IEEE DESIGN TEST REPORT
Report No. EU1588-H-00.1
Type EVP Station Class
Surge Arrester

This report records the results of the design tests made on Type EVP Station Class surge arresters in accordance with IEEE Standard C62.11-2012 "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 practices, tests performed on the Type EVP arresters demonstrate full compliance with the relevant clauses of the referenced standard.

Dennis W. Lenk
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/14

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

Report No.	Description	Clause	Issue Date
EU1588-H-01.1	**Insulation Withstand**	8.1	1/10/14
EU1588-H-02.1	**Discharge Voltage**	8.2	1/10/14
EU1588-H-03.1	**MOV Disc Accelerated Aging**	8.5	1/10/14
EU1588-H-04.1	**Polymer Accelerated Aging**	8.6	1/10/14
EU1588-H-05.1	**Contamination**	8.8	1/10/14
EU1588-H-06.1	**Internal Ionization and RIV**	8.10	1/10/14
EU1588-H-07.1	**Partial Discharge**	8.11	1/10/14
EU1588-H-08.0	**Switching Surge Energy Rating**	8.14	1/10/14
EU1588-H-09.0	**Single-Impulse Withstand Rating**	8.15	1/10/14
EU1588-H-10.1	**Duty Cycle**	8.16	1/10/14
EU1588-H-11.1	**Temporary Overvoltage**	8.17	1/10/14
EU1588-H-12.1	**Short Circuit Pressure Relief**	8.18	1/10/14
EU1588-H-13.1	**Maximum Design Cantilever Load**	8.22	1/10/14
EU1588-H-14.1	**Thermal Equivalency Test**	7.2.2	1/10/14

IEEE Design Test Report
Report No. EU1588-H-01.1
Type EVP Station Class Arrester

Insulation Withstand

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, “IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV).”

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
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
Insulation Withstand

INTRODUCTION: The following table lists the Type EVP arresters' minimum strike distance, 1.2/50 required and actual impulse withstand levels, and 60 HZ required and actual wet withstand levels as defined in Sections 8.1.2.4 of IEEE C62.11-2012 standard.

CONCLUSION: All housings meet or exceed these levels of voltage.

Arrester MCOV	Strike Distance (in)	Lightning Imp w/s Req'd (KVc)	Lightning Imp w/s Actual (KVc)	60 HZ Wet w/s Req'd (kVrms)	60 HZ Wet w/s Actual (kVrms)
2.55	6.9	12	101	5	50
5.1	6.9	23	101	10	50
7.65	8.7	35	127	15	63
8.4	8.7	38	127	16	63
10.2	8.7	47	127	20	63
12.7	10.5	58	153	25	75
15.3	10.5	70	153	30	75
17	14.2	78	207	33	101
19.5	14.2	89	207	38	101
22	14.2	100	207	43	101
24.4	14.2	111	207	47	101
29	17.9	133	261	56	125
31.5	17.9	144	261	61	125
36.5	21.5	166	313	71	148
39	21.5	178	313	75	148
42	21.5	201	313	85	148
48	25.2	221	367	94	172
57	28.9	266	421	113	194
70	43.3	333	631	141	275
74	43.3	338	631	143	275
76	43.3	356	631	151	275
84	43.3	401	631	170	275
88	43.3	401	631	170	275
98	44.7	447	652	197	283
106	44.7	487	652	215	283
115	52	532	758	235	320
131	63.5	621	926	274	372
140	69	639	1006	282	395
144	69	664	1006	293	395
152	69	709	1006	313	395
180	80	842	1166	371	436

IEEE Design Test Report
Report No. EU1588-H-02.1
Type EVP Station Class Arrester

Discharge Voltage

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, “IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV).”

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
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Principal Engineer

Saroni Brahma
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Design Engineer

Date: 1/10/2014

IEEE Design Test Report
Discharge Voltage Characteristic

TESTS PERFORMED: Residual voltage measurements were made on three single resistor elements. Tests were conducted in accordance with clause 8.3 of the IEEE C62.11-2012 standard, to determine steep current impulse residual voltages at 10 kA, lightning impulse residual voltages at 1.5 kA, 3 kA, 5 kA, 10 kA and 20 kA, and switching impulse residual voltages at 0.5 kA and 1 kA. Oscillograms of current and voltage were obtained for each test.

For each test sample, all measured voltages have been rationalized to the lightning impulse residual voltage of that sample at nominal discharge current (10 kA 8/20), and the results have been displayed in graphical form.

RESULTS: Tables 1, 2 and 3 show the residual voltages measured on test samples 1, 2 and 3, respectively. For each test sample, the measured residual voltages have been expressed in per unit of the lightning impulse residual voltage at nominal discharge current (10 kA, 8/20).

Table 1: Measurements made on test sample 1

	Current Magnitude	Wave-shape	Residual Voltage		Oscillogram
Test Wave	kA	µs	kV	p.u.	Number
Steep front	10	1/2	14.583	1.09	34
8/20 Impulse	1.5	8/20	11.32	0.846	1
	3	8/20	11.903	0.889	4
	5	8/20	12.471	0.932	7
	10	8/20	13.385	1	10
	20	8/20	14.452	1.08	13
Switching Impulse	0.5	43/91	10.651	0.796	22
	1	40/86	11.05	0.826	25

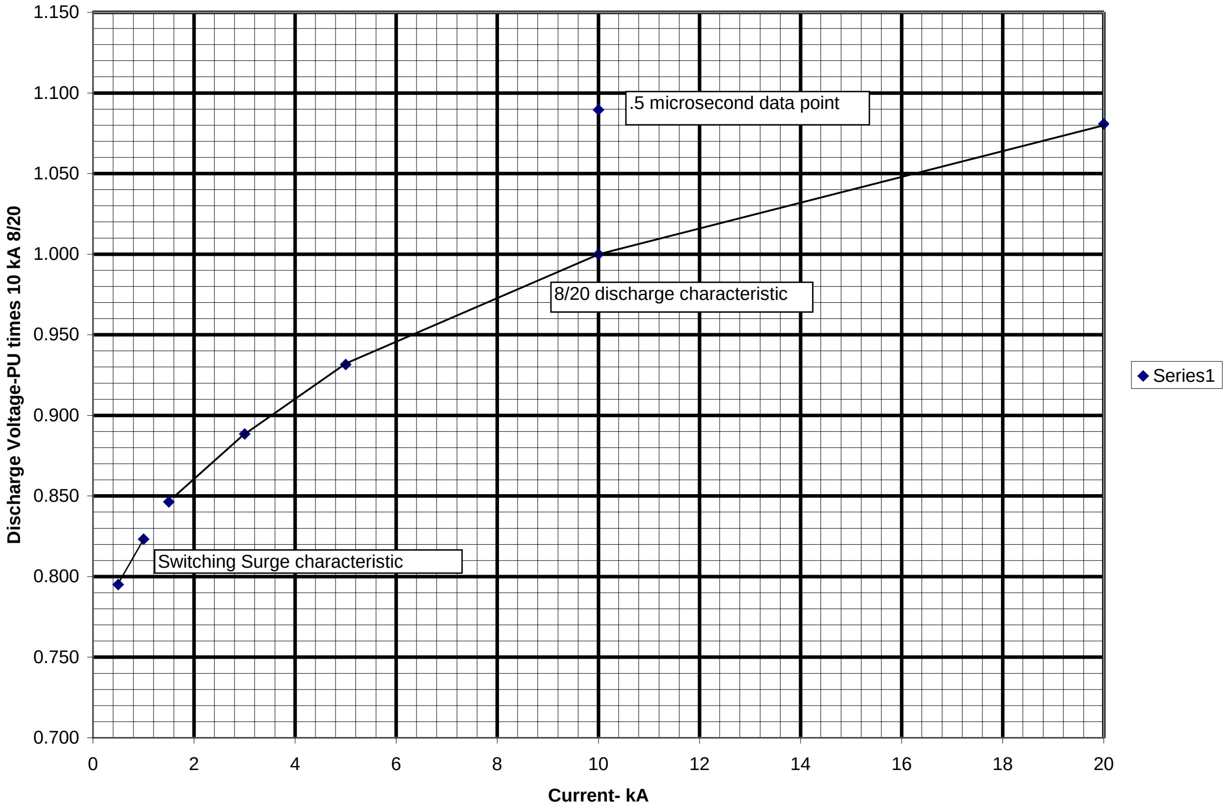
Table 2: Measurements made on test sample 2

Test Wave	Current Magnitude kA	Wave-shape µs	Residual Voltage kV	Residual Voltage p.u.	Oscillogram Number
Steep front	10	1/2	14.545	1.087	35
8/20 Impulse	1.5	8/20	11.304	0.845	2
	3	8/20	11.899	0.889	5
	5	8/20	12.465	0.932	8
	10	8/20	13.38	1	11
	20	8/20	14.436	1.079	14
Switching Impulse	0.5	43/91	10.651	0.796	23
	1	40/86	11.05	0.826	26

Table 3: Measurements made on test sample 3

Test Wave	Current Magnitude kA	Wave-shape µs	Residual Voltage kV	Residual Voltage p.u.	Oscillogram Number
Steep front	10	1/2	14.596	1.090	36
8/20 Impulse	1.5	8/20	11.338	0.846	3
	3	8/20	11.902	0.888	6
	5	8/20	12.479	0.932	9
	10	8/20	13.396	1	12
	20	8/20	14.478	1.081	15
Switching Impulse	0.5	43/91	10.651	0.795	24
	1	40/86	11.029	0.823	27

The results of the discharge voltage testing are shown graphically in the following chart.



The values shown in this chart are all normalized to the lightning impulse residual voltage at nominal discharge current (10 kA). These values (*Per-unit* $U_{res\text{-}chart}$) are used to calculate the residual voltage characteristics ($U_{res\text{-}arrester}$) of assembled EVP series arresters. For the cases of switching impulse and lightning impulse residual voltages, the arrester residual voltages are calculated as follows:

$$U_{res\text{-}arrester} = \textit{Per-unit}\ U_{res\text{-}chart} \ \ x \ \ U_{res\text{-}nom}$$

Where: Ures-nom is the published maximum lightning impulse residual voltage of the arrester, as verified by routine test at time of arrester manufacture.

For the case of steep current impulse residual voltage, the arrester residual voltage is calculated as follows:

$$U_{res\text{-}arrester} = \textit{Per-unit}\ U_{res\text{-}chart} \ \ x \ \ U_{res\text{-}nom} + L'\,h\,I_n / T_f$$

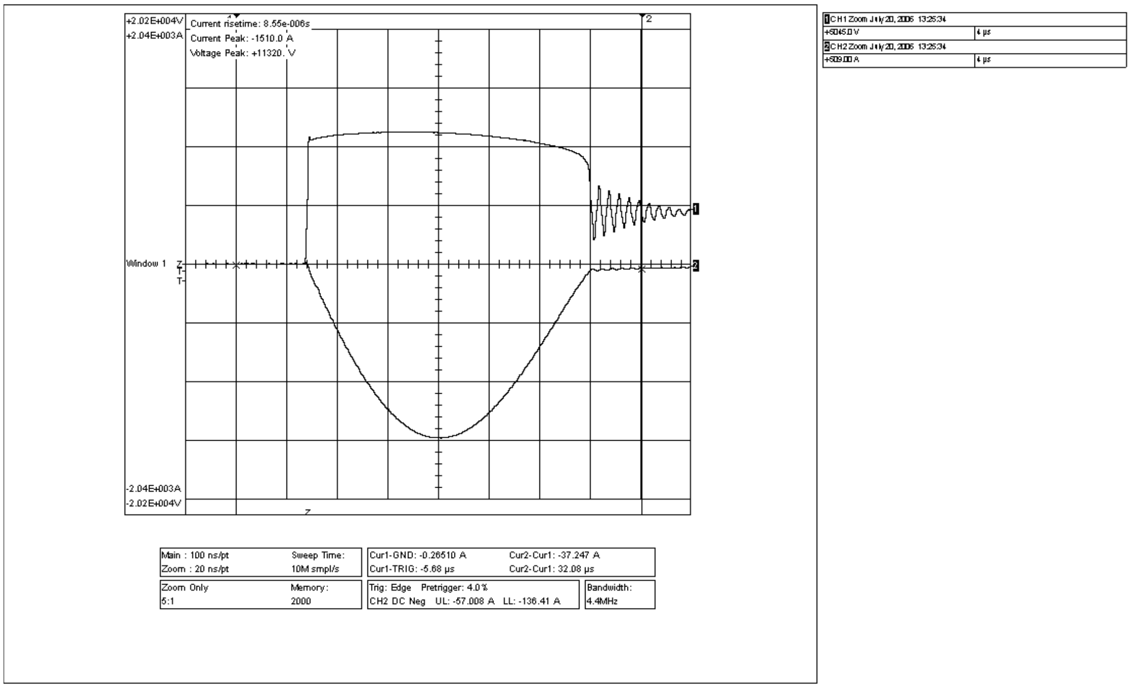
Where:
L' is the inductivity per unit length (= 1 µH/m)
h is the length of the arrester (excluding the resistors since resistor inductance is already included in the test measurements)
I_n is the nominal discharge current (= 10 kA)
T_f is the front time of the steep current impulse (= 1µs)

Oscillograms

Sample 1, Oscillogram 1

Nicolet Accura100

Printed : 13:26 Thursday, July 20, 2006 Serial Number : IDA0200151



Sample 2, Oscillogram 2

Nicolet Accura100

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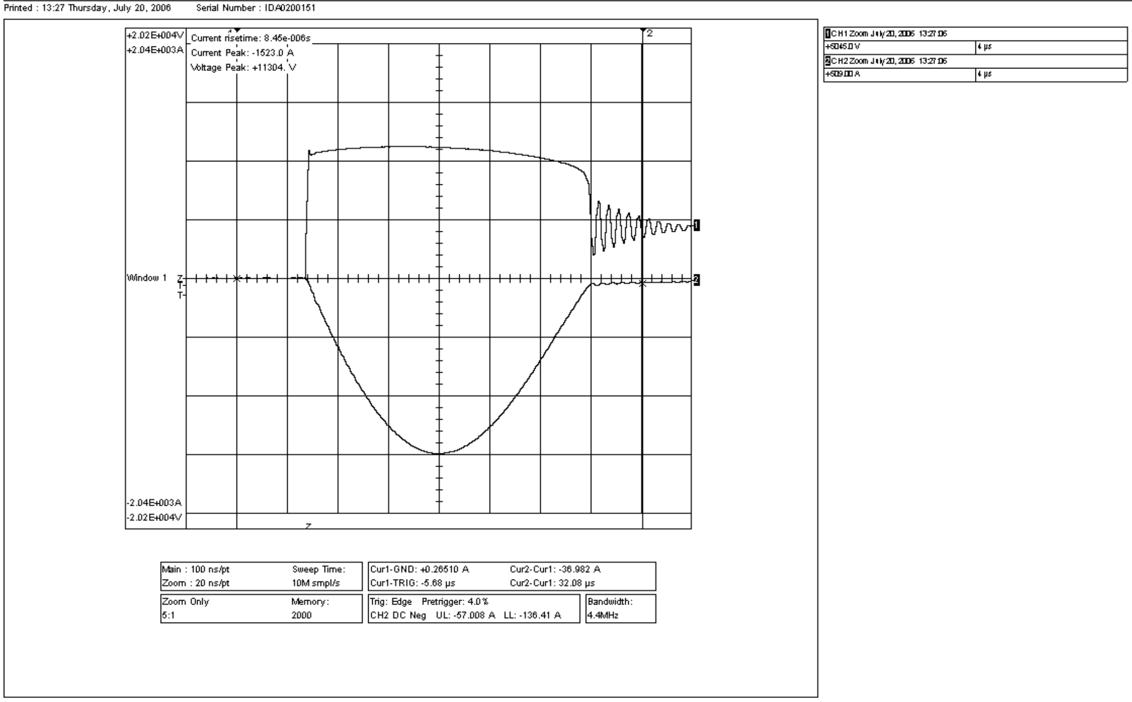

HUBBELL Power Systems

Sample 3, Oscillogram 3

Nicolet Accura100

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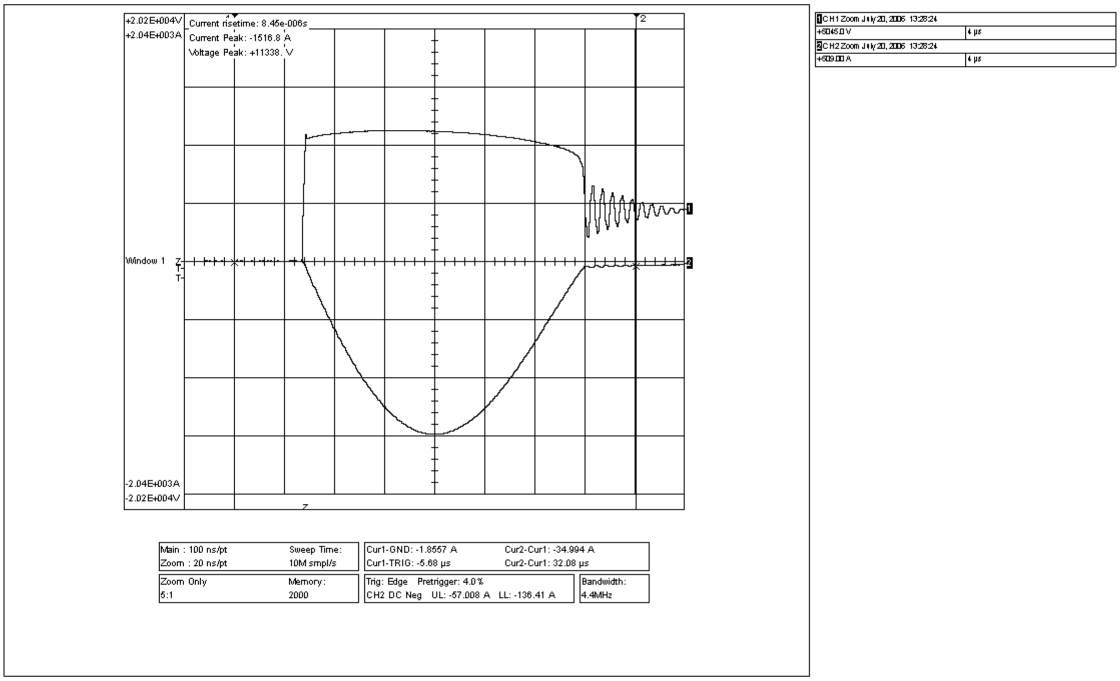

Sample 1, Oscillogram 4

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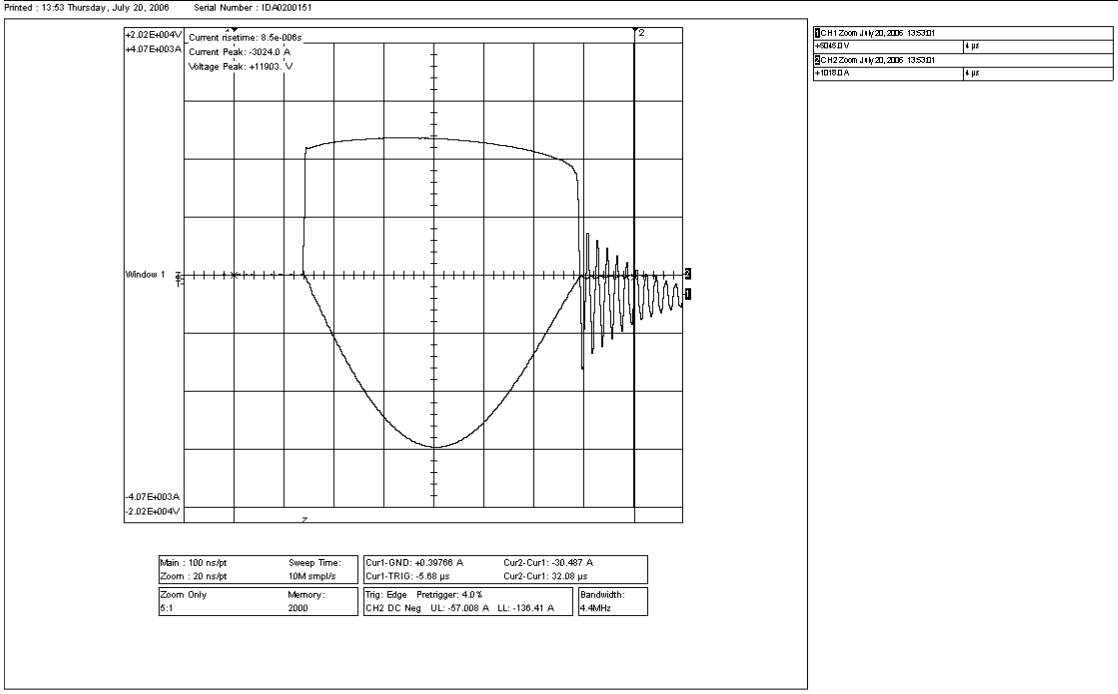
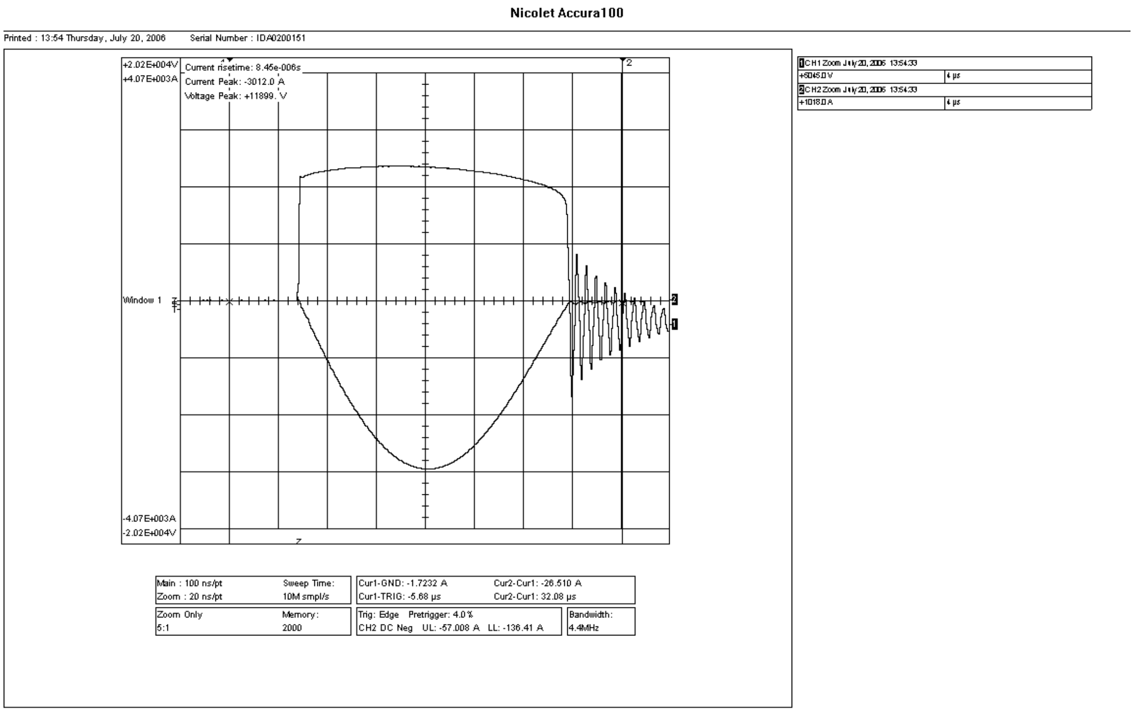
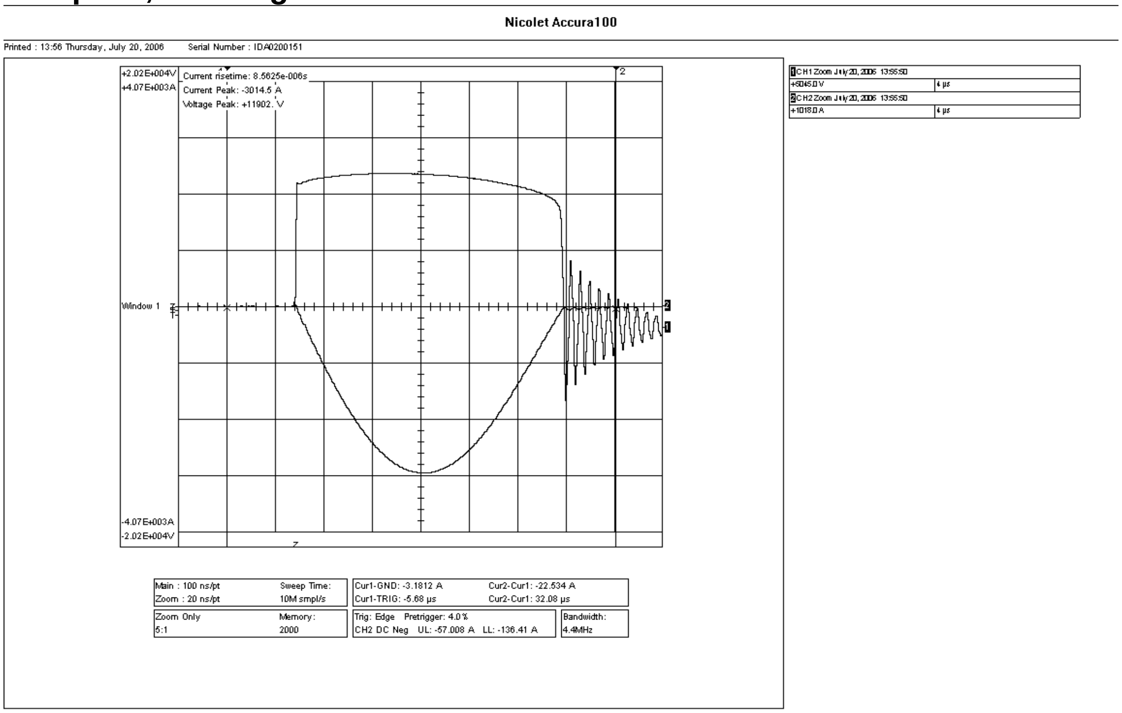


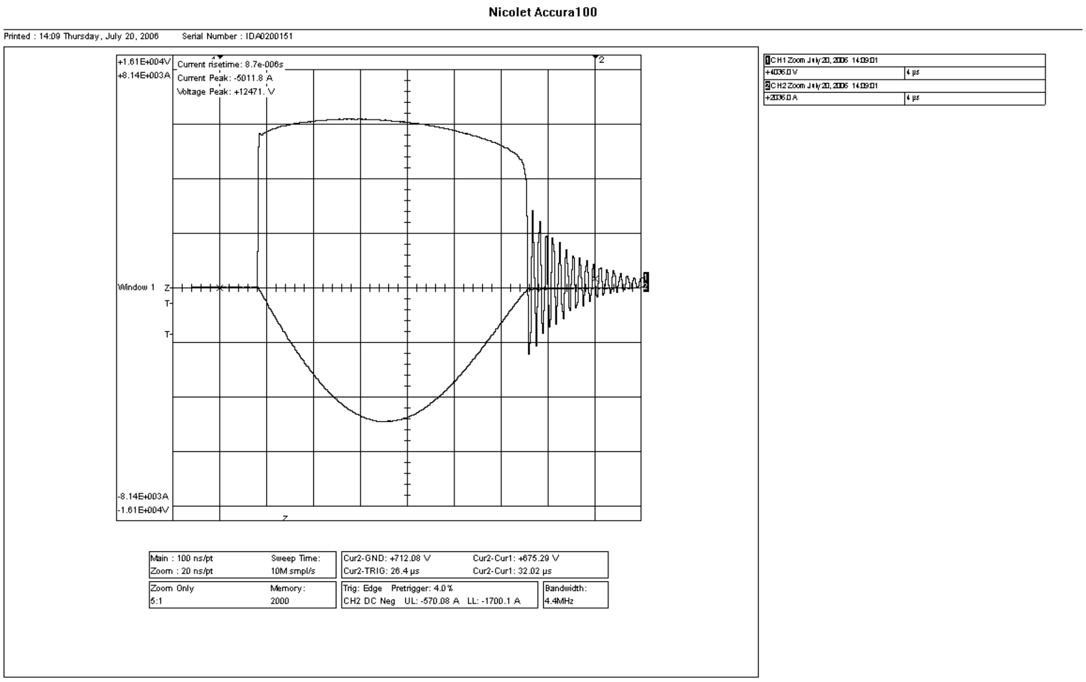
Sample 2, Oscillogram 5



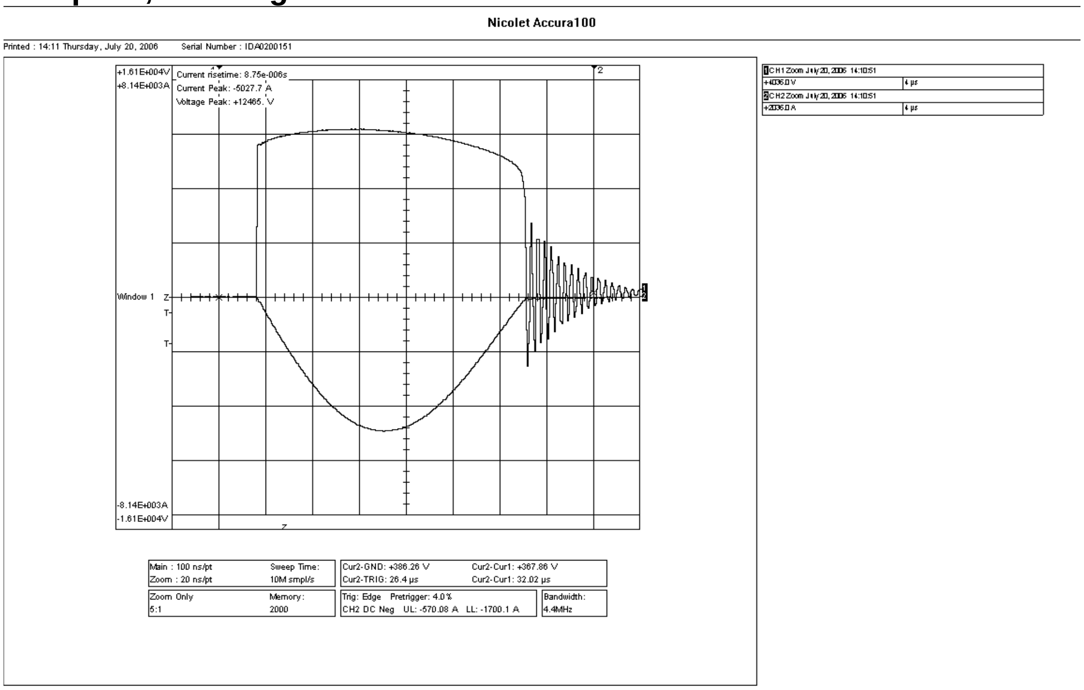
Sample 3, Oscillogram 6



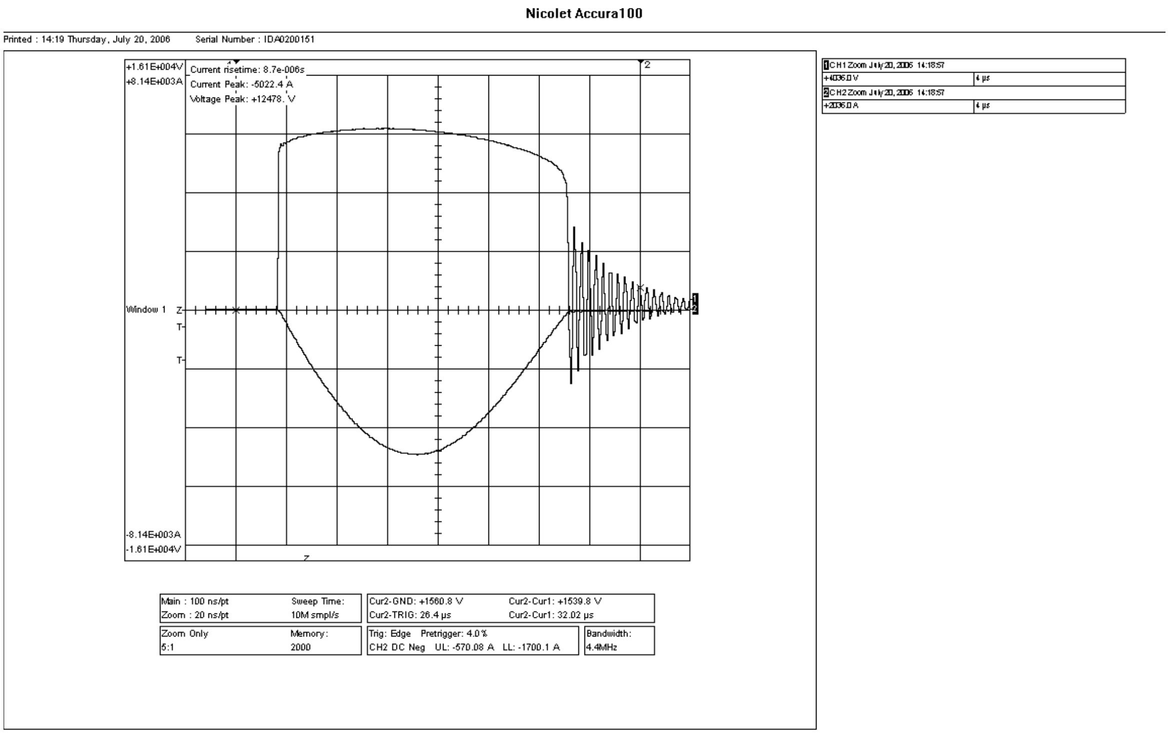
Sample 1, Oscillogram 7



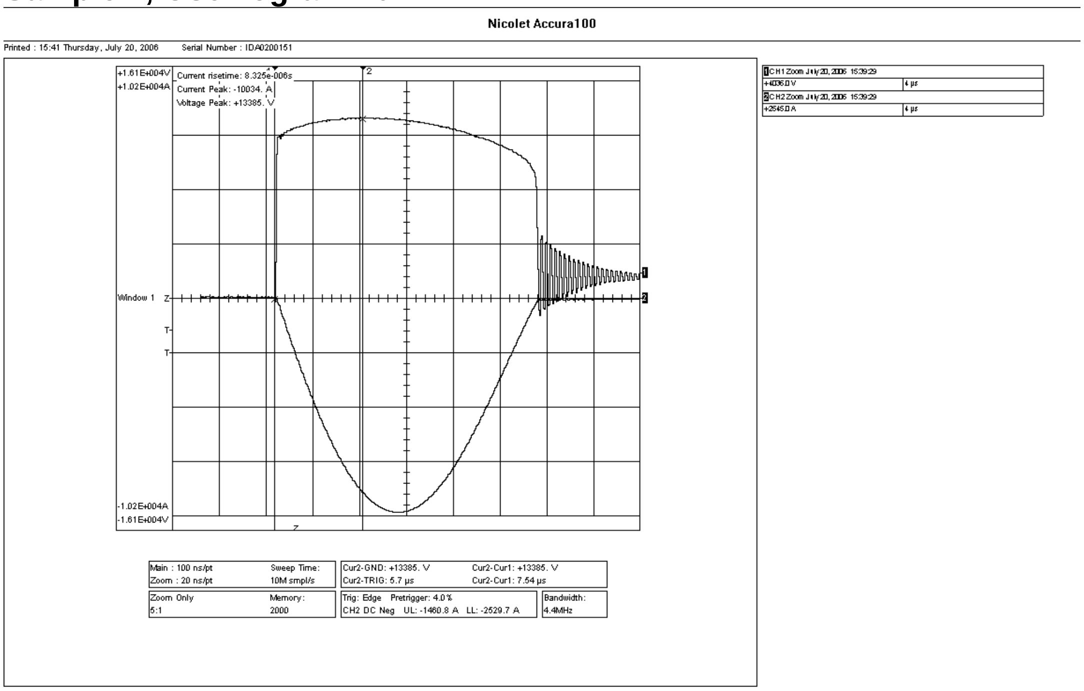
Sample 2, Oscillogram 8



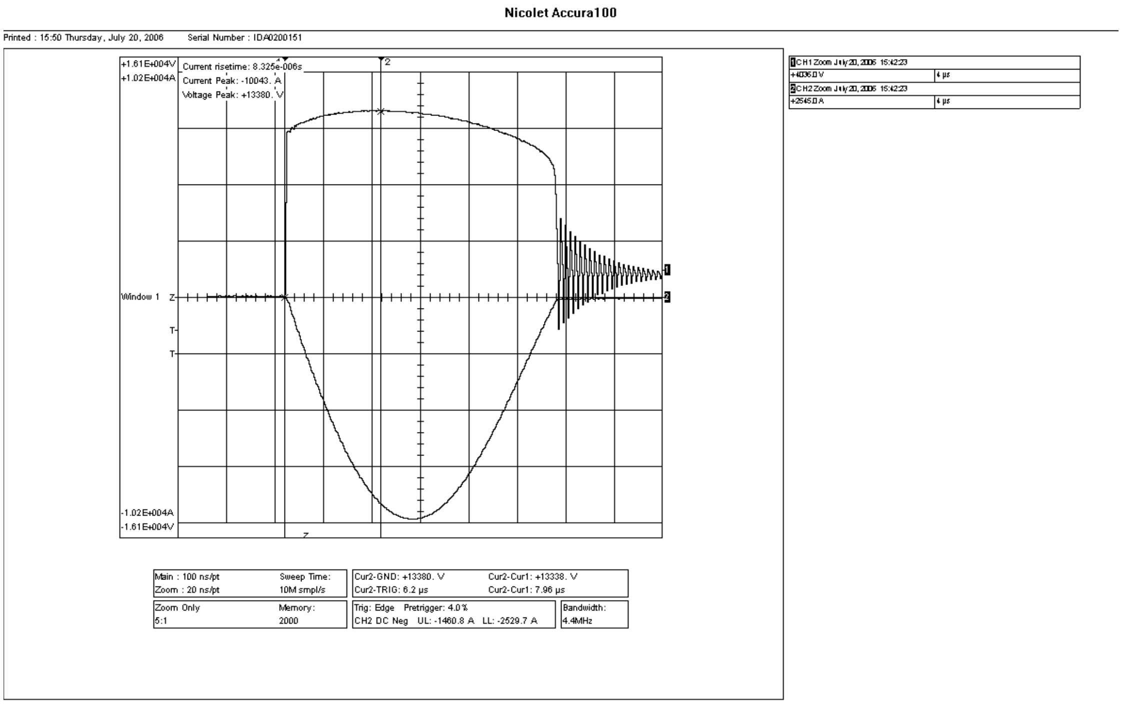
Sample 3, Oscillogram 9



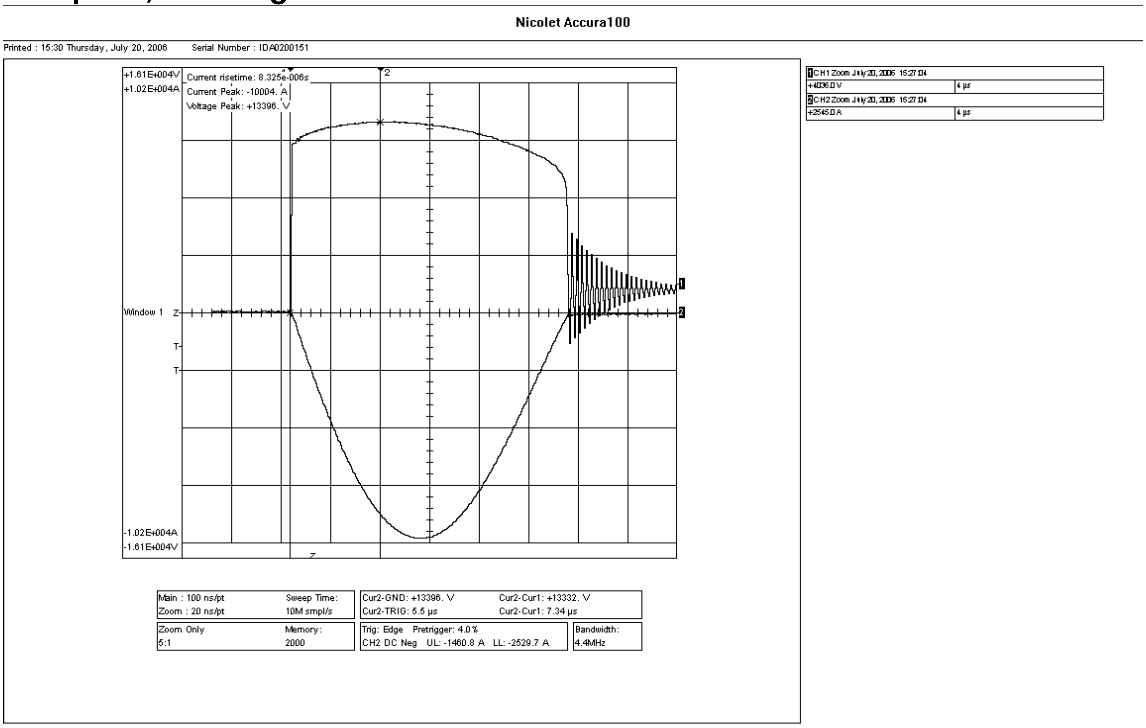
Sample 1, Oscillogram 10



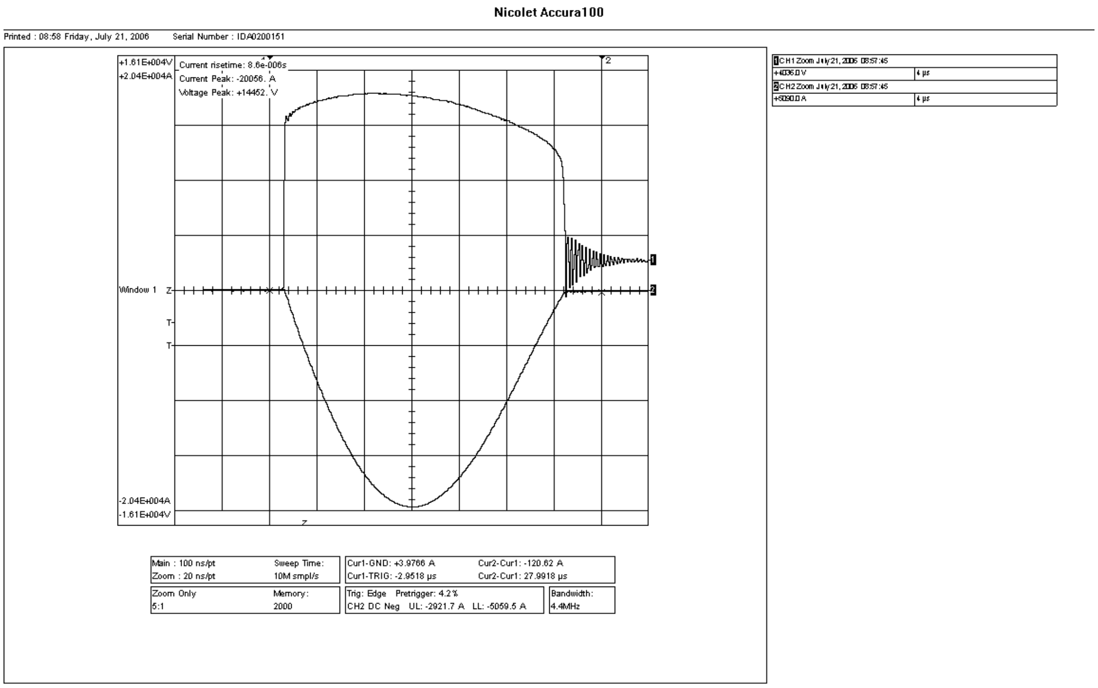
Sample 2, Oscillogram 11



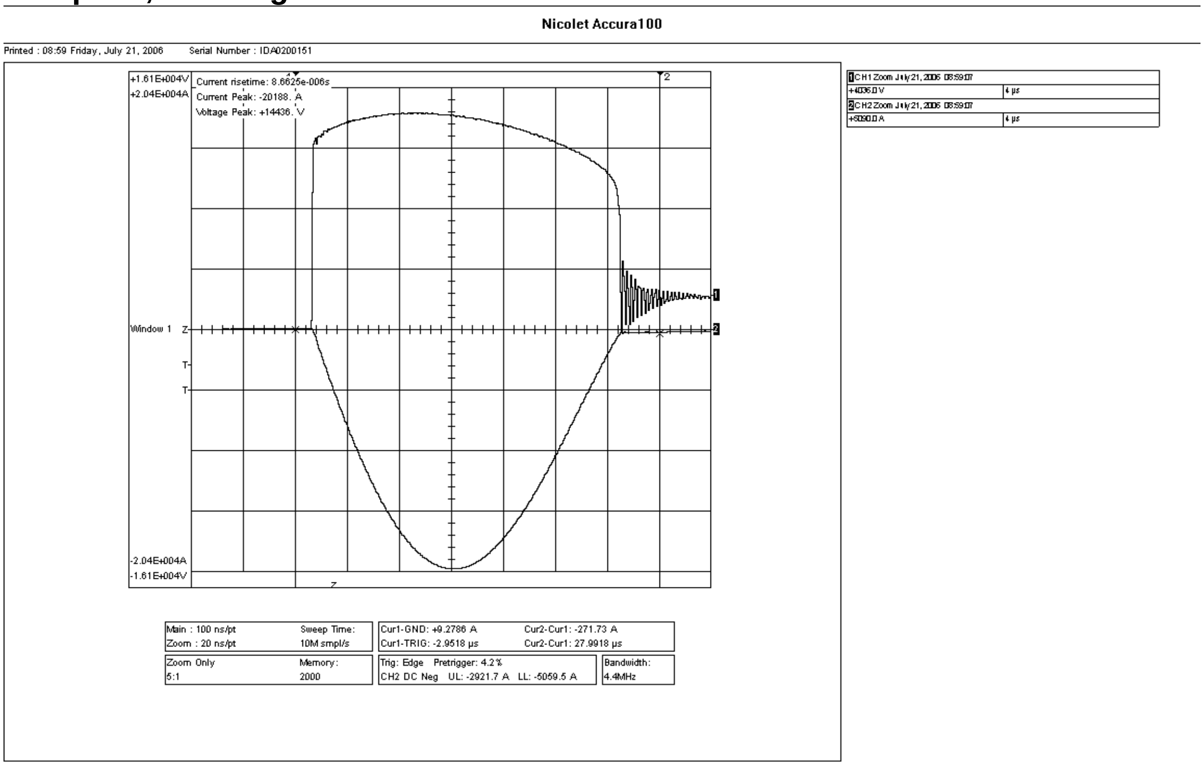
Sample 3, Oscillogram 12



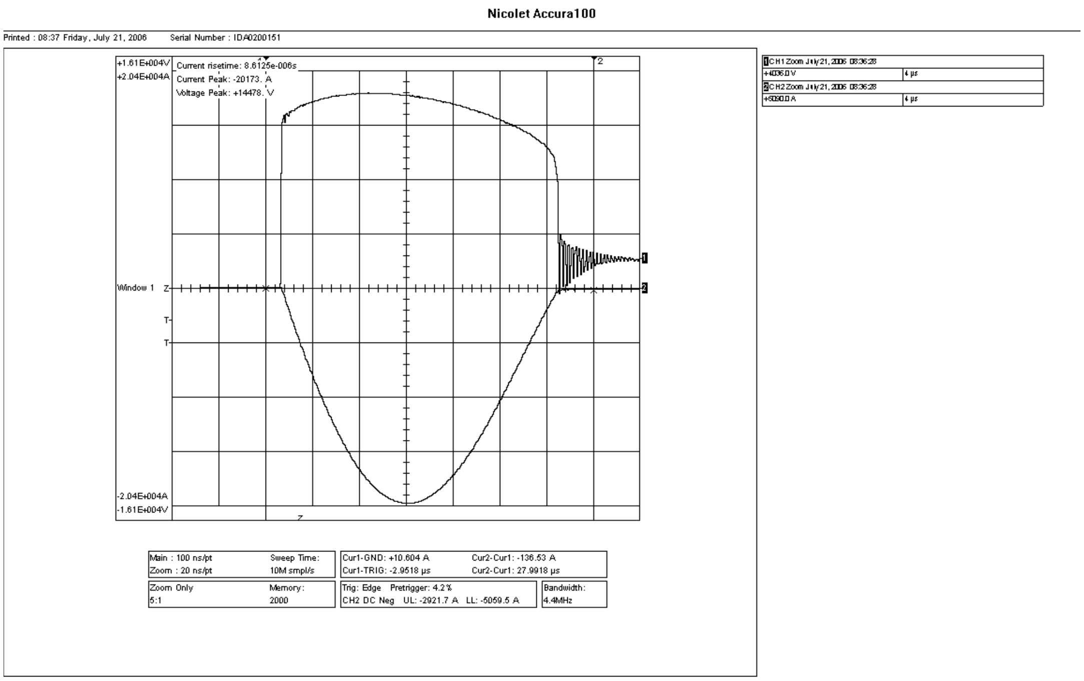
Sample 1, Oscillogram 13



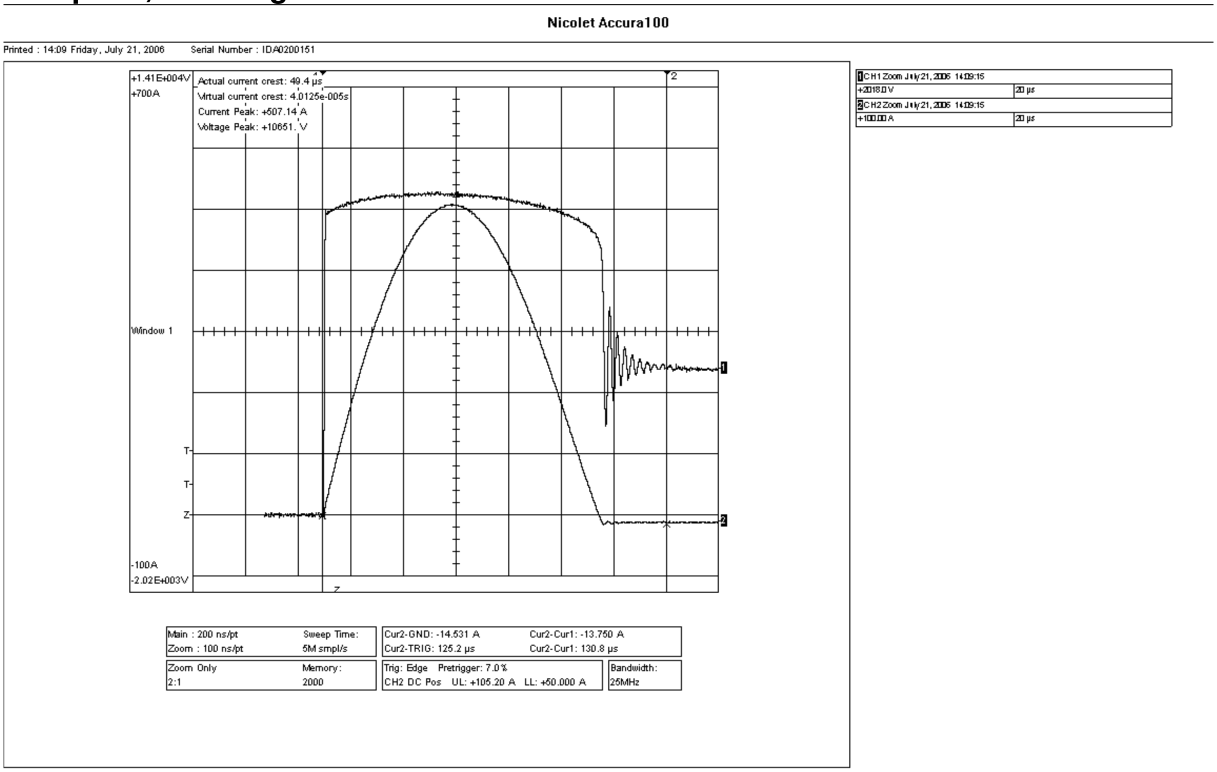
Sample 2, Oscillogram 14



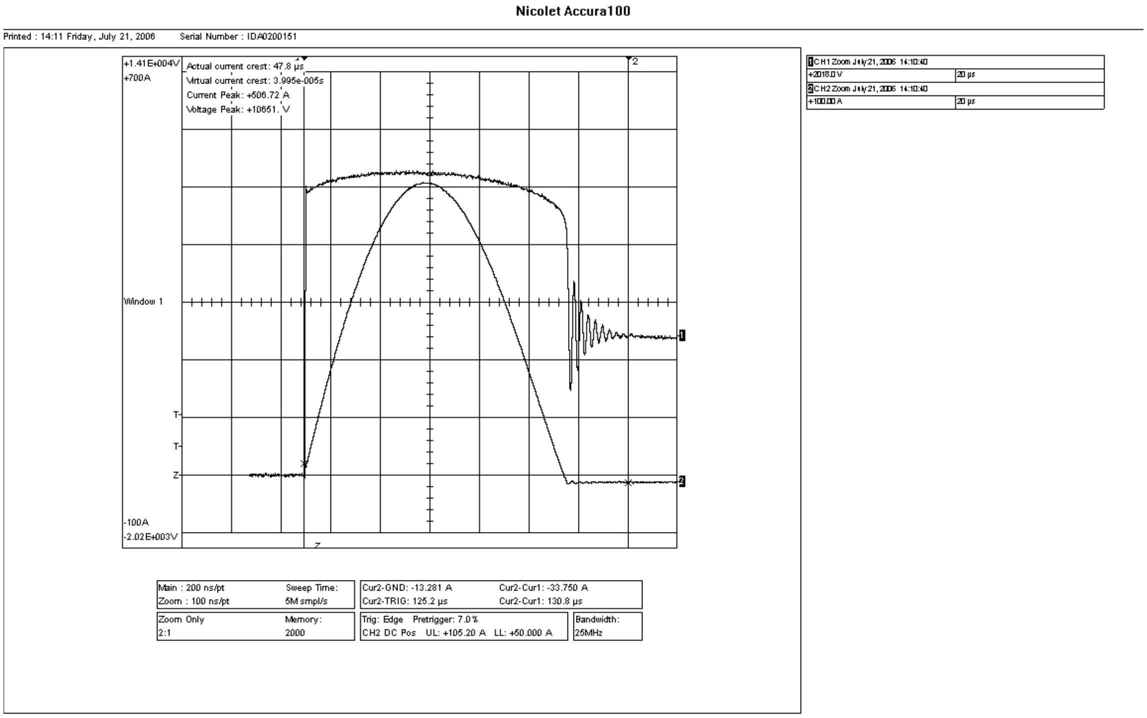
Sample 3, Oscillogram 15



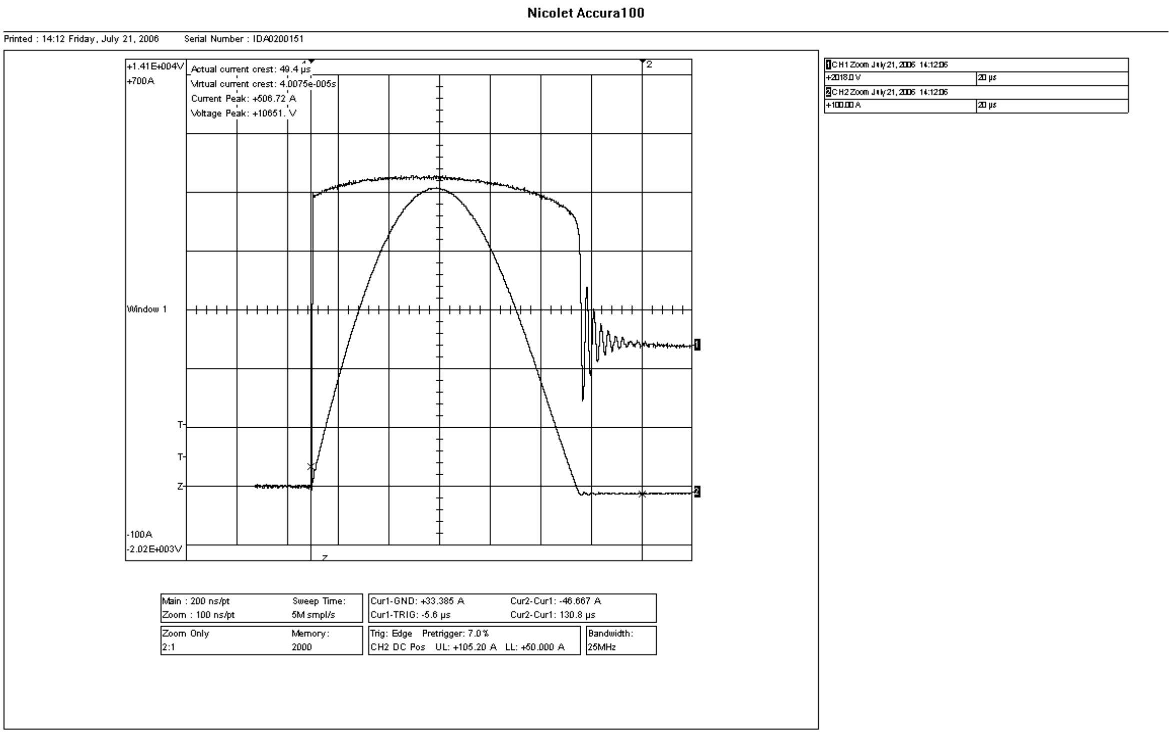
Sample 1, Oscillogram 22



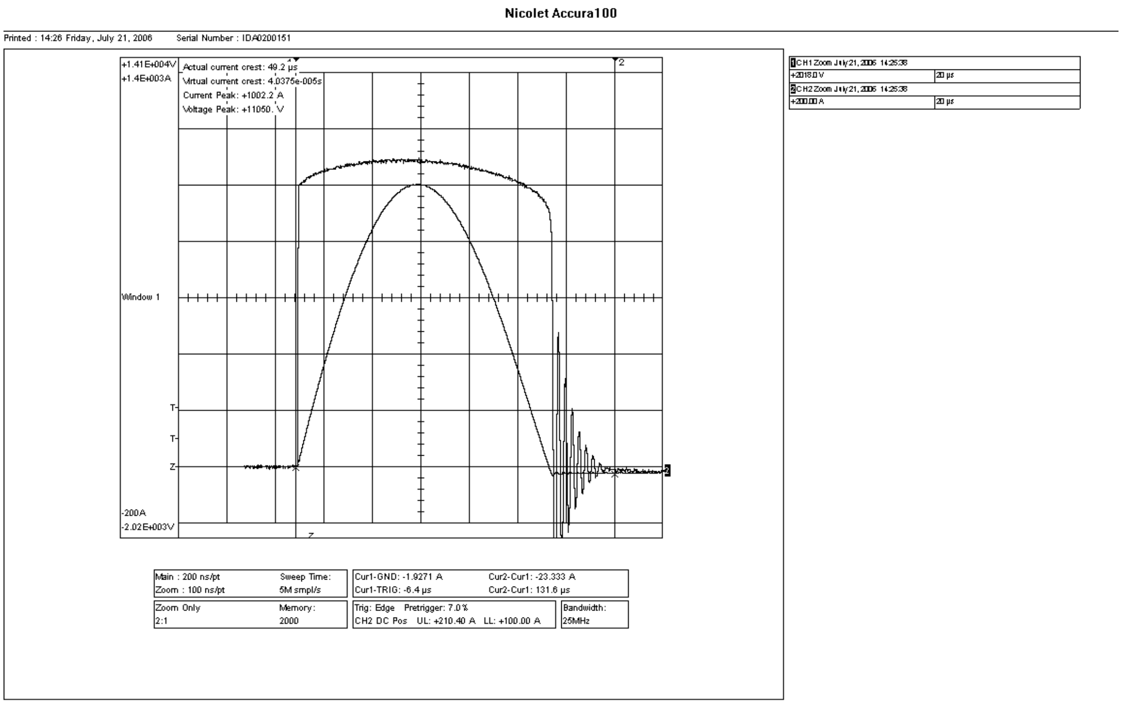
Sample 2, Oscillogram 23



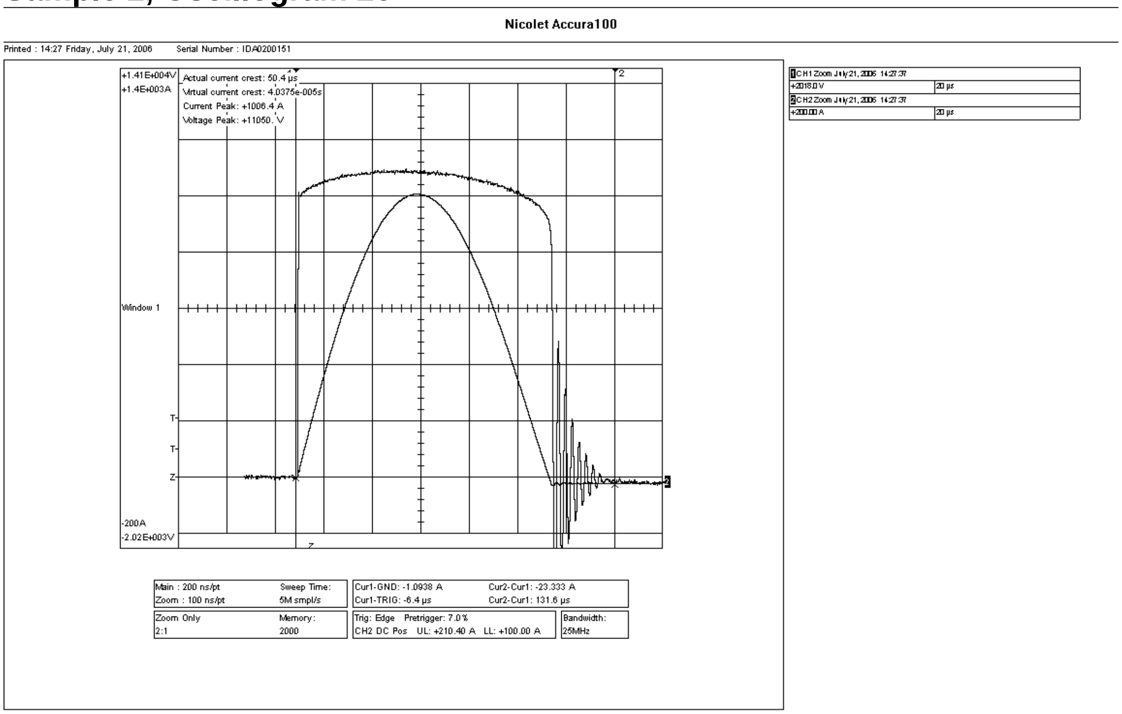
Sample 3, Oscillogram 24



Sample 1, Oscillogram 25



Sample 2, Oscillogram 26



Sample 3, Oscillogram 27

Nicolet Accura100

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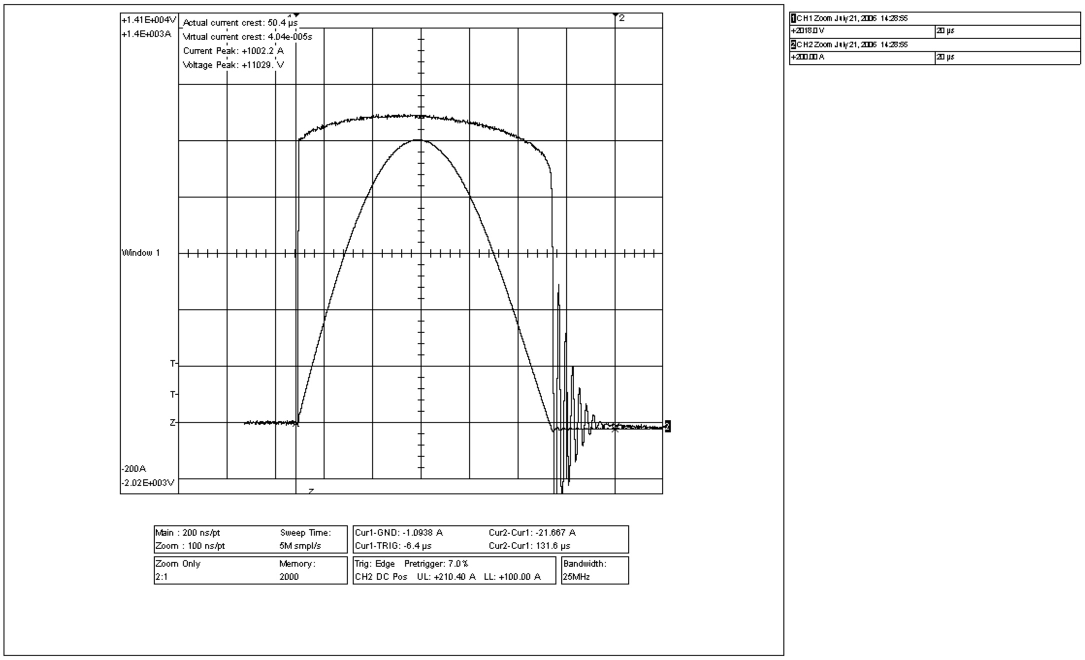

Sample 1, Oscillogram 34

Nicolet Accura100

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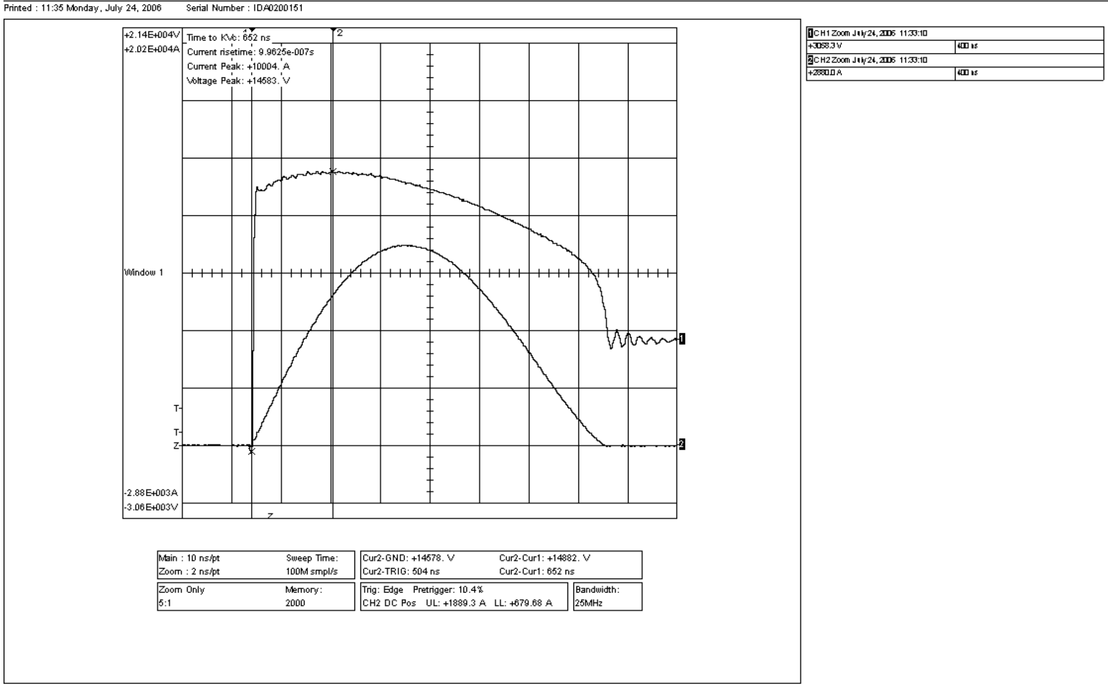
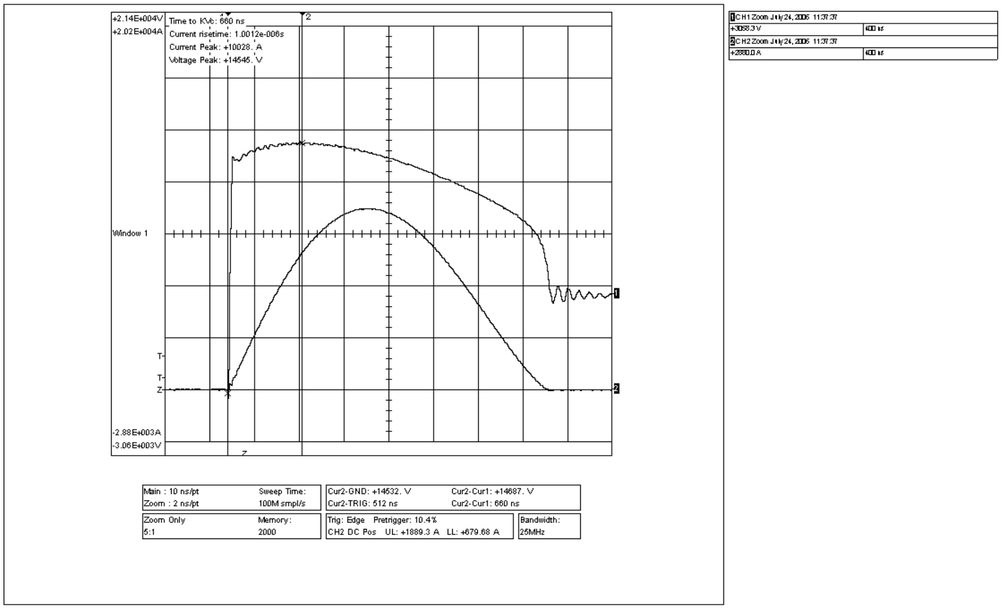


Sample 2, Oscillogram 35

Nicolet Accura100

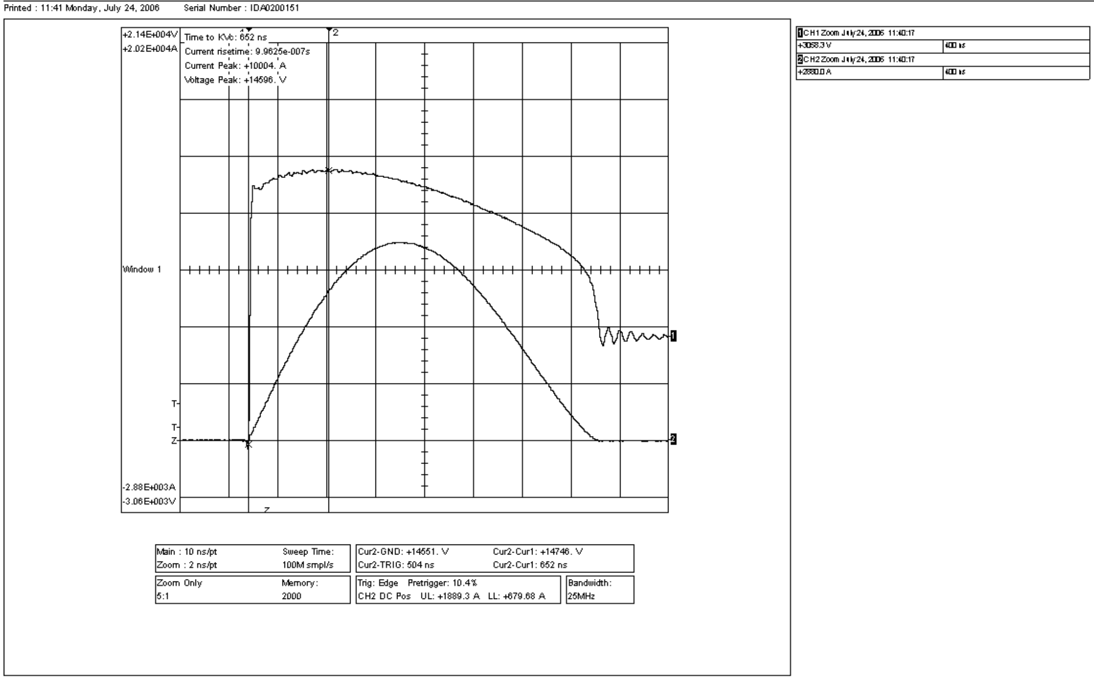
Printed : 11:38 Monday, July 24, 2006 Serial Number : IDA0200151



Sample 3, Oscillogram 36

Nicolet Accura100

Printed : 11:41 Monday, July 24, 2006 Serial Number : IDA0200151



IEEE Design Test Report
Report No. EU1588-H-03.1
Type EVP Station Class Arrester

MOV Disc Accelerated Aging

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
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Date: 3/27/14

Type EVP Station Class Surge Arrester
Disc Accelerated Aging

INTRODUCTION: 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.

TEST SAMPLES: Six arrester modules (three with the longest MOV disc and 3 with the shortest MOV disc) were tested.

TEST PROCEDURE: Tests were performed per section 8.5 of the IEEE C62.11-2012 standard. Samples were placed inside a 115°C ±2°C oven and energized at a voltage level greater than MCOV for 1,000 hours.

TEST RESULTS: Watts loss for each sample was measured at relevant MCOV two hours after energization and at the completion of the 1000 hour test duration. The table below summarizes test data.

Accelerated aging test data

Sample No. -length	Watts loss @ 2Hr-5Hr P1c (w)@ MCOV	Watts loss at 1000 Hr @ MCOV P2c (w)	Elevation Factor Kc
1-24	1.62	1.07	1
2-24	1.73	1.13	1
3-24	1.57	1.06	1
1-41	3.49	2.29	1
2-41	3.38	2.17	1
3-41	3.4	2.2	1

CONCLUSION: Each test sample demonstrated continually declining Watts loss at MCOV. Therefore, k_c factors equal 1.0.

IEEE Design Test Report
Report No. EU1588-H-04.1
Type EVP Station Class Arrester

Polymer Aging

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, “IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV).”

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
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Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
Polymer Housing Aging

INTRODUCTION:

The polymer housing accelerated aging tests were performed per Section 8.7 of the IEEE C62.11-2012 standard. The purpose of this test was to verify the electrical integrity of the arrester polymer housing after being subjected to 1000 hours in a salt fog environment.

SAMPLE PREPARATION:

A 115 kV MCOV EVP arrester (longest electrical unit) was assembled for this test.

Note: EVP was called PVN optima at the time of launch. The catalogue number in the third party test report (PSCPVN011500) is an equivalent EVP011500.

TEST PROCEDURE:

The 1000 hour weathering test was performed per Section 8.7.3 of the IEEE C62.11-2012 standard.

TEST RESULTS:

The test arrester successfully withstood the 1000 hour salt fog exposure test with no evidence of surface tracking, erosion, or puncturing. Per Section 8.7.4, the reference voltage change, as a result of the 1000 hour test, was less than the allowed 5%. In addition, the partial discharge measured at the completion of the test was less than the allowed 10pC.

TEST CONCLUSIONS:

The EVP Station Class arrester design successfully passed the 1000 hour salt fog test, as defined in Section 8.7 of the IEEE C62.11-2012 standard.

ANNEX- Salt Fog Test

The following attachment confirms the successful completion of the salt fog polymer aging test performed on the longest Type EVP electrical unit.

6.3 Salt fog test and summary

No tracking occurred, erosion does not occur through the entire thickness of the external coating up to the next layer of material and the sheds and housing are not punctured. The reference voltage measured before and after the test has not decreased by more than 5 %, and the partial discharge measurement performed before and after the test is satisfactory, i.e. the partial discharge level was not higher than 10 pC. No overcurrent trip-out occurred during the test.

The test is passed successfully.

Figure 7 Test object after the test

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IEEE Design Test Report
Report No. EU1588-H-05.1
Type EVP Station Class Arrester

Contamination

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
Contamination

INTRODUCTION: The polymer housing accelerated aging tests were performed per Section 8.8 of the IEEE C62.11-2012 standard. The tests were performed on a three unit 180 kV MCOV arrester.

TEST PROCEDURE: The partial wetting contaminant was prepared per Section 8.8.2.2 and the test procedure was performed per Section 8.8.2.3 of the IEEE C62.11-2012 standard. Prior to the application of contaminant (450 ohm-cm resistivity), the arrester was energized at MCOV for 1 hour. After 1 hour of energization, the arrester was de-energized and slurry contaminant was applied over the entire surface of the bottom half of the arrester. After a 7 minute wait, the arrester was energized at MCOV for 15 minutes, at which time the voltage was turned off and the bottom half of the arrester re-sprayed with contaminant. Within 5 minutes of de-energization, the arrester was reenergized at MCOV. After 15 minutes, the arrester resistive component of current was recorded. After 30 additional minutes at MCOV, re-measurement of the resistive current confirmed thermal stability at which time the test was completed.

TEST RESULTS: The 180 kV MCOV arrester demonstrated thermal stability after the second partial wetting test series. No unit or arrester flashover occurred during the above testing. Disassembly of the test arresters revealed no damage to the internal components as a result of the partial wetting contamination test.

IEEE Design Test Report
Report No. EU1588-H-06.1
Type EVP Station Class Arrester

Radio Influence Voltage

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
Contamination

TEST PROCEDURE AND SAMPLE:

Internal ionization and RIV testing was performed per clause 8.10 of the IEEE C62.11-2012 standard. The test was performed on a 180 kV MCOV EVP arrester.

TEST EQUIPMENT:

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.

TEST RESULTS:

A background noise level of 1.2 μV was measured at an open circuit voltage of 189 kV (105% MCOV). With the 180 kV arrester placed in the circuit, a noise level of 1.2 μV was measured.

CONCLUSION:

The 180 kV MCOV EVP arrester passed test requirements per Section 8.10 of the IEEE C62.11-2012 standard, as measured noise levels were within the 10 μV RIV test limit.

IEEE Design Test Report
Report No. EU1588-H-07.1
Type EVP Station Class Arrester

Partial Discharge

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
Partial Discharge

INTRODUCTION:

The polymer housing partial discharge test was performed per Section 8.11 of the IEEE C62.11-2012 standard. The test was performed on a 180 kV MCOV EVP arrester.

TEST EQUIPMENT:

Equipment and test methods conformed to the IEEE 454-1979 standard.

TEST RESULTS:

The arrester with grading ring was energized at 1.05 times MCOV. At 189 kV, the arrester's partial discharge level measured 6.5 pC, with an ambient 5.8 pC background level.

CONCLUSION:

The 180 kV MCOV EVP arrester passed test requirements per Section 8.11 of the IEEE C62.11-2012 standard, as measured partial discharge levels were within the 10 pC test limit.

IEEE Design Test Report
Report No. EU1588-H-08.0
Type EVP Station Class Arrester

Switching Surge Energy Rating

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
Switching Surge energy Rating

INTRODUCTION: Switching surge energy rating tests were performed per section 8.14 of the IEEE C62.11-2012 standard. Tests were performed per Station Class arrester requirements. The main objective of this test is to claim an energy class as per Table 13 of the above mentioned standard.

TEST SAMPLE: As required by the standard, the prorated test sections contained the minimum MOV mass required for the design.

TEST PROCEDURE: The test sections were conditioned with six groups of three current impulses corresponding to energy class F (11kJ/kV). The assigned conditioning level testing was followed by two 65kA, 4/10 impulses, spaced 50 to 60 seconds apart. The prorated sections were then placed into an oven until the temperature stabilized at 68°C.

After stabilization, test samples were subjected to long duration current impulses (2000 to 3000 µs). Within 100ms from the application of the second discharge the duty cycle rated voltage was applied for 10s followed by power frequency recovery voltage for 30mins to demonstrate thermal recovery.

TEST RESULTS:

MCOV = 0.795*Vref;
Duty cycle rated voltage = 1.236*MCOV
MCOV of Sample ≤ 9.302 kV rms (calculated from measured Vref)

The targeted energy class for this design was Class F with a 2-shot energy rating of 11 kJ per kV MCOV. As such, all test sections were subjected to 18 shots having a 5.5 kJ per kV MCOV energy rating.

Figure 1 shows the Class F conditioning impulse while Figure 2 shows an oscillogram of a typical 65 kA high current impulse.

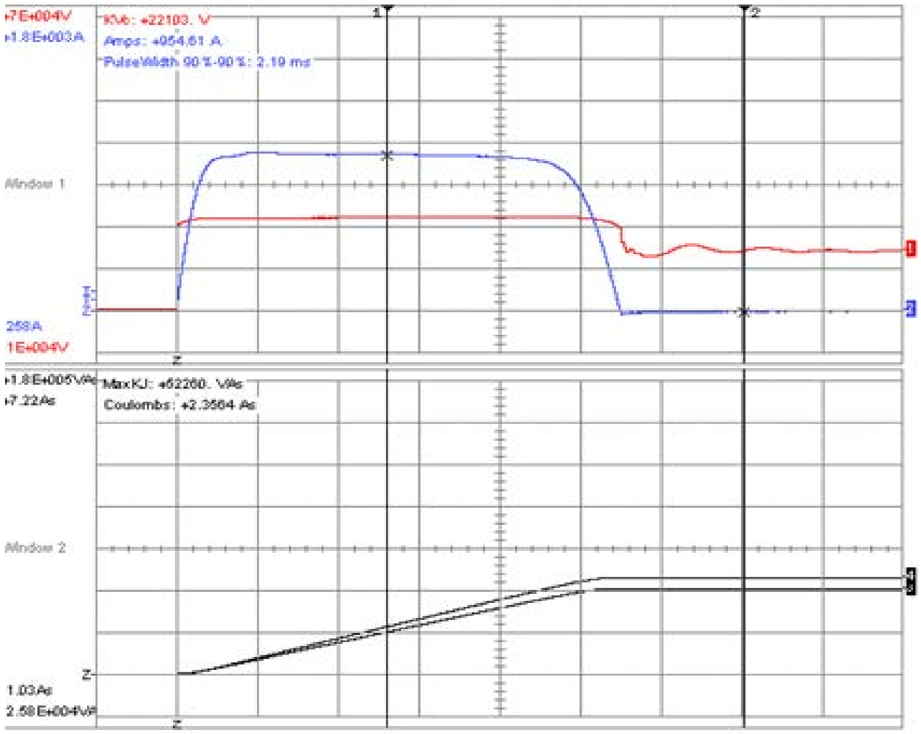


Figure 1: Conditioning impulse at class F

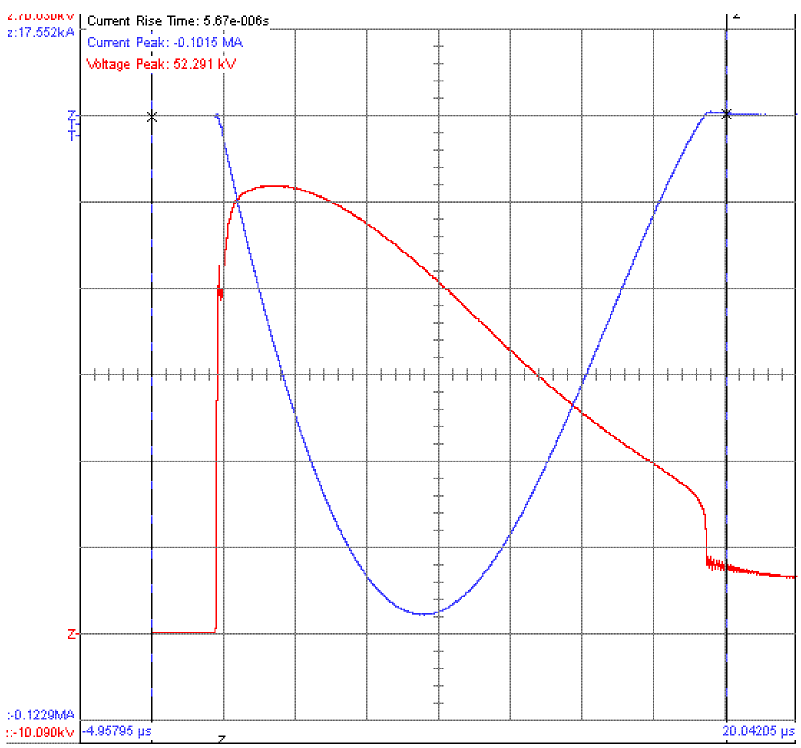


Figure 2: Example of 65kA (4/10) impulse waveform

During the thermal recovery portion of the switching surge energy rating test, it was discovered that the prorated test sections could not thermally recover after exposure to the required Class F 11 kJ per kV MCOV energy discharges, followed by 10 seconds at rated voltage.

The thermal recovery testing was repeated at the Class E 2-shot energy rating level of 9 kJ per kV MCOV. Figure 3 shows an oscillogram of the energy discharge followed by 10 seconds at rated voltage on sample 2, while Figure 4 demonstares the thermal stability of the test section during the recovery voltage portion of the test.

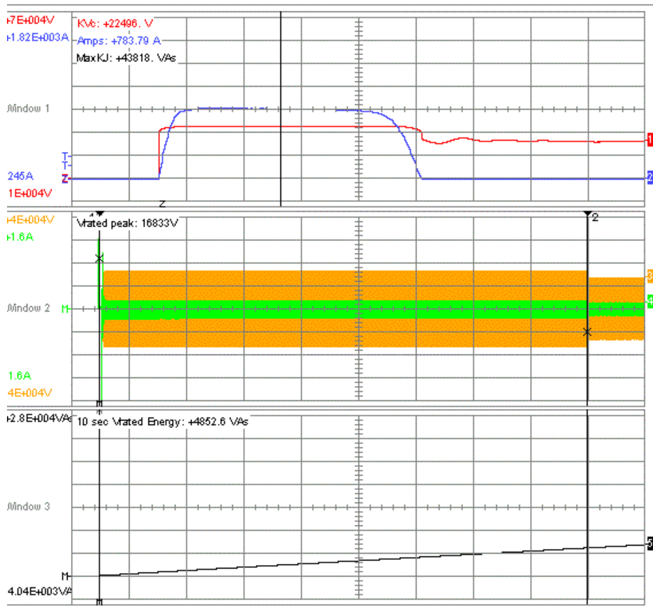


Figure 3: Class E energy shot on Sample 2 (41.859kJ/shot)

Tables 1 and 2 illustrate the duty cycle and thermal recovery data respectively.

Time (sec)	Vrated (KVc)	60Hz (mA)
0.060	16.521	161.7
1.032	16.531	158.3
2.064	16.573	154.2
3	16.594	154.2
4.008	16.594	151.3
5.016	16.583	147.5
6.048	16.583	148.8
7.08	16.583	147.9
8.136	16.563	144.6
9.10	16.573	147.1
10.20	16.594	148.3

Table 1: 10 sec Duty Cycle Voltage data on Sample 2

Elapsed Time	Recovery (KV_{RMS})	It (mA_C)	Ir (mA_C)	Watts
0:00:00	9.59	-12.53	-11.82	48.25
0:00:30	9.62	-10.57	-10.26	40.55
0:01:00	9.56	-9.02	-8.65	35.68
0:02:00	9.59	-8.56	-7.94	33.22
0:05:00	9.56	-7.04	-6.78	28.32
0:10:00	9.56	-6.28	-6.06	24.75
0:20:00	9.54	-5.17	-4.73	20.71
0:30:00	9.57	-4.87	-4.55	19.12

Table 2: 30 min Recovery Voltage data on Sample 2

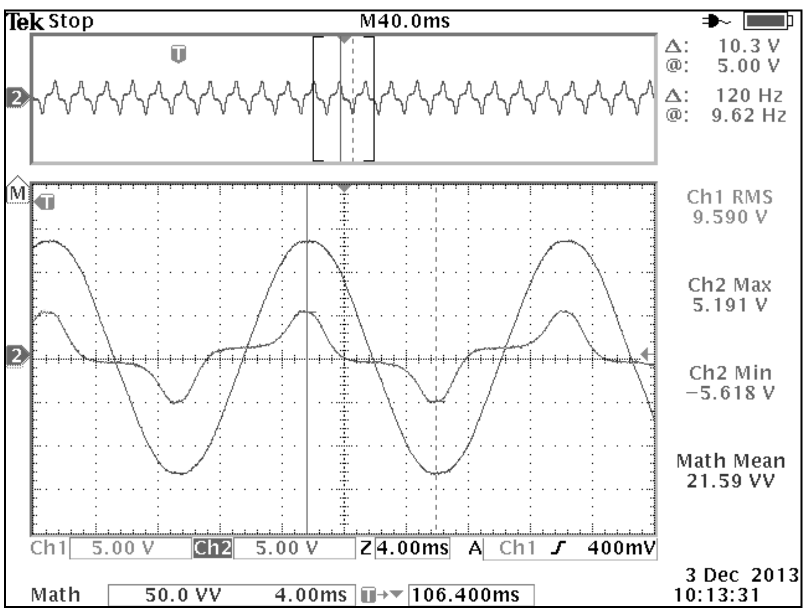


Figure 4: Recovery Oscillogram- Sample 2

Per the test evaluation procedure as specified in Section 8.14.5 of the standard, the switching surge voltage of each test section was measured before and after the energy surge duty testing. Table 3 summarizes the results of this testing. Additionally, each test section showed no evidence of physical damage.

Sample no.	1 kA IR Before(kVc)	1 kA IR After (kVc)	% Change
1	22.866	22.553	-1.37%
2	22.900	22.419	-2.10%
3	22.883	22.410	-2.06%
4	22.874	22.444	-1.88%

Table 3: 1kA IRs before and after

Conclusion:

The Type EVP prorated sections successfully passed the switching surge energy requirements of Energy Class E as specified in Table 13 of IEEE C62.11-2012.

IEEE Design Test Report
Report No. EU1588-H-09.0
Type EVP Station Class Arrester

Single Impulse Withstand Rating

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
Single Impulse Withstand rating test

INTRODUCTION: The single-impulse withstand rating test was performed per Section 8.15 of the IEEE C62.11-2012 standard, on ten MOV blocks.

TEST PROCEDURE: Test was performed on 10 of the longest MOV blocks used in the EVP product line. The discharge voltage (10kA, 8/20) and the reference voltage (at 9.5mA) were measured before and after the long duration impulses for evaluation. Each sample was then subjected to ten groups of two long duration impulses of 2.22 ms and a charge content of 2.66 C.

Figure 1 shows the long duration impulse waveform applied on each of the MOV discs.

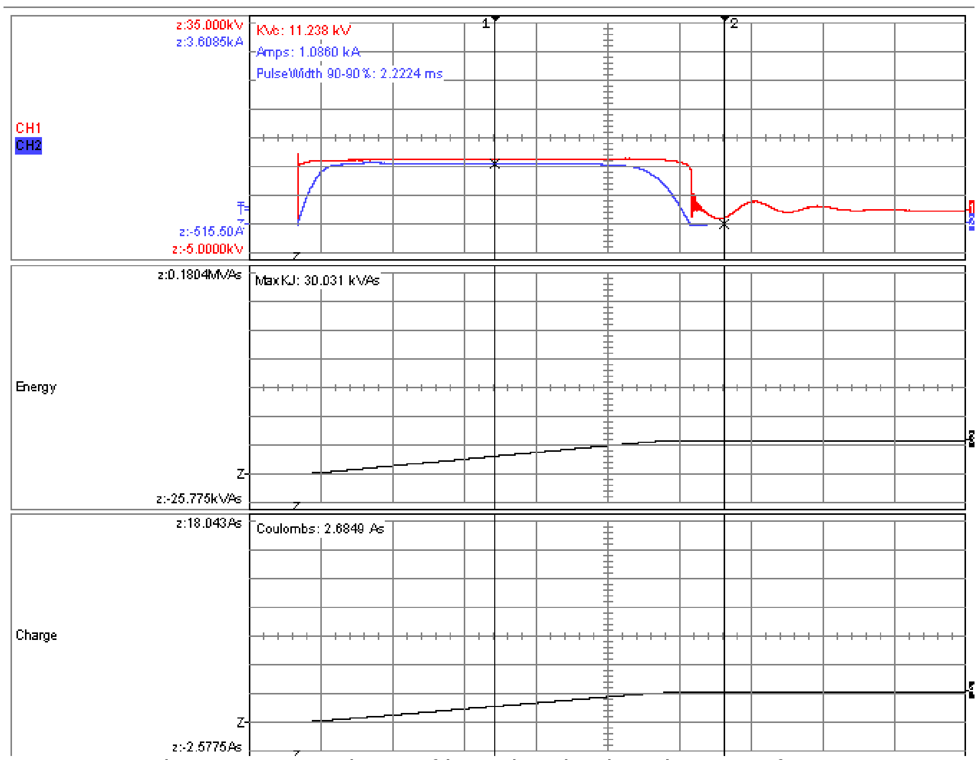


Figure 1: Wave shape of long duration impulse wave form

Sample No	10 kA IR Before (kVc)	10 kA IR After (kVc)	% Change	Vref @ 9.5mA Before (kVc)	Vref @ 9.5mA After (kVc)	% Change
1	13.63	13.68	0.37%	8.39	8.56	1.98%
2	13.60	13.64	0.29%	8.39	8.55	1.84%
3	13.50	13.54	0.30%	8.32	8.46	1.68%
4	13.61	13.65	0.29%	8.39	8.54	1.76%
5	13.58	13.63	0.37%	8.34	8.51	1.95%
6	13.56	13.6	0.29%	8.36	8.52	1.84%
7	13.62	13.67	0.37%	8.40	8.56	1.86%
8	13.63	Failed	-	8.38	Failed	-
9	13.59	13.63	0.29%	8.37	8.55	2.12%
10	13.57	13.61	0.29%	8.36	8.54	2.14%

Table 1: Before and After Discharge Voltages and Reference Voltages

Conclusion: The test was successfully completed as per the IEEE C.62.11-2012 requirements. The change in discharge voltage and reference voltage were well within 5% of initial value. The claimed single-impulse withstand rating for the Type EVP arrester is 2.4 C.

IEEE Design Test Report
Report No. EU1588-H-10.1
Type EVP Station Class Arrester

Duty Cycle

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
Duty Cycle

INTRODUCTION: The duty cycle testing was performed per Section 8.16 of the IEEE C62.11-2012 standard.

TEST OBJECTIVE: Section 8.16.3 of the IEEE C62.11-2012 standard specifies that the 20-shot rated voltage portion be performed with 10 kA, 8/20 μs lightning impulses and the 2-shot recovery portion of the Duty Cycle test also be performed with 10 kA, 8/20 μs lightning impulses.

TEST SAMPLE: As required by clause 8.16.1, 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 test data shows the results of testing performed on three test sections.

TEST PROCEDURE: The prorated test section was energized at its rated voltage and subjected to twenty 10 kA, 8/20 μs discharges spaced at 1 minute intervals. Following the twentieth impulse, the test section was placed in an oven at 68°C. After reaching 68°C, the sample was subjected to two additional 10 kA, 8/20 μs discharges. 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.

TEST RESULTS: The following data summarizes the results of the duty cycle test. Figures 1 and 2 show the 1st and 20th shot performed during the rated voltage portion of the duty cycle test.

Figure 1
1st Shot @ Rated Voltage

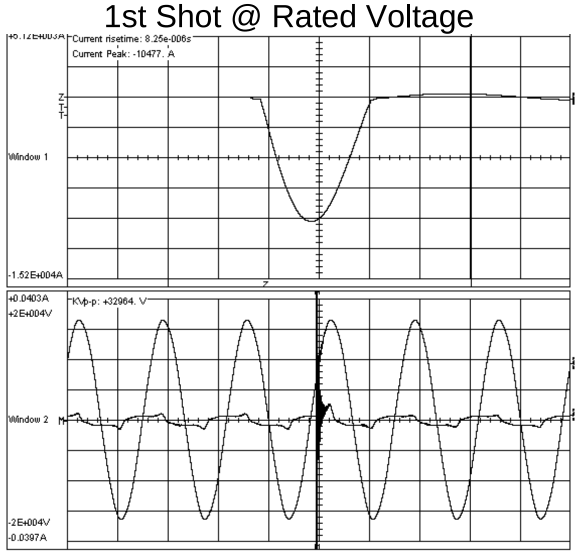


Figure 2
20th Shot @ Rated Voltage

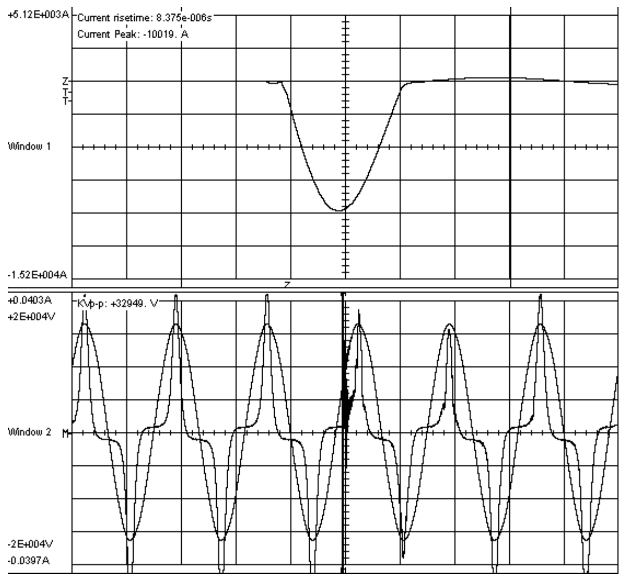
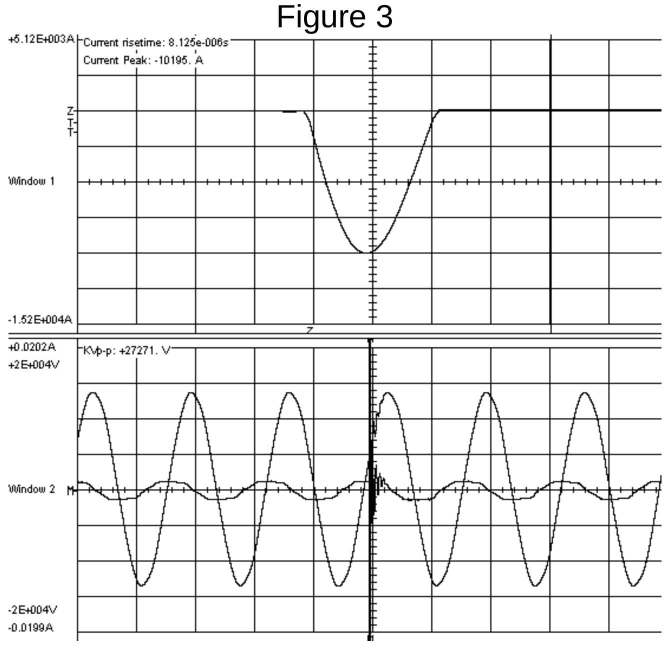


Figure 3 shows the oscillogram for the 2nd 10 kA impulse applied to the section during the recovery portion of the duty cycle test.

Figure 3



Figures 4 and 5 show the grading current through the test section at time zero and 30 minutes, demonstrating thermal recovery has occurred.

Figure 4
Recovery @ Time = 0 Minutes

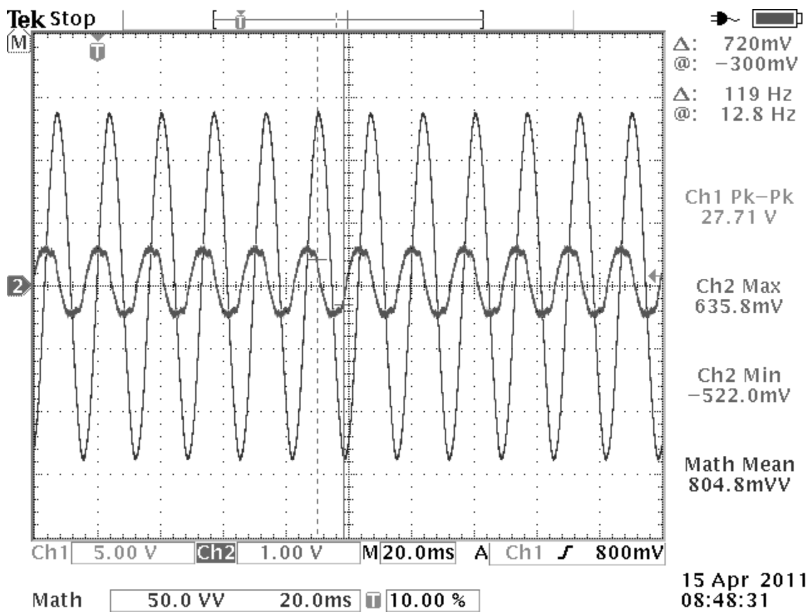
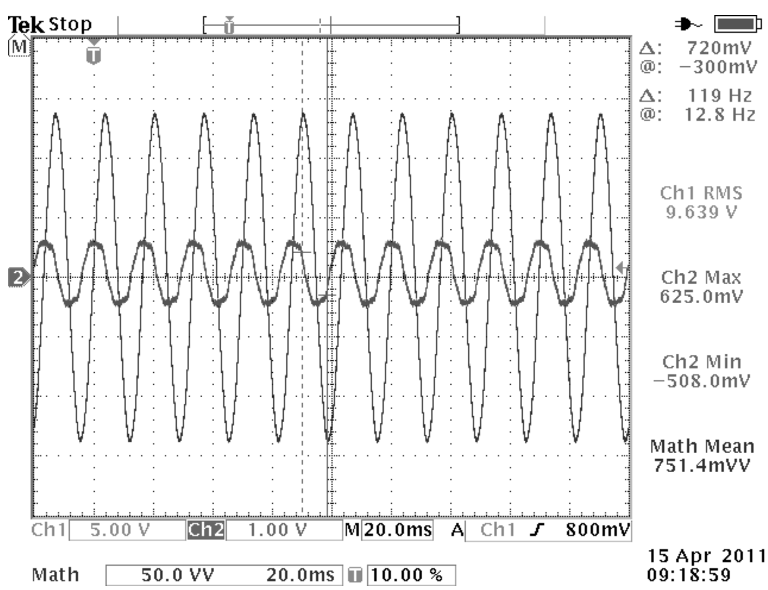


Figure 5
Recovery @ Time = 30 Minutes



Prior to and after the duty cycle test, the sample 10 kA, 8/20 µs discharge voltage is measured. Table 2 summarizes this test data.

Table 2

10 kA IR Before kVc	10 kA IR After kVc	% Change in 10 kA IR
27.63	27.82	+0.7

CONCLUSION: The prorated test sample successfully completed Duty Cycle testing and demonstrated thermal stability during the recovery test. The 10 kA discharge voltage increased 0.7%, less than the allowed 10% limit specified in Section 8.16.4 of the IEEE C62.11-2012 standard. Disassembly revealed no evidence of physical damage to the test sample. The EVP arrester successfully met the Duty Cycle requirements of a Station Class arrester.

IEEE Design Test Report
Report No. EU1588-H-11.1
Type EVP Station Class Arrester

Temporary Overvoltage

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
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Design Engineer

Date: 1/10/2014

HUBBELL
Power Systems

Type EVP Station Class Surge Arrester
Temporary Overvoltage

INTRODUCTION: The temporary overvoltage tests were performed per Section 8.17 of the IEEE C62.11-2012 standard. Prorated sections were used to facilitate testing of the lowest MOV mass, highest stressed arrester rating at voltages within available laboratory facility capabilities.

TEST PROCEDURE: Per clause 8.17.3, 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 8.17.3.1, 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 67.7^{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. Per clause 8.17.3.2 each prorated section was subjected to a “prior duty” energy discharge corresponding to class E of the switching surge energy test followed by a similar procedure of clause 8.17.3.1.

TEST RESULTS: Tests were successfully completed on five EVP 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. The following table summarizes the results of the TOV test program and applies to EVP arresters through 228 kV rating.

Table 1: Data points on Prior/No Prior Duty Curve

TOV Duration [s]	No Prior Duty TOV [p.u. MCOV]	Prior Duty TOV Class E [p.u. MCOV]
0.02	1.527	1.483
0.1	1.485	1.433
1	1.421	1.355
10	1.36	1.279
100	1.299	1.206
1000	1.236	1.128
10000	1.175	1.054

The following curve plots the individual data points and curves of the claimed TOV capability.

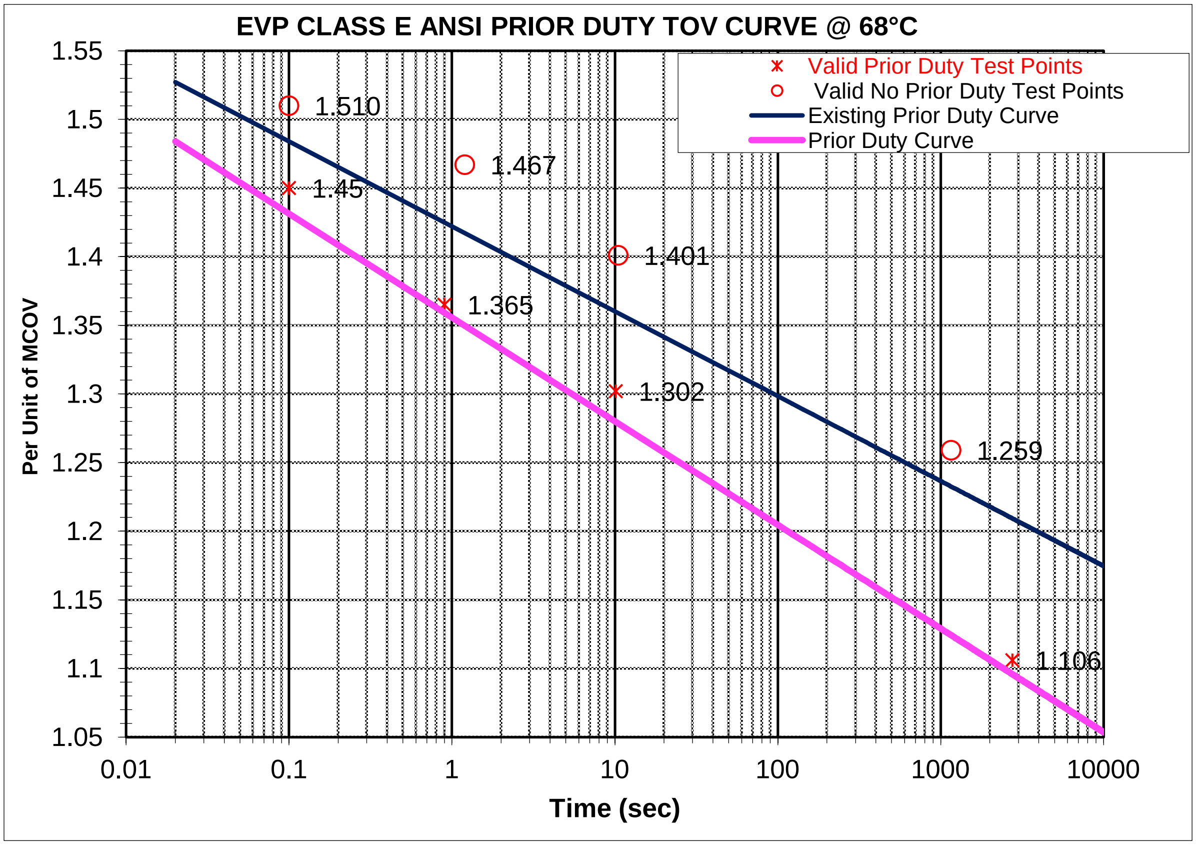

Figure 1: TOV curve for no prior and prior duty

Sample No	10KA IR Before (kVc)	10KA IR After (kVc)	% Change
1	26.802	27.148	1.29%
2	26.844	27.212	1.37%
3	26.928	27.000	0.27%
4	26.844	27.105	0.97%

Table 2: 10 kA IR Before and After – Prior Duty Samples

Sample No	10KA IR Before (kVc)	10KA IR After (kVc)	% Change
5	26.907	27.418	1.90%
6	26.781	27.283	1.87%
7	26.886	27.364	1.78%
8	26.844	27.23	1.44%

Table 3: 10 kA IR Before and After – No Prior Duty Samples

Conclusion: Tests were successfully completed on four prorated samples in four specified time ranges. Each sample demonstrated thermal stability after TOV exposure. Residual voltage at 10 kA measured prior to and after the TOV test series changed much less than the allowed 10%. There was no evidence of physical damage to the test sections, validating the EVP arrester TOV capability claim.

IEEE Design Test Report
Report No. EU1588-H-12.1
Type EVP Station Class Arrester

Short Circuit Pressure Relief

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
Dennis Lenk
Principal Engineer

Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

HUBBELL

HUBBELL Power Systems

Type EVP Station Class Surge Arrester
Short Circuit Pressure Relief

INTRODUCTION: The short circuit pressure relief tests were performed per Section 8.18 of the IEEE C62.11-2012 standard. The short circuit testing was performed in the Powertech High Power Laboratory in Surrey, B.C. Canada on April 1, 2011.

SAMPLE PREPARATION: Samples were made in conformance to section 8.18.2.4, Design B. A 61 kV MCOV sample (longest single mechanical unit) was made for the rated current test of 63 kA_{rms}, and a 24.4 kV MCOV sample was made for the 400-800 A_{rms} low current test. An internal fuse wire (per Note 2 of the standard) was used through the middle of both samples. This wire passed through drilled holes, 3.5 mm in size, within a half radius of the center of the internal valve elements.

TEST PROCEDURE: To achieve the high levels of fault current from a limited voltage source (5.6 kV), the samples were pre-faulted with the fuse wire, as described above. The fault was initiated with the fuse wire, followed by the application of the target fault current for each arrester.

TEST RESULTS: Test results are summarized in the table below.

Test Number			1	2
Arrester MCOV		kV_{rms}	61	24.4
Test Current	Actual RMS	kA_{rms}	62.3	0.6
	Eff. Claimable	**kA_{rms}**	**63**	**0.6**
	Peak	kA_{peak}	94.2	(Not measured)
	Duration	ms	243	1010
Heaviest part outside circle	Soft	g	864	0
	Hard	g	0	0
Duration of flames		s	0	0

CONCLUSION: High current passed the test at a 62.3 kA_{rms} rating. Assignment of 63 kA_{rms} rating is based on recognizing that the $I^2t=894x10^6$ A^2s achieved (due to a longer duration of 1010 ms) is more severe than the target of $I^2t=794x10^6$ A^2s. Missing the exact target current is not uncommon due to the unpredictability of the arc impedance, hence the increase in arc duration to help compensate for any test mishap in not meeting the target current exactly (i.e. hedging with an ultimately more severe short circuit event).

The 24.4 kV MCOV sample passed the low current short circuit test at 600 A_{rms} for 1 second.

IEEE Design Test Report
Report No. EU1588-H-13.1
Type EVP Station Class Arrester

Maximum Design Cantilever Load (MDCL) And Moisture Ingress Test

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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
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Saroni Brahma
Saroni Brahma
Design Engineer

Date: 1/10/2014

Type EVP Station Class Surge Arrester
MDCL and Moisture Ingress Test

INTRODUCTION: The maximum design cantilever load (MDCL) and moisture ingress test were performed per Section 8.22 of the IEEE C62.11-2012 standard.

SAMPLE PREPARATION: Sample was made in conformance to section 8.22.1 of the standard, using the longest EVP mechanical unit, 61 kV MCOV, in the form of a tripod base and a single bolt mount cap base (which also serves as a multi-unit joint and optional base for the purposes of this test).

TEST PROCEDURE: Initial electrical tests were performed, followed by terminal preconditioning to the amount of 25 ft*lbs for a duration of 30 s. The sample was mounted in a thermal cycling oven and load was applied at 10,000 in*lbs for the tripod base and 6,667 in*lbs for the cap base in the four principal directions as outlined in the procedure, while thermally cycling in each direction following the alternating temperature extremes from the standard. At each stage of this rotation, the total deflection and residual deflection were measured.

Within 24 hours of the thermal cycling the arrester was once again tested in all four principle directions for maximum deflection and residual deflection at ambient temperature.

Next the arrester was subjected to the 42 hour water immersion boiling portion of the test. Within the 8 hour time frame after this test, with allowance of the sample to return to room temperature, the samples were once again electrically tested for comparison to the initial measurements.

TEST RESULTS: The evaluation requirements and actual measurements are compared in the tables below and demonstrate compliance to the standard.

Table #1: Electrical Comparisons – Initial vs. Final

Initial Measure (@ 22.6°C)	Final Measure (@ 24.1°C)	Requirement	Evaluation
7.48 W @ 100% MCOV	7.68 W (+ 2.7%)	< 20% increase	PASS
177.4 kV, 10 kA discharge	177.1 kV (- 0.2%)*	< 5% change	PASS
(Oscillograms of V and I)	(Oscillograms)	No breakdown	PASS
4.1 pC PD @ 105% MCOV	3.4 pC*	< 10 pC	PASS

***Could not complete this portion within the 8 hour timeframe due to lab constraints

Table #2: Deflection during thermal testing

Angle of Load Applied [degrees]	Max Deflection at Rated Load [mm]	Permanent Deflection at Rated Load [mm]
0	45	2
180	46	3.5
270	43	1
90	43.5	2

Table #3: Deflection at ambient after thermal testing

Angle of Load Applied [degrees]	Max Deflection at Rated Load [mm]	Permanent Deflection at Rated Load [mm]
0	43.5	1
180	46	1
270	44	0.5
90	43.5	1

CONCLUSION: The comparison of electrical values before and after the test falls within the limits of the C62.11 standard and demonstrate strong seal integrity under extreme conditions. The deflection values recorded, in combination with the electrical values measured, demonstrate that the manufacturer's claimed mechanical requirements resulted in no permanent damage to the arrester.

IEEE Design Test Report
Report No. EU1588-H-14.1
Type EVP Station Class Arrester

Thermal Equivalency

This report summarizes the results of design tests made on the Type EVP Station Class arrester design. Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)."

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

Dennis Lenk
Principal Engineer

Saroni Brahma

Saroni Brahma
Design Engineer

Date: 1/10/2014

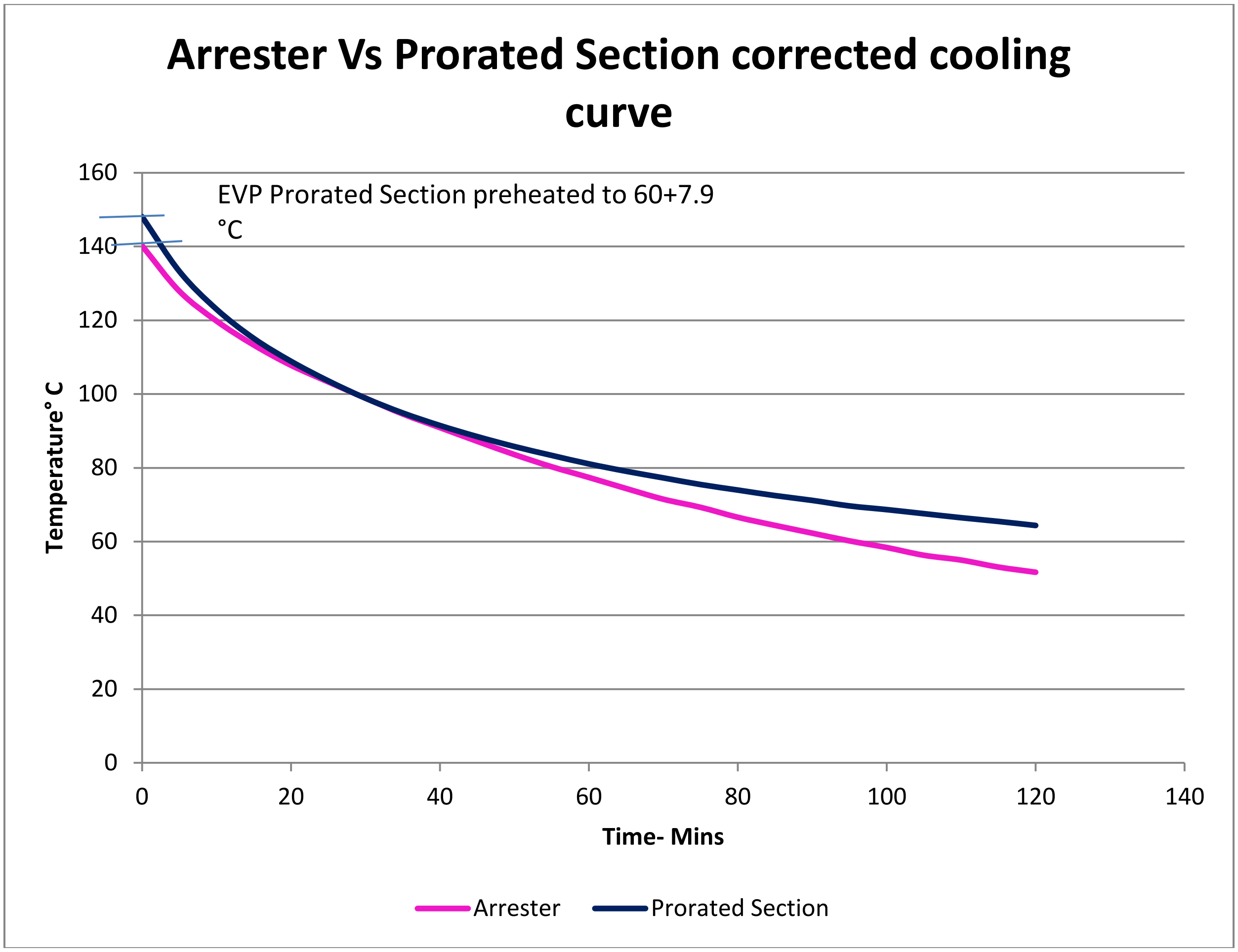
Type EVP Station Class Surge Arrester
Thermal Equivalency

INTRODUCTION: The polymer housing accelerated aging tests were performed per Section 7.2.2.3 of the IEEE C62.11-2012 standard.

PURPOSE: The purpose of this test is to verify that the thermal cooling curve for the Type EVP prorated section, when internally heated, will cool slower than that of a full size EVP arrester unit.

PROCEDURE: The full size arrester and the prorated section were heated up by applying a temporary overvoltage to the test samples. The test procedure is defined in Section 7.2.2.3 of IEEE C62.11-2005 Standard. The full size arrester unit (72kV rated) was instrumented with (1) internal thermocouple located in the middle of the MOV disc stack. The temperature of the arrester thermocouple was monitored at 5 minute intervals to develop the arrester unit cooling curve. The prorated section was instrumented with a single thermocouple and its cooling rated was also monitored at 5 minute intervals. The cooling rate during the 1st 15 minutes was slower for the EVP section than the arrester. To assure thermal equivalency, as allowed by the standard, the starting temperature of the section cooling curve was raised from the targeted 140 ºC point (for the arrester) to 147.7 ºC for the prorated section.

SUMMARY: The following cooling curve confirms that the cooling rate of the EVP prorated section is slower than that of the full size EVP arrester unit, confirming the thermal equivalency of the prorated section to the full size arrester.


Arrester Vs Prorated Section corrected cooling curve
EVP Prorated Section preheated to 60+7.9 °C
Temperature° C
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Time- Mins
Arrester
Prorated Section