# IEC Type Test Report
# Report No. TD 01 41 E00
# Type PDV100 Optima
# 10 kA Distribution Class DH Arrester

This report records the results of this type test made on 10 kA Distribution Class DH arresters rated 3 thru 42 kV in accordance with IEC Standard 60099-4, Ed. 3.0, 2014-06, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

Type tests performed on 10 kA Distribution Class DH arresters demonstrate full compliance with the relevant clauses of the referenced standard and apply to all Hubbell 10 kA Distribution Class DH arresters of this design manufactured and assembled at the following ISO 9001:2008 certified Hubbell locations:

Hubbell Power Systems
1850 Richland Avenue, East
Aiken, South Carolina
29801

Hubbell Electric (Wuhu) Company, Ltd.
Exports Processing Zone, No 68
North Jiuhua Road, Wuhu City
Anhui Province, PR China

The above locations manufacture, assemble, and test utilizing manufacturing, quality, and calibration procedures developed from Hubbell Engineering Department Specifications. Engineering Department Specifications are controlled by Arrester Business Unit design engineering in the USA.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

Separate reports provide details of each test, according to the following table:

| Report No. | Description | Clause | Issue date |
|---|---|---|---|
| TD 01 41 E01 | Insulation Withstand Test on Arrester Housing | 10.8.2 | 4/10/2015 |
| TD 01 41 E02 | Residual Voltage | 10.8.3 | 4/10/2015 |
| TD 01 41 E03 | MOV Disc Accelerated Aging | 10.8.4 | 4/10/2015 |
| TD 01 41 E04 | Repetitive Charge transfer Rating Qrs | 10.8.5 | 4/10/2015 |
| TD 01 41 E05 | Thermal Equivalency | 10.8.6 | 4/10/2015 |
| TD 01 41 E06 | Operating Duty Test | 10.8.7 | 4/10/2015 |
| TD 01 41 E07 | Power Frequency Voltage-Versus-Time Test | 10.8.8 | 4/10/2015 |
| TD 01 41 E08 | Short Circuit Tests | 10.8.10 | 4/10/2015 |
| TD 01 41 E09 | Bending Moment | 10.8.11 | 4/10/2015 |
| TD 01 41 E10 | Disconnector Test | 8.9.3, 8.11.6 | 4/10/2015 |
| TD 01 41 E11 | Salt Fog Test | 10.8.17.2 | 4/10/2015 |
| TD 01 41 E12 | UV Light Test | 10.8.17.3 | 4/10/2015 |

# IEC TYPE TEST REPORT
# Report No. TD 01 41 E01
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## Insulation Withstand Test on Arrester Housing
## IEC Clause 10.8.2

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

## Type PDV100 Optima Distribution Class DH Arrester
## Insulation Withstand Clause 10.8.2

**Introduction**: The following table lists the strike distance and height for the PDV100 Optima arrester mounted on the insulating support bracket. The table also summarizes the 1 minute 48-62 Hz and impulse withstand requirements for each arrester rating.

**Conclusion:** In all cases, the actual withstand values shown of each arrester rating exceed the minimum values specified in the Standard.

| Ur kV rms | Uc kV rms | Arrester Strike w/Brkt mm | Arr Total Ht W/Brkt mm | 8/20 10kA IR kVc | Reqd BIL WS kVc | Actual Imp WS Arr w/Brkt kVc | Reqd 1 minute wet power frequency WS kVc | Actual 1 min wet WS Arr w/Brkt kVc |
|---|---|---|---|---|---|---|---|---|
| 3 | 2.55 | 141 | 173 | 9.9 | 12.8 | 85 | 8.7 | 25 |
| 6 | 5.1 | 161 | 193 | 19.8 | 25.7 | 100 | 17.4 | 35 |
| 9 | 7.65 | 190 | 221 | 29 | 37.7 | 120 | 25.5 | 41 |
| 10 | 8.4 | 190 | 221 | 31.6 | 41.1 | 120 | 27.8 | 41 |
| 12 | 10.2 | 212 | 236 | 37.6 | 48.9 | 125 | 33.1 | 45 |
| 15 | 12.7 | 268 | 295 | 47.8 | 62.1 | 155 | 42.1 | 58 |
| 18 | 15.3 | 268 | 295 | 56.4 | 73.3 | 155 | 49.6 | 58 |
| 21 | 17 | 291 | 315 | 63.5 | 82.5 | 170 | 55.9 | 71 |
| 24 | 19.5 | 360 | 389 | 76.2 | 99.1 | 210 | 67.1 | 85 |
| 27 | 22 | 385 | 417 | 85.5 | 111 | 230 | 75.2 | 89 |
| 30 | 24.4 | 400 | 429 | 94 | 122 | 240 | 82.7 | 92 |
| 36 | 29 | 456 | 490 | 112.9 | 147 | 260 | 99.4 | 102 |
| 42 | 34 | 500 | 533 | 127.1 | 165 | 280 | 111.8 | 112 |

# IEC Type Test Report
# Report No. TD 01 41 E02
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## Residual Voltage Test
## IEC Clause 10.8.3

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

# IEC Type Test Report

## RESIDUAL VOLTAGE TEST
## IEC CLAUSE 10.8.3

Sample Preparation

Residual voltage tests were performed on three of the longest 36mm x 42 mm MOV discs.

Test Procedure

The following tests were performed on each sample. Each sample was allowed to cool to ambient temperature between discharges.

1. Steep Current Impulse Residual Voltage Test: 1/2 µs, 10 kA;
2. Lightning Impulse Residual Voltage Test: 8/20 µs, 1.5, 3, 5, 10, 20 kA;
3. Switching Impulse Residual Voltage Test: 30-100/60-200 µs and 500 A.

Test Results

Each of the three test samples was subjected to a 10 kA, 1/2 µs steep current impulse with and without an aluminum disc with the same geometry of the MOV disc. The difference in the residual voltages is the inductive drop across the aluminum spacer. Figures 1a and 1b show the oscillograms of the measured FOW residual voltage discharges of Sample 3 without and with an aluminum spacer, respectively.

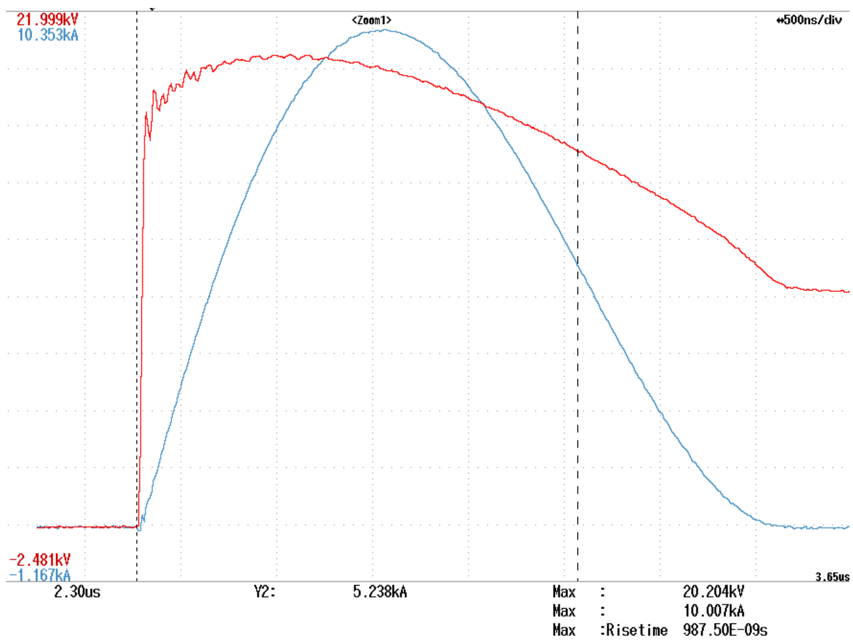



Figure 1a: Sample 3, 10.007 kA, 20.204 kV w/o Aluminum spacer.

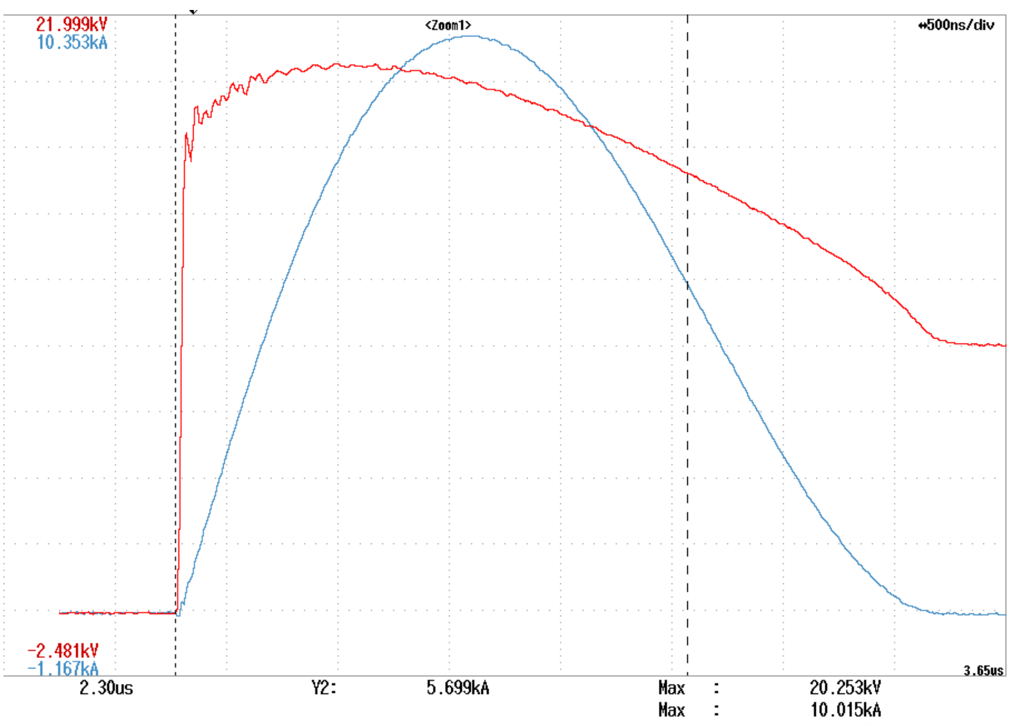



Figure 1b: Sample 3, 10.015 kA, 20.253 kV with Aluminum spacer.

Each sample was then subjected to 1.5, 3, 5, 10 and 20 kA lightning surge impulses. Figure 2 shows the oscillogram of the 10kA 8/20 discharge of Sample 3.

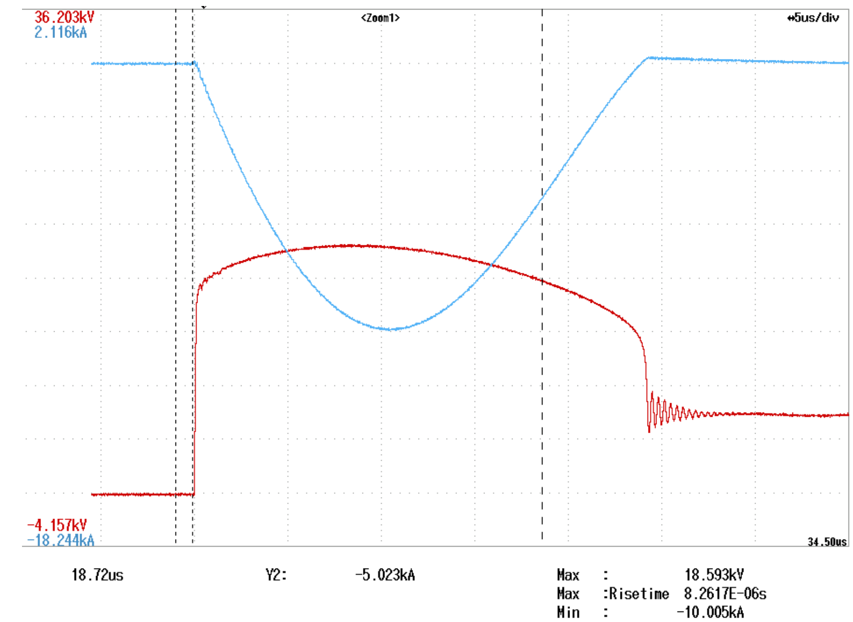



Figure 2: Sample 3, 10.005 kA, 18.593 kV.

Each sample was then subjected to 500 A switching surge impulses. Figure 3 shows the oscillogram of the switching surge residual voltage of Sample 3.

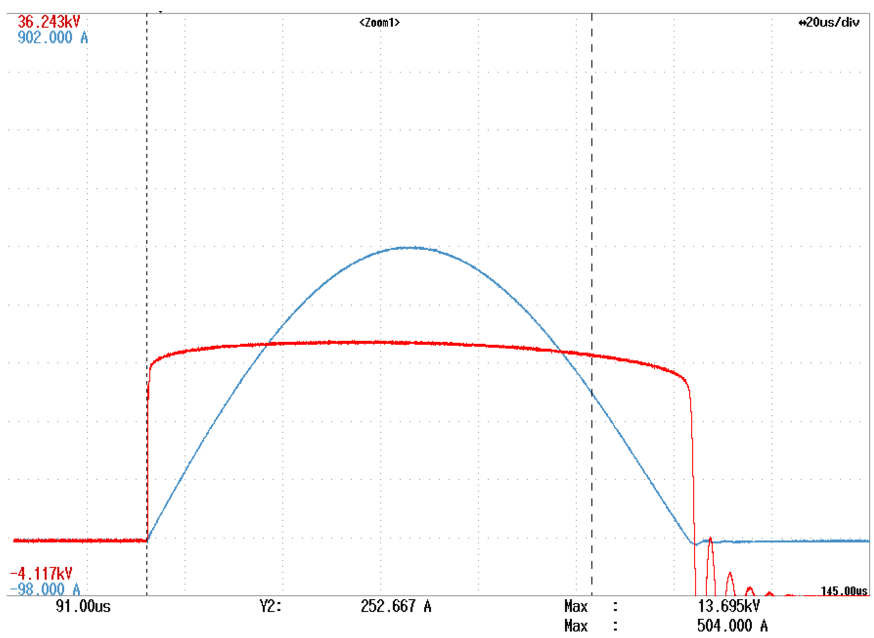



Figure 3: Sample 3, 504 A, 13.695 kV.

Table 1 shows the 10kA IRs of the steep front wave measured with and without the aluminum disc.

Table 1: Measurement of Inductive effect on MOV discs

| Sample No. | I (kA) | IR (KVpk) with Al disc | IR (KVpk) w/o Al disc | L(di/dt) effect (kV) | Voltage drop across MOV disc w/o inductive effect (kV) |
|---|---|---|---|---|---|
| 1 | 10 | 20.318 | 20.188 | .130 | 20.058 |
| 2 | | 20.318 | 20.237 | .081 | 20.156 |
| 3 | | 20.253 | 20.204 | .049 | 20.155 |

Table 2 summarizes the design factors used to extrapolate the 1.5 through 20 kA 8/20 residual voltage, the 500 amp switching surge residual voltage, and MOV disc .5 microsecond FOW residual voltage. The highest factor for each wave shape is shown bolded and is multiplied by the 10 kA residual voltage of each rating to develop the family of residual voltage values. Table 3 summarizes the residual voltage values measured and claimed for each arrester rating.

Table 2: Residual Voltage Test.

| Impulse Current (kA) | Wave Shape (µs) | Residual Voltage (kVpk) | | | Residual Voltage Ratio (IR/10kV IR) | | |
|---|---|---|---|---|---|---|---|
| | | Sample 1 | Sample 2 | Sample3 | Sample 1 | Sample 2 | Sample3 |
| 0.5 | 43/91 | 13.695 | 13.776 | 13.695 | 0.736 | **0.740** | 0.737 |
| 1.5 | 8/20 | 15.014 | 15.041 | 15.041 | 0.806 | 0.808 | **0.809** |
| 3 | 8/20 | 16.064 | 16.118 | 16.104 | 0.863 | **0.866** | 0.866 |
| 5 | 8/20 | 17.031 | 17.071 | 17.004 | 0.915 | **0.917** | 0.915 |
| **10** | 8/20 | **18.619** | **18.619** | **18.593** | 1 | 1 | 1 |
| 20 | 8/20 | 21.04 | 21.067 | 21.121 | 1.130 | 1.131 | **1.136** |
| 40 | 8/20 | 24.808 | 24.889 | 24.889 | 1.332 | 1.337 | **1.339** |
| 10 | 1/2 (w/o inductive effect) | 20.058 | 20.156 | 20.156 | 1.077 | 1.083 | **1.084** |

Table 3: Summary of Arrester Residual Voltages

| | | IR Multipliers | 0.74 | 0.809 | 0.866 | 0.917 | 1 | 1.136 | 1.339 | 1.075 | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Waveshape | 60/100 | 8/20 | 8/20 | 8/20 | 8/20 | 8/20 | 8/20 | Disc 0.5 usec | Unit Ht | 10 kA Induct Drop | Total FOW |
| MCOV | Rating | I (kA) | 0.5 | 1.5 | 3 | 5 | 10 | 20 | 40 | 10 | m. | kV | 10 |
| 2.55 | 3 | Measured IR | 7.2 | 7.8 | 8.4 | 8.9 | 9.7 | 11.0 | 13.0 | 10.4 | 0.076 | 0.76 | 11.2 |
| | | Catalog IR | 7.3 | 8.0 | 8.6 | 9.1 | 9.9 | 11.2 | 13.3 | 10.6 | 0.076 | 0.76 | 11.4 |
| 5.1 | 6 | Measured IR | 14.4 | 15.7 | 16.8 | 17.8 | 19.4 | 22.0 | 26.0 | 20.9 | 0.096 | 0.96 | 21.8 |
| | | Catalog IR | 14.7 | 16.0 | 17.1 | 18.2 | 19.8 | 22.5 | 26.5 | 21.3 | 0.096 | 0.96 | 22.2 |
| 7.65 | 9 | Measured IR | 21.1 | 23.0 | 24.7 | 26.1 | 28.48 | 32.4 | 38.1 | 30.6 | 0.124 | 1.24 | 31.9 |
| | | Catalog IR | 21.5 | 23.5 | 25.1 | 26.6 | 29 | 32.9 | 38.8 | 31.2 | 0.124 | 1.24 | 32.4 |
| 8.4 | 10 | Measured IR | 22.9 | 25.1 | 26.8 | 28.4 | 30.98 | 35.2 | 41.5 | 33.3 | 0.124 | 1.24 | 34.5 |
| | | Catalog IR | 23.4 | 25.6 | 27.4 | 29.0 | 31.6 | 35.9 | 42.3 | 34.0 | 0.124 | 1.24 | 35.2 |
| 10.2 | 12 | Measured IR | 27.3 | 29.8 | 31.9 | 33.8 | 36.88 | 41.9 | 49.4 | 39.6 | 0.139 | 1.39 | 41.0 |
| | | Catalog IR | 27.8 | 30.4 | 32.6 | 34.5 | 37.6 | 42.7 | 50.3 | 40.4 | 0.139 | 1.39 | 41.8 |
| 12.7 | 15 | Measured IR | 34.7 | 37.9 | 40.6 | 43.0 | 46.86 | 53.2 | 62.7 | 50.4 | 0.198 | 1.98 | 52.4 |
| | | Catalog IR | 35.4 | 38.7 | 41.4 | 43.8 | 47.8 | 54.3 | 64.0 | 51.4 | 0.198 | 1.98 | 53.4 |
| 15.3 | 18 | Measured IR | 40.9 | 44.7 | 47.9 | 50.7 | 55.3 | 62.8 | 74.0 | 59.4 | 0.198 | 1.98 | 61.4 |
| | | Catalog IR | 41.7 | 45.6 | 48.8 | 51.7 | 56.4 | 64.1 | 75.5 | 60.6 | 0.198 | 1.98 | 62.6 |
| 17 | 21 | Measured IR | 46.1 | 50.4 | 54.0 | 57.1 | 62.3 | 70.8 | 83.4 | 67.0 | 0.218 | 2.18 | 69.2 |
| | | Catalog IR | 47.0 | 51.4 | 55.0 | 58.2 | 63.5 | 72.1 | 85.0 | 68.3 | 0.218 | 2.18 | 70.4 |
| 19.5 | 24 | Measured IR | 55.3 | 60.4 | 64.7 | 68.5 | 74.7 | 84.9 | 100.0 | 80.3 | 0.292 | 2.92 | 83.2 |
| | | Catalog IR | 56.4 | 61.6 | 66.0 | 69.9 | 76.2 | 86.6 | 102.0 | 81.9 | 0.292 | 2.92 | 84.8 |
| 22 | 27 | Measured IR | 62.0 | 67.8 | 72.6 | 76.8 | 83.78 | 95.2 | 112.2 | 90.1 | 0.32 | 3.2 | 93.3 |
| | | Catalog IR | 63.3 | 69.2 | 74.0 | 78.4 | 85.5 | 97.1 | 114.5 | 91.9 | 0.32 | 3.2 | 95.1 |
| 24.4 | 30 | Measured IR | 68.2 | 74.6 | 79.8 | 84.5 | 92.18 | 104.7 | 123.4 | 99.1 | 0.332 | 3.32 | 102.4 |
| | | Catalog IR | 69.6 | 76.0 | 81.4 | 86.2 | 94 | 106.8 | 125.9 | 101.1 | 0.332 | 3.32 | 104.4 |
| 29 | 36 | Measured IR | 81.8 | 89.5 | 95.8 | 101.4 | 110.6 | 125.6 | 148.1 | 118.9 | 0.393 | 3.93 | 122.8 |
| | | Catalog IR | 83.5 | 91.3 | 97.8 | 103.5 | 112.9 | 128.3 | 151.2 | 121.4 | 0.393 | 3.93 | 125.3 |
| 31.5 | 39 | Measured IR | 87.5 | 95.6 | 102.4 | 108.4 | 118.2 | 134.3 | 158.3 | 127.1 | 0.414 | 4.14 | 131.2 |
| | | Catalog IR | 88.8 | 97.1 | 103.9 | 110.0 | 120 | 136.3 | 160.7 | 129.0 | 0.414 | 4.14 | 133.1 |
| 34 | 42 | Measured IR | 92.2 | 100.8 | 107.9 | 114.3 | 124.6 | 141.5 | 166.8 | 133.9 | 0.436 | 4.36 | 138.3 |
| | | Catalog IR | 94.0 | 102.7 | 110.0 | 116.5 | 127 | 144.3 | 170.1 | 136.5 | 0.436 | 4.36 | 140.9 |

Test Summary

Table 1 summarizes the result of FOW discharge testing performed, per the standard, with and without an aluminum spacer. The MOV disc FOW residual voltage is combined with the inductive drop (associated with the arrester height) to develop each rated arrester's Total FOW residual voltage.

Table 2 summarizes residual voltage measurements for the three test samples across the range of specified wave shapes and current values. The residual voltage of each MOV disc is measured as a routine test with a discharge current of 10 kA, 8/20 μs. The MOV discs of each arrester are accumulated within 10 kA residual voltage ranges as specified for each arrester rating. To verify the catalog maximum residual voltage levels, a residual voltage ratio was established at each current level based on the 10 kA residual voltage of each test sample, as shown in Table 2. This ratio was multiplied by the maximum 10-kA residual voltage accumulation specified for each rating. As summarized on Table 3, the residual voltage calculated based on the prorated test samples were less than the maximum declared catalog levels.

# IEC Type Test Report
# Report No. TD 01 41 E03
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## Disc Accelerated Aging
## IEC Clause 10.8.4

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

**DESIGN TEST REPORT**
**PDV100 Optima IEC Distribution Class DH Surge Arrester**

**TITLE: MOV Disc Accelerated aging procedure**

**TEST PROCEDURE:** Tests were performed to verify that the varistors remain stable and do not increase in power dissipation at MCOV during their expected lifetime.

**TEST SAMPLES:** Six arrester sections were prepared. Three sections consisted of the longest 36mm diameter disc and three consisted of a shorter 36mm diameter disc. Each section also consisted of a spring, end terminals, barrier film and fiberglass/epoxy wrap using standard module construction.

**TEST PROCEDURE**: Tests were performed per section 10.8.4 of the standard. Samples were placed inside a 115 °C ±2 °C. oven and energized at Uc for 1,000 hours.

**TEST RESULTS:** Watts loss for each sample was measured at Uc and Ur two hours after energization and at the completion of the 1000 hour test duration. The table below summarizes test data. Watts loss was periodically monitored at Uc during the 1000 hour test duration and found to be continuously decreasing.

**Accelerated aging test data**

| Sample No. - length | Watts Loss at 2 Hr @Uc $P_{1c}$ (w) | Watts Loss at 1000 Hr @Uc $P_{2c}$ (w) | Watts Loss at 2 Hr @Ur $P_{1r}$ (w) | Watts Loss at 1000 Hr @Ur $P_{2r}$ (w) | Elevation Factors | |
|---|---|---|---|---|---|---|
| | | | | | $K_c$ | $K_r$ |
| 1-35 | 1.05 | .67 | 14.6 | 4.1 | 1 | 1 |
| 2-35 | 1.01 | .66 | 16.6 | 4.5 | 1 | 1 |
| 3-35 | 1.00 | .63 | 13.4 | 3.5 | 1 | 1 |
| 4-42 | 1.43 | .97 | 21.4 | 5.3 | 1 | 1 |
| 5-42 | 1.23 | .82 | 18.4 | 4.1 | 1 | 1 |
| 6-42 | 1.35 | .84 | 18.9 | 4.2 | 1 | 1 |

**CONCLUSION:** Each test sample demonstrated continually decreasing watts loss at Uc. The watts loss at Ur similarly decreased. Therefore, $K_c$ and $K_r$ factors equal 1.0.

POWER SYSTEMS

# IEC Type Test Report
# Report No. TD 01 41 E04
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## Repetitive Charge Transfer Rating Qrs
## IEC Clause 10.8.5

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

**Type PDV100 Optima IEC Distribution Class DH Surge Arrester**
**Repetitive Charge Transfer Rating test**

**INTRODUCTION:** The repetitive charge transfer rating test was performed per Section 10.8.5 of the IEC 60099-4, Ed. 3.0, 2014-06 Standard on ten MOV blocks.

**TEST PROCEDURE**: Test was performed on 10 of the longest MOV blocks used in the PDV100 Optima product line. The residual voltage (5kA, 8/20) and the reference voltage (at 4 mA) were measured before and after the long duration impulses for evaluation. Each sample was then subjected to ten groups of two 8/20 impulses having a charge content of .55 C.

Figure 1 shows a typical oscillogram of the impulse waveform applied on each of the MOV discs.

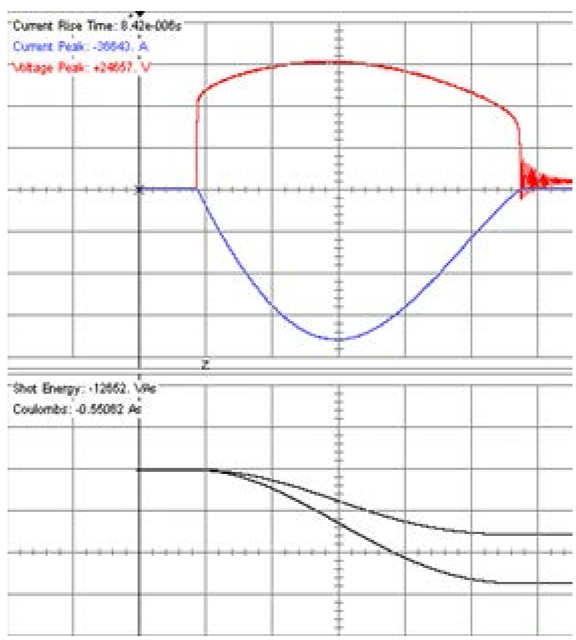



Figure 1: Wave shape of 8/20 impulse wave form

**Test Results:** Ten of (10) MOV discs successfully withstood the 20 shot durability test performed at .55 coulomb charge. Per section 8.5.3, the MOV discs were examined and found to have no physical damage. Additionally, each MOV disc was tested for 10 kA IR and 4ma Uref reference voltage. The results of this testing is summarized in Table 1.

Table 1: Residual and Reference Voltages Before and After Qrs Testing

| Sample No | 10 kA IR Before (kVc) | 10 kA IR After (kVc) | % Change | Vref @ 4 mA Before (kVc) | Vref @ 4 mA After (kVc) | % Change |
|---|---|---|---|---|---|---|
| 1 | 18.15 | 18.38 | +1.2 | 10.13 | 10.18 | +0.5 |
| 2 | 18.14 | 18.35 | +1.1 | 10.13 | 10.19 | +0.6 |
| 3 | 18.16 | 18.40 | +1.3 | 10.16 | 10.21 | +0.5 |
| 4 | 18.21 | 18.43 | +1.2 | 10.19 | 10.22 | +0.3 |
| 5 | 18.06 | 18.27 | +1.2 | 10.06 | 10.10 | +0.4 |
| 6 | 18.18 | 18.41 | +1.2 | 10.16 | 10.16 | 0 |
| 7 | 18.11 | 18.34 | +1.3 | 10.11 | 10.16 | +0.5 |
| 8 | 18.11 | 18.33 | +1.2 | 10.12 | 10.16 | +0.4 |
| 9 | 18.15 | 18.38 | +1.3 | 10.12 | 10.20 | +0.8 |
| 10 | 18.12 | 18.37 | +1.4 | 10.15 | 10.20 | +0.5 |

**Final Evaluation:** The final evaluation confirming the electrical integrity of the ten tested MOV discs requires that each disc be subjected to a single 8/20 current discharge having a magnitude greater than 0.5 kA/sq cm of disc area. For the 36mm diameter disc, each MOV disc was subjected to a single 8/20 impulse exceeding 5.1 kA in magnitude. Table 2 summarizes the results of this testing confirming no damage to the tested MOV discs.

Table 2: Final 8/20 0.5 kA/ sq cm times MOV Disc Area Test

| MOV Disc # | Current Magnitude kAc | Pass/Fail |
|---|---|---|
| 1 | 5.51 | Pass |
| 2 | 5.49 | Pass |
| 3 | 5.51 | Pass |
| 4 | 5.68 | Pass |
| 5 | 5.71 | Pass |
| 6 | 5.56 | Pass |
| 7 | 5.67 | Pass |
| 8 | 5.64 | Pass |
| 9 | 5.53 | Pass |
| 10 | 5.61 | Pass |

**Conclusion:** The test was successfully completed as per the IEC 60099-4, Ed. 3.0, 2014-06 standard requirements. The change in residual voltage and reference voltage were well within 5% of initial value. The claimed repetitive charge transfer rating for the Type PDV100 Optima IEC Distribution Class DH arrester is .5 Coulomb.

# IEC Type Test Report
# Report No.TD 01 41 E05
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## Thermal Equivalency
## IEC Clause 10.8.6

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

**PDV 100 Optima IEC Distribution Class DH Surge Arrester**
**Thermal Equivalency Test**

**INTRODUCTION:** Tests were performed as required per Section 10.8.6 of the IEC 60099-4, Ed. 3.0. 201406 Standard, to compare the cooling characteristics of the prorated test sections used for type tests with those of a full-size arrester unit.

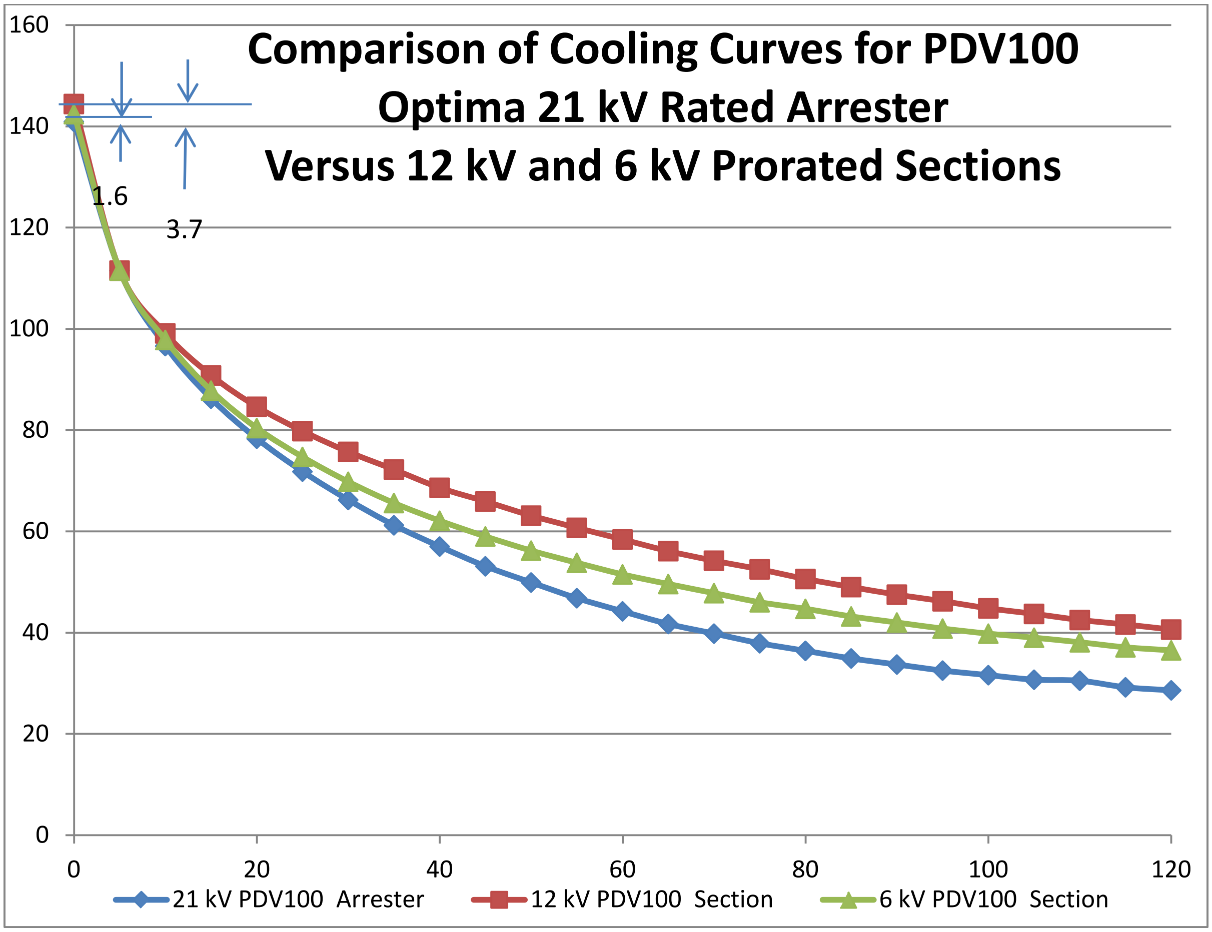
**PURPOSE:** The purpose of this test is to verify that the thermal cooling curve for the Type PDV 100 Optima prorated sections, when internally heated, will cool slower than that of a full size 21 kV rated arrester unit.

**PROCEDURE:** A full size single unit 21 kV rated Type PDV 100 Optima arrester and a 12 kV and a 6 kV prorated section were heated up by applying a temporary overvoltage to the test samples. Per Annex B, all samples (the arrester and the prorated sections) were energized in approximately 10 minutes to a starting temperature of 140 ºC, at which time the voltage was removed. The full size arrester and the two prorated sections were instrumented with (1) fiber-optic sensors located in the middle of the MOV disc stack. During the cooling portion of the test, the temperatures of the arrester and the test sections were monitored at 5 minute intervals to develop the cooling curve for each sample.

**SUMMARY:** As allowed in Annex B, the cooling curves for both the 12 kV and 6 kV prorated sections were adjusted higher to assure that, at no time during the 120 minute cooling period, do the section cooling curves drop below that of the full size arrester. The adjusted temperature shown for each rated section was added to the durability tests requiring a 60 degree C. preheat.

The cooling curve (Figure 1 below) confirms that the cooling rate of the 12 kV and 6 kV prorated sections is slower than that of the full size 21 kV Rated Type PDV 100 Optima arrester unit, confirming the thermal equivalency of the prorated sections to the full size arrester.

**Figure 1**


Comparison of Cooling Curves for PDV100
Optima 21 kV Rated Arrester
Versus 12 kV and 6 kV Prorated Sections
160
140
120
100
80
60
40
20
0
1.6
3.7
0
20
40
60
80
100
120
21 kV PDV100 Arrester
12 kV PDV100 Section
6 kV PDV100 Section

**IEC Type Test Report**
**Report No. TD 01 41 E06**
**Type PDV100 Optima**
**IEC Distribution Class DH Arrester**

**Operating Duty Test**
**IEC Clause 10.8.7**

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 “Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems.”

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

# IEC Type Test Report

## OPERATING DUTY TEST
## IEC CLAUSE 10.8.7

Sample Preparation

High Current Impulse Operating Duty tests were performed on three prorated test sections prepared based on the thermal equivalency test results. During the conditioning tests the disconnectors were tested separately from the prorated sections as accommodated in section 8.9.2.1. During the actual operating duty test, all three 10.2 kV COV size prorated sections were tested in series with the arrester disconnector in accordance with clause 8.9.2.3. The MOV discs for each sample were selected to represent the lowest acceptable reference voltage level.

Test Procedure

Prior to the conditioning series, initial 10 kA, 8/20 µs residual voltage of each section was measured.

Conditioning tests consisted of subjecting each prorated section to one high current (100 kA, 4/10 µs) impulse as stated in Table 4 of the standard. Tests were performed in still air at an ambient temperature of 20°C. These samples were then preheated to 64°C for eight hours. See report TD 01 41 E05 Thermal Equivalency for explanation of 64°C preheat point.

During the operating duty test, each section was subjected to two lightning impulses (8/20µs) 1 minute apart containing a total charge of 1.1 Coulombs (Table 5). Within 100 milliseconds of the last high current impulse, rated voltage ($U_r$) was applied to each section for 10 seconds immediately followed by $U_c$ for a recovery test of 30 min. During the recovery period, power dissipation of each section was monitored.

After this test sequence, each section was allowed to cool to ambient temperature and then its 10 kA, 8/20 µs residual voltage was measured. Each section was then subjected to two more impulses of 10kA (8/20µs) to make sure that the MOV discs were not mechanically damaged.

## Test Results

Initial measurements and parameters of the prorated sections are shown in Table 1.

Table 1. Initial Measurements and Parameters of Prorated Sections.

| Test Parameters | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Initial Residual Voltage (kV) @ 10 kA, 8/20 µs | 36.078 | 36.182 | 36.344 |
| Reference Current (mA) $I_{ref}$ | 4 | 4 | 4 |
| Reference Voltage (kV peak) $U_{ref}$ | 20.015 | 20.038 | 20.080 |
| Maximum COV (kV rms): $U_c$ | 10.79 | 10.80 | 10.82 |
| Maximum Rating (kV rms): $U_r$ | 13.49 | 13.50 | 13.53 |

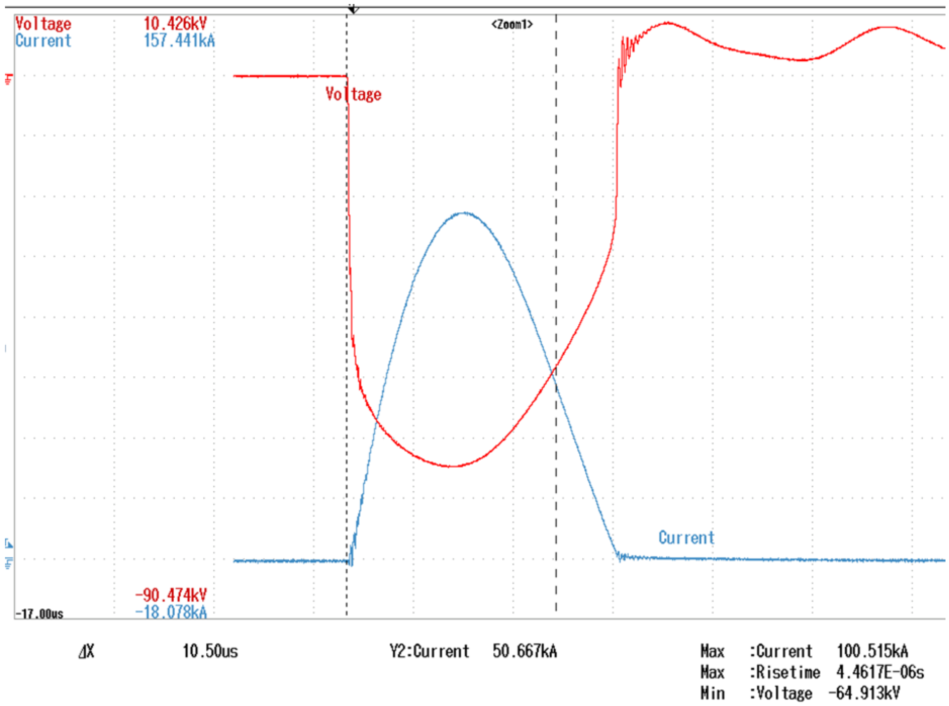
Subsequently each section and each disconnector was subjected to one (1) 100 kA nominal 4/10 µs impulse as specified in IEC Standard 60099-4, Ed. 3.0. Table 2 shows test results of the 100 kA impulse for the three sections. The conditioning test was performed in still air at room temperature. Figure 1 shows oscillograms of the test for one of the three samples (Sample 1).

Table 2 - 100 kA, 4/10 µs Conditioning Test

| Prorated Section | | | |
|---|---|---|---|
| IMPULSE | Sample 1<br>I (kA) | Sample 2<br>I (kA) | Sample 3<br>I (kA) |
| 1 | 100.51 | 101.10 | 102.50 |

| Disconnector | | | |
|---|---|---|---|
| IMPULSE | Sample 1<br>I (kA) | Sample 2<br>I (kA) | Sample 3<br>I (kA) |
| 1 | 98.76 | 101.80 | 101.22 |

Figure 1 - 100 kA nominal 4/10 µs impulses
Sample 1, Discharge Current = 100.51 kA




The 100kA conditioning was followed by preheating of all the prorated sections to 64°C. The preheated samples were subjected to two 8/20 µs lightning discharges with a total charge content of 1.1 Coulombs. Figure 2 shows a waveform (Sample 1) of the current impulse and the total thermal charge contained within it. The application of Ur is shown in Figure 3.

Figure 2 - 8/20 µs and total thermal charge on Sample 1 - Shot 1

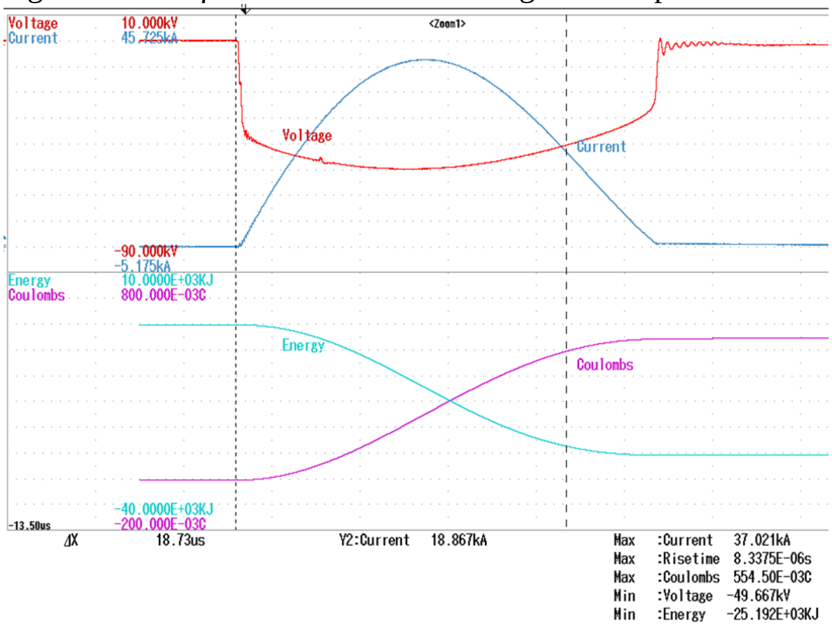



Figure 3 - Application of Ur within 100 ms for 10 s - Sample 1

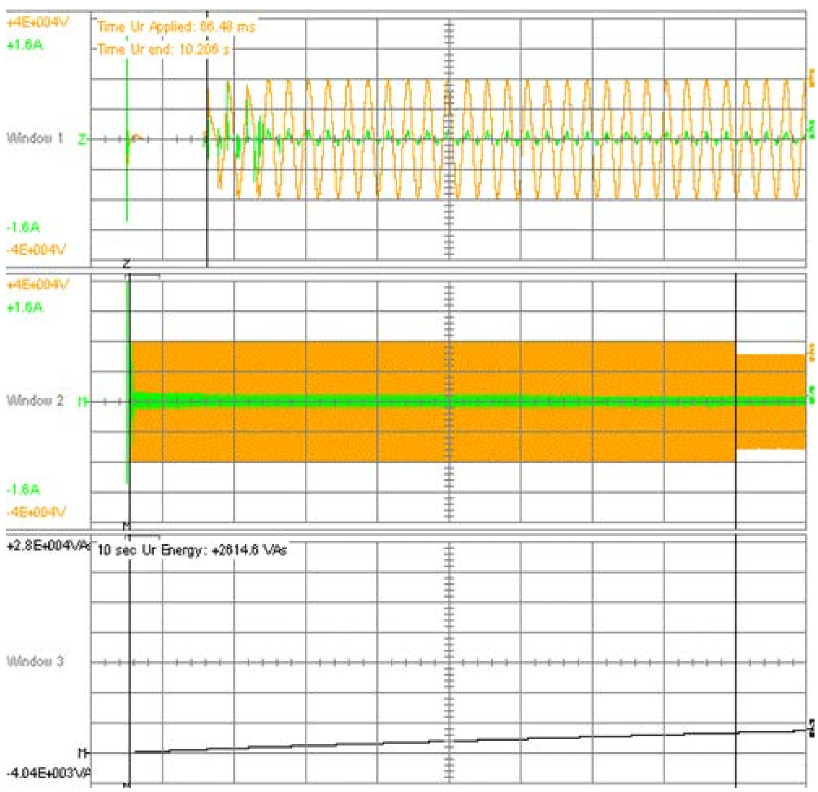


Table 3 – 10 Second Rated Voltage Test

| **Sample 1** | | | **Sample 2** | | | **Sample 3** | | |
|---|---|---|---|---|---|---|---|---|
| **Time (s)** | **Rated Ur (kVc)** | **Current I (mA)** | **Time (s)** | **Rated Ur (kVc)** | **Current I (mA)** | **Time (s)** | **Rated Ur (kVc)** | **Current I (mA)** |
| 1.08 | 19.55 | 82.1 | 1.03 | 19.62 | 88.8 | 1.06 | 19.74 | 91.3 |
| 2.06 | 19.52 | 75.0 | 2.04 | 19.63 | 82.5 | 2.06 | 19.74 | 84.2 |
| 3.07 | 19.52 | 69.6 | 3.02 | 19.60 | 76.3 | 3.07 | 19.73 | 78.8 |
| 4.03 | 19.56 | 69.2 | 4.03 | 19.62 | 74.6 | 4.03 | 19.75 | 77.5 |
| 5.06 | 19.57 | 66.7 | 5.01 | 19.61 | 71.3 | 5.06 | 19.74 | 75.4 |
| 6.04 | 19.52 | 62.5 | 6.12 | 19.60 | 69.6 | 6.04 | 19.74 | 71.7 |
| 7.08 | 19.53 | 61.3 | 7.00 | 19.58 | 66.7 | 7.08 | 19.76 | 72.1 |
| 8.18 | 19.50 | 59.2 | 8.16 | 19.65 | 68.8 | 8.18 | 19.75 | 70.4 |
| 9.36 | 19.52 | 58.8 | 9.22 | 19.66 | 68.8 | 9.36 | 19.79 | 72.5 |
| 10.20 | 19.51 | 57.1 | 10.20 | 19.63 | 65.8 | 10.20 | 19.79 | 70.8 |

Thermal stability defined by Section 8.7.2.3 of IEC Standard 60099-4, Ed. 3.0, was verified during the recovery period by continuous monitoring of power dissipation of the test sections. The resulting measurements are shown in Table 4. The recovery voltage and current oscillograms for Sample 1 are shown in Figure 4 and 5. The results indicated that all three sections demonstrated thermal stability.

Table 4 - Power Dissipation in Thermal Models during Recovery

| **RECOVERY TIME (hh:mm:ss)** | **Sample 1 Watts Loss (W)** | **Sample 2 Watts Loss (W)** | **Sample 3 Watts Loss (W)** |
|---|---|---|---|
| 0:00:00 | 23.44 | 24.02 | 28.15 |
| 0:00:30 | 10.28 | 11.35 | 12.44 |
| 0:01:00 | 5.83 | 7.11 | 7.65 |
| 0:02:00 | 3.27 | 3.90 | 4.19 |
| 0:05:00 | 1.71 | 1.85 | 2.10 |
| 0:10:00 | 1.18 | 1.28 | 1.37 |
| 0:20:00 | .81 | .89 | .97 |
| 0:30:00 | .61 | .65 | .72 |

Sample 1 And Disconnector 1 Recovery oscillograms

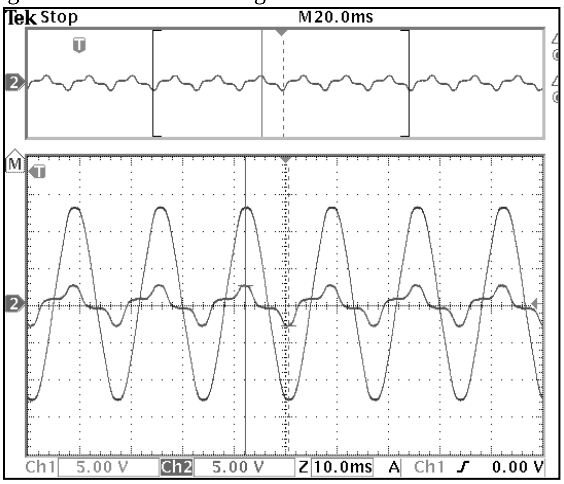



Figure 4: Current and Voltage waveforms at t=0min

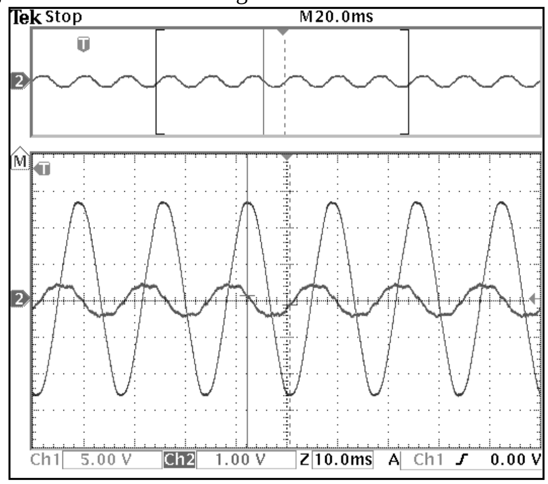



Figure 5: Current and Voltage waver forms at t=30min

## Evaluation:

Results of the residual voltages measured are given in Table 5. The maximum change of residual voltages for the three sections was less than the permissible value of 5 %.

Table 5 - Summary of Residual Voltage Measurements

| SECTION | RESIDUAL VOLTAGE (kV) | | Change |
|---|---|---|---|
| | Before | After | |
| 1 | 36.078 | 36.701 | +1.7% |
| 2 | 36.182 | 36.768 | +1.6% |
| 3 | 36.344 | 36.835 | +1.3% |

After the residual voltage check, the prorated sections were subjected to two additional impulses (5.38kA, 8/20µs) 50 to 60 s apart (see Table 6). The oscillograms (Figures 6 & 7) of the impulses revealed no breakdown therefore no mechanical damage is indicated. These oscillograms were typical for all three samples.

Table 6 - Summary of Evaluation Shots

| Sample | Impulse 1 IR (kV) | Impulse 2 IR (kV) | % Change |
|---|---|---|---|
| 1 | 36.701 | 36.835 | +0.4% |
| 2 | 36.768 | 37.037 | +0.7% |
| 3 | 37.037 | 37.306 | +0.7% |

Figure 6 - Evaluation shot 1: sample 1

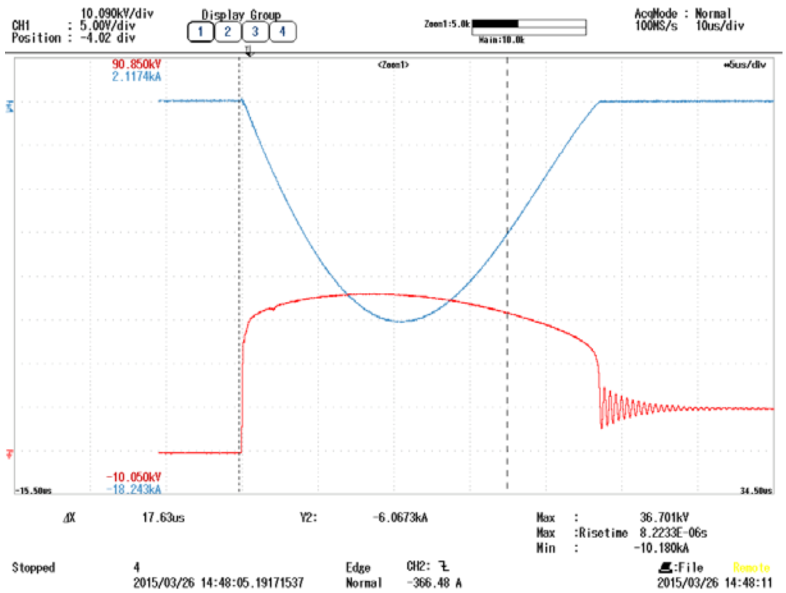
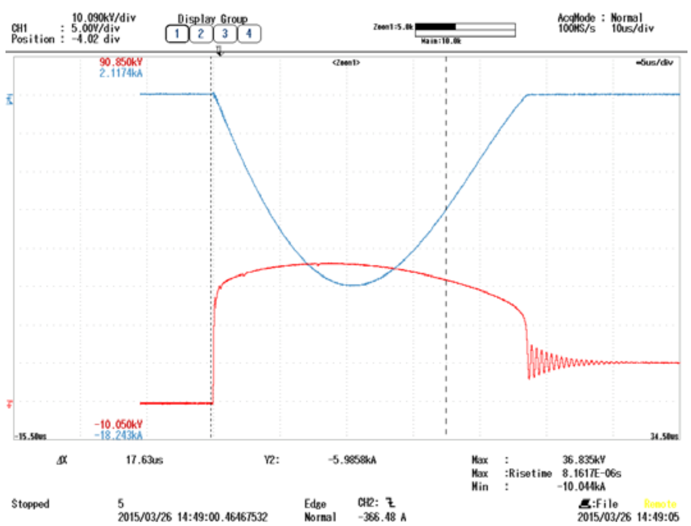



Figure 7 - Evaluation shot 2: sample 1




None of the disconnector samples operated and the capacitance of the disconnectors remained well within the range of 20% per section 8.9.2.4 of the standard (Table 7).

Table 7: Capacitance Before and After Test

| Sample No. | Cap. Before 100 kA (pF) | Cap. After ODC (pF) | % Change |
|---|---|---|---|
| 1 | 4660 | 4652 | 0.2% |
| 2 | 4070 | 4076 | -0.1% |
| 3 | 4610 | 4635 | -0.5% |

## Test Summary

All three sections demonstrated thermal stability. The change of residual voltage measured before and after the test was less than 5% (Table 5). The sections were subjected to two more lightning discharges (8/20 µs, 10 kA – 50-60 s apart). The oscillograms of both the voltage and current showed no signs of breakdown. The disconnector assemblies did not operate and the change in capacitance of each disconnector was well within limits. Therefore, the three prorated sections along with the disconnector successfully passed the operating duty test per Section 10.8.7 and section 8.9.2.3 of IEC Standard 60099-4, Ed 3.0. The claimable Qth rating is 1.1 Coulombs.

# IEC Type Test Report
# Report No. TD 01 41 E07
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## Power Frequency Voltage Versus Time
## IEC Clause 10.8.8

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

# IEC Type Test Report

## POWER FREQUENCY VOLTAGE VERSUS TIME CHARACTERISTICS IEC 10.8.8

Figures 1 and 2 summarize the actual test data for prior duty (Figure 1) and no prior duty (Figure 2). Figure 3 is a plot of the combined Prior Duty and No Prior Duty TOV Capability curves for the PDV100 Optima arrester. The basic test procedure for determining the prior duty characteristics is listed below:

1. Measure the initial residual voltage of each sample at 10kA (8/20 µs).
2. Preheat to 65°C. See report TD 01 41 E05 Thermal Equivalency for explanation of 65°C preheat point.
3. For Prior Duty samples apply two energy discharges 1 minute apart. Each waveform (8/20 µs) shall have Qth value of 0.55 C.
4. Within 100 ms of the second discharge, apply the selected p.u. of voltage for a time greater than the abscissa value on Figure 1.
5. Apply the continuous operating voltage ($U_c$) for 30 minutes and monitor the power loss to confirm stability.

The PDV100 Optima arresters met the requirements of this clause.

Table 1A

| ***Prior Duty Points*** | |
|---|---|
| **Time** | **p.u. Ur** |
| 0.1 | 1.215 |
| 1 | 1.155 |
| 10 | 1.095 |
| 100 | 1.055 |
| 1000 | 1.015 |
| 10000 | 0.975 |

Table 1B

| ***No Prior Duty Points*** | |
|---|---|
| **Time** | **p.u. Ur** |
| 0.1 | 1.300 |
| 1 | 1.225 |
| 10 | 1.150 |
| 100 | 1.120 |
| 1000 | 1.090 |
| 10000 | 1.062 |

Tables 1A and 1B above summarize the prior duty and no prior duty capabilities of the PDV100 Optima as a function of time-duration of voltage.

Figure 1 - Prior Duty Curve

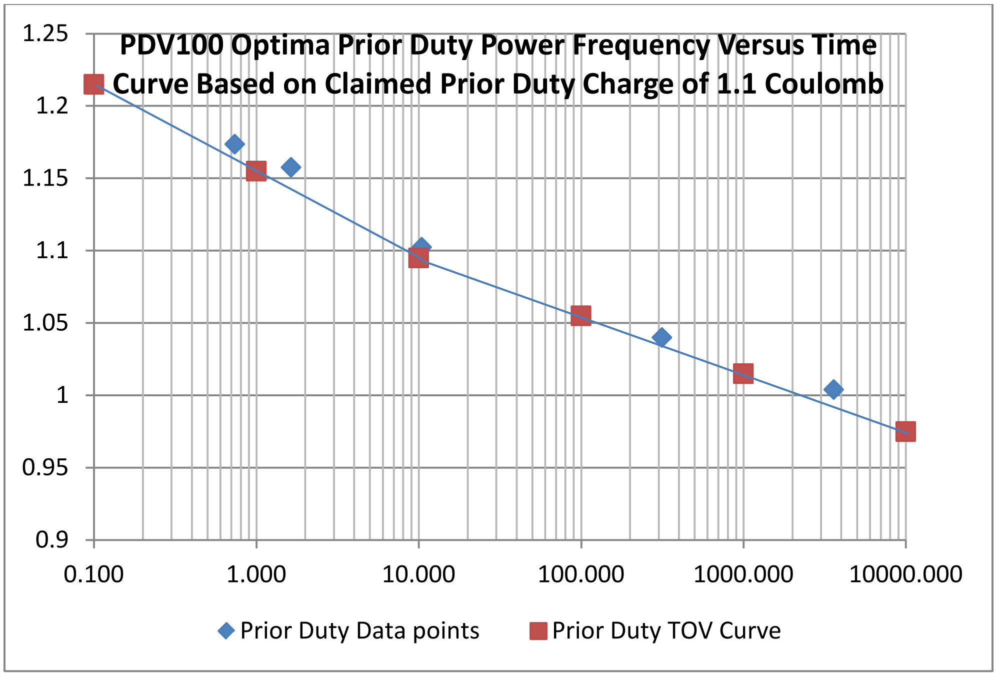



Figure 2 - No Prior Duty Curve

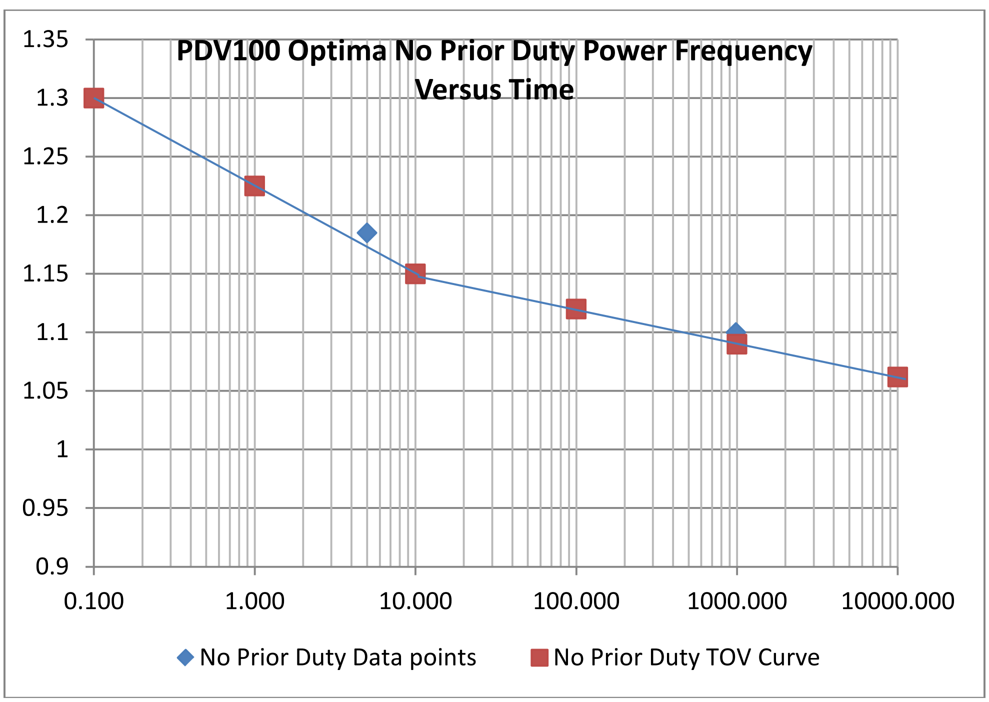


Figure 3 – Combined Prior and No Prior Duty Curves

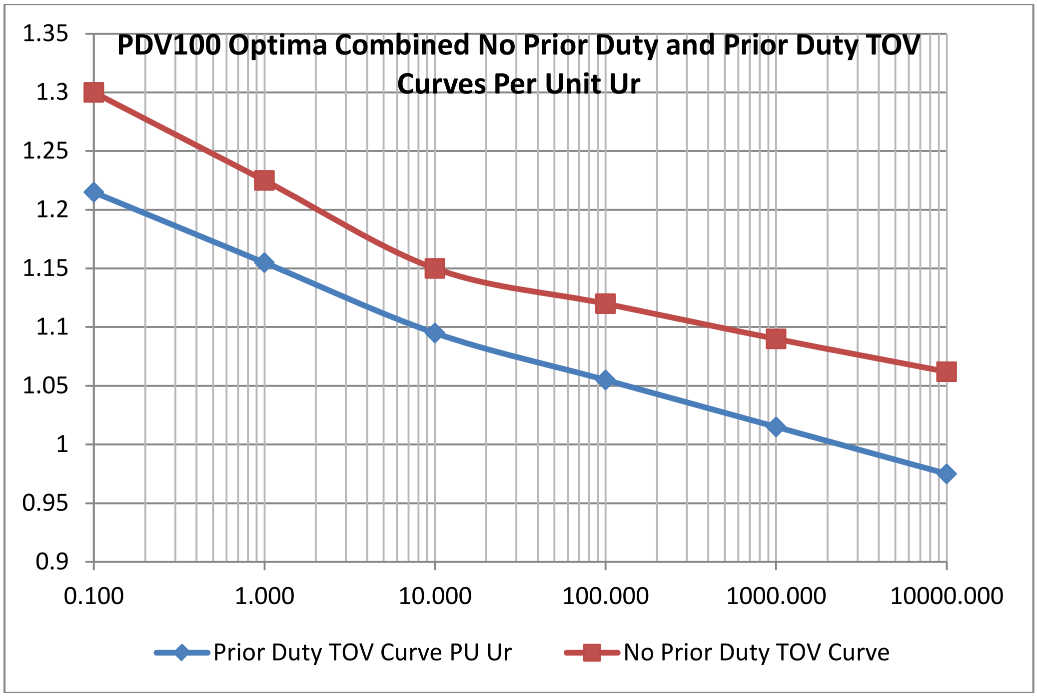



Table 3 – Before and After IR Comparison

| Sample No. | Test | 10kA IR (KVc) Before | 10kA IR (KVc) After | % Change |
|---|---|---|---|---|
| 1 | Prior Duty | 36.130 | 37.037 | +2.5% |
| 5 | Prior Duty | 36.161 | 36.768 | +1.7% |
| 8 | Prior Duty | 36.092 | 36.902 | +2.2% |
| 14 | Prior Duty | 36.135 | 36.970 | +2.3% |
| 15 | Prior Duty | 36.113 | 36.902 | +2.2% |
| 11 | No Prior Duty | 35.809 | 36.297 | +1.4% |
| 24 | No Prior Duty | 35.555 | 36.028 | +1.3% |

Table 3 summarizes the pre and post test residual voltages of each sample. The change in residual voltage was less than ±5%. After the residual voltage post check, the prorated sections were subjected to two additional impulses (5.1 kA, 8/20 µs) 50 to 60s apart summarized in Table 4. The oscillograms of the impulses revealed no breakdown. Therefore, no mechanical damage was indicated on any of the test samples. The evaluation impulse oscillograms of Sample 11 are shown in Figures 4 and 5.

Table 4 - Summary of Post Test Evaluation Shots

| Sample No. | Test | 5.1kA IR (KVc) Shot 1 | 5.1kA IR (KVc) Shot 2 | % Change |
|---|---|---|---|---|
| 1 | Prior | 34.279 | 34.279 | 0% |
| 5 | Prior | 33.808 | 33.943 | +0.4% |
| 8 | Prior | 33.94 | 34.01 | +0.2% |
| 14 | Prior | 34.01 | 34.07 | +0.2% |
| 15 | Prior | 33.94 | 34.01 | +0.2% |
| 11 | No Prior | 33.17 | 33.39 | +0.6% |
| 24 | No Prior | 33.60 | 33.12 | -1.0% |

Figure 4 - Evaluation Shot 1 on Sample 11

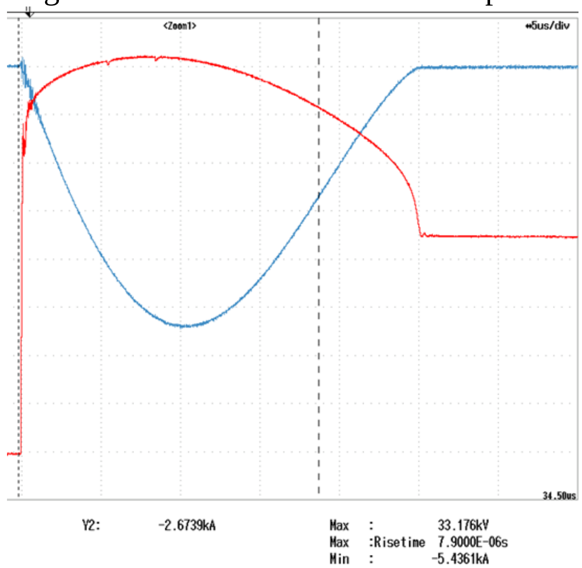
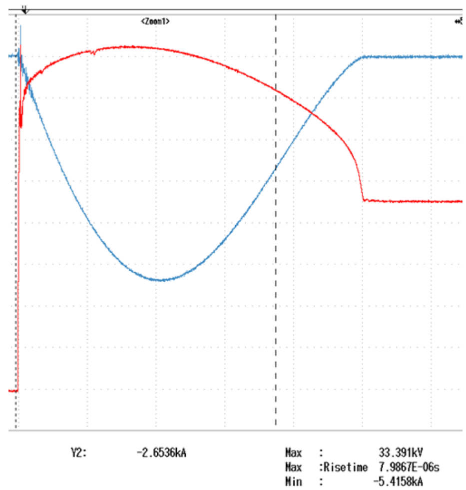



Figure 5 - Evaluation Shot 2 on Sample 11




<u>Test Summary</u>

All test samples successfully passed the power frequency voltage versus time characteristics test per Section 10.8.8 of IEC Standard 60099-4, Ed. 3.0. For all samples, the change in 10 kA 8/20 µs residual voltage measured before and after the discharges (Table 3) was well within the limit of 5%. All samples remained physically intact. Oscillograms of two 5.1 kA 8/20 impulses, 50-60 s apart, applied after the 10kA residual voltage measurement, did not reveal any breakdown. Therefore, no mechanical damage was indicated.

# IEC Type Test Report
# Report No. TD 01 41 E08
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## Short Circuit Test
## IEC Clause 10.8.10

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 “Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems.”

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.


Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer


Date: 4/10/2015

**PDV100 Optima IEC Distribution Class DH Surge Arrester**
**Short Circuit Test**

**TEST OBJECTIVE:** Short Circuit tests were performed on the PDV100 Optima IEC Distribution Class DH polymer-housed arrester per ANNEX N of IEC 60099-4, 2005 standard.

**TEST SAMPLES:** Per Annex N, tests were performed on fusewire shorted and overvoltage failed arresters as defined in Table N.2 of the referenced standard. Short circuit tests were performed on the longest mechanical section, as required in Clause N.8.7.2.2 of the standard.

**TEST PROCEDURE:** Per clause 10.8.10.2 of 60099-4, Ed. 3.0, 2014, the polymer-housed PDV100 Optima is a "Design B" arrester. As such, per Table 8 of 60099-4, Ed. 3.0, 2014, four short circuit tests are required. All four short circuit tests are to be performed per Table 7 and Table 8 on unfailed arresters using the 2-source test method.

As short circuit tests were originally performed per Annex N, two test samples for the high current test were assembled with a fuse wire oriented axially between the mov disc stack and the fiberglass-epoxy wrap. These samples were subjected to the full offset current test. In addition, six samples represented standard production arresters. These samples were failed using the specified 2-source failure mode procedure. All tests were performed at full voltage. Therefore, the prospective fault current, as measured during the bolted fault test on the generator, is the claimable short circuit capability of the design. It should be noted that the IEC 60099-4, Ed. 3.0, 2014 short circuit test is similar to that defined in Annex N of new IEC 60099-4-2005 standard, except reduced level high current testing was performed only at 10 kA, instead of 12 kA and 6 kA as required in the IEC 60099-4, Ed. 3.0, 2014, standard. Also note that the original IEC testing was performed on (8) total arresters versus only (4) per IEC 60099-4 Ed. 3.0, 2014.

**TEST RESULTS:** The following table summarizes the results these tests which validated the claimed maximum 20 $kA_{rms}$ symmetrical, 12 cycle fault current withstand capability of this design, with an applied ratio of 1.55 between total asymmetrical to symmetrical rms currents. This corresponds to a 2.6 ratio, in the first half loop of fault current, between the crest asymmetrical to rms symmetrical current, i.e., full offset. In addition to testing at the claimed maximum capability, tests were also performed, using the 2-source procedure, at half the claimed capability and at 600 amps as specified in Table 14 of the standard.

All tests were performed at full voltage. Therefore, the prospective fault current, as measured during the bolted fault test on the generator, is the claimable fault current capability of the design.

Table 1

Calibration Test 20.3 kA Symmetrical RMS 55.3 $kA_{peak}$

| Sample # | Failure Mode | Test Duration-seconds | Condition of Module/Polymer Housing After Test |
|---|---|---|---|
| 1 | Fuse Wire | .204 | Module Intact/Hsg Torn but in Place |
| 2 | Fuse Wire | .203 | Module Intact/Hsg Torn but in Place |
| 3 | 2-Source | .207 | Module Intact/Hsg Torn but in Place |
| 4 | 2-Source | .207 | Module Intact/Hsg Torn but in Place |

Calibration Test 10.1 kA Symmetrical RMS No Asymmetrical Requirement

| Sample # | Failure Mode | Test Duration-seconds | Condition of Module/Polymer Housing After Test |
|---|---|---|---|
| 5 | 2-Source | .204 | Module Intact/Hsg Torn but in Place |
| 6 | 2-Source | .209 | Module Intact/Hsg Torn but in Place |

Calibration Test 568 Amp Symmetrical RMS No Asymmetrical Requirement

| Sample # | Failure Mode | Test Duration-seconds | Condition of Module/Polymer Housing After Test |
|---|---|---|---|
| 7 | 2-Source | 1.17 | Module Intact/Hsg Torn but in Place |
| 8 | 2-Source | 1.22 | Module Intact/Hsg Torn but in Place |

**CONCLUSION:** The eight test arresters assembled with the longest mechanical unit met the test evaluation criteria as specified in the standard. In all tests, the arrester module remained intact after the completion of each test. The flexible polymer housing wall section split, as intended, on all samples to allow venting of internal arcing gases to the outside of the arrester. In all cases, flames associated with the fault current test extinguished immediately after completion of the test, well within the allowed 2 minute duration. These tests have demonstrated the capability of the Type PDV100 Optima IEC Distribution Class DH arrester design to successfully discharge a maximum claimable 20 $kA_{rms}$ symmetrical fault current.

# IEC TYPE TEST REPORT
# Report No. TD 01 41 E09
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## Bending Moment Test
## IEC Clause 10.8.11

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 “Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems.”

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

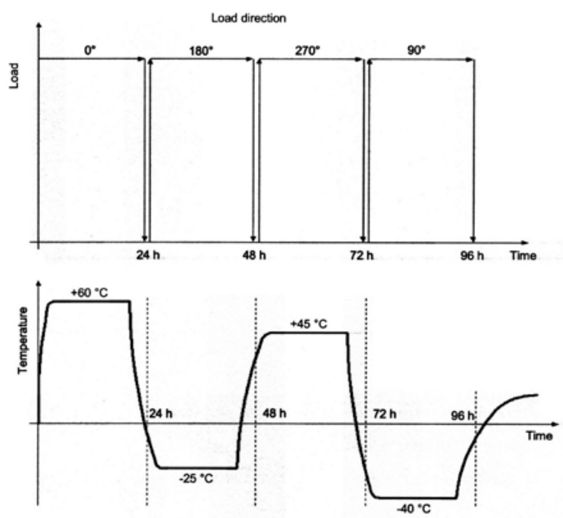
**Type PDV100 Optima Distribution Class DH Arrester**
**Bending Moment Clause 10.8.11**

**Introduction**: The bending moment test has two test procedure requirements as shown in Figure G.5 of the IEC 60099-4 Ed. 3.0 2014-06 Standard:

- Specified Long Term Loading (SLL)
- Specified Short Term Loading (SSL)

**SLL Test Procedure:** The test was performed per section 10.8.1.3.1 of IEC 60099-4 Ed.3.0 2014-06 Standard. The test arrester was subjected to PD, watts loss, and residual voltage tests prior to the bending moment and boiling water immersion test. The mechanical portion of the test consisted of first applying a 20 ft-lb torque to the arrester end terminals for 30 second duration. One of the test arresters was then placed inside a thermal cycling oven and mechanically loaded to its 700 in-lb continuous cantilever rating. The load application and test temperature is shown on Figure 1.

Figure 1




After completion of the mechanically loading portion of the test procedure, the water immersion portion of the bending moment test was performed per para. 8.22.3.3.a) and consists of placing the mechanically stressed arrester into a boiling salt water bath for 42 hours, after which the same is cooled to room temperature and electrical tests are repeated.

**SSL Test procedure:** Per the Figure G.5, Section 10.8.11.3 b), Step 1.1 defines the specified short-term load (SSL) bending moment test. Each of these two test units was securely mounted to the horizontal base of the test equipment and lateral (horizontal) loading was applied to the free end of the unit, in a direction perpendicular to the axis of the unit, at a rate necessary to reach the bending moment corresponding to the specified short-term load (SSL) in approximately 50 s. The load was then maintained at this level for about 90 s. Deflection was measured prior to release of the load. After release of load, the test sample was inspected to verify that no mechanical damage had occurred, and the load-deflection curve was examined to verify that there was no discontinuity which might indicate mechanical damage. The unloaded residual deflection was measured on each sample.

**Water Immersion Test Procedure:** Subsequent to the SSL and SLL tests, the three test samples were immersed in a bath of de-ionized water with 1 $kg/m^3$ of NaCl for 42 hours after which the samples were electrically evaluated.

**Test Results:** Per Clause 10.8.11.2 of IEC 60099-4 Ed. 2.2 2009-05 Standard, preliminary electrical tests were performed on the three PDV100 Optima arresters

Per step 2.1 of Clause 10.8.9.3.a), test samples # 2 and 4 were rigidly base mounted in a cantilever fixture and loaded within 30 to 90 seconds to the arresters claimed specified 135 Nm (1200 in-lb) short-term load (SSL) and maintained at this moment load for 60 to 90 seconds, after which the applied load was slowly removed. Figure 2 shows the test sample's top end deflection as plotted against time for test sample #2. The maximum recorded top end deflection under load was .153 inches while the recorded residual deflection was .01".

Figure 2

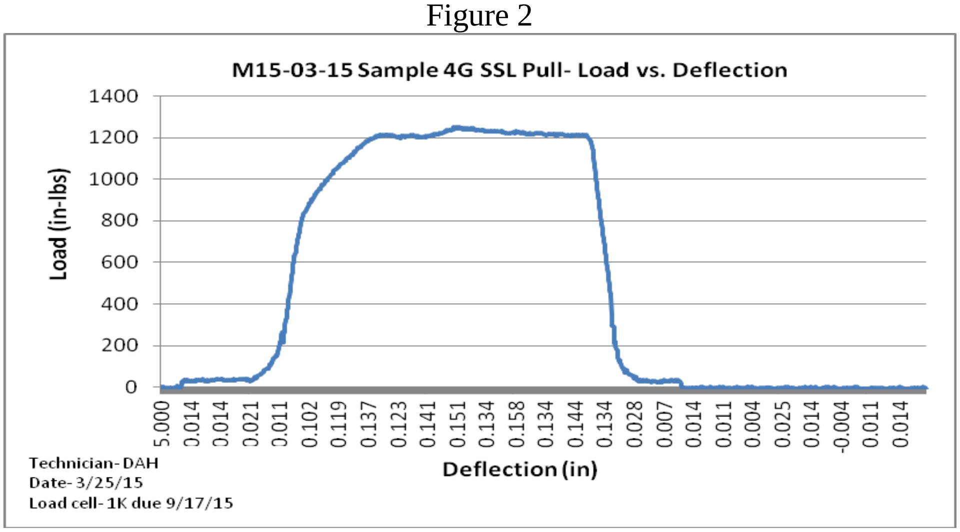
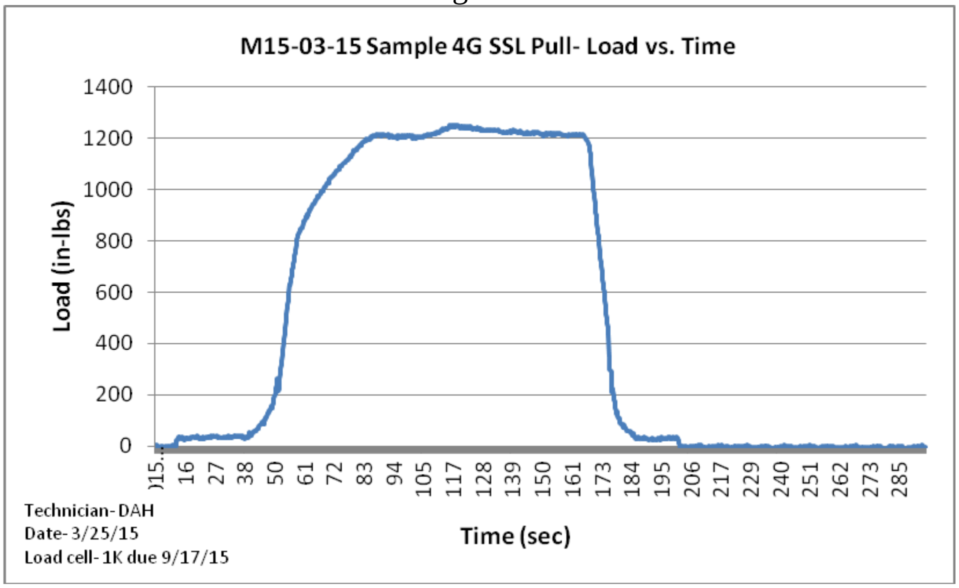


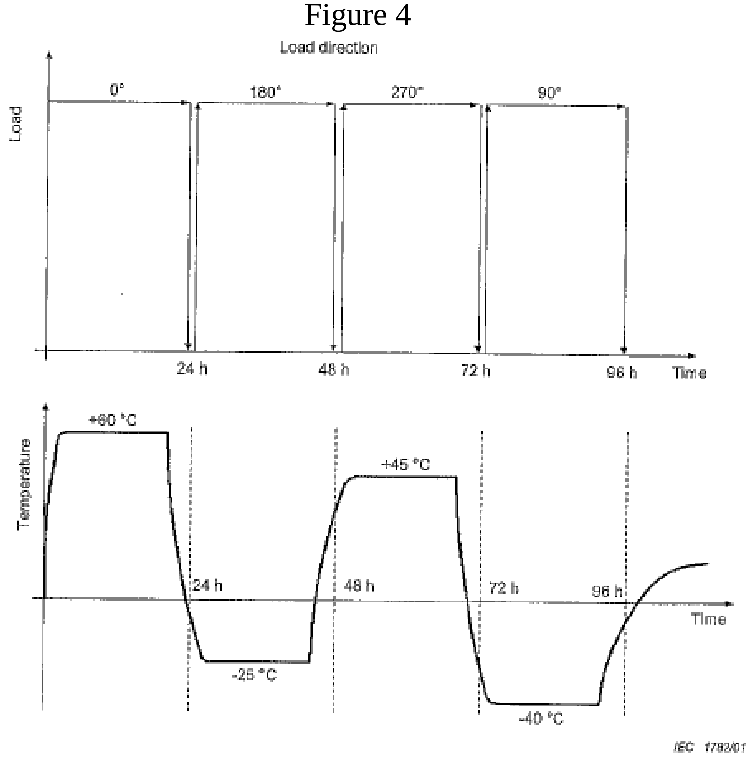

Figure 3 shows moment applied to the top end of sample #4 during the SSL loading cycle.

Figure 3




Per step 2.2 of Clause 10.8.11.3.a), test sample #1 was subjected to thermo-mechanical preconditioning as specified in Clause 10.8.11.3.1.2. During this test, the test sample is placed inside a thermal cycling oven which loads the top end of the sample to its claimed 79 Nm(700 in-lb) SLL. Figure 4 shows the sample's load and temperature cycle.

Figure 4



At the completion of the specified mechanical loading, samples 1, 2, and 4 were placed into boiling NaCl water for 42 hours, as specified in Clause 10.8.11.3.2. After 42 hours exposure, the water bath temperature was reduced to 50 deg C. After stabilizing in 50 deg C water bath, the test samples were dried off and 60 Hz electrical tests were repeated per Clause 10.8.11.4. Table 2 summarizes the results of electrical tests performed on the test samples prior to and after the 42 hour boiling water test.

Table 2

| Test Parameter | Sample #1 | Sample #2 | Sample #4 |
|---|---|---|---|
| Initial watts Loss at Uc | .143 | .154 | .159 |
| Final Watts Loss at Uc | .146 | .152 | .165 |
| Watts Loss % Increase | +2.1% | -1.3% | +3.8% |
| Final PD at 1.05*Uc-pC | 0 | 0 | 0 |

As specified in Clause 10.8.11.4, to further confirm the electrical integrity, each test sample was subjected to the following test before and after the boiling water test. Results are shown in Table 3.

Table 3

| Final Test Steps | Test Description | Test Sample 1 | Test Sample 2 | Test Sample 4 |
|---|---|---|---|---|
| Before | 4 ma Uref kVc | 19.971 | 19.876 | 19.604 |
| Before | 8/20 10 kA IR-kVc | 36.030 | 35.809 | 35.461 |
| After | 8/20 10 kA IR-kVc | 36.852 | 35.963 | 35.741 |
| After | 4 ma Uref kVc | 19.936 | 19.825 | 19.584 |

Finally, each sample was subjected to two additional 10 kA IR surges spaced 1 minute apart. Close examination of oscillograms showed the traces to be smooth and less than 1% apart, confirming the integrity of each test sample.

**CONCLUSION:** Three Type PDV100 Optima arresters were subjected to bending moment tests as defined in Clause 10.8.9 of IEC 60099-4 Ed 3.0 2014 Standard. Specified short-term load (SSL) testing was successfully completed at 135 Nt-M, while specified long-term load (SLL) testing was successfully completed at 79 Nt-M. 60 HZ electrical tests, performed on each arrester prior to and after the mechanical and moisture ingress tests, confirmed arrester PD levels below the allowed 10 pC and watts loss was <1%, well below the allowed 20% change. 10 kA residual voltage tests also confirmed the electrical integrity of the three test arresters. In summary, the three PDV100 IEC Distribution Class DH test arresters successfully passed the bending moment test at the designated SLL and SSL levels.

# IEC Type Test Report
# Report No. TD 01 41 E10
# Type PDV100 Optima
# IEC Distribution Class DH

## Test on Arrester Disconnectors
## IEC Clauses 10.8.9, 8.11.6

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

# IEC Type Test Report

## TESTS ON ARRESTER DISCONNECTORS
## IEC CLAUSES 10.8.9, 8.11.6

**Time Vs Current Characteristics: IEC Clause 8.9.3.1**
The ground lead disconnector is an integral part of the insulating base bracket. High current short duration and low current long duration duty tests and duty cycle tests were performed on thermally prorated test sections having the disconnector assembly connected in series. Disconnectors did not operate when subjected to these tests.

Disconnector detonation tests were performed on five (5) bracket/disconnector assemblies each at 20, 200, and 800 A rms. Detonation times were extended to 1 and 5 amps to confirm the disconnector's low current capability. Figure 1 shows the rms value of the current and time duration to the first movement of the disconnector. This test was performed without the arrester. The ground lead arrester disconnectors tested met the requirements of this IEC Clause 8.9.3.1.

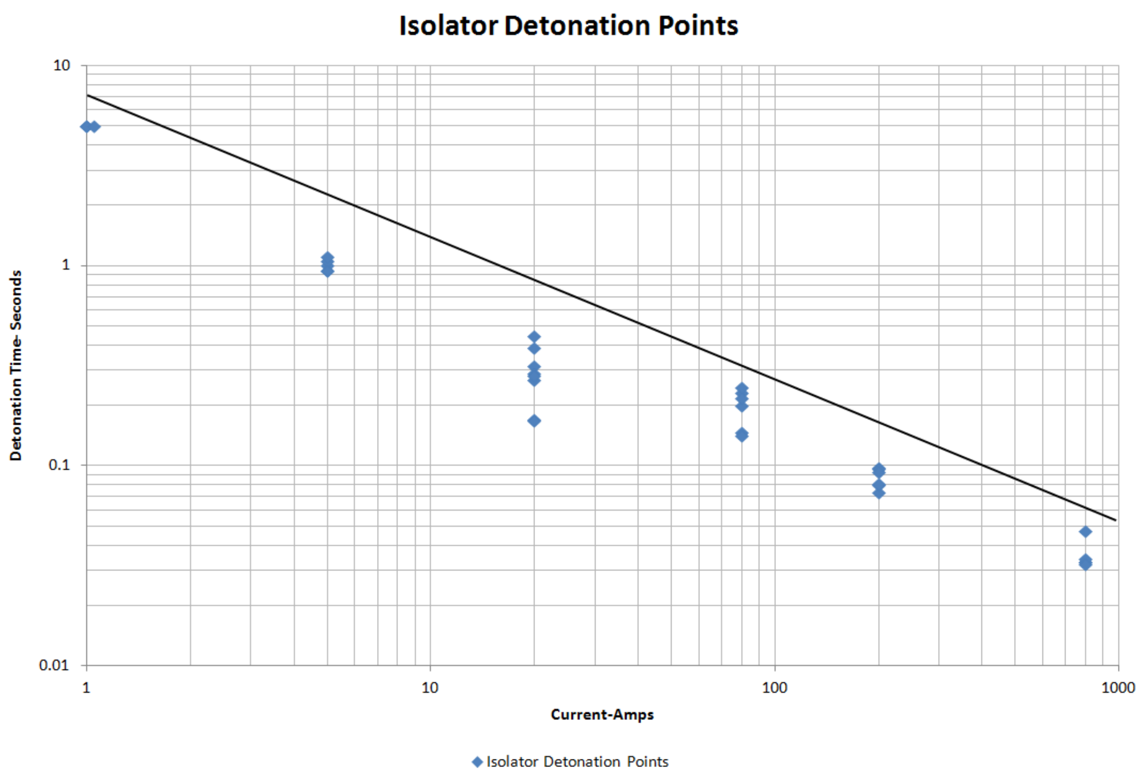



**Figure 1. Time vs. current characteristics of disconnectors.**

**Temperature Cycling and Seal Pumping test: IEC Clause 8.9.5**

The purpose of this test is to test the seal integrity of the disconnector brackets under stress simulated by the hot and cold temperature cycling. This test was performed on disconnector brackets with an end terminal and a gasket torque on one end.

**Temperature Cycling**: 10 samples were subjected to a temperature cycling test per clause 8.12.3.1 followed by a seal pumping test. The samples were subjected to a hot temperature of 60°C for 4 hours and a cold temperature of -25°C for 4 hours during one cycle of the temperature cycling. There were a total of 10 cycles.

**Seal Pumping**: The test samples were uniformly heated to 60°C and maintained at that temperature for a minimum of 1 hour. The samples were then placed in a cold water bath having a temperature of 4°C for a minimum of 2 hours within 5 minutes. The test cycle was repeated 10 times.

**Evaluation:** The capacitance was measured (table 1) and a visual inspection was performed.

| Sample | Pre test Capacitance (pF) | Post temp cycling and seal pumping (pF) | %Change | REMARKS |
|---|---|---|---|---|
| **1** | 4718 | 4695 | 0.5% | No moisture present |
| **2** | 4340 | 4371 | -1% | No moisture present |
| **3** | 4508 | 4491 | 0.4% | No moisture present |
| **4** | 4695 | 4657 | 1% | No moisture present |
| **5** | 4757 | 4720 | 0.8% | No moisture present |
| **6** | 4540 | 4506 | 1% | No moisture present |
| **7** | 4777 | 4721 | 1.2% | No moisture present |
| **8** | 4793 | 4759 | 1% | No moisture present |
| **9** | 4722 | 4690 | 0.7% | No moisture present |
| **10** | 4121 | 4195 | -2% | No moisture present |
| **11** | 4719 | 4691 | 0.6% | No moisture present |
| **12** | 3968 | 4022 | -1% | No moisture present |

**Table 1**

**Result:** The change in capacitance was well within the limits of 20% there were no traces of moisture inside the disconnector.

**Bending Moment Test: IEC clause 8.11.6**

Three samples of each size were tested. On each sample the bending load was increased smoothly to a load equivalent to the arrester SSL (1000 in-lbs) within 30s to 90s. When the test load was reached, it was maintained steadily for 60s to 90s and released smoothly. Table 2 shows the test results.

| Sample | Catalog # | 60-90 sec hold at 1000 in lbs moment | Max Load (in-lbs) | Pass/ Fail |
|---|---|---|---|---|
| 1 | 273554-4001 (short) | X | 1,101 | Pass |
| 2 | 273554-4001 (short) | X | 1,118 | Pass |
| 3 | 273554-4001 (short) | X | 1,062 | Pass |
| 4 | 273903-4003 (medium) | X | 1,091 | Pass |
| 5 | 273903-4003 (medium) | X | 1,074 | Pass |
| 6 | 273903-4003 (medium) | X | 1,104 | Pass |
| 7 | 273555-4004 (long) | X | 1,092 | Pass |
| 8 | 273555-4004 (long) | X | 1,110 | Pass |
| 9 | 273555-4004 (long) | X | 1,100 | Pass |

**Table 2**

**Result:** All mounting brackets passed the test with no visible mechanical damage.

**Qrs test on Arrester Disconnectors: IEC Clause 8.9.2.2**

This test was performed in accordance with section 8.5 of IEC 60099-4, 2014. The charge transfer value (0.57C) corresponding to the highest classification of arresters with which the disconnector is designed, had been used. Lightning impulses (8/20 µs) with a charge content of 0.57C were applied on three disconnector brackets. Table 3 shows the summary of the test. Figure 2 shows a sample Oscillogram of the impulse.

| Shot | Sample 1 | | | | Sample 2 | | | | Sample 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IR (KVc) | I (kA) | Energy (KJ) | Charge (C) | IR (KVc) | I (kA) | Energy (KJ) | Charge (C) | IR (KVc) | I (kA) | Energy (KJ) | Charge (C) |
| 1 | 16.978 | 40.381 | 9.000 | 0.566 | 17.005 | 40.347 | 9.027 | 0.565 | 17.059 | 40.652 | 9.130 | 0.569 |
| 2 | 17.032 | 40.754 | 9.127 | 0.570 | 17.059 | 40.822 | 9.173 | 0.572 | 17.113 | 41.297 | 9.307 | 0.578 |
| 3 | 17.032 | 40.924 | 9.163 | 0.573 | 17.032 | 40.754 | 9.140 | 0.570 | 17.032 | 40.822 | 9.143 | 0.571 |
| 4 | 17.086 | 41.059 | 9.220 | 0.574 | 17.086 | 41.161 | 9.257 | 0.576 | 17.113 | 41.297 | 9.307 | 0.578 |
| 5 | 16.817 | 40.991 | 9.000 | 0.576 | 16.844 | 40.958 | 9.007 | 0.575 | 16.870 | 41.059 | 9.037 | 0.576 |
| 6 | 16.844 | 41.263 | 9.093 | 0.579 | 16.870 | 40.822 | 8.995 | 0.573 | 16.951 | 41.263 | 9.123 | 0.579 |
| 7 | 16.844 | 41.161 | 9.050 | 0.578 | 16.870 | 41.433 | 9.150 | 0.582 | 16.870 | 40.550 | 8.935 | 0.570 |
| 8 | 16.844 | 41.127 | 9.063 | 0.577 | 16.897 | 40.584 | 8.965 | 0.570 | 16.951 | 40.856 | 9.037 | 0.574 |
| 9 | 16.844 | 40.924 | 9.007 | 0.575 | 16.870 | 41.059 | 9.050 | 0.576 | 16.844 | 40.720 | 8.972 | 0.572 |
| 10 | 16.897 | 41.161 | 9.083 | 0.578 | 16.844 | 40.652 | 8.965 | 0.571 | 16.924 | 40.822 | 9.040 | 0.573 |
| 11 | 16.817 | 40.991 | 9.010 | 0.576 | 16.844 | 41.025 | 9.040 | 0.576 | 16.870 | 40.822 | 9.000 | 0.573 |
| 12 | 16.870 | 40.924 | 9.027 | 0.575 | 16.924 | 40.822 | 9.023 | 0.573 | 16.951 | 40.652 | 8.982 | 0.570 |
| 13 | 16.817 | 41.161 | 9.047 | 0.578 | 16.897 | 40.958 | 9.027 | 0.575 | 16.870 | 40.788 | 8.993 | 0.573 |
| 14 | 16.844 | 40.856 | 9.020 | 0.574 | 16.924 | 40.958 | 9.047 | 0.575 | 16.924 | 40.686 | 9.000 | 0.572 |
| 15 | 16.870 | 41.331 | 9.103 | 0.581 | 16.924 | 41.161 | 9.077 | 0.578 | 16.897 | 41.059 | 9.067 | 0.577 |
| 16 | 16.897 | 40.958 | 9.043 | 0.575 | 16.924 | 40.415 | 8.933 | 0.568 | 16.951 | 40.958 | 9.063 | 0.575 |
| 17 | 16.870 | 41.195 | 9.073 | 0.578 | 16.870 | 41.025 | 9.057 | 0.576 | 16.870 | 40.652 | 8.968 | 0.571 |
| 18 | 16.870 | 40.958 | 9.050 | 0.575 | 16.924 | 40.516 | 8.955 | 0.569 | 16.951 | 40.720 | 9.020 | 0.572 |
| 19 | 16.951 | 40.856 | 9.103 | 0.572 | 17.059 | 40.958 | 9.147 | 0.573 | 17.032 | 40.584 | 9.057 | 0.568 |
| 20 | 17.032 | 40.822 | 9.123 | 0.571 | 17.059 | 40.822 | 9.157 | 0.572 | 17.140 | 40.822 | 9.173 | 0.572 |

**Table 3: Summary of Impulses on Each sample**

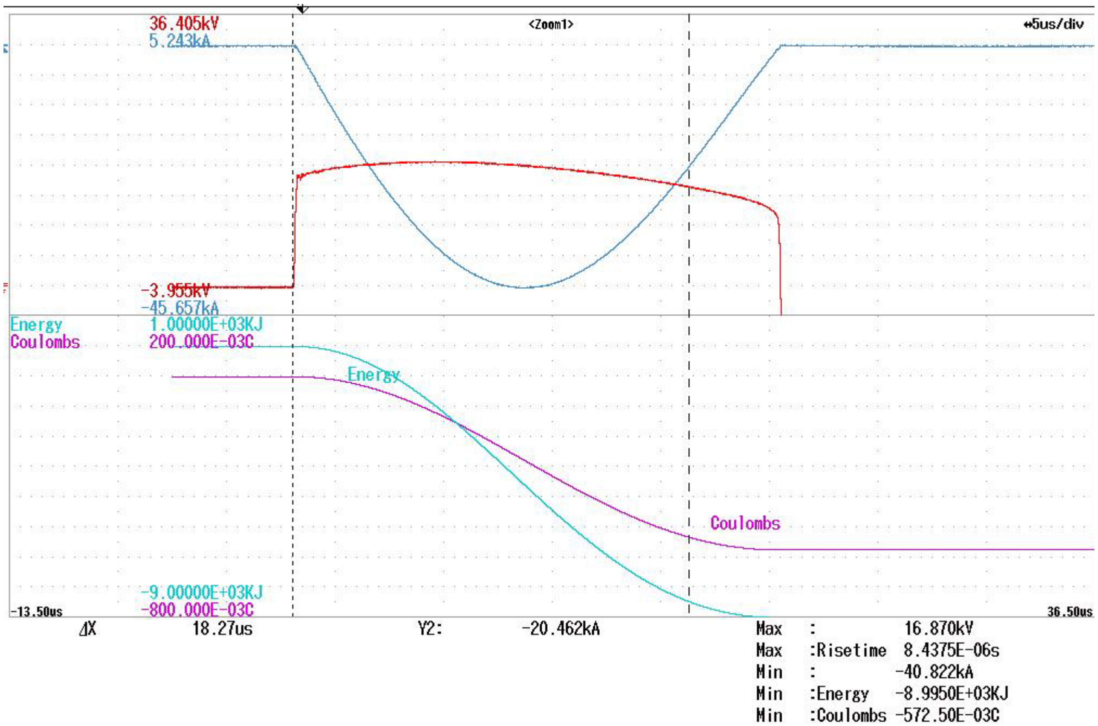



**Figure 2: Oscillogram of waveshape**

Table 4 shows the percentage change in capacitance of the disconnectors before and after the test.

| Sample | Initial C (pF) | After Qrs C (pF) | % Change |
|---|---|---|---|
| 1 | 4341 | 4458 | 3% |
| 2 | 4384 | 4502 | 3% |
| 3 | 4234 | 4460 | 5% |

**Table 4: Change in capacitance of disconnector brackets**

**Result:** The change in capacitance on all three samples remained well within 20%.

The operating duty test (in accordance with section 8.9.2.3) was performed in series with prorated arrester sections. Details of this test will be found in TD 01 41 E06.

Therefore the disconnector brackets have successfully passed all tests required by IEC 60099-4, 2014-06.

# IEC TYPE TEST REPORT
# Report No. TD 01 41 E11
# Type PDV 100 Optima
# IEC Distribution Class DH Arrester

## Salt Fog Accelerated Aging Test
## IEC Clause 10.8.17.2

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

**Type PDV 100 Optima Distribution Class DH Surge Arrester**
**Salt Fog test**

**TEST OBJECTIVE**: Perform 1000 hour salt fog exposure test per section 10.8.17.2 of IEC 60099-4 Ed. 3.0, 2014-06 Standard.

**TEST SAMPLE**: Two 29 kV MCOV arresters were tested. Arrester #1 was tested with its insulating support bracket attached to the base end of the arrester. Arrester #2 was tested without the insulating support bracket.

**TEST PROCEDURE**: The arresters were mounted vertically inside the salt fog chamber. Prior to and after the 1000 hour test, the reference voltage and partial discharge of the sample were measured. The 1000 hour test was performed with a spray having an NaCl salt content of 10 $kg/m^3$ per the procedure specified in section 10.8.17.2.2 of the standard

**TEST RESULTS**: The test arrester passed the 1000 hour salt exposure. The physical condition of the polymer housings showed no signs of surface tracking or surface erosion. There was no evidence of housing or shed punctures. The following table summarizes the results of the electrical testing.

| Sample # | Reference Voltage kVc Before Salt Fog | Reference Voltage kVc After Salt Fog | Reference Voltage % Change | Partial Discharge After Salt Fog PC |
|---|---|---|---|---|
| 1 | 44.5 | 45.0 | +1.1 | <1 |
| 2 | 45.6 | 46.0 | +0.9 | <1 |

Photograph #1 shows the salt-contaminated surfaces of the two arresters after completion of the 1000 hour duration salt fog test. Photograph # 2 shows a close-up view of the undamaged condition of the polymer housings. There was no evidence of surface tracking, erosion, or shed punctures.

**CONCLUSION:** The physical condition of the test arrester and the electrical testing confirmed that the PDV 100 Optima arrester successfully passed the 1000 hour salt fog exposure test.

Photograph #1

Photograph #2

# IEC Type Test Report
# Report No. TD 01 41 E12
# Type PDV100 Optima
# IEC Distribution Class DH Arrester

## UV Light Test
## IEC Clause 10.8.17.3

This report summarizes the results of design tests made on the Type PDV100 Optima IEC Distribution Class DH arrester design. Tests were performed in accordance with procedures of IEC 60099-4, Ed. 3.0, 2014 "Surge arresters- Part 4: Metal oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Principal Engineer

Saroni Brahma
Design Engineer

Date: 4/10/2015

**Type PDV100 Optima Distribution Class DH Surge Arrester**
**UV Light Test**

**INTRODUCTION:** Polymer arrester housings are exposed to ultra violet (UV) radiation not only from sunlight, but also from corona and dry band arcing. Resistance to surface degradation resulting from UV exposure is an important factor in confirming the service life of a polymer arrester.

**TEST PROCEDURE:** The UV life test was performed per clause 10.8.17.3 of IEC 60099-4, Ed. 3.0, 2014, Standard. Tests on polymer housing material used the fluorescent UVB technique specified in clause 10.8.17.3.1. As specified, ASTM G154, ISO 4892-1, and ISO 4892-3 provided details for performing the test. Test duration was 1000 hours on three samples of material.

**CONCLUSION:** There was no evidence of surface degradation, cracking or crazing on the arrester housings after completion of the 1000 hour on-voltage test. Therefore, the PDV100 Optima IEC Distribution Class DH arrester successfully passed the polymer housing UV life test as defined in the IEC 60099-4, Ed. 3.0, 2014, Standard.