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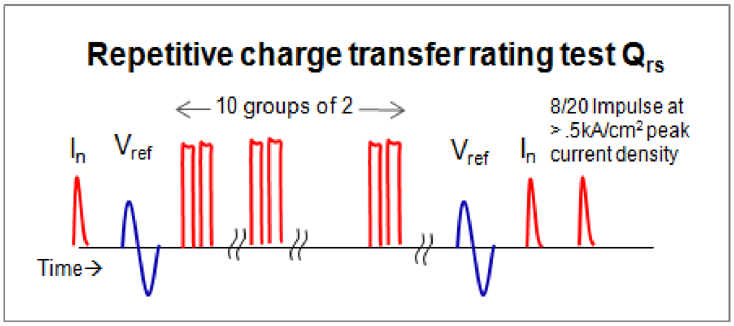
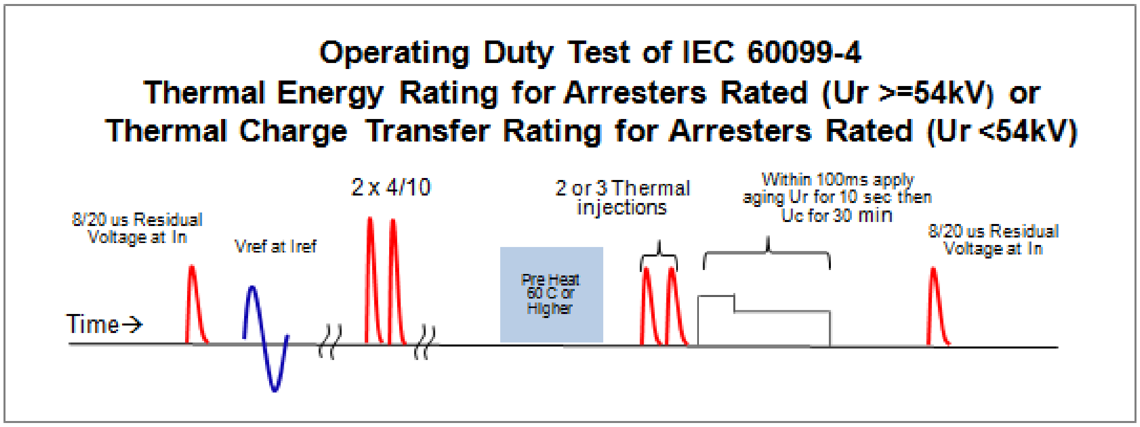
ArresterFacts 033

Overview of the Proposed IEC 60099-4 Energy Handling Tests





Prepared by
Jonathan Woodworth
Consulting Engineer
ArresterWorks

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Overview of the Proposed IEC 60099-4 Energy Handling Tests

Jonathan Woodworth ArresterWorks

Topics

New Definitions
New Arrester Classification System
New Operating Duty Test (Thermal Rating)
Impulse Energy Ratings (Charge Transfer Rating)
Selecting the Right Energy Rating
How to Calculate Charge

Introduction

It has been apparent to stakeholders in surge arresters for many years that the Line Discharge Classification system used to quantify an arrester's energy handling capability was flawed. After considerable contemplation by the IEC maintenance team TC37 MT4 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 develop their own procedures for calculating product data, typically resulting in energy ratings that vary from one manufacture to another.
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 directly) 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.

This year or early in 2013 the IEC will publish the 3rd Edition of IEC 60099-4, the most widely used arrester tests standard worldwide. The maintenance team is working at a fast pace to navigate through all the needs of the industry and IEC organization at the same time but in spite of that, it looks like the document will publish on time. Substantive changes are coming in the area of arrester energy handling capabilities and in the means of classifying arresters.

To address the needed changes in energy testing, two tests have been developed that quantify the impulse type surge durability and thermal withstand capability separately. The issues with arrester classification have been resolved by adopting an IEEE system where arresters are classified as either Station Class or Distribution Class arresters. Each arrester class has a specific set of tests to pass which in turn defines their class. The Line Discharge Classification of arrester will be replaces with this new classification system.

As a member of the IEC maintenance TC37 MT4 that developed these tests, I realize that this change could be difficult to understand, so I have written this ArresterFacts to help users have a clearer understanding. This document will also address how to apply these new tests to the benefit of all.

New and Important Definitions

Distribution Class Arrester: Arresters intended for use on distribution systems, typically of Us ≤ 52 kV, and are meant to protect components primarily from the effects of lightning. The arrester classification is assigned based on the test series applied during type tests.

> NOTE Distribution class arresters may have nominal discharge currents, In, of 2.5 kA; 5 kA or 10 kA

Station Class Arrester: Arresters intended for use in substations to protect the equipment from lightning and switching surges and are typically but not only intended for use on systems of Us ≥ 72,5 kV. The classification is assigned based on the test series applied during the type test.

> NOTE Station class arresters will have nominal discharge currents, *I*n, of 10 kA or 20 kA

Thermal Charge Transfer Rating, Qth: The charge, given in coulombs (C) that may be transferred through an arrester or arrester section in a thermal recovery test without causing a thermal runaway.

Thermal Energy Rating, W_{th}: The energy, given in kJ/kV of Ur, which may be dissipated by an arrester or arrester section in a thermal recovery test without causing a thermal runaway.

Repetitive Charge Transfer Rating, Q_{rs}: The charge, given in coulombs (C) in the form of a single event that can be transferred at least 20 times (at time intervals that allow for cooling to ambient temperature) through an arrester without causing mechanical failure or unacceptable electrical degradation to the MO resistors.

Charge Transfer: A unit of measure that quantifies the current flow through the arrester over the time of the event. It is calculated as the integral of the absolute value of the current over the time of the surge and is measured in coulombs.

New Arrester Classifications

The classification of an IEC rated arrester will be based on the data provided in Table 1. If the arrester is tested per the tests in the selected column and passes all levels, then it may be rated at that level.

This classification scheme replaces the previous Line Discharge (LD) Class. With this new system, there is no possibility that a 10kA Station arrester can be classified as a 20kA Station Arrester as may have been the case in the previous LD system by increasing the discharge voltage of the arrester. Not only must the energy dissipation (kJ/kV) be at an acceptable level, but the charge transfer (in coulombs) must also be acceptable in order to classify an arrester at the next level up.

Table 1 Arrester Classification

Arrester class	Station	
Nominal discharge current	20 kA	10 kA
Switching impulse discharge current	2 kA	1 kA
Q_{rs} (C)	≥ 2.4	≥ 1.2
W_{th} (kJ/kV)	≥10	≥ 4
Q_{th} (C)	--	--

Arrester class	Distribution		
Nominal discharge current	10 kA	5 kA	2.5 kA
Switching impulse discharge current	--	--	--
Q_{rs} (C)	≥ 0.4	≥ 0.2	≥ 0.1
W_{th} (kJ/kV)	--	--	--
Q_{th} (C)	1.1	0.7	0.45

Repetitive Charge Transfer Rating Q_{rs}: Test Rationale

This test is applied to all non-gapped MOV type arresters. The only difference in the test between Station and Distribution Class arresters is the waveshape of the 20 impulses in the rating test. The Qrs test has been designed to test the capability of an arrester to withstand discharges such as lightning or switching surges. It is performed on disks only and does not need to be a thermal equivalent section. It is explicitly the desire of the working group to separate the thermal energy handling capability and the impulse energy handling capability. Therefore, ten sets of two impulses each are applied in succession. This is believed to be an acceptable number that will not drive the disk to a temperature that would damage the materials. There is a cooling between sets to insure that this rating is not a one or two shot rating but rather that it can sustain this rating for many surges during its service life.

Test Procedure

The repetitive charge transfer test replaces the long-duration current impulse withstand test and is applied to disks only, not arresters. For station type arresters, a switching surge or half sine surge is applied. For arresters applied to systems <=52kV (distribution arresters) a half sine wave of 200us is used for the test.

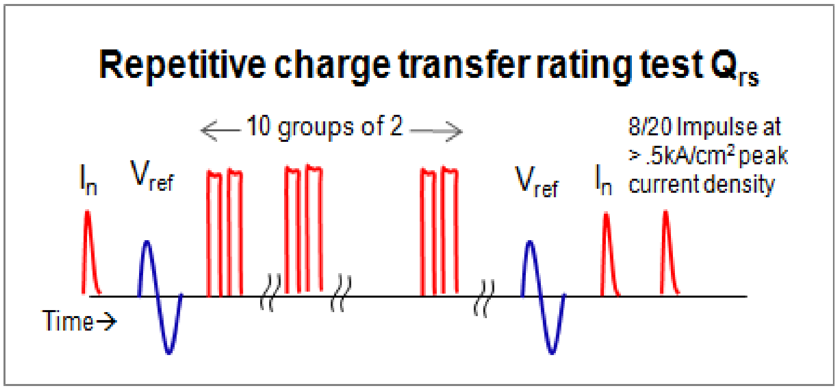


Figure 1: Repetitive Charge Transfer Rating Test Sequence

Test Procedure Details

The test procedure is written for both Station and Distribution Class arresters. The only difference between the two is the wave shapes and amplitudes. In preparation for the repeated impulse, the residual voltage at In and Vref are measured. Both are measured after the test as part of the pass/fail evaluation.

For the first time in arrester testing, the reference voltage of the arrester is used as part of the pass/fail criteria. It has been determined during the research and development of this test that small changes in Vref are a sign of degradation of the varistor material. Therefore a greater than a 5% change in Vref is considered a sample failure. The residual voltage is also sensitive to degradation and a greater than 5% change in residual voltage is also considered a sample failure.

The repeated impulse is a switching surge for station class arresters and the amplitude is set by the manufacturer at 110% of the desired charge transfer rating of the device. For distribution arresters the impulse is an 8/20 impulse. Transmission line arresters use 200us to peak surge. Each sample is impulsed 20 times in 10 sets of two impulses ~1 minute apart per impulses. Ample cooling time is allowed between each impulse set to allow disk to return to ambient temperature.

At the end of the energy injection test sequence, after the disks have returned to ambient temperature, three final tests are applied:

1. Vref,
2. Residual voltage at In
3. One 8/20 current surge of .5kA/cm2 peak current

The final impulse is to stress the disk one last time to make sure that the final Vref or residual voltage impulse did not create any internal cracks in the material that could go undetected.

The disk is considered passed if it has not exceeded the 5% change limit of Vref and residual voltage at In and is not physically damaged. If one sample fails, 10 more samples can be tested and evaluated. No failures are allowed in the second 10 samples.

Rating Considerations

The Q_{rs} characteristic will be quantified in terms of charge (coulombs) and not energy dissipation (joules). Charge has been chosen as a test basis for the purpose of better comparison between different makes of MOV arresters. Energy values can be calculated from this information by multiplying the charge with the related switching impulse protection level.

$$Q=\int_0^{t_1} i(t)=\frac{\hat{I}}{\eta}\cdot\int_0^{t_1} e^{\frac{-t}{\tau}}\cdot\sin(\omega t)=\frac{\hat{I}}{\eta}\cdot\frac{e^{\frac{-t}{\tau}}}{\frac{1}{\tau^2}+\omega^2}\cdot\left(-\frac{1}{\tau}\cdot\sin(\omega t)-\omega\cdot\cos(\omega t)\right)\Bigg|_{t=0}^{t=\pi/\omega}$$

	Impulse 8/20	Impulse 4/10
τ	24 µs	12 µs
ω	120023 s^{-1}	110012 s^{-1}
η	0,615	0,615
Time instant t_1 of first zero crossing	π/ω = 26,2 µs	π/ω = 13,1 µs

Note: *i(t)* must be an absolute value

The equation for calculating charge looks intimidating, but there are easier ways to determine charge using a simplified trapezoidal rule for calculating a definite integral in a spreadsheet as shown in Annex A of this document or mathlab program. At the moment, most transient analysis programs can readily output the energy dissipated by an arrester, but outputting charge requires some extra modelling until the software packages are updated.

For the Q_{rs} test and final rating it is expected that the values will be between .5 and 25 coulombs. The rating will be expressed in coulombs and not as a class or level. However each class of arrester does have a minimum requirement to meet and is stated in Table 1 above. The rating is determined as 90% of the repeated impulse level during the 20 shot series.

New Operating Duty Test

To verify the thermal energy rating W_{th} (U_r>=54kV) **(Station Class Arresters)**
To verify thermal charge transfer rating Q_{th} (U_r<54kV) **(Distribution Class Arresters)**

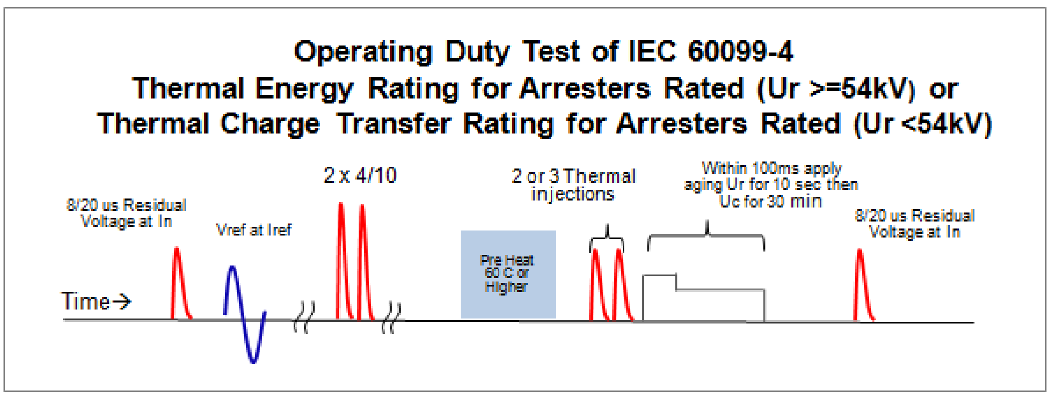


Figure 2 Thermal Rating Test Sequence (New Operating Duty Test)

Test Rationale

This new operating duty test is designed to quantify the energy dissipation or charge transfer necessary to raise an arresters temperature to a level where it is not stable while at operating conditions. For a high voltage arrester the unit of measure can be joules or coulombs. For arresters used on distribution systems the unit of measure will be coulombs or charge transfer. Again the use of charge transfer eliminates the potential confusion caused by joule ratings with respect to residual voltage. It is again the explicit goal of the developers of this test to separate the thermal rating from the impulse rating of the arrester.

Test Procedure

This test will become the new Operating Duty Test. The thermal energy/charge transfer rating will be expressed in joules for station class arresters with typical but not always rating >=54kV and coulombs for distribution class arresters rated < 54kV. Where a station class arrester is rated below 54kV, it can be tested and rated with a thermal energy rating. Substation type arresters rated below 54kV can be tested and rated in a same manner as ratings => 54kV.

The characterization and conditioning part of the test may be performed on the disks in still air, however they may be tested in a dielectrically prorated section to avoid dielectric testing later. The thermal recovery part of this test must be performed on thermally prorated sections. A temperature sensor must be integrated in the sample such that the temperature of the active part can be measured. If not dielectrically equivalent, then another test is necessary to qualify the dielectrics. (This separate test is not part of this overview)

The initial Vref and In tests in the sequence are to set the baseline for evaluation after the thermal stresses.

The next two surges are meant to dielectrically stress the internal components. The current amplitude of these two high current impulses is the same as the two high current impulses in the present Operating Duty Test.

The fourth and final set of energy inputs to the arrester are the ones that will be used to rate the arrester. Prior to the last set of impulses, the arrester must be heated to 60 C unless the arrester is a UHV arrester. (For UHV arresters the temperature for this test is determined using another test sequence) Per the test procedure, the energy inputs are as follows:

Arresters of Ur 54 kV (for system voltages Us 72,5 kV): Rated energy injection within three minutes by one or more long-duration current impulses or by unipolar sine half-wave current impulses or, in case of NGLA, by lightning discharge impulses

Arresters of U_r < 54 kV (for system voltages U_s ≤ 52 kV): Rated charge transfer within one minute by two lightning current impulses 8/20 µs

Within 100 ms from the energy or charge application, a voltage equal to the elevated rated voltage Ur shall be applied for 10 s and thereafter a voltage equal to the elevated continuous operating voltage Uc shall be applied for a minimum of 30 minutes to demonstrate thermal stability. Resistive component of current or power dissipation or temperature or any combination of them shall be monitored until the measured value is appreciably reduced (success), or thermal runaway condition (failure) is evident.

The thermal charge transfer or thermal energy rating will be 100% of the sum of the thermal charge transfer or thermal energy rating of these two impulses. The sample must also not experience a change in residual voltage at In of more than 5%.

Rating System

There are minimum rating requirements for Station and Distribution Class Arresters, however the actual Thermal Rating will not be mandated by this test. Station Class arrester will have a Thermal Rating as given by the manufacturer and tested per the above test. Station Class Arresters will have Thermal Energy Ratings Wth from 4 kJ/kV-Ur to 30 kJ/kV-Ur Distribution Class arrester will only have Thermal Charge Ratings and must meet the minimum requirements as shown in Table 1.

Units of Measure

If joules are used in the evaluation, the unit of measure is joules/kV-Ur. If charge transfer is used then the unit of measure is coulombs. The method to calculate both joules and coulombs is the same as shown in annex A of this document with the only difference being for joules, the product of the voltage and current is integrated over time instead of just the current.

Comparison of Old and New Classification System

Annex K of the new standard shows a detailed comparison of the old and new classification methods. Table 2 is an example of the potential rating and the equivalent rating from the current system and comes directly from the annex. The Old LDC Class 1 is very similar to the new Distribution Class Arrester and the Old LDC 2,3,4,5 will become Station Class Arresters.

Table 2 Comparison of the Old and New Energy Rating Levels

Old LDC	Required minimum test energy* kJ/kV	Corresponding ***new*** thermal energy rating W_{th} kJ/kV	Estimated current at ***old*** LD test ** A	Charge calculated with the same current and duration as for ***old*** LDC to give the required minimum energy C	Corresponding ***new*** repetitive charge transfer rating Q_{rs} C	Approximate range of system voltage *** kV
1	1,0	2	277	0,56	0,4	
2	2,1	4	538	1,10	1	up to 300
3	3,3	7	721	1,78	1,6	up to 420
4	5,0	10	962	2,75	2,4	up to 525
5	6,9	14	1118	3,75	3,6	up to 800

Selecting the Right Station Class Arrester Energy Rating

With this new energy rating system, the required energy rating of an arrester can be determined by first calculating the level of energy the system will discharge into the arrester and then selecting the arrester with a Thermal Energy Rating Wth that is above the system response. The prospective energy that a system will require of an arrester can be determined using transient analysis software, but if that is not available a simplified formula is in IEC 60099-5. The simplified arrester energy formulae is based on the assumption that the entire line is charged to a prospective switching surge voltage and is discharged through the arrester at its protective level during twice the travel time of the line. (for switching surges)

$$W = U_{ps} \times (U_{rp} - U_{ps}) / Z_s \times 2 \times L/c$$

W is the energy in Joules that will be dissipated by the arrester for the given surge level
L is the line length;
c is the speed of light;
Z is the line surge impedances;
U_{ps} is the arrester residual voltage at the lower of the two switching impulse currents;
U_{rp} is the representative maximum switching voltage.

For example, if the calculated energy dissipated by an arrester using the above formula is 7kJ/kV then the desired thermal energy rating W_{th} of the arrester should be a minimum of 7kJ/kV.

Other Tests that are changing in the Upcoming edition of 60099-4

There are several other significant changes that are coming with Ed 3.0 of 60099-4 including:

Temporary Overvoltage Test: This is now a mandated test and not an option as in the past.

Steep Front Residual Voltage Test: This test has new methods required to reduce the potential of misunderstanding the data.

Disk Aging Tests: In the past this test was a procedure that allowed for an increasing watts at the end of the test. As of this new standard, disk aging with an upward trending watts loss will not be allowed. As a result of this change, there is no required voltage adjustment for aging in the thermal evaluation tests.

5000 hr Aging Test of Housings: This test is no longer suggested as an alternative to the 1000 hr test.

UHV Arresters: Requirements and tests for UHV arresters (for highest system voltages Us > 800 kV) are introduced.

Conclusions

With the publication of this new standard, the industry will now have a test standard that finally reduces the ambiguity of energy rating and energy testing in general. Arresters of different designs can be accurately compared and fairly evaluated. Specifiers of arrester can request a specific energy rating and all those submitting quotes will be submitting the same type of arrester. Users of arresters can now be confident that they are applying the correct arrester for the application at hand. Manufacturers can now run a test that is standardized and meaningful to the users and specifiers.

End Notes: It is important to remember that as of this ArresterFacts publication, the final version of the standard is not published. It has a few more months of review before it is published. However a secondary objective of this ArresterFacts is to solicit comments on the proposed changes. Please Email me at Jonathan.Woodworth@ArresterWorks.com if you would like to make comments or discuss.

About ArresterFacts

References

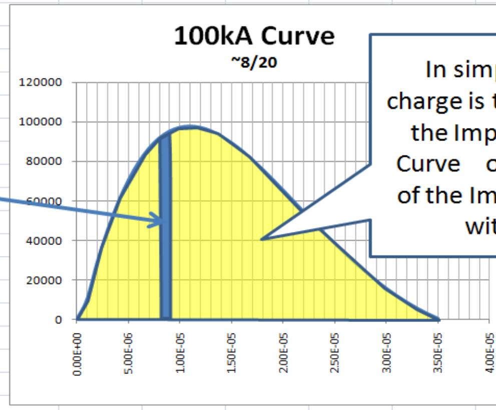
[1] Hinrichsen, Reinhard, Richter (on behalf of Cigré WG A3.17), *Energy handling capability of high-voltage metal-oxide surge arresters Part 1: A critical review of the standards*, Cigré SC A3 Technical Colloquium, Rio de Janeiro, September 12/13, 2007

[2] IEC TC37 MT4 CD 37_381e_CD Energy Handling and UHV Arrester revisions

[3] http://en.wikipedia.org/wiki/Trapezoidal_rule

Annex A Calculating Charge using a simple trapezoidal rule in Excel [3]

Time	100kA Curve	Area under each slice
0	0	
1.00E-06	10156	1.02E-02
2.00E-06	29099	2.91E-02
3.00E-06	45375	4.54E-02
4.00E-06	59121	5.91E-02
5.00E-06	70488	7.05E-02
6.00E-06	79634	7.96E-02
7.00E-06	86725	8.67E-02
8.00E-06	91931	9.19E-02
9.00E-06	95423	9.54E-02
1.00E-05	97370	9.74E-02
1.10E-05	97939	9.79E-02
1.20E-05	97292	9.73E-02
1.30E-05	95587	9.56E-02
1.40E-05	92974	9.30E-02
1.50E-05	89593	8.96E-02
1.60E-05	85581	8.56E-02
1.70E-05	81060	8.11E-02
1.80E-05	76146	7.61E-02
1.90E-05	70945	7.09E-02
2.00E-05	65553	6.56E-02
2.10E-05	60057	6.01E-02
2.20E-05	54533	5.45E-02
2.30E-05	49050	4.90E-02
2.40E-05	43666	4.37E-02
2.50E-05	38433	3.84E-02
2.60E-05	33393	3.34E-02
2.70E-05	28582	2.86E-02
2.80E-05	24027	2.40E-02
2.90E-05	19751	1.98E-02
3.00E-05	15768	1.58E-02
3.10E-05	12091	1.21E-02
3.20E-05	8727	8.73E-03
3.30E-05	5681	5.68E-03
3.40E-05	2960	2.96E-03
3.50E-05	577	5.77E-04
		1.92 Coulombs



In simple terms, the charge is the area under the Impulse Current Curve or the Integral of the Impulse current with time.

The area of each time slice is the product of the current and the delta T

Sum of this column is the total area under the curve and the Charge