.

•Computer lock-ups or latch-ups
•Unexplainable data corruption
•Equipment shutdown
•Flickering lights
•Premature failure of electronic ballasts or printed circuit boards

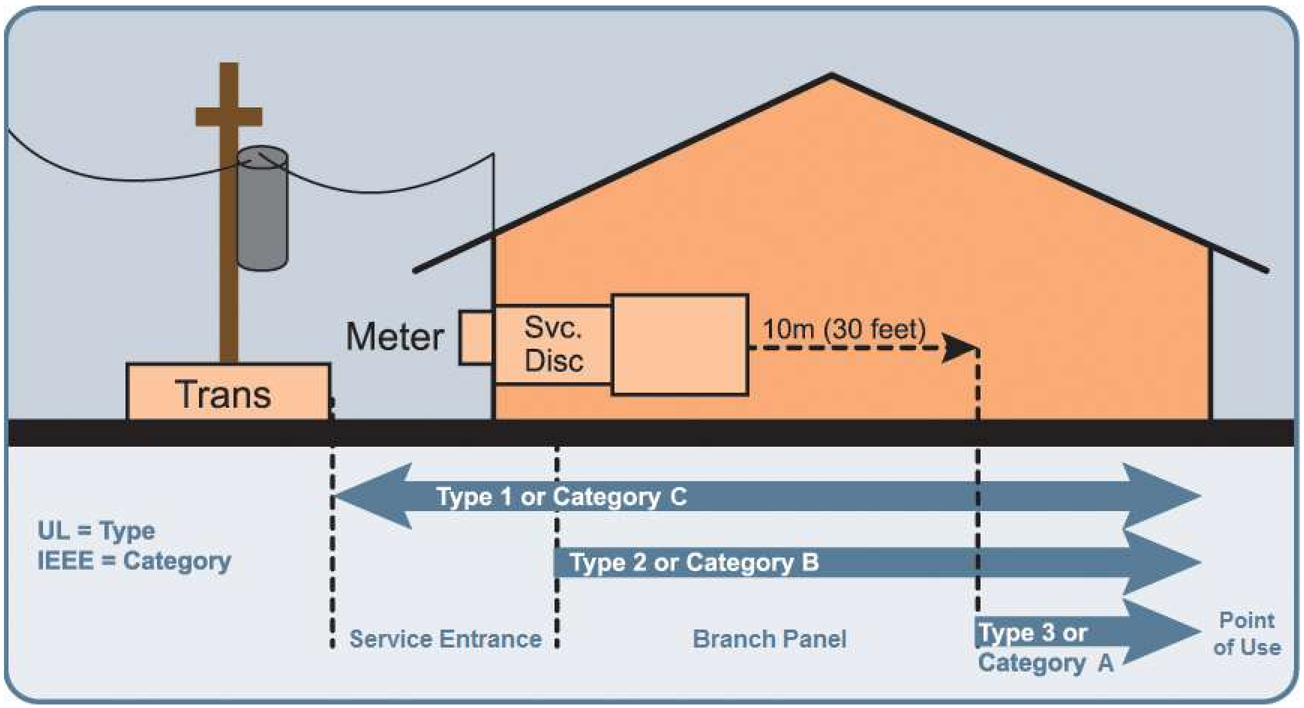
There is no such thing as a transient free facility. Many people do not realize that their company's productivity and profitability is being significantly impacted by the effects of transients. The problems described above result in billions of dollars of lost profits to U.S. businesses every year.

Typical SPD configuration for use in power systems



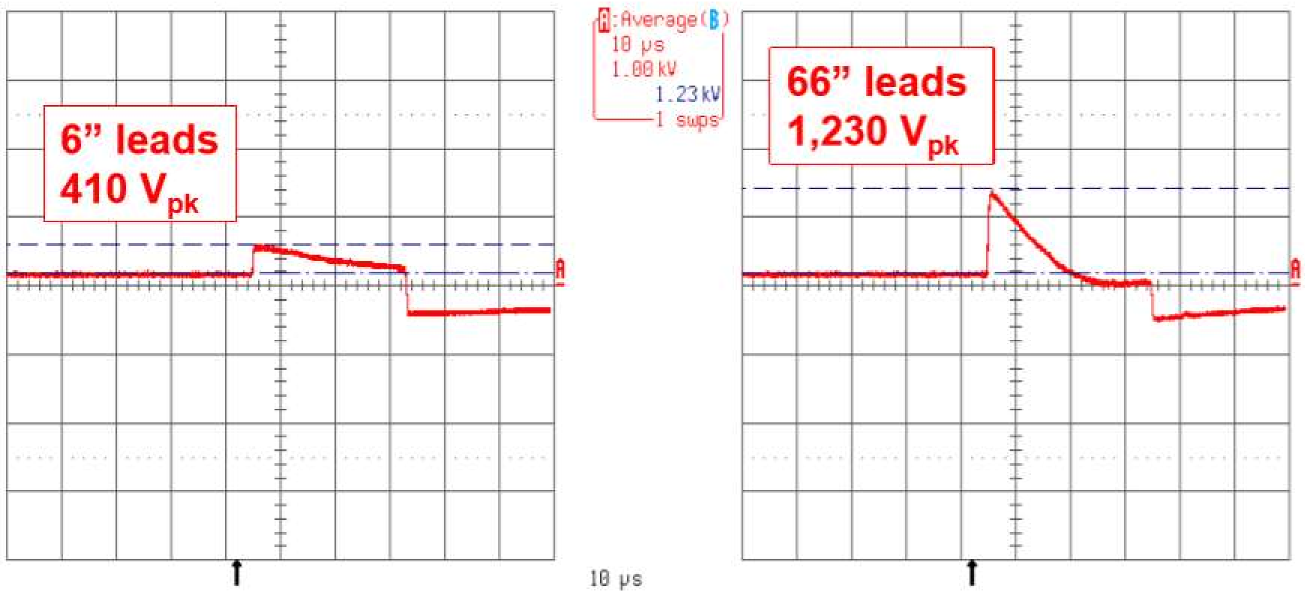
The Essential Advantages and Disadvantages of the MOV and Other Commonly Used SPD Components.

Metal Oxide Varistor (MOV):	Readily available, higher energy capability, excellent reliability and consistent performance. Non-linear clamping curve, rapid fatigue at higher amperage levels, leaky.
Silicon Junction Diode/ Diode (SAD):	Readily available, flatter clamping curve, excellent Avalanche reliability and consistent performance. Very low energy capability, some capacitive problems, expensive.
Gas Tubes:	Higher energy capability than either diodes or MOV's, non-capacitive or leaky in data line applications. Unpredictable and unstable repetitive behavior, tendency to "crow-bar" to ground, higher cost than MOV's.
LCR Filters:	Excellent noise attenuation, clamping harmonic elimination and predictable performance at given frequency. Expensive, frequency dependent, low energy capability, leaky and low amperage capable. (The LCR filter is not a suppressor in and of itself.)
TVSS Hybrid:	If properly designed, the Hybrid incorporates all of the major advantages of many of the available components while collectively overcoming their individual faults. The hybrid is inherently more expensive than the single component TVSS.



Trans
Meter
Svc.
Disc
10m (30 feet)
UL = Type
IEEE = Category
Type 1 or Category C
Type 2 or Category B
Type 3 or
Category A
Point
of Use
Service Entrance
Branch Panel

- SPD coordination considerations
  - Surge waveform and duration
  - **SPD conductor (lead) length**
  - Distance between SPDs, types, location categories and IEC test classes
  - Distance between the origin of a surge and the end-use equipment
  - Surge-protective device voltage coordination
  - Surge current capacity and Nominal Discharge Current (I_n) Ratings of the SPDs
  - Aging of SPDs
  - Coordination of modes of protection
- **Installation is critical for SPDs!!**


6” leads
410 V_{pk}
A:Average(B)
10 μs
1.00 kV
1.23 kV
1 swps
66” leads
1,230 V_{pk}
10 μs

SPD Standards Overview

Breadth of Industry Standards

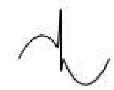
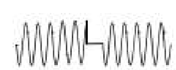
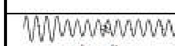
- Telcordia GR-1089 (Communications) *
- AREMA – Manual Section 11 (Wayside Signal)
- MILSTD – 461, 646C, 1757A, 188-125-1 (HEMP)
- FAA-STD 019e – Lightning & Surge Protection
- IEC 61000-4-5
- IEEE C62 series
- UL 1449 / NEC

* – Telcordia GR-1089 core for America with 2/10 μs and 10/1000 μs surges
– ITU-T K series for the rest of the world with 10/700 μs surges

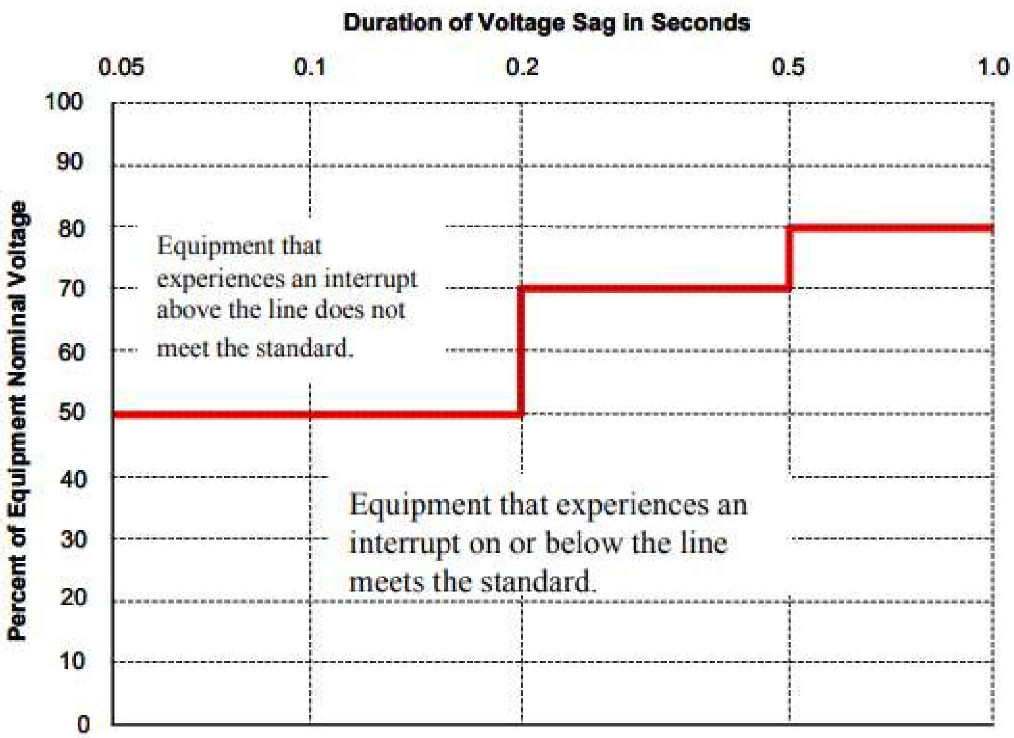
IEEE Standard 1159-1995 Categories and Typical Characteristics of Power System Electromagnetic Phenomena

Categories	*Typical Spectral Content*	*Typical Duration*	*Typical Voltage Magnitude*
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond	*5 ns rise*	*<50 ns*	
1.1.2 Microsecond	*1 s rise*	*50 ns–1 ms*	
1.1.3 Millisecond	*0.1 ms rise*	*>1 ms*	
1.2 Oscillatory			
1.2.1 Low frequency	*<5 kHz*	*0.3–50 ms*	*0–4 pu*
1.2.2 Medium frequency	*5–500 kHz*	*20 s*	*0–8 pu*
1.2.3 High frequency	*0.5–5 MHz*	*5 s*	*0–4 pu*
2.0 Short duration variations			
2.1 Instantaneous			
2.1.1 Sag		*0.5–30 cycles*	*0.1–0.9 pu*
2.1.2 Swell		*0.5–30 cycles*	*1.1–1.8 pu*
2.2 Momentary			
2.2.1 Interruption		*0.5 cycles–3 s*	*<0.1 pu*
2.2.2 Sag		*30 cycles–3 s*	*0.1–0.9 pu*
2.2.3 Swell		*30 cycles–3 s*	*1.1–1.4 pu*
2.3 Temporary			
2.3.1 Interruption		*3 s–1 min*	*<0.1 pu*
2.3.2 Sag		*3 s–1 min*	*0.1–0.9 pu*
2.3.3 Swell		*3 s–1 min*	*1.1–1.2 pu*
3.0 Long duration variations			
3.1 Interruptions, sustained		*>1 min*	*0.0 pu*
3.2 Undervoltages		*>1 min*	*0.8–0.9 pu*
3.3 Overvoltages		*>1 min*	*1.1–1.2 pu*
4.0 Voltage imbalance		*steady state*	*0.5–2%*
5.0 Waveform distortion			
5.1 DC offset		*steady state*	*0–0.1%*
5.2 Harmonics	*0–100th H*	*steady state*	*0–20%*
5.3 Interharmonics	*0–6 kHz*	*steady state*	*0–2%*
5.4 Notching		*steady state*	
5.5 Noise	*broad-band*	*steady state*	*0–1%*
6.0 Voltage fluctuations	*<25 Hz*	*Intermittent*	*0.1–7%*
7.0 Power frequency variations		*< 10 s*	

Waveform Summary of Power Quality Variation Categories

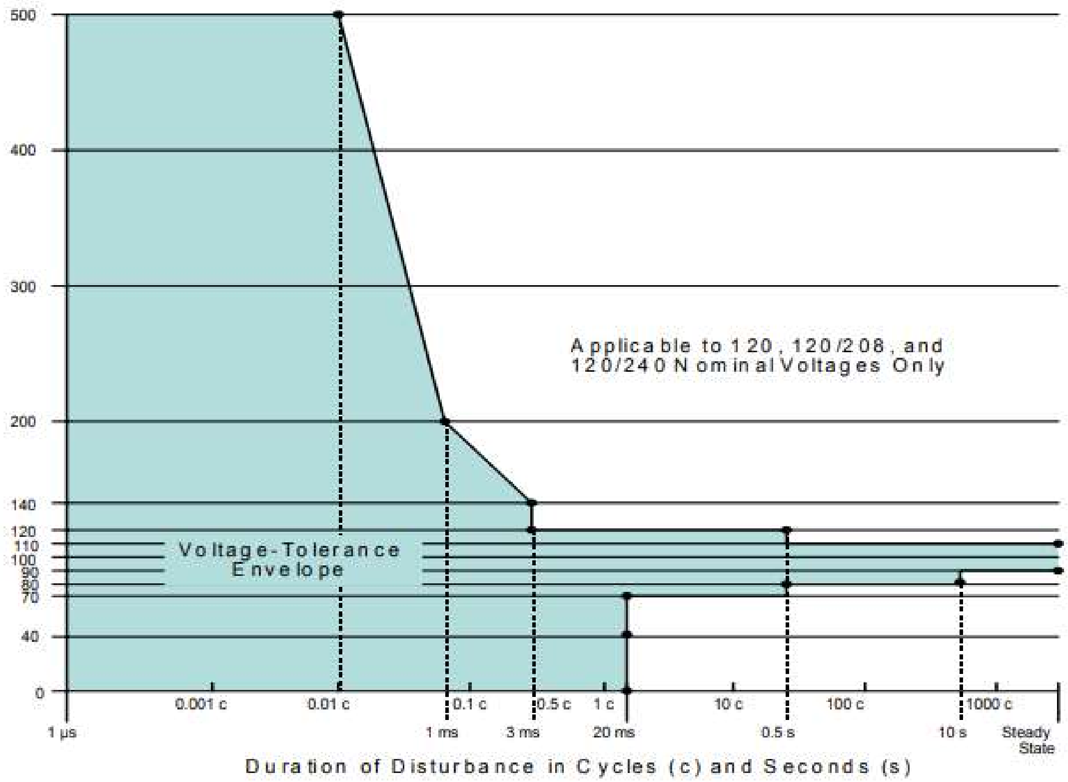
Example Waveshape or RMS variation	Power Quality Variation Category	Method of Characterizing	Typical Causes
	Impulsive Transients (transient disturbance)	Peak Magnitude, Rise Time, Duration	Lightning, Electro-Static Discharge, Load Switching, Capacitor Switching
	Oscillatory Transients (transient disturbance)	Waveforms, Peak Magnitude Frequency Components	Line/Cable Switching, Capacitor Switching, Load Switching
 sag  swell	Sags/Swells (rms disturbance)	RMS vs. Time, Magnitude, Duration	Remote System Faults
	Interruptions (rms disturbance)	Duration	System Protection (Breakers, Fuses), Maintenance
 undervoltage  overvoltage	Undervoltages/ Overvoltages (steady state variation)	RMS vs. Time, Statistics	Motor Starting, Load Variations, Load Dropping
	Harmonic Distortion (steady state variation)	Harmonic Spectrum, Total Harm. Distortion, Statistics	Nonlinear Loads, System Resonance
	Voltage Flicker (steady state variation)	Variation Magnitude, Frequency of Occurrence, Modulation Frequency	Intermittent Loads, Motor Starting, Arc Furnaces

SEMI F47 Curve



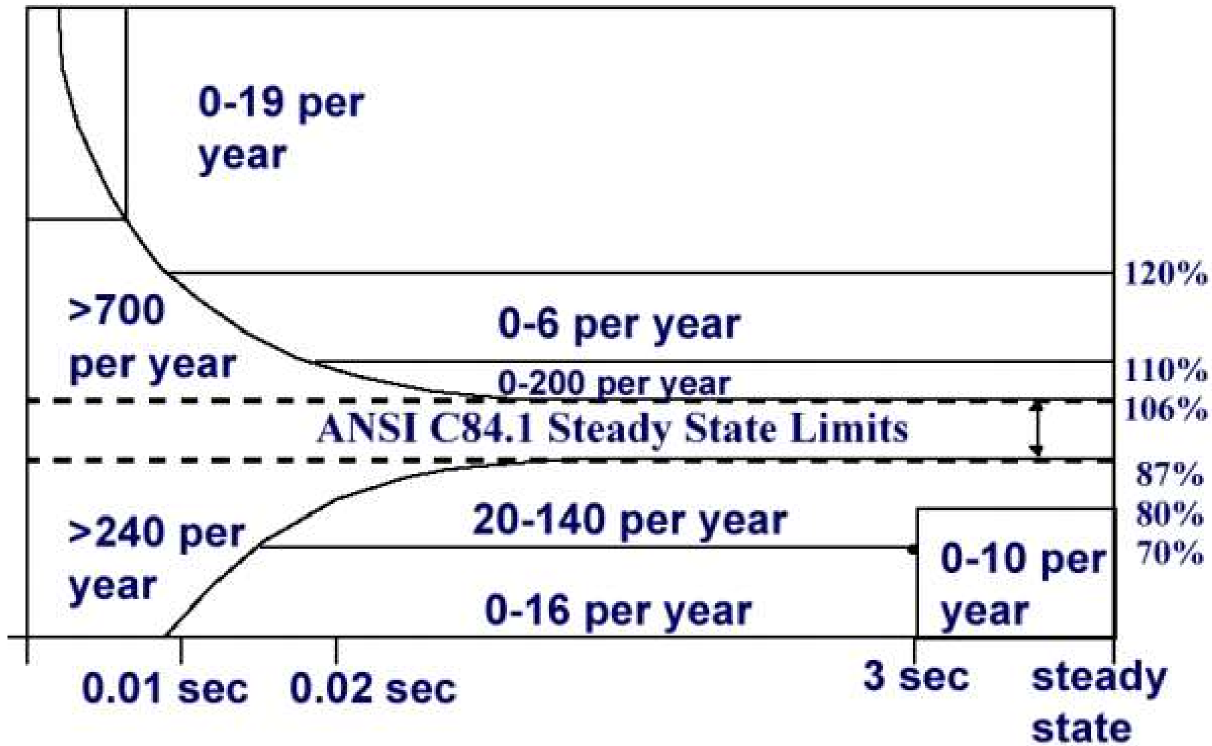
SEMI F47 sets out the required voltage sag tolerance for semiconductor fab equipment; IEC 61000-4-34 is used as the test standard

ITIC (CBEMA 96) Curve



The CBEMA and ITIC curves are both used to visibly represent voltage events. ... It defines various regions based on input voltage where computer equipment may encounter operational issues.
The ITIC (Information Technology Industry Council) curve is a modified version of the CBEMA curve created in the 1990's.

The Electric Power Research Institute (EPRI) Distribution Power Quality (DPQ) Study:



Projected 95% Probability for Any Site to Fall Within the Range of Events Shown in a Given Area

IEEE SPD Standards Overview

- C62.41.1 - Guide on the Surge Environment in Low-Voltage (1000 V and less) AC Power Circuits
- C62.41.2 - Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and less) AC Power Circuits
- C62.42 - Guide for the Application of Component Surge-Protective Devices for Use in Low-Voltage [Equal to Or Less Than 1000 V (ac) Or 1200 V (dc)] Circuits
- C62.43 - Application of Surge Protectors Used in Low-Voltage (Equal to or Less than 1000 V, rms, or 1200 V, DC) Data, Communications, and Signaling Circuits
- C62.44 - Guide for the Application of Low-Voltage (1000 Volts rms or Less) Surge Protective Devices Used on Secondary Distribution Systems (Between the Transformer Low-Voltage Terminals and the Line Side of the Service Entrance Panel) - New standard
- C62.45 - Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000V and Less) AC Power Circuits => C62.41.4
- C62.48 - Guide on Interactions between Power System Disturbances and Surge-Protective Devices => C62.41.3

Common Communication SPD Standards:

IEEE C62.43-2005: Guide for the Application of Surge Protectors Used in Low-Voltage Data, Communication and Signaling Circuits

IEEE C62.64-2009: Standard Specifications for Surge Protectors Used in Low-Voltage Data, Communication and Signaling Circuits

UL 497: Primary Protectors for Communications Circuits
UL 497A: Secondary Protectors for Communications Circuits
UL 497B: Isolated Loop Circuit Protectors - Protectors for Data Communications and Fire-Alarm Circuits
UL 497C: Primary Protectors for Coaxial Communications Circuits

Telcordia (Now Ericsson) GR-974-CORE: General Requirements for Telecommunications Line Protector Units (TLPUs)

C62.11
IEEE Standard For Metal-Oxide Surge Arresters for AC Power Circuits (>1 KV)

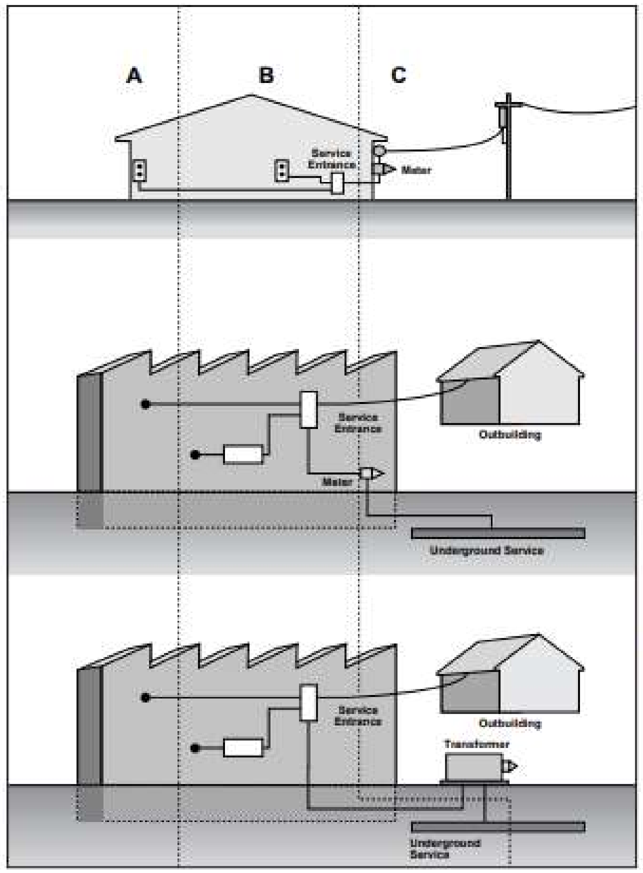
Table 3 —Distribution arrester classifications

Distribution Class Arrester	Lightning impulse classifying current I_{class} (kA)	High current impulse (kA)	Minimum single impulse charge transfer rating Q_{rs} (C)	Minimum Thermal Energy Withstand Rating Q_{th} (C)
Heavy Duty (HD)	10	100	0.4	1.1
Normal Duty (ND)	5	65	0.2	0.7
Light Duty (LD)	5	40	0.1	0.45

Table 4—Station and intermediate arrester impulse classifying currents

Arrester Class	MCOV range (kV RMS)	Lightning impulse classifying current I_{class} (kA)	Switching impulse classifying current (A)
Station	>448	20	2000
Station	246–448	15	2000
Station	116–245	10	1000
Station	2.55–115	10	500
Intermediate	2.55–115	5	500

IEEE C62.41.1 Operating Environment Categories



Category C environments are located on the LINE side of the service disconnect.

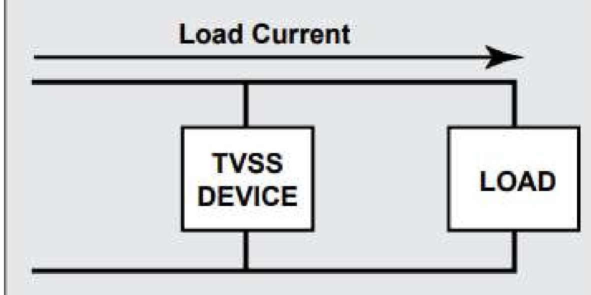
- Outside and service entrance
- Service drop from pole to building
- Run between meter and panel
- Overhead line to detached building
- Underground line to well pump

Category B environments are immediately adjacent on the LOAD side of the service disconnect breaker. Category B environments are characterized as having short branch circuits and feeder lines.

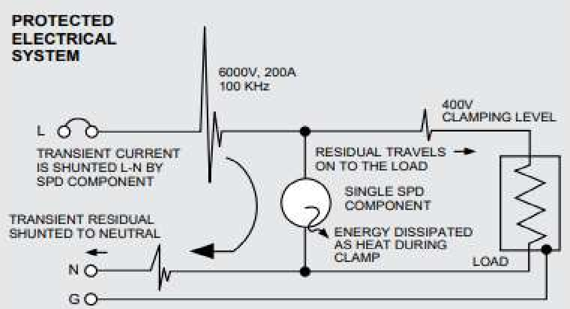
- Distribution panel devices
- Bus and feeder industrial plants
- Heavy appliance outlets with "short" connections to service entrance
- Lighting systems in large buildings

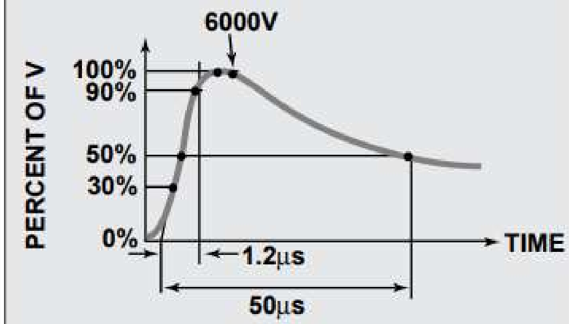
Category A environments have long branch circuits and outlets more than 30 feet from a Category B environment, or more than 60 feet from Category C locations.

IEEE C62.41 Standard Test Waveforms

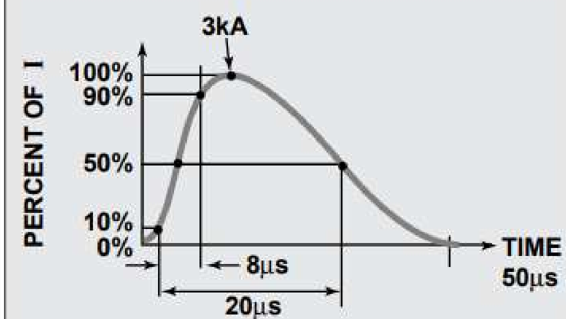


Parallel Operated SPD's





Combination Wave, Open-Circuit Voltage



Combination Wave, Short-Circuit Current

IEEE C62.41.2

Table 4 – Scenario I tests for SPDs intended for Location Category C[3]			
	Standard tests		Optional test
Exposure	1.2/50µs Voltage generator Minimum open-circuit voltage to be applied to SPD	8/20µs Current generator Current to be driven through the SPD[b]	100kHz Ring Wave for front-of-wave response evaluation
Low	6kV	3kA[c]	6kV
High	10kV	10kA	6kV

Table 3 – Standard 1.2/50µs – 8/20µs Combination Wave Expected voltages and current surges in Location Categories[a] A and B[b] Single-phase modes[c] : L-N, L-G and [L&N]-G Polyphase modes: L-L, L-N, L-G and [L's]-G (See Table 5 for N-G modes)			
	Peak Values[d]		
Location Category[a]	Voltage (kV)	Current (kA)	Effective Impedance (Ω)
A	6	0.5	12[f]
B	6	3	2

Standard 0.5 ms-100 kHz Ring Wave Voltages and Current Surges Expected in Location Categories A and B Low, Medium and High Exposures Single-Phase Modes: L-N, L-G, and [L&N]-G Polyphase Modes: L-L, L-G, and [L's]-G					Standard 1.2/50 ms-8/20 ms Combination Wave Voltages and Current Surges Expected in Location Categories B and C Low, Medium and High Exposures Single-Phase Modes: L-N, L-G, and [L&N]-G Polyphase Modes: L-L, L-N, L-G, and [L's]-G				
		Peak Values					Peak Values		
Location Category	System Exposure	Voltage (kV)	Current (kA)	Effective Impedance (Ω)	Location Category	System Exposure	Voltage (kV)	Current (kA)	Effective Impedance (Ω)
A1	Low	2	0.07	30	B1	Low	2	1	2
A2	Medium	4	0.13	30	B2	Medium	4	2	2
A3	High	6	0.2	30	B3	High	6	3	2
B1	Low	2	0.07	12	C1	Low	6	3	2
B2	Medium	4	0.33	12	C2	Medium	10	5	2
B3	High	6	0.5	12	C3	High	20	10	2

C62.62-2018 – SPD Documentation

- Ratings and characteristics
  - Declared nominal system voltage and type
  - Declared Maximum Continuous Operating Voltage (one value for each mode of protection)
  - Declared SPD Type
  - Measured Limiting Voltages, as applicable
  - Nominal Discharge Current—IN (one value for each mode of protection, if applicable to SPD Type)
  - Rated Load Current—IL (if required, two-port and In-Line SPDs)
  - Enclosure rating - degree of protection
  - Short-circuit current rating
  - Description of status indicator operation (if any)
  - Description of external SPD disconnector/OCPD requirements (if required)
  - Terminal markings (if necessary)
  - Installation procedure (e.g., connections, mechanical dimensions, lead lengths, etc.)
  - Storage temperature range
  - Operating temperature range
  - Agency listings and markings
  - Voltage regulation (two-port SPDs and In-Line SPDs)

Max. Surge Current Rating

- I max also known as surge rating, max discharge current, or kA rating: The maximum single surge capability usually specified by an 8/20µs waveshape. This means that the SPD can withstand a single surge at this level.
- This rating has become a legacy rating in the surge industry which establishes how robust the SPD is …..it should be verified by actual test data ….Not a theoretical calculated sum of the number of MOV's
- UL does not require this rating. Virtually all 26 43 13 Specs do.
- Reality check: Secondary Surge Arresters are rated at 65kA max
- Also, historical data has shown approx. 2% probability of a 100kA induced lightning strike. Avg induced lightning stroke is approx. 35kA (8x20us)
  - Most meterbase gaps spark-over at 6 to 10KV.

IEEE SPDC Application Guides

- C62.41.1 - IEEE Guide on the Surge Environment in Low-Voltage (1000 V and less) AC Power Circuits
- C62.41.2 - IEEE Recommended Practice on Characterization of Surges in Low-Voltage AC Power Circuits
- C62.42 – IEEE Guide for the Application of Component Surge-Protective Devices for Use in Low-Voltage Circuits (1000 V AC or 1500 V DC or less)
- C62.43 - Application of Surge Protectors Used in Low-Voltage Data, Communications, and Signaling
- C62.44 - Guide for the Application of Low-Voltage Surge Protective Devices Used on Secondary Distribution Systems (Between the Transformer Low-Voltage Terminals and the Line Side of the Service Entrance Panel)
- C62.45 - IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits
- C62.48 - IEEE Guide on Interactions between Power System Disturbances and Surge-Protective Devices
- C62.55 - IEEE Guide for Protection of Power Feeds to Remote Radio Heads

This guide begins by discussing the characteristics of single-stroke lightning that might strike a tower. The nature of the resulting current on the DC feed are then discussed. After that consideration is given to lightning flashes having multiple strokes. That is followed by guidance on selecting a SPD for the DC feed, and practical considerations.

- C62.72 - IEEE Guide for the Application of Surge-Protective Devices for Low-Voltage AC Power Circuits.

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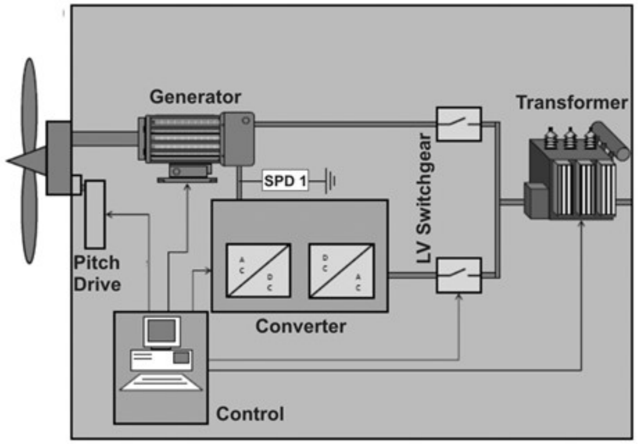
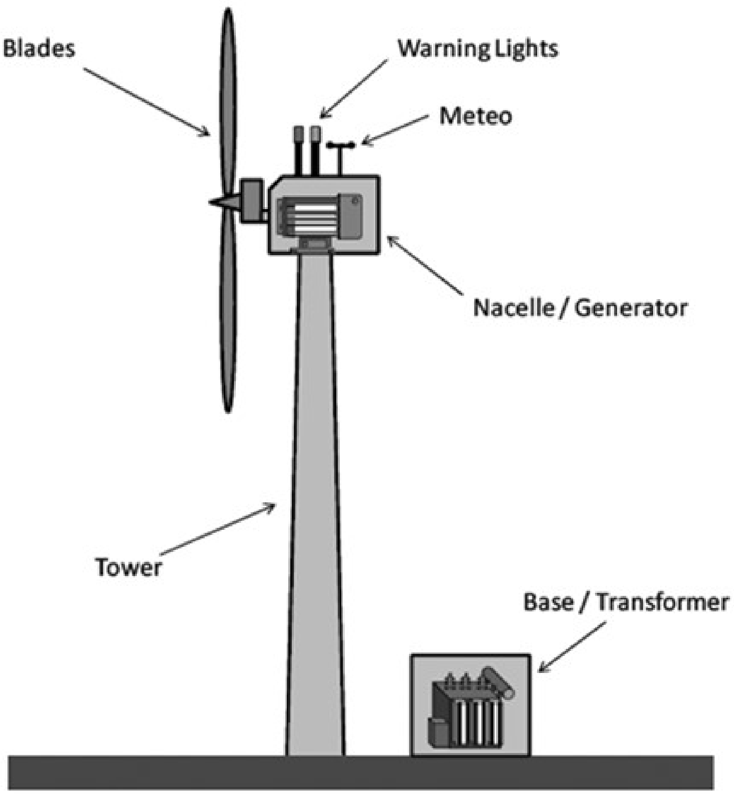
IEEE SPDC Standards Development Working Groups

- WG 3.6.11 – SPD guide for Wind Power Facilities applications
- WG 3.6.12 – SPD guide for Photovoltaic Facilities applications
- WG 3.6.13 – SPD guide for Smart Grid applications
- WG 3.6.14 – SPD guide for Electric Vehicle Supply Equipment

PC62.200 Draft Guide for the Application of Surge Protective Devices for Wind Power Facility





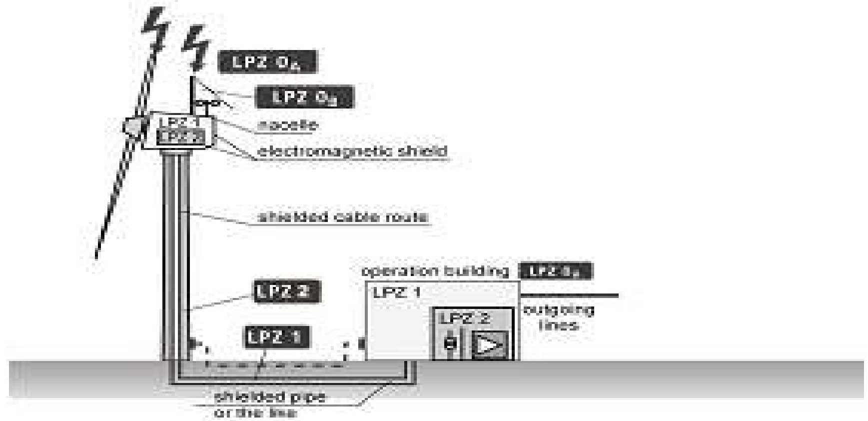


Figure __ – Example: Division of wind turbine into different lightning protection zones

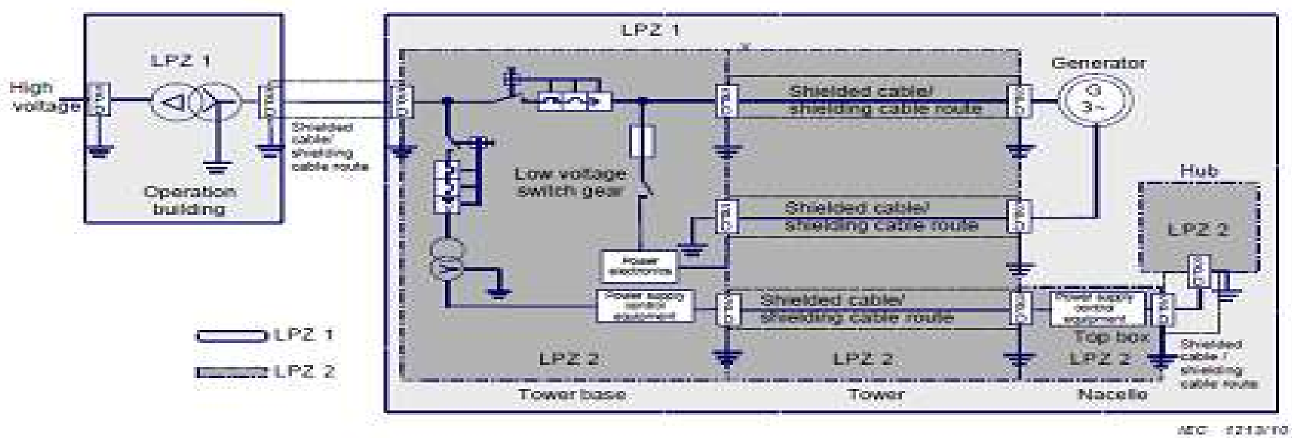


Figure __ – Example of how to document LPMS division of electrical system into protection zones with indication of where circuits cross LPZ boundaries and showing the long cables running between tower base and nacelle

WG 3.6.12 PV Facilities Protection Guide – white paper

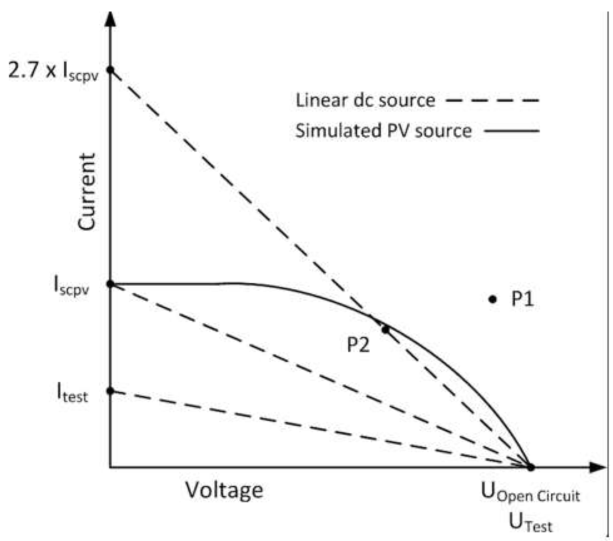


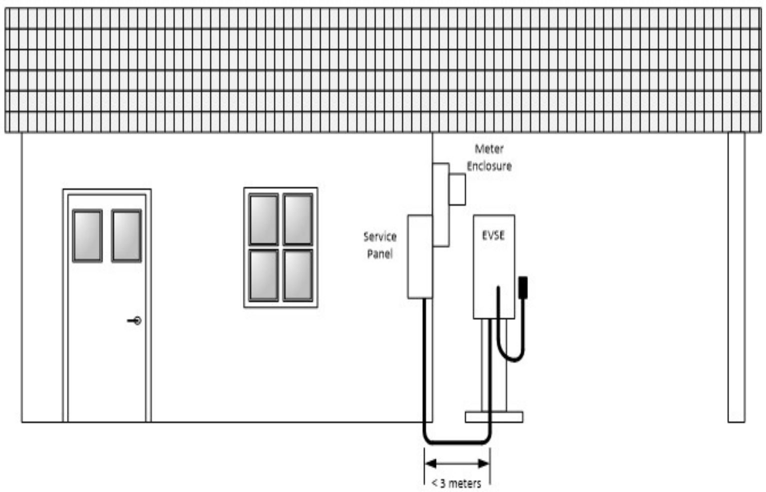
Figure 1. Characteristic Power Source Representations

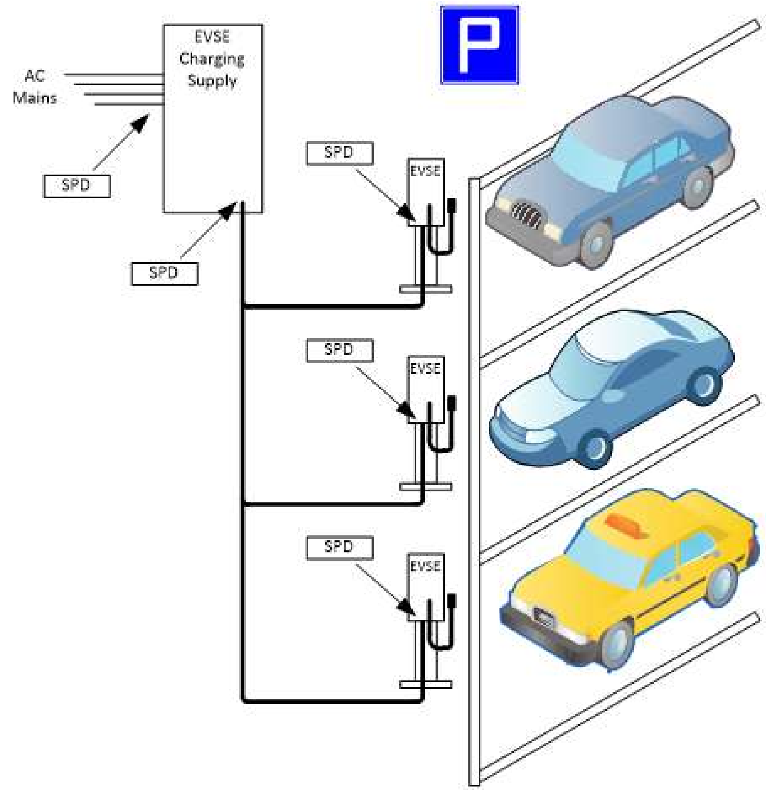
- IEC 61643-31
- UL1449 Supplement

In general, DC PV power sources behave like constant current sources as opposed to linear power sources. Photovoltaic installations can create a challenging environment with regard to SPD failure conditions. One of the inherent properties of DC constant current source is its ability to oppose change, which requires extra attention to the disconnection of the SPD under fault conditions. Safety considerations are different from SPDs used in alternating current applications and have unique properties similar to pure DC voltages. One of the inherent challenges to DC disconnection is the fact that there is no zero cross for voltage and current extinguishing.

Table 1 - Ratings Comparison				
UL		IEC		Comments
Description	Symbol	Description	Symbol	
Maximum Continuous Operating Voltage	V_{pvdc}	Maximum Continuous Operating Voltage	U_{cpv}	Equivalent
Nominal Discharge Current	I_n	Nominal Discharge Current For Class II Test	I_n	Similar
-	-	Impulse Discharge Current For Class I Test	Iimp	No match
-	-	Maximum Discharge Current For Class II	Imax	No match
-	-	Total Discharge Current For Multipole SPD	ITotal	No match
Voltage Protection Rating	VPR	Voltage Protection Level	U_p	Comparable under specific conditions, however the testing process is different
Leakage Current	I_q	Residual Current at UCPV	I_{PE}	Equivalent
Short-Circuit Current	SCCR	Short-Circuit Current	I_{scpv}	Not comparable; tests are different
Maximum ambient Temperature	Temp	Ambient Temperature	Normal or Extended	Similar
Load Current	I_L	Rated Load Current	I_L	Similar
SPD Type	Type 1 or Type 2	SPD Test Class	Test Class I, II and/or III	Not comparable; tests are different

PC 62.230™/D8
Draft Guide for Surge Protection
of Electric Vehicle Infrastructure





IEEE PES/SPDC
WG 3.6.13
Surge Protection Overview for the Smart Grid

Matt Wakeham – Consulting Engineer

Working Group Chair

IEEE PES/SPDC WG3.6.13: PC62.220

Scope:
The purpose of this document is to outline how surge protective devices play an integral part in improving the operability and reliability of the Smart Grid. This document focuses on surge protective devices that operate on systems with voltages 1,000 Volts(ac)/1500 Volts(dc) and below. Included within this scope are communications and data acquisition equipment and associated circuitry and interfaces.

The basic concept of Smart Grid is to add monitoring, analysis, control, and communication capabilities to the national electrical delivery system to maximize the throughput of the system while reducing the energy consumption. The Smart Grid will allow utilities to move electricity around the system as efficiency and economically as possible. It will also allow the homeowner and business to use electricity as economically as possible.

Importance of Surge Protection for Smart Grid

Key aspects of Smart Grid point to an increased need for surge protection due to:

1. Addition of electronic based monitoring, analysis, control and communication equipment. – Surge protection is required to protect this electronic equipment from damage due to voltage transients.

2. Proliferation of communications, control and monitoring devices and the addition of distributed and alternative power sources, increases the exposure of equipment to lightning and other surges.

Manufacturers of electronic equipment and appliances might need to install surge protective devices to mitigate surges. Immunity levels are discussed in IEC Std 61000 series and IEEE Std1100™.

3. Increase in residential, commercial and industrial use of energy management systems and distributed generation cause more switching of loads and generation sources within the premise; thereby increasing the need for point-of-use protection inside the premise.

4. The overall geographical reach of the Smart Grid poses an increased exposure to lightning damage or disruption. This risk is proportional to the lightning strike density and capture area of the grid.

IEEE PES/SPDC WG3.6.13: PC62.220

- Two key aspects of Smart Grid that require an increased need for surge protection are: 1. Addition of electronic-based monitoring, analysis, control and communication equipment. - Surge protection is required to protect this electronic equipment from damage due to voltage transients. 2. Increase in utilities moving electricity around the system from multiple new sources such as wind, solar, cogeneration and other sources This increased level of switching of electrical sources can lead to increased levels of switching transients that can damage electrical and electronic loads.

- This document will focus on protecting the variety of mostly electronic equipment that will be added to homes, businesses, government facilities and industrial plants. Since the scope is 1,000v ac and below, this document will not discuss protective devices used by utilities on electrical distribution or transmission systems. However, it may include cases that involve smart grid equipment attaching or coupling to higher voltage circuits such as electric utility medium voltage distribution.

Importance of Surge Protection for ICT (Information and Communications Technology) Circuits

Many factories, campuses, and job sites use twisted pair communications cables that may be in close proximity to or parallel with power line distributions, and may run up to 0.5 mile or more. Examples are 20 mA current loop, RS-422, building to building Ethernet links, 24 V fire alarm circuits, and correctional institute fence detection circuits.

Industrial sites may use SCADA systems, which can be either local or remote. They generally consist of PLCs to control equipment and a communications controller. If the SCADA system is local (for example in a substation), then communication within it is often either by a serial bus (nowadays usually a RS485) or via Ethernet. For PLCs in remote locations SCADA systems can use dedicated serial-lines based communication or ethernet.

Importance of Surge Protection for ICT Circuits

Any of these systems may be subjected to surges due to lightning or induction from nearby power circuits. These surges can disrupt the operation of system's ICT circuits, with potentially serious consequences. Hence the need to protect these systems from surges.

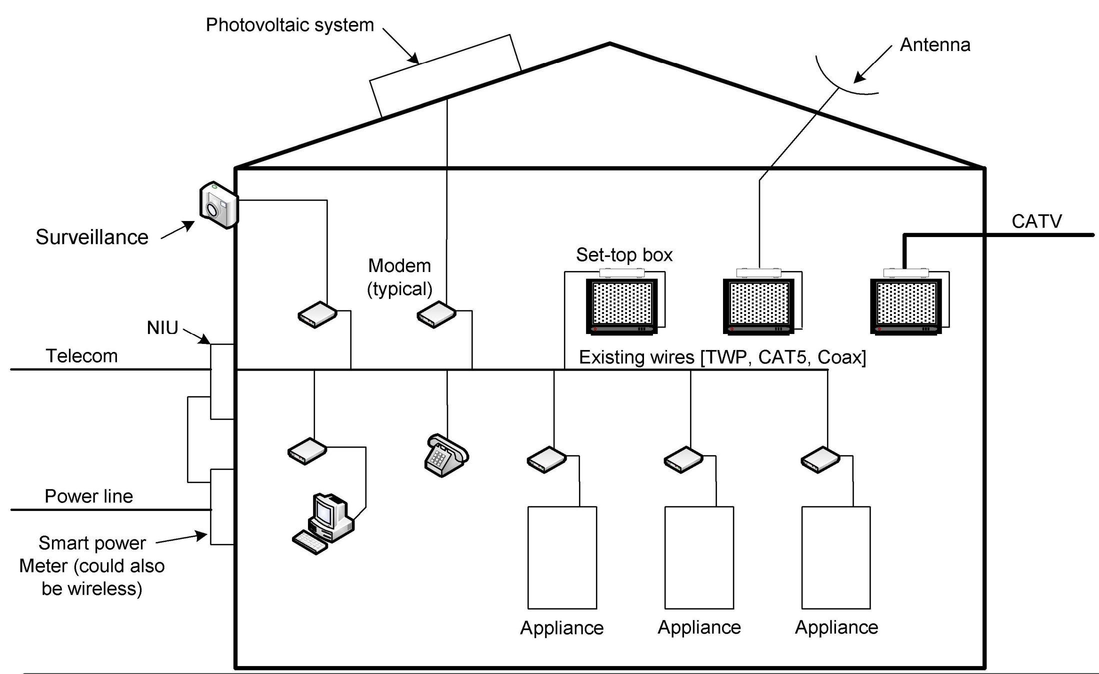
The standards developed by WG3.6.7 and in force are:

C62.36™ IEEE Standard Test Methods for Surge Protectors and Protective Circuits Used in Information and Communications Technology (ICT) Circuits, and Smart Grid Data Circuits

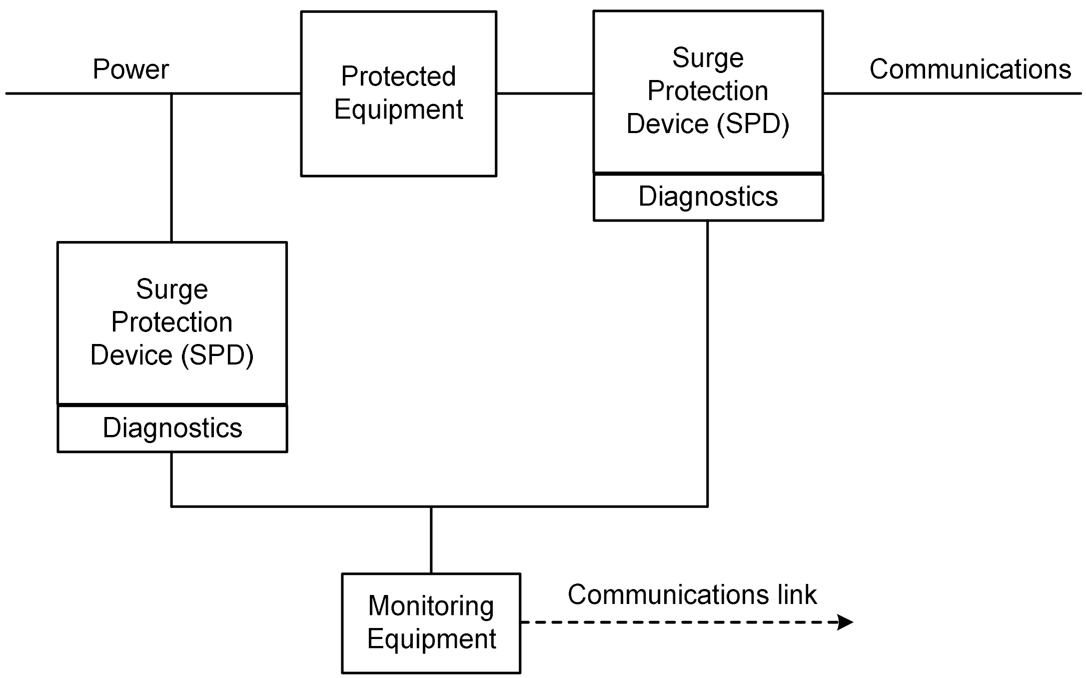
C62.43.0™ IEEE Guide for Surge Protectors and Protective Circuits Used in Information and Communications Technology Circuits, Including Smart Grid Data Networks—Overview

C62.55™ IEEE Guide for Surge Protection of DC Power Feeds to Remote Radio Heads

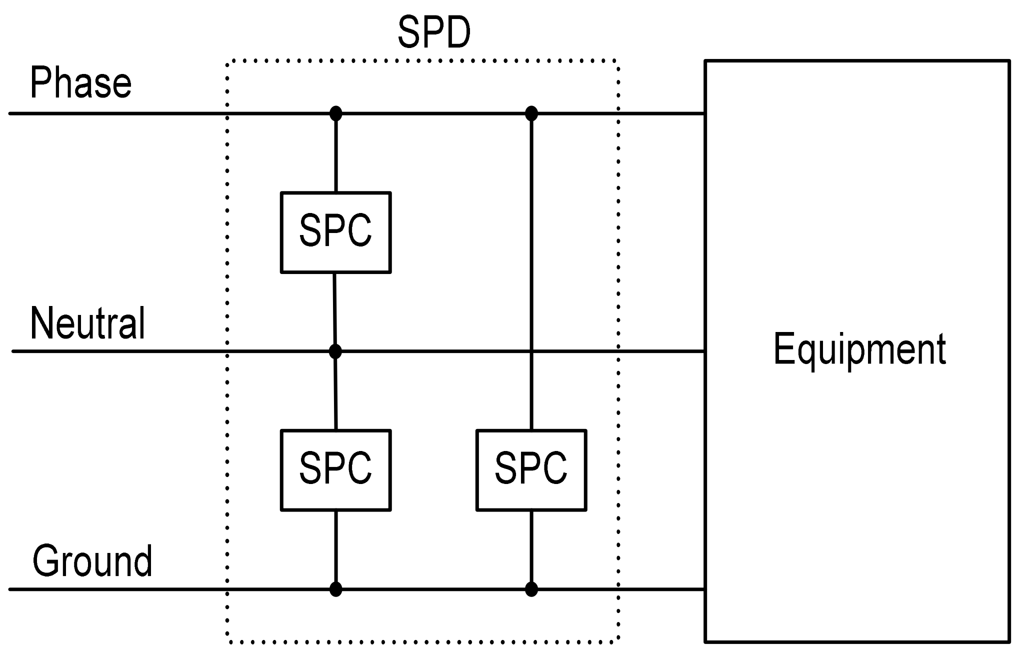
Representative home network including electronic equipment connected to a gateway via an Ethernet link



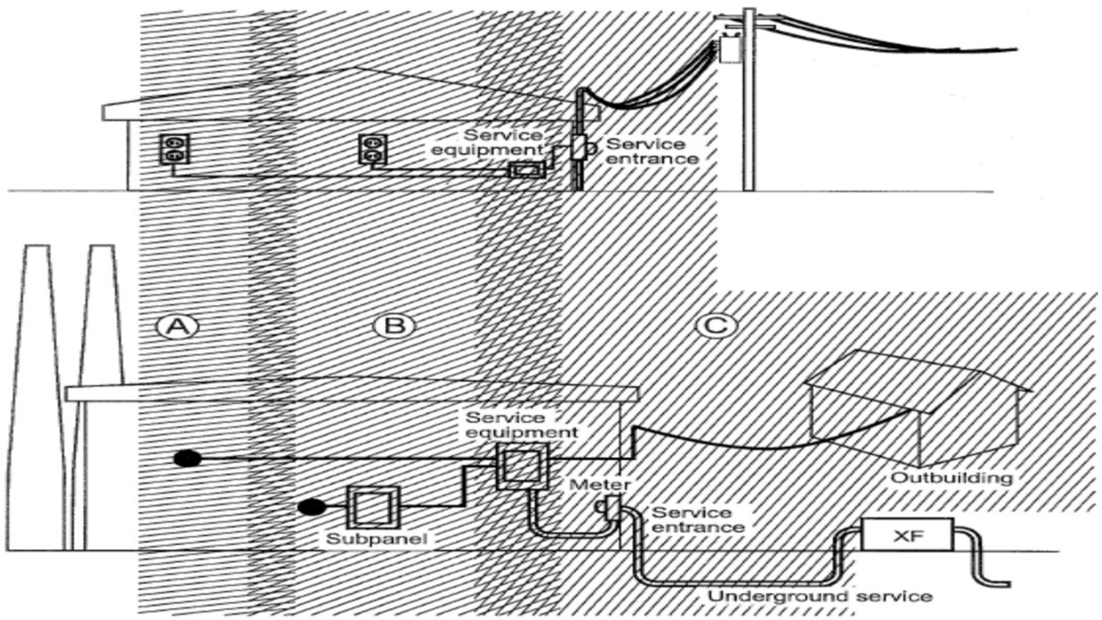
Block Diagram of SPD Applications



Typical SPD configuration for use in power systems.

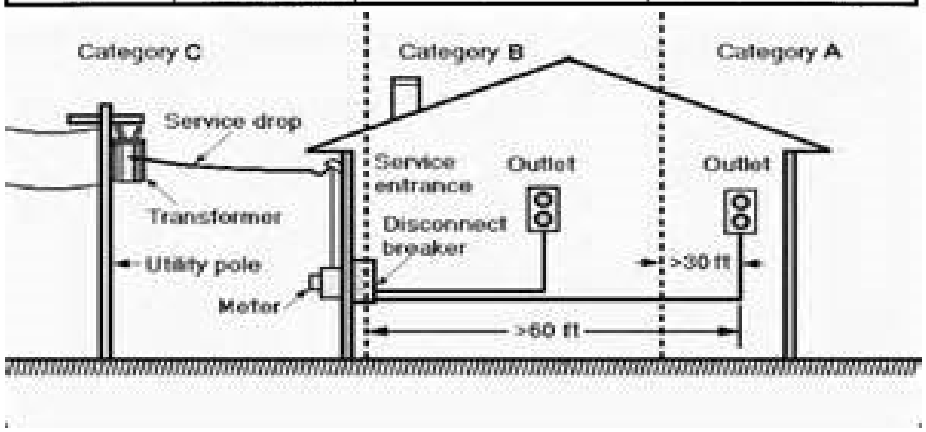


The concept of location categories and transitions as simplification approach



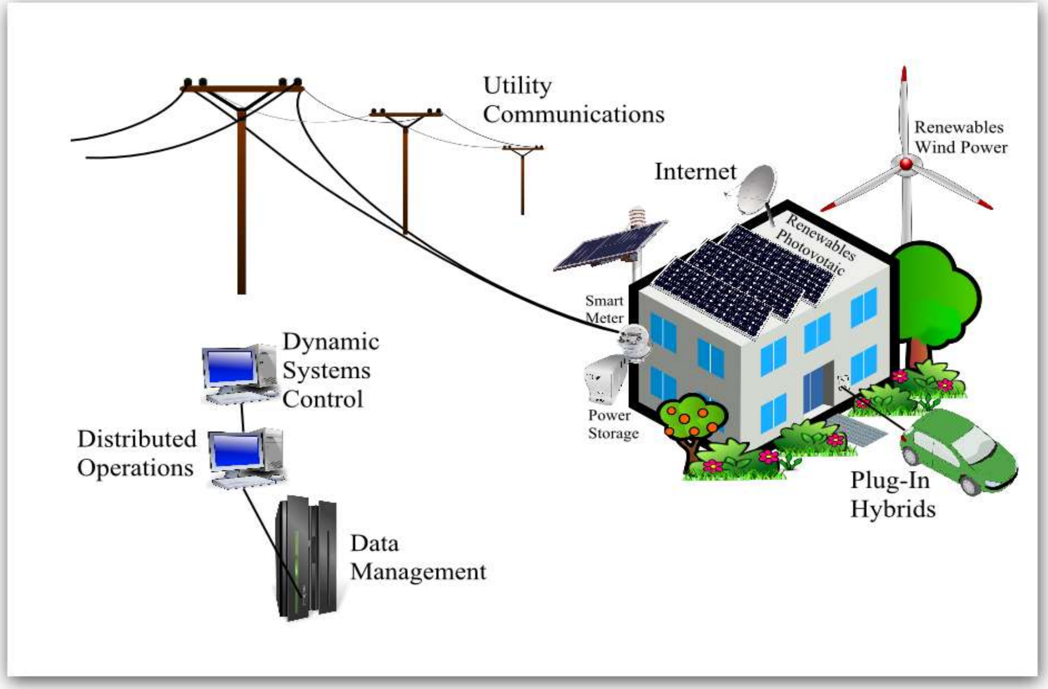
Source: IEEE C62.41.1

Category	Exposure	Voltage /Amperage		Waveforms
C1 C2 C3	Low Medium High	6,000 V 10,000 V 20,000 V	3,000 A 5,000 A 10,000 A	Impulsive Waveforms 1.2μsx50μS Voltage 8μsx20μs Amperage
B1 B2 B3	Low Medium High	2,000 V 4,000 V 6,000 V	1,000 V 2,000 A 3,000 A	Impulse Waveforms 1.2μsx50μS Voltage 8μsx20μs Amperage
B1 B2 B3	Low Medium High	2,000 V 4,000 V 6,000 V	170 A 330 A 500A	Ring Waveforms .5μsx100KHZ.
A1 A2 A3	Low Medium High	2,000 V 4,000 V 6,000 V	70 A 130 A 200A	Ring Waveforms .5μsx100KHZ.



Source: IEEE

Some functions of the Smart Grid



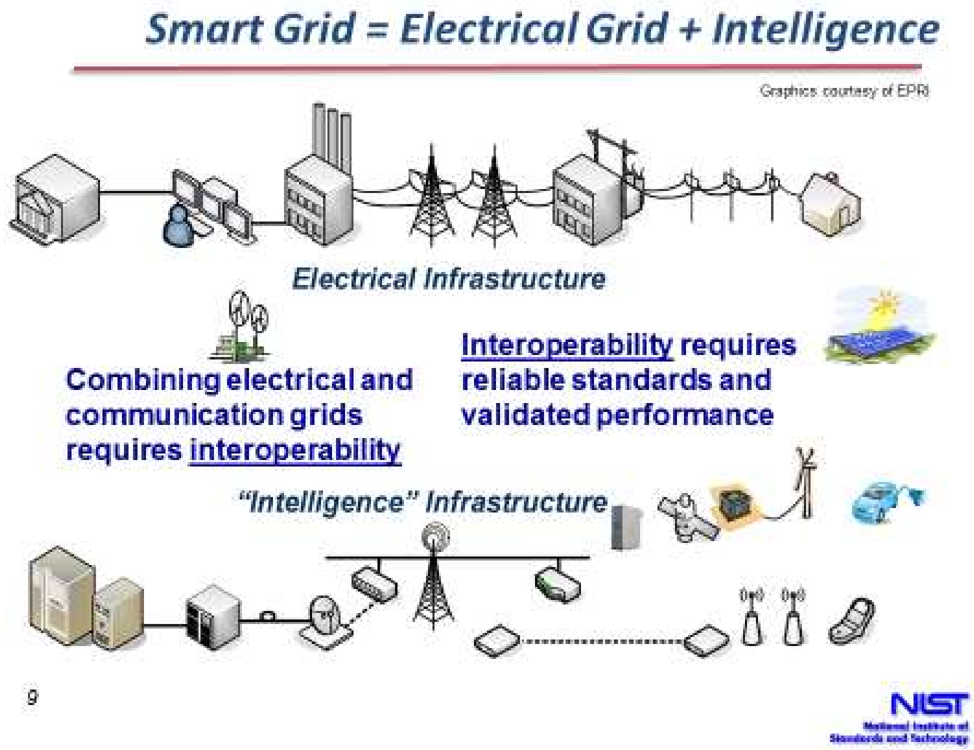
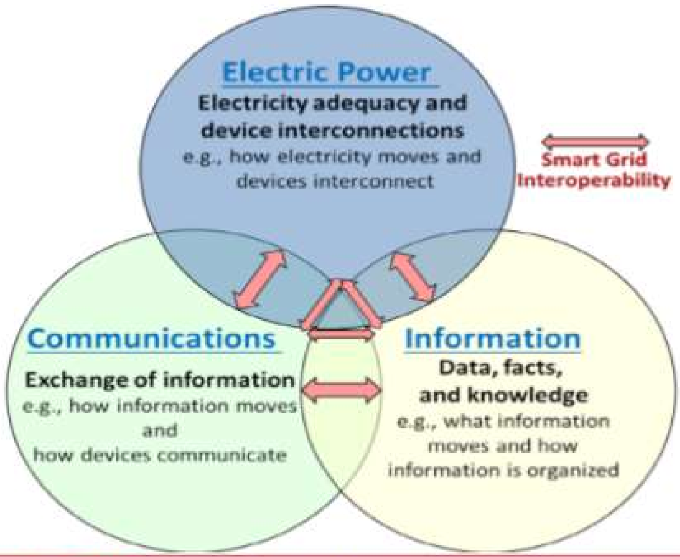


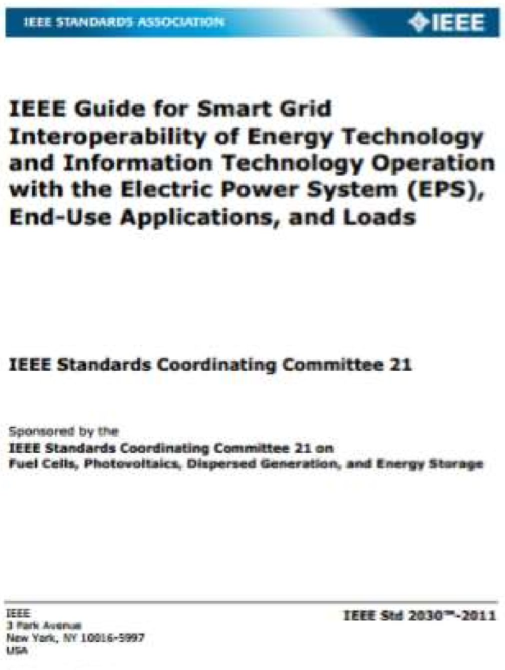
Figure 1: Application of Smart Grid technology - NIST

Smart Grid Interoperability– Power and Communications



Interoperability: the capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely & effectively. (Std 2030)

Reference Standards: IEEE 2030 & 1547


IEEE STANDARDS ASSOCIATION IEEE

IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads

IEEE Standards Coordinating Committee 21

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IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 2030™-2011


1547™-2003

IEEE Standards

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IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

Standards Coordinating Committee 21

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Energy Storage

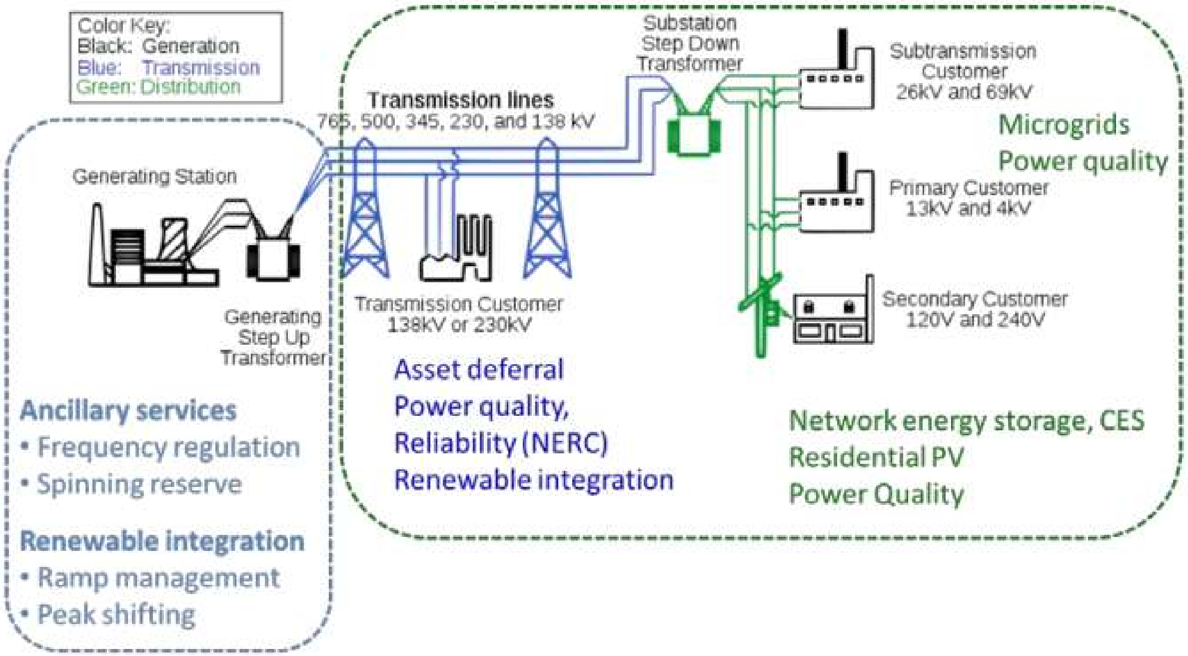

Figure 5. Example applications of energy storage systems integrated with the grid (IEEE 2030.2)

Safety Standards

- UL 96A - Standard for Installation Requirements for Lightning Protection Systems
- NFPA 780 – Standard for the Installation of Lightning Protection Systems
- UL 1449 – Standard for Safety for Surge Protective Devices
- UL 497 – Standard for Protectors for Paired-Conductor Communications Circuits
- UL 497A – Secondary Protectors for Communications Circuits
- UL 497B – Protectors for fire alarm signaling circuits that are covered by the Standard for Protectors for Data Communications and Fire-Alarm Circuits
- NFPA 70 – National Electrical Code

UL 1449

STANDARD FOR SAFETY

Surge Protective Devices

AUGUST 20, 2014
(Title Page Reprinted: March 26, 2015)

ANSI/UL 1449-2015

1

UL 1449

Standard for Surge Protective Devices

First Edition – August, 1985
Second Edition – August, 1996
Third Edition – September, 2006

Fourth Edition

August 20, 2014

This ANSI/UL Standard for Safety consists of the Fourth Edition including revisions through March 26, 2015.

The most recent designation of ANSI/UL 1449 as an American National Standard (ANSI) occurred on March 26, 2015. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, or effective date information.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at http://csds.ul.com.

UL Standard for Safety for Surge Protective Devices, UL 1449

Fourth Edition, Dated August 20, 2014

Summary of Topics

Revision pages have been issued for the Standard for Safety for Surge Protective Devices, UL 1449, to reflect the latest ANSI approval date and to incorporate the proposals dated October 31, 2014 and February 20, 2015, which include the following:

- ***Correction to requirements in 7.1.4.4***
- ***Definition and clarification of the use of cheesecloth and tissue paper.***
- ***Clarifications to Sections 40 and 44.***
- ***Clarification of Table 36.1 and Table 36.2.***
- ***Clarification of requirements for SPDs intended for rack mounting.***
- ***Addition of requirements for outdoor use Type 3 SPDs.***
- ***Revision of 44.1.11(f) and 44.2.5(c).***
- ***Revision of 44.4.1 regarding SPD temperature equilibrium.***
- ***Addition of exception to 44.1.7 to address cheesecloth placement for enclosures with conduit openings.***

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated October 31, 2014 and February 20, 2015.

UL 1449 – Standard for Safety for Surge Protective Devices

- Creates SPD types (Type 1, Type 2, Type 3, Type 4, Type 5
- New Nominal Discharge Surge Current test, I_n Thermal “stress” test
- Tested MCOV per mode (No longer a claimed value)
- SVR 6kV, 500A replaced with VPR 6kV, 3kA
- Surge Arrestor incorporated into UL1449 as Type 1 device

SPD Types – UL 1449

Type 1 SPD (LINE SIDE)

Permanently Connected SPD – Installation between the secondary of the service transformer and the LINE side of the service disconnect over current device, as well as the LOAD side, including watt-hour meter socket enclosures.
(Not exceeding 1000V)

Type 2 (Load Side)

Permanently connected SPD intended for installation on the LOAD side of there service disconnect over current device, including SPDs located at the branch panel.

Type 3

Point of utilization SPDs, installed a minimum of 10 meters (30 feet) from the electrical service panel, for example cord connected, direct plug-in (DPI), receptacle type and SPDs installed at the utilization equipment being protected.

Type 4 and 5

Component SPDs, including discrete components as well as component assemblies.

Measured Limiting Voltage (MLV)

- All SPD Types are to be tested to 6kV/3kA - 3 pulses per mode with applied voltage. VPR is determined by averaging results. (per 34.9 and Table 34.1)

- SVR 6kV/500A
  – Good reading 400v or 500v

- VPR 6kV/3kA
  – Good reading 700v, 800v, 900v, or as high as 1000v

- Higher surge current results in higher clamping voltages

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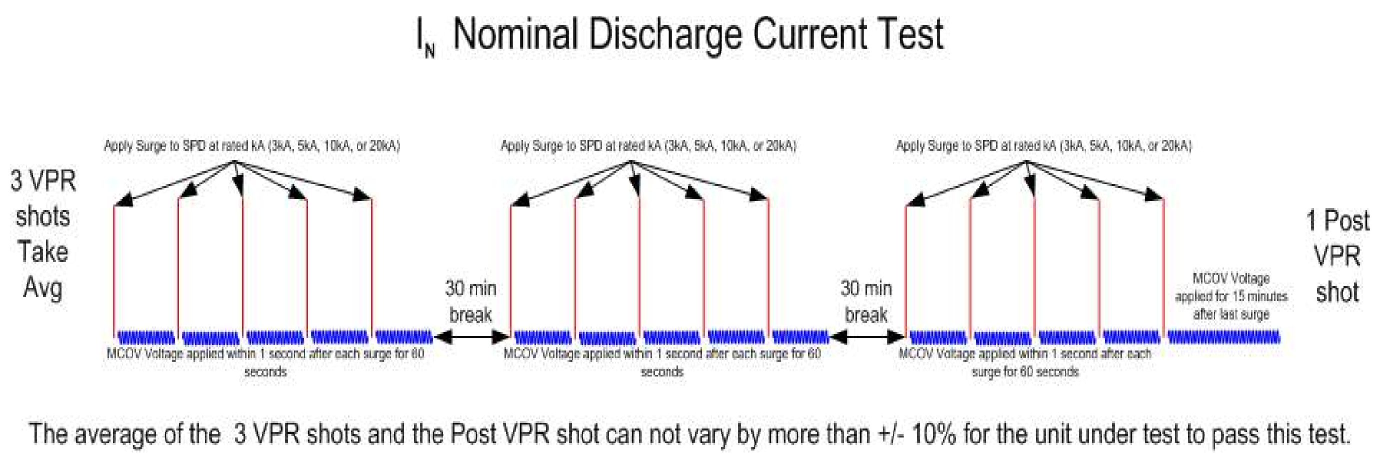
Nominal Discharge Current Test

- Exercises an SPD's ability to be subjected to repetitive current surges of a selected value without degradation in performance
- Demonstrates the performance of an SPD in response to surges that can be expected at the service equipment and/or within a building
- Repetitive in nature – duty cycle – severe!

Nominal Discharge Current Test (I_n)

- Type 1 – Choose 10kA or 20kA/Mode
- Type 2 – Choose 3kA, 5kA, 10kA, or 20kA
- Surge unit at chosen surge value
- Apply chosen overvoltage to unit within 1s for 1min



UL Product iQ™

VZCA.E319871 - SURGE-PROTECTIVE DEVICES

Model No.	SPD Type	Volts (V)	AC/DC/ DC PV	PH	AMPS (A)	AMB (°C)Min	AMB (°C)Max	MODE	VPR (Vpk)	MCOV (V)	In (kA)	SCCR (kA)
Permanently Connected												
20PSP120H12/T1	1	240/120	AC	3H	N/A	-40	75	L-L L-N L-G N-G H-L H-N H-G	1200 700 700 700 2000 1200 1200	300 150 150 150 470 320 320	20	200
20PSP120HC12/T1A	1	480/277	AC	3Y	N/A	-40	75	L-L H-G	1200 1200	300 320	20	200
20PSP120S12/T1	1	120	AC	1	N/A	-40	75	L-N L-G N-G	700 700 700	150 150 150	20	200
20PSP120SP12/T1	1	240/120	AC	1S	N/A	-40	75	L-L L-N L-G N-G	1200 700 700 700	300 150 150 150	20	200

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UL497B

UL Product iQ™

QVGQ.E504171 - ISOLATED LOOP CIRCUIT PROTECTORS

Isolated Loop Circuit Protectors

See General Information for Isolated Loop Circuit Protectors

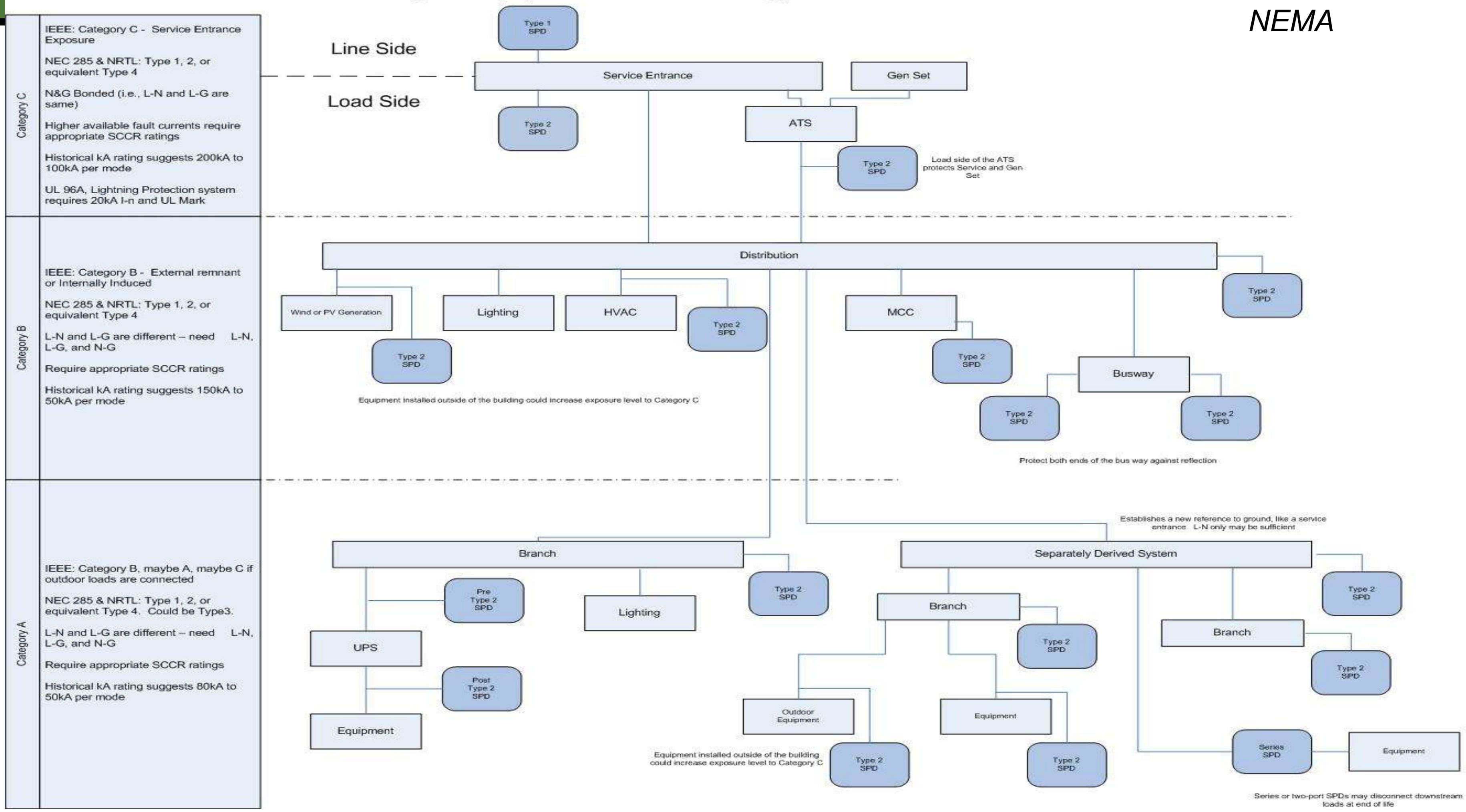
PROSURGE ELECTRONICS CO LTD E504171
Building 20, Liando U Valley
Jiansha Road, Danzao, Nanhai
Foshan, Guangdong 528216 CHINA

Isolated Loop Circuit Protector, "DM", Model(s) DM-XX-M2N1, where XX is 5, 12, 24, 48, or 110, DM-XX-M2N2, where XX is 5, 12, 24, 48, or 110, DM-XX-M2N3, where XX is 5, 12, 24, 48, or 110, DM-XX-M2N4, where XX is 5, 12, 24, 48, or 110, DM-XX-M2N5, where XX is 12, 24, 48, or 110, DM-XX-M2N6, where XX is 5, 12, 24, or 48, DM-XX-M2N7, where XX is 5, 12, 24, or 48, DM-XX-M4N1, where XX is 5, 12, 24, or 48, DM-XX-M4N2, where XX is 5, 12, 24, or 48, DM-XX-M4N6, where XX is 5, 12, 24, or 48, DM-XX-M4N7, where XX is 5, 12, 24, or 48

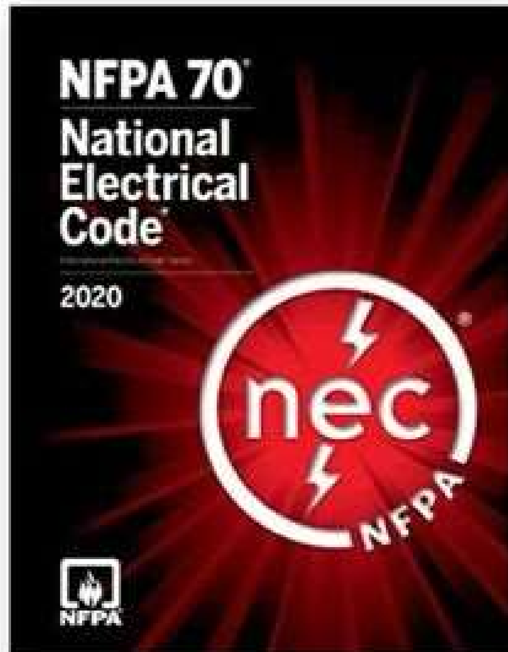
Last Updated on 2019-09-26

AC Voltage Application Surge Protection Guide

Source: NEMA



National Electrical Code and Surge Protection



National Electric Code

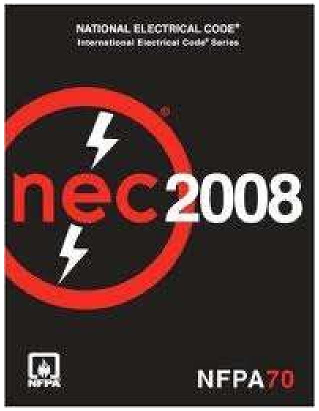
- COPS - Critical Operations Power Systems
  - NEC guideline to increase protection and reliability of the power infrastructure for critical facilities

- What are Critical Facilities?
  - Government agency (Federal, state, municipal)
  - Facility engineering
  - Facilities that if destroyed may disrupt:
    - National security, the economy, public health, or safety

- To include
  - HVAC, fire alarm, security, communications, and signaling

- NEC Section 708.20 (D)

- Surge Protective Devices must be used to comply
- SPDs must be used for each voltage at the facility
  - Service Entrance
  - Distribution panels



NEC

- 700.8 “ A listed SPD shall be installed in or on all emergency switchboards and panelboards

- 694.10 (D) “ A SPD shall be installed between a wind electric system and any loads served by the premises electrical system.”

- 240.21 (1) b “Where listed equipment, such as a SPD, is provided with specific instructions on minimum conductor sizing, the ampacity of the tap conductors supplying that equipment shall be permitted to be determined base on the manufacturer’s instructions.”

230.67 Surge Protection for Dwelling Units

A new requirement is being proposed to necessitate a surge protection device (SPD) on all services in dwelling units. This requirement is intended to address the recognized need for surge protection to protect sensitive electronics and systems found in most modern appliances, safety devices (AFCIs, GFCIs, and smoke alarms) and equipment used in modern dwelling units. The expanded use of distributed energy resources (DERs) within electrical systems often results in more opportunity or greater exposure for the introduction of surges into electrical systems.

Additionally, there is another revision that combines the “over 1000V” and “under 1000V” requirement into a single new Article 242 and deletes Articles 280 and 285.

Article 242 is where the installation requirements for SPDs will be found. Requirements for SPDs to be listed, how to be connected within the panelboard, and short-circuit current ratings can be found in Article 242

ARTICLE 285
Surge-Protective Devices (SPDs), 1000 Volts or Less

I. General

285.1 Scope. This article covers general requirements, installation requirements, and connection requirements for surge-protective devices (SPDs) permanently installed on premises wiring systems of 1000 volts or less.

Informational Note: Surge arresters 1000 volts or less are also known as Type 1 SPDs.

285.3 Uses Not Permitted. An SPD device shall not be installed in the following:

(1) Circuits over 1000 volts
(2) On ungrounded systems, impedance grounded systems, or corner grounded delta systems unless listed specifically for use on these systems
(3) Where the rating of the SPD is less than the maximum continuous phase-to-ground power frequency voltage available at the point of application

285.4 Number Required. Where used at a point on a circuit, the SPD shall be connected to each ungrounded conductor.

285.5 Listing. An SPD shall be a listed device.

285.6 Short-Circuit Current Rating. The SPD shall be marked with a short-circuit current rating and shall not be installed at a point on the system where the available fault current is in excess of that rating. This marking requirement shall not apply to receptacles.

II. Installation

285.11 Location. SPDs shall be permitted to be located indoors or outdoors and shall be made inaccessible to unqualified persons, unless listed for installation in accessible locations.

285.12 Routing of Connections. The conductors used to connect the SPD to the line or bus and to ground shall not be any longer than necessary and shall avoid unnecessary bends.

285.13 Type 4 and Other Component Type SPDs. Type 4 component assemblies and other component type SPDs shall only be installed by the equipment manufacturer.

III. Connecting SPDs

285.21 Connection. Where an SPD device is installed, it shall comply with 285.23 through 285.28.

285.23 Type 1 SPDs. Type 1 SPDs shall be installed in accordance with 285.23(A) and (B).

(A) Installation. Type 1 SPDs shall be installed as follows:

(1) Type 1 SPDs shall be permitted to be connected to the supply side of the service disconnect as permitted in 230.82(4), or

(2) Type 1 SPDs shall be permitted to be connected as specified in 285.24.

(B) At the Service. When installed at services, Type 1 SPDs shall be connected to one of the following:

(1) Grounded service conductor

(2) Grounding electrode conductor

(3) Grounding electrode for the service

(4) Equipment grounding terminal in the service equipment

285.24 Type 2 SPDs. Type 2 SPDs shall be installed in accordance with 285.24(A) through (C).

(A) Service-Supplied Building or Structure. Type 2 SPDs shall be connected anywhere on the load side of a service disconnect overcurrent device required in 230.91, unless installed in accordance with 230.82(8).

(B) Feeder-Supplied Building or Structure. Type 2 SPDs shall be connected at the building or structure anywhere on the load side of the first overcurrent device at the building or structure.

(C) Separately Derived System. The SPD shall be connected on the load side of the first overcurrent device in a separately derived system.

285.25 Type 3 SPDs. Type 3 SPDs shall be permitted to be installed on the load side of branch-circuit overcurrent protection up to the equipment served. If included in the manufacturer's instructions, the Type 3 SPD connection shall be a minimum 10 m (30 ft) of conductor distance from the service or separately derived system disconnect.

285.26 Conductor Size. Line and grounding conductors shall not be smaller than 14 AWG copper or 12 AWG aluminum.

285.27 Connection Between Conductors. An SPD shall be permitted to be connected between any two conductors — ungrounded conductor(s), grounded conductor, equipment grounding conductor, or grounding electrode conductor. The grounded conductor and the equipment grounding conductor shall be interconnected only by the normal operation of the SPD during a surge.

285.28 Grounding Electrode Conductor Connections and Enclosures. Except as indicated in this article, SPD grounding connections shall be made as specified in Article 250, Part III. Grounding electrode conductors installed in metal enclosures shall comply with 250.64(E).

National Electrical Code® 2020

Major Changes to the Code

The National Electrical Code®, which has been **adopted by all 50 states**, sets the minimum standard for safe electrical design, installation, and inspection to keep people and property protected from electrical hazards. The NEC® is **revised every three years** using public input, commentary, and technical sessions. With the introduction of the 2020 code, there have been 15 NEC® revisions since 1977, the year the median American home was built.

1 Surge Protection is Required for Dwelling Units NEW

New and replaced service equipment supplying dwellings are now required to be protected by listed **Type 1 or Type 2 Surge-Protective Devices**. These protect electrical devices and appliances that may not be protected by point-of-use SPDs. It is estimated that the average home has **$15,000** worth of equipment that can be damaged by surges.

Type 1 SPD

Permanently connected SPDs intended for installation between the **secondary of the service transformer** and the **line side of the service disconnect overcurrent device**.

Type 2 SPD

Permanently connected SPDs intended for installation on the **load side of the service disconnect overcurrent device**, including SPDs located at the branch panel.

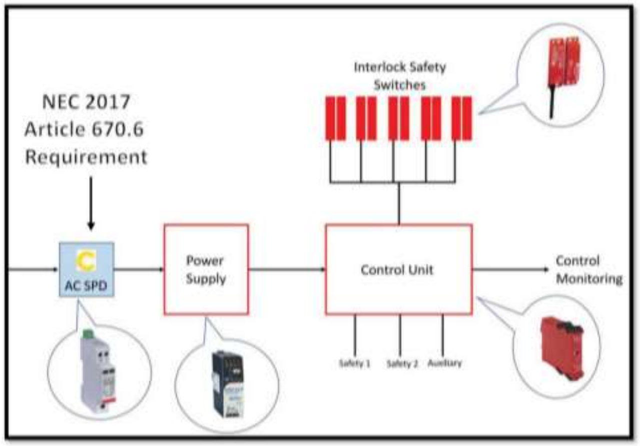
Power & Energy Society®

Type of machines covered by NFPA 79

Type	Description
Machine Tools	Metal cutting Metal forming
Plastics Machinery	Injection molding machines Extrusion machinery Blow molding machines Specialized processing machines Thermoset molding machines Size reduction equipment
Wood Machinery	Woodworking machinery Laminating machinery Sawmill machines
Material-Handling Machines	Industrial robots Transfer machines Sortation machines
Inspection/Testing Machines	Coordinate measuring machines In-process gauging machines
Packaging Machines	Carton-strapping machines Drum-filling machines Palletizing machines

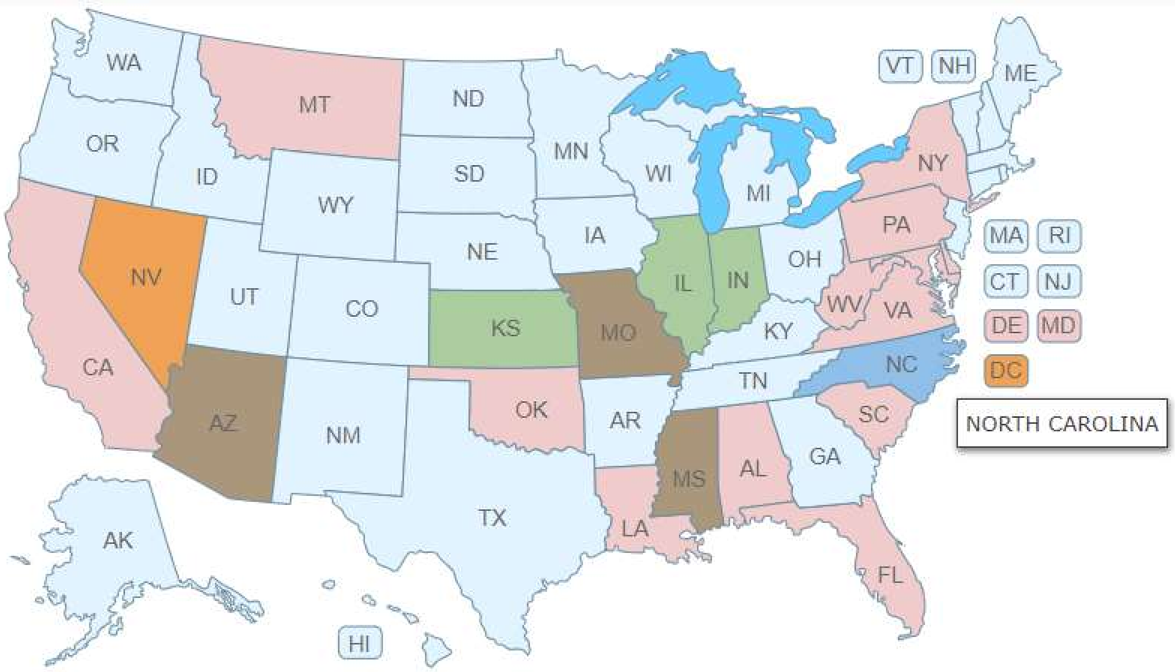
Application
480V AC Incoming Supply
120V AC Power Supply
24V DC Power Supply
RS485 twisted pair

Interlock Safety Circuit SPD Primary Location



NEC Adoptions

Keeping in mind
AHJ ….
Authority Having
Jurisdiction



Blue = 2017 *NEC* | Red = 2014 *NEC* | Orange = 2011 *NEC* | Green = 2008 *NEC* Brown =Local adoption only

Surge Protection Institute

https://www.nemasurge.org/

IEEE Power & Energy Society

SPDC

Surge Protective Devices Committee

https://www.pes-spdc.org/

ATIS is where companies in the information and communications technology (ICT) industry come together to address common, critical priorities.

PEG PROTECTION ENGINEERS GROUP

Electrical Protection of Communications Networks

https://pegconference.com/

Guidelines for the Surge Protective Devices Used in ICP UL Certification Requirement Decision

WG3.6.13 WHITE PAPERS:

THE OPERATION OF SPDS IN THE SMART GRID

AND

AN OVERVIEW OF SURGE PROTECTION FOR THE SMART GRID

MAY BE ACCESSED AT:

HTTPS://PES-SPDC.ORG/CONTENT/LOW-VOLTAGE-TUTORIALS

Questions / Comments ………..

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Thank you!

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