HUBBELL®

POWER SYSTEMS

ANSI/IEEE Design Test Report
EU1480-HR

Riser Pole Heavy Duty Polymer Distribution (PVR™) Arrester

Heavy Duty Distribution Class Design tests were run in accordance with ANSI/IEEE Standard C62.11-1999, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1kV)"

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

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Note: Tests performed on Heavy Duty Distribution Class Riser Pole, Catalog Series # 2216xx

SECTION I Arrester insulation withstand tests:

Tests were run on arresters assembled with insulation elements in place of MOV disks. Arrester assemblies were tested per Section 8.1 of IEEE C62.11-1999 Standard using the appropriate insulating bracket supplied for each arrester rating.

Table 1 lists PVR arrester minimum strike distance and minimum leakage distance as well as minimum required 1.2/50 impulse withstand, 60 Hz wet, and 60 Hz dry withstand capabilities. All PVR arrester ratings meet or exceed these levels of withstand voltage.

In addition, the insulated bracket assembly for each rating was tested per Section 8.1.1 to assure that the 60 Hz wet withstand of the bracket exceeded 1.5 times the MCOV of the associated arrester.

Table 1
Summary Data - Insulation Withstand Test

Catalog Number	MCOV (kV)	Rated Voltage (kV)	Arrester Strike Distance (in.)	Strike Distance w/o NEMA Bracket (in.)	Leakage Distance (in.)	60 Hz 10 s Wet Withstand (kVrms)	60 Hz 1 min Dry Withstand (kVrms)	1.2/50 μs Impulse Withstand (kV crest)
221603	2.55	3	2.9	2.9	8.0	13	15	45
221605	5.1	6	6.1	5.2	15.4	20	21	60
221608	7.65	9	6.1	5.2	15.4	24	27	75
221609	8.4	10	6.1	5.2	15.4	24	27	75
221610	10.2	12	6.1	6.1	15.4	27	31	85
221613	12.7	15	9.7	7.1	26.0	30	35	95
221615	15.3	18	9.7	7.1	26.0	36	42	125
221617	17.0	21	9.7	7.1	26.0	36	42	125
221620	19.5	24	11.3	7.7	30.8	60	70	125
221622	22.0	27	18.0	12.2	52.0	60	70	150
221624	24.4	30	18.0	12.2	52.0	60	70	150
221629	29.0	36	18.0	12.2	52.0	80*	95*	200*

* Station and intermediate arrester requirement, distribution arrester requirements are not listed for this rating.

SECTION II Discharge-voltage tests:

Discharge voltage tests were performed on three prorated test samples consisting of two MOV disks, an aluminum end terminal, solid steel spacer, and contact spring plate. The material selection and configuration facilitated accurate proration of inductive and resistive effects of all components in the impulse path of a full arrester.

Tests were conducted in accordance with clause 8.3 of ANSI/IEEE Standard C62.11-1999" IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1kV)". Prorated test sections were subjected to 8/20 current waves with magnitudes ranging from 1.5 kA through 20 kA. In addition, Front-of-wave and switching surge discharge voltage tests were performed.

Arresters are assembled from discs accumulated within 10 kA IR ranges as specified for each arrester rating. To verify catalog maximum IR levels were not exceeded, a discharge voltage ratio was established at each current level based on the test sections 10 kA IR (Table 2). That ratio was multiplied by the maximum 10 kA IR accumulation specified for each rating. As summarized on Table 3, the IR calculated based on the prorated test sections were under the maximum declared catalog levels.

Figures 1-11 contain oscillograms for test section 1 at each current and wave shape. Figure 12 contains a graph of the 10 kA voltage vs. time to crest function. Figure 13 contains a graph of discharge voltage vs. current magnitude.

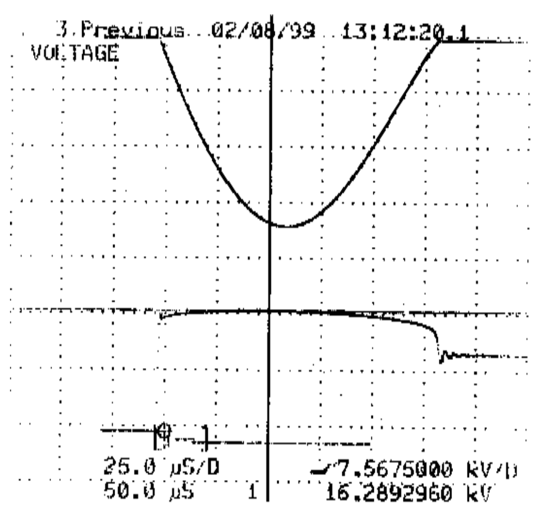


figure 1

126.7 A

16.289 kV

51/102 µs

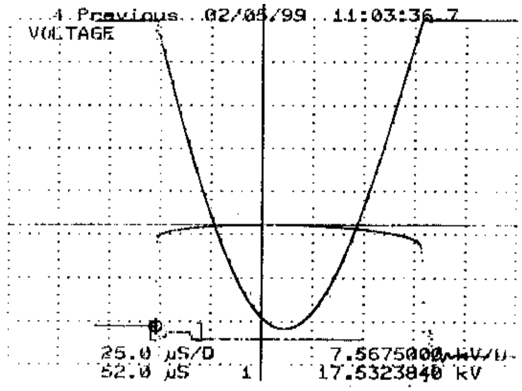


figure 2

534.7 A
17.532 kV
62.5/108 µs

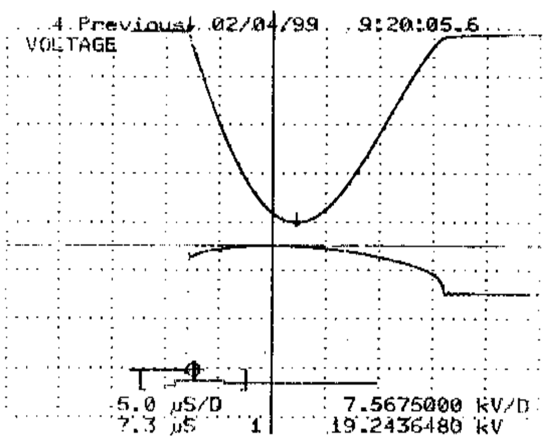


figure 3

1.51 kA
19.244 kV
8.0/18.8 µs

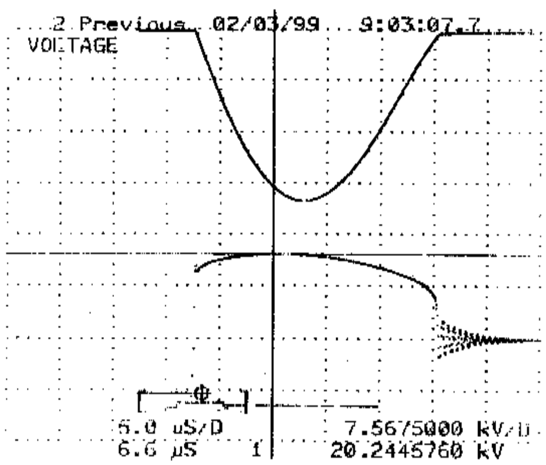


figure 4

2.52 kA
20.245 kV
8.0/18.4 µs

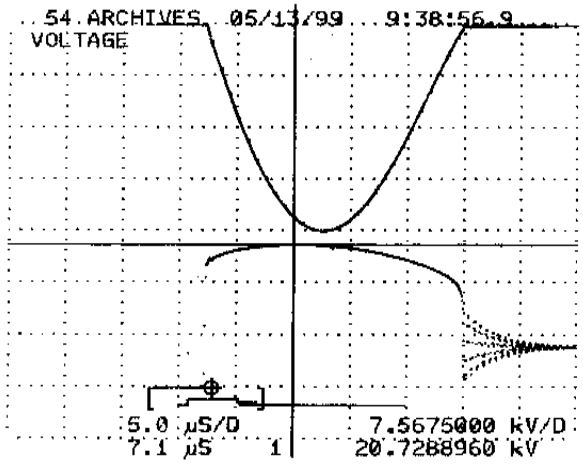


figure 5

3.04 kA

20.729 kV

8.2/18.3 µs

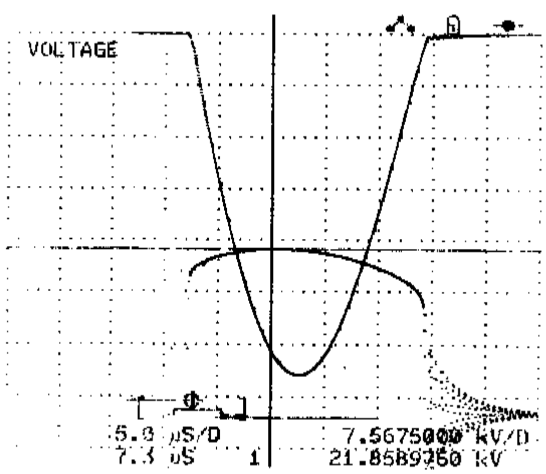


figure 6

5.03 kA

21.859 kV

8.1/ 18.1µs

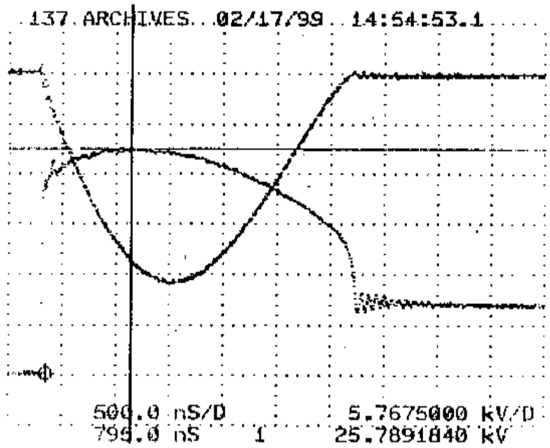


figure 7

10.15 kA
24.184 kV
8.6/18.5 μs

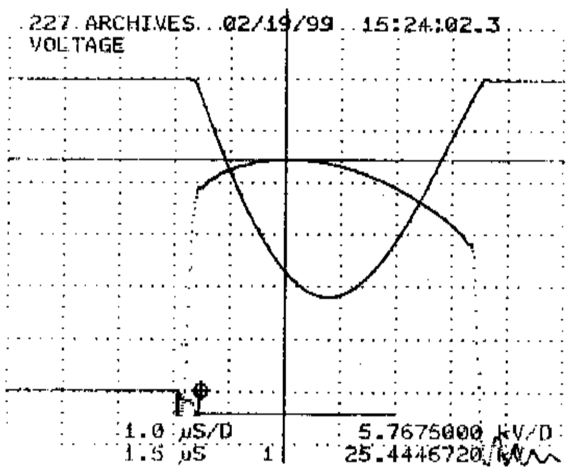


figure 8

10.06 kA
25.445 kV
2.0/4.2 μs

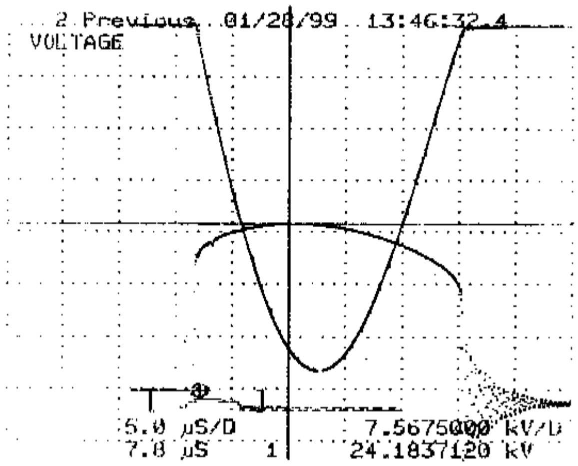


figure 9

10.16 kA
25.789 kV
1.0/ 2.2 μs

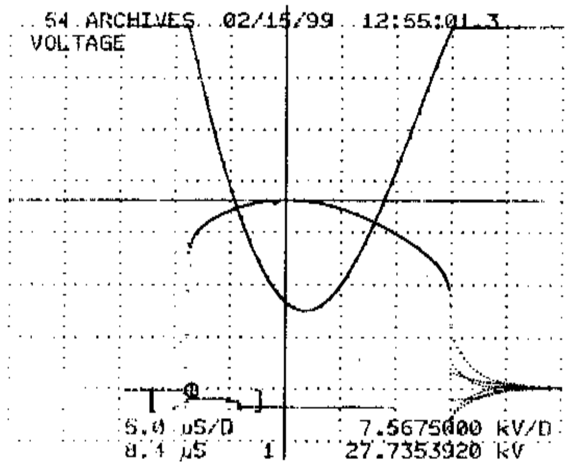


figure 10

20.95 kA
27.735 kV
8.5/19.2 μs

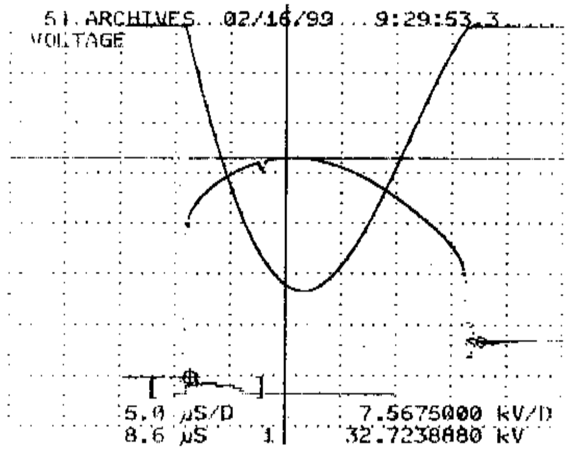


figure 11

40.50 kA

32.724 kV

8.5/19.7 μs

figure 12 - Discharge voltage verses rate of rise

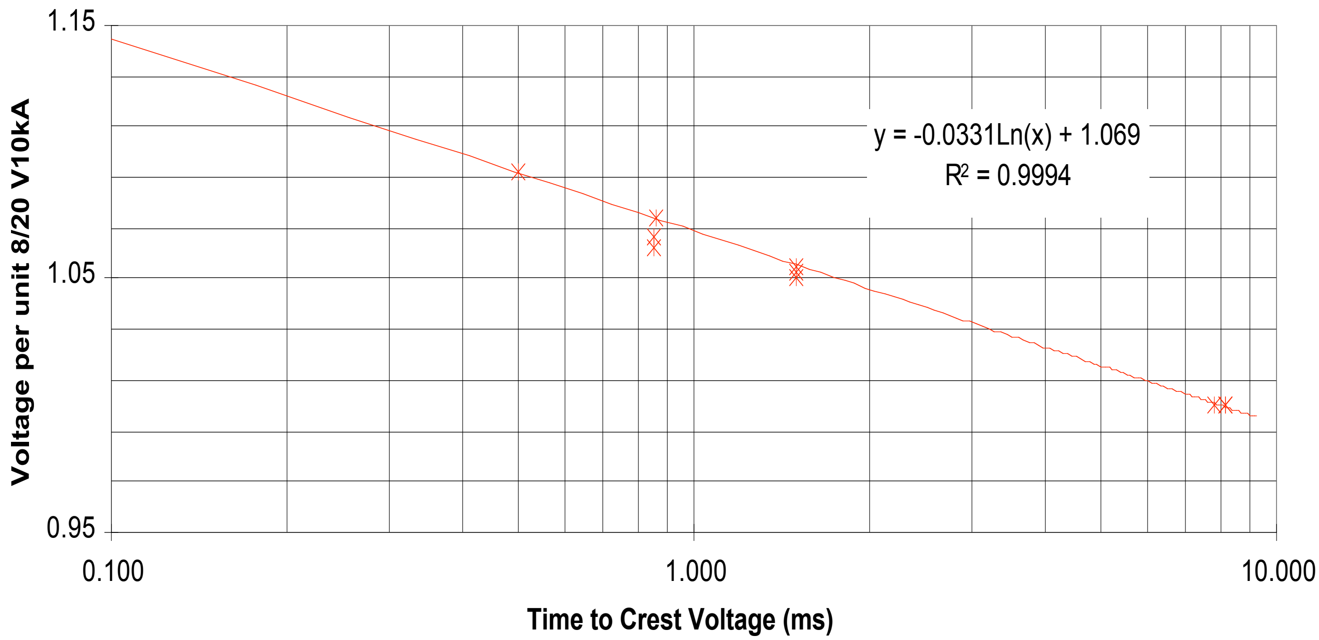


figure 13 - Discharge Voltage Curve

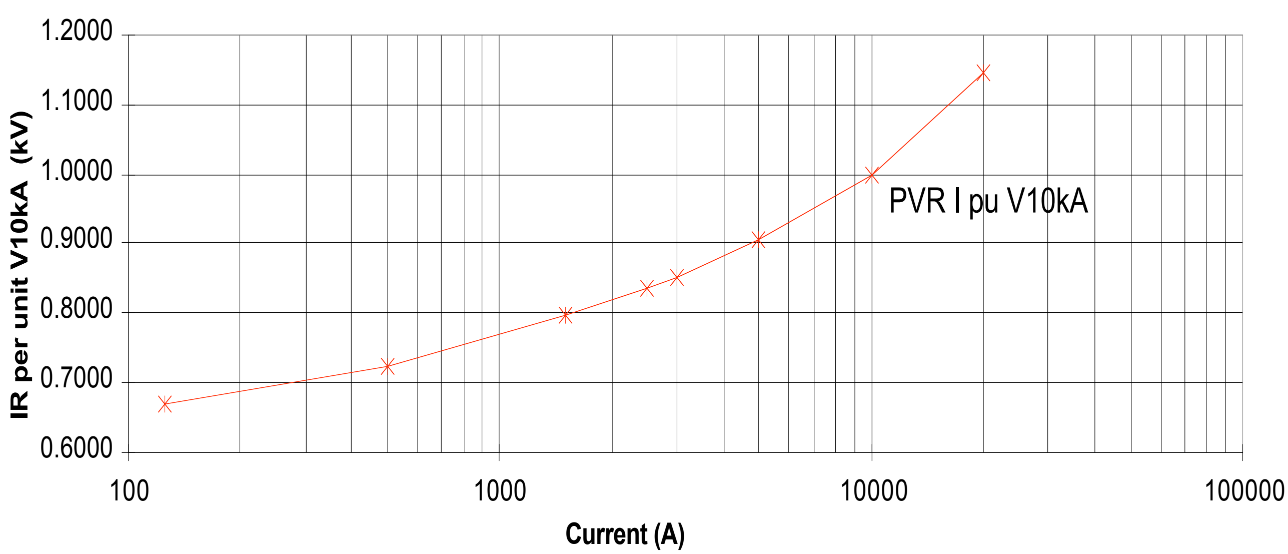


Table 2
Sample Discharge Voltage Data Summary

Impulse Current (A)	Wave Shape	Discharge Voltage (kV)			Discharge Voltage Ratio		
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
125	60/100	16.289	16.225	16.144	0.674	0.671	0.670
500	60/100	17.532	17.468	17.371	0.725	0.722	0.721
1,500	8/20	19.244	19.260	19.163	0.796	0.796	0.796
2,500	8/20	20.244	20.244	20.132	0.837	0.837	0.836
3,000	8/20	20.729	20.664	20.567	0.857	0.854	0.854
5,000	8/20	21.859	21.875	21.778	0.904	0.905	0.904
10,000	8/20	24.184	24.184	24.087	1.000	1.000	1.000
20,000	8/20	27.735	27.655	27.622	1.147	1.144	1.147
40,000	8/20	32.724	32.740	32.611	1.353	1.354	1.354
10,000	_	25.789	25.986	25.592	1.066	1.075	1.062
10,000	2/4	25.445	25.506	25.297	1.052	1.055	1.050
		Time to Crest Voltage (μs)					
10,000	8/20	7.800	8.200	8.200			
10,000	_	0.850	0.865	0.850			
10,000	2/4	1.500	1.500	1.500			

Table 3
PVR Arrester Discharge Voltage Summary

		IR Multipliers	0.674	0.725	0.796	0.837	0.857	0.905	1.000	1.147	1.354	1.092
		Impulse Wave	60/100	60/100	8/20	8/20	8/20	8/20	8/20	8/20	8/20	0.5µsecV
MCOV	Rating	I Magnitude (A)	125	500	1500	2500	3000	5000	10000	20000	40000	10000
2.55	3	Prorated Sect Max IR	6.10	6.56	7.20	7.57	7.76	8.19	9.05	10.38	12.25	9.88
		Catalog Maximum IR	6.1	6.6	7.2	7.6	7.8	8.2	9.1	10.4	12.3	9.9
5.10	6	Prorated Sect Max IR	12.27	13.20	14.49	15.23	15.60	16.47	18.2	20.88	24.64	19.87
		Catalog Maximum IR	12.3	13.3	14.6	15.3	15.7	16.6	18.36	21.0	24.8	20.0
7.65	9	Prorated Sect Max IR	16.47	17.71	19.45	20.45	20.94	22.11	24.43	28.02	33.08	26.68
		Catalog Maximum IR	16.5	17.8	19.5	20.5	21.0	22.2	24.5	28.1	33.2	26.8
8.4	10	Prorated Sect Max IR	18.06	19.43	21.33	22.43	22.97	24.25	26.80	30.74	36.29	29.27
		Catalog Maximum IR	18.2	19.6	21.5	22.6	23.1	24.4	27.0	31.0	36.6	29.5
10.2	12	Prorated Sect Max IR	21.8	23.4	25.7	27.0	27.7	29.2	32.3	37.0	43.7	35.3
		Catalog Maximum IR	21.9	23.6	25.9	27.2	27.9	29.4	32.5	37.3	44.0	35.5
12.7	15	Prorated Sect Max IR	27.2	29.2	32.1	33.7	34.5	36.5	40.3	46.2	54.6	44.0
		Catalog Maximum IR	27.3	29.4	32.2	33.9	34.7	36.7	40.5	46.5	54.8	44.2
15.3	18	Prorated Sect Max IR	32.8	35.3	38.8	40.8	41.7	44.1	48.7	55.9	65.9	53.2
		Catalog Maximum IR	33.0	35.5	38.9	40.9	41.9	44.3	48.9	56.1	66.2	53.4
17	21	Prorated Sect Max IR	37.3	40.1	44.0	46.3	47.4	50.0	55.3	63.4	74.9	60.4
		Catalog Maximum IR	37.5	40.3	44.3	46.5	47.6	50.3	55.6	63.8	75.3	60.7
19.5	24	Prorated Sect Max IR	43.5	46.8	51.4	54.1	55.4	58.5	64.6	74.1	87.5	70.5
		Catalog Maximum IR	43.7	47.1	51.7	54.3	55.6	58.7	64.9	74.4	87.9	70.9
22	27	Prorated Sect Max IR	48.3	51.9	57.0	59.9	61.4	64.8	71.6	82.1	96.9	78.2
		Catalog Maximum IR	48.5	52.2	57.3	60.3	61.7	65.2	72.0	82.6	97.5	78.6
24.4	30	Prorated Sect Max IR	54.3	58.4	64.2	67.5	69.1	72.9	80.6	92.4	109.1	88.0
		Catalog Maximum IR	54.6	58.7	64.5	67.8	69.4	73.3	81.0	92.9	110	88.5
29	36	Prorated Sect Max IR	64.4	69.3	76.1	80.0	81.9	86.5	95.6	109.7	129.4	104.4
		Catalog Maximum IR	64.8	69.7	76.5	80.4	82.4	87.0	96.1	110	130	105

SECTION III Accelerated aging procedure

Tests were performed to measure MOV disc aging characteristics. Measured watts values are used to develop elevated voltage ratios k_c and k_r for use in proration of duty cycle and discharge current withstand test samples.

Six arrester modules were prepared. The first (3) modules consisted of the shortest 40 mm diameter MOV disc , spring, end terminals, barrier film and fiberglass/epoxy wrap using standard module construction. The second (3) modules were constructed similarly with the longest 40mm diameter discs.

Tests were performed per Section 8.5 of ANSI/IEEE C62.11-1999 Standard. Samples were placed inside a 115 °C ±2 °C. oven and energized at MCOV for 1,000 hours. As with the durability tests, MCOV and rated test voltages were prorated to design limits based on 5 mA Vref.

Watts loss for each sample was recorded at MCOV and duty cycle rated voltage two hours after energization and at the completion of the 1000 hour test duration. The following table summarizes test data.

Accelerated aging test data

Sample Number	Watts Loss At 2 h @MCOV P_{1c} (W)	Watts Loss at 1000 h @MCOV P_{2c} (W)	Watts Loss at 2 h @Rating P_{1r} (W)	Watts Loss at 1000 h @Rating P_{2r} (W)	Elevation Factors k_c	k_r
1	.928	.608	3.97	3.43	1.0	1.0
2	.997	.594	4.06	3.32	1.0	1.0
3	1.129	.713	4.64	3.80	1.0	1.0
4	1.481	.973	5.48	4.02	1.0	1.0
5	1.397	.995	5.34	4.08	1.0	1.0
6	1.286	1.271	5.75	5.27	1.0	1.0

Conclusion: Each test sample demonstrated decreasing watts loss at MCOV. The watts loss at rating also declined. Therefore, k_c and k_r factors equal 1.0.

SECTION IV Accelerated aging tests of external polymeric insulating systems for distribution arresters:

These tests were performed per clause 8.6 of IEEE Standard C62.11-1999

Accelerated aging tests by exposure to light were performed per clause 8.6.1 test method 8.6.1.2.c. Tests on polymer housing and insulating bracket material using the fluorescent UV technique described in ASTM G53-1996. Test duration was 1000 hours on three samples of each material.

Accelerated aging tests by exposure to electrical stress were performed per clause 8.6.2. Three PVR 10.2 kV MCOV and three PVR 17 kV MCOV arresters were tested. These represent the highest MCOV stress based on leakage distance and arcing distance. Tests were performed by attaching arresters to a vertical Ferris wheel. As the wheel rotates, each arrester is sequentially dipped into a 400 ohm-centimeter water bath. Each arrester is allowed to drip off excessive contaminant and is then energized at MCOV to force the arrester housing into a dry band arcing condition. The test is performed until each arrester has reached 1000 hours of energized test time. Prior to and after the 1000 hour test, each arrester is subjected to a 10 kA 8/20 discharge to confirm its electrical integrity.

The final portion of the test procedure consists of subjecting each arrester insulating bracket to 20 hours on voltage with the insulating bracket energized at MCOV. At the completion of the above tests, the arresters are examined to ensure there is no evidence of surface tracking.

Conclusion: Both polymer housing and insulating bracket materials passed the test requirements of clause 8.6.1.3, as there were no cracks greater than the allowed depth of 0.1 mm. The arresters also passed the requirements of clause 8.6.2.4, as the arrester discharge voltage changed by less than 1 % as a result of the 1000 hour Ferris wheel test. There was no evidence of external flashovers, punctures, or internal breakdowns during the described tests. There was no evidence of surface tracking on the PVR arrester housings after the 1000 hour on-voltage test or on the insulating bracket after the 20 hour on-voltage test.

SECTION V Contamination tests:

Tests were performed in accordance with clause 8.7 of IEEE Standard C62.11-1999 on the highest rated arrester (36 kV).

Contaminant was prepared per clause 8.7.2.2 and the test procedure run per clause 8.7.2.3. The arrester was energized at MCOV for 1 hour prior to application of the slurry mixture. The arrester watts loss was measured throughout the test to monitor thermal stability.

Immediately following the 1 hour preheat, slurry was applied to the bottom half of the arrester. Within 3 minutes, MCOV was applied and watts loss measured for 15 minutes. At the end of this 15 minute test, the arrester was de-energized and the second slurry coating was applied. The arrester was then energized for an additional 15 minutes. At the end of this second 15 minute test, the arrester was maintained at MCOV until thermal stability was demonstrated. The following table summarizes the results of this test.

Time (min)	Applied Voltage (kV rms)	Arrester Watts Loss (W)	Arrester Module Temperature (C)
0	29	1.4	21.5
15	29	1.3	
45	29	1.3	
60	29	1.3	22.1
Partial Wetting Slurry Application			
0	29	1.3	
1	29	1.3	
5	29	1.3	
10	29	1.3	
15	29	1.3	22.1
Partial Wetting Slurry Application			
0	29	1.3	
1	29	1.3	
5	29	1.3	
10	29	1.3	
15	29	1.3	22.1
Thermal Recovery			
0	29	1.3	
10	29	1.3	
20	29	1.3	
30	29	1.3	22.1

Conclusion: The PVR 29 kV MCOV arrester successfully passed the contamination test as specified in Section 8.7 of IEEE C62.11-1999 Standard.

SECTION VI Distribution class surge arrester seal integrity design test:

Seal integrity tests were performed per clause 8.8 of IEEE Standard C62.11-1999. Tests were run on four 12 kV rated arresters and four 18 kV arresters.

The seal integrity test consisted of the following steps:

a) Initial Electric Test: Each arrester was energized at rating, watts loss and IIV was measured.
b) Terminal Torquing: A _" diameter hard lead was inserted between the wire clamp and arrester end stud on one side only. The clamping nut was torqued to 22 ft-lb.
c) Thermal Conditioning: Each arrester was placed in a 70^{o}C ± 3 C environment for 14 days, after which the arresters were stabilized at ambient room temperature and watts was measured.
d) Seal Pumping: The arresters were heated to 60^{o}C ± 3 C for one hour, then placed into a 4^{o}C ± 3 C water bath for two hours, after which the samples were returned to the 60^{o}C oven. Each arrester was subjected to ten repetitions of this cycle. The transfer time between media was 1-2 minutes.
e) Final Electric Test: Procedure (a) was repeated.
f) Final Inspection: The arresters were disassembled to verify no moisture penetration was evident.

As indicated on Table 6, all arresters demonstrated adequate sealing with no evidence of internal moisture or change in watts loss or IIV.

Table 6
Seal Test data summary

Sample Number	Applied Voltage (kV rms)	Initial Watts Loss	Final Watts Loss	Initial Internal Noise (microvolts)	Final Internal Noise (microvolts)
1	18	1	1	0.5	0.5
2	18	1	1.1	0.5	0.5
3	18	1	0.9	0.5	0.5
4	18	1.1	1.2	0.5	0.5
5	12	0.8	0.7	0.6	0.6
6	12	0.8	0.8	0.6	0.6
7	12	0.8	0.8	0.6	0.5
8	12	0.7	0.7	0.6	0.5

Conclusion: The PVR arrester successfully met the requirements of the Seal Integrity Test as specified in Section 8.8 of IEEE C62.11-1999 Standard.

SECTION VII Internal-ionization voltage (IIV) and RIV tests:

Internal ionization and RIV testing was performed per clause 8.9 of IEEE Standard C62.11-1999. The test was performed on a 36 kV rated, 29.0 kV MCOV PVR arrester.

Equipment and test methods conformed to NEMA LA 1-1992 requirements. Prior to the test, the Stoddart Noise Meter NM-25T was calibrated using a General Radio Signal Generator Type 1001-A.

A background noise level of 0.5 μV was measured at an open circuit voltage of 30.5 kV (105%MCOV). With the unshielded 36 kV arrester placed in the circuit, a noise level of 0.6 μV was measured at the 30.5 kV test voltage.

Conclusion: The 36 kV rated PVR arrester passed test requirements per Section 8.9 of IEEE C62.11-1999 Standard, as measured noise levels were well within the 10 μV test limit.

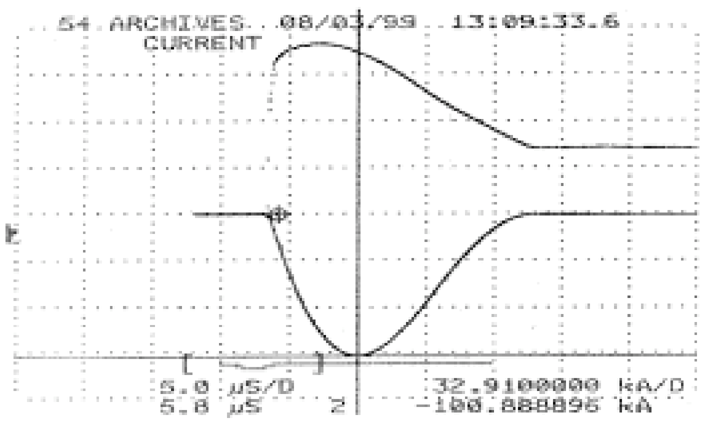
SECTION VIII High Current, Short Duration Discharge Withstand Test

High current, short duration discharge withstand tests were performed per clause 8.10.1 of IEEE Standard C62.11-1999. Tests were performed per Heavy Duty Distribution arrester requirements using a prorated test section.

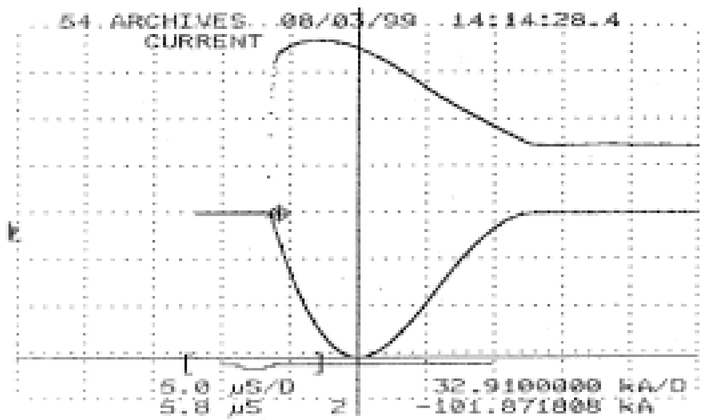
As required by clause 7.2.2, the prorated sample contains the minimum MOV mass allowed for the design. MCOV voltage was also prorated per unit Vref to reflect the lowest margin case of the standard voltage ratings offered in this design. Assigned MCOV of the prorated section was 9.65 kVrms.

The test sample was subjected to two 100 kA, 4/10 discharges. Sufficient time was allowed between discharges for the sample to cool to ambient temperature 23 °C. Within 5 minutes after the second high current discharge, the sample was energized at the prorated recovery voltage. Watts loss was monitored over a 30 minute period demonstrating thermal stability.

First Shot
100.9 kA Magnitude
5.1/12.6 Waveshape

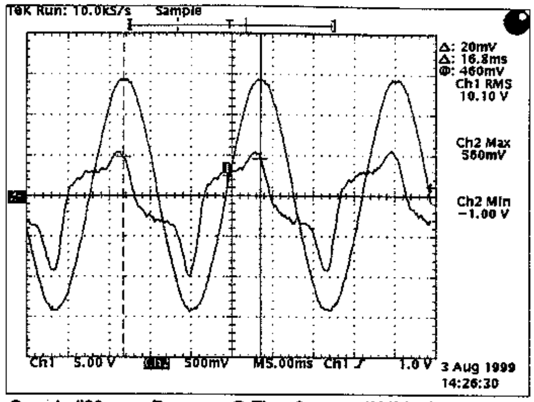


Second Shot
101.9 kA Magnitude
5.1/12.6 Waveshape



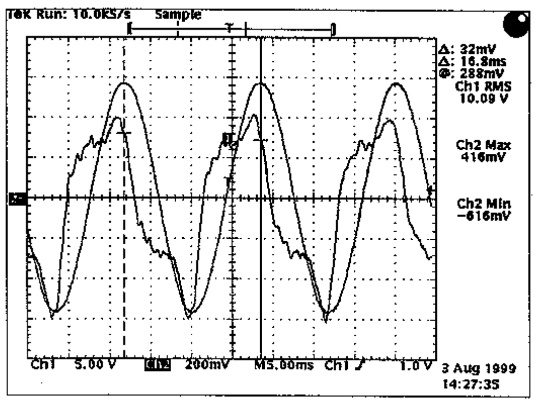
The following oscillograms monitor the arrester voltage and grading current during the 30 minute recovery test.

Osc 1



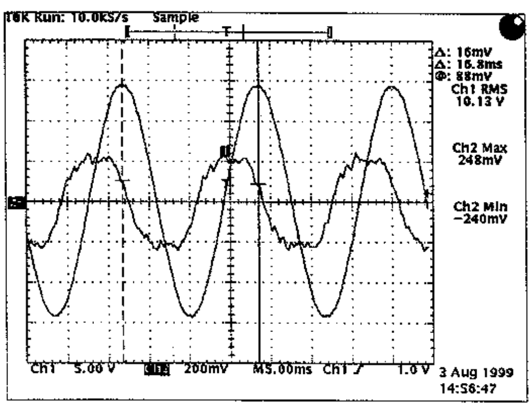
Sample #26 Recovery @ Time 0 1kV/V 2.508mA/V

Osc 2



Sample #26 Recovery @ 1 min 1kV/V 2.508mA/V

Osc 3



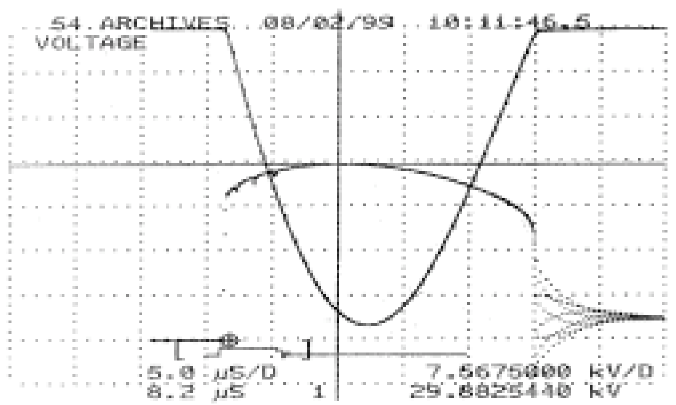
Sample #26 Recovery @ 30 min 1kV/V 2.508mA/V

The following table summarizes the thermal recovery portion of the HCSD test.

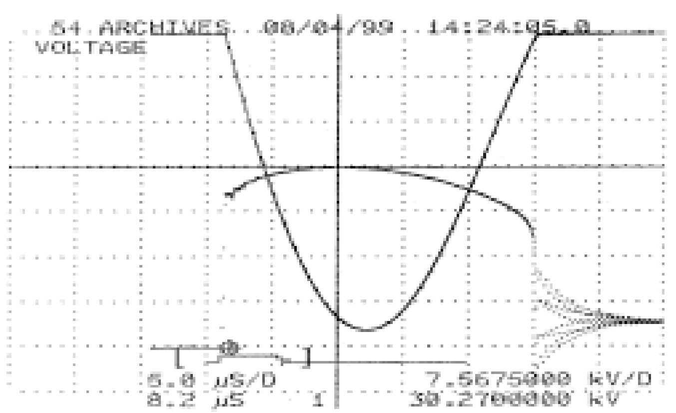
Time (minutes)	Recovery Volts (kVrms)	Section Watts	Section Current (mac)
0	10.10	7.02	2.51
1	10.09	4.67	1.56
2	10.09	4.01	1.32
5	10.06	2.78	0.90
10	10.09	2.18	0.74
20	10.10	1.56	0.64
30	10.13	1.30	0.62

Residual voltage at 10 kA was measured prior to and after the 100 kA discharge and thermal recovery tests. The following oscillograms verified the 10 kA discharge voltage remained unchanged within acceptable limits.

10 kA IR Before HCSD Test = 29.9 kV



10 kA IR After HCSD Test = 30.3 kV



Conclusion: The prorated test sample successfully completed the high current test and demonstrated thermal stability during the recovery test. The 10 kA residual voltage increased 1.3%, less than the allowed 10%. Disassembly revealed no evidence of physical damage to the test sample. The PVR design successfully met the High Current, Short Duration requirements of a Heavy Duty Distribution Class Arrester.

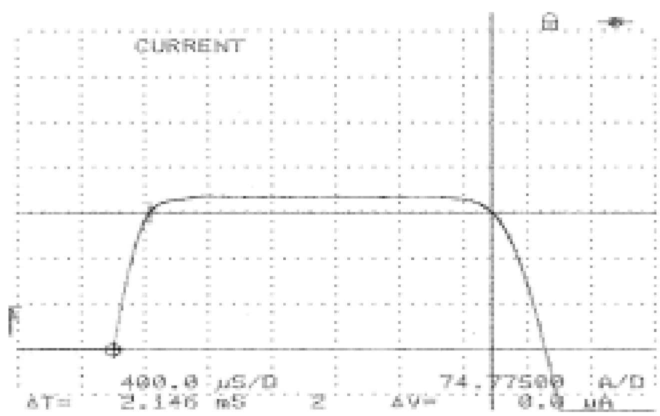
SECTION IX Low current, long duration discharge withstand test:

The low current, long duration discharge withstand test was performed per clause 8.10.2.2 of IEEE Standard C62.11-1999. Tests were performed per Heavy Duty distribution arrester requirements using a prorated test section.

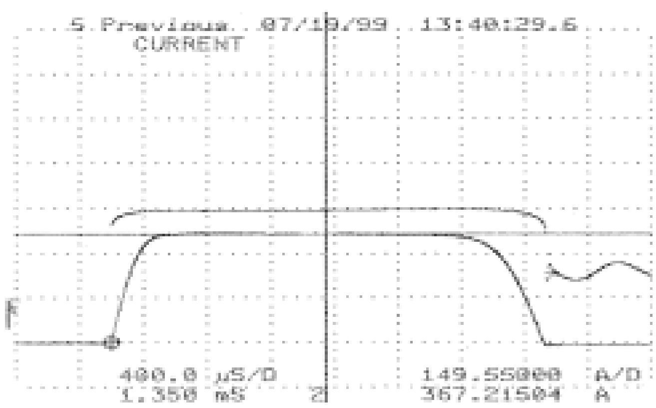
As required by clause 7.2.2, the prorated sample contained the minimum MOV mass per specified for the design. MCOV voltage was also prorated per unit Vref to reflect the lowest margin case of the standard voltage ratings offered in this design

The test sample was subjected to three sets of six 250 A, 2000 µs discharges. Sufficient time was allowed between discharges for the sample to cool to an ambient temperature of 23 °C. Following the eighteenth impulse, the test section was placed in an oven at 60 °C. After reaching 60 °C, the sample was subjected to two additional 250 A discharges. Within 5 minutes after the twentieth low current, long duration discharge, the sample was energized at the prorated recovery voltage. Watts loss was monitored over a 30 minute period demonstrating thermal stability.

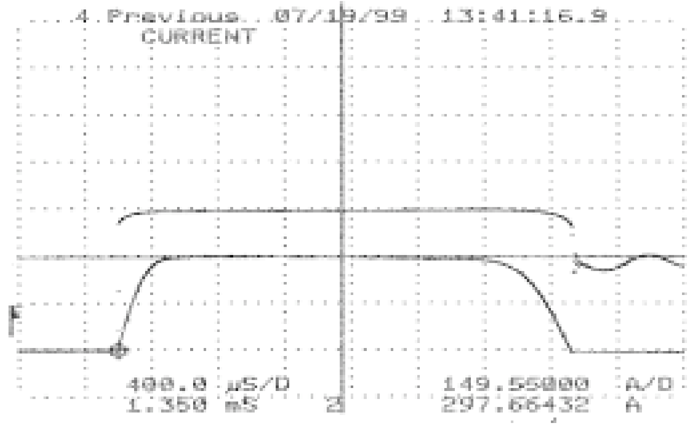
Short Circuit Waveform Validating 2.14 Millisecond Duration



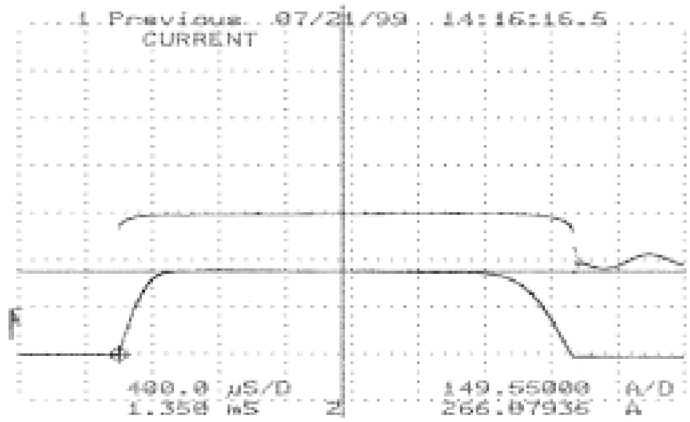
First LCLD Shot @ 367 Amps



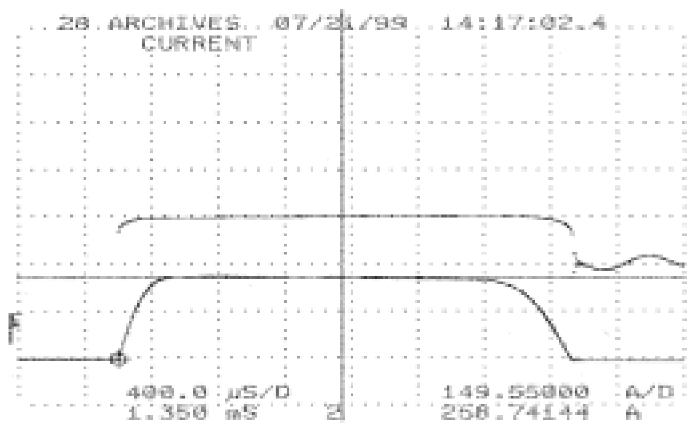
Second LCLD Shot @ 297 Amps



Nineteenth LCLD Shot @ 266 Amps

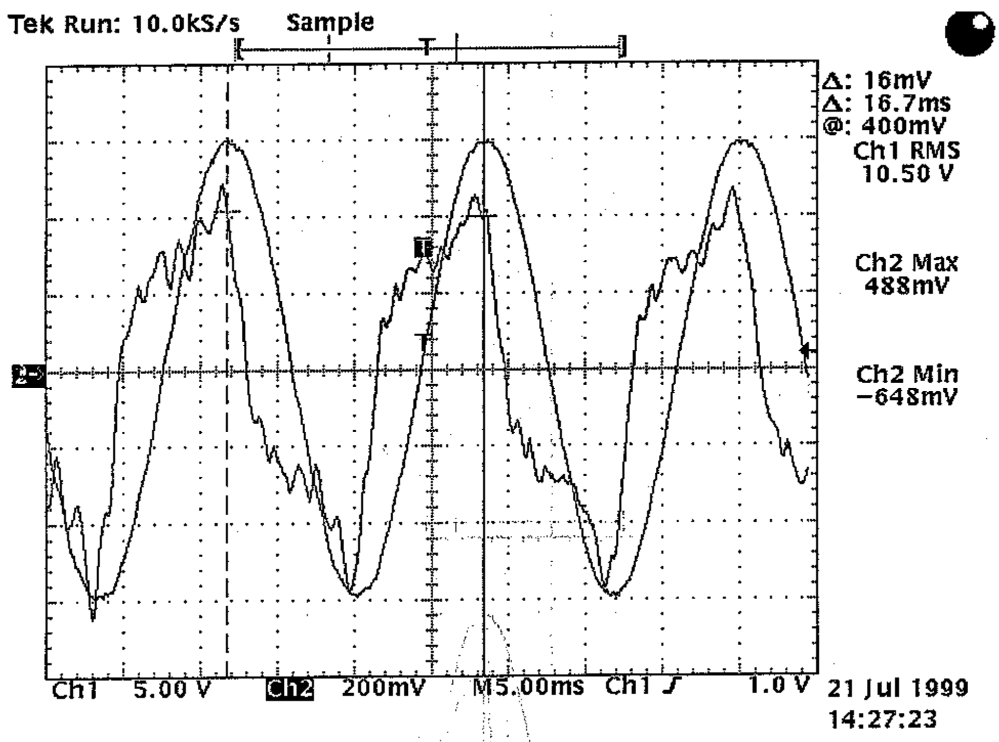


Twentieth LCLD Shot @ 258 Amps

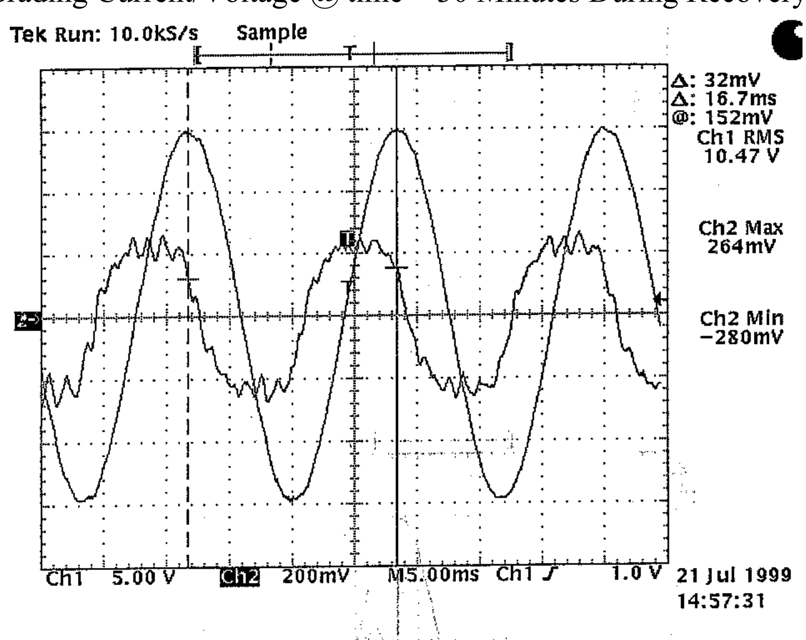


Immediately after the 20th LCLD shot, the test section was energized at 10.35 kVrms recovery voltage and watts and grading current monitored for 30 minutes. The following two oscillograms show the section voltage and grading current at the start of the recovery test and after 30 minutes.

Grading Current/Voltage @ time = 0 Minutes During Recovery



Grading Current/Voltage @ time = 30 Minutes During Recovery



The following table summarizes the 20 shot LCLD test, including the 2 shots prior to thermal recovery.

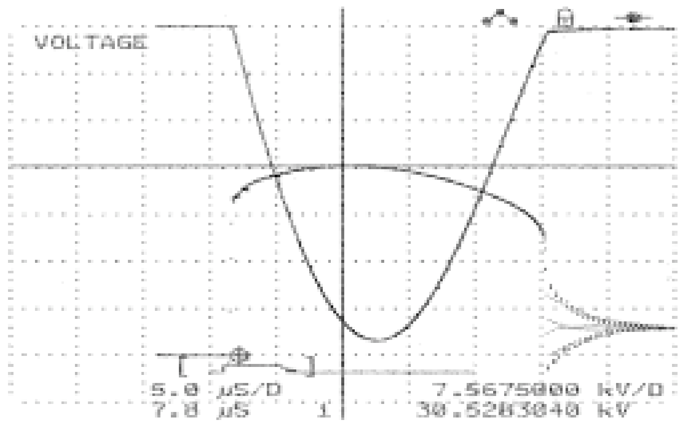
Shot #	Discharge Voltage - kVc	Discharge Current- kAc	Discharge Energy-KJ
1	22.5	367	20.0
2	22.5	298	16.3
3	22.5	261	14.4
4	22.7	259	14.3
5	22.8	254	14.1
6	23.0	260	14.6
Cool to ambient			
7	22.1	276	14.9
8	22.4	268	14.6
9	22.5	262	14.4
10	22.7	259	14.3
11	22.8	255	14.2
12	22.9	260	14.6
Cool to ambient			
13	22.2	284	15.3
14	22.4	276	15.1
15	22.6	271	14.9
16	22.7	268	14.8
17	22.8	263	14.6
18	22.9	258	14.4
Pre-heat to 62°C			
19	22.4	266	14.7
20	22.7	259	14.3

Immediately after the 20th shot, the arrester section was energized at its 10.35 kV_{rms} recovery voltage and watts and grading current monitored for 30 minutes to demonstrate thermal stability.

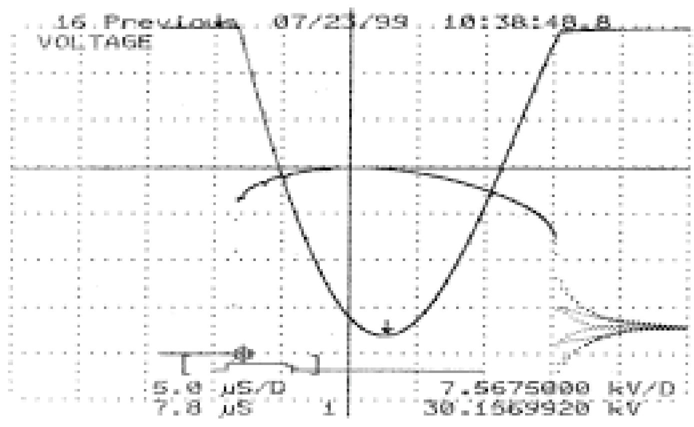
Time-minutes	Applied Volts-kV_{rms}	Watts	Grading current-ma_c
0	10.41	5.14	1.63
1	10.39	4.11	1.28
2	10.39	3.79	1.18
5	10.43	3.26	1.06
10	10.36	2.61	.84
20	10.36	2.03	.76
30	10.37	1.76	.70

Residual voltage at 10 kA was measured prior to and following the 250 A discharge and thermal recovery tests.

10 kA IR Before LCLD Test = 30.15 kV



10 kA IR After LCLD Test = 30.53 kV



Conclusion: The prorated test sample successfully completed the low current, long duration test and demonstrated thermal stability during the recovery test. The section discharge voltage increased 1.2%, below the 10% change allowed in Section 8.10.2.2.3 of IEEE C62.11-1999 Standard. Disassembly revealed no evidence of physical damage to the test samples. The PVR arrester successfully met the LCLD requirements of the Heavy Duty Distribution Class arrester.

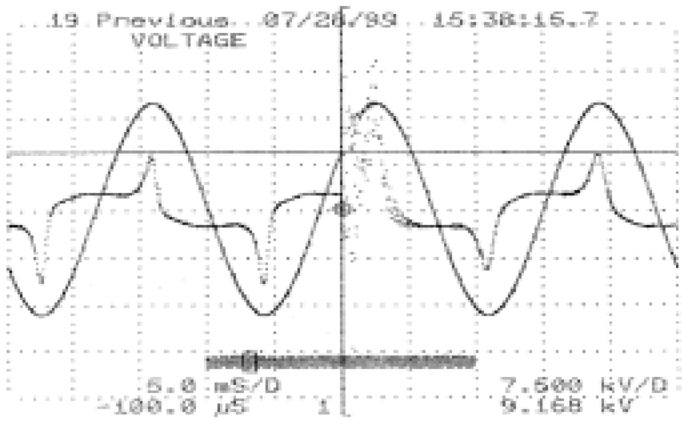
SECTION X Duty Cycle Test:

Duty cycle tests were performed per clause 8.11 of IEEE Standard C62.11-1999. Tests were performed on the PVR design per Heavy duty distribution arrester requirements.

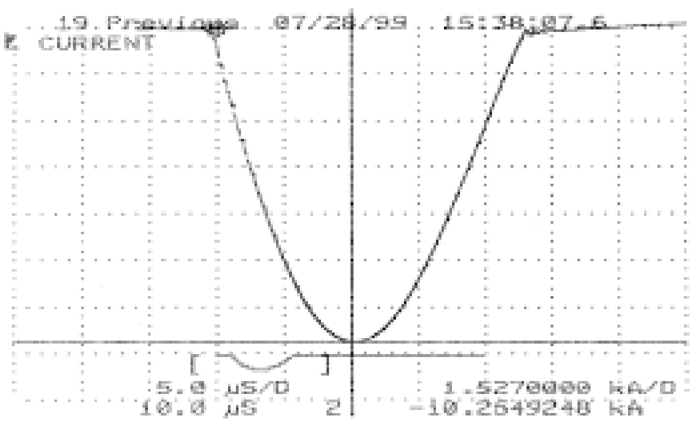
As required by clause 7.2.2, prorated samples contained the minimum MOV mass per specified for the design. MCOV and rated voltages were also prorated per unit Vref to reflect the lowest margin case of the standard voltage ratings offered in this design.

The 9.75 kVrms MCOV test sample was energized at its 11.82 kVrms rated voltage and subjected to twenty 10 kA, 8/20 discharges spaced at 1 minute increments. Following the twentieth impulse, the test section was placed in an oven at 60 $^{\circ}$C. After reaching 60 $^{\circ}$C, the sample was subjected to two 40 kA, 8/20 discharges. Within 5 minutes after the second high current discharge, the sample was energized at the prorated recovery voltage of 10.19 kVrms. Watts loss was monitored over a 30 minute period demonstrating thermal stability.

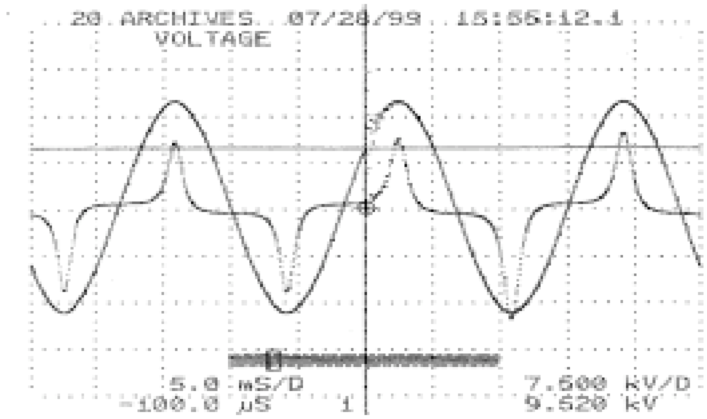
First Shot of 20 Shot Rated Voltage Duty Cycle Test



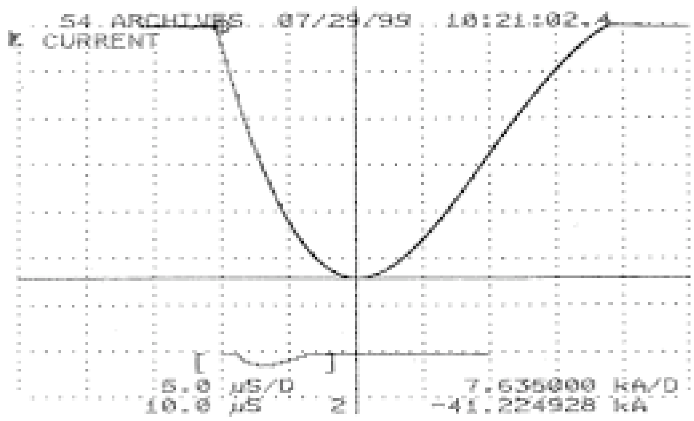
10 kA 8.1/18.8 Waveshape for 20 Shot Test



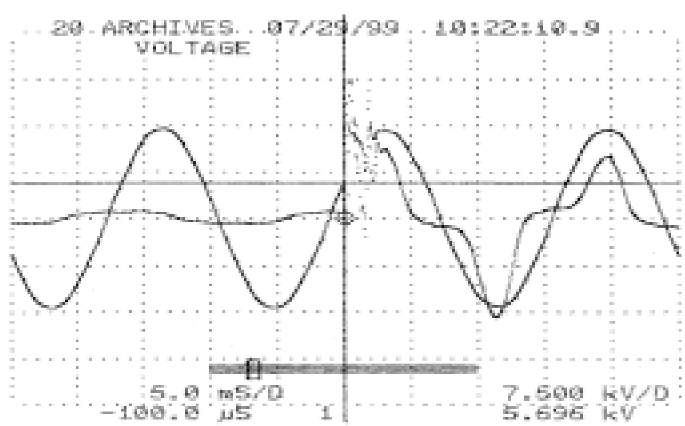
20th Shot of 20 Shot Rated Voltage Duty Cycle Test



41.2 kA 8.1/20.8 Waveshape for 2-Shot Test

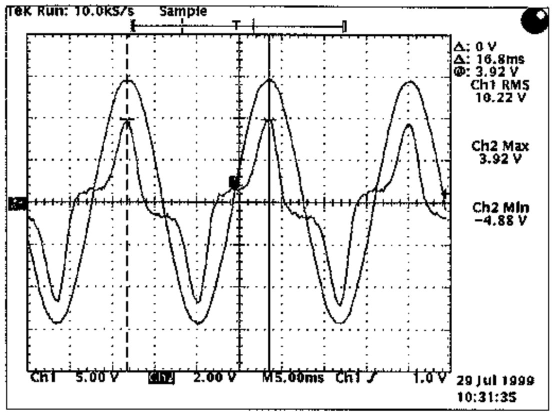


Oscillogram of 22nd Shot



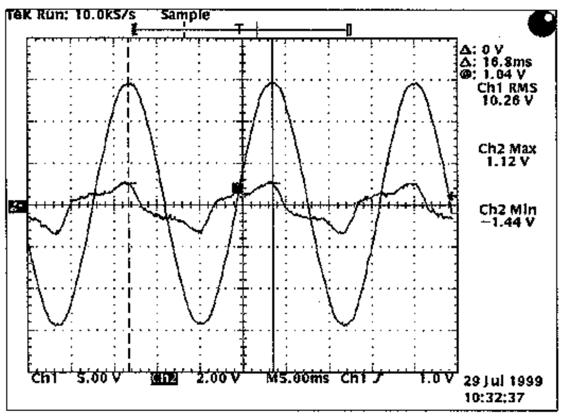
Immediately after the 22nd shot, the arrester section was energized at recovery voltage. The following oscillograms show section grading current measured at time 0, 1 minute, and 30 minutes.

Osc 4



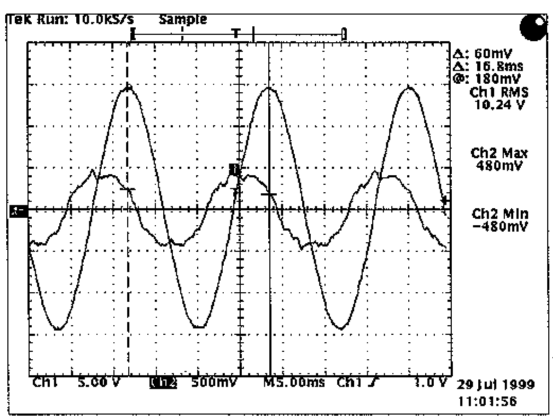
PVR #1CS Recovery @ Time 0 1kV/V 2.508mA/V

Osc 5



PVR #1CS Recovery @ 1 min 1kV/V 2.508mA/V

Osc 6



PVR #1CS Recovery @ 30 min 1kV/V 2.508mA/V

The following table summarizes the results of the 20 shot rated duty cycle voltage test.

Shot No.	Applied Voltage (kV_{rms})	Watts	Grading Current (ma_c)	8/20 Impulse (kA)
1	11.85	8.5	3.9	10.2
2	11.85	9.5	4.1	10.5
3	11.85	10.1	4.5	10.6
4	11.86	10.7	5.2	10.0
5	11.87	12.0	5.7	10.2
6	11.87	12.8	5.8	10.5
7	11.87	14.0	6.3	10.5
8	11.86	15.0	7.1	10.1
9	11.86	17.0	8.1	10.0
10	11.86	18.8	8.8	10.4
11	11.86	21.1	9.4	10.4
12	11.86	24.3	10.7	10.4
13	11.86	27.2	11.7	10.3
14	11.85	31.7	13.6	10.3
15	11.85	34.5	14.3	10.4
16	11.84	40.6	17.0	10.3
17	11.85	48.7	20.3	10.2
18	11.84	58.4	22.7	10.2
19	11.84	76.3	29.2	10.2
20	11.84	109.2	41.4	10.2

The following table summarizes the 21^{st} and 22^{nd} shots after sample preheating to $60^{o}C$.

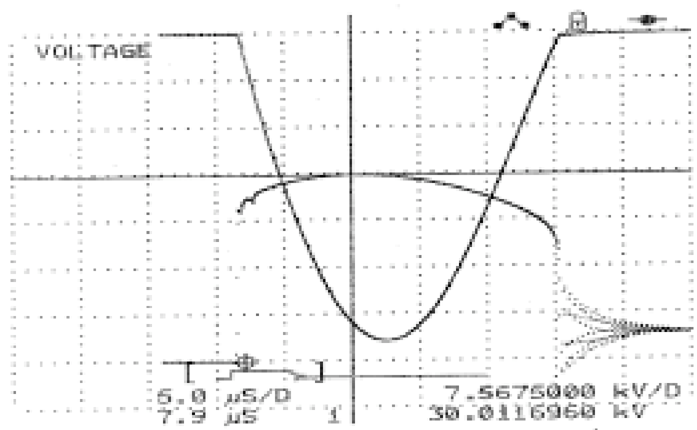
Shot No.	Applied Voltage (kV_{rms})	Watts	Grading Current (ma_c)	8/20 Impulse (kA)
21	10.19	6.1	1.81	40.6
22	10.22	40.6	12.24	51.2

The following table summarizes the recovery voltage portion of the duty cycle test.

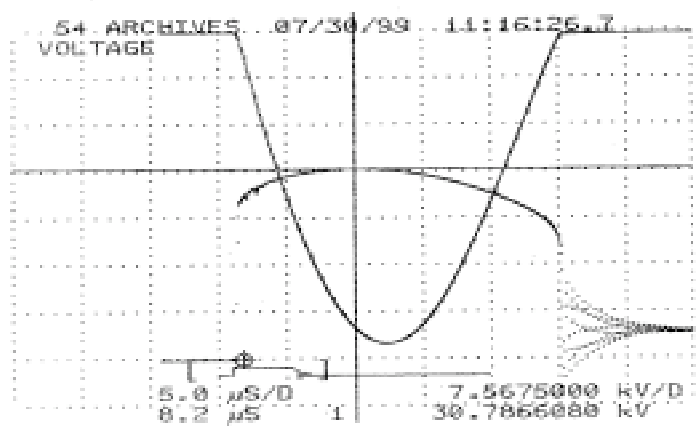
Time (minutes)	Applied Voltage (kV_{rms})	Watts	Grading Current (ma_c)
0	10.22	40.6	12.2
1	10.26	10.7	3.6
2	10.25	8.9	2.4
5	10.24	5.9	1.6
10	10.20	4.4	1.4
20	10.17	3.5	1.3
30	10.24	3.0	1.2

Residual voltage at 10 kA was measured prior to and following the Duty Cycle test series.

10 kA IR Before Duty Cycle Tests = 30.01 kV



10 kA IR After Duty Cycle Tests = 30.79 kV

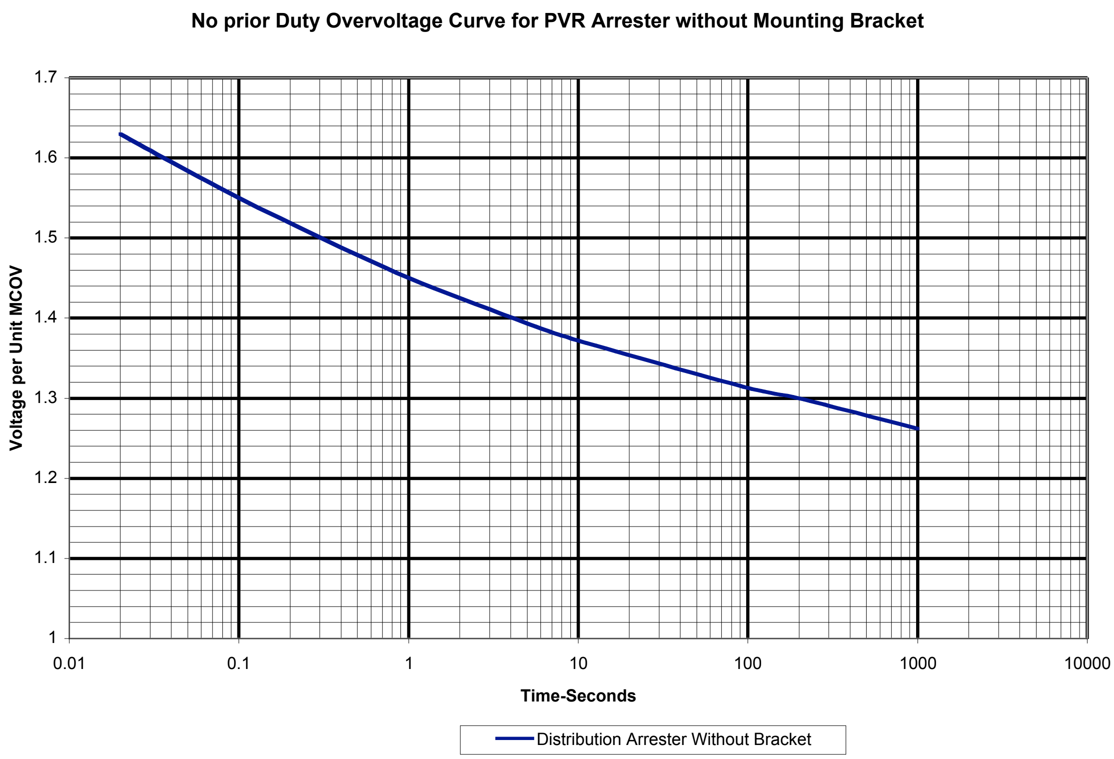


Conclusion: The prorated test sample successfully completed Duty Cycle testing and demonstrated thermal stability during the recovery test. The 10 kA discharge voltage increased 2.6%, less than the acceptable 10% limit specified in Section 8.11.1.4 of C62.11-1999 Standard. Disassembly revealed no evidence of physical damage to the test sample. The PVR arrester successfully met the duty cycle requirements of the Heavy Duty Distribution Class arrester.

SECTION XI Temporary over-voltage tests (TOV):

Temporary over-voltage tests were performed per clause 8.15 of IEEE Standard C62.11-2005. Tests were performed per Heavy Duty distribution arrester requirements using five prorated test sections. Prorated sections were used to facilitate testing of the lowest MOV mass, highest stressed arrester rating at voltages within available laboratory facility capabilities. These tests cover ratings 3 - 36 kV with corresponding MCOV levels of 2.55 - 29.0 kV.

Per clause 8.15.3, each prorated sample was tested within five of the six designated time ranges a - f, spanning over-voltage durations of .01 - 10,000 seconds. Per clause 8.15.3.1, the tests were performed demonstrating TOV capability of the design under "no prior duty" conditions. For each TOV voltage setting, the test circuit applied voltage to the sample (preheated to 60^{o}C) for a time duration sufficient to exceed that claimed on the "no prior duty" curve. TOV voltage was superimposed over recovery voltage such that when TOV was removed, there was no delay prior to application of recovery voltage. Recovery voltage was applied for 30 minutes to demonstrate thermal stability. The following curve summarizes the results of the TOV test program.



The following table summarizes the TOV capability curve as a function of time, as required by Section 8.12.3.

Time-Seconds	TOV Per Unit Times MCOV
.02	1.630
.10	1.550
1.0	1.450
10	1.372
100	1.313
1000	1.262

Conclusion: Tests were successfully completed on five prorated samples in five specified time ranges. Each sample demonstrated thermal stability after TOV exposure having no signs of physical damage during inspection. Residual voltage at 10 kA measured prior to and following the complete TOV test series verified characteristics remained unchanged within acceptable limits.

SECTION XII Short-circuit test for polymer housed distribution arresters:

Short circuit tests were performed on the Type PVR polymer-housed Distribution Class arrester per Section 8.15 of IEEE C62.11-1999 Standard. Tests were performed per Table 14 of the referenced standard.

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.

Fault current test were performed on the longest mechanical section, as required in Section 8.15.1 of the standard. As required in Section 8.15.1.1, 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 fault current capability of the design.

Calibration Test 21.85 kA Symmetrical RMS 34.74 kA Asymmetrical RMS

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

Calibration Test 10.1 kA Symmetrical RMS No Asymmetrical Requirement

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

Calibration Test 600 Amp Symmetrical RMS No Asymmetrical Requirement

Sample #	Failure Mode	Minimum Test Duration-seconds	Condition of Module/Polymer Housing After Test
7	2-Source	1.0	Module Intact/Hsg Torn but in Place
8	2-Source	1.0	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 Section 8.15.3 of IEEE C62.11-1999 Standard. In all tests, the arrester module remained intact on the insulating support bracket 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 PVR arrester design to discharge a maximum claimable 20 kA_{rms} symmetrical fault current using the test procedure defined in Section 8.15 of IEEE C62.11-1999 Standard.

SECTION XIII **Distribution arrester disconnector tests:**

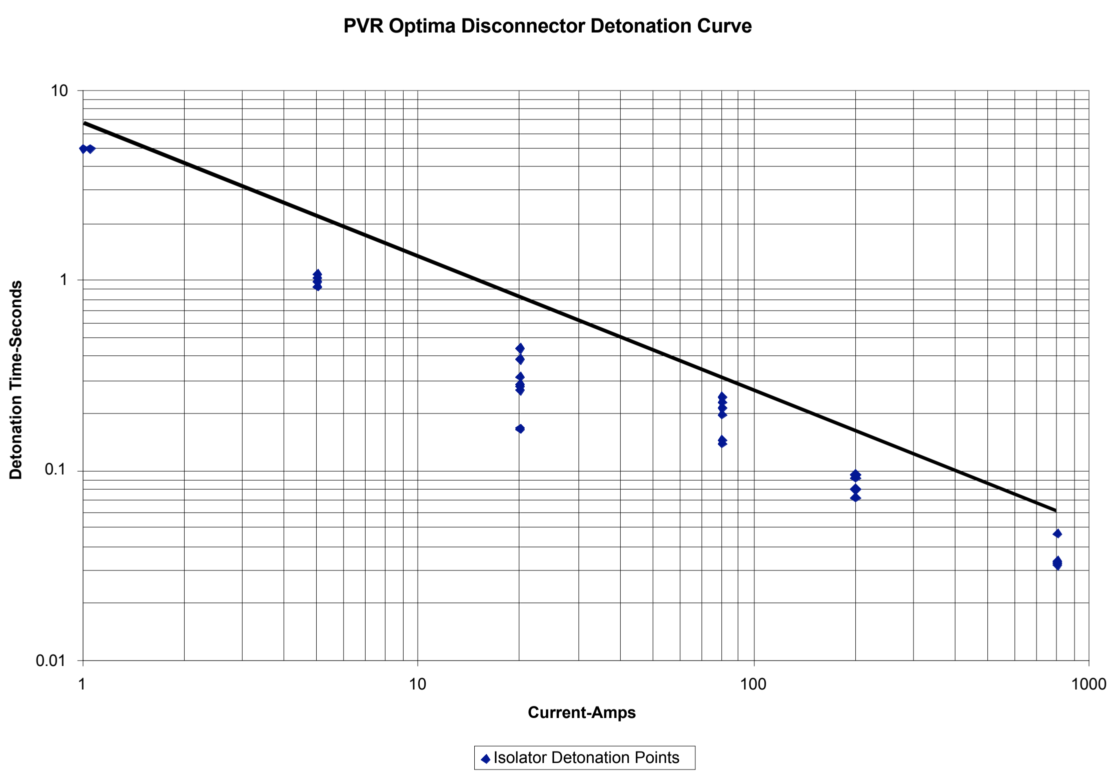
Tests were performed per clause 8.21 of IEEE Standard C62.11-2005

High current short duration and low current long duration discharge duty tests and duty cycle tests were performed on thermally prorated test sections having the disconnector assembly connected in series.

Contamination withstand testing was performed on a 36 kV rated arrester supported on the insulated bracket/isolator assembly. The arrester internal grading and external leakage currents flowed through the internal components or across the surface of the disconnector.

Disconnector detonation testing was performed on five bracket/isolator assemblies each at 20, 80, 200, and 800 A_{rms}.

Disconnectors did not operate when subjected to high current, short duration and low current, long duration discharge duty tests and duty cycle tests on the thermally prorated test sections. The disconnector also did not operate when subjected to contamination tests. In all cases, disconnectors separated during detonation tests at each of the required current levels.



Conclusion: The PVR arrester disconnector successfully passed all requirements of Section 8.21 of IEEE C62.11-2005 Standard.

SECTION XIV Maximum Design Cantilever Load-Static Test

The maximum design cantilever load (static) test was performed on three PVR 15.3 kV MCOV arresters, representing the longest PVR mechanical unit. Tests were performed on this 8.5" long arrester to validate the claimed 1200 inch-pound continuous cantilever rating.

Testing was performed per the procedures specified in Section 8.19.2 of IEEE Std C62.11-1999. Per paragraphs a) and b), each test arrester was rigidly mounted at its base and top end loading applied to develop 1200 inch-pound cantilever load. With the arrester under load, the arrester was energized at 1.05 times MCOV and internal ionization was measured. Also, top end deflection measured at this load. . Per paragraph c), successive testing was performed at 0^{o}, 90^{o}, 180^{o}, and 270^{o}. The results of this initial testing before temperature thermal cycling is summarized below. Background noise level was 0.7 microvolts for arrester #1 and 0.4 microvolts for arresters #2 and #3.

Mechanical Loading Tests Prior to Thermal Cycling

Arrester #	Direction of Applied 1200 in-lb Load (Degrees)	IIV @ 1.05 Times MCOV (Microvolts)	Top End Deflection (inches)
1	0	0.8	.44
1	90	0.8	.44
1	180	0.8	.44
1	270	0.8	.44
2	0	0.5	.44
2	90	0.4	.44
2	180	0.6	.44
2	270	0.6	.44
3	0	0.5	.44
3	90	0.7	.44
3	180	0.7	.44
3	270	0.7	.44

Per paragraph d), each arrester was placed inside a thermal cycling oven for 96 hours and subjected to a combination of 1200 inch-pound load rotations and temperature excursions as specified in Figures 3 and 4 of C62.11-1999 Standard.

After completion of the thermocycling testing, the testing per paragraphs b) and c) was repeated. The results of this testing is summarized below with 0.7 microvolts of background noise.

Mechanical Loading Tests After Thermal Cycling

Arrester #	Direction of Applied 1200 in-lb Load (Degrees)	IIV @ 1.05 Times MCOV (Microvolts)	Top End Deflection (inches)
1	0	0.8	.44
1	90	0.8	.44
1	180	0.8	.44
1	270	0.8	.44
2	0	0.7	.44
2	90	0.7	.44
2	180	0.7	.44
2	270	0.8	.44
3	0	0.7	.44
3	90	0.7	.44
3	180	0.7	.44
3	270	0.7	.44

Conclusion: Per Section 8.19.3, the internal ionization levels and top end deflection measurements were unchanged as a result of the thermal cycling test. Visual examination revealed no evidence of mechanical damage. The above tests have validated the 1200 inch-pound continuous cantilever rating of the base mounted PVR arrester.