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Surge Protection in Low-Voltage AC Power Circuits - An Anthology Part 1 - Annotated Bibliography

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U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary

TECHNOLOGY ADMINISTRATION
Phillip J. Bond, Under Secretary for Technology

NATIONAL INSTITUTE OF STANDARDS
AND TECHNOLOGY
Arden L. Bement, Jr., Director

FOREWORD

This is the first part of a multi-part anthology, offered to promote better understanding of surge protection techniques through a historical perspective and easy access to relevant papers on the fundamental principles and application of surge-protective devices. It might also serve as a refresher to avoid reinventing surge-protective devices or techniques.

This first part, Annotated Bibliography, provides a list of papers, standards, and textbooks written by many contributors to the development of surge protection technology. Subsequent parts of this anthology will be compiled to include reprints of the public-domain papers by the author as cited in this Bibliography. Those published after 1985 under the umbrella of NIST are in the public domain. Those written before1985 will be reprinted in by permission of the copyright holders or with declassification of proprietary reports; these releases are gratefully acknowledged.

This bibliography is provided to give the interested reader a source of reference material with a few lines of comments on content or comments on the significance of the cited document. The compilation is divided into eight categories, as listed below. Publications relevant to more then one category are listed in each category of interest to allow browsing only through a particular category and still find the listing. The listing is arranged by alphabetical order and chronology of the lead author in each category. The following are the categories for the listing:

1. Standards relevant to surge protection
2. Development of standards — Reality checks
3. Recorded surge occurrences, surveys and staged tests
4. Propagation and coupling of surges (Experiments and numerical simulations)
5. Monitoring instruments, laboratory measurements, and test methods
6. Textbooks and tutorial reviews
7. Mitigation techniques
8. Coordination of cascaded surge-protective devices

Each of the categories 2 through 8 will be compiled in installments and issued as separate booklets. In addition to the printed booklets available from the U.S. Superintendent of Documents, this Anthology will also be available on the Web, thus opening the door for suggestions of additional entries for periodic updates of the listing. The site URL is: **http://www.eeel.nist.gov/811/spd-anthology/**

This bibliography was initially compiled by the author as a contribution to the IEEE "Trilogy" of the Surge-Protective Devices Committee (a set of three standards on the surge environment). This initial compilation is now complemented with additional relevant papers and reports written by the author. Undertaking a listing of "relevant papers" entails the risk of offending researchers whose papers might have been overlooked in the compilation. Sincere apologies are offered in such cases, as the omission was not a deliberate act of rejection, but an unfortunate accident in an imperfect literature search that was initially focused on the Trilogy development rather than aiming to be a comprehensive and exhaustive project. Nevertheless, the volume of this Bibliography is testimony to the contributions from all the listed authors to a data base for the Trilogy. Members of the IEEE working group that developed the Trilogy also contributed suggestions for entries in the listing. All these contributions are gratefully acknowledged.

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December 2001
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Contents

Surge Protection in Low-Voltage AC Power Circuits – An Anthology
Part 1 – Annotated Bibliography

1. Published standards related to surges

1.1 The IEEE C62 Series

A bound-book collection of all ANSI and ANSI/IEEE C62 standards that were compiled periodically by the IEEE. The last such collection was published in 1995 and included all published IEEE standards applicable to Low-Voltage Surge-Protective Devices at the time of the edition. More recent updates of individual standards are listed after the following contents of the 1995 edition:

C62.1-1989 (Reaff 1994)	IEEE Standard for Gapped Silicon-Carbide Surge Arresters for AC Power Circuits
C62.2-1987 (Reaff 1994)	IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for AC Systems
C62.11-1993	IEEE Standard for Metal-Oxide Arresters for AC Power Circuits
C62.22-1991	IEEE Guide for the Application of Metal Oxide Surge Arresters for AC Systems
C62.31-1987 (Reaff 1993)	IEEE Standard Test Specifications for Gas-Tube Surge-Protective Devices
C62.32-1981 (Reaff 1993)	IEEE Standard Test Specifications for Low-Voltage Air-Gap Surge-Protective Devices
C62.33-1982 (Reaff 1994)	IEEE Standard Test Specifications for Varistor Surge-Protective Devices
C62.35-1987 (Reaff 1993)	IEEE Standard Test Specifications for Avalanche Junction Semiconductor Surge-Protective Devices
C62.36-1994	IEEE Standard Test Methods for Surge Protectors Used in Low-Voltage Data, Communications, and Signaling Circuits (Now withdrawn)
C62.38-1994	IEEE Guide on Electrostatic Discharge (ESD): ESD Withstand Capability Evaluation Methods
C62.41-1991 (Reaff 1995)	IEEE Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits
C62.42-1992	IEEE Guide for the Application of Gas Tube Arrester Low-Voltage Surge-Protective Devices
C62.45-1992	IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits
C62.47-1992 (Reaff 1997)	IEEE Guide on Electrostatic Discharge (ESD): Characterization of the ESD Environment
C62.92.x	(A series of IEEE Guides on neutral grounding practices)

1.2 Additional C62 Standards

Additional C62 Standards, or major revisions published since the 1995 collection include:

C62.11-1999	IEEE Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits (>1kV)
C62.22-1997	IEEE Guide for Application of Metal-Oxide Surge Arresters for Alternating-Current Systems
C62.22.1-1996	IEEE Guide for the Connection of Surge Arresters to Protect Insulated, Shielded Electric Power Cable Systems
C62.34-1996	IEEE Standard for Performance of Low-Voltage Surge Protective Devices (Secondary Arresters)
C62.37-1996	IEEE Standard Test Specifications for Thyristor Diode Surge Protective Devices
C62.37.1-2000	IEEE Guide for the Application of Thyristor Surge Protective Devices
C62.43-1999	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
C62.48-1995	IEEE Guide on Interactions Between Power System Disturbances and Surge-Protective Devices
C62.62-2000	IEEE Standard Test Specifications for Surge Protective Devices for Low Voltage AC Power Circuits
C62.64-1997	IEEE Standard Specifications for Surge Protectors Used in Low-Voltage Data, Communications, and Signaling Circuits

1.3 Other Standards

[1] The IEEE SPD "Trilogy" – Pending approval by the IEEE Standards Board expected in early 2002, includes three documents:
- C62.41.1 Guide on the surge environment in low-voltage ac power circuits
- C62.41.2 Recommended practice on characterization of surges in low-voltage ac power circuits
- C62.45 Recommended practice on surge testing for equipment connected to low-voltage ac power circuits

[2] ANSI C2-1999 *National Electrical Safety Code*
– Rules for the protection of persons during installation, operation and maintenance of power and communications lines and equipment for utilities and for systems under the control of qualified persons.
– For building utilization wiring, refer to ANSI/NFPA 70 (National Electrical Code).
– 257 pages, 77 reference documents

[3] ANSI C84.1-1989 *American National Standard for Electric Power Systems and Equipment Voltage Ratings (60 Hz).* (Reaffirmed 1995).
– Defines steady-state limits of system voltages for the United States.
– Addresses only steady-state voltages or short-term departures from nominal conditions.
– Provides list of related standards.

[4] ANSI/NFPA-70-1999 *National Electrical Code*.
– A fundamental document providing minimum requirements for safe installation practices (USA)
– A companion handbook provides explanations for application of the code.
– Specifies minimum requirements for safety, not necessarily optimum surge protection.
– Allows connection of SPDs between any pair of conductors.
– Updated every three years.

[5] IEC *Multilingual Dictionary of Electricity*. The Institute of Electrical and Electronic Engineers, 1983.
– A conversion of parts of the IEC International Electrotechnical Vocabulary (IEV) into a dictionary

[6] IEC 60060-2 (1994) High voltage test techniques — Part 2: Measuring systems
– Defines parameters of impulse waveforms.

[7] IEC 60364-4-442 (1999) *Electrical installation of buildings - Part 4: Protection for safety - Chapter 44: Protection against overvoltages - Section 442: Protection of low-voltage installations against temporary overvoltages and faults between high-voltage systems and earth.*
– Earthing systems and arrangements in transformer substations.
– Earthing arrangements and earthing systems in low-voltage installations.
– Stress voltages in cases of lost neutral (TN and TT), accidental earthing (IT), and line-to neutral short.

[8] IEC 664 (1980) *Insulation coordination within low-voltage systems including clearances and creepage distances for equipment.*
– Superseded, but significant historical document. See IEC 60664 below.
– Introduced the staircase concept of surge voltage reduction.

[9] IEC 60664-1 (2002) *Insulation coordination within low-voltage systems Part 1: Principles, requirements and tests.*
– Major revision and update of IEC 664 (above).
– No longer shows a descending staircase of voltages.
– Does not discuss surge source impedance considerations as it is concerned with insulation withstand.

[10] IEC 61000-2-5 (1995) *Electromagnetic Compatibility - Part 2: Environment - Section 5: - Classification of electro-magnetic environments*
– Basic EMC publication (Technical Report)
– Not a test or performance specification, but a guide to what levels of disturbances might be expected.
– Proposes and arrangement with five classes of locations and corresponding characterized by levels.

[11] IEC 61000-4-4 (1995) *Electromagnetic Compatibility - Part 4: Testing and measurement techniques - Section 4: Electrical fast transient/burst immunity tests.*
– Specifies interference immunity test with bursts of fast-transient pulses applied to EUT in "common mode" by a coupling clamp or in selective mode by capacitor coupling.

[12] IEC 61000-4-5 (2001) *Electromagnetic Compatibility - Part 4: Testing and measurement techniques - Section 5: Surge immunity test.* Consolidated Edition.
– Specifies the Combination Wave (1.2/50 –8/20) only for power circuits (no mention of Ring Wave)
– Line-to-earth test voltage levels are twice the levels specified for line-to-line.

[13] IEC/TS 61312-3 (2000) *Protection against LEMP; Part 3: Requirements of Surge Protective Devices.*
– Presents the IEC TC81 perception of "requirements" for service-entrance SPDs.
– Approved according to the IEC operating procedures, but with only 68% of the votes.

[14] IEC 61643-1 (2002) *Surge protective devices connected to low-voltage power distribution systems - Part 1: Performance requirements and testing methods*
- Defines three classes of tests, I, II, and III with specific energy and charge stress levels.
- Does not relate the test levels to the location of application.

[15] IEC 62066 *(To be published 2002) General basic information regarding surge overvoltages and surge protection in low-voltage a.c. power circuits.*
- A tutorial technical report describing the origins, propagation, and mitigation of surges.
- Bibliography with 58 citations, similar to the present bibliography.

[16] IEEE C37.90.1-1989 *IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relays Systems* [Note: Revision in progress as PC37.90.1 - 2000]
- A document developed for the environment of high-voltage substation equipment. Its fast transient requirement, with a rise time of less than 10 ns, is similar to the IEC EFT burst requirement.
- Calls for a 1 MHz to 1.5 MHz ring wave and a 4 kV to 5 kV peak impulse, < 10 ns rise time.
- 14 references

[17] IEEE Std 4-1995 *IEEE Standard Techniques for High-Voltage Testing*
- Defines impulse parameters.

[18] IEEE Std 446-1995 *IEEE Recommended Practice for Emergency and Standard Power Systems for Industrial and Commercial Applications*
- The earliest publication of the "CBEMA Curve" (updated as "ITIC Curve") occurred in the 1980 edition of this standard.

[19] IEEE Std 518-1982 (Reaff 1996), *IEEE Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources.*
- Discusses the sources of electrical noise; provides an example of the "showering arc" leading to the EFT concept.
- Provides guidance on noise reduction (not suppression) and installation practices.

[20] IEEE Std 1100-1999, *IEEE Recommended Practice for Powering and Grounding Electronic Equipment*
- Recommended engineering principles and practices for powering and grounding electronic equipment in commercial and industrial applications.
- 400 pages, 120 bibliographic citations

[21] IEEE Std 1159-1995 *IEEE Recommended Practice for Monitoring Electric Power Quality*
- Provides definitions of power systems disturbances.
- Makes recommendations on deployment of surge monitoring instruments.
- Makes recommendations on interpretation of power quality surveys.

[22] UL Std 93-1975, *Standard for Safety — Ground Fault Circuit Interrupters.*
- First proposal to industry of what became the 100 kHz Ring Wave.

[23] UL Std 1449 *Standard for Safety -- Transient Voltage Surge Suppressors*, Underwriters Laboratories.
- First Edition: 1985; Second Edition, 1996
- The second edition which became effective in 1998, features a new set of failure mode tests.
- Specifies safety aspects of suppressor design, with some performance implications.
- Requires citation of limiting voltage level, from a tabulation of values starting at 330 V.

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[14] IEC 61643-1 (2002) ...

Does not ...

2 Development of Standards — Reality checks

[24] ANDERSON, L.M. and BOWES, K.B., "The Effects of Power-line Disturbances on Consumer Electronic Equipment," *IEEE Transactions PWRD-5*, No.2, April 1990.

- Experimental study of the immunity of typical electronic equipment to sags and surges.
- Surges applied were not the ANSI C62.41, but a 100 µs or 300 µs pulse, presumably open-circuit voltage.
- Surges of 1000 V (open-circuit voltage of generator) did not cause any failure of PCs.

[25] BACHL, H., MARTZLOFF, F.D. and NASTASI, D., "Using Incandescent Lamp Failure Levels for Assessment of the Surge Environment," *Proceedings, 12th International Zürich Symposium on Electromagnetic Compatibility*, 1997.

- Shows failure mechanisms and levels, by electrical measurements, with high-speed video recording.
- 120-V lamps can fail in the range of 800 V to 1200 V, depending on waveshape and phase angle.
- Makes the point that surges are unlikely to occur frequently at levels above the failure level of lamps.
- 5 references

[26] BARTKOWIAK, M., COMBER, M.G., and MAHAN, G.D., "Failure Modes and Energy Absorption Capability of ZnO Varistors," IEEE Transactions PWRD-14, January 1999.

- Simulation of varistor behavior under current pulses of various magnitudes and duration.
- Comparison with experimental results.
- Demonstrates that energy-handling capability is not a constant, but depends on intensity and duration.
- 14 references, 1 discussion

[27] FENIMORE, C. and MARTZLOFF, F.D., "Incompatibility Between the 100/1300 Surge Test and Varistor Failure Rates." *Proceedings, 9th International Zürich Symposium on Electromagnetic Compatibility, 1991*

- Numerical computations of the energy deposition associated with a proposed IEC standard indicate that massive failure of ubiquitous metal-oxide varistors should occur – but they do not.
- The proposed test was eventually removed from the menu of IEC EMC test methods.
- 10 references

[28] FENIMORE, C. and MARTZLOFF, F.D., "Validating Surge Test Standards by Field Experience: High-Energy Tests and Varistor Performance," *IEEE Transactions IA-28* No.6, December 1992. *(First publication in Conference Record, IEEE/IAS Annual Meeting*, Oct. 1990).

- Computer modeling of the resulting current and energy deposition into typical varistors subjected to the proposed 10/1300 µs waveform.
- Yields a prediction of failure for the small varistors and survival for the larger varistors.
- Because small varistors do not fail in the field at the rate that is predicted by the model, the conclusion is that stresses associated with this proposed waveform make it unrealistic.
- 15 references

[29] GOEDDE, G.L., KOJOVIC, Lj.A., and WOODWORTH, J.J., "Surge Arrester Characteristics that Provide Reliable Overvoltage Protection in Distribution and Low-Voltage Systems," *Proceedings, IEEE-PSE Summer Meeting, Seattle WA, July 2000.*

- Describes field experience of arresters designed in accordance with IEEE Std C62.11-1999.
- Concludes that tests with a 10/350 µs waveform are not necessary.
- 11 references

[30] KEY, T.S., MARTZLOFF, F.D., WITT, R., MAY, J., and BLACK, S., "Developing a Consumer-Oriented Guide on Surge Protection," *Proceedings, PQA'97 North America*, 1997.

- Progress report on the development of a tutorial on surge protection.
- Presents the need for "intersystem bonding" at the entrance of power and communications utilities.
- Brief discussion of the need for surge reference equalizers.
- 6 references

[31] MACIELA, F., "Energetic Design and EDF Distribution Network Experience of MV Metal Oxide Surge Arresters," *CIGRE SC33.95* (1995 Colloquium).

- Field experience of EDF on 700 000 arresters.
- Failure rate lower (1/4) than calculated in [44] Rousseau, 1989 (CIRED).

[32] MANSOOR, A., MARTZLOFF, F.D., and NASTASI, D., "Applying Reality Checks to Standards on the Surge Environment," *Proceedings, 23rd International Conference on Lightning Protection*, Florence, 1996.
- Shrinking surge recordings vs. proliferation of SPDs.
- Applying equipment failure rates to assess the surge environment.
- Limits to pushing surges into branch circuits.
- 19 references

[33] MANSOOR, A. and MARTZLOFF, F.D., "Driving High Surge Currents into Long Cables: More Begets Less," *IEEE Transactions PWRD-12*, No.3, July 1997.
- Measurements and modeling, validating each other, show the physical impossibility for large surge currents to propagate very far into the branch circuits of a building, because flashover will occur at the service entrance.
- Demonstrates the importance of considering the maximum rate of rise (early in the surge) rather than the peak value and overall rise time.
- 13 references

[34] MANSOOR, A. and MARTZLOFF, F.D., "The Effect of Neutral Earthing Practices on Lightning Current Dispersion in a Low-Voltage Installation," *IEEE Transactions PWRD-13*, July 1998.
- Compares the TN and TT for dispersion of lightning current in several scenarios.
- Shows the need for careful review of grounding practices in effect at service entrances.
- Questions the applicability of high amplitude, long duration requirement for service entrance SPDs.
- 20 references

[35] MANSOOR, A. and MARTZLOFF, F.D., "The Dilemma of Surge Protection vs. Overvoltage Scenarios: Implications for Low-Voltage Surge-Protective Devices," *Proceedings, 8th International Conference on Harmonics and Power Quality*, Oct 14-16, 1998, Athens, Greece.
- Three examples of temporary overvoltage conditions that can produce failure of SPDs.
- The significance of available fault current and the need for more explicit standards.
- 17 references

[36] MANSOOR, A., MARTZLOFF, F.D., and PHIPPS, K., "The Fallacy of Monitoring Surge Voltages: SPDs and PCs Galore!" *Proceedings, EPRI PQA'99 Conference*, May 1999
- Experimental measurements of effective mitigation by multiple SPDs.
- Numerical simulation of the effect of proliferating SPDs and PCs.
- Calls for an industry-wide reassessment of surge monitoring parameters.
- 20 references

[37] MARTZLOFF, F.D. and FISHER, F.A., "Transient Control Level Philosophy and Implementation," Part 1: The Reasoning Behind the Philosophy," *Proceedings, 2nd Symposium on Electromagnetic Compatibility*, Montreux, 1977.
- Presents the concept of testing low-voltage equipment patterned on the high-voltage BIL concept.
- Techniques and equipment for making TCL tests.
- 10 references

[38] MARTZLOFF, F.D., "Varistor Versus Environment: Winning the Rematch," *IEEE Transactions PWRD-1*, No. 2, April 1986.
- Staged test of capacitor switching on remote MV side produces ring waves on low-voltage load.
- Coordination between 3 kV and 480 V varistor-based SPDs.
- 5 references, 1 discussion

[39] MARTZLOFF, F.D., "Testing Varistors Against the VDE 0160 Standard," *Proceedings, Open Forum on Surge Protection Application, NISTIR-4654*, August 1991.
- Reports tests performed with a prototype 100/1300 surge generator, resulting in failure of the ubiquitous 20-mm diameter varistors, hence demonstrating that the proposed standard is unrealistic.
- 9 references

[40] MARTZLOFF, F.D. and PELLEGRINI, G., "Real, Realistic Ring Waves for Surge Testing," *Proceedings, 9th International Zürich Symposium on Electromagnetic Compatibility*, 1991.
- Reports measurements on the propagation of oscillatory waves in typical low-voltage circuits, as opposed to the unidirectional waves initially defines for high-voltage power systems.
- Shows how impinging unidirectional surges can produce oscillatory waves responses.
- 17 references

[41] MARTZLOFF, F. D.. "On the Dispersion of Lightning Current after a Direct Flash to a Building," *Proceedings, 25th International Conference on Lightning Protection*, Rhodes, 2000.
- Computer modeling of the current dispersion among available paths to ground.
- Comparison between proposed SPD ratings based on computer modeling and field experience.
- 9 references

[42] MEISSEN, W., "Überspannungen in Niederspannungsnetzen" [Overvoltages in low-voltage networks], *ETZ Bd. 104*, 1983.
- The seminal paper proposing a long waveform with extremely high energy-deposition capability, leading to the development of German Standard DIN 0160.

[43] RICHMAN, P., "New Fast-Transient Test Standards Inadvertently Permit Overstressing by as much as 600 Percent," *EMC Test and Design*, Vol.2, No.5, Sept/Oct 1991.
- Points out ambiguities in the test procedures.

[44] ROUSSEAU, A., *"Requirements for Rating of MV Zinc Oxide Surge Arresters on EDF Distribution Networks,"* CIRED 1989.
- Design of ZnO MV arresters based on statistics of lightning current magnitude and tail.
- Sharing of current between many arresters as well as number of lightning strike per year and per km of overhead line are used in calculations.
- Design based on an energy requirement converted in lab into a 4/10 standard waveshape.
- 13 references

[45] SMITH, S.B. and STANDLER, R.B., "The Effects of Surges on Electronic Appliances," *IEEE Transactions PWRD-7*, No.3, July 1992.
- Clocks, TV receivers, and switching power supplies were subjected to surges from 0.5 kV to 6 kV.
- The switching power supplies and television receivers were damaged with surges from 4 kV to 6 kV.
- Three of five models of digital clocks were upset with surges from 1.6 kV to 6 kV.
- The conventional wisdom that electronic appliances are easily damaged by surges with a peak voltage of a few kilovolts greatly exaggerates the effect of surges on modern consumer appliances.
- 15 references

[46] STANDLER, R.B., "Development of a Performance Standard for Surge Arresters and Suppressors," *Proceedings, IEEE 1991 International Symposium on Electromagnetic Compatibility*.
- Some critical issues in the development of a performance standard for surge arresters and suppressors for use on low-voltage mains are discussed.
- A series of electrical tests to determine the safety and adequacy of surge protective devices is described.
- 4 references

[47] STANDLER, R.B., "Calculation of Energy in Transient Overvoltages," *Proceedings, IEEE EMC Symposium*, 1989.
- Shows that using the integral of $V^2/50\Omega \, . \, dt$ to compute energy in a surge is invalid.
- A quantitative error analysis is presented that uses an artificial AC line network to simulate a long branch circuit and to give the impedance of the AC line as a function of frequency.
- A method for measuring energy dissipated in a varistor is advocated for use in future experiments.
- 18 references

[48] STANDLER, R.B., "Standards for Surge-protective Devices for Connection to the Low-voltage Ac Supply Mains in the USA," *Proceedings, Lightning Protection 92 - Buildings, Structures and Electronic Equipment Conference and Exhibition*, 1992.
- A review major standards in the USA for low-voltage AC power surge-protective devices prepared for presentation at a European based forum.
- Since it is clear that international standards are greatly preferable for both manufacturers and users, the US position [in 1992] on the IEC SC37A drafts is also briefly reviewed.
- 9 references

[49] VANCE, E.F., NANEVICZ, J.E., and GRAF, W., "Unification of Electromagnetic Specifications and Standards," *Defense Nuclear Agency Report DNA 5433F*-1, Washington DC, 1980.
- Describes the need for dual capability of a test generator to adapt inherently to the impedance of the EUT, even during the surge event.

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3 Recorded surge occurrences, surveys, and staged tests

[50] ACKERMANN, G., HUDASCH, M., SCHWETZ, S., and STIMPER, K., "Überspannungen in Niederspannungs-anlagen" [Overvoltages in low-voltage installations], *ETZ Bd. 114* (1993).
- Reports surge monitoring performed in Germany.

[51] ACKERMANN, G., SCHEIBE, K., and STIMPER, K., "Isolationgefährdende Überspannungen im Niederspannungsbereich," [Overvoltages hazardous to insulation in low-voltage systems], *ETZ, Bd 118* (1997).
- Reports surge measurements in Germany that include "energy content" in Ws (watts x seconds).
- 10 references

[52] AIEE Committee Report "Switching Surges - I - Phase to Ground Switching Voltages," AIEE Transactions PAS-80, June 1961.
- Comprehensive report, 1961 vintage, of the subject.
- 84 references, 10 discussions

[53] ALLEN, G.W. and SEGALL, D., "Monitoring of Computer Installation for Line Disturbances," presented at the IEEE Power Engineering Society Winter Meeting, New York, NY, Jan. 1974, *Paper C74 (Conference preprint only.)*
- Reports occurrence rates at computer sites, recorded with CRT memory scopes.
- Possible artifact of insufficient writing speed discussed but not appended to conference preprint. See IEEE Std C62.41.1-2002 data base for that discussion.
- 7 references

[54] ANDERSON, R.B. and ERIKSSON, A.J., "Lightning Parameters for Engineering Application," *ELECTRA No.69*, 1980.
- Probability of occurrence of lightning flashes.
- Peak current amplitude and waveshape parameters.
- 55 references.

[55] ASPNES, J.D., EVANS, B.W., and MERRITT, R.P., "Rural Alaska Electric Power Quality," *IEEE Transactions PAS-104*, No.3, March 1985.
- Survey with digital-output disturbance monitors.
- Did not consider the effect of SPDs integrated in the instrument power supply that limited observed surges.
- 28 references, 2 discussions

[56] BACHMAN, L., GULLBERG, M., STRICKLER, F., and SACHS, H., "An Assessment of Shipboard Power Line Transients."*Proceedings, International IEEE EMC Symposium*, Aug. 1981.
- Surge recordings with storage oscilloscope and disturbance analyzers.

[57] BARKER, P.P., MANCAO, R.T., KVALTINE, D.J., and PARRISH, D.E., "Characteristics of Lightning Surges Measured at Metal-Oxide Distribution Arresters," IEEE Transactions PWRD-8, January 1993.
- Recording of 1309 lightning surges at four sites of distribution systems.
- Uses a modified MOV arrester as transducer to bring signals down to low-voltage input of recorder.
- 23 references

[58] BEJLERI, M., RAKOV, V.A., UMAN, M.A., RAMBO, K.J., MATA, C.T., and FERNANDEZ, M.I., "Triggered Lightning Testing of an Airport Runway Lighting System," *Proceedings, 25th International Conference on Lightning Protection*, Rhodes, September 2000.
- Injection of triggered lightning current into a runway lighting system at Camp Blanding.
- Measurements of the dispersion of lightning current among ground rods and counterpoise.
- 3 references

[59] BELHOMME, R., PLAMONDON, M., NAKRA, H., DESROSIERS, D., and GAGNON, C., "Case Study on the Integration of a Non-Utility Induction Generator to the Hydro-Québec Distribution Network," *IEEE Transactions PWRD-10*, No.3, July 1995.
- Investigates the influence of load, capacitive compensation, machine parameters on resulting overvoltages.
- Presents results of simulation of a distribution network.
- 11 references

[60] BERGER, K., ANDERSON, R.B., and KRÖNINGER, H., "Parameters of Lightning Flashes," *ELECTRA No*.41, 1975.
- The seminal paper on lightning parameters.
- Statistical distribution of 10 parameters, including peak current, charge, and waveshape.
- 8 references

[61] BODLE, D.W., GHAZI, A.J., SYED, M., and WOODSIDE, R.L., *Characterization of the Electrical Environment*, University of Toronto Press, 1976.
- Book initially written from the communications point of view but applicable to AC power circuits.
- 124 references, 320 pages

[62] BOEHNE, E.W. and LOW, S.S., "Shunt Capacitor Energization with Vacuum Interrupters — A Possible Source of Overvoltage," *IEEE Transactions, PAS-88*, No. 9, Sept. 1969.
- Field tests and computer analysis for overvoltages on transformers and arresters, with corrective measures.
- 15 references, 11 discussions

[63] BULL, J.H. and NETHERCOT, M.A., "The Frequency of Occurrence and Magnitude of Short Duration Transients in Low-Voltage Supply Mains," *Radio Electronic Engineer*, September 1964.
- Peak-reading recordings at substations, bus-bars, and point-of use.
- 5 references

[64] CANNOVA, S.F., "Short-Time Voltage Transients in Shipboard Electrical Systems,"*IEEE Transactions IA-9*, No.5, Sept/Oct 1973.
- Oscilloscope recordings and histograms.
- 18 references

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- 12 references

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- Products equipped with overcurrent fuses or magnetic circuit breakers might catch fire in rare cases. This is true for those having both plastic and metal housings and components rated for both 130 V and 150 V.
- A fire hazard test is proposed to be added to safety agency tests for surge suppressors and similar products.
- 3 references

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8 Coordination of cascaded SPDs

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- An effective MOV protection coordination scheme is described and recommended.
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- Contains details of the data base used for the Lai & Martzloff *IEEE Transactions IA-24* 1993 paper [291].
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- While the 8/20 µs waveform can still result in a contribution from both devices to sharing the energy, the 10/1000 µs waveform does not produce any inductive separation of the devices past the rise time, so that energy is equally shared between devices of equal rating.
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- 23 references

[293] MARTZLOFF, F.D., "Surge Voltage Suppression in Residential Power Circuits," *Unclassified GE TIS Report 76CRD092*, 1976.
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- Introduction of the concept of cascade coordination achieved by the inductance of wiring.
- 4 references

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- Where an unidirectional current is injected into the ground system only, the response of the system is an oscillating voltage involving the phase conductors.
- Without substantial connected loads in the system, the open-circuit surges appearing at the service entrance propagate along the branch circuits with very little attenuation.
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- 13 references

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- As a compromise, a cascade with equal voltage ratings for the arrester and the suppressor can offer successful coordination, if the impinging surges are presumed to be relatively short.
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- Bibliography with 32 citations

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- Damage caused by low-side surges can be avoided if properly coordinated arresters are installed at the transformer secondary, service entrance, and load device.
- 15 references

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- Shows that it is better to design the arrester with a smaller conduction voltage than the suppressor, in order to obtain better coordination, better electromagnetic compatibility, and lower cost.
- Computations were made with only resistance of wire between cascaded devices, no inductance.
- 9 references

[299] STRINGFELLOW, M.F. and STONELY, B.T., "Coordination of Surge Suppressors in Low-Voltage AC Power Circuits," *Proceedings, Forum on Surge Protection Application, NISTIR-4657*, August 1991.
- Experiments showing the effect of line length and impinging surge waveform on sharing energy between service entrance arrester and surge suppressor inside building.
- Metal-oxide varistors were applied at three points on the system. These were at the service entrance, at the distribution panel and at the load.
- Removal of protection at either load or distribution panel resulted in unacceptably large oscillatory voltages. Best load protection was achieved with MOVs in all three locations.
- 4 references

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