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Keeping the Customer Online:

End-User Facility Protection Against Surge Events

Transformer Protection

THE UTILITY SOURCE

Products and Services for Today's Electric, Telecom, and CATV Utilities

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Transformer Protection

By Mike Dickinson

Transformers of varied sizes and configurations are at the heart of all power systems. As a critical and an expensive component of the power systems, transformers play an important role in power delivery and the integrity of the power system network as a whole.

Transformers, however, have operating limits beyond which the transformer loss of life can occur. If subjected to adverse conditions there can be a heavy damage to the system and system equipment, besides intolerable interruption of service to the customers. Since the lead time for repair and replacement of transformers is usually very long, limiting the damage to faulted transformers is the foremost objective of transformer protection.

Economic impact of a Transformer Failure

• The direct economic impact of repairing or replacing the transformer.
• The indirect economic impact due to production loss.

Operating conditions like transformer overload, through faults, etc often result in transformer failure, highlighting a need for transformer protection functions, such as over excitation protection and temperature-based protection. Extended functioning of the transformer under abnormal condition such as faults or overloads can compromise the life of the transformer. Adequate protection should be provided for quicker isolation of the transformer under such conditions. The type of protection used should reduce the disconnection time for faults within the transformer and minimize the risk of catastrophic breakdown to simplify eventual repair.

Transformer Failure

The risk of a transformer failure is two-dimensional: the frequency of failure, and the severity of failure. Most often transformer failures are a result of "insulation failure". This category includes inadequate or defective installation, insulation deterioration, and short circuits, as opposed to exterior surges such as lightning and line faults.

Failures in transformers can be classified into

• Winding failures resulting from short circuits (turn-turn faults, phase-phase faults, phase-ground, open winding)

• Core faults (core insulation failure, shorted laminations)
• Terminal failures (open leads, loose connections, short circuits)
• On-load tap changer failures (mechanical, electrical, short circuit, overheating)
• Abnormal operating conditions (overfluxing, overloading, overvoltage)
• External faults

Other causes of transformer failure may include:

Overloading - Transformers that experience a sustained loading that exceeds the nameplate capacity often face failure due to overloading.

Line Surge - Failure caused by switching surges, voltage spikes, line faults/flashovers, and other T&D abnormalities suggests that more attention should be given to surge protection, or the adequacy of coil clamping and short circuit strength.


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Loose Connections - Loose connections, improper mating of dissimilar metals, improper torquing of bolted connections etc can also lead to failures in transformers.

Oil Contamination - Oil contamination resulting in sludging, carbon tracking and humidity in the oil can often result in transformer failure.

Design/Manufacturing Errors - This includes conditions such as: loose or unsupported leads, loose blocking, poor brazing, inadequate core insulation, inferior short circuit strength, and foreign objects left in the tank.

Improper Maintenance/Operation - Inadequate or improper maintenance and operation are a major cause of transformer failures. It includes disconnected or improperly set controls, loss of coolant, accumulation of dirt & oil, and corrosion.

External Factors - Several external factors like floods, fire explosions, lightening and moisture can be established as the causes of the failure as well.

Transformers Protection Best Practices

Transformer failures and safety hazards can be avoided or minimized by ensuring that the conductors and equipment are properly sized, protected and adequately grounded. Incorrect installation of transformers can result in fires from improper protection, as well as electric shock from inadequate grounding.

*Once the transformer is placed, the tank must be permanently grounded with a correctly sized and properly installed permanent ground.

*Access should be restricted to the transformer liquid-filled compartment in conditions of excessive humidity or rain.

* Dry air should be continuously pumped into the gas space if humidity exceeds 70%.

*Transformer should be given protection against rain such that no water gets inside.

*All equipment used in the handling of the fluid (hoses, pumps, etc.) should be clean and dry. If the insulating liquid for inspection is drawn out, its level should not go below the top of windings.

* Sufficient gas pressure must be maintained to allow a positive pressure of 1 psi to 2 psi at all times (even at low ambient temperature) when liquid-filled transformers are stored outside.

* Final inspection of the transformer is essential before

it is energized. All electrical connections, bushings, draw lead connections should be checked.

* Upon loading the transformer should be kept under observation during the first few hours of operation. All temperatures and pressures should be checked in the transformer tank during the first week of operation.

* Surge arresters must be installed and connected to the transformer bushing / terminals with the shortest possible leads to protect the equipment from line switching surges and lightning.

Transformer Oil Maintenance

Energy transformers are critical components of the energy distribution grid and it is therefore important to have a monitoring and maintenance plan in place to preempt their failure. One of the critical components of an energy transformer is the transformer oil. RELATED ARTICLES

A transformer operates in a moisture free environment and even the slightest moisture can seriously reduce its life. Most companies have an oil maintenance schedule to monitor the condition of oil and detect a problem before it causes extensive damage. Oil testing during maintenance also helps detect problems like contact arcing, aging insulating paper and other latent faults.

Steps for Collecting Oil Sample for Transformer Oil Testing:

Oil testing is a critical process it can be done before the transformer start-up, during a routine transformer inspection or in any circumstances indicating possibility of damage to the transformer, particularly when a protective device is triggered.

To collect an oil sample a sampling valve located near the bottom of the tank is used. Transformer oil is a hygroscopic substance and must be protected from contact with moisture. It is therefore important to place the collected oil sample in a clean dry container.

Oil Treatment Guidelines

Following are the oil treatment guidelines which can prolong the life of transformer and save a company thousands of dollars:

Purify when the acid level is still low, i.e. <0.1 mg

Regenerate preferably from 0.1 mg KOH/g oil to avoid precipitation of sludge

Desludge when the acid level is >0.20 mg KOH/g oil

Dry-out when the solid insulation is wet >3.5 % MDW

Purification, a method of transformer oil maintenance

Purification is the process by which moisture and gasses are removed from the insulating oil. This process readily dries up the oil but not the insulation system, this is because the drying depends on the rate of diffusion of water through the paper into the oil, which is slow. Frequent processing is necessary to attain the degree of dryness desired in the cellulose insulation.

Even though the purification method is not the best, it is an effective moisture management tool. It is used widely in the industry to effectively reduce the moisture content and elevate the dielectric strength of the oil in wet core situations.

Mike Dikinson-contributing writer for Pacific crest transformers. To know more about Transformers maintenance check out Pacific crest transformers website. www.pacificcresttrans.com


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Ronald W. Hotchkiss, Senior Member, IEEE; IEEE PES Surge Protective Devices Committee Chair;

Executive Vice President, Surge Suppression Incorporated

I. INTRODUCTION

Keeping the customer online – which includes protection against electrical surges from a variety of sources at the end user's facility – is a priority for any utility. When there are service outages, the utility is usually the first call to be made. This is also true when it comes to power and signal quality issues. Uptime is the likely most important aspect of the utilities relationship to the customer.

One issue that can be a source of downtime for customers is service interruptions due surge events at their facility. For many years, utilities have implemented standards-based surge protection for both electrical transmission and distribution systems as well as communication systems. However, often the customer of the utility might desire additional protection of their internal power and communication systems. This article will provide insight into protecting electrical and communication services at the user's facility through an overview of the expected electrical surge environment and standards-based application guidance on how to implement protection of those systems.

II. THE SURGE ENVIRONMENT

The IEEE has made extensive efforts to characterize the electrical surge environment for low-voltage systems. This has resulted in several key standards. Two of these are:

- IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits, IEEE Std C62.41.1TM-2002 (R2008)

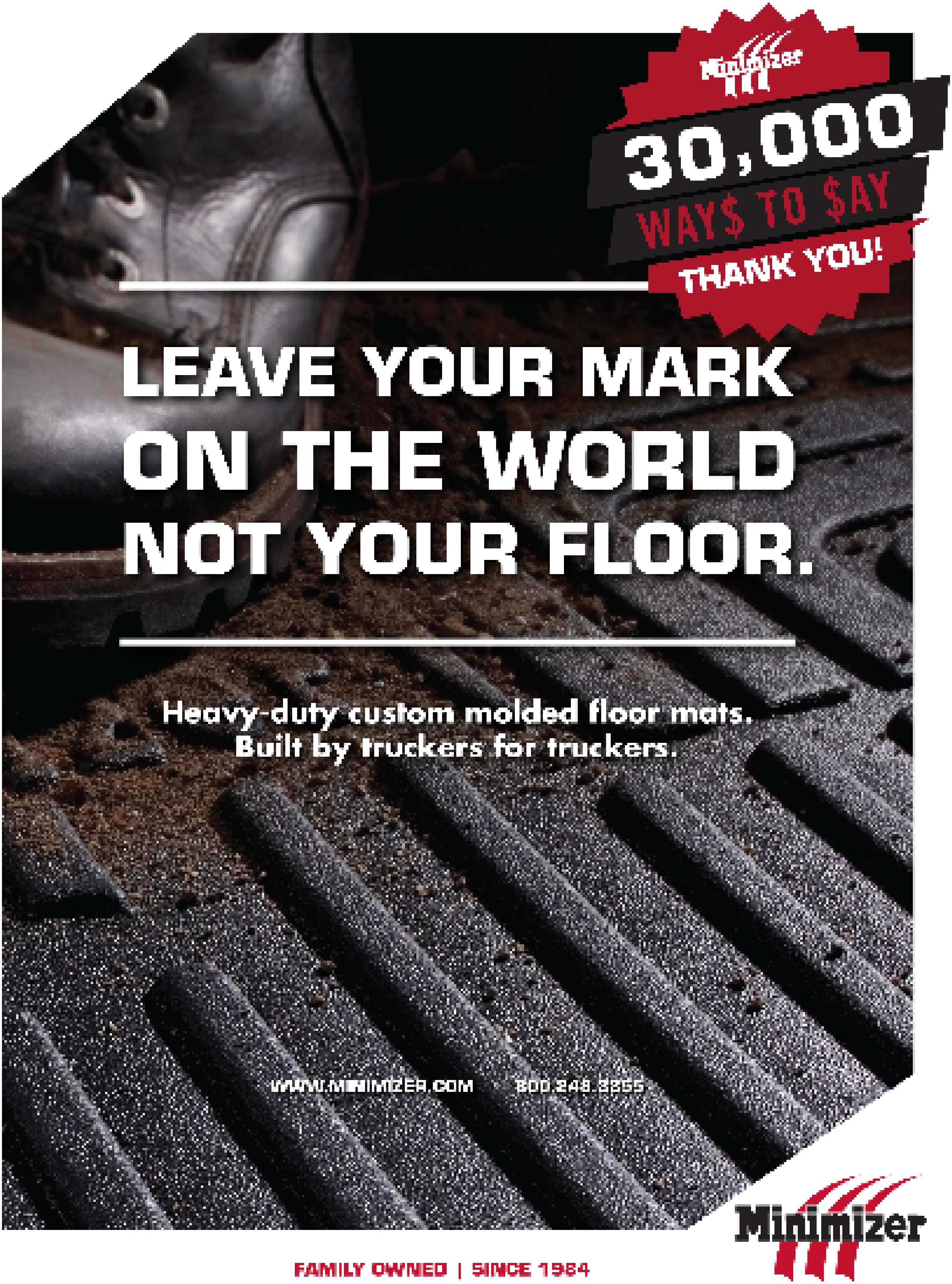
- IEEE Guide for the Application of Component Surge-Protective Devices for Use in Low-Voltage [Equal to or Less than 1000 V (ac) or 1200 V (dc)] Circuits, IEEE Std C62.42TM-2005

Electrical voltage and current surges that occur in low-voltage circuits originate from two major sources, lightning (or environmental causations) and system switching (or system or component causations) [1], [2], [3]. Another aspect that needs identification and understanding is how surges on the ac power circuits can interact with adjacent, differing electrical circuits such as control and communication circuits (and vice-versa) [3], [4].

A. Lightning

Lightning is the physical, recognizable phenomenon that is most frequently and notably associated with electrical surges. Although the frequency of occurrence of lightning is much less than that of switching surges, the effects can be pronounced and devastating to an electrical system.
Lightning events that can influence the electrical system include direct strikes to the power system, near strikes to the area surrounding the electrical system or nearby the structure, and distant or far strikes that can induce voltage surges onto the electrical and communication systems [3], [4].
The direct strike couples directly to the structure or even the electrical system itself in the case of an exposed conductor. The electrical surges related to this type of event are typically the most severe and this level of stress is likely to be immediately damaging to electrical and electronic equipment if left unprotected. Surge coupled or induced onto other circuits are often damaging in nature and can affect systems other than the electrical power system including control and communication systems.

A near, or nearby, strike does not necessarily directly couple to the structure nor the electrical system but interacts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through magnetic, capacitive or inductive coupling. In this case, the threat to the electrical system is similar to that of the direct flash with regard to the coupled surges except that the direct coupling effect is reduced by the fact that only a fraction of total lighting current is involved [4].

During a far strike event, the threat of induced voltages is even further reduced as compared to the direct or near strike due to the additionally increased distance from the lightning channel to the impacted circuits. However, repeated events may still cause disruption, deterioration or cumulative damage to sensitive electrical, electronic and communication circuits over time.

B. Switching (Ringing) Surges

Although much more frequent in their occurrence, switching surges are less notable than and not visible like lightning. Switching surges are not always immediately recognized as being damaging or disruptive to electrical circuits. Switching surges occur as part of every-day normal, intended operations and abnormal, unintentional operations of components within the end user facility electrical system – and not just from the electrical utility.

Often switching surges are caused by the normal and intended action of the electrical system and its components. These sources of surges are deliberately and frequently activated and their actions are completed repeatedly and regularly, as part of the normal operational function of the electrical system. Therefore, it is intuitive that the electrical system may be littered with switching surges. Examples of sources of switching surges that are considered normal events or operations follow.

- Contactor, relay, and breaker operations
- Switching of capacitor banks
- Discharge of inductive devices
- Starting and stopping of loads
- Fault or arc initiation

In contrast, other sources of switching surges are created by abnormal operations. These sources of switching surges are sometimes intentionally activated but typically are due to an undesired or unintended event, such as a fault in the system. Even though these scenarios are undesired or unintended, they are also common. Examples of sources of switching surges that are considered abnormal events or operations follow.

- Arcing faults and arcing ground faults.
- Fault clearing.
- Power system recovery.
- Loose connections.

III. COUPLING OF ELECTRICAL SURGES

The coupling of electrical surges occurs when energy

generated by a lightning or switching surge is transferred to another system. This can occur due to the mutual resistance, capacitance and/or inductance of the circuits [2]. For example, if a communication circuit is physically near a power circuit and the power circuit is subjected to a surge, the mechanisms of inductive coupling through magnetic flux can cause surge energy to be deposited onto the communication circuit. For additional information on and a further explanation of this topic refer to [2]. These coupled or even direct, as in the case of lightning, events are often damaging to communication equipment or even the physical cabling, connectors and interfaces.

Further, it is important to understand that surges are not only coupled from the power conductors to communication or control conductors – the reverse is also true. A surge propagating on communication or control circuits can also couple to power circuits as well. It is a common mistake for one to assume that since a power related component in a multi-service device has failed that a surge must have originated on the incoming power. Further discussion of this topic is available in [4].

IV. PROPAGATION OF ELECTRICAL SURGES

As discussed in [4] the distance of propagation of the surge will depend on the source of the surge and the amplitude of the surge. For directly coupled events, the circuit to which the surge is coupled will most likely have higher impedance than the source of the surge. This may cause flashover in the system and limit the propagation of the surge.

For switching surges, the waveforms of these surges are characterized by rapid changes in voltage and current (dv/dt and di/dt) or "ringing". Further, these surges tend to be oscillatory and decaying in nature. They tend to dampen quickly due to the inherent impedance of the system. However, the lower frequency components of fast oscillating surges and switching surges (switching surges from capacitor banks, for example [4]), can propagate for much longer distances and for longer times.

Generally speaking, the fast-rising wave fronts of the impulse and switching surges are slowed by the distributed capacitance and series inductance of the building wiring; hence, the closer electrically that the equipment is to the source(s) of switching surges, the higher the risk of the equipment being affected by the surge [2]. However, one must not fall into the trap of assuming the impedance of the system will attenuate the surge.

V. SURGE TESTING, WAVEFORMS AND AMPLITUDES

In conjunction with characterizing the electrical surge environment, IEEE has produced standards that provide test procedures and guidance on the representative waveforms, surge amplitudes, and procedures that are recommended when testing SPDs. The documents are:

- IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and less) AC Power Circuits, IEEE Std C62.41.2TM-2002 (R2008)
- IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits, IEEE Std C62.45TM-2002 (R2008)
- IEEE Standard Test Specifications for Surge-Protective Devices (SPDs) for Use on the Load Side of the Service Equipment in Low-Voltage (1000 V and Less) AC Power Circuits, IEEE Std C62.62TM-2010
- IEEE IEEE Standard for Performance of Low-Voltage Surge-Protective Devices (Secondary Arresters), IEEE Std C62.34TM-1996 (R2001)

Based on the electrical surge environment that has been characterized in [3] and [4] (and described above), the waveforms and surge testing described in the above standards represent the switching (ringing) and impulse surges previously discussed. The recommended surge amplitudes are based on the exposure of an SPD to the surge environment. This concept is expressed as "location categories". Location categories include A, B, and C, with C having the highest exposure and A having the least exposure. The associated recommended surge amplitudes range from 6,000 volts and 200 amps for Category A to 10,000 volts and 10,000 amps for Category C. The waveform varies from an oscillatory wave to an impulse. For additional information on the specific parameters of these waveforms and amplitudes, see IEEE Std C62.41.2TM-2002 listed above.

VI. LIGHTNING PROTECTION SYSTEMS AND SPDS

The purpose of the lighting protection system is to create an intentional attachment point for the lightning strike and route it to earth. NFPA 780, Standard for the Installation of Lightning Protection Systems, and UL 96A, Installation Requirements for Lightning Protection Systems, are North American standards that apply to the installation requirements for lightning protection systems. Beyond the very specific requirements for air terminal placement, cabling and down conductor placement – all the mechanical aspects of the system; these standards have specific requirements that a Type 1 SPD or Type 2 SPD with a 20 kA Nominal Discharge Current (In) rating be installed at the service equipment location of the power distribution system. Further, these standards have requirements that all communication and signal incoming services be protected using an SPD with a rating of 10 kA.

VII. SPD APPLICATION

There are many documents published by the IEEE that address various SPD application recommendations and application concerns and issues. Just a sampling of those important issues are outlined here. The standards specifically referenced in this article include:

- IEEE Guide for the Application of Surge-Protective

Devices for Low-Voltage (1000 V or Less) AC Power Circuits, IEEE C62.72TM-2007

- IEEE Guide for the Application of Surge Protectors Used in Low-Voltage (Equal to or Less than 1000 Vrms or 1200 Vdc) Data, Communications, and Signaling Circuits, IEEE C62.43TM-2005

- IEEE Recommended Practice for Powering and Grounding Electronic Equipment, IEEE 1100™-2005

- IEEE Guide on Interactions Between Power System Disturbances and Surge-Protective Devices, IEEE C62.48TM-2005

A. Location Categories – Typical Applications

Based on the location categories established in [4] and [5], [6] provides the following samples of "typical" category installation locations. Category C is the most severe ranging down to Category A for power systems. Typical Category C locations are as follows:

- Outside and including the service entrance equipment.
- Service drop from pole or transformer to a building.
- Conductors between the utility's revenue meter and service entrance equipment.
- Overhead line to detached buildings.
- Underground line to a well pump or other outdoor electrical equipment.
- Typical Category B locations are as follows:
- Service entrance equipment located inside a facility, feeder circuits, and short branch circuits.
- Distribution panelboards and devices.
- Busways and feeders in industrial plants.
- Heavy appliance outlets with short connections to the service entrance equipment.
- Lighting systems in large building or facilities.
- Typical Category A locations are as follows:
- All outlets more than about 10 m from Category B or about 20 m from Category C that do not have external exposure.

B. Installation Lead Length of SPDs

Most SPDs utilized for installation within facilities on electrical panels or equipment are installed in parallel to the electrical systems – that is, the load current does not flow through the SPD. The benefit of a parallel connection of the SPD is that the conductors going to the SPD are small relative to the conductor size that would have to be utilized to carry the full load current through the SPD. Therefore, installations of very large series connected SPDs are often impractical. The detriment of a parallel connection of the SPD to the electrical system is the lead length influences the performance of the SPD – that is, typically, the longer the leads are that connect the SPD to the electrical system, the higher the resultant voltages are that the system is exposed to after the action of the SPD.

Most SPD performance tests are conducted with 15 cm (6 in) of lead length. This standard length is used to allow the comparison of SPDs. Therefore, in order to achieve the optimal performance of SPD when it is installed is required to minimize the lead length of the connection leads. From [6], it is stated:

In general, the lead inductance is assumed as 1 µH/m. The inductive voltage drop caused by an impulse with a rate of rise of 1 kA/µs will be approximately 1 kV/m of lead length. If the steepness of di/dt is greater, this value will increase. This statement indicates that for common surges that are experienced with the electrical system, it is possible that the resultant voltage of the SPD could be increased by 1,000 volts for every meter of lead length used to connect the SPD to the system.

In further support of this concept, IEEE provides guidance from [1]:

Recommended SPD installation practice is for all lead lengths to be short and shaped to minimize open-loop geometry between the various conductors. This is accomplished by removing excess and unneeded lead lengths to the SPDs; by twisting all the phase, neutral, and equipment grounding conductors together; and by avoiding any sharp bends and coils in the conductors.

For further information and extensive discussion of the topics of installation lead length and open-loop geometry, see [7], [1], and [6].

C. Non-Power Circuits

Although not always specifically mentioned in the discussions above, a number of the same concepts and issues apply to non-power (data, telecommunications, signal, sensing, etc.) circuits. For further detail on specific issues and recommendations that may not be included here, see [3].

VIII. CONCLUSION

The electrical surge environment will include electrical surges from a wide range of sources. As described, these surges can propagate through the electrical system and couple to other circuits and systems. The result will be an environment that is potentially harmful to key components and systems relied upon for operation. However, through the use of properly specified, applied and installed surge protective devices, the detrimental effects of the surge environment can be mitigated to a level that promotes better power quality, uptime, and overall system performance and reliability – keeping the customer online.

For additional information regarding our full line of surge protective devices including medium voltage to low voltage power, SPDs for lightning protection systems, communication and signal SPDs, visit Surge Suppression Incorporated's website at www.surgesuppression.com.

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More information can be found at www.towmaster.com or call Towmaster at 800-462-4517.

REFERENCES AND RECOMMENDED READING

[1] IEEE Recommended Practice for Powering and Grounding Electronic Equipment, IEEE Standard 1100-2005

[2] IEEE Guide on Interactions Between Power System Disturbances and Surge-Protective Devices, IEEE Standard C62.48-2005

[3] IEEE 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, IEEE Std C62.42™-2005

[4] IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits, IEEE Standard C62.41.1-2002

[5] IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and less) AC Power Circuits, IEEE Standard C62.41.2-2002

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[12] IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits, IEEE Std C62.45™-2002

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BIOGRAPHY

Ronald W. Hotchkiss (M '97, SM '06) is an IEEE Senior Member and has been actively involved in the design, development and certification testing of surge protective devices since 1990. He is the Executive Vice President of Engineering for Surge Suppression Incorporated® in Brooksville, FL, USA and manages engineering, safety agency listings, and compliance/quality operations.

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