



*A NEMA Low Voltage Surge Protective Devices Section White Paper
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Susceptibility of Electrical and Electronic Components to Surge Damage

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Foreword

This is a new NEMA white paper based on member-supported testing. To ensure that a meaningful publication was developed, draft copies were distributed to groups within NEMA that have an interest in this topic. Their comments and suggestions provided vital input prior to final NEMA approval and resulted in a number of substantive changes in this publication. To remain up to date with advancing technology, this publication will be periodically reviewed by the Low Voltage Surge Protective Devices Group of the NEMA Commercial Products Division.

Proposed or recommended revisions should be submitted to:

Senior Technical Director, Operations
National Electrical Manufacturers Association
1300 North 17th Street, Suite 900
Rosslyn, Virginia 22209

This white paper was developed by the Low Voltage Surge Protective Devices Group of the NEMA Commercial Products Division. Approval of this white paper does not necessarily imply that all members of the Product Group voted for its approval or participated in its development.

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The National Electrical Manufacturers Association (NEMA) provides information to assist with answering various questions related to the application and use of surge protective devices.

Executive Summary

The NEMA Low Voltage Surge Protection Devices, 05VS, has been asked to provide an overview of electrical and electronic equipment surge susceptibility. This overview will help the electrical community, engineers, consumers, and technicians understand the various transient conditions to which electrical and electronic equipment may be subjected. The intent is not to evaluate individual companies' equipment as to safety or product performance, but to create awareness and offer guidance based on real-world testing on protection. This will be helpful in preventing problems with products. While there are many documents, papers, standards, web sites, and other media that talk about the harmful effects of transient impulses practical and empirical data is not readily available. Some of the explanations for this lack of data are the variable conditions electrical equipment is subjected to events such as electrical equipment failure, electronic equipment process interruption, insulation breakdown in electric conductors and electronic circuits, electronic component breakdown, premature aging of electrical and electronic components, etc. The standards community has many test procedures and evaluation practices for a prescribed environment. The challenge is that these environments are normally under standard test conditions, for example, 25°C. There are two issues that are not covered under these standard test conditions.

- a. What is the upset capability of the equipment?
- b. What level of voltage or current would cause damage to equipment?

Quantitative data on how big or how many transient impulses are required to significantly reduce the life of or cause failure of an electrical or electronic device is almost nonexistent. Reasons for this lack of available information are the variable conditions under which an electrical device is subjected, i.e., at one location normal operating voltage might have a range of 110 to 135 Vac. Other locations may have more consistent supply voltage, but how many times does it fluctuate? When it does change, how long was the unstable condition? How large was the transient condition? When a system is influenced by another device or system, how large is the impact on the rest of the equipment?

The 05VS section understands that every possible combination of events and test equipment cannot be tested. The burden placed upon manufactures and consumers would be impractical. For instance, what happens when a transient impulse occurs to an electrical device when it is at its maximum operating temperatures, upper and lower boundaries? As every electrical device has its own unique set of environmental conditions, a frequent request is, "How many surges does it take to damage my equipment" or "How much longer will my equipment last with and without surge protection?"

Another missing piece of information is data on the cumulative effect of transient impulses. The average person, unless taught otherwise, often believes that surge damage is a one-time event. When lightning strikes and a piece of equipment is damaged, the damage may be attributed to a transient impulse. But when a piece of equipment fails due to the accumulation of numerous smaller magnitude surges, the failure is attributed to the age of equipment, poor quality of the equipment, or a hundred other unexplained conditions.

For this paper, the term "surge" and "transient" are used interchangeably.

Scope

The purpose of this paper is to present the test results of actual devices in a real-world surge environment. This white paper will generate some information on the surge susceptibility for various electrical components. This white paper is not meant to be an exhaustive study, nor a complete test spectrum. It is merely a means to provide useful information to the electrical community, both for those who design electronic and electrical equipment and for those who install and use electronic and electrical equipment. The tests were performed in certified testing laboratories. The tests were completed using standardized test sequences and parameters. The test specimens used were off-the-shelf devices; they were not modified or altered in any way. The electrical products used were selected to represent a broad spectrum of common electrical components familiar to all users of electrical appliances.

The results obtained by this testing can be used as a guide to the reaction of electrical devices under various conditions. Some devices might show malfunctions, and some may experience upset events caused by surge events in actual installations. Upset conditions will be a concern if any other electronics are controlling a critical safety component. For example, a control transformer with an upset output could cause process failure for equipment being run by the transformer.

Test Methodology

A variety of waveforms were selected to represent surge conditions. These waveforms are based on the standard waveforms found in the current edition of IEEE C62.41.2 with the addition of some intermediate waveforms from an earlier version of this standard. They are a representation of impulse events created by interruptions in the electrical system. Most equipment is designed to handle minor variations in nominal operating voltages. However, surges can range in impact and adversity and may affect nearly all equipment under certain conditions. Here are some of the standard waveforms for equipment surge susceptibility. While most equipment has a nominal level of intrinsic resistibility, based on environment, application, and installation, additional or redundant levels of surge protection may be recommended.

The following standard waveforms were used in the testing protocol:

- a) Category C Low / Category B Combination Wave (6,000 V / 3,000 A)
- b) Category C Low / Category B Combination Wave (4,000 V / 2,000 A)
- c) Category B Combination Wave (2,000 V / 1,000 A)
- d) Category B Ring Wave (6,000 V / 500 A)
- e) Category B Ring Wave (4,000 V / 333 A)
- f) Category B Ring Wave (2,000 V / 167 A)
- g) Category A Ring Wave (6,000 V / 200 A)
- h) Category A Ring Wave (4,000 V / 133 A)
- i) Category A Ring Wave (2,000 V / 67 A)

Note: See IEEE Std. C62.41.2 TM-2002 especially Clause 6.2; Tables 2, 3 and 4; and the notes associated with those tables for further explanation of the surge test levels selected.

The 6,000 V combination wave was developed to represent a variety of surge events. These events may be externally or internally generated electrical surges, such as when a utility capacitor bank is switched into or out of an electrical system. Internal events can come from inductive load switching. This surge is not meant to be a replication of lightning impulses, but rather a representation of the energy produced from an impulse during normal electrical operating conditions. For additional information on lightning impulses, please see NFPA 780 *Standard for the Installation of Lightning Protection Systems*.

These tests were designed to determine the number and magnitude of surges some common electrical devices used in residential, commercial and industrial applications could withstand before failure. Each

sample was tested starting with the highest magnitude IEEE C62.41.2 waveform from the list above, the 6,000 V / 3,000 A Category C Low Combination Wave. If the sample could withstand 300 surges, the test was stopped.

If the sample failed before 300 surges in this category were applied, then the surge generator was re-calibrated to output the next lower surge waveform. This continued until the sample withstood 300 surges.

The following common electrical and electronic devices were tested:

- a) Incandescent Bulb
 - o Common 120 V, 60 W screw-base bulb
- b) Compact Fluorescent Bulb
 - o Common 120 V, 60 W (equivalent) screw-base bulb
- c) Electronic Ballast & Fluorescent Bulb
 - o Common 120 V electronic ballast with two 25 W, 36 inch fluorescent tubes
- d) LED Bulb
 - o Common 120 V, 60 W (equivalent) screw-base bulb
- e) Control Transformer
 - o Industrial 50 VA, 120 V to 24 V transformer
- f) Variable Frequency Drive (VFD)
 - o Industrial 120 V single-phase, 0.33 HP VFD
- g) Uninterruptable Power Supply (UPS)
 - o Common 120 V, 500 VA, off-line UPS

The test procedure was designed to subject the test samples to a range of surges of different types and magnitudes representing real-world applications. The testing started with IEEE Category C and then proceeded to Categories B and A (decreasing in severity). If the sample failed during the first series of test surges, a new sample was tested with surges of the next lower level until the test sample passed 300 surges without issue.

Note: that the test samples were not directly connected to the surge generator. The samples were connected through a 10 meters (30 feet) length of cable. This is a better representation of a practical and actual electrical installation.

The following steps were taken to conduct the test on each device:

- a) The open circuit voltage waveform and short circuit current waveform were measured to verify the test waveform.
- b) The sample to be tested was attached to the output of the generator using a 10 meters cable (12-2 non-metallic sheathed cable).
- c) Apply the highest combination surges from Table 1 to the first test sample. Perform up to 300 strikes unless the sample fails. The impulses are injected at 60 second intervals and are applied at the peak of the AC sine wave (90 degrees of the power frequency).
- d) If the sample fails, apply the surge waveform in the next column to the right in Table 1 in 60 second intervals at 90 degrees of the power frequency for up to 300 strikes or until the device fails and record results.
- e) Continue testing with the test waveform in the next column to the right in Table 1 until one sample passes the test of 300 surges.

Test Results

Table 1 contains the compiled results of the surge susceptibility testing. The first column describes the device being tested. The devices tested were all commercially available products manufactured by a variety of companies. The second column lists the number of the sample being tested. This is followed by the nine different surge waveforms used in the testing, starting with the highest voltage and current waveforms on the left and working to the lowest magnitude waveforms on the right.

The number in the columns under the different test waveforms are the number of surges of that surge type when the sample failed. None of the samples survived more than one of Category C Low Combination Wave (6,000 V / 3,000 A) waveform. When a number “1” appears in a column, then the test sample failed on the first surge in that category. When there is a “300” in a column under one of the test waveforms, then the test sample survived 300 of those waveforms without damage. At that point, the testing was stopped, as the sample would have passed all the surge waveforms to the next lowest value (to the right in Table 1).

Table 1: Test Results

Sample	Sample Number	Category C Low / Category B Combination Wave			Category B Ring Wave			Category A Ring Wave		
		6 kV 3,000 A	4 kV 2,000 A	2 kV 1,000 A	6 kV 500 A	4 kV 333 A	2 kV 167 A	6 kV 200 A	4 kV 133 A	2 kV 67 A
Incandescent Bulb	1	1								
	2		1							
	3			1						
	4				1					
	5					1				
	6						1			
	7							44		
	8								300	
Compact Fluorescent Bulb	1	1								
	2		1							
	3			1						
	4				300					
Electronic Ballast & Fluorescent Bulb	1	1								
	2		1							
	3			1						
	4				300					
LED Bulb	1	1								
	2		1							
	3			1						
	4				300					
50 VA Control Transformer	1				53					
VFD 0.33 HP	1	1								
	2				300					
	3*				20, L-G					
500 VA UPS	1				300					

Note: All VFD surges were performed Line to Neutral in positive polarity except for VFD sample number 3 which was tested Line to Ground.

Conclusions

Table 1 in this document shows the surge test results for some common products. They cover a range of products from an incandescent light bulb to an uninterruptible power supply. These are common devices that are connected to an electrical supply and are exposed to everyday electrical surges that can be damaged by these events. The surges applied in this testing are at the same levels to be expected in common electrical installations.

As documented in the test results, the surge environment can produce a variety of effects. Surge damage can be experienced in a single event or as the result of an accumulation of surges. For example, in the case of an incandescent light bulb, the damage can be immediate or from repeated surges as shown by the quantity of the 44 surges in the Category A environment (i.e., test sample 7 in the table above). The application of a quality surge protective device can prevent damage to common electrical or electronic products. Surge protection is just as effective when used in commercial and industrial environments.

Electrical equipment is subject to surge damage, and these results show conclusively that everyday electrical devices are damaged by surges of the level expected in a normal electrical distribution system. The application of a surge protective device within a home or facility can alleviate the effects and save the cost or replacement for many electrical or electronic devices. For additional information on surge protection and its applications, visit www.NEMASurge.org.

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