EU1590-H-00.1

IEC Type Test Report
Report No. EU1590-H-00.2
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

S. A. Senthil Kumar (signature) — Michael G. Comber (signature)

Senthil S. A. Kumar
Product Design Engineer
Date: 6/17/2011

M.G. Comber
Manager, Engineering
Date: 6/17/2011

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

Report No.	Description	Clause	Issue date
EU1590-H-01	Insulation Withstand Test on Arrester Housing	8.2.6, 8.2.7, 8.2.8	June 17, 2011
EU1590-H-02	Residual Voltage	8.3.1, 8.3.2, 8.3.3	June 17, 2011
EU1590-H-03	Long Duration Current Withstand	8.4	June 17, 2011
EU1590-H-04	Accelerated Aging Procedure	8.5.2	June 17, 2011
EU1590-H-05	Heat Dissipation Behavior of Test Section	8.5.3	June 17, 2011
EU1590-H-06	Switching Surge Operating Duty	8.5.4	June 17, 2011
EU1590-H-07.1	Short Circuit	8.7	September 11, 2014
EU1590-H-08	Internal Partial Discharge	8.8	June 17, 2011
EU1590-H-09	Bending Moment	8.9	June 17, 2011
EU1590-H-10	Environmental	8.10	June 17, 2011
EU1590-H-11	Seal Leak Rate	8.11	June 17, 2011
EU1590-H-12	RIV	8.12	June 17, 2011
EU1590-H-13	Power Frequency Voltage Versus Time	Annex D	June 17, 2011
EU1590-H-14	Artificial Pollution	Annex F	June 17, 2011

IEC Type Test Report
Report No. EU1590-H-01
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Insulation Withstand Test on Arrester Housing

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

S. A. Senthil Kumar

Senthil S. A. Kumar
Product Design Engineer
Date: 6/17/2011

Michael G. Comber

M.G. Comber
Manager, Engineering
Date: 6/17/2011

IEC TYPE TEST REPORT
Insulation Withstand Test on Arrester Housing

TESTS PERFORMED:
Insulation withstand tests were made on arrester units with internal components removed. Tests were conducted according to the procedures of Clauses 8.2.6, 8.2.7 and 8.2.8 of IEC 60099-4, which stipulate that the external insulation withstand of the arrester housing shall conform to the following:

- Lightning impulse withstand voltage (LIWV) in dry conditions shall not be less than the lightning impulse protective level (LIPL) of the arrester unit multiplied by 1.3.
- Switching impulse withstand voltage (SIWV) in wet conditions shall not be less than the switching impulse protective level (SIPL) of the arrester unit multiplied by 1.25.
- Power frequency withstand voltage (PFWV) peak value in wet conditions shall not be less than the switching impulse protective level (SIPL) of the arrester unit multiplied by 1.06 for a duration of 1 min.

RESULTS:

The MH3 series of arresters use five different housing lengths, all of the same individual weathershed geometry. The insulation withstand tests were performed on five samples, each constructed with a different length housing. Table 1 lists the principal characteristics of the samples together with the minimum required insulation withstand levels.

Table 1. Principal characteristics of test samples and minimum required withstand levels

		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Overall length	mm	663	826	978	1143	1308
Creep	mm	1116	1905	2540	3207	3874
Dry Arc Distance	mm	445	616	768	940	1099
Max U_r for unit	kVrms	60	81	99	120	144
LIPL	kV	151	205	250	302	362
SIPL	kV	125	169	207	249	298
Min. required LIWV	kV	197	267	325	393	471
Min. required SIWV	kV	157	212	259	312	373
Min. required PFWV	kVpk	133	180	220	264	316

Lightning impulse
The lightning impulse test was performed under dry conditions by applying 15 positive and 15 negative full-wave lightning-impulse voltages to the test sample. The impulse voltages had a virtual front time of 1.2 µs (±30%) and a virtual time to half value of 50 µs (±20%). The test sample withstood all impulses without disruptive discharge. The withstand voltages obtained were corrected to standard atmospheric conditions in accordance with IEC 60060-1.

Switching impulse
The switching impulse test was performed under wet conditions by applying 15 positive and 15 negative full-wave switching-impulse voltages to the test sample. The precipitation conditions and resistivity of the water were in accordance with the requirements of IEC 60060-1. The impulse voltages had a time to crest value of 250 µs (±20%) and a time to half value of 2500 µs (±60%). The test sample withstood all impulses without disruptive discharge. The withstand voltages obtained were corrected to standard atmospheric conditions in accordance with IEC 60060-1.

Power frequency
The power frequency test was performed under wet conditions by applying a 60 Hz voltage for a duration of 1 min. The precipitation conditions and resistivity of the water were in accordance with the requirements of IEC 60060-1. The test sample withstood the applied voltage without disruptive discharge.

Tests were successfully performed at levels that exceeded the minimum levels indicated above. Results are summarized in Tables 1-3.

Table 1. Measured and corrected withstand LIWS values

Test Sample	Uncorrected LIWS	Atmospheric conditions			Correction factors		Corrected LIWS
		Ambient temperature	Air pressure	Absolute humidity	Air density	Humidity	
	kV pk	^{o}C	kPa	gm^{-3}	k_1	k_2	kV pk
Unit 1	249	20.9	97.7	3.24	0.961	0.935	276
Unit 2	320	20.9	97.7	3.24	0.961	0.924	360
Unit 3	392	20.9	97.7	3.24	0.961	0.924	441
Unit 4	462	21.2	97.7	3.30	0.962	0.944	509
Unit 5	548	21.2	97.7	3.30	0.962	0.944	603

Table 2. Measured and corrected withstand wet SIWS values

Test Sample	Uncorrected SIWS	Atmospheric conditions			Correction factors		Corrected SIWS
		Ambient temperature	Air pressure	Absolute humidity	Air density	Humidity	
	kV pk	^oC	kPa	gm^{-3}	k_1	k_2	kV pk
Unit 1	209	20.9	97.7	2.48	0.950	1.000	220
Unit 2	285	20.9	97.7	2.48	0.950	1.000	300
Unit 3	382	20.9	97.7	2.48	0.950	1.000	402
Unit 4	450	21.2	97.7	5.10	0.961	1.000	468
Unit 5	515	21.2	97.7	5.10	0.965	1.000	532

Table 3. Measured and corrected withstand wet PFWS values

Test Sample	Uncorrected PFWS	Atmospheric conditions			Correction factors		Corrected PFWS
		Ambient temperature	Air pressure	Absolute humidity	Air density	Humidity	
	kV pk	^oC	kPa	gm^{-3}	k_1	k_2	kV pk
Unit 1	151	20.9	96.5	2.47	0.979	1.000	154
Unit 2	220	20.9	96.5	2.47	0.980	1.000	225
Unit 3	295	20.9	96.5	2.47	0.979	1.000	301
Unit 4	410	21.2	97.8	5.10	0.985	1.000	416
Unit 5	480	21.2	97.8	5.10	0.985	1.000	488

IEC Type Test Report
Report No. EU1590-H-02
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Residual Voltage

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar	M.G. Comber
Product Design Engineer	Manager, Engineering
Date: 6/17/2011	Date: 6/17/2011

IEC TYPE TEST REPORT
Residual Voltage

TESTS PERFORMED:
Residual voltage measurements were made on three single resistor elements. Tests were conducted in accordance with clause 10.8.3 of IEC 60099-4, to determine steep current impulse residual voltages at 10 kA, lightning impulse residual voltages at 5 kA, 10 kA and 20 kA, and switching impulse residual voltages at 0.25 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

Test Wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	µs	kV	p.u.	number
Steep current	10	1/2	14.583	1.090	34
Lightning impulse	5	8/20	12.471	0.932	7
	10		13.385	1.000	10
	20		14.452	1.080	13
Switching impulse	0.25	43/91	10.040	0.777	19
	1	40/86	11.050	0.826	25

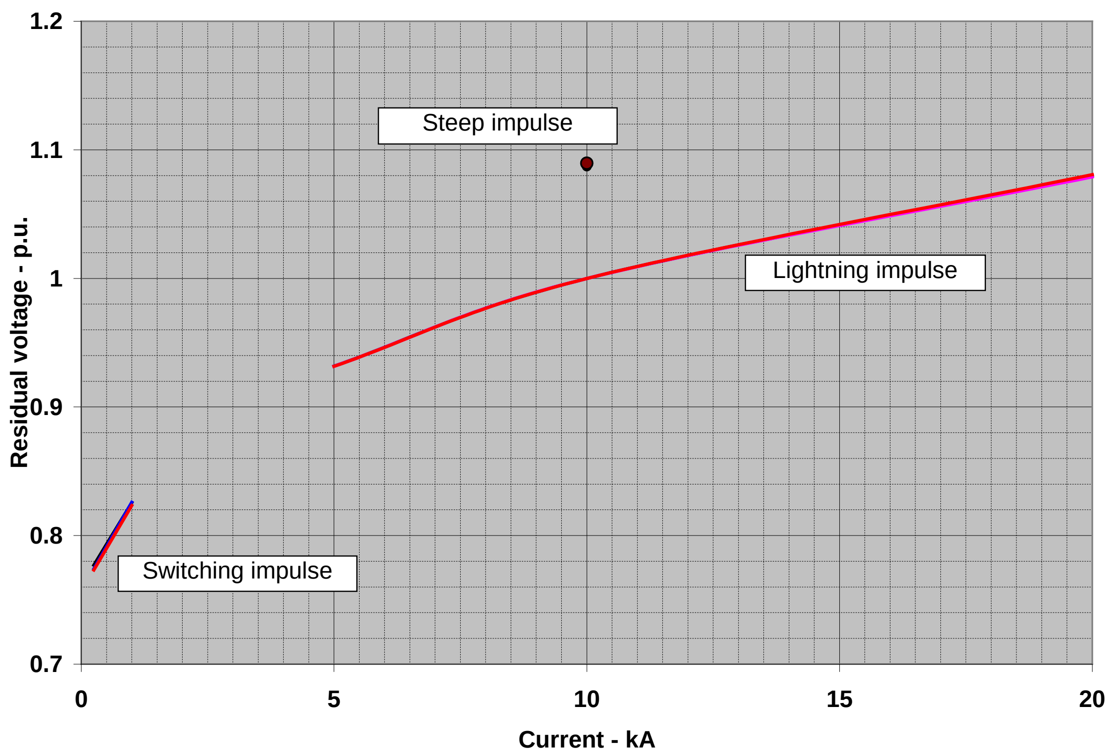
Table 2. Measurements made on test sample 2

Test wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	µs	kV	p.u.	number
Steep current	10	1/2	14.545	1.087	35
Lightning impulse	5	8/20	12.465	0.932	8
	10		13.380	1.000	11
	20		14.436	1.079	14
Switching impulse	0.25	43/91	10.358	0.774	20
	1	40/86	11.050	0.826	26

Table 3. Measurements made on test sample 3

Test wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	µs	kV	p.u.	number
Steep current	10	1/2	14.596	1.090	36
Lightning impulse	5	8/20	12.479	0.932	9
	10		13.396	1.000	12
	20		14.478	1.081	15
Switching impulse	0.25	43/91	10.358	0.773	21
	1	40/86	11.029	0.823	27

The results 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 MH3 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:

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

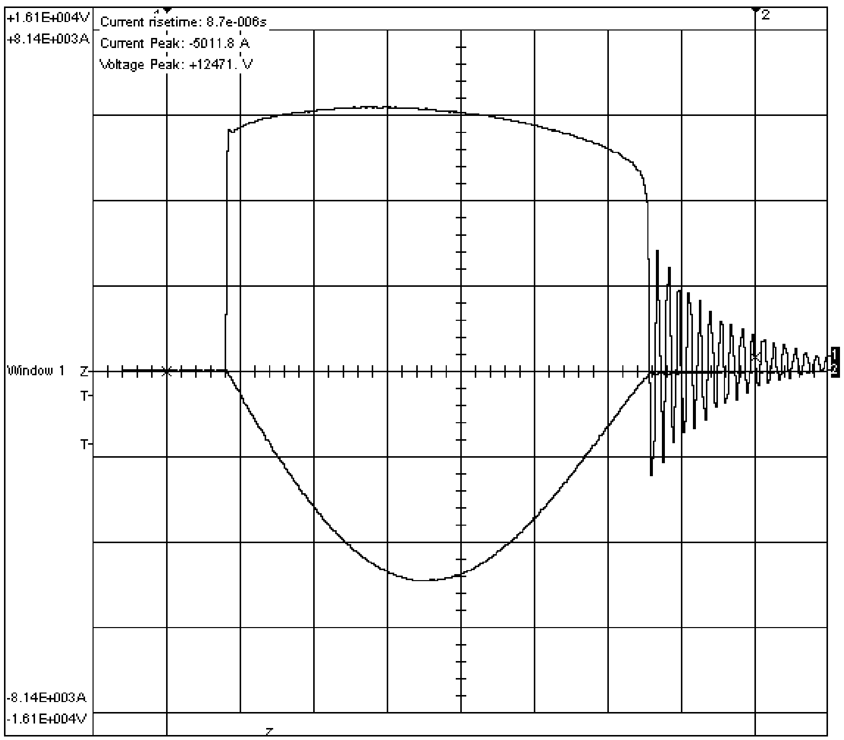
where
L' is the inductivity per unit length (= 1 µH/m)
h is the length of the arrester (excluding the resistors since resistor inductance is already included in the test measurements)
I_n is the nominal discharge current (= 10 kA)
T_f is the front time of the steep current impulse (= 1µs)

Oscillograms

Oscillogram 7
Sample 1

Nicolet Accura100

Printed : 14:09 Thursday, July 20, 2006   Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s
Zoom Only	Memory:
5:1	2000

Cur2-GND: +712.08 V	Cur2-Cur1: +675.29 V
Cur2-TRIG: 26.4 µs	Cur2-Cur1: 32.02 µs

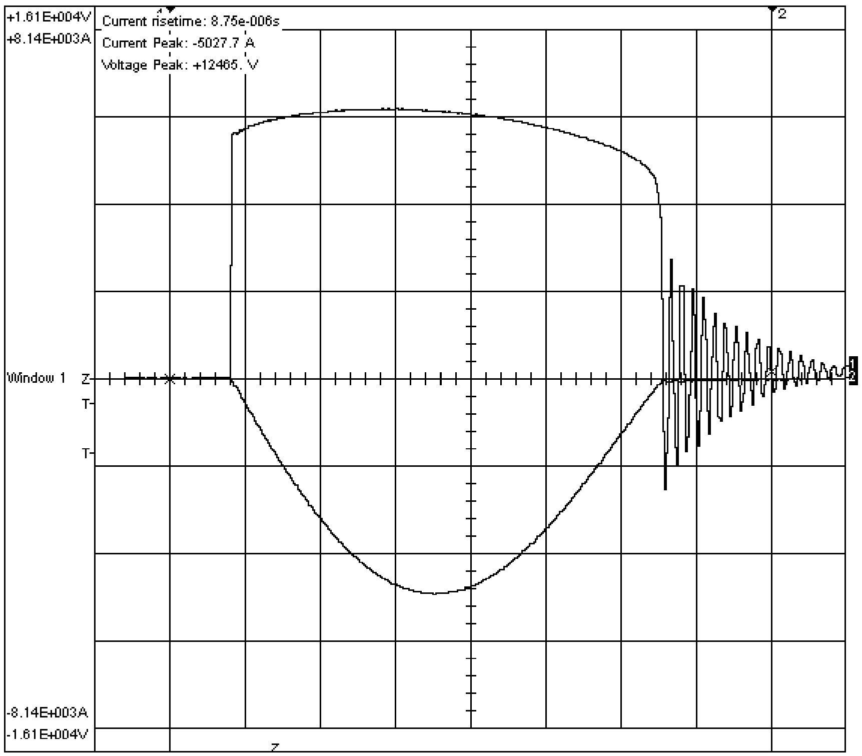
Trig: Edge Pretrigger: 4.0%	Bandwidth:
CH2 DC Neg UL: -570.08 A LL: -1700.1 A	4.4MHz

1 CH1 Zoom July 20, 2006 14:09:01	
+4036.0 V	4 µs
2 CH2 Zoom July 20, 2006 14:09:01	
+2036.0 A	4 µs

Oscillogram 8
Sample 2

Nicolet Accura100

Printed : 14:11 Thursday, July 20, 2006 Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s

Cur2-GND: +386.26 V	Cur2-Cur1: +367.86 V
Cur2-TRIG: 26.4 µs	Cur2-Cur1: 32.02 µs

Zoom Only	Memory:
5:1	2000

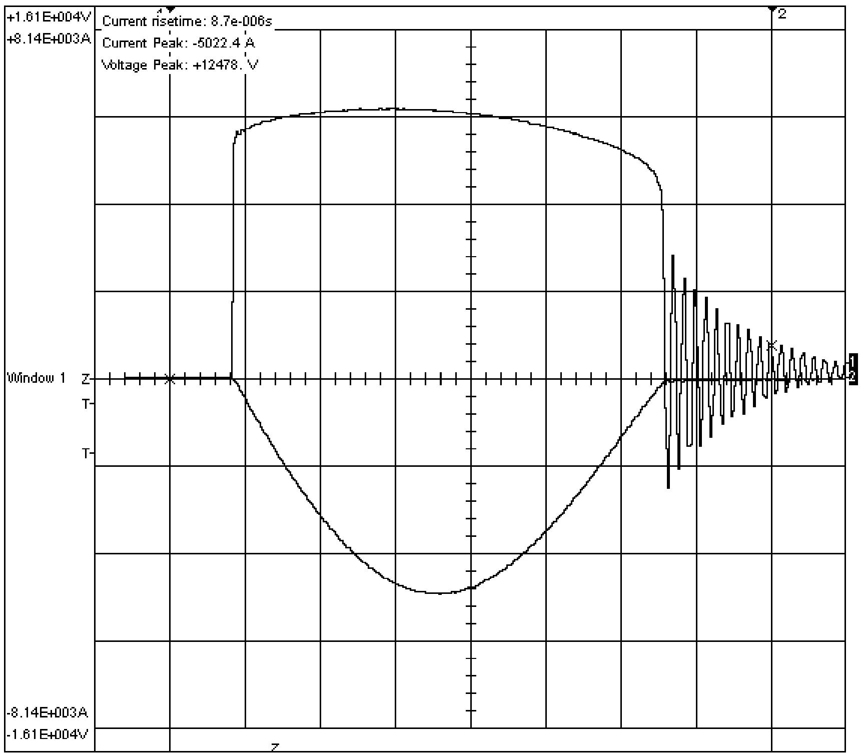
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -570.08 A LL: -1700.1 A	4.4MHz

1 CH1 Zoom July 20, 2006 14:10:51	
+4036.0 V	4 µs
2 CH2 Zoom July 20, 2006 14:10:51	
+2036.0 A	4 µs

Oscillogram 9
Sample 3

Nicolet Accura100

Printed : 14:19 Thursday, July 20, 2006 Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s

Cur2-GND: +1560.8 V	Cur2-Cur1: +1539.8 V
Cur2-TRIG: 26.4 µs	Cur2-Cur1: 32.02 µs

Zoom Only	Memory:
5:1	2000

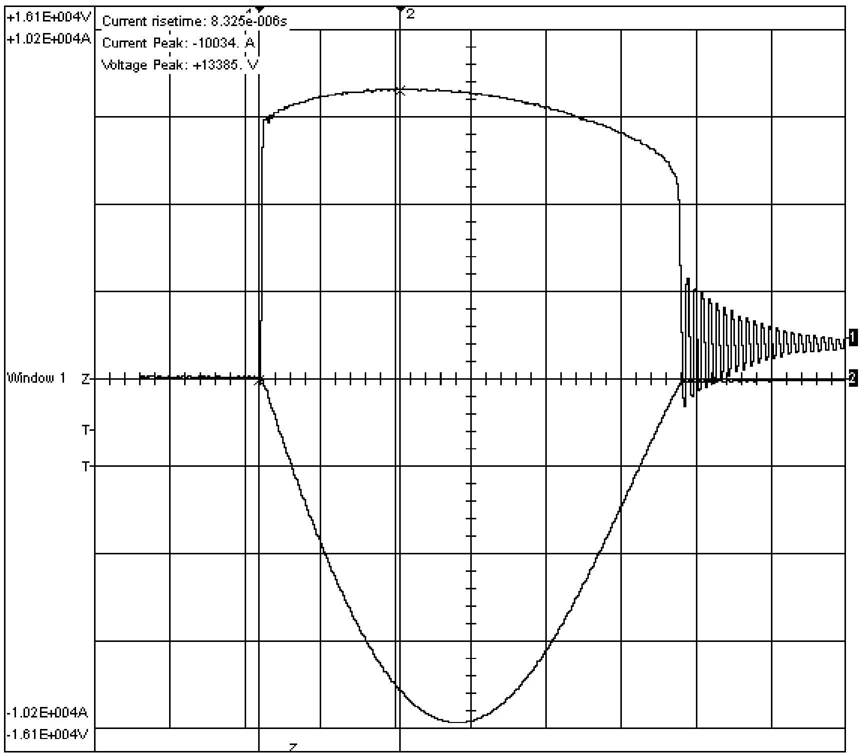
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -570.08 A LL: -1700.1 A	4.4MHz

1 CH1 Zoom July 20, 2006 14:18:57	
+4036.0 V	4 µs
2 CH2 Zoom July 20, 2006 14:18:57	
+2036.0 A	4 µs

Oscillogram 10
Sample 1

Nicolet Accura100

Printed : 15:41 Thursday, July 20, 2006   Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s

Cur2-GND: +13385. V	Cur2-Cur1: +13385. V
Cur2-TRIG: 5.7 μs	Cur2-Cur1: 7.54 μs

Zoom Only	Memory:
5:1	2000

Trig: Edge Pretrigger: 4.0 %
CH2 DC Neg UL: -1460.8 A LL: -2529.7 A

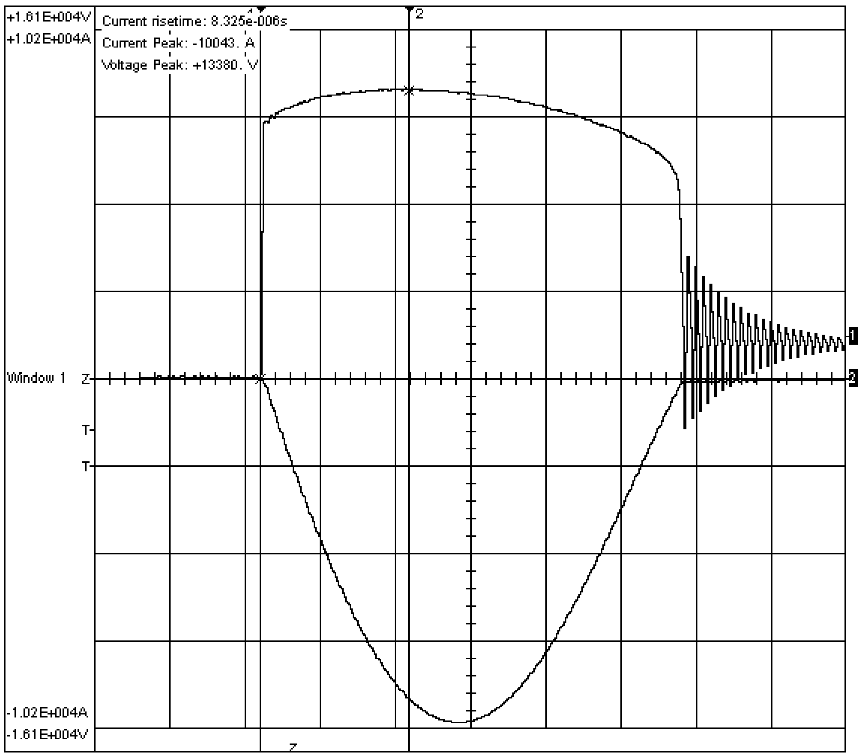
Bandwidth:
4.4MHz

1 CH1 Zoom July 20, 2006 15:39:29	
+4036.0 V	4 μs
2 CH2 Zoom July 20, 2006 15:39:29	
+2545.0 A	4 μs

Oscillogram 11
Sample 2

Nicolet Accura100

Printed : 15:50 Thursday, July 20, 2006 Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s

Cur2-GND: +13380. V	Cur2-Cur1: +13338. V
Cur2-TRIG: 6.2 µs	Cur2-Cur1: 7.96 µs

Zoom Only	Memory:
5:1	2000

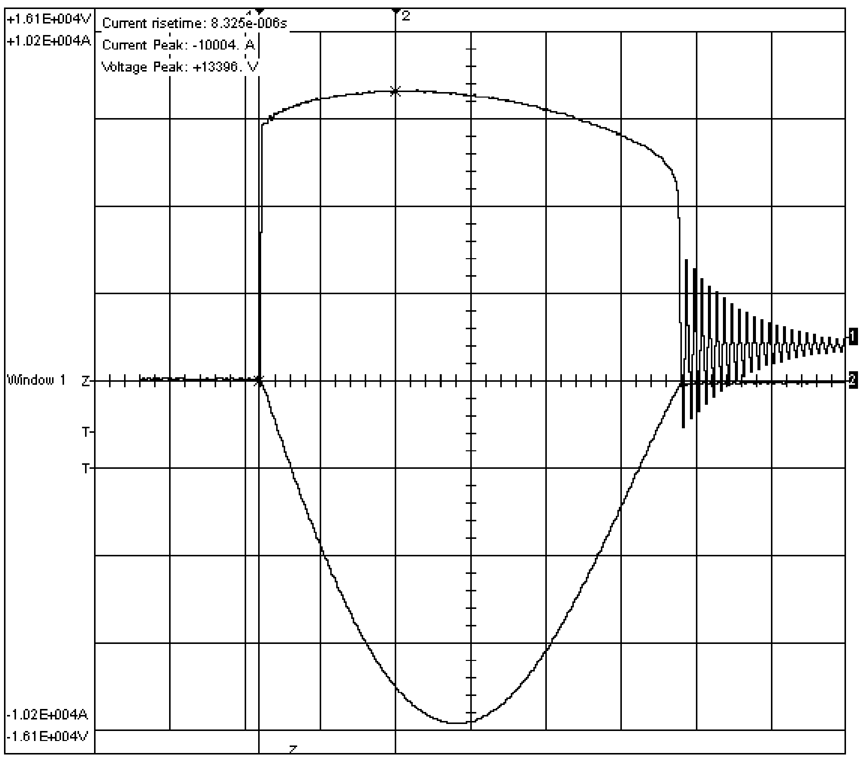
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -1460.8 A LL: -2529.7 A	4.4MHz

1 CH1 Zoom July 20, 2006 15:42:23	
+4036.0 V	4 µs
2 CH2 Zoom July 20, 2006 15:42:23	
+2545.0 A	4 µs

Oscillogram 12
Sample 3

Nicolet Accura100

Printed : 15:30 Thursday, July 20, 2006 Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:	Cur2-GND: +13396. V	Cur2-Cur1: +13332. V
Zoom : 20 ns/pt	10M smpl/s	Cur2-TRIG: 5.5 µs	Cur2-Cur1: 7.34 µs

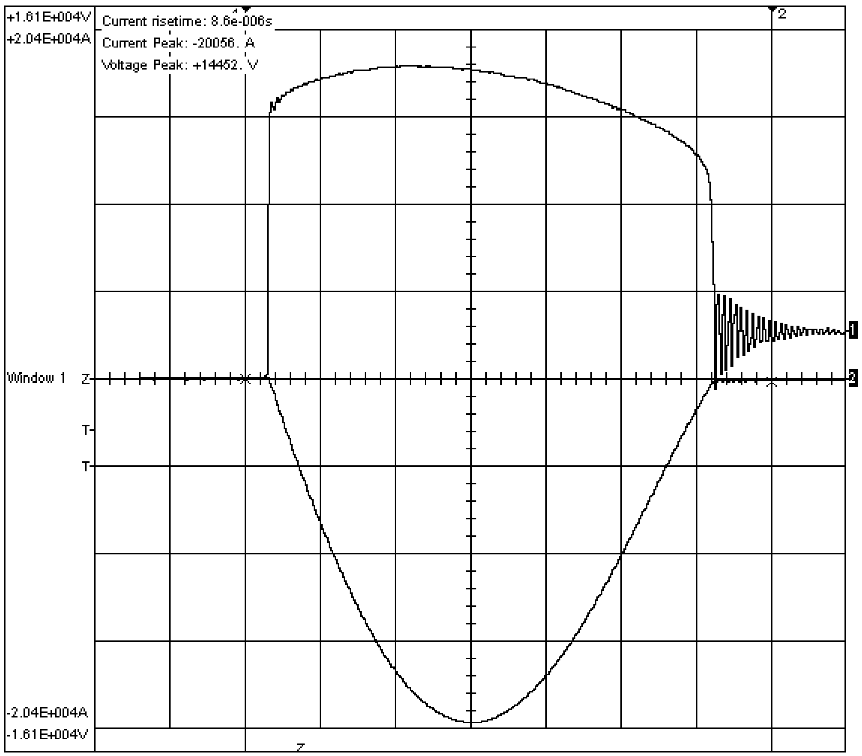
Zoom Only	Memory:	Trig: Edge Pretrigger: 4.0 %	Bandwidth:
5:1	2000	CH2 DC Neg UL: -1460.8 A LL: -2529.7 A	4.4MHz

1 CH1 Zoom July 20, 2006 15:27:04	
+4036.0 V	4 µs
2 CH2 Zoom July 20, 2006 15:27:04	
+2545.0 A	4 µs

Oscillogram 13
Sample 1

Nicolet Accura100

Printed : 08:58 Friday, July 21, 2006   Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s

Cur1-GND: +3.9766 A	Cur2-Cur1: -120.62 A
Cur1-TRIG: -2.9518 µs	Cur2-Cur1: 27.9918 µs

Zoom Only	Memory:
5:1	2000

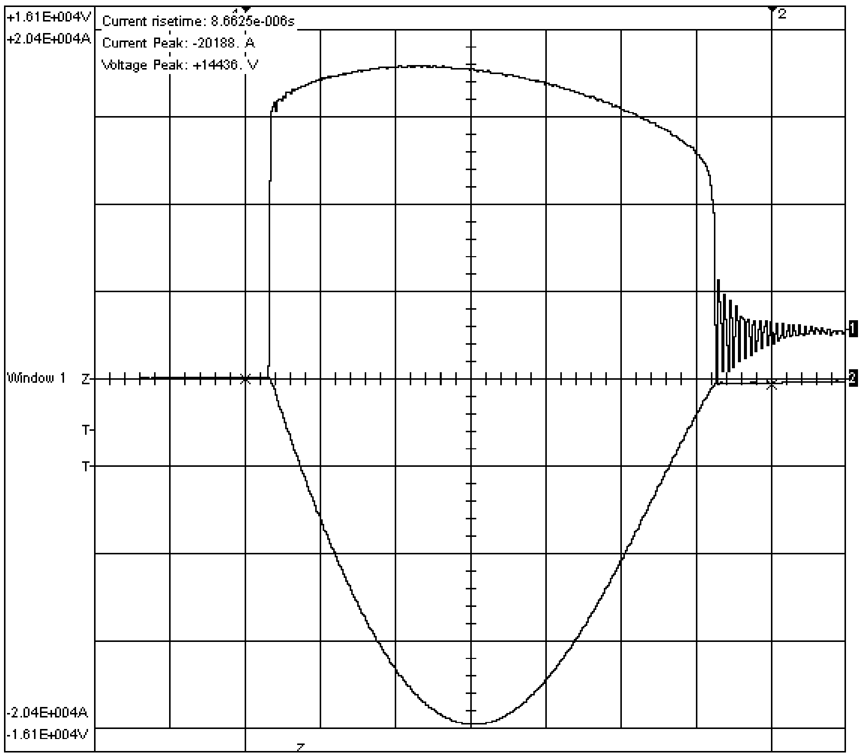
Trig: Edge Pretrigger: 4.2 %	Bandwidth:
CH2 DC Neg UL: -2921.7 A LL: -5059.5 A	4.4MHz

1 CH1 Zoom July 21, 2006 08:57:45	
+4036.0 V	4 µs
2 CH2 Zoom July 21, 2006 08:57:45	
+5090.0 A	4 µs

Oscillogram 14
Sample 2

Nicolet Accura100

Printed : 08:59 Friday, July 21, 2006   Serial Number : IDA0200151



1 CH1 Zoom July 21, 2006 08:59:07	
+4036.0 V	4 µs
2 CH2 Zoom July 21, 2006 08:59:07	
+5090.0 A	4 µs

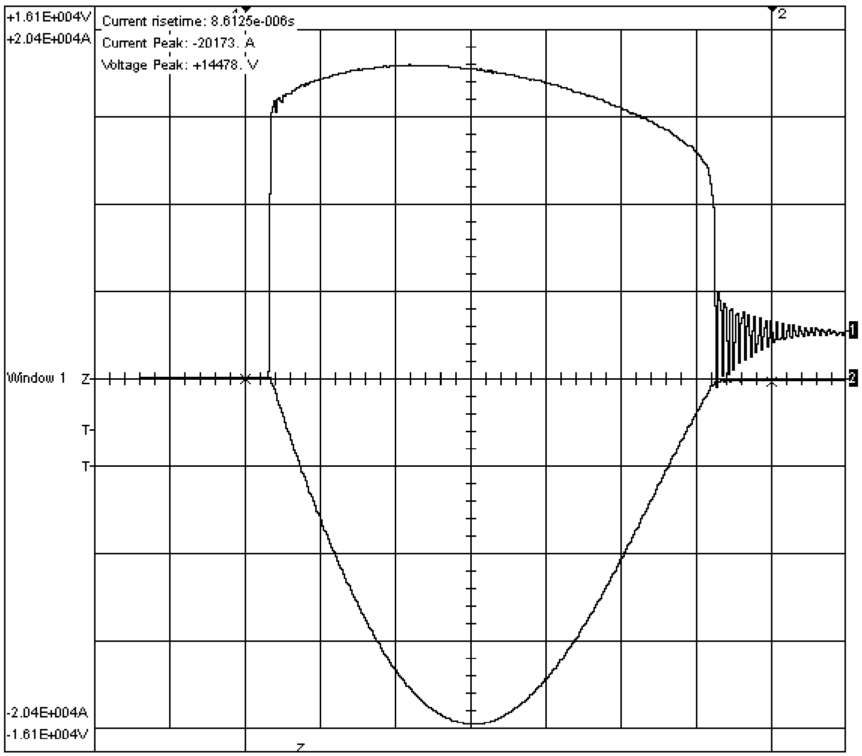
Main : 100 ns/pt	Sweep Time:	Cur1-GND: +9.2786 A	Cur2-Cur1: -271.73 A
Zoom : 20 ns/pt	10M smpl/s	Cur1-TRIG: -2.9518 µs	Cur2-Cur1: 27.9918 µs

Zoom Only	Memory:	Trig: Edge Pretrigger: 4.2 %	Bandwidth:
5:1	2000	CH2 DC Neg UL: -2921.7 A LL: -5059.5 A	4.4MHz

Oscillogram 15
Sample 3

Nicolet Accura100

Printed : 08:37 Friday, July 21, 2006   Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:	Cur1-GND: +10.604 A	Cur2-Cur1: -136.53 A
Zoom : 20 ns/pt	10M smpl/s	Cur1-TRIG: -2.9518 µs	Cur2-Cur1: 27.9918 µs

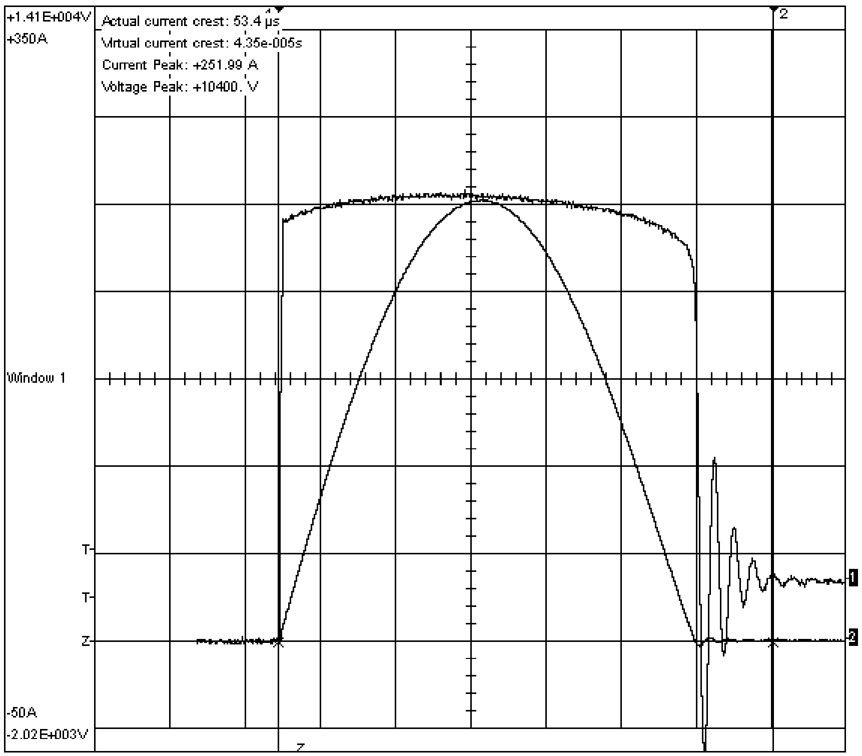
Zoom Only	Memory:	Trig: Edge Pretrigger: 4.2 %	Bandwidth:
5:1	2000	CH2 DC Neg UL: -2921.7 A LL: -5059.5 A	4.4MHz

1 CH1 Zoom July 21, 2006 08:36:28	
+4036.0 V	4 µs
2 CH2 Zoom July 21, 2006 08:36:28	
+5090.0 A	4 µs

Oscillogram 19
Sample 1

Nicolet Accura100

Printed : 13:07 Friday, July 21, 2006 Serial Number : IDA0200151



Main : 200 ns/pt	Sweep Time:
Zoom : 100 ns/pt	5M smpl/s

Cur1-GND: -0.091146 A	Cur2-Cur1: -0.41667 A
Cur1-TRIG: -6 µs	Cur2-Cur1: 131.6 µs

Zoom Only	Memory:
2:1	2000

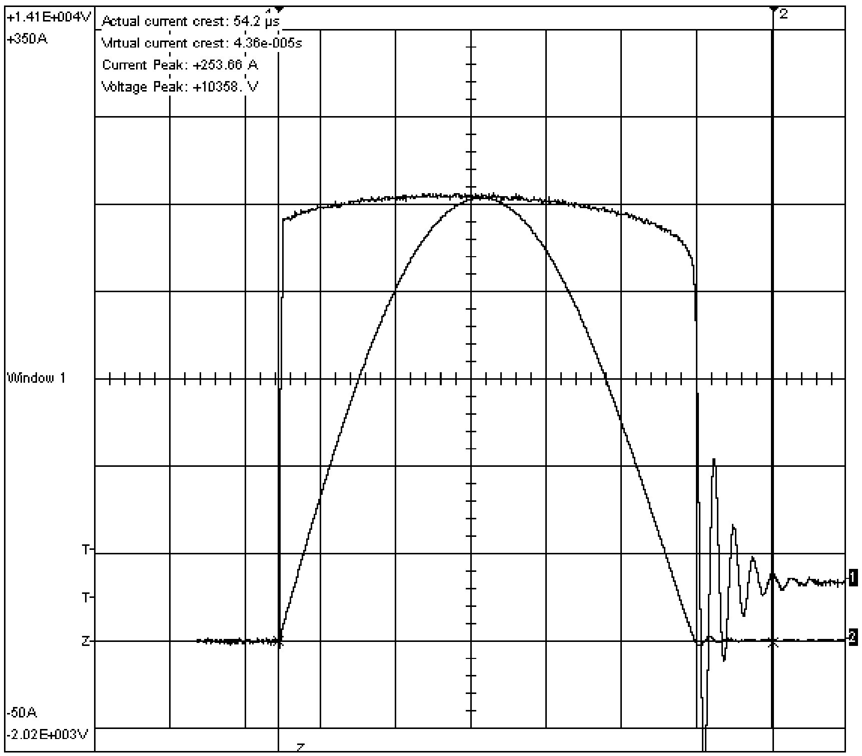
Trig: Edge Pretrigger: 7.0 %	Bandwidth:
CH2 DC Pos UL: +52.600 A LL: +25.000 A	25MHz

1 CH1 Zoom July 21, 2006 13:04:50	
+2018.0 V	20 µs
2 CH2 Zoom July 21, 2006 13:04:50	
+50.000 A	20 µs

Oscillogram 20
Sample 2

Nicolet Accura100

Printed : 13:09 Friday, July 21, 2006 Serial Number : IDA0200151



Main : 200 ns/pt	Sweep Time:
Zoom : 100 ns/pt	5M smpl/s

Cur1-GND: +0.11719 A	Cur2-Cur1: -0.83333 A
Cur1-TRIG: -6 µs	Cur2-Cur1: 131.6 µs

Zoom Only	Memory:
2:1	2000

Trig: Edge Pretrigger: 7.0 %	
CH2 DC Pos UL: +52.600 A	LL: +25.000 A

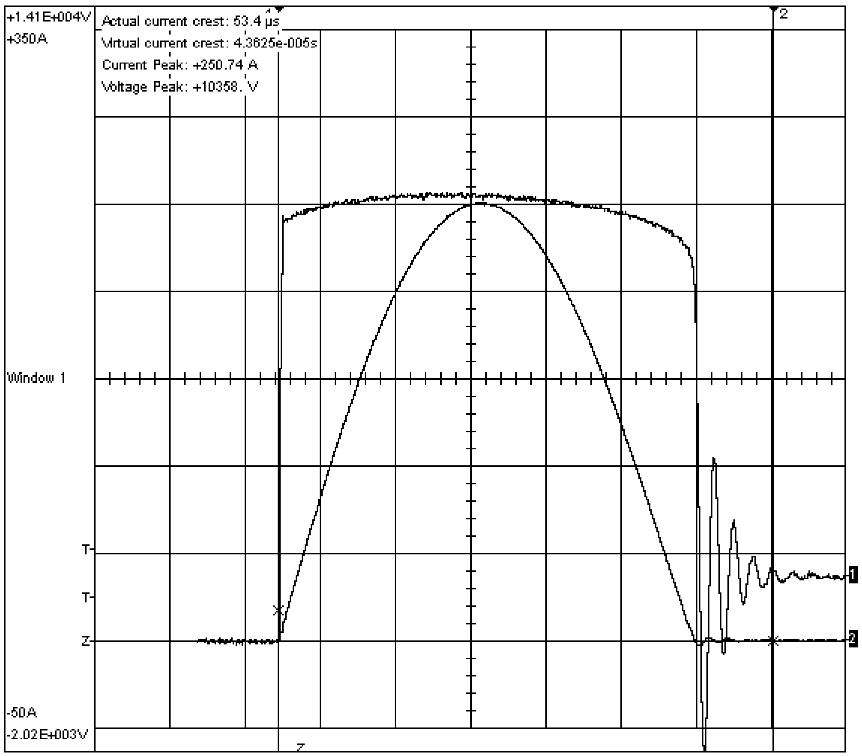
Bandwidth:
25MHz

1 CH1 Zoom July 21, 2006 13:08:43	
+2018.0 V	20 µs
2 CH2 Zoom July 21, 2006 13:08:43	
+50.000 A	20 µs

Oscillogram 21
Sample 3

Nicolet Accura100

Printed : 13:10 Friday, July 21, 2006 Serial Number : IDA0200151



Main : 200 ns/pt	Sweep Time:
Zoom : 100 ns/pt	5M smpl/s

Cur1-GND: +18.034 A	Cur2-Cur1: -17.917 A
Cur1-TRIG: -6 µs	Cur2-Cur1: 131.6 µs

Zoom Only	Memory:
2:1	2000

Trig: Edge Pretrigger: 7.0 %	
CH2 DC Pos UL: +52.600 A	LL: +25.000 A

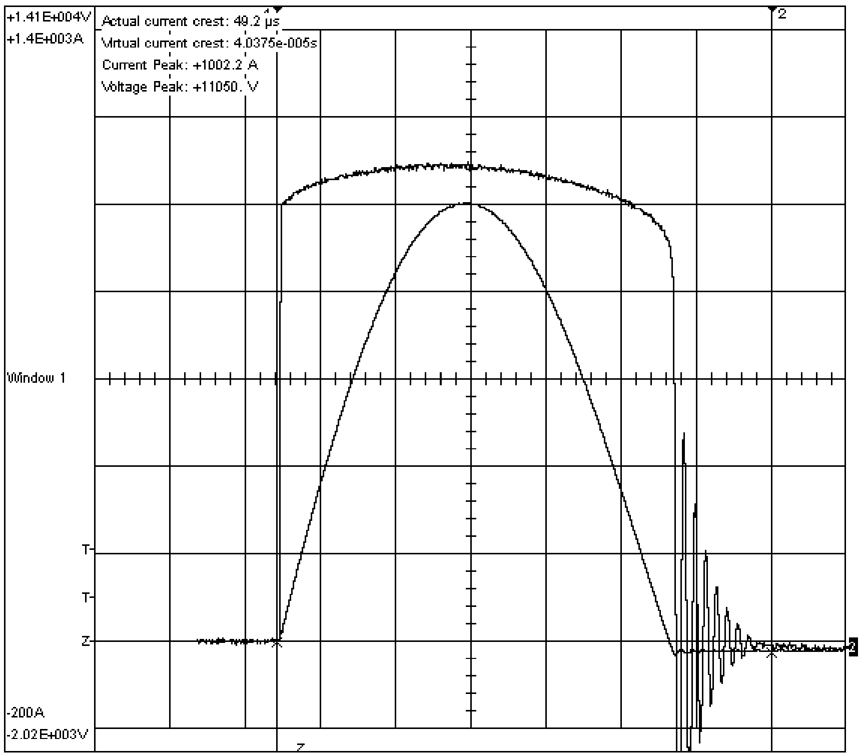
Bandwidth:
25MHz

1 CH1 Zoom July 21, 2006 13:10:32	
+2018.0 V	20 µs
2 CH2 Zoom July 21, 2006 13:10:32	
+50.000 A	20 µs

Oscillogram 25
Sample 1

Nicolet Accura100

Printed : 14:26 Friday, July 21, 2006 Serial Number : IDA0200151



1 CH1 Zoom July 21, 2006 14:25:38	
+2018.0 V	20 µs
2 CH2 Zoom July 21, 2006 14:25:38	
+200.00 A	20 µs

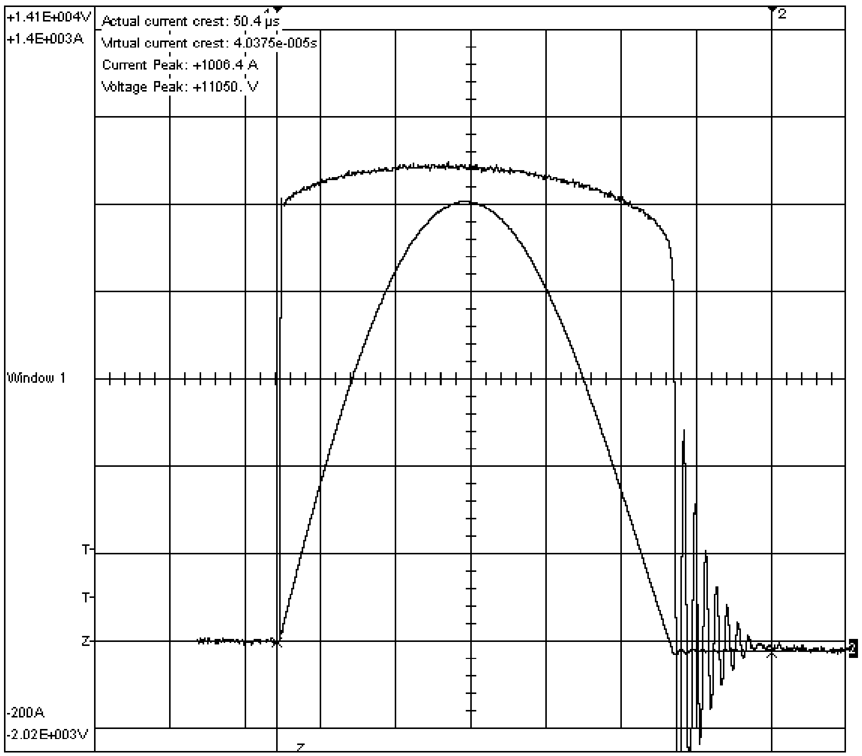
Main : 200 ns/pt	Sweep Time:	Cur1-GND: -1.9271 A	Cur2-Cur1: -23.333 A
Zoom : 100 ns/pt	5M smpl/s	Cur1-TRIG: -6.4 µs	Cur2-Cur1: 131.6 µs

Zoom Only	Memory:	Trig: Edge Pretrigger: 7.0 %	Bandwidth:
2:1	2000	CH2 DC Pos UL: +210.40 A LL: +100.00 A	25MHz

Oscillogram 26
Sample 2

Nicolet Accura100

Printed : 14:27 Friday, July 21, 2006   Serial Number : IDA0200151



1 CH1 Zoom July 21, 2006 14:27:37	
+2018.0 V	20 µs
2 CH2 Zoom July 21, 2006 14:27:37	
+200.00 A	20 µs

Main : 200 ns/pt   Sweep Time:
Zoom : 100 ns/pt   5M smpl/s

Cur1-GND: -1.0938 A   Cur2-Cur1: -23.333 A
Cur1-TRIG: -6.4 µs   Cur2-Cur1: 131.6 µs

Zoom Only   Memory:
2:1   2000

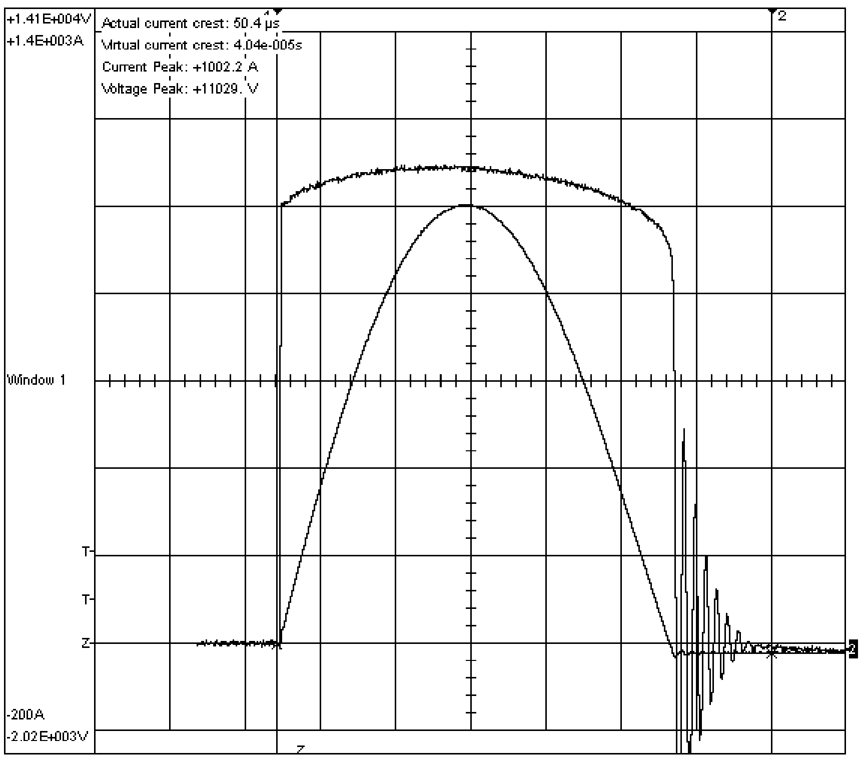
Trig: Edge   Pretrigger: 7.0 %
CH2 DC Pos   UL: +210.40 A   LL: +100.00 A

Bandwidth:
25MHz

Oscillogram 27
Sample 3

Nicolet Accura100

Printed : 14:29 Friday, July 21, 2006 Serial Number : IDA0200151



Main : 200 ns/pt	Sweep Time:
Zoom : 100 ns/pt	5M smpl/s

Cur1-GND: -1.0938 A	Cur2-Cur1: -21.667 A
Cur1-TRIG: -6.4 µs	Cur2-Cur1: 131.6 µs

Zoom Only	Memory:
2:1	2000

Trig: Edge Pretrigger: 7.0 %
CH2 DC Pos UL: +210.40 A LL: +100.00 A

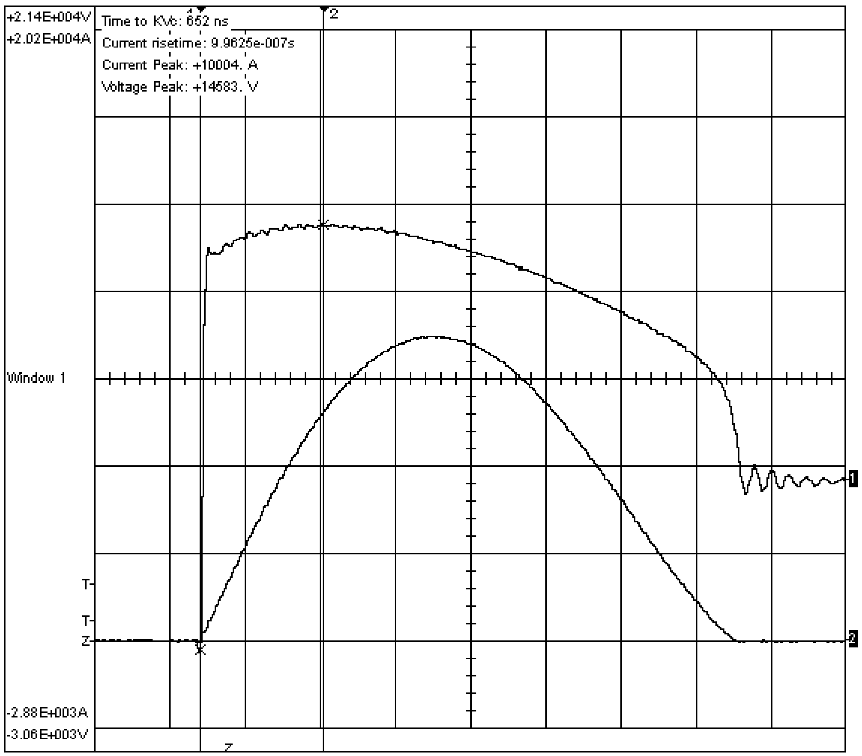
Bandwidth:
25MHz

1 CH1 Zoom July 21, 2006 14:28:55	
+2018.0 V	20 µs
2 CH2 Zoom July 21, 2006 14:28:55	
+200.00 A	20 µs

Oscillogram 34
Sample 1

Nicolet Accura100

Printed : 11:35 Monday, July 24, 2006   Serial Number : IDA0200151



Main : 10 ns/pt	Sweep Time:
Zoom : 2 ns/pt	100M smpl/s

Cur2-GND: +14578. V	Cur2-Cur1: +14882. V
Cur2-TRIG: 504 ns	Cur2-Cur1: 652 ns

Zoom Only	Memory:
5:1	2000

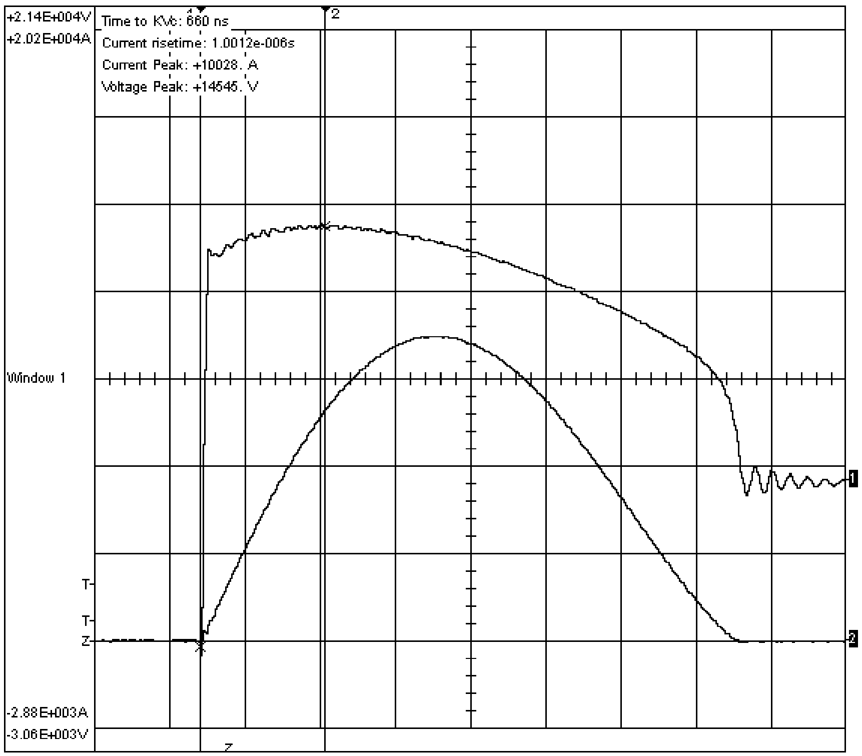
Trig: Edge Pretrigger: 10.4%	Bandwidth:
CH2 DC Pos UL: +1889.3 A LL: +679.68 A	25MHz

1 CH1 Zoom July 24, 2006 11:33:10	
+3058.3 V	400 ns
2 CH2 Zoom July 24, 2006 11:33:10	
+2880.0 A	400 ns

Oscillogram 35
Sample 2

Nicolet Accura100

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



Main : 10 ns/pt	Sweep Time:	Cur2-GND: +14532. V	Cur2-Cur1: +14687. V
Zoom : 2 ns/pt	100M smpl/s	Cur2-TRIG: 512 ns	Cur2-Cur1: 660 ns

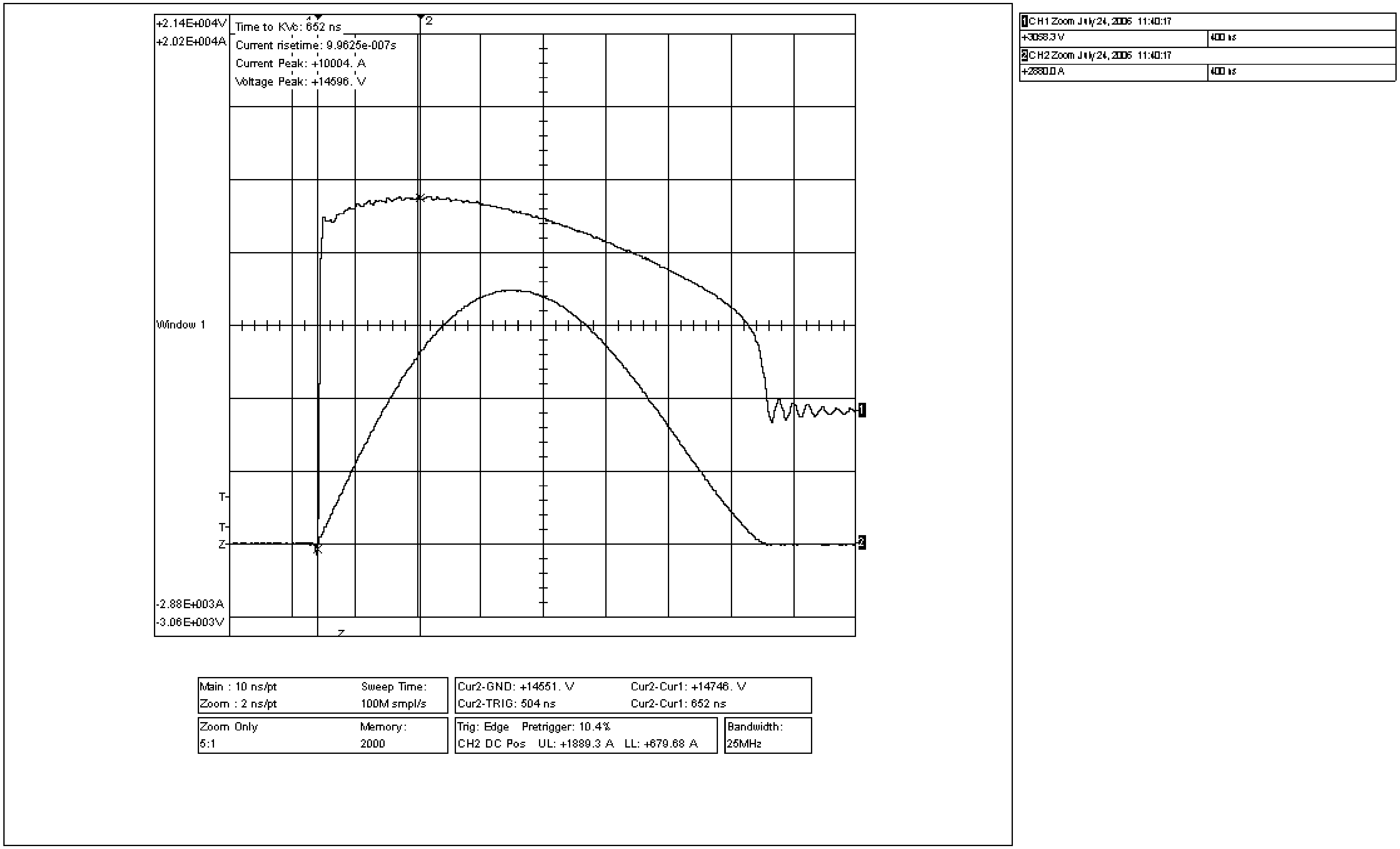
Zoom Only	Memory:	Trig: Edge Pretrigger: 10.4%	Bandwidth:
5:1	2000	CH2 DC Pos UL: +1889.3 A LL: +679.68 A	25MHz

1 CH1 Zoom July 24, 2006 11:37:37	
+3058.3 V	400 ns
2 CH2 Zoom July 24, 2006 11:37:37	
+2880.0 A	400 ns

Oscillogram 36
Sample 3

Nicolet Accura100

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



EU1590-H-03

IEC Type Test Report
Report No. EU1590-H-03
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Long Duration Current Impulse Withstand Tests

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar	M.G. Comber
Product Design Engineer	Manager, Engineering
Date: 6/17/2011	Date: 6/17/2011

IEC TYPE TEST REPORT
Long Duration Current Impulse Withstand Tests

TESTS PERFORMED:

Long duration current impulse withstand tests were performed on three test samples, each consisting of two resistors (56 mm diameter, 44 mm long) in series. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with clause 10.8.4 of IEC 60099-4. Prior to the administering of line discharges, measurements were made of the residual voltage and reference voltage on each test sample. The transmission line parameters conformed to the requirements for Line Discharge Class 3 in Table 5 of IEC 60099-4.

Table 1 lists the parameters of the test sections and the corresponding transmission line parameters used for the test. U_c for the MH3 series of arresters has been established as 0.795 times the lowest acceptable reference voltage in routine tests, and U_r has been established as 1.25 times U_c . This would normally be represented in the type test by assigning the test sample U_c equal to 0.795 x U_{ref} of the test sample, and test sample U_r at 1.25 times this value . However, in this particular test, U_c was set at a higher value than that used in the actual design (specifically, 0.81 x U_{ref}), thereby making the test more onerous. The minimum energy required for each line discharge for Class 3 arresters is determined from the following formula given in Clause 8.4.2 of IEC 60099-4

$$W = U_{res} \text{ x } (U_L - U_{res}) \text{ x } 1/Z \text{ x } T$$

where U_{res} is the switching impulse residual voltage at 250 A.

Table 1. Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Switching impulse residual voltage (kV) U_{res}	20.62	20.56	20.64
Initial Residual Voltage (kV) @ 10 kA, 8/20	26.67	26.67	26.65
Reference Current (mA) I_{ref}	9.5	9.5	9.5
Reference Voltage ($kV_c / \sqrt{2}$) V_{ref}	11.51	11.51	11.50
COV (kV rms) U_c	9.33	9.32	9.32
Rating (kV rms) U_r	11.66	11.65	11.65
Arrester Classification (kA)	10	10	10
Line Discharge Class	3	3	3
Virtual Duration of Peak (μs, 90-90%) - min	2 400	2 400	2 400
Surge Impedance (Ω) Z_g - max (1.3 U_r)	15.16	15.15	15.15
Charging Voltage (kV) U_L – min (2.8 U_r)	32.65	32.62	32.62
Energy required (kJ) - min	39.3	39.3	39.3

Each sample was subjected to 18 line discharges, administered in six groups of three discharges. Within each group of three discharges, the time interval between discharges was 50 to 60 seconds. The samples were allowed to cool to ambient temperature between groups of discharges.

RESULTS:

A short circuit test was performed on the generator to confirm that generator impedance and duration of the current discharge met the requirements listed in Table 1. The oscillogram of Figure 1 shows

Z_g = 13 221 V / 876.38 A = 15.086 Ω   Virtual Duration of Peak = 2 453 μs

Table 2 lists the current and voltage magnitudes and discharge energy measured on each of the 18 discharges on each of the three test samples. Figures 2, 3 and 4 show oscillograms of the first and eighteenth discharges for each of the three samples, respectively. Ambient air temperature at the time of the test was 22 °C.

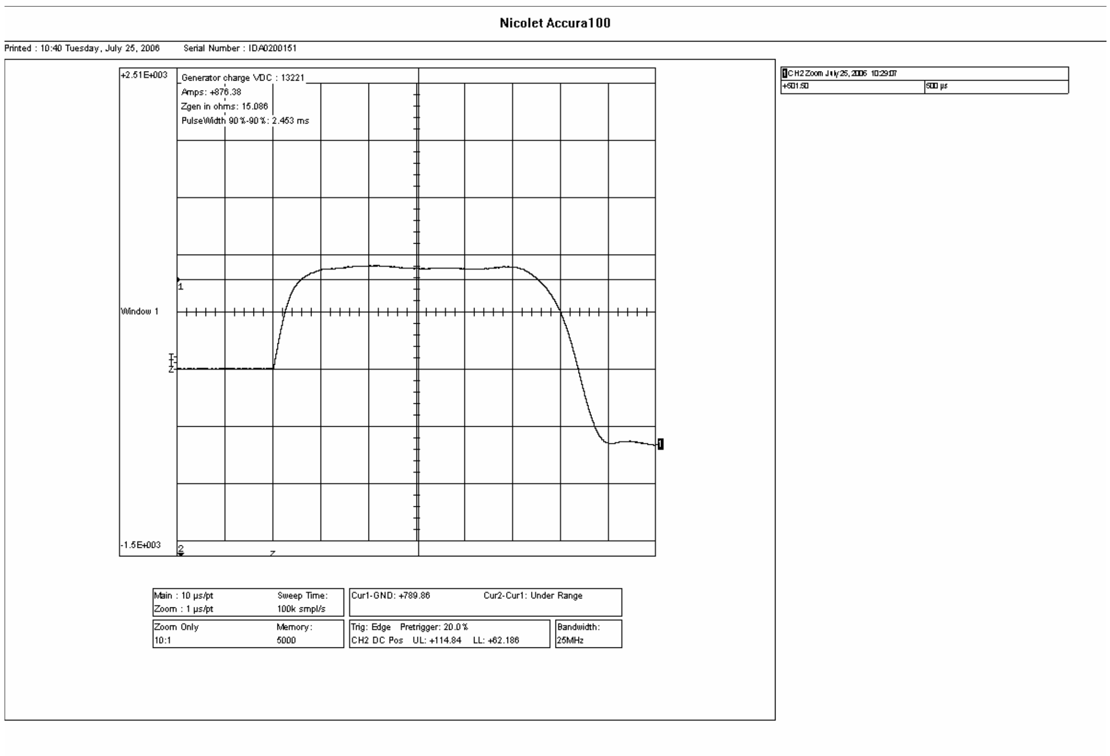


Figure 1. Oscillogram of discharge current for generator short circuit set up test

Table 2. Line Discharge Test Measurements

Impulse	Sample 1			Sample 2			Sample 3		
	I (A)	V (kV)	E (kJ)	I (A)	V (kV)	E (kJ)	I (A)	V (kV)	E (kJ)
1	711	22.18	45.0	765	21.45	46.7	763	21.43	47.1
2	738	21.83	45.9	747	21.78	46.4	742	21.88	46.3
3	717	22.16	45.3	721	22.14	45.7	721	22.22	45.7
4	772	21.51	47.2	774	21.47	47.2	767	21.51	47.0
5	738	21.83	45.9	751	21.85	46.5	740	21.91	46.2
6	744	21.89	46.5	717	22.20	45.7	719	22.28	45.5
7	763	21.51	47.0	763	21.49	46.8	761	21.53	46.9
8	742	21.93	46.1	736	21.87	46.1	738	21.93	46.0
9	719	22.26	45.5	717	22.16	45.4	717	22.24	45.4
10	717	22.42	45.4	772	21.45	46.9	759	21.53	46.7
11	740	21.89	46.1	736	21.89	46.0	740	21.88	46.0
12	717	22.20	45.5	715	22.20	45.5	719	231.88	45.2
13	763	21.51	46.9	763	21.47	46.9	761	21.53	46.8
14	738	21.93	46.0	736	21.91	46.1	736	21.89	45.9
15	717	22.24	45.4	715	22.24	45.5	717	22.28	45.4
16	779	21.56	47.8	770	21.47	47.2	764	21.56	47.0
17	752	21.97	46.9	745	21.85	46.5	745	21.95	46.3
18	724	22.31	46.1	722	22.18	45.8	714	22.24	45.6

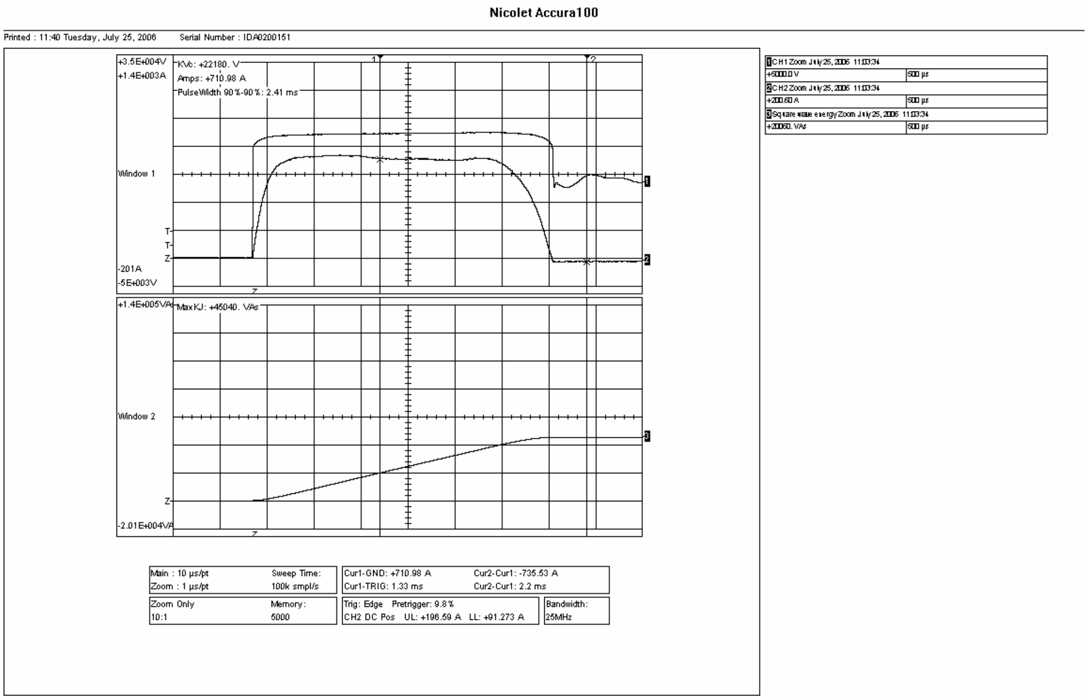
Subsequent to the completion of the transmission line discharges, the residual voltage at nominal discharge current was re-measured and compared to the initial values for each test sample. Results are summarized in Table 3. The maximum change of residual voltage of the three samples is less than the permissible change of 5 % defined by IEC 60099-4.

Table 3. Initial and final residual voltage measurements

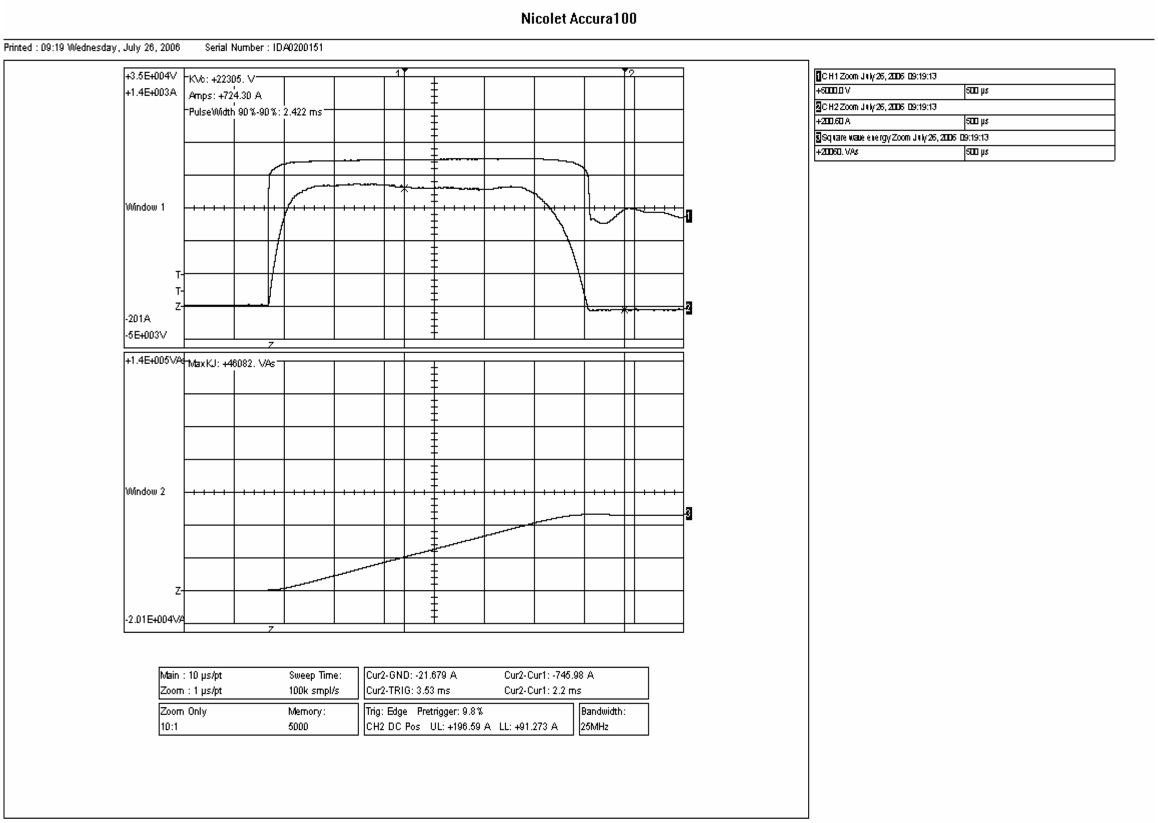
Sample	Residual voltage (kV)		Change
	Before	After	
1	26.67	26.65	- 0.08%
2	26.67	26.60	- 0.27%
3	26.65	26.65	0%

Disassembly of the test samples at the end of the electrical tests revealed no evidence of physical damage.

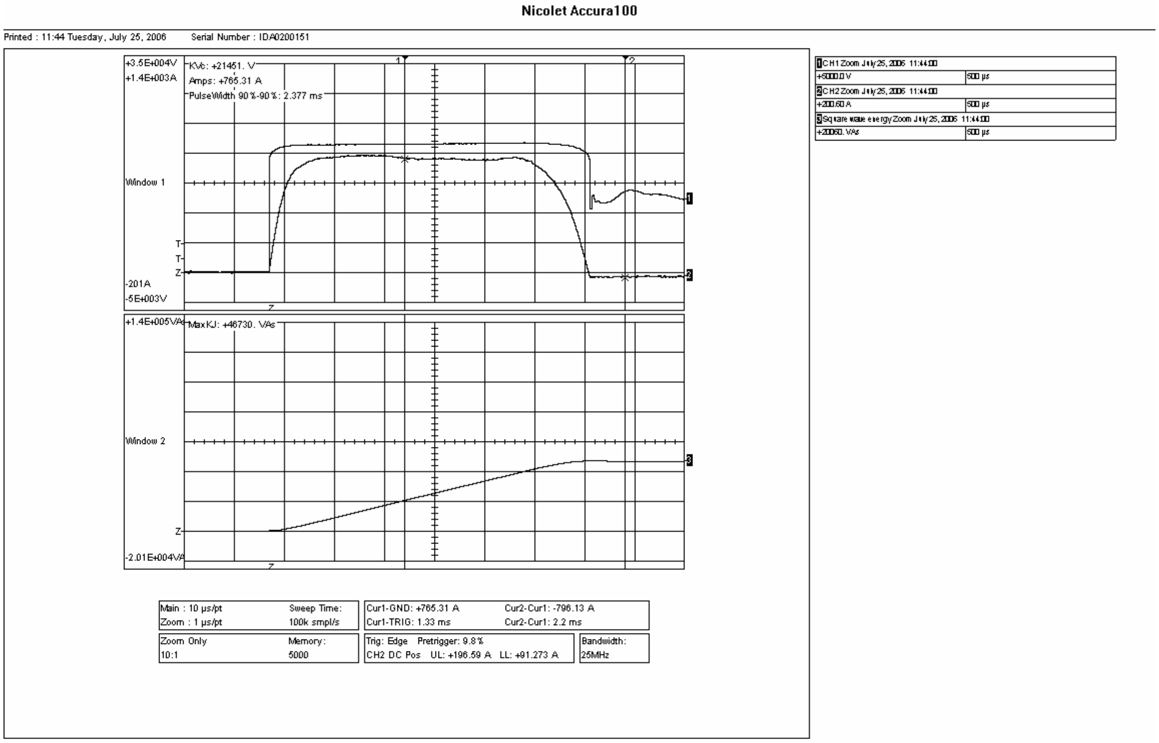
Sample 1, Discharge 1



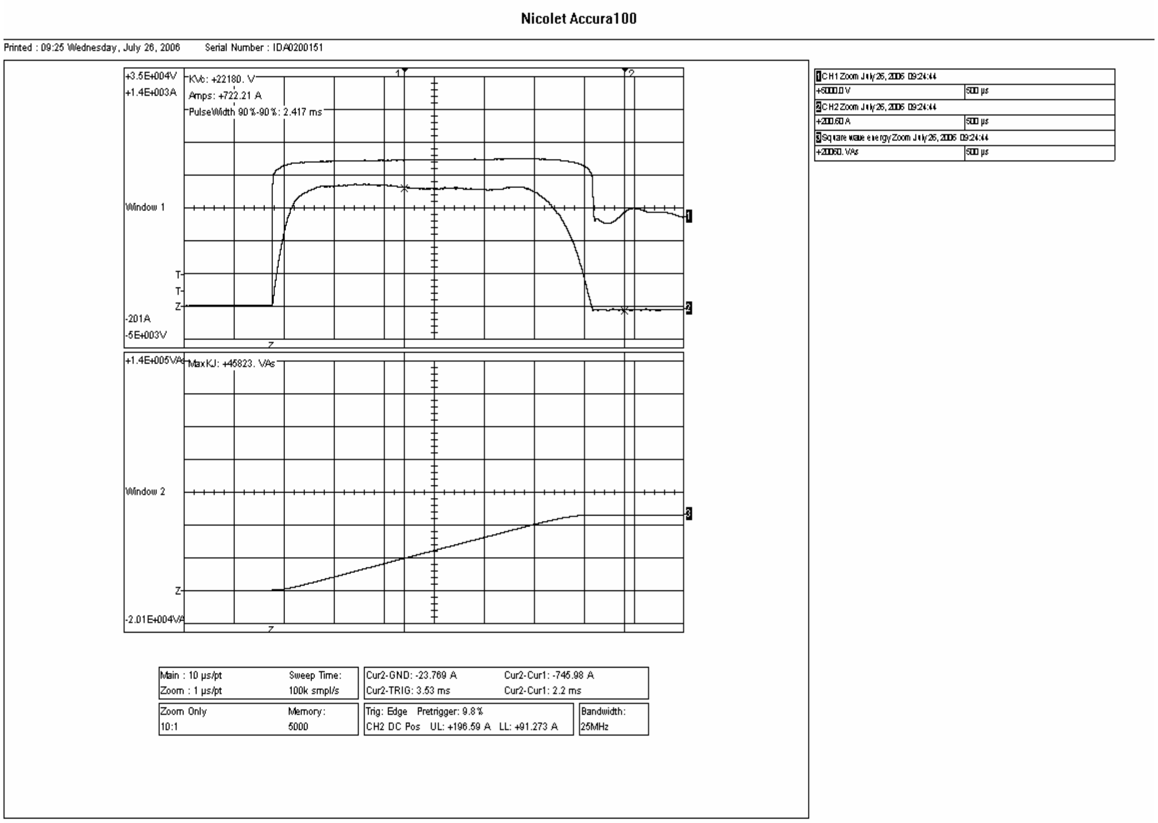
Sample 1, Discharge 18



Sample 2, Discharge 1



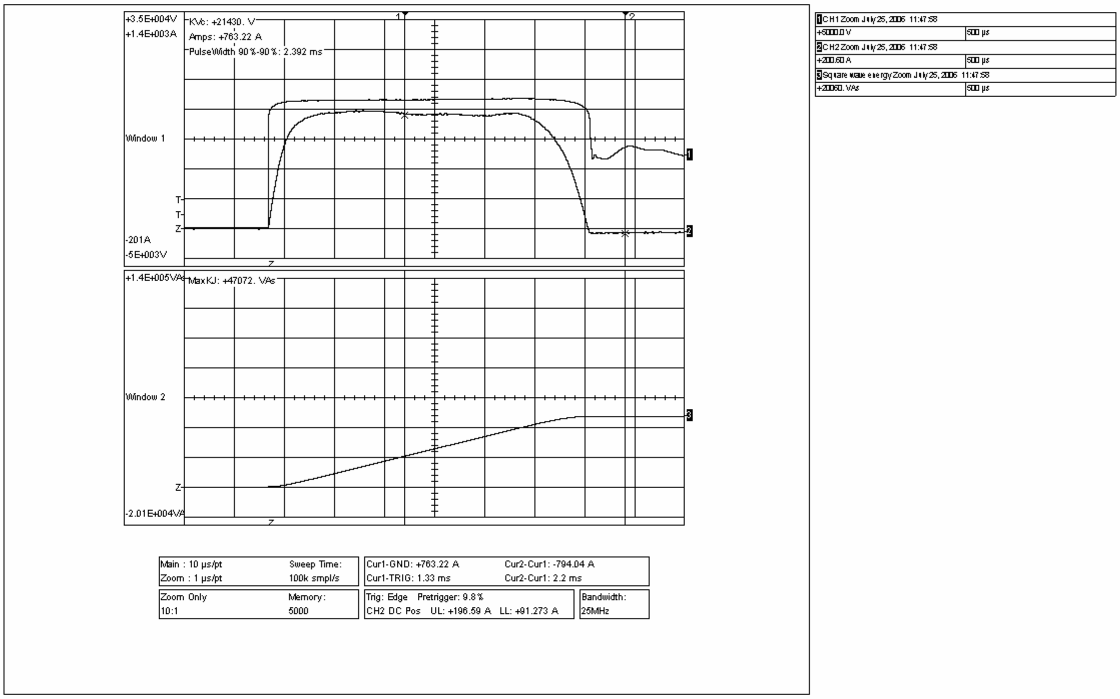
Sample 2, Discharge 18



Sample 3, Discharge 3

Nicolet Accura100

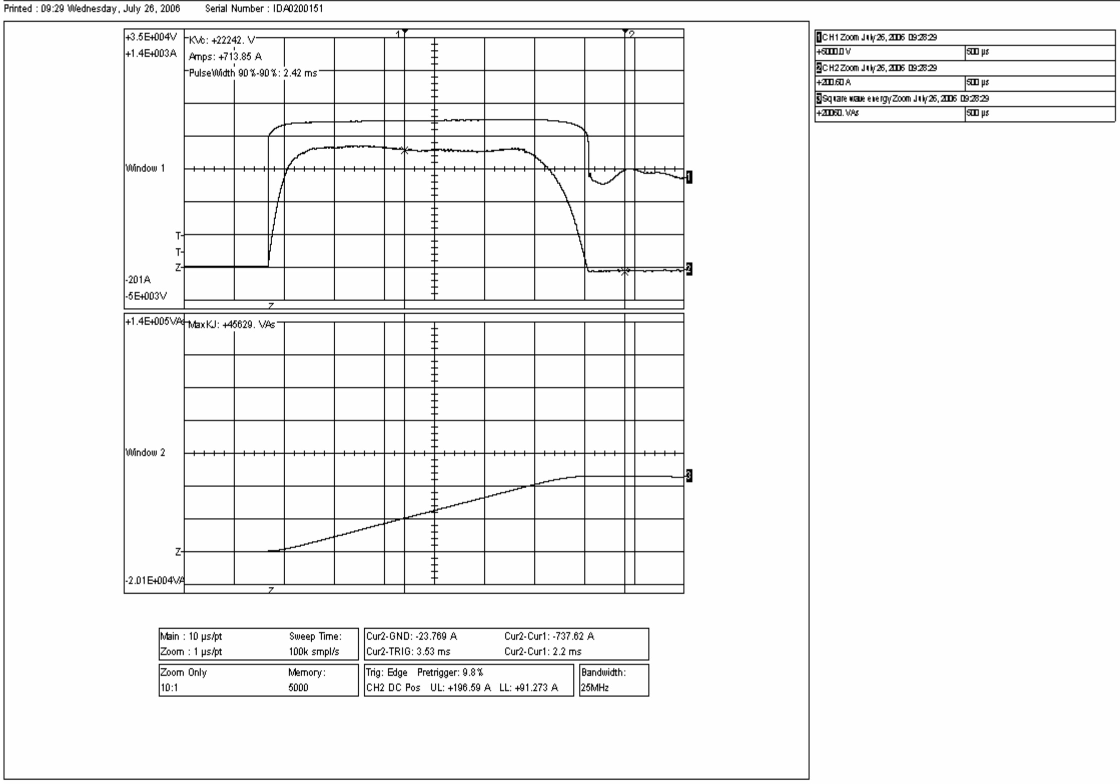
Printed : 11:48 Tuesday, July 25, 2006   Serial Number : IDA0200151



Sample 3, Discharge 18

Nicolet Accura100

Printed : 09:29 Wednesday, July 26, 2006   Serial Number : IDA0200151



IEC Type Test Report
Report No. EU1590-H-04
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Accelerated Aging Procedure

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar
Product Design Engineer
Date: 6/17/2011

M.G. Comber
Manager, Engineering
Date: 6/17/2011

IEC TYPE TEST REPORT
Accelerated Ageing Procedure

TESTS PERFORMED:

Accelerated aging tests were performed on three resistor elements, each 56mm diameter and 41mm long. The tests were conducted in accordance with the requirements of clause 10.8.5 of IEC 60099-4 (requiring the accelerated ageing procedure of clause 8.5.2 to be administered). The test samples were placed in an air oven and energized at a voltage equal to the corrected maximum continuous operating voltage, U_{ct}, for 1000 hours. U_{ct} is the voltage that corresponds to the maximum voltage to which a resistor would be subjected in a complete arrester, taking into account non-uniform voltage distribution along the arrester length. MH3 arresters are designed such that the maximum voltage stress at any point along the resistor column is not more than 1.15 times the average stress along the column.

The temperature of the samples was maintained at 115 °C ± 2 °C for the duration of the test.

Power dissipation was measured on each sample throughout the 1000 h test period.

Clause 8.5.2 of IEC 60099-4 defines three power dissipation values:

- P_{1ct}, measured 1 h to 2 h after the initial voltage application
- P_{2ct}, measured after 1000 h
- P_{3ct}, the minimum value attained during the 1000 h test period.

If P_{2ct} is equal to or less than 1.1 times P_{3ct}, then the switching surge operating duty test of Clause 8.5.5 of IEC 6099-4 is to be performed on new resistors. Furthermore, if P_{2ct} is equal to or less than P_{1ct}, then the rated voltage and continuous operating voltage used for the operating duty test are not subject to any modification.

RESULTS:

Table 1 lists sample characteristics and calculated minimum test voltage U_{ct}. The test voltage was set to 5.30 kVrms

Table 1. Parameters for accelerated ageing test

	Sample 1	Sample 2	Sample 3
Reference current - mA	9.5	9.5	9.5
Reference voltage, U_{ref} – kVpk/√2	5.76	5.75	5.74
U_c (0.795 x $U_{ref)}$ - kVrms	4.58	4.57	4.56
U_{ct} (1.15 x U_c) - kVrms	5.27	5.26	5.25

Figure 1 graphically displays the measurements made during the 1000 h test period. Table 1 summarizes the values of P_{1ct}, P_{2ct} and P_{3ct} for each sample. The requirements that P_{2ct} is equal to or less than 1.1 times P_{3ct}, and P_{2ct} is equal to or less than P_{1ct} are met for all three samples. Consequently, no modification needs to be made to the rated voltage and continuous operating voltage in the operating duty test, and the operating duty test can be performed on new resistors.

Table 1. Power dissipation values

Sample Number	Power dissipation at 2 h	Power dissipation at 1000 h	Minimum power dissipation
	P_{1ct} (W)	P_{2ct} (W)	P_{3ct} (W)
1	6.39	4.11	4.11
2	6.36	4.11	4.11
3	6.17	4.01	4.01

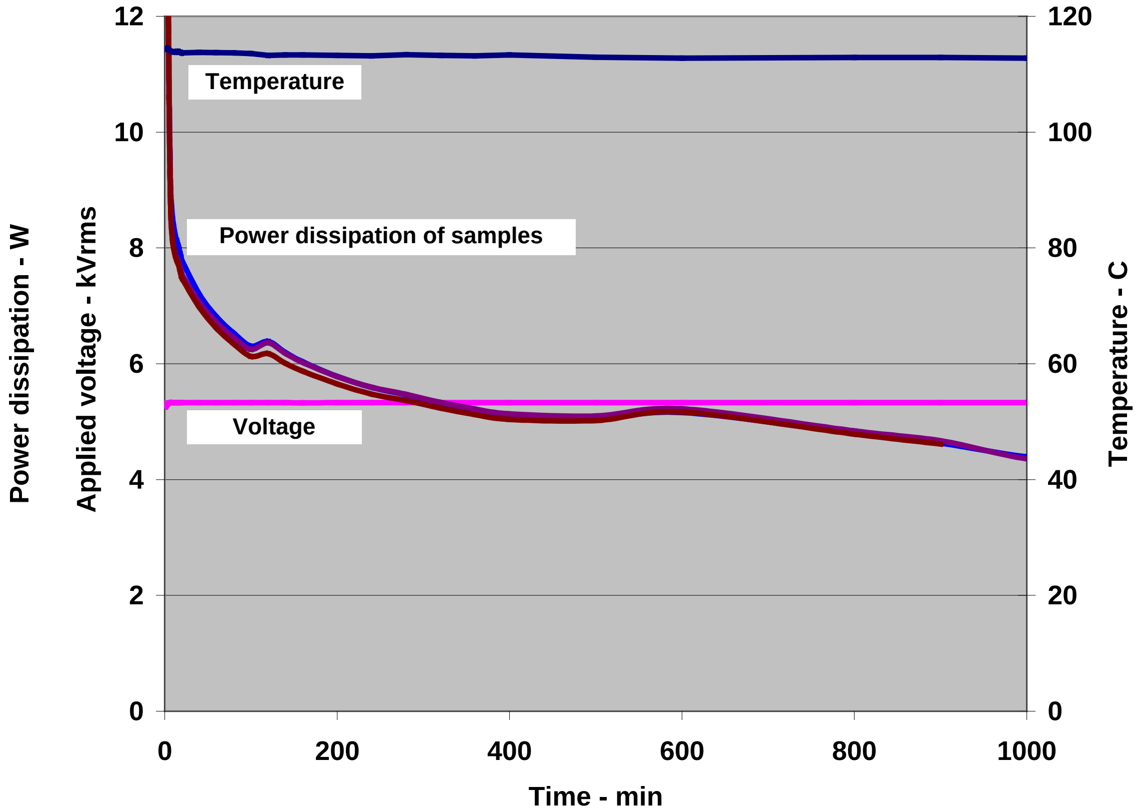


Figure 1. Power dissipation, voltage and temperature measurements during 1000 h test period

IEC Type Test Report
Report No. EU1590-H-05
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Heat Dissipation Behaviour of Test Section

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar	M.G. Comber
Product Design Engineer	Manager, Engineering
Date: 6/17/2011	Date: 6/17/2011

IEC TYPE TEST REPORT
Heat Dissipation Behaviour of Test Section

TESTS PERFORMED:

Tests were performed as required by clause 10.8.5 and Annex B of IEC 60099-4, to compare the cooling characteristics of the test section used for type tests with those of a full-size arrester unit. For this purpose, a specially modified arrester unit with U_r = 150 kV unit and a test section with U_r = 10.6 kV were prepared. The 150 kV rated unit, which represents the highest individual unit rated voltage and the most resistors per unit length of all units used in the arrester design, was equipped with thermocouples located at one-third (top), one-half (middle) and two-thirds (bottom) positions along the unit length. The test section was comprised of two resistor elements (56 mm diameter, 41 mm long) assembled into a short section of porcelain housing, insulated on top and bottom ends to control the rate of cooling to meet the requirements that the test section cools at a rate not greater than that of the assembled unit. A thermocouple was located at the mid-height of the two-resistor stack

Both assembled unit and test section were heated electrically with a power frequency overvoltage to raise the average temperature of the resistors to 120^{o}C in the same amount of time. The voltage was removed and the samples allowed to cool naturally. Temperature measurements were made throughout the cooling period.

RESULTS:

The resistors in both the assembled unit and the test section were heated by applying a voltage sufficiently above U_r to raise the resistor temperature to 120^{o}C in approximately 4 min. Figure 1 graphically displays the cooling of both samples over a period of approximately 3.5 hours.

With both samples starting from the same initial temperature of 120^{o}C, the temperature of the resistors in the test section above the temperature of the resistors in the fully assembled unit throughout the cooling period. This demonstrates the validity of the test section for use in type tests involving thermal recovery.

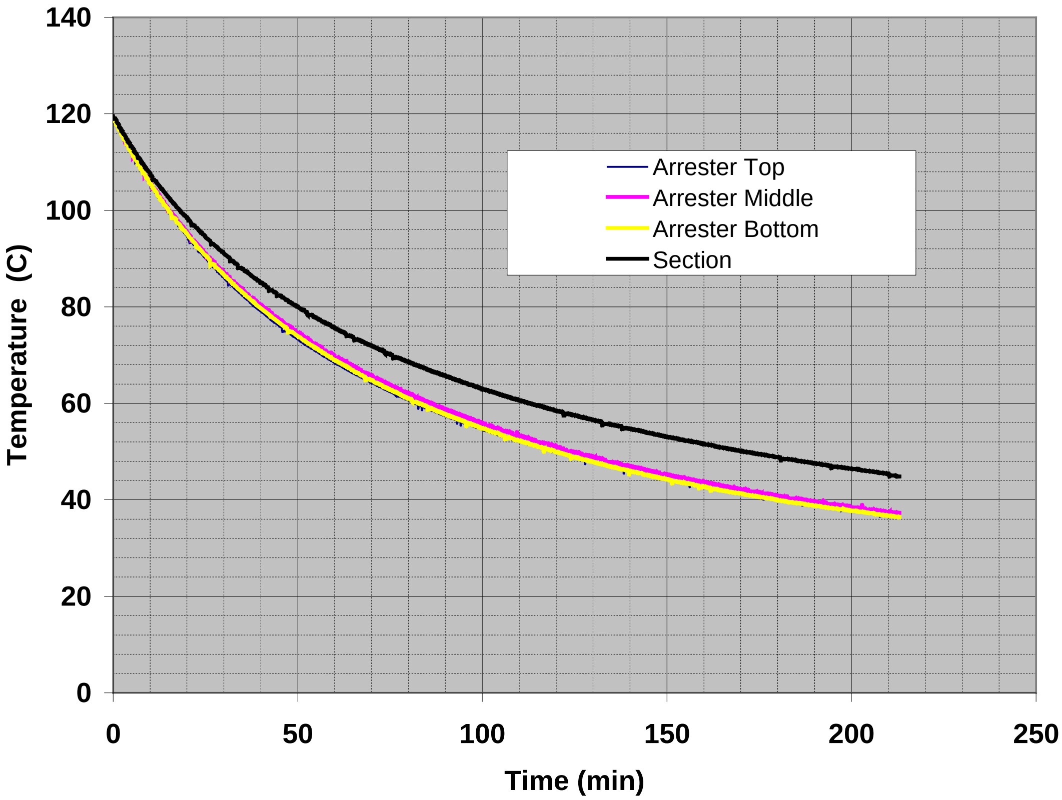


Figure 1. Cooling curves of fully assembled arrester unit and test section

IEC Type Test Report
Report No. EU1590-H-06
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Switching Surge Operating Duty Test

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar	M.G. Comber
Product Design Engineer	Manager, Engineering
Date: 6/17/2011	Date: 6/17/2011

IEC TYPE TEST REPORT
Switching Surge Operating Duty Test

TESTS PERFORMED:
Switching surge operating duty tests, in accordance with the requirements of clause 10.8.5 of IEC 60099-4, were performed on three prorated test sections. The test sections were prepared based on the results of the tests to verify heat dissipation behaviour of test sample (see EU1590-H-05 section of MH3 type test report). Each section consisted of two resistors (56 mm diameter, 41 mm long) in series. The resistors were selected to represent the lowest acceptable reference voltage level. Prior to the conditioning portion of the test, measurements were made of the lightning impulse residual voltage of each section, and also of reference voltage of each section.

The conditioning portion of the test consisted of two parts. In the first part, a series of twenty 8/20 lightning current impulses was applied to each section, with peak value of the impulses being equal to the nominal discharge current. The series of impulses was divided into four groups of five, with the interval between impulses within each group being between 50 and 60 seconds and the interval between groups being between 25 and 30 minutes. Test sections were energized at 60 Hz voltage of $1.2 \times U_c$ during the application of the impulses within each group. The impulses were timed to occur 60° before the crest of the 60 Hz voltage with the same polarity of the impulse. In the second part, a series of two 100kA 4/10 impulses were applied to each section, with the section allowed to cool to ambient temperature between impulses.

Following the conditioning portion of the test, each section was placed in an oven and heated overnight to 60 ± 3 °C. After removal from the oven, each section was subjected to two long duration current impulses, with time between impulses being between 50 and 60 seconds. The parameters of the transmission line used to generate these impulses conformed to the requirements for Line Discharge Class 4 in Table 5 of Clause 8.4.2 of IEC 60099-4. Within 100 milliseconds of the second long duration current impulse, rated voltage (U_r) was applied to each section for 10 seconds, immediately followed by U_c for 30 minutes, during which period the power dissipation was monitored to verify thermal stability.

At the end of the above test sequence, each section was allowed to cool to ambient temperature, at which point the lightning impulse residual voltage at nominal discharge current was re-measured.

Table 1 lists the parameters of the test sections and the corresponding transmission line parameters used for the test. U_c for the MH3 series of arresters has been established as 0.795 times the lowest acceptable reference voltage in routine tests, and U_r has been established as 1.25 times U_c . This is represented in this type test by assigning the test sample U_c equal to 0.795 x U_{ref} of the test sample, and test sample U_r at 1.25 times this value . The minimum energy required for each line discharge for Class 3 arresters is determined from the following formula given in Clause 8.4.2 of IEC 60099-4

$$W = U_{res} \times (U_L - U_{res}) \times 1/Z \times T$$

where U_{res} is the switching impulse residual voltage at 250 A.

Table 1. Initial Measurements and Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Switching impulse residual voltage (kV) U_{res}	20.64	20.64	20.64
Initial Residual Voltage (kV) @ 20 kA, 8/20	26.71	26.71	26.70
Reference Current (mA) I_{ref}	9.5	9.5	9.5
Reference Voltage ($kV_c / \sqrt{2}$) V_{ref}	11.51	11.51	11.50
COV (kV rms) U_c	9.15	9.15	9.14
Rating (kV rms) U_r	11.44	11.44	11.43
Arrester Classification (kA)	10	10	10
Line Discharge Class	3	3	3
Virtual Duration of Peak (µs, 90-90%) - min	2400	2400	2400
Surge Impedance (Ω) Z_g - max (1.3 U_r)	14.87	14.87	14.87
Charging Voltage (kV) U_L – min (2.8 U_r)	32.03	32.03	32.00
Energy required (kJ) - min	38.0	38.0	38.0

RESULTS:

Figures 1, 2 and 3 show recordings made during application of the 1st and 20th lightning impulse conditioning discharges on each section. Figures 4, 5 and 6 show recordings made during application of the 1st and 2nd high current conditioning impulse on each section.

A short circuit test was performed on the generator to confirm that generator impedance and duration of the current discharge met the requirements listed in Table 1. The oscillogram of Figure 7 shows

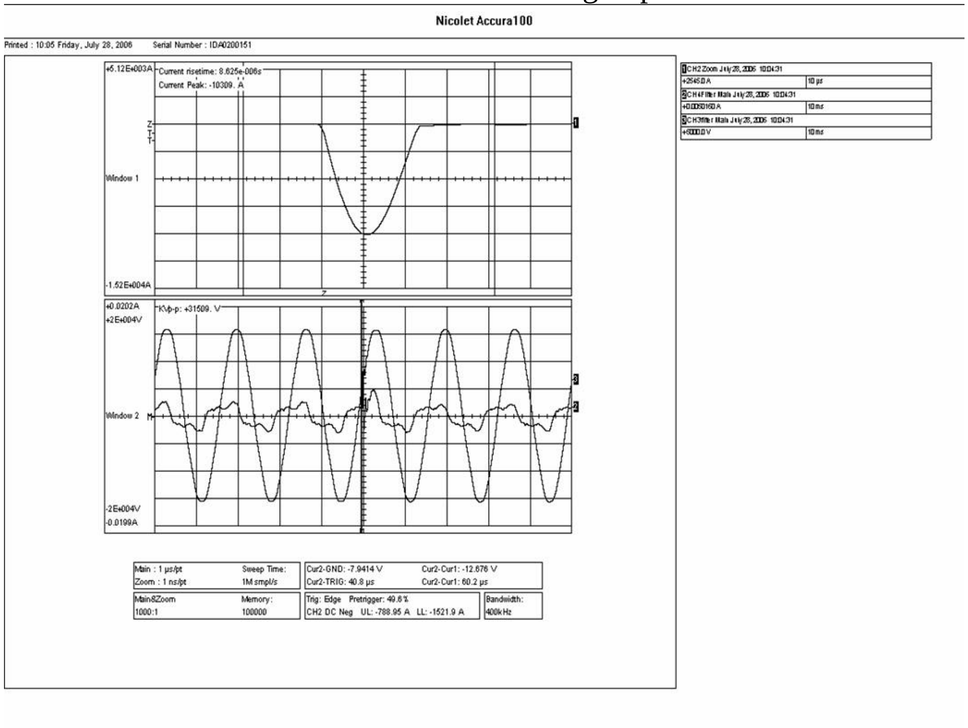
Z_g = 10 708 V / 728.09 A = 14.707 Ω Virtual Duration of Peak = 2 457 µs

Table 2 lists the current and voltage magnitudes and discharge energy measured on each of the two line discharges for each of the three test samples.

Table 2. Line Discharge Test Measurements

Impulse	Section 1			Section 2			Section 3		
	I (A)	V (kV)	E (kJ)	I (A)	V (kV)	E (kJ)	I (A)	V (kV)	E (kJ)
1	639	21.71	39.6	636	21.72	39.6	627	21.71	39.2
2	617	22.01	38.9	615	22.01	38.9	606	21.96	38.2

Section 1: 1st conditioning impulse



Section 1: 20th conditioning impulse

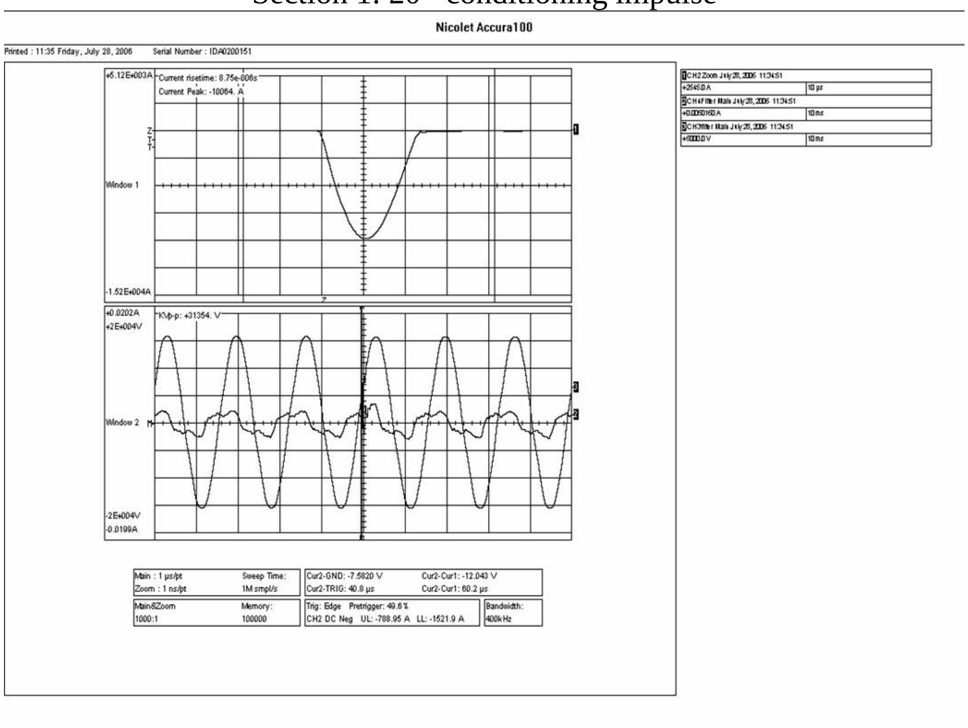
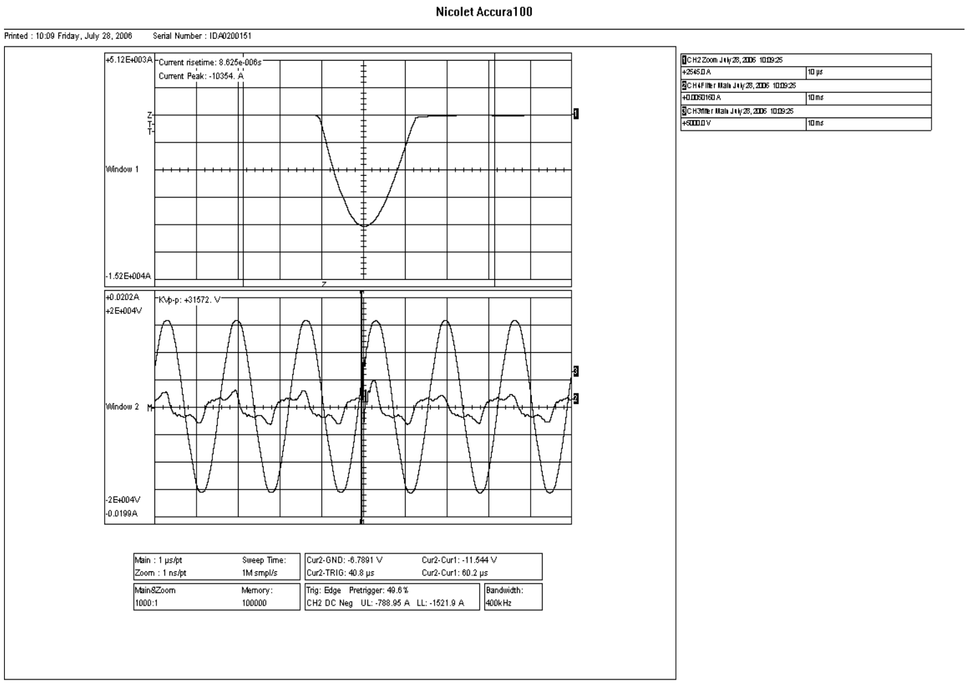


Figure 1. Oscillograms of 10kA 8/20 conditioning impulses for section 1

Section 2: 1st conditioning impulse



Section 2: 20th conditioning impulse

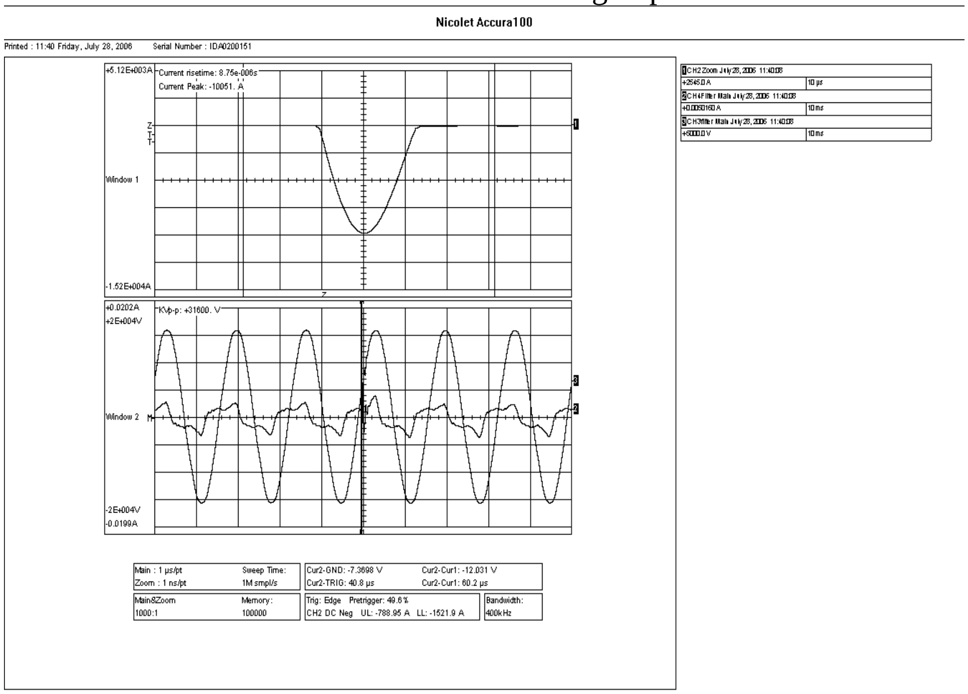
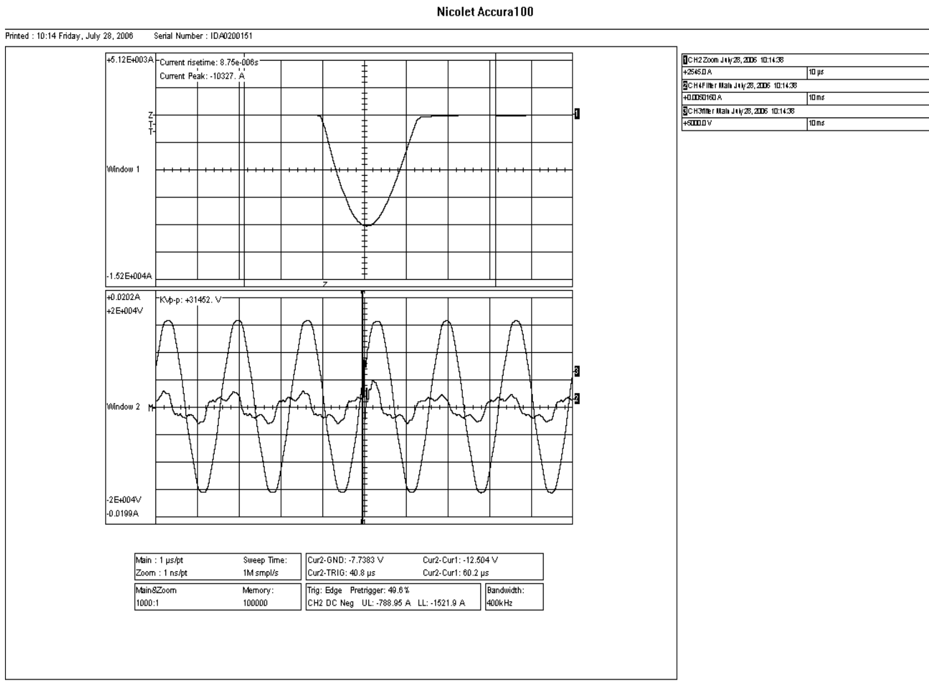


Figure 2. Oscillograms of 10kA 8/20 conditioning impulses for section 2

Section 3: 1st conditioning impulse



Section 3: 20th conditioning impulse

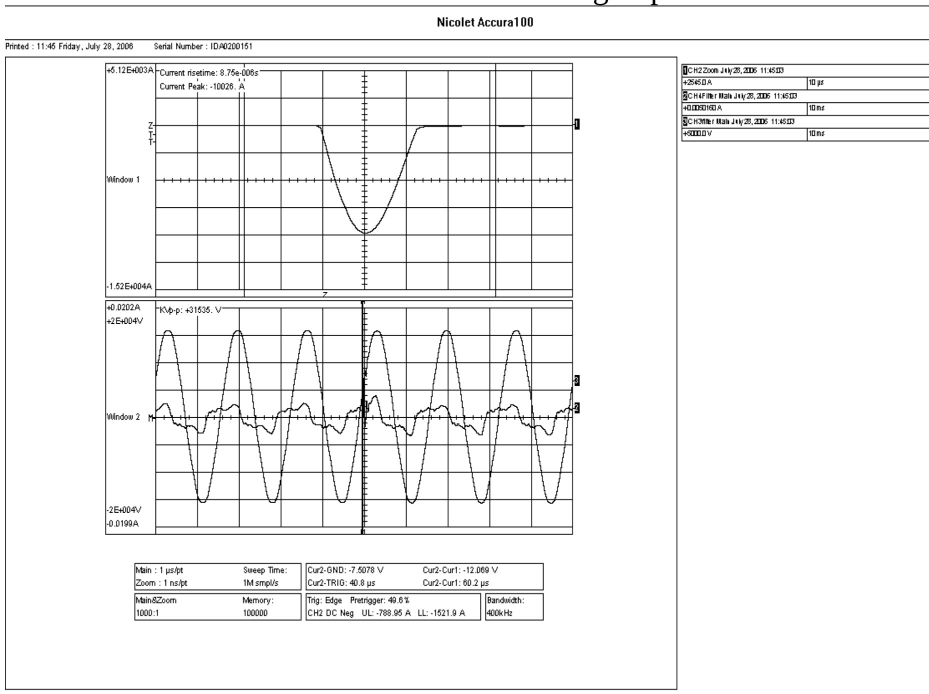
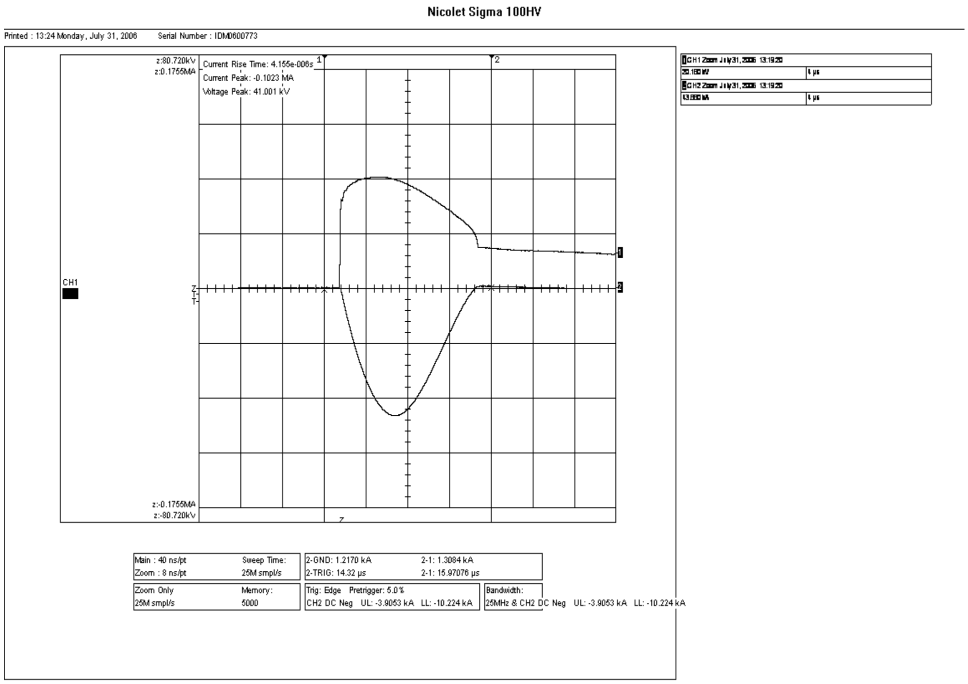


Figure 3. Oscillograms of 10kA 8/20 conditioning impulses for section 3

Section 1: 1st conditioning impulse



Section 1: 2nd conditioning impulse

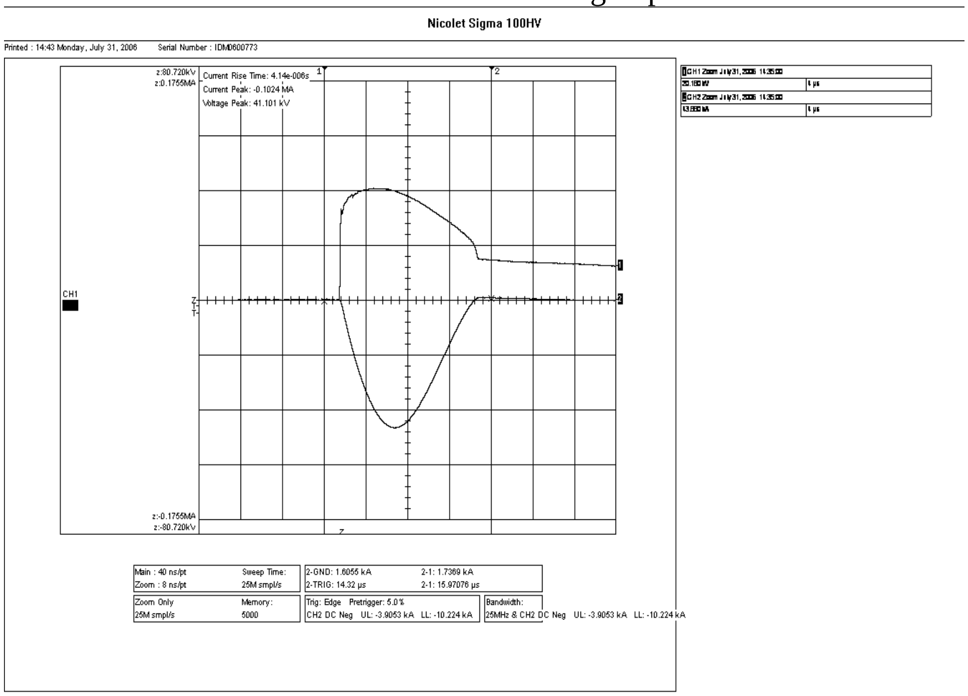
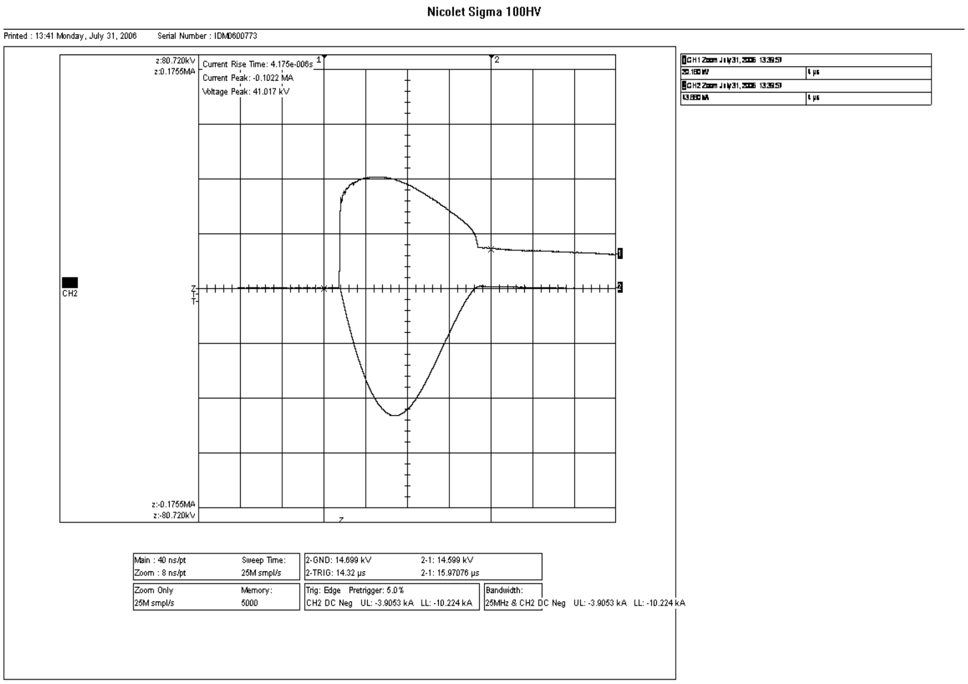


Figure 4. Oscillograms of 100kA conditioning impulses for section 1

Section 2: 1st conditioning impulse



Section 2: 2nd conditioning impulse

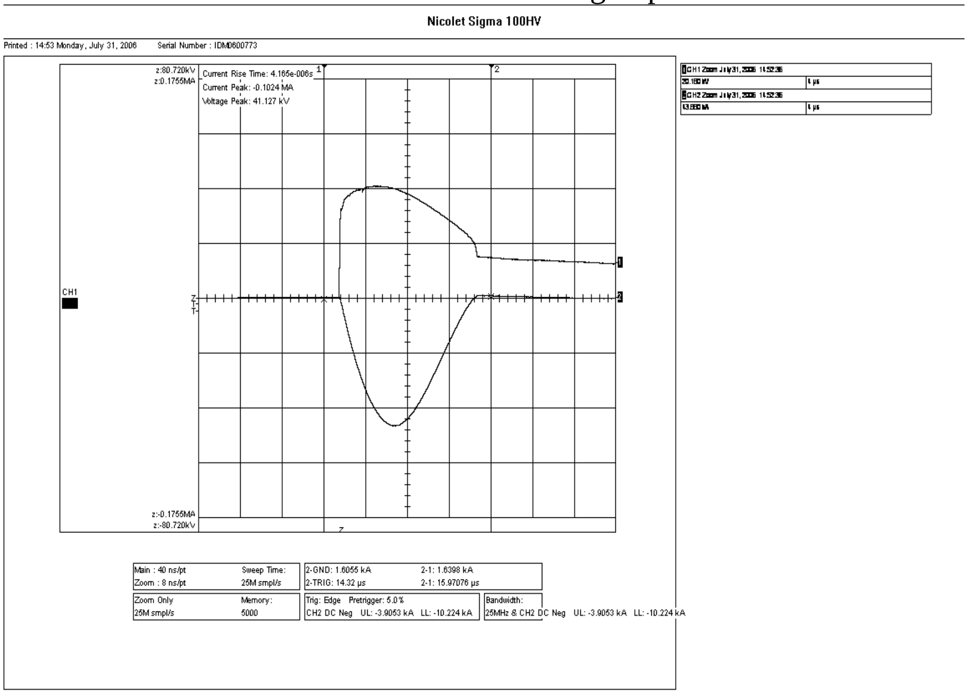
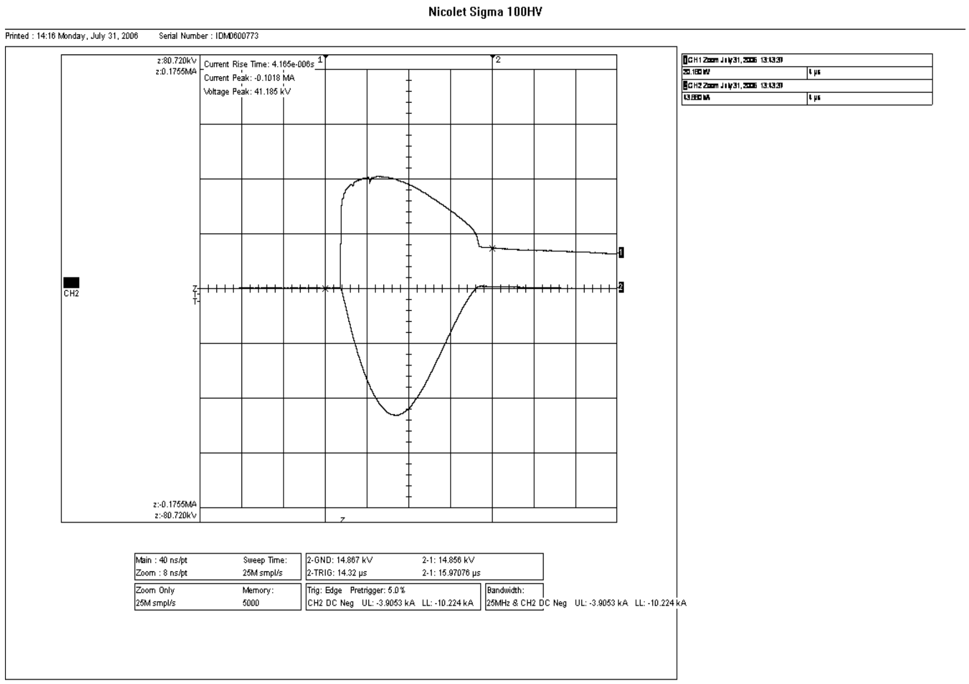


Figure 5. Oscillograms of 100kA conditioning impulses for section 2

Section 3: 1st conditioning impulse



Section 3: 2nd conditioning impulse

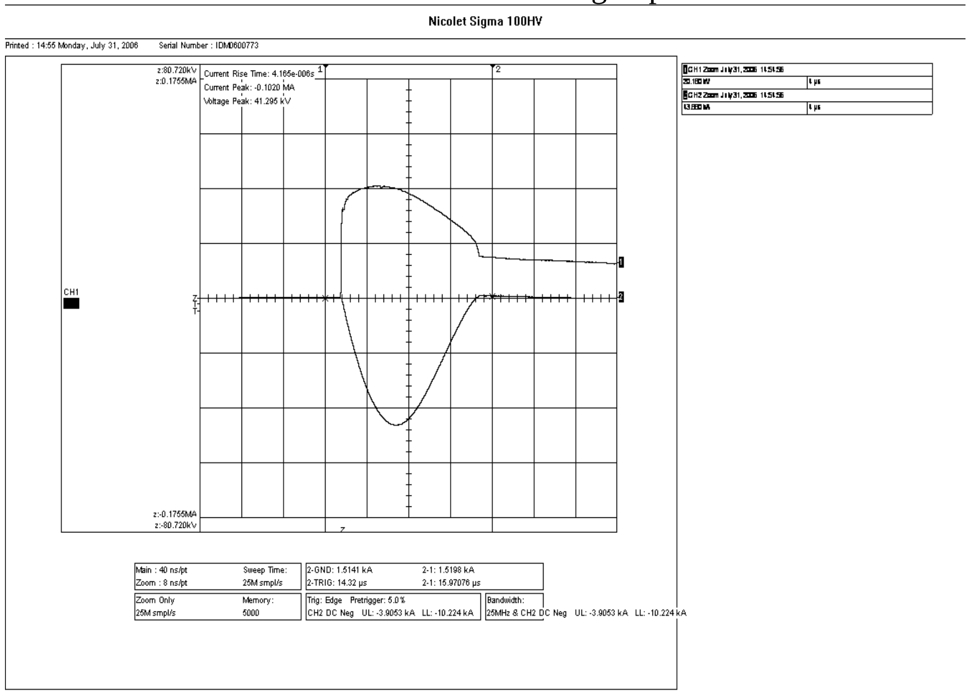


Figure 6. Oscillograms of 100kA conditioning impulses for section 3

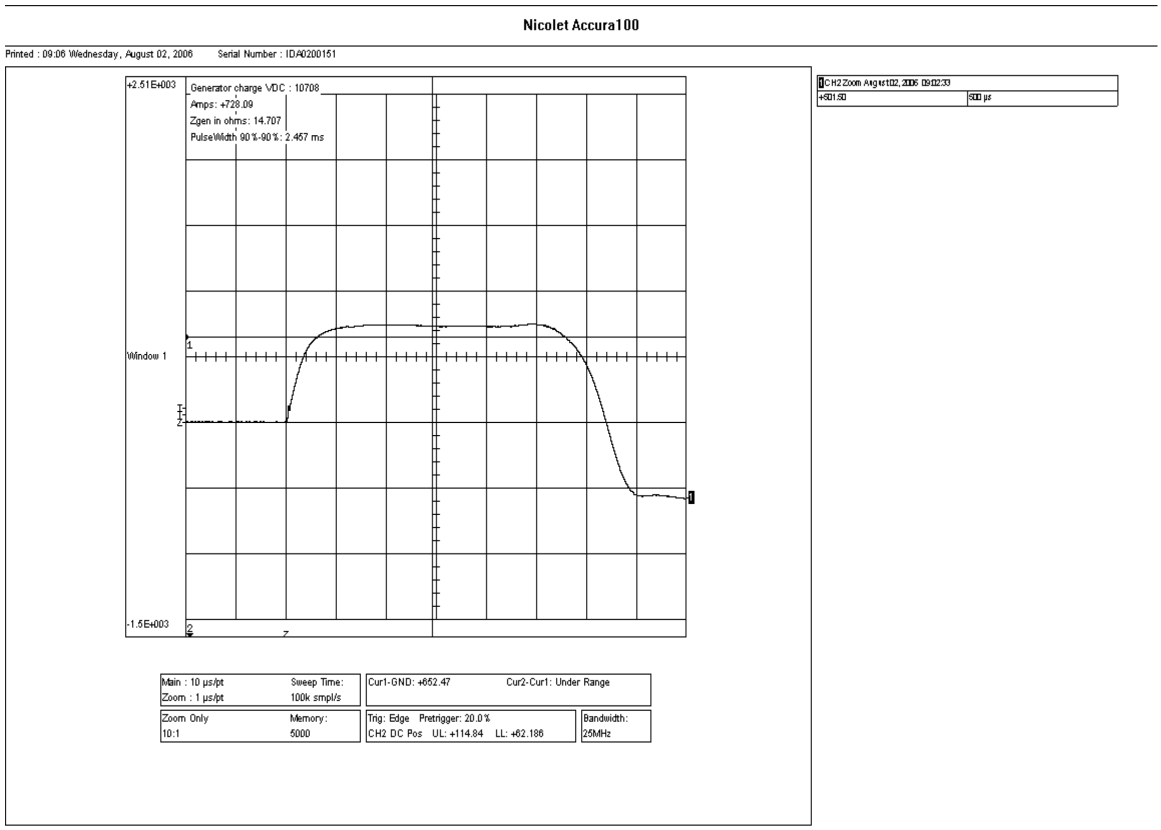


Figure 7. Oscillogram of discharge current for generator short circuit set up test

Figures 8, 9 and 10 show oscillograms of the second line discharge and the 10 s application of U_r on each section. Ambient air temperature at the time of the test was 22 °C. Table 3 lists measurements made during this period.

Table 3. Measurements made during 10 s application of U_r.

Section 1			Section 2			Section 3		
Time (s)	**Voltage (kVc)**	**Current (mAc)**	**Time (s)**	**Voltage (kVc)**	**Current (mAc)**	**Time (s)**	**Voltage (kVc)**	**Current (mAc)**
0	16.17	98	0	16.16	118	0	16.28	130
1	16.31	101	1	16.33	119	1	16.52	130
2	16.35	101	2	16.39	119	2	16.55	131
4	16.37	101	4	16.39	117	4	16.55	127
6	16.35	103	6	16.38	116	6	16.55	127
8	16.37	105	8	16.39	119	8	16.57	133
10	16.34	103	10	16.40	123	10	16.56	133
Avg rms voltage during 10s	11.55 kV		Avg rms voltage during 10s	11.57 kV		Avg rms voltage during 10s	11.69 kV	

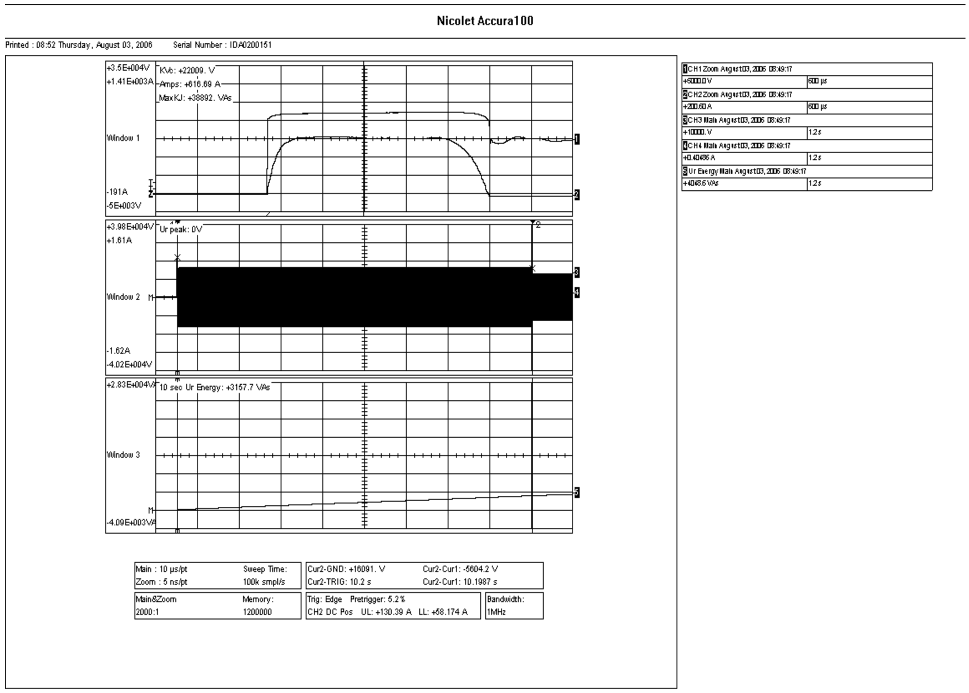


Figure 8. Oscillogram of second line discharge for section 1

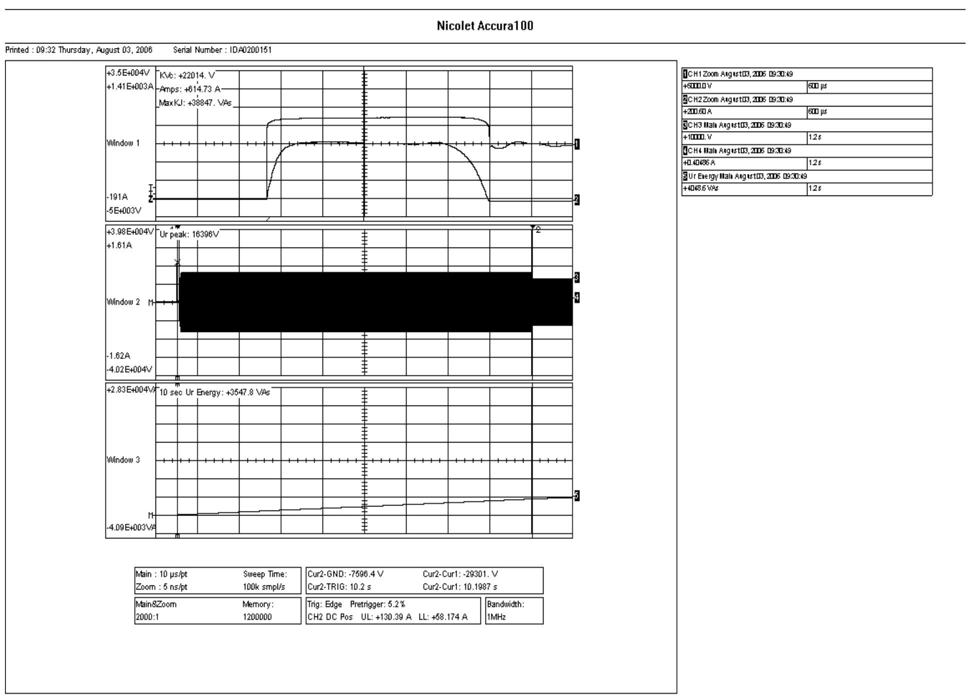


Figure 9. Oscillogram of second line discharge for section 2

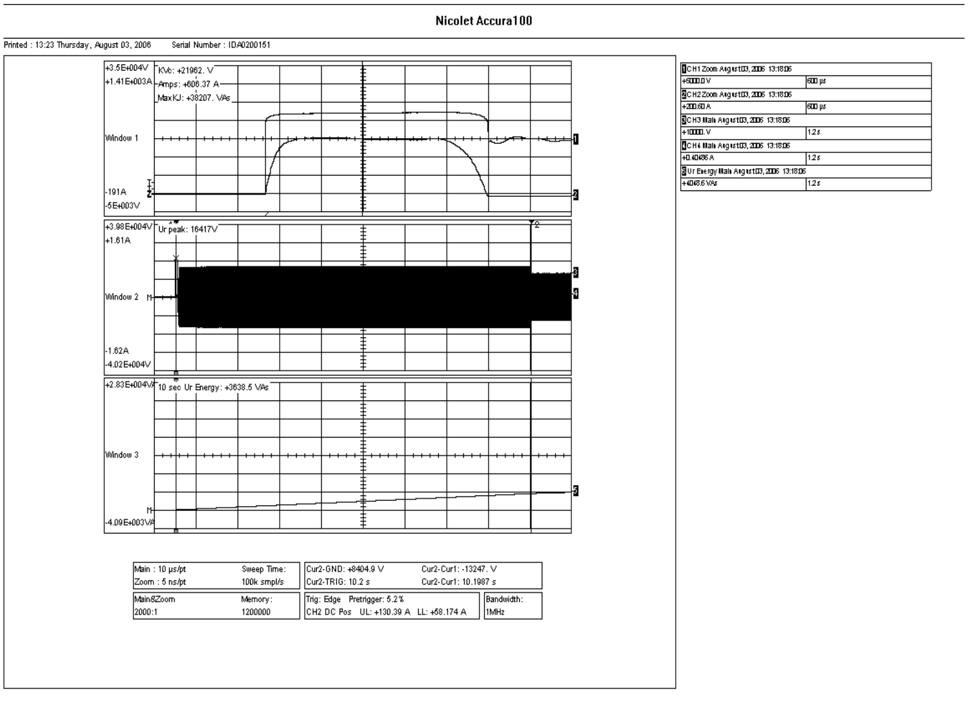
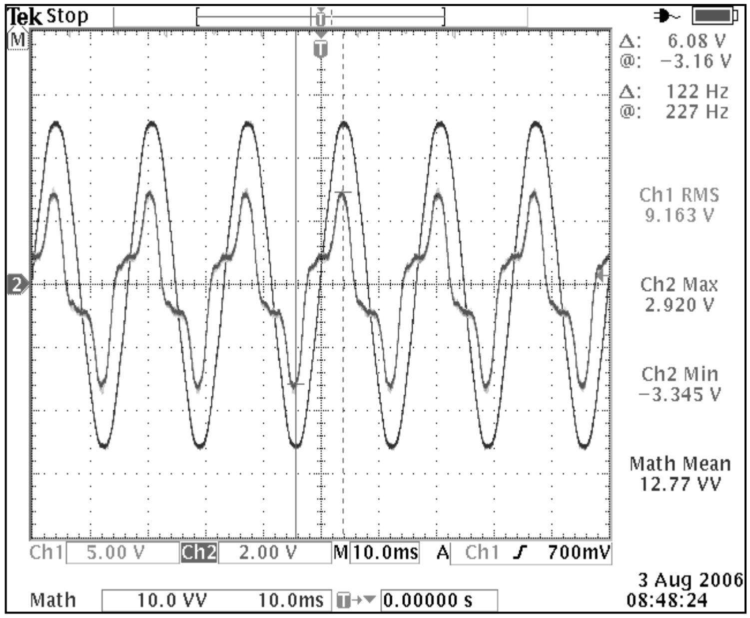


Figure 10. Oscillogram of second line discharge for section 3

Figures 11, 12 and 13 show oscillograms of voltage and current at the beginning and end of the 30 min application of U_c on each section. Table 4 lists measurements of power dissipation made during this period.

Table 4. Measurements of power dissipation made during 30 min at U_c

Time (min)	Power Dissipation (W)		
	Section 1	Section 2	Section 3
0	28.5	31.8	26.8
0.5	25.7	27.8	24.3
1	24.1	27.5	23.0
2	22.3	25.4	20.5
5	18.5	23.0	17.1
10	15.5	20.7	15.0
20	12.5	17.9	11.2
30	10.1	15.7	9.2



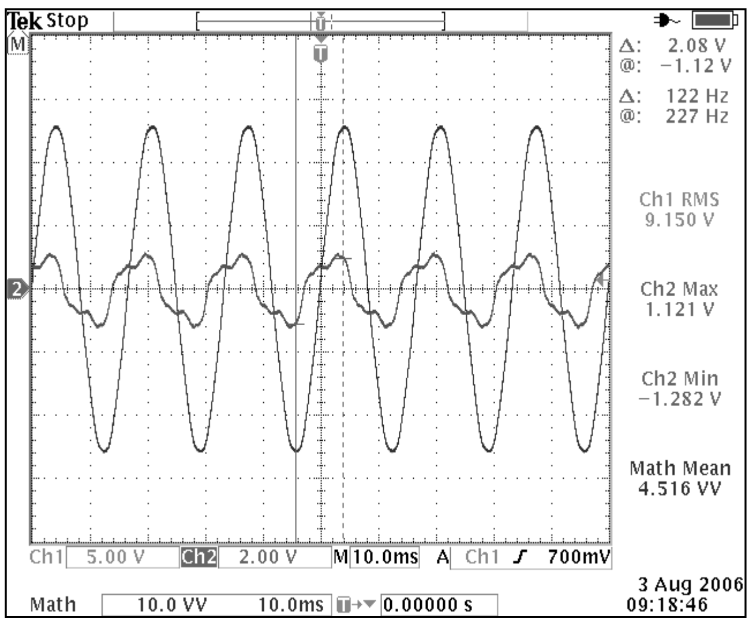
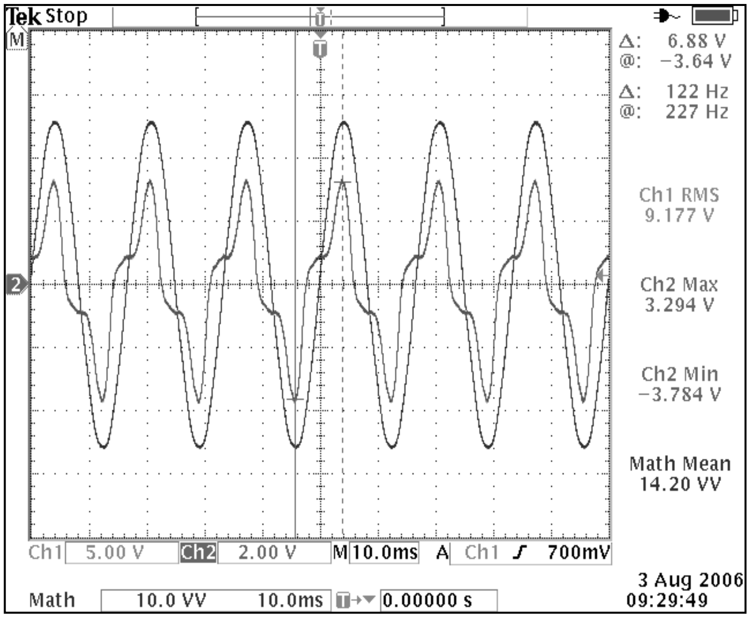


Figure 11. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c for section 1



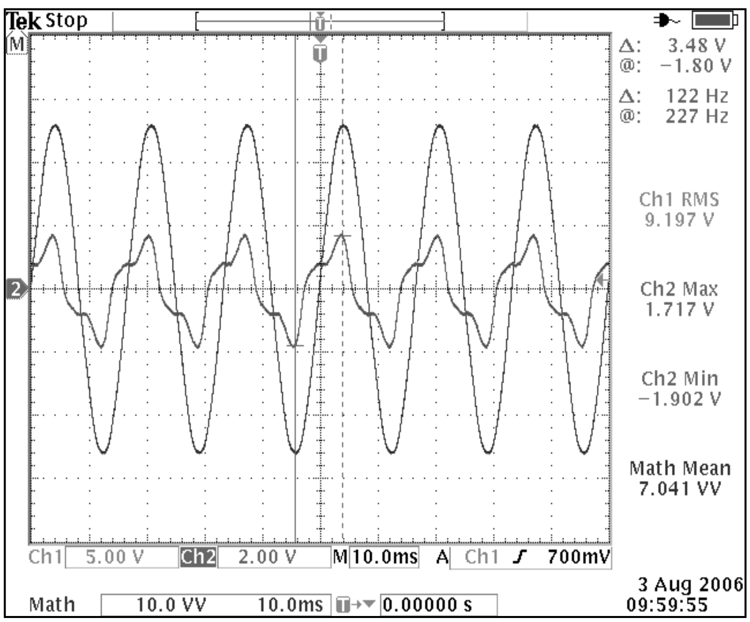
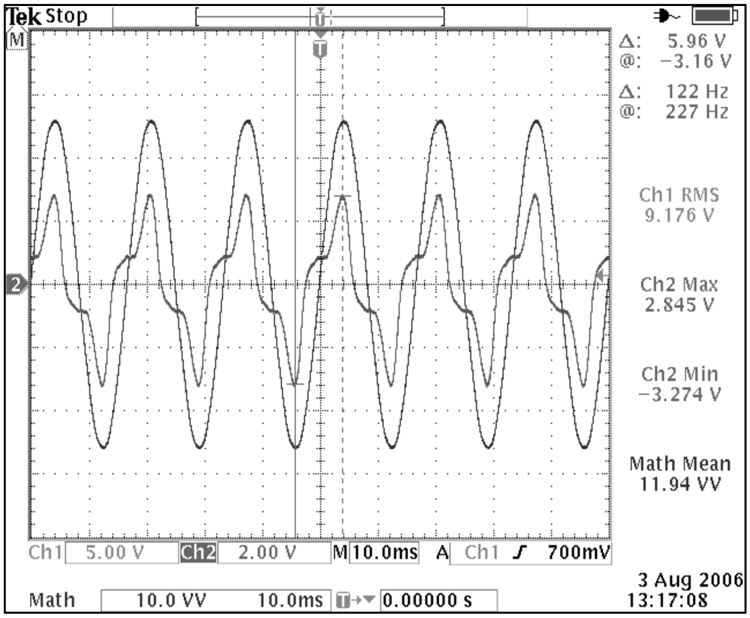


Figure 12. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c for section 2



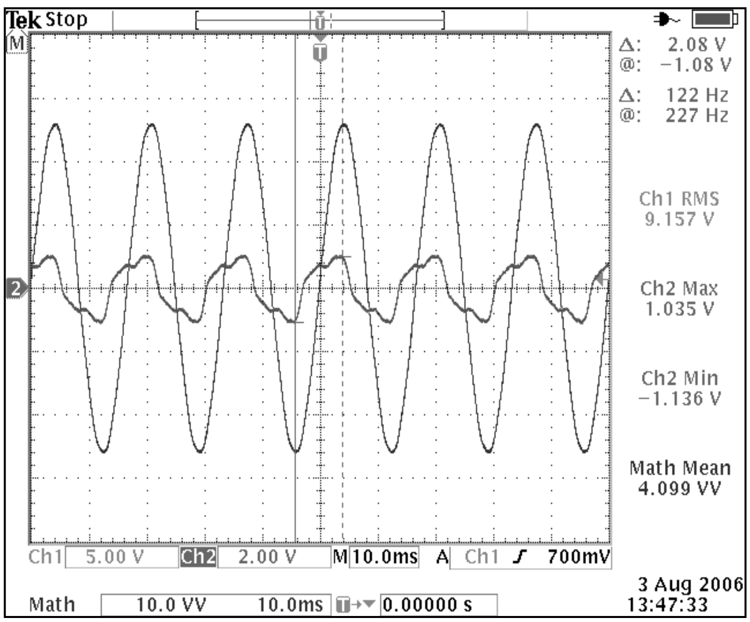


Figure 13. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c for section 3

Subsequent to the completion of the thermal recovery, and after the sections had cooled to ambient temperature, the residual voltage at nominal discharge current was re-measured and compared to the initial values for each test sample. Results are summarized in Table 5. The maximum change of residual voltage of the three samples is less than the permissible change of 5 % defined by IEC 60099-4.

Table 5. Initial and final residual voltage measurements

Section	Residual voltage (kV)		Change
	Initial	Final	
1	26.712	27.017	+ 1.1 %
2	26.712	26.965	+ 0.9 %
3	26.702	27.101	+ 1.5 %

Disassembly of the test samples at the end of the electrical tests revealed no evidence of physical damage.

IEC Type Test Report
Report No. EU1590-H-07.1
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Short Circuit

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Saroni Brahma
Design Engineer

Michael L Kelley
Business Unit Manager

9/11/2014

IEC TYPE TEST REPORT
Short Circuit

TESTS PERFORMED:

High current short circuit tests were performed at the CESI high power laboratory in Milan, Italy according to the procedures described in Clause 8.7 of IEC 60099-4. The MH3 series of arresters has a rated short circuit capability of 63000 A symmetrical. Verification of capability requires three high current tests, performed with rated short circuit current (63000 A) and two reduced short circuit currents (25000 A and 12000 A). For these tests, fully assembled test units were prepared, each containing as many MOV elements as possible within the available stacking length. The internal elements of each test unit were shorted by a fuse wire running along the outside of the stack of MOV elements. The units tested represented the longest unit used in the MH3 series of arresters. The tests were performed in October 2013, in accordance with IEC 60099-4 Ed. 2.2-2009-05.

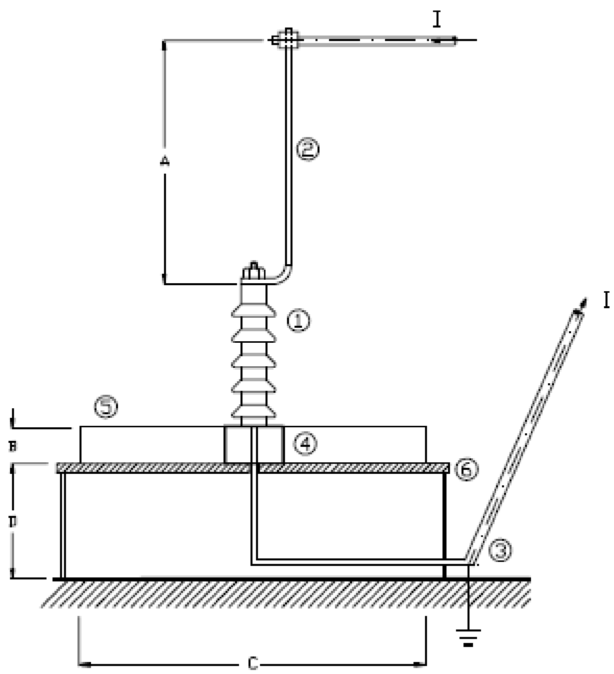
RESULTS:

Complete results of the testing are contained in a CESI test report that is available on request. Results are summarized in the following extracts from the CESI report.

The test samples had an overall unit length of 1286 mm (for 600A) and 1451mm (for 63kA, 25kA and 12kA). Figure 1 shows the general arrangement of the test set up. Figure 2 shows one of the units in the test chamber.

All four samples successfully withstood their respective short circuit current tests with no fracturing of the porcelain housing. Actual prospective rms values of test currents were 590A, 12600 A, 24500 A and 65500 A. For the rated current test, the peak of the first half cycle of test current was 162000 A, meeting the requirement that this be at least 2.5 times the rms value of the rated short circuit current. Data sheets for the tests are shown in Figures 3– 6, and associated oscillograms are shown in Figures 7 - 10.

D8045 - Test arrangement



1 : Surge arrester
2 : Flexible conductor
3 : Rigid conductor
4 : Base
5 : Surrounding fence
6 : Insulating wood platform

A : 1,00 m
B : 0,40 m
C : 3,30 m
D : 1,00 m

The arrester to be tested was installed on a base at 1,40 m to ground in the middle of a square enclosure of 3,30 m in side.
The enclosure was positioned on an insulating wood platform.
The pressure relief device was directed toward the supply bus bar, inside of the current loop.
The live side of the supply was connected to the upper end of the arrester while the return circuit, earthed, was connected to the lower end.
The live conductor was directed to the same direction as the earth conductor

Figure 1. Test circuit arrangement

Figure 2. Test sample mounted in test chamber

D1232IG

High-current short-circuit test with 12,6 kA for 0,21 s

Test circuit : See D0046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
In order to achieve the internal discharge, the Client supplied CESI with the surge arrester having the non-linear resistors bypassed by a fuse wire.
A photo detector was used to determine the operating time of the pressure relief device

Condition of the apparatus before the tests: new

Date: October 1, 2013

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Operating time of the Pressure relief device		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms	-	No.
4	11	1	Type 2 - 4	0,21	15,0	23,6	12,6	7,60	-	-

Condition of the apparatus after the tests: see photos No.9 to 11

- there was not violent shattering
- the arrester structure remained intact
- the arrester remained connected to the supply and return circuit
- no fragments were found outside the enclosure
- no flame of any component was noted

Figure 3. Data sheet for 12000 A test

D1232IG

High-current short-circuit test with 24,5 kA for 0,21 s

Test circuit : See D0046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
In order to achieve the internal discharge, the Client supplied CESI with the surge arrester having the non-linear resistors bypassed by a fuse wire.
A photo detector was used to determine the operating time of the pressure relief device

Condition of the apparatus before the tests: new

Date: October 1, 2013

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Operating time of the Pressure relief device		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms	-	No.
3	10	1	Type 2 - 3	0,21	15,0	44,1	24,5	6,10	-	-

Condition of the apparatus after the tests: see photos No.6 to 8

- there was not violent shattering
- the arrester structure remained intact
- the arrester remained connected to the supply and return circuit
- no fragments were found outside the enclosure
- the flame self-extinguished after 4 minutes

Figure 4. Data sheet for 25000 A test

D1232IG

High-current short-circuit test with 65,5 kA for 0,21 s

Test circuit : See D0046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
In order to achieve the internal discharge, the Client supplied CESI with the surge arrester having the non-linear resistors bypassed by a fuse wire.
A photo detector was used to determine the operating time of the pressure relief device

Condition of the apparatus before the tests: new

Date: October 1, 2013

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Operating time of the Pressure relief device		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms	-	No.
2	9	1	Type 2 - 2	0,21	15,0	162	65,5	3,40	-	-

Condition of the apparatus after the tests: see photos No.3 to 5

- there was not violent shattering
- the arrester structure remained intact
- the arrester remained connected to the supply and return circuit
- no fragments were found outside the enclosure
- no flame of any component was noted

Figure 5. Data sheet for 63000 A test

Low-current short-circuit test with 590 A for 1,02 s

Test circuit : See D0046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
In order to achieve the internal discharge, the Client supplied CESI with the surge arrester having the non-linear resistors bypassed by a fuse wire.
A photo detector was used to determine the operating time of the pressure relief device.

Condition of the apparatus before the tests: new, see photo No.1

Date: October 1, 2013

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Operating time of the Pressure relief device		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	A	A	ms	-	No.
1	6	1	Type 1 - 4	1,02	15	1640	590	271	-	-

Condition of the apparatus after the tests: see photo No.2

- there was not violent shattering
- the arrester structure remained intact
- the arrester remained connected to the supply and return circuit
- no fragments were found outside the enclosure
- no flame of any component was noted

Figure 6. Data sheet for 600 A test

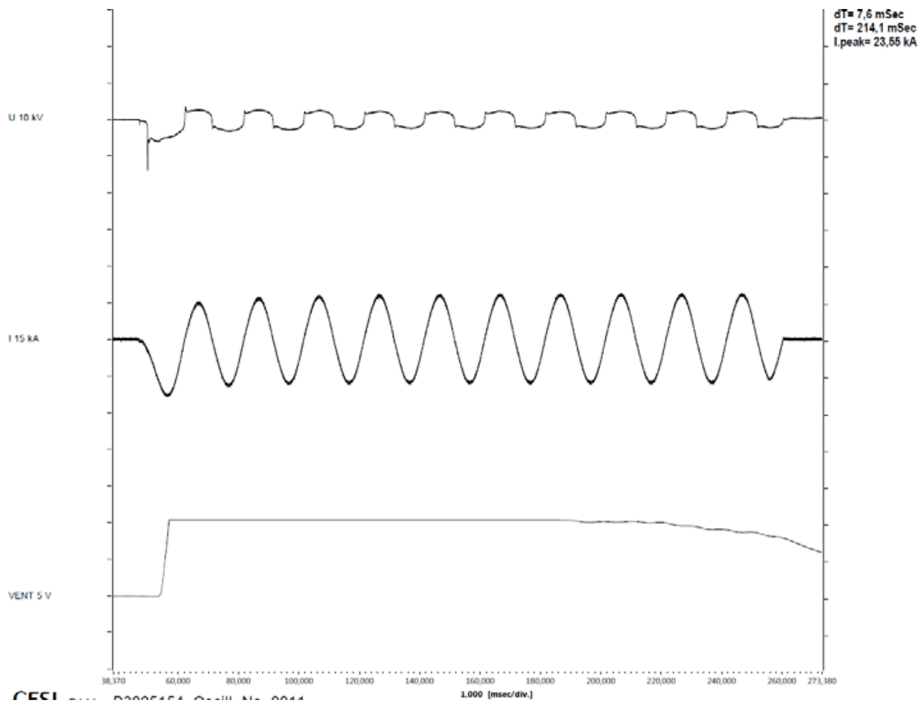


Figure 7. Oscillograms for 12000A test

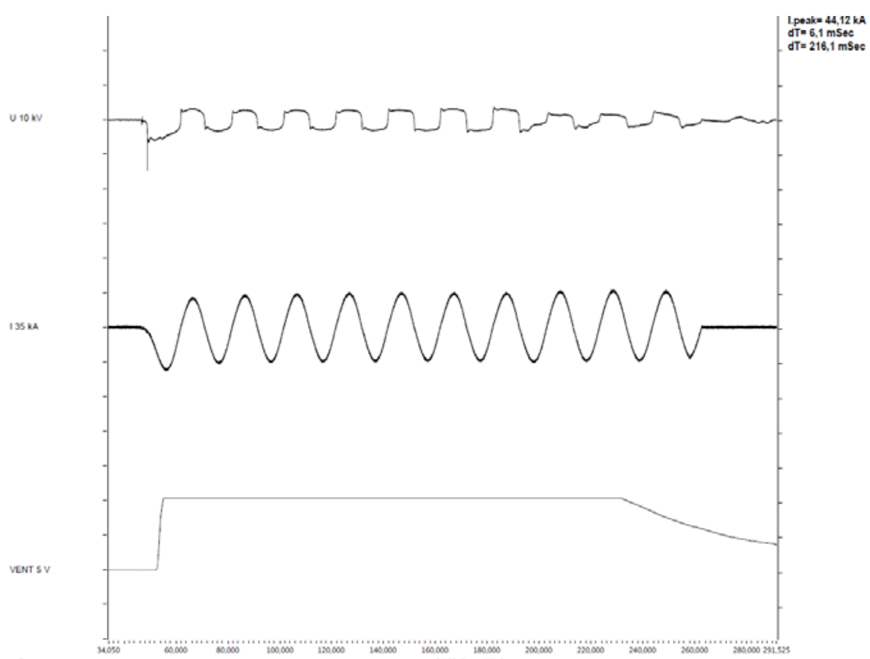


Figure 8. Oscillograms for 25000A test

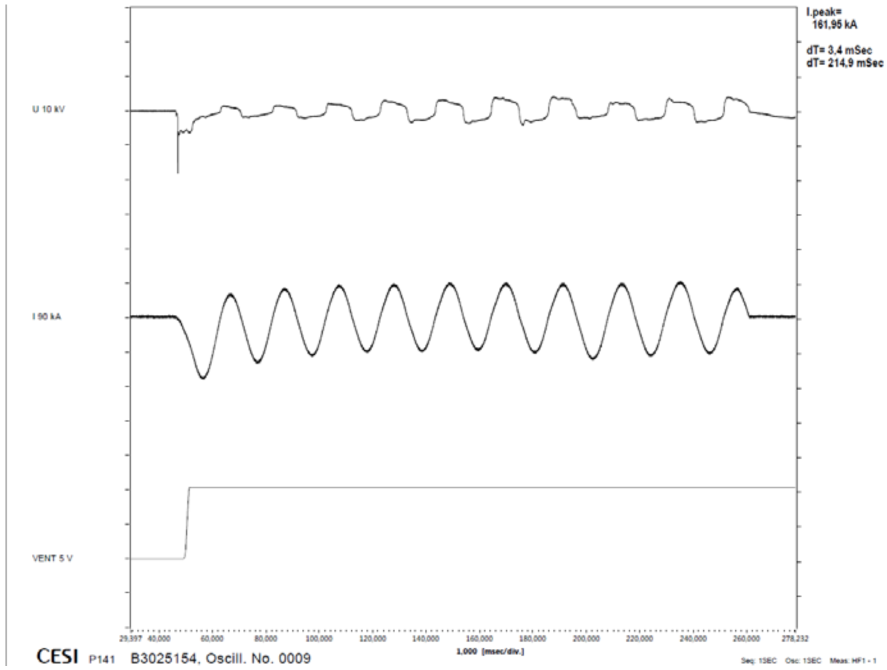


Figure 9. Oscillograms for 63000A test

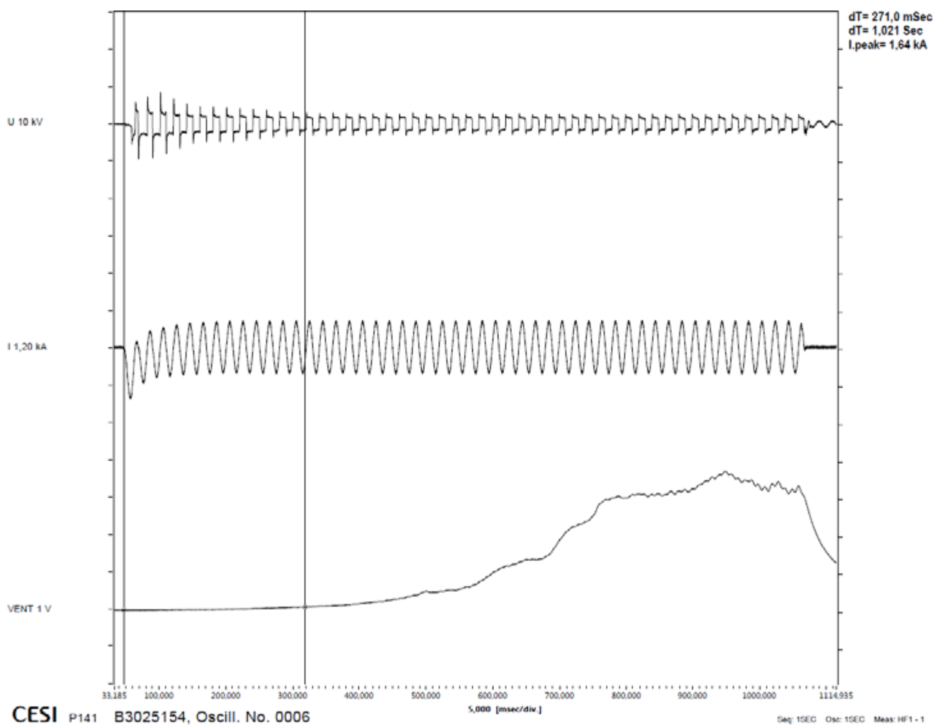


Figure 10. Oscillograms for 600A test

EU1590-H-08

IEC Type Test Report
Report No. EU1590-H-08
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Internal Partial Discharge

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar	M.G. Comber
Product Design Engineer	Manager, Engineering
Date: 6/17/2011	Date: 6/17/2011

IEC TYPE TEST REPORT
Internal Partial Discharge

Clause 10.8.8 of IEC 60099-4, in reference to Clause 8.8, requires that the longest electrical unit of the arrester design be subjected to an internal partial discharge type test. Under the prescribed testing procedure, the partial discharge level at 1.05 times the continuous operating voltage of the unit shall not exceed 10 pC.

Clause 9.1 c) of this same standard requires that all manufactured units be subjected to an internal partial discharge test that is identical to that of Clause 8.8, and that the partial discharge level of all units produced shall not exceed 10 pC. Routine test reports are provided on request verifying that this requirement has been met.

By performing the routine testing of units according to Clause 9.1 c), the type test requirements of Clause 8.8 are automatically met.

IEC Type Test Report
Report No. EU1590-H-09
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Bending Moment

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar	M.G. Comber
Product Design Engineer	Manager, Engineering
Date: 6/17/2011	Date: 6/17/2011

IEC TYPE TEST REPORT
Bending Moment

TESTS PERFORMED:

Bending moment tests were performed to demonstrate compliance with the requirements of Clause 8.9 of IEC 60099-4. IEC 60099-4 requires that the mean breaking load (MBL) determined from tests on three samples be at least 1.2 times the specified short-term load (SSL). Tests were performed on units of the longest length used in the MH3 series of arresters. The units were securely mounted to the horizontal base of the test equipment and lateral (horizontal) loading was applied at a rate necessary to reach the desired bending moment of in 30 s to 90. After reaching the target load in the SSL test, the load was maintained at not less than this level for at least 60 s. After release of load, the test sample was inspected to verify that no mechanical damage had occurred, and then the test sample was subjected to standard seal leak and partial discharge tests to verify that no damage to the sealing mechanism or to the internal structure had occurred.

Additional tests were performed on the same units to demonstrate a MBL of at least 1.2 times the SSL.

RESULTS:

The MH3 series of arresters uses one general porcelain housing type (all housings have the same diameter and weathershed profile, differing only in height), and one design of end fitting. The SSL assigned to MH3 arresters is the load that results in a bending moment of 17000 Nm at the base of the arrester.

To verify the design capability, SSL bending moment tests were performed on three units of the longest length used in the MH3 series of arresters. Loading curves for the three tests are shown in Figures 1 - 3.

Subsequent to the SSL loading tests, the test units were examined and found to have suffered no visual mechanical damage, and have remaining permanent deflection of less than 3 mm at the top end of the units. The units were then returned to the factory for seal leak rate check and partial discharge tests. On all three units, seal leak rate was found to be less than $1x10^{-7}$ $Pa.m^3s^{-1}$, and partial discharge at 1.05 U_c was found to be less than 10pC, both levels being below the limits allowed by IEC 60099-4.

Additional tests were performed on the same three units, with applied load to produce a bending moment of at least 20.4 kNm (1.2 times SSL). Loading curves for these tests are shown in Figures 4 – 6. The porcelain housings of all three units remained intact after this test. While the test was terminated before the porcelains fractured, and the absolute value of MBL was not be determined, the tests were sufficient to verify that the MBL is at least 1.2 times SSL, and therefore meets the requirement of IEC 60099-4.

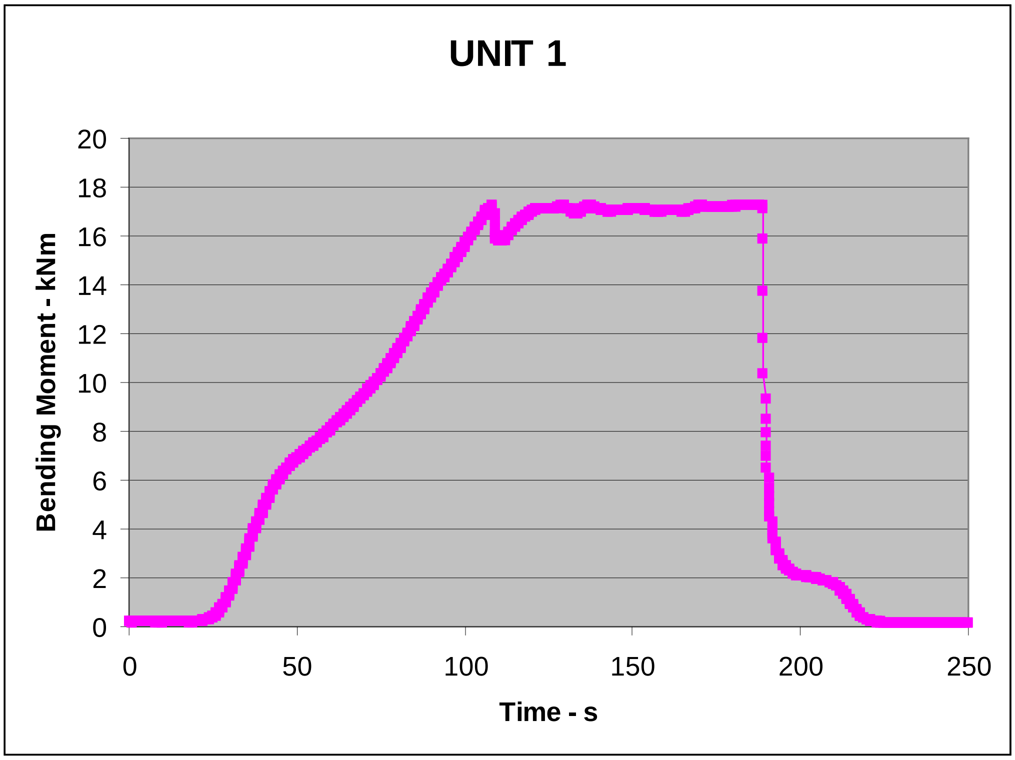


Figure 1. Loading curve to SSL for Unit 1

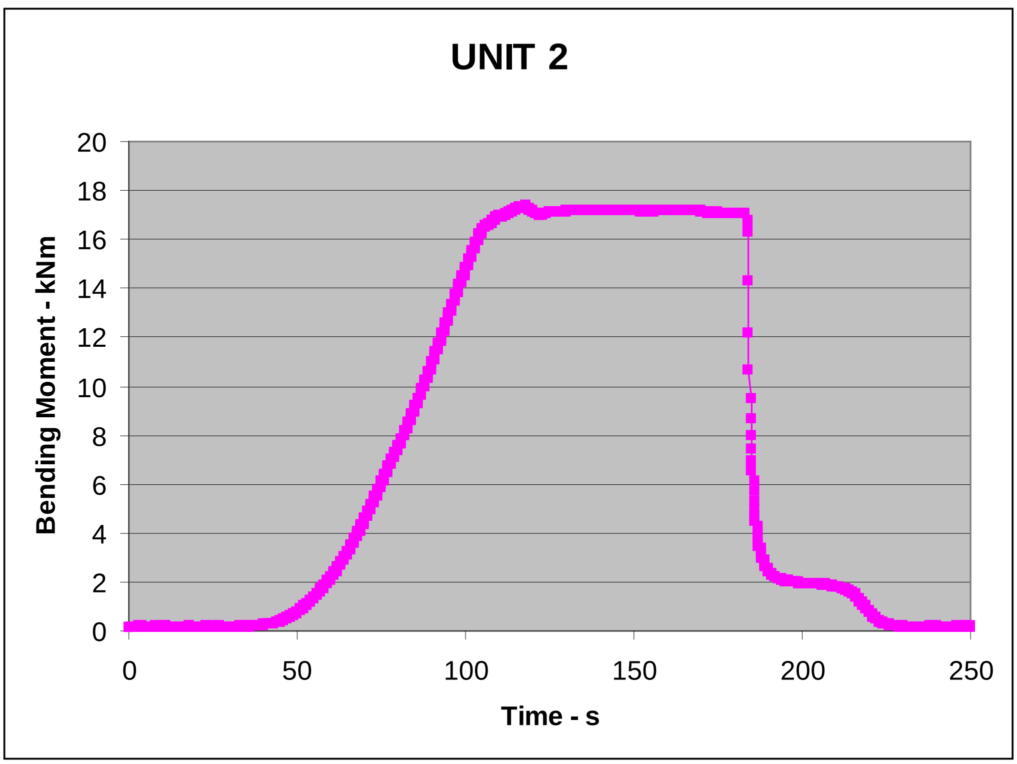


Figure 2. Loading curve to SSL for Unit 2

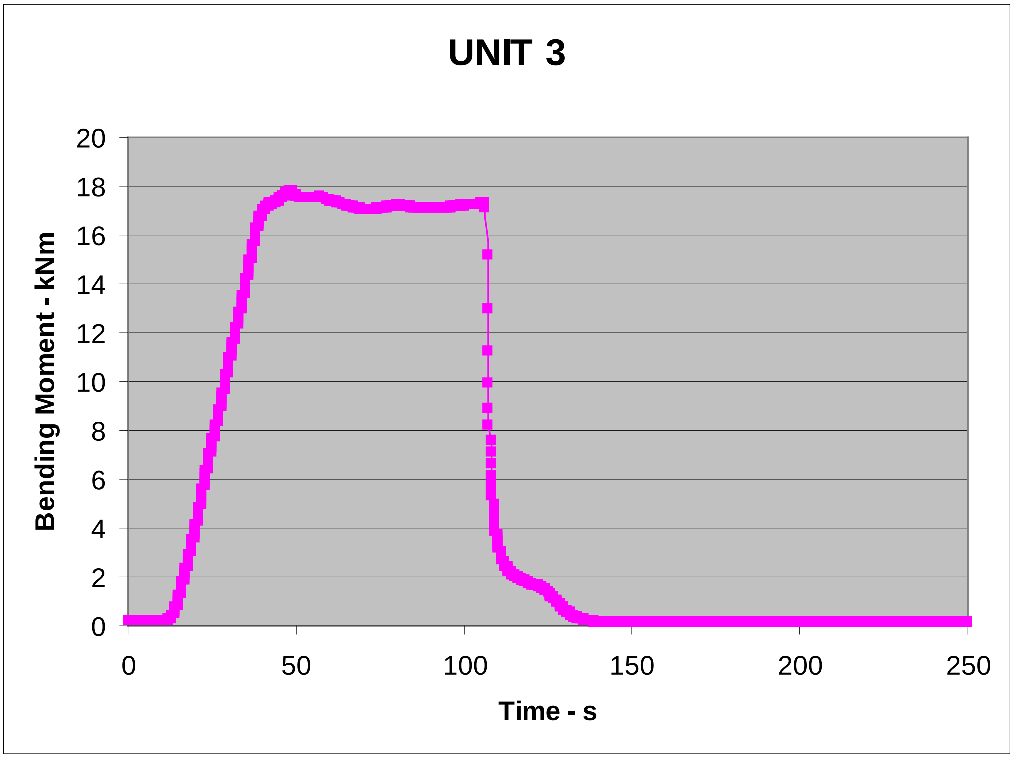


Figure 3. Loading curve to SSL for Unit 3

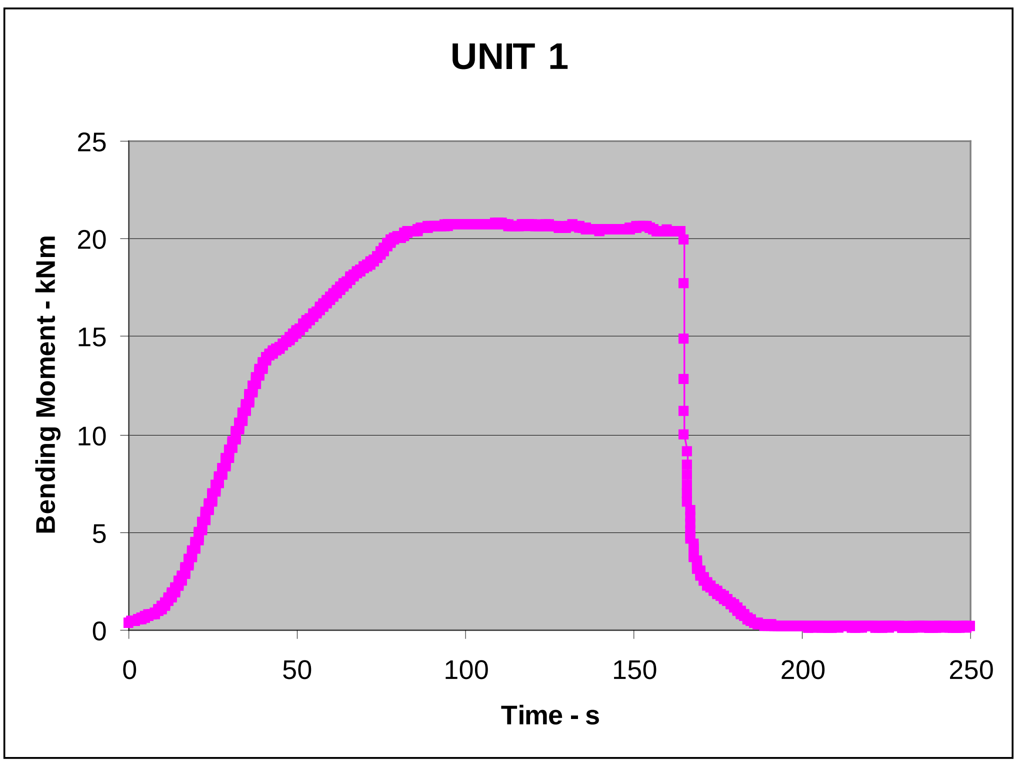


Figure 4. Loading curve to 1.2 times SSL for Unit 1

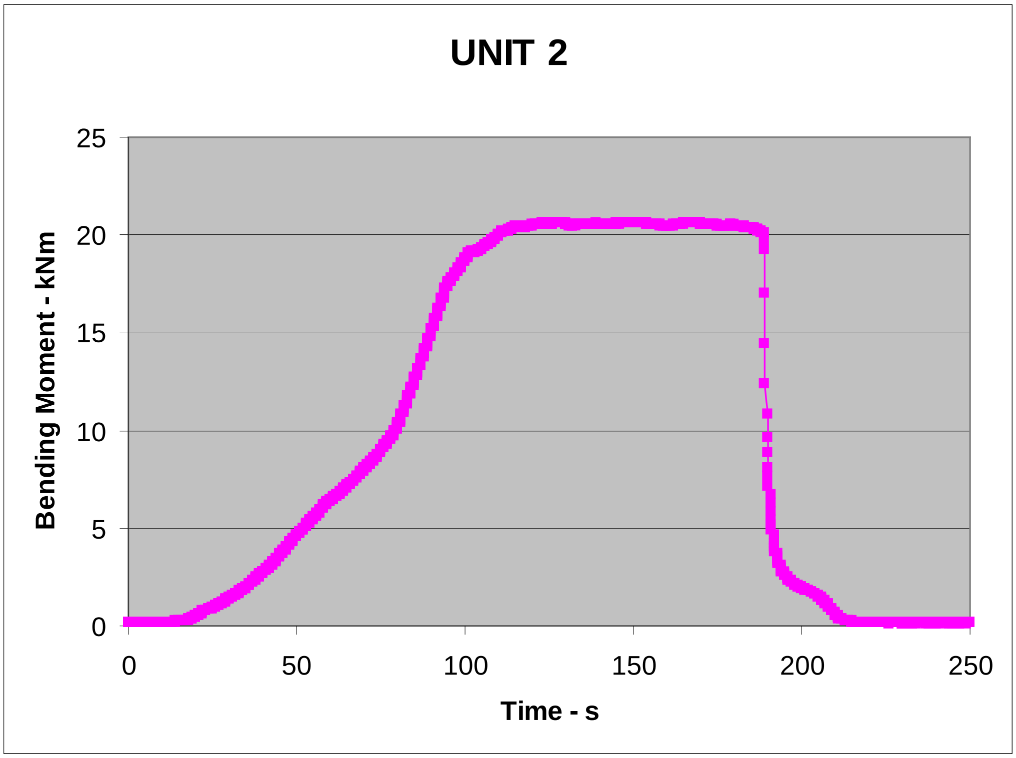


Figure 5. Loading curve to 1.2 times SSL for Unit 2

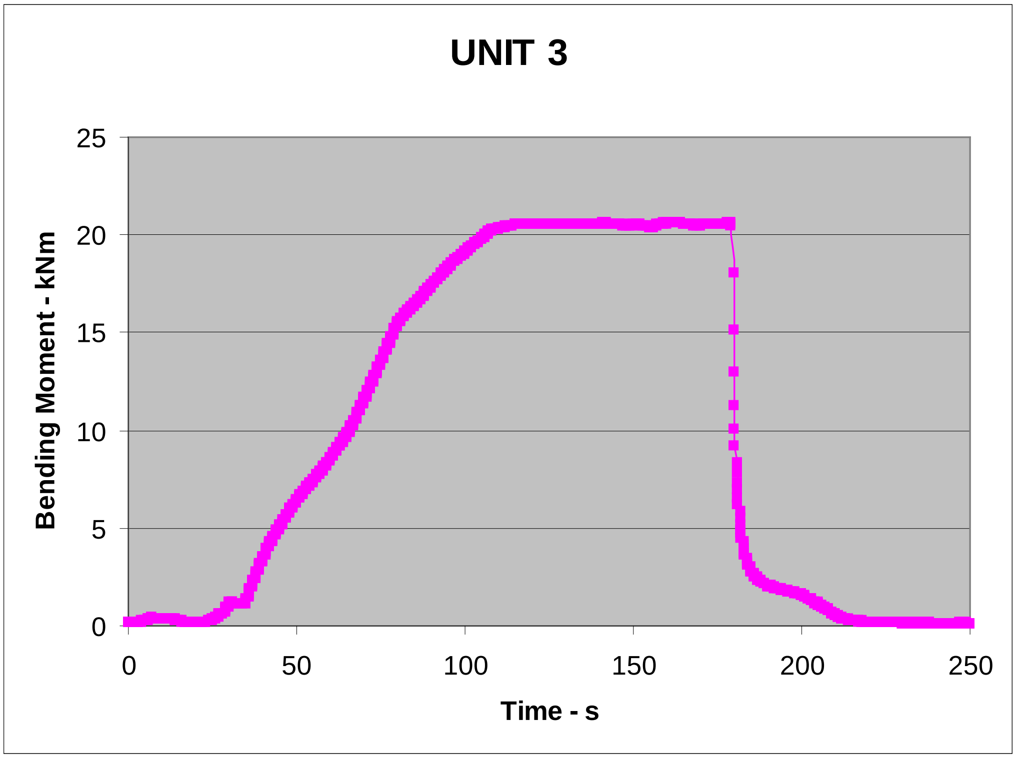


Figure 6. Loading curve to 1.2 times SSL for Unit 3

IEC Type Test Report
Report No. EU1590-H-10
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Environmental Test

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar	M.G. Comber
Product Design Engineer	Manager, Engineering
Date: 6/17/2011	Date: 6/17/2011

IEC TYPE TEST REPORT
Environmental Test

TESTS PERFORMED:

An Environmental test was performed on one completely assembled arrester unit in accordance with the requirements of Clause 8.10 of IEC 60099-4. The purpose of the test is to verify that the sealing system of arresters with enclosed gas volume is not affected by environmental exposure to wide variations in temperature and exposure to heavy amounts of pollution.

The test sample was a completely assembled unit of the MH3 series of arresters. The sample was initially subjected to a leak test according to Clause 9.1 d) of IEC 60099-4.

The unit was then subjected to the temperature cycling portion of the test, which consisted of 10 complete cycles of 3 hours at 50 ^{o}C and 3 hours at -35 ^{o}C, with a temperature gradient change between temperature levels of 1 K/min.

The unit was subsequently subjected to a continuous salt-mist for 96 hours. The salt concentration of the mist was maintained between 4% and 6% by weight (equivalent to 40-60 g/l of salt to water).

After the salt mist test, the unit was again subjected to the leak test of Clause 9.1 d) of IEC 60099-4.

RESULTS:

The unit successfully passed the initial leak check, with leak rate less than 1 x 10^{-6} $Pa.m^3.s^{-1}$.

Figure 1 shows the temperature profile during temperature profile portion of the test.

Figures 2-4 shows the condition of the unit at the end of the salt mist portion of the test.

After being removed from the salt mist chamber, the unit successfully passed the repeat leak check, with leak rate less than 1 x 10^{-6} $Pa.m^3.s^{-1}$, thereby meeting the requirements of IEC 60099-4.

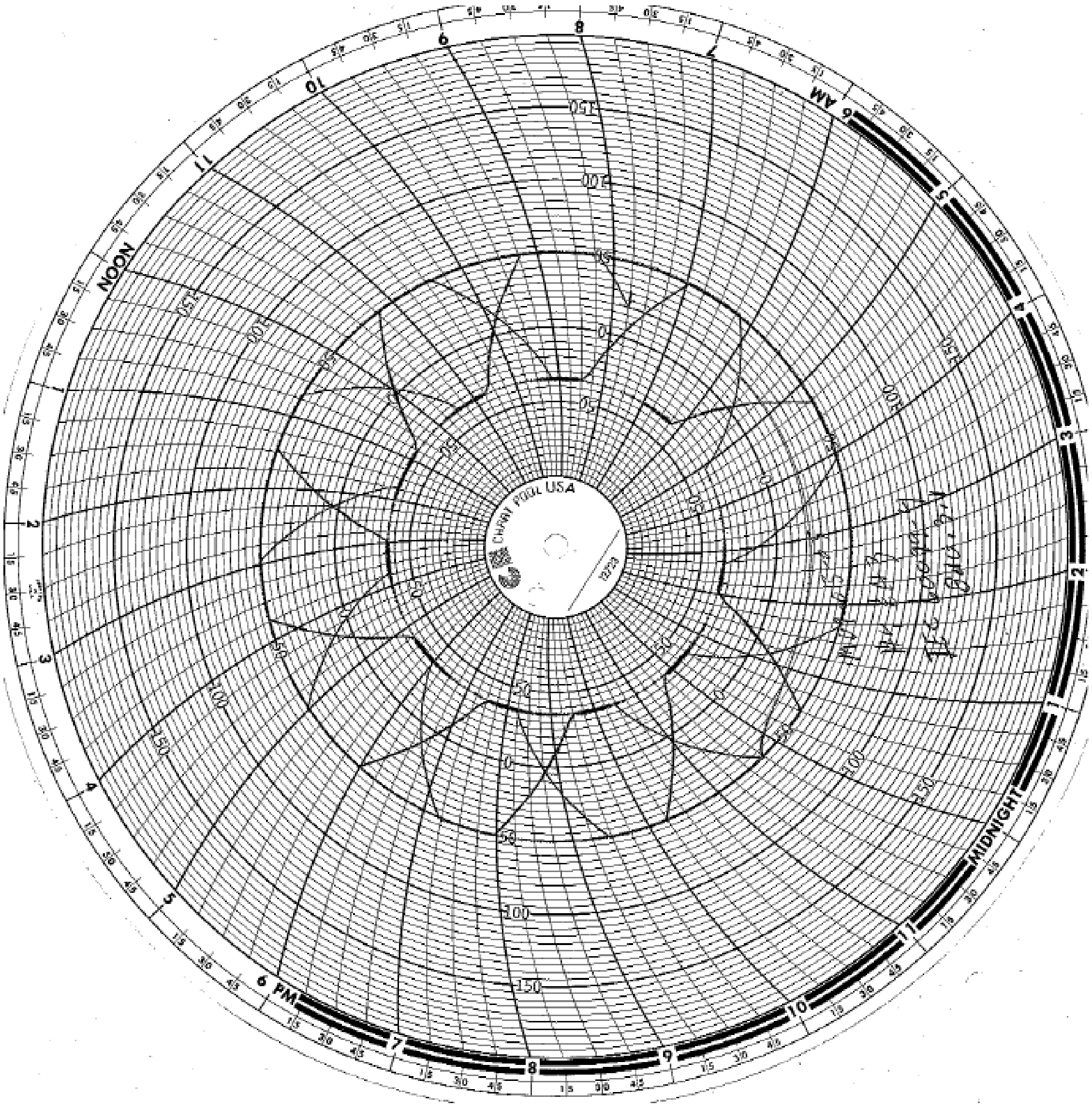


Figure 1. Copy of temperature profile recorded during the temperature cycling portion of the test.

Figure 2. Test sample at end of salt mist portion of test

Figure 3. Top end of test sample at end of salt mist portion of test

Figure 4. Bottom end of test sample at end of salt mist portion of test

IEC Type Test Report
Report No. EU1590-H-11
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Seal Leak Rate

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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.

Senthil S. A. Kumar	M.G. Comber
Product Design Engineer	Manager, Engineering
Date: 6/17/2011	Date: 6/17/2011

IEC TYPE TEST REPORT
Seal Leak Rate

Clauses 10.8.11 of IEC 60099-4 requires that one complete arrester be subjected to a seal leak rate test, using any sensitive method suitable for the measurement of the specified seal leak test. Using the adopted method, the seal leak rate shall be lower than $1x10^{-6}$ $Pa.m^3s^{-1}$.

Clause 9.1 d) of this same standard requires that, for arrester units with sealed housing, all manufactured units be subjected to a seal leak test as a routine test. In this test, the method used for MH3 series arresters is the “vacuum helium mass spectrometer” method. With this method, the internal air space of the arrester unit is evacuated, resulting in a one atmosphere pressure differential between outside and inside, under which conditions the outside of the arrester is flooded with helium. The evacuation port is monitored by a mass spectrometer tuned to detect helium, and any helium detected is quantitatively measured to provide a leak rate. The maximum leak rate accepted for MH3 series arrester units is $1x10^{-7}$ $Pa.m^3s^{-1}$, one order of magnitude below the maximum allowed by IEC 60099-4. Routine test reports are provided on request verifying that this requirement has been met.

By performing the routine testing of units according to Clause 9.1 d), the type test requirements of Clause 10.8.11 are automatically met.

IEC Type Test Report
Report No. EU1590-H-12
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Radio Influence Voltage (RIV)

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar
Product Design Engineer
Date: 6/17/2011

M.G. Comber
Manager, Engineering
Date: 6/17/2011

TESTS PERFORMED:
A fully-assembled arrester, with voltage rating U_r of 420 kV and continuous operating voltage U_c of 336 kV, was subjected to the RIV test as prescribed in Clause 8.11 of IEC 60099-4. Tests were performed on the arrester equipped with a 990 mm diameter grading ring and equipped with a 1530 mm diameter grading ring. In both cases, the voltage application was as follows:

- raised to 386 kV (1.15 U_c)
- lowered to 352 kV (1.05 U_c)
- held at 352 kV for 5 min
- lowered in steps of approximately 0.1 U_c until reaching 0.5 U_c
- increased in similar steps until reaching 352 kV (1.05 U_c)
- held at 352 kV for 5 min
- lowered again in steps of approximately 0.1 U_c until reaching 0.5 U_c

RIV measurements were made at each voltage level. The variable-frequency RIV meter was tuned to 0.55 MHz for the measurements.

RESULTS:
Prior to installing the arrester in the test circuit, an open circuit test was run to determine the background noise of the circuit. The arrester was installed and the sequence of voltage applications described above was applied. Figures 1a and 1b show the arrester installed for test. Results of the RIV measurements are shown in Table 1.

At all test voltage levels, the RIV was well below the maximum of 2500 µV allowed by IEC 60099-4.

It is noted that, although this arrester has a nameplate U_c of 336 kV, it would be applied on a system with U_m of 420 kV, for which the maximum line-to-ground voltage is 242 kV. At this level, the RIV was at or below background level for both tests.

(a) with 990 mm diameter ring **(b) with 1530 mm diameter ring**

Figure 1. 420 kV rated arrester installed for test

Table 1. Measured RIV values

Test condition	Test voltage (kV rms)	RIV with 990 mm ring (μV)	RIV with 1530 mm ring (μV)
Open circuit	400	60	60
Arrester installed	386	180	50
Arrester installed	352	160	40
Arrester installed	318	160	32
Arrester installed	264	80	24
Arrester installed	230	12	8
Arrester installed	196	0.6	0.6
Arrester installed	168	0.6	0.6
Arrester installed	196	0.6	0.6
Arrester installed	230	12	8
Arrester installed	264	70	20
Arrester installed	318	160	40
Arrester installed	352	200	40
Arrester installed	318	160	24
Arrester installed	264	80	22
Arrester installed	230	12	10
Arrester installed	196	0.6	0.6
Arrester installed	168	0.6	0.6

IEC Type Test Report
Report No. EU1590-H-13
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Power Frequency Voltage Versus Time

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

Senthil S. A. Kumar
Product Design Engineer
Date: 6/17/2011

M.G. Comber
Manager, Engineering
Date: 6/17/2011

IEC TYPE TEST REPORT
Power Frequency Voltage Versus Time

TESTS PERFORMED:

Power frequency voltage versus time tests were performed on a prorated test section prepared based on the results of the tests to verify heat dissipation behavior of test sample. Each section consisted of two resistors in series. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with Annex D of IEC 60099-4.

Prior to the test, measurements were made on the test section to determine its switching impulse residual voltage and its reference voltage.

Tests were made for three different time durations (1.1 s, 10 s and 210 s) of elevated voltage application. For each test, the section was placed in an oven and heated overnight to 60 ± 3 °C. After removal from the oven, the section was subjected to two long duration current impulses, with time between impulses being between 50 and 60 seconds. The parameters of the transmission line used to generate these impulses conformed to the requirements for Line Discharge Class 3 in Table 5 of Clause 8.4.2 of IEC 60099-4. Within 100 milliseconds of the second long duration current impulse, an elevated power frequency voltage (above U_c) was applied for a measured period of time, following which the voltage was reduced to the adjusted value U_c for 30 min. During the 30 min period at U_c the power dissipation was monitored to verify thermal stability.

Table 1 lists the parameters of the test sections and the corresponding transmission line parameters used for the test. U_c for the MH3 series of arresters has been established as 0.795 times the lowest acceptable reference voltage in routine tests, and U_r has been established as 1.25 times U_c . This is represented in this type test by assigning the test sample U_c equal to 0.795 x U_{ref} of the test sample, and test sample U_r at 1.25 times this value . The minimum energy required for each line discharge for Class 3 arresters is determined from the following formula given in Clause 8.4.2 of IEC 60099-4

$$W = U_{res} \times (U_L - U_{res}) \times 1/Z \times T$$

where U_{res} is the switching impulse residual voltage at 250 A.

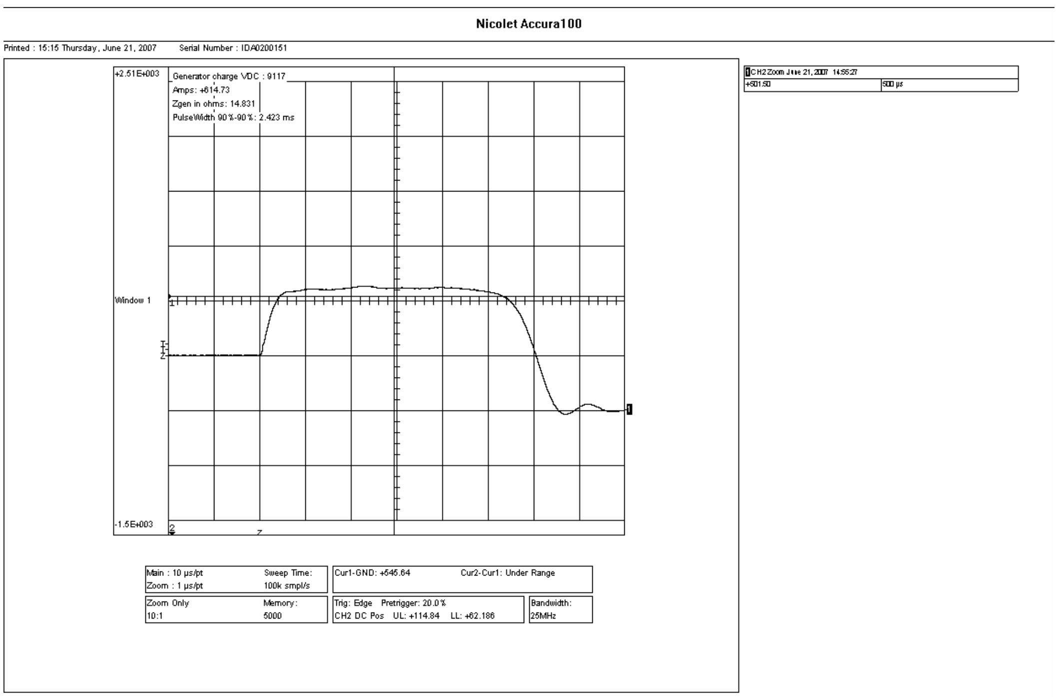
Table 1. Test section and transmission line parameters

Parameter	Value
Switching impulse residual voltage (kV) U_{res}	20.62
Reference Current (mA) I_{ref}	9.5
Reference Voltage ($kV_c / \sqrt{2}$) V_{ref}	11.50
COV (kV rms) U_c	9.15
Rating (kV rms) U_r	11.44
Arrester Classification (kA)	10
Line Discharge Class	3
Virtual Duration of Peak (µs, 90-90%) T - minimum	2400
Surge Impedance (Ω) Z - max (1.3 U_r)	14.87
Charging Voltage (kV) U_L – min (2.8 U_r)	32.03
Energy required (kJ) - min	38.0

RESULTS:

A short circuit test was performed on the generator to confirm that generator impedance and duration of the current discharge met the requirements listed in Table 1. The oscillogram of Figure 1 shows

Z_g = 9 117 V / 614.7 A = 14.831 Ω   Virtual Duration of Peak = 2 423 µs



test

Table 2 lists measurements made during the application of the line discharges for the three tests. Oscillograms made during this portion of the test are shown in Figures 2 – 4.

Tables 3 and 4, respectively, list measurements made during the application of elevated voltage and during the subsequent 30 min application of U_c.

Figure 5 shows the three test points (elevated voltages for 1.1 s, 10 s and 210 s) superimposed on the characteristic of power frequency voltage vs. time for MH3 series of arresters.

Table 2. Line discharge measurements

Discharge parameters	Sample for 1.1 s test		Sample for 10 s test		Sample for 210 s test	
	1st discharge	2nd discharge	1st discharge	2nd discharge	1st discharge	2nd discharge
Current (A)	623	650	667	648	666	642
Voltage (kV)	21.1	22.1	21.9	22.2	21.7	22.0
Energy (kJ)	38.3	38.8	39.5	38.8	38.9	38.1

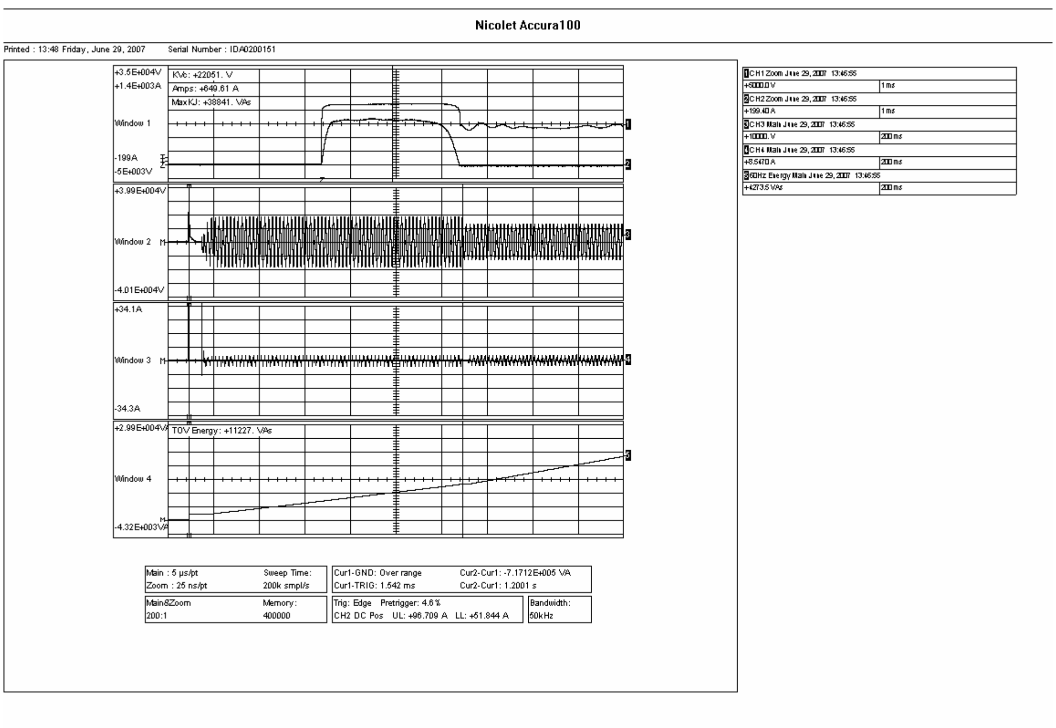


Figure 2. Oscillograms of line discharge and 1.1 s application of elevated voltage

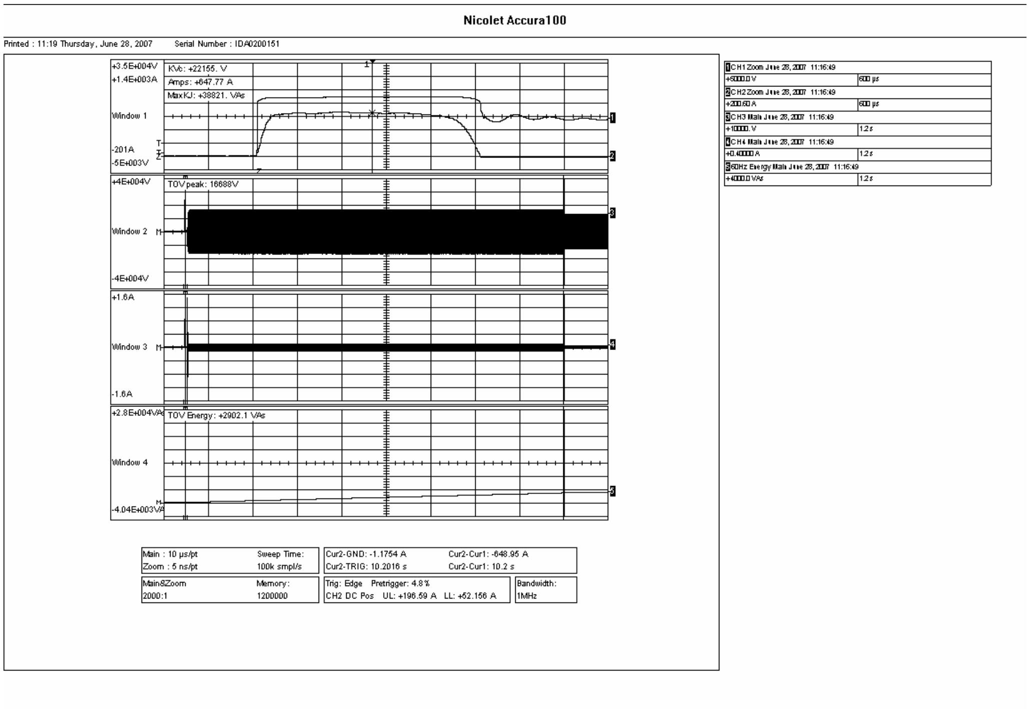


Figure 3. Oscillograms of line discharge and 10 s application of elevated voltage

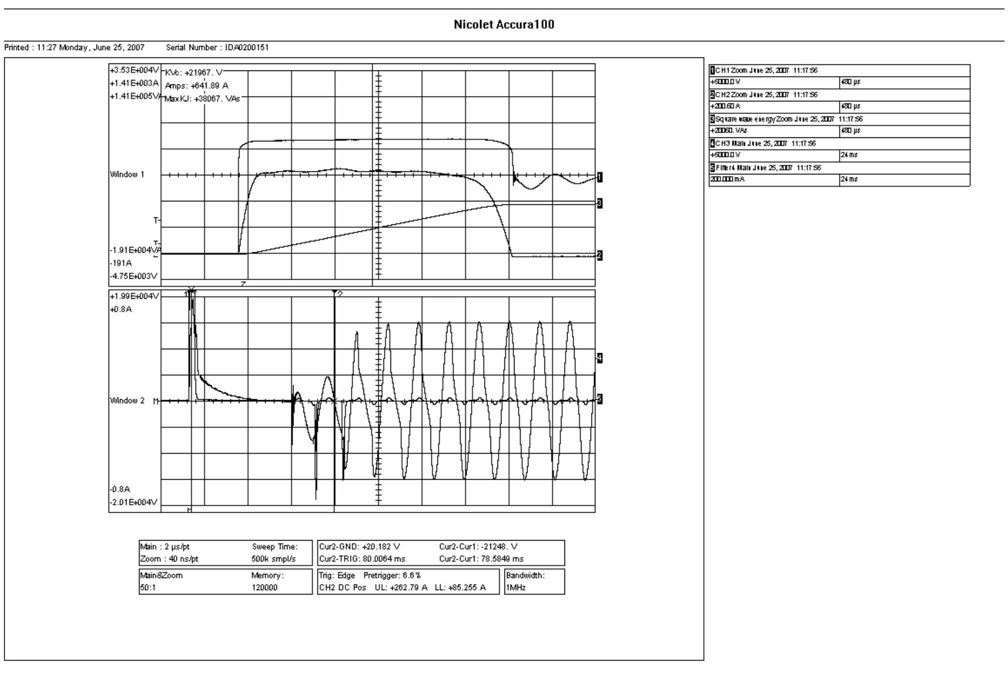


Figure 4. Oscillograms of line discharge and first several cycles of 210 s application of elevated voltage

Table 3. Measurements of voltage and current during application of elevated voltage

1.1 s elevated voltage				10 s elevated voltage				210 s elevated voltage			
Elapsed time	Applied voltage		Current	Elapsed time	Applied voltage		Current	Elapsed time	Applied voltage		Current
s	kVrms	pu Ur	mA peak	s	kV peak	pu Ur	mA peak	s	kVrms	pu Ur	mA peak
0.07	12.84	1.116	3.13	0.07	11.63	1.011	101.7	0	10.91	0.948	36.9
0.21	12.84	1.116	3.15	1.06	11.74	1.021	109.2	13	10.94	0.952	32.7
0.31	12.87	1.119	3.18	2.04	11.76	1.022	106.7	39	10.95	0.952	32.2
0.40	12.89	1.121	3.25	3.00	11.77	1.024	110.8	50	10.94	0.952	32.5
0.51	12.90	1.122	3.25	4.03	11.76	1.022	105.8	64	10.91	0.949	32.8
0.61	12.90	1.122	3.24	5.06	11.76	1.023	108.3	70	10.92	0.949	32.6
0.70	12.88	1.120	3.26	6.02	11.76	1.022	105.8	89	10.93	0.950	32.2
0.81	12.92	1.123	3.31	7.03	11.76	1.023	106.7	101	10.94	0.952	33.6
0.90	12.91	1.122	3.37	8.11	11.76	1.022	109.2	120	10.98	0.955	35.0
1.00	12.89	1.121	3.35	9.24	11.77	1.024	112.1	210	10.96	0.953	39.2
1.20	12.89	1.121	3.41	10.20	11.77	1.024	112.1				
Avg rms voltage during period	12.88	1.120		Avg rms voltage during period	11.75	1.022		Avg rms voltage during period	10.94	0.951	

Table 4. Measurements of power dissipation and current during 30 min at U_c

1.1 s elevated voltage				10 s elevated voltage				210 s elevated voltage			
Elapsed time	Applied voltage	Power diss.	Current	Elapsed time	Applied voltage	Power diss.	Current	Elapsed time	Applied voltage	Power diss	Current
mm:ss	kVrms	W	mA peak	mm:ss	kVrms	W	mA peak	mm:ss	kVrms	W	mA peak
00:00	9.26	35.02	9.52	00:00	9.27	18.58	5.15	00:00	9.26	27.96	8.14
00:30	9.20	27.83	7.54	00:30	9.23	16.30	4.69	00:30	9.18	25.62	7.35
01:00	9.17	25.25	7.24	01:00	9.24	15.62	4.44	01:00	9.17	24.56	6.76
02:00	9.19	23.06	6.42	02:00	9.21	14.22	4.09	02:00	9.16	23.04	6.30
05:00	9.19	18.82	5.41	05:00	9.18	11.87	3.48	05:00	9.22	20.72	5.92
10:00	9.17	15.03	4.29	10:00	9.21	9.93	3.06	10:00	9.18	16.64	4.80
20:00	9.19	11.16	3.30	20:00	9.17	7.38	2.43	20:00	9.16	12.13	3.57
30:00	9.22	9.04	2.77	30:00	9.18	5.97	2.07	30:00	9.22	9.84	2.92

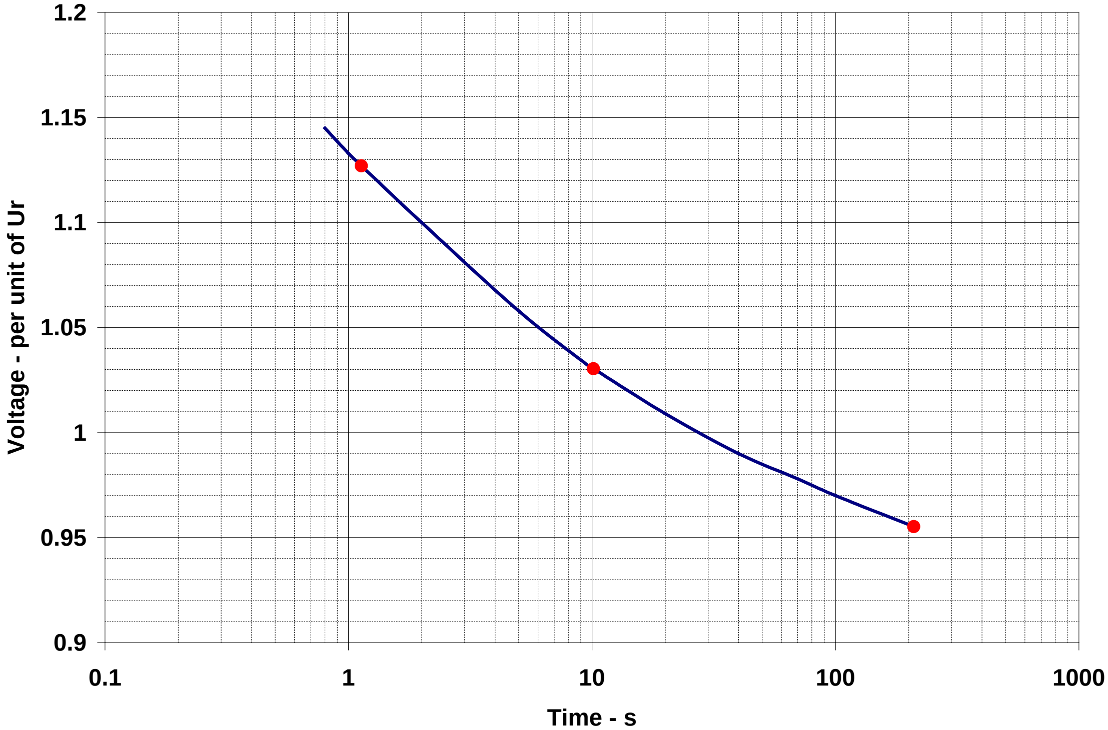


Figure 5. Power frequency voltage vs. time characterstic for MH3 series arresters, with test points for 1.1 s, 10 s and 210 s

IEC Type Test Report
Report No. EU1590-H-14
MH3 Series Porcelain-housed Arrester
10,000 A Line Discharge Class 3

Artificial Pollution

This report records the results of type tests made on MH3 series 10 kA Line Discharge Class 3 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.2, 2009, "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.

S. A. Senthil Kumar

Senthil S. A. Kumar
Product Design Engineer
Date: 6/17/2011

Michael G. Comber

M.G. Comber
Manager, Engineering
Date: 6/17/2011

IEC TYPE TEST REPORT
Artificial Pollution

INTODUCTION:
The MH3 series of arresters are available with different specific creepage distances for application in environments with different pollution levels. IEC 60815 provides guidelines for specific creepage distances, namely: 16 mm / kV maximum system voltage for light pollution conditions; 20 mm / kV maximum system voltage for medium pollution conditions; 25 mm / kV maximum system voltage for heavy pollution conditions; and 31 mm / kV maximum system voltage for very heavy pollution conditions. The MH3 series of arresters are available with specific creepage distances meeting the IEC 60815 guidelines for each of these pollution conditions.

Annex F of IEC 60099-4 prescribes procedures for determining the temperature rise of resistor elements when the arrester is subjected to different levels of artificial pollution. If the temperature rise is found to be greater than 40 K, then the pre-heating temperature for the operating duty test must be increased from 60^{o}C by an amount that the temperature rise exceeds 40 K. If the temperature rise is not greater than 40 K, no modification to the pre-heating temperature in the operating duty test is required. An analytical procedure is provided to determine the temperature rise in absence of performing physical tests. These procedures are used in the following to validate the MH3 "medium pollution" design.

DEFINITION OF TERMS:

q_Z [C/hm] Mean external charge flowing on the surface of insulators and surge arrester housings during pollution events in service, relevant to a pollution event lasting a time t_Z. This parameter is used for the classification of the pollution severity of a site.

t_Z [h] Duration of a pollution event in service.

β [K/C] Ratio between the temperature rise of the internal parts of the arrester and the relevant charge flowing internally as determined in the preliminary heating test.

τ [h] Equivalent thermal time constant of the arrester as determined in the preliminary heating test.

D_m [m] Average diameter of the surge arrester housing: it is calculated according to the method reported in IEC 60815.

$\Delta T_{Z\ max}$ [K] Maximum theoretical temperature rise in service calculated as a function of β, q_Z, t_Z, D_m and τ.

U_r [kV] is the rated voltage of the surge arrester.

$U_{r\ min}$ [kV] is the minimum rated voltage among the surge arrester units.

PRELIMINARY HEATING TEST: MEASUREMENT OF THE THERMAL TIME CONSTANT τ AND CALCULATION OF β:

A procedure similar to that specified in Annex B of IEC 60099-4 was performed on an assembled arrester unit equipped with thermocouples at three locations distributed along the length of the resistors. The unit represented the maximum unit length used in the arrester design, and contained the maximum number of resistors used for this length unit. The following results were obtained:

- the ambient temperature (T_a) was 23.3 ^oC
- the heating time (t_h) was 9 min (required to be less than 10 min);
- the charge (Q_h) applied to the surge arrester during the heating was 11.5 C
- the temperature rise (ΔT_h) during the application of charge (Q_h) was 98.0 K
- the time (τ) derived from the cooling curve of the arrester between the temperatures of 60 °C and 22 + 0.63 T_a was 2.24 h (see cooling curve shown in Figure 1)

The parameter β is calculated according to:

$$\beta = \frac{\Delta T_h}{Q_h} = 8.52 \ \text{kC}^{-1}$$

CALCULATION OF THEORETICAL MAXIMUM TEMPERATURE RISE OF RESISTORS:

This calculation assumes that all the charge expected in service (q_z) flows internally. In this hypothesis, $\Delta T_{z\ max}$ is derived as follows:

$$\Delta T_{z\ max} = \beta\, q_z\, D_m\, \tau \left(1 - e^{\left(-\frac{t_z}{\tau}\right)}\right)\left(\frac{U_r - U_{r\ min}}{U_r}\right) \qquad (1)$$

The average diameter (D_m) of the arrester unit is determined according to IEC 600815 as

$$D_m = (D_{e1} + D_{e2} + 2D_i) / 4$$

For the housing used for this arrester

$$D_{e1} = 0.305 \text{ m}$$
$$D_{e2} = 0.260 \text{ m}$$
$$D_i = 0.165 \text{ m}$$

giving

$$D_m = 0.224 \text{ m}$$

The worst case (highest value) of the term *$(U_r - U_{rmin})/U_r$* for the MH3 series "medium pollution" design occurs for an arrester rating *(Ur)* of 444 kV, for which the smallest unit has a rated voltage (U_{rmin}) of 84 kV.

The values of t_z and q_z are obtained from Table F.1 of IEC 60099-4. For **medium** pollution zone, two sets of values are given:

$$t_z = 2\text{ h}, \; q_z = 3.3\text{ C} \quad \text{and} \quad t_z = 6\text{ h}, \; q_z = 2.4\text{ C}$$

Substituting the known, measured and provided values of parameters into (1), the calculated theoretical maximum temperature rise of resistors for light pollution events is

$$\Delta T_{zmax} = 6.8\text{ K} \quad \text{for a 2 h pollution event}$$
$$\Delta T_{zmax} = 7.8\text{ K} \quad \text{for a 6 h pollution event}$$

Since these calculated temperature rises are less than 40 K, it is not necessary to adjust the 60°C pre-heating temperature for the operating duty test.

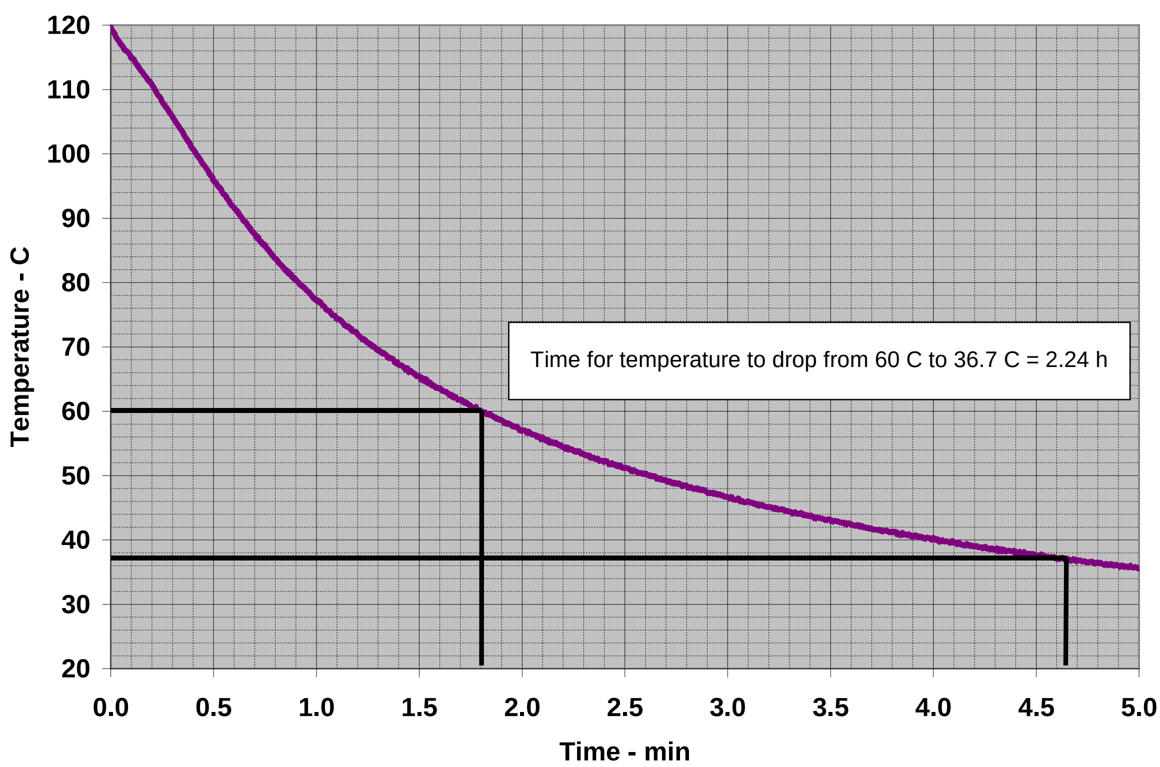


Figure 1. Resistor temperature vs. time after heating to 120°C