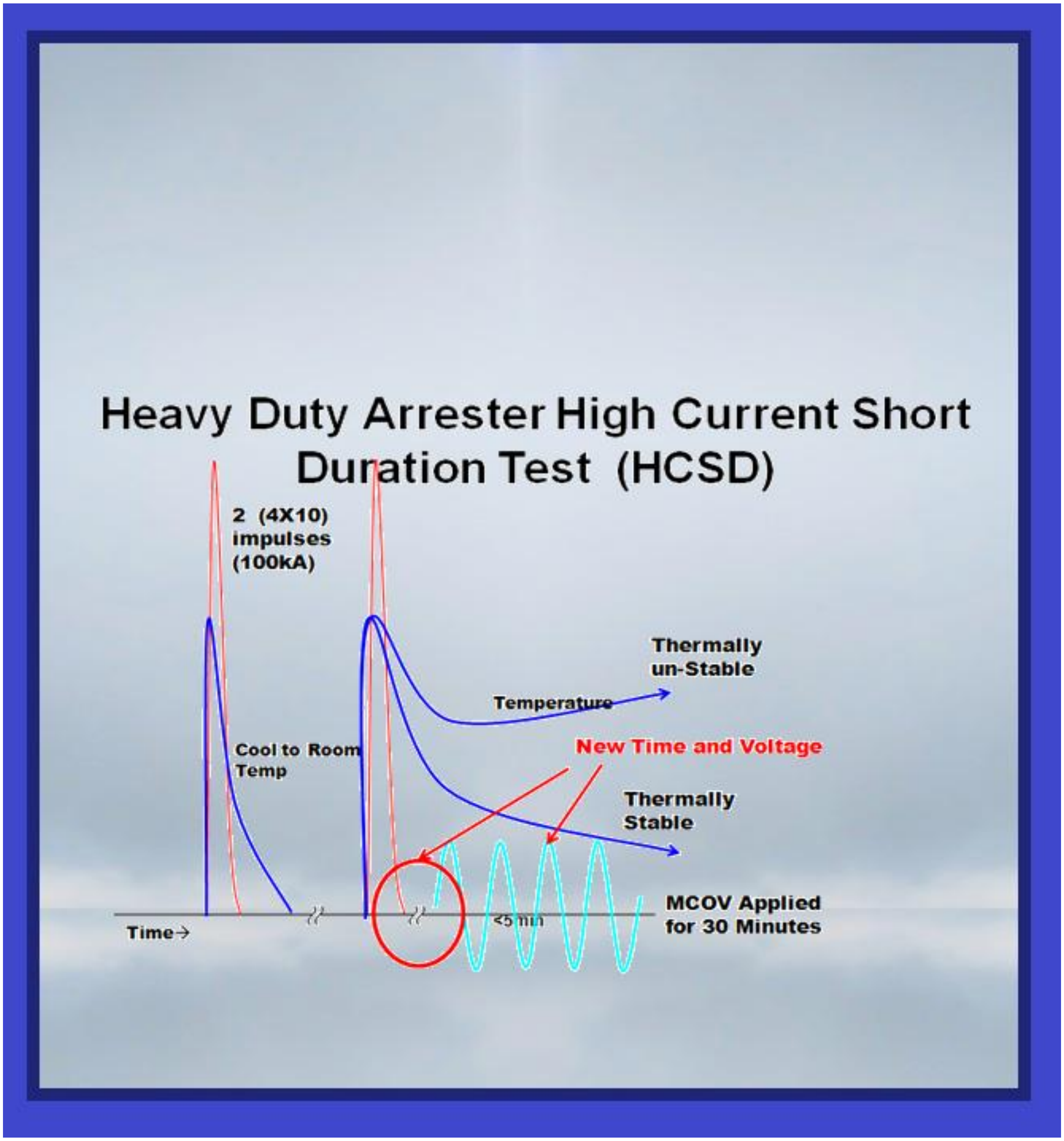
ArresterWorks

New IEEE C62.11-2012 Arrester Test Requirements



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By Jonathan Woodworth and Michael Comber

Introduction

Since the introduction of Metal Oxide Varistor (MOV) arresters in the late 1970s there has been no adequate means of assessing the realizable energy handling capability of these arresters. The tests prescribed in IEEE C62.11 to date that have been essentially the same as those used for testing the earlier generation silicon carbide arresters. Even though the tests subject arrester samples to several different types of surges, there has been no standardized quantification of the energy handling capability. This lack of standardization with respect to energy handling has resulted in considerable misunderstanding of published arrester characteristics. Some arresters appeared to have as much as twice the energy handling capability of arresters of very similar construction and rating where, in fact, they were just tested differently. A somewhat similar situation existed with the IEC 60099-4 test standard. Members of both IEEE and IEC arrester standards writing teams have participated in the activities of CIGRE Working Group A3.17 (and later Working Group A3.25) which undertook an experimental investigation of the energy handling characterization of MOV arresters, with the goal of providing information to help shape future standardized tests. From the 2004 initiation of this work to the present, the CIGRE studies have yielded new understanding of how MOV arresters respond to various energy inputs. This new understanding is the basis of the energy related changes in

After the previous edition of C62.11 was published in 2005, a comprehensive review of the test requirements was proposed, with the objective of making the tests more relevant and of more benefit to the industry. Through this review, it was hoped that parts of the standard that could not be justified as "valuable to the realistic characterization of an arrester" would be modified or eliminated. As a result of this review process, several tests (including TOV, residual voltage, accelerated aging procedure, low current long duration, duty cycle, and failure mode of liquid immersed arresters and deadfront arresters were modified.

Energy Handling Tests for Station and Intermediate Arresters

It has been apparent to stakeholders in surge arresters for many years that the methods used to quantify a station or intermediate arrester's energy handling capability has been flawed. After considerable contemplation of the working group the following issues clearly needed resolution:

1. Existing tests do not provide a standardized means of establishing and verifying energy handling capability, leaving it to manufactures to "invent" their own procedures and claims, typically resulting energy ratings that do not mean the same thing.
2. Users, who perform transient studies of their systems to determine protective needs require data that is more realistic.
3. Impulse withstand and thermal withstand characteristics are tested (in some form) using the same tests. However, they are not discernible from one another.

It became clear early on that it would be desirable to modify the tests to provide means of independently verifying arrester thermal withstand and impulse withstand capabilities. Previously, the two were intermingled in both the operating duty cycle tests and the low-current long-duration (transmission line discharge) tests.

Switching Surge Energy Rating

During the act of clamping a surge on a power system, the arrester absorbs energy, resulting in a temperature rise of the MOV disks. If the temperature rises to a level that leaves the arrester unable to operate stably then it will become thermally overloaded, leading to thermal runaway and likely ultimate failure. In the new edition of C62.11, the maximum energy that the arrester can handle without overload is referred to as the switching surge energy rating.

Switching surges are typically of low enough amplitude that a single impulse will not cause electro-mechanical damage to the MOV disks of a properly sized arrester. What is of more concern is how much total energy(from multiple surges) can the arrester absorb and still remain thermally stable.

Test Description

The new test is combines elements of the existing high-current short–duration and transmission line discharge tests, and its introduction will allow both of the existing tests to be eliminated for station and intermediate arresters. The test sample, which practically needs to be a prorated section, must first be verified to have thermal properties that are equivalent to the complete arrester. The sample need only be 6kV but can be has high is desired.

Test steps and their rationale are as follows (see Figure 1):

1. Impulse samples with an 8/20 current waveshape at nominal current. Record the discharge voltage of the samples.
2. Precondition the samples with six sets of three square wave impulses. This conditioning is to produce an effect of aging over the service life of the arrester. The energy injection during this part of the test is 50% of the claimed switching surge energy rating.
3. Impulse the samples with two 65kA high-current short duration impulses, also intended to produce an effect of aging over the service life of the arrester.
4. Heat the samples to 60 °C. This temperature represents the maximum operating temperature of the arrester under normal operating conditions.
5. Subject the samples to two switching surges of rectangular waveshape. Record the energy absorbed during these two surges. The energy absorption from each surge of the sample shall be equal to 50% of the projected switching surge energy.
6. Within 100 ms after the second switching surge, subject the samples to a temporary overvoltage (TOV) for 10 seconds. Voltage shall equal the duty cycle voltage rating of the arrester.
7. Immediately following the TOV, subject the samples to MCOV for 30 minutes or until thermal stability is attained.

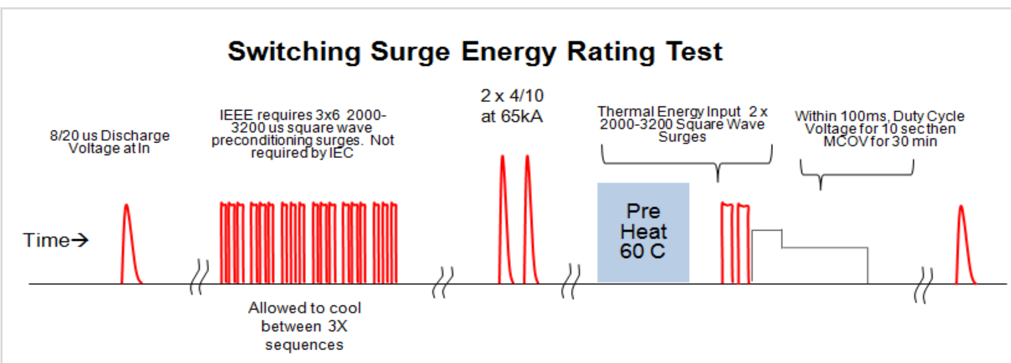

Figure 1 Switching Surge Energy Test Sequence

8. Repeat the initial discharge voltage measurement.

Evaluation

If the arrester remains stable at the end of the test, there is no physical damage visible, and the discharge voltage has not changed by more than 10% the sample is consider to have passed the test.

Energy Rating Calculation

The claimed switching surge energy rating of the sample will be 2 times the energy injected during each of the two switching surges just prior to the TOV application.

Typical Switching Surge Energy Classifications and Suggested System Application		
Max system rms L-L voltage kV	**Min rms MCOV rating kV**	**Minimum Switching Surge Energy Handling Class and kJ Rating**
Station Arresters		
72	42	A (3.0)
121	70	A (3.0)
145	84	A (3.0)
169	98	A (3.0)
242	140	B (4.5)
362	209	C (6.0)*
550	318	F (11.0)*
800	462	H (15.0)*
Intermediate Arresters		
4.37–145	2.55–84	A (3.0)

Table 1 Typical Switching Surge Energy Ratings and Suggested Application

*Note: These ratings are still under consideration by the IEEE application working group.

If each surge contained 1.5kJ, the energy rating of the sample will be 3.0kJ. Classes of ratings will span from Class A at 3.0kJ/kV MCOV to Class N at 30kJ/kV MCOV. Note that the rating is expressed as a function of the arrester MCOV.

Selecting the Right Energy Rating

The energy requirement for a station or intermediate class arrester is a function of the system voltage, length of the line, and arrester rating. For most accurate estimates of required energy handling capability, a detailed transient analysis should be performed using transient software. In the absence of a transient analysis, IEEE C62.22, the arrester application guide, offers several simple formulae that can be used to estimate the energy absorption requirements of arresters. The following formula is most commonly used:

$$J = 2D_L E_A I_A / v \qquad (1)$$

where

E_A is arrester switching impulse discharge voltage (in kilovolts) for I_A ,

I_A is switching impulse current (in kiloamperes),

D_L is line length (in kilometers), and

v is the speed of light, 300 km/ms.

The equation assumes that the entire line is charged to a prospective switching surge voltage (which exists at the arrester location) and is discharged through the arrester during twice the travel time of the line. The discharge voltage E_A and current I_A are related by :

$$I_A = (E_s - E_A)/Z \qquad (2)$$

where

E_S is prospective switching surge voltage (in kilovolts)

Z is single-phase surge impedance of line (in ohms).

Note, this is a single discharge, and if reclosing is common where the arrester is applied, then twice the energy rating should be considered. Once the energy absorption requirement of an arrester (typically expressed as kJ/kV MCOV) is determined, the switching surge energy rating can be selected from manufacturers' catalogs. The next higher energy class above the minimum required should be selected. See examples in Table 1 for energy ratings when reclosing is not considered.

Note that this rating is based on the assumption that the arrester will be energized at system line-to-ground voltage after the surge event. If this is not the case, then the single impulse withstand rating may be more relevant for selection of the arrester energy handling capability.

Also, note that a joule rating may sometimes be misleading. Arresters of equal rating may have different energy capabilities merely as a result of differences in their switching surge discharge voltages (see example of Table 2). Since the primary objective of the arrester is to clamp voltages, the higher energy rated arrester may in fact be a poorer choice, not better.

Comments on Test Improvements

For the first time in the history of arrester standards, switching surge energy ratings will be comparable across arrester designs and between different arrester suppliers.

Other firsts include:

- a test that quantifies the thermal limits of an arrester while not confounding it with impulse withstand capabilities
- the "aging" effect of high current short duration and low current long duration impulses will be combined in a single test
- published arrester energy handling capabilities can be used with confidence in selecting an arrester based on results of transient analyses results

Single Impulse Energy Withstand Rating

The working group had been petitioned numerous times to develop a standard test that quantified the single impulse withstand capability of an arrester. In this case, the concern is not with thermal recovery but with maximum duty that an arrester can handle in a single event without physical damage. This characteristic is related to the electro-mechanical strength of the material. High magnitude and/or rapidly rising impulses can create a physical shock wave resulting from the rapid rise in temperature at the grain boundaries in the MOV material.

Again, the CIGRE research led to a means of testing to determine and verify this capability, which is defined as the maximum charge of a single current impulse that the arrester can withstand multiple times during its life without causing physical or electrical damage to the varistors of the arrester. While energy can always be associated with an impulse current conducted by an arrester, it was determined that the charge content of the impulse is a more relevant measure of the single impulse capability.

Test and Unit of Measure Rationale

Arrester MCOV	Switching Surge Discharge Voltage	Joules Absorbed	Charge Transferred
kV rms	kV peak	kJ/kV MCOV	Coulombs
98	247	5.04	2.0
98	325	6.63	2.0

Table 1 Comparison of Energy and Charge Unit of Measure for 1000 A, 2 ms Current Impulse

The single impulse capability has not been quantified in the past. Based on the CIGRE findings, it was agreed that the best quantification of this characteristic would be charge transfer, measured in Coulomb (C), rather than energy. One Coulomb is one Ampere-second, and the Coulomb charge content of an impulse current is the integral of the current over its duration. This unit of measure is completely independent of the arrester's discharge voltage and voltage rating. It is completely a function of the current amplitude and duration. This is somewhat similar to quantifying a distribution arrester's high current capability as 100kA or 65kA. Table 2 contrasts the joule and charge ratings of similar arresters both impulsed with a 1000 A, 2 ms rectangular wave.

Shortcut Estimate of Charge

The charge content of a current impulse is the integral of the current over the duration of the impulse, and is equivalent to the average current multiplied by the duration of the impulse. For a switching impulse, the current is typically of rectangular waveshape, with more or less constant current magnitude over its duration, and the average current can be approximated as the peak current. Thus the charge content of the impulse is approximated by the peak amplitude multiplied by the duration. For example if the test impulse is a rectangular wave of 1000 A magnitude and 2 ms duration, the charge transferred in the test would be 1000 x .002 = 2.0 C.

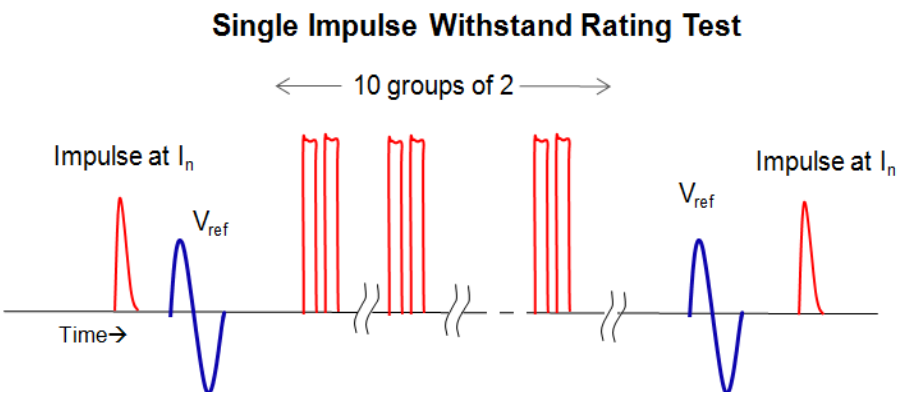

Figure 2 Single Impulse Withstand Rating Test Sequence

Single Impulse Withstand Rating Test

This test is performed on single MOV disks that do not need to thermally represent the arrester. The test is referred to as the single impulse withstand rating test, although it actually involves multiple impulses. The reason for the multiple impulses is to demonstrate that the arrester is capable of withstanding the impulse duty many times during its lifetime. The arrester is allowed to cool between impulses to assure that the result is not affected by the high temperatures that would occur with repeated impulses.

After the sample is characterized with reference voltage V_{ref} and discharge voltage at classifying current I_n , it is surged 20 times at 110% of the single impulse charge rating being verified. The extra 10% is a "safety margin" to account for the fact that the test is performed on a relatively small number of samples. After the 20 impulses, the sample is re-characterized with V_{ref} and discharge voltage at I_n.

The evaluation is based on three criteria;

1. No physical damage.
2. V_{ref} not changed by more than 5%
3. Discharge voltage not changed by more than 5%.

Comments on new Test

This is the first time that V_{ref} has been used to evaluate degradation in an arrester. It has been well known for some time by manufacturers that high current surges can degrade the varistor material and that small changes in V_{ref} were a precursor to serious degradation. Using this characteristic to evaluate durability is a very positive move.

Recommended Ratings

At the present time, there are no recommended charge transfer ratings for arresters. However, Table 3 offers the charge levels associated with various surge events.

Surge Event Type	Approximate Charge Content (C)
1000 A 2 ms square wave	2.0
100kA 4/10	0.96
65kA 4/10	0.62
First stroke of a lightning surge	5.0
Full Lightning Surge including all strokes	25.0

Table 2 Typical Charge Transfer levels of Power System Surges

Improved Discharge Voltage Tests

Three fundamental changes in the discharge voltage tests will come with the next edition of C62.11:

1. The test will now "normalize" discharge voltages of the design test to the discharge voltage of the routine test to validate the manufacturer's published protective levels
2. The front-of-wave test will now include a "correction" to account for self-inductance of the arrester.
3. The front-of-wave test use is simplified by using a single impulse waveshape instead of extrapolating results from tests with three impulse waveshapes.

Normalization of Data

Because it is acceptable to run the production routine test for arresters at current magnitudes different from those specified for design tests, a method of relating design test data to routine test data is necessary. The process for doing this has been undocumented in the past. With the new normalization procedure, the design test data can be used in conjunction with the routine test data to demonstrate that the arrester being produced will meet the manufacturer's published protective characteristics. The term normalization simply refers to the process of dividing the design test voltage measurement by the maximum voltage allowed in the production routine test. Annex A of the standard provides numerical examples of the use of this new procedure.

Front-of-Wave Inductance Effect

In the past, the inductance of the arrester, which is only an issue for the front-of-wave waveshape (because of its high rate of rise of current), has not been well documented. The test now calls for specific measurement of the inherent inductive voltage drop of the arrester and it must be reflected in the published data. Future published data will have two columns of data for front-of-wave data. One will include the inductive voltage drop of the arrester and one will not. This is an important change that will now show the real difference between front-of-wave discharge voltage characteristic of longer and shorter arresters with the same MCOV rating.

The method of quantifying the inductive voltage drop is to place a metal disk similar in size to the MOV disk being tested in series with the disk during the test. First measure the discharge voltage of the MOV disk and then switch position of the MOV disk and metal disk. During a second impulse, measure the impulse voltage drop across the metal disk. By subtracting the voltage of the metal disk from the voltage of the MOV disk, the MOV discharge characteristic represents a disk without inductance. Figure 3 shows this graphically.

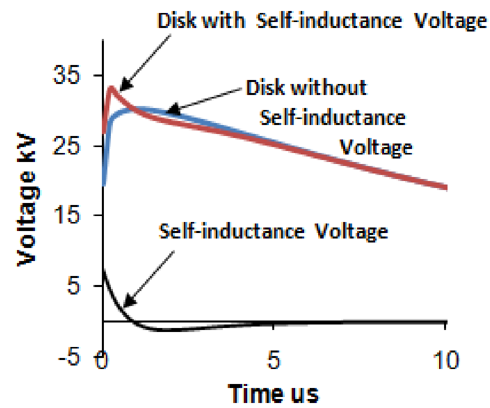

Figure 3: Front-of-wave discharge voltage with and without inductive voltage

This new front-of-wave characteristic will be useful for those running transient analysis and those modeling arresters.

For publication data, the column of data including the inductive voltage will be calculated from the data excluding the inductive effect.

The inductive voltage to add to the non-inductive characteristic will be a function of the arrester length and the rate of rise of current, and is given by:

$$V_{ind} = L' \times h \times \frac{di}{dt} \qquad (3)$$

where

h = actual arrester height in ft (or m)

L' = .33 µH/ft (or 1 µH/m) for air insulated arresters

dt = time to crest in µsec

The current magnitudes to be used in the calculation are the same as those of the arrester's nominal classifying current.

Front-of-wave Waveshape

The front-of-wave test in IEEE C62.11 for MOV arresters was a carryover from the earlier generation silicon carbide arrester standard IEEE C62.1. When those tests were developed, it was much more difficult to attain a 1 µs time-to-crest current surge in the lab than it is today. Consequently, to determine the front-of-wave characteristic, three slower current waveshapes were used and the final front-of-wave voltage was extrapolated from the resulting voltage of the three surges.

After discussion of this test during the test rationale meetings, it was suggested that this test be vastly simplified and instead of using three waveshapes and extrapolating, that one fast front waveshape be used. This was adopted and for future front-of-wave tests, only a single, 1 µs time-to-crest surge will be used on several samples to measure the front-of-wave characteristic.

This test will not only supply those modeling arresters with better data, it will also correlate with the method used in the IEC community. It will also ensure that when accounting for the inductance of an arrester, a standard method will be used across all test labs and by all manufacturers.

Improved Duty Cycle Test

The duty cycle test is one of the most complex tests performed on arresters. The arresters are impulsed repeatedly with surge currents while energized at an AC voltage. The first change in this test is the level of the AC voltage applied during the 20 preconditioning surges. In the past, the applied voltage was modified based on a factor K_r to take account of MOV disk aging and a factor K_w to take account of the fact that tested MOV disks may not have the highest watts loss permissible in production. Since disk aging is considered an issue of the past that should no longer exist with modern MOV disks, a separate test is required to show that no aging occurs, thereby eliminating the K_r factor from the duty cycle test. The test voltage is now only adjusted by the K_w factor.

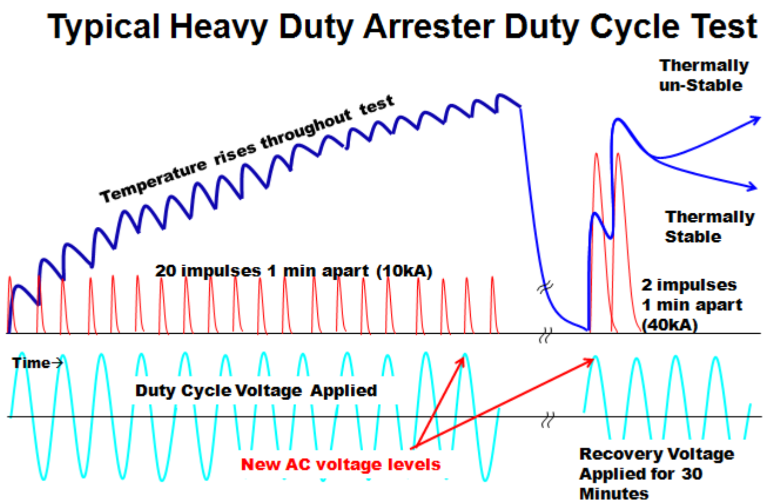

Figure 4 Graphic Overview of Duty Cycle Test

Improved High-Current Short-Duration Test

Two changes in this procedure may appear minor, but could have significant impact on the results of the tests. Again, during the rationale review process it was noted that the allowed delay (5 min) between the second high current impulse and the application of recovery voltage was not realistic. In the real world there would be no delay since the arrester would be energized when the surge hits. The allowed delay has been in all previous editions of C62.11 and was implemented to give sufficient time to move the sample from the impulse lab to the AC lab. Since it is practically universal that today's labs have these test cells located together it was agreed that the 5 min delay could be drastically reduced. The allowable delay is now 100 ms,

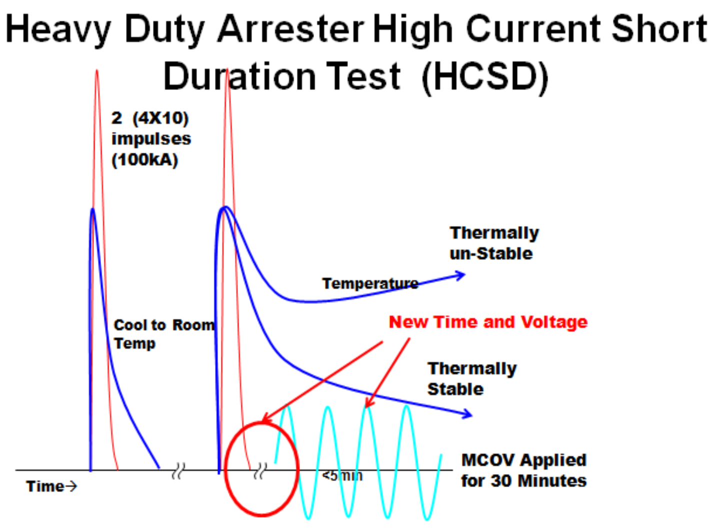

Figure 5 High-Current Short-Duration Test

sufficient to allow for switching circuits from impulse to AC.

The second change is similar to that in the duty cycle test; namely, recovery voltage does not need to account for an aging correction factor and needs adjustment only for watts loss limits. Figure 5 show an overview of the test sequence.

Improved Low-Current Long-Duration Test

Two significant changes have been made to this test.

1. Station and Intermediate arresters are now exempt from this test since their energy handling capability is covered in other tests.
2. The test has been changed for distribution arresters to an impulse withstand test (very similar to the station class impulse withstand test) from a combination of impulse withstand and switching surge energy withstand test.

The test as performed in the past was an odd combination of impulse withstand and thermal withstand. It was agreed by the working group that since the duty cycle test adequately evaluates the thermal capability of a distribution arrester, then this test should be focused on impulse withstand. Therefore, two changes have been made. The first is to the square wave application, which is changed from three groups of six impulses to six groups of three impulses. This eliminates testing the disks at extreme temperatures which is not the purpose of an impulse withstand test. The second change is to eliminate the thermal recovery portion of the test.

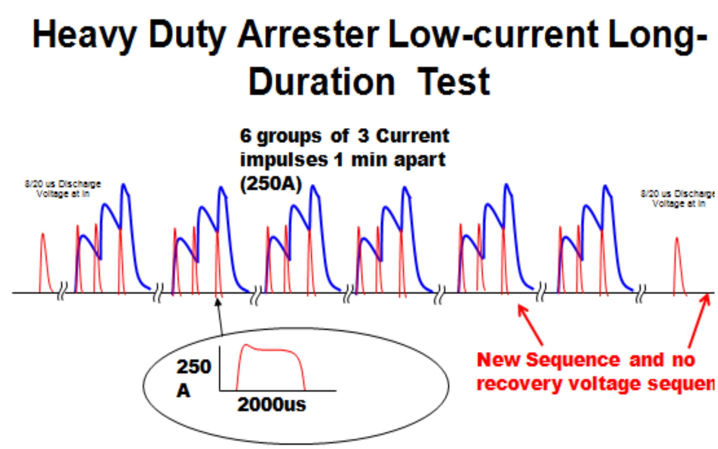

Figure 6 New low-current long-duration test sequence with temperature predication

Improved Accelerated Aging Test

Since the first MOV arrester standard, the accelerated aging test has served two purposes. First, it provided assurance that the disk formulation had long term stability and, secondly, it provided correction factors used in all the thermal recovery tests.

With advances in MOV technology over the years, the validity of the aging test has come into question. The long term behavior of today's MOV disks clearly do not follow the Arrhenius aging model that has been used from the first days of MOV arresters. This model considers that watts loss steadily increase over time at a given voltage and temperature (hence the "aging" effect). However, it is now widely recognized that current technology MOV disks should not exhibit a trend of increasing watts over time, essentially showing no "aging" in the previously understood manner.

Consequently, the accelerated aging test has been changed to reflect the technology advance. Instead of using the test as a means to determine a correction factor to account for aging, it

is now a test to demonstrate that there is not an aging effect. The criterion for passing the test is simple. No aging of disks will be allowed. This means that the watts loss at the end of the test cannot be higher than the start of the test.

Temporary Overvoltage Test

The temporary overvoltage test has been changed with simplification in mind. The basic procedure was considered appropriate for determining the TOV vs. time curve, but the number of tests was onerous. It was the general opinion and agreement of those experienced in the test that the extra samples and repetitive tests did not add any value to the data or the test. Five samples were reduced to 4 samples, and instead of testing them 5 times at 5 time frames, the 4 samples are tested one time at 4 time frames. The number of tests is reduced from 25 to 4. All other aspects of the test remained the same.

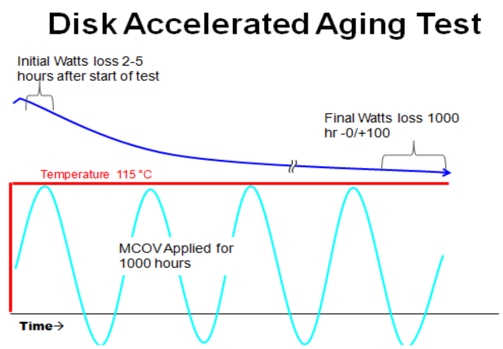

Figure 7 New Accelerated Aging Test of Disks

Improved Accelerated Aging Test of Polymer Housings

The only change to this test has been the elimination of the 5000 h alternative test option. Elimination of this test was justified in that all too often it was specified by users, not as an alternative, but as a requirement in their specification. The reason the test was often required in the specifications was a lack of understanding and instead of leaving it as an alternative test it was added in an effort to be conservative. Because the test is not believed to add any more information to the quality of the arrester housing performance data, it was agreed to just eliminate it.

Elimination of Conformance Tests

After 35 years of MOV production, it was determined that no manufacturer of arresters had ever performed this test. For lack of value to the standard, it was eliminated. Routine tests remain unchanged.

Annex D Test Rationale

A process to review the arrester test standard in detail was proposed in 2005. To meet this objective a taskforce was organized to write a rationale for each required test. It was believed that in the process of writing the rationale, test improvements would surface.

After several rationales were written it became obvious to the working group that this process was indeed quite valuable for the following reasons.

1. It gave the working group a formal method of reviewing the tests in minute detail.
2. It provided the working group members a history lesson of where the test came from and why they were needed.
3. It gave the working group a forum to discuss realistic potential improvements.

After several discussion sessions, it was decided that maintaining the rationale as an annex to C62.11 would be very beneficial to future standards writers. It was further agreed that whenever possible the rationale would have the following sections:

1. Stated Purpose: This is a repeat of the purpose of each section. It is usually very short so it served as a local reminder of the objective of the test.
2. Historical Notes: For some tests, this section is very valuable for understanding the test and the reasoning behind them.
3. Rationale of Sample Selection
4. Rationale of Procedures
5. Rationale of Evaluation
6. Future Considerations: In this section of the rationale, tests that need more consideration can be identified and left for future work.

The results of the rationale taskforce were substantial in providing direction to the working group on where the standard needed improvement. Test Rationale Annex D will be updated whenever a test is updated and a clear explanation of the test rationale will always be available to the present and future users of the standard.

Summary

The working group has made major modifications to this standard with very positive outcomes in the value of the data and the product to which it certifies. The only major areas where future work should be considered are mechanical and electrical tests on transmission line arresters.

Acknowledgements

This vastly improved edition of C62.11 would not have been possible without volumes of input from many members of the SPD Working Group 3.3.11. Their cooperation and insight over the last five years were remarkable.

References

1. C62.11-2005 Standard for Metal-Oxide Surge Arresters for AC Power Circuit(>1 kV)
2. PC62.11 D12 has served as the latest version of text. PC62.22a D1 has served as the latest revision used in the application of energy handling tests.

ArresterFacts are a compilation of facts about arresters to assist all stakeholders in the application and understanding of arresters. All ArresterFacts assume a base knowledge of surge protection of power systems; however, we always welcome the opportunity to assist a student in obtaining their goal, so please call if you have any questions. Visit our library of ArresterFacts for more reading on topics of interest to those involved in the protection of power system at:

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Jonathan started his career after receiving his Bachelor's degree in Electronic Engineering from The Ohio Institute of Technology, at Fermi National Accelerator Laboratory in Batavia, IL. As an Engineering Physicist at Fermi Lab, he was an integral member of the high energy particle physics team in search of the elusive quark. Wishing to return to his home state, he joined the design engineering team at McGraw Edison (later Cooper Power Systems) in Olean, New York. During his tenure at Cooper, he was involved in the design, development, and manufacturing of arresters. He served as Engineering Manager as well as Arrester Marketing Manager during that time. Jonathan has been active for the last 30 years in the IEEE and IEC standard associations. Jonathan is inventor/co-inventor on five US patents. Jonathan received his MBA from St. Bonaventure University.

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Michael G Comber (M'72, SM'80, F'02, LF'11) Mr. Comber received his B.Sc. (Electrical Engineering) and M.Sc. (Power Systems Engineering) from the University of Aston, Birmingham, England, in 1966 and 1967, respectively. After 2 years with the Central Electricity Generating Board in England, he joined the General Electric Company in Pittsfield, Massachusetts. During 20 years with General Electric, he held various positions in high voltage research and product development, the last 7 years being the head of GE's arrester engineering and development group. In 1989, he joined Ohio Brass Company (now Hubbell Power Systems), where he currently holds the position of Manager-Engineering for Arresters. He is chair of IEEE SPDC WG 3.3.11, which is responsible for the ongoing maintenance of the C62.11 arrester test standard. He is also active in IEC and CIGRE, currently being the Secretary of the surge arrester technical committee, TC37, as well as being a US expert to IEC TC37 MT4, which is responsible for the IEC 60099-4 arrester test standard, and a member of CIGRE WG A3.25.