HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-00.1
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

This report records the results of type tests made on PH3 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.

Michael G. Comber

M. G. Comber
Manager, Engineering

Date: 8/24/2007

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

Report No.	Description	Clause	Issue date
EU1527-H-01	Insulation Withstand Test on Arrester Housing	10.8.2	9/29/2006
EU1527-H-02	Residual Voltage	10.8.3	9/29/2006
EU1527-H-03	Long Duration Current Withstand	10.8.4	9/29/2006
EU1527-H-04	Accelerated Aging Procedure	10.8.5	9/29/2006
EU1527-H-05	Heat Dissipation Behavior of Test Section	10.8.5	9/29/2006
EU1527-H-06	Switching Surge Operating Duty	10.8.5	9/29/2006
EU1527-H-07	Short Circuit	10.8.7	9/29/2006
EU1527-H-08	Internal Partial Discharge	10.8.8	9/29/2006
EU1527-H-09	Bending Moment	10.8.9	9/29/2006
EU1527-H-10	Seal Leak Rate	10.8.11	9/29/2006
EU1527-H-11	RIV	10.8.12	9/29/2006
EU1527-H-12	Moisture Ingress	10.8.13	9/29/2006
EU1527-H-13	Weather Ageing	10.8.14	9/29/2006
EU1527-H-14.1	Power Frequency Voltage Versus Time	Annex D	8/24/2007

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-01
PH3 Series Polymer-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 PH3 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.

Michael G. Comber

M. G. Comber
Manager, Engineering

Date: 9/29/2006

IEC TYPE TEST REPORT
Insulation Withstand Test on Arrester Housing

TESTS PERFORMED:
Insulation withstand tests were made on one arrester unit with internal components removed, in accordance with the requirements of clause 10.8.2 of IEC 60099-4. It is required that the external insulation withstand of the arrester housing conforms to the following:

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

RESULTS:

The PH3 series of arresters use four different housing lengths, all using the same weathershed geometry. The insulation withstand tests were performed on a sample constructed with the longest housing. The highest U_c used in this housing is 120 kV, for which the lightning impulse protective level is 358 kV at 10kA, and the maximum switching impulse protective level is 296 kV at 1kA.

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.

The required minimum lightning impulse withstand voltage is 1.3 times the maximum lightning impulse protective level, or 1.3 x 358 = 466 kV.

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.

The required minimum switching impulse withstand voltage is 1.25 times the maximum switching impulse protective level, or 1.25 x 296 = 370 kV.

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.

The required minimum power frequency withstand voltage is 1.06 times the maximum switching impulse protective level, or 1.06 x 296 = 312 kVpeak.

Tests were successfully performed at levels higher that exceeded the minimum levels indicated above. Results are summarized in Table 1.

Table 1. Measured and corrected withstand values

Withstand test	Uncorrected withstand voltage	Atmospheric conditions			Correction factors		Corrected withstand
		Ambient temperature	Air pressure	Absolute humidity	Air density	Humidity	
	kV pk	°C	KPa	gm^{-3}	k_1	k_2	kV peak
Lightning impulse, pos	669	27.2	97.9	13.3	.943	1.027	690
Lightning impulse, neg	830	18.4	97.9	11.8	.971	1.005	850
Switching impulse, pos	500	18.7	98.1	Wet test	--	1.000	500
Switching impulse, neg	634	18.7	98.1	Wet test	--	1.000	634
60 Hz	355	18.6	98.0	Wet test	--	1.000	355

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-02
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Residual Voltage

This report records the results of type tests made on PH3 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.

M. G. Comber
Manager, Engineering

Date: 9/29/2006

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	_s	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

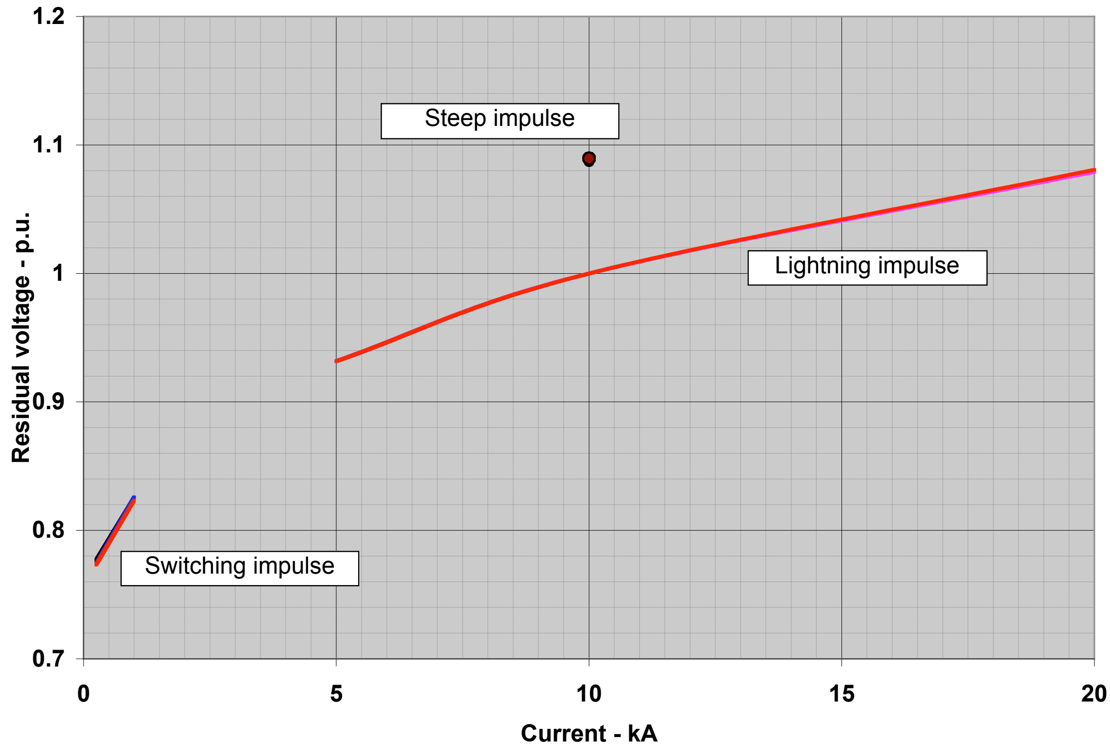
Table 2. Measurements made on test sample 2

Test wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	_s	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	_s	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 PH3 series arresters. For the cases of switching impulse and lightning impulse residual voltages, the arrester residual voltages are calculated as follows:

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

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:

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

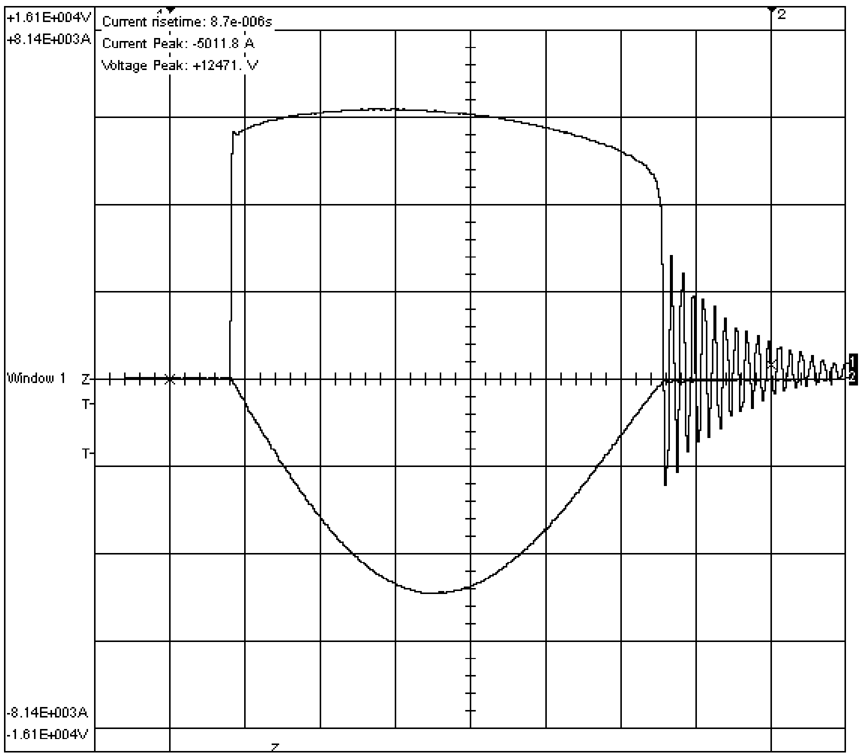
where
L' is the inductivity per unit length (= 1 μH/m)
h is the length of the arrester (excluding the resistors since resistor inductance is already included in the test measurements)
I_n is the nominal discharge current (= 10 kA)
T_f is the front time of the steep current impulse (= 1μs)

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

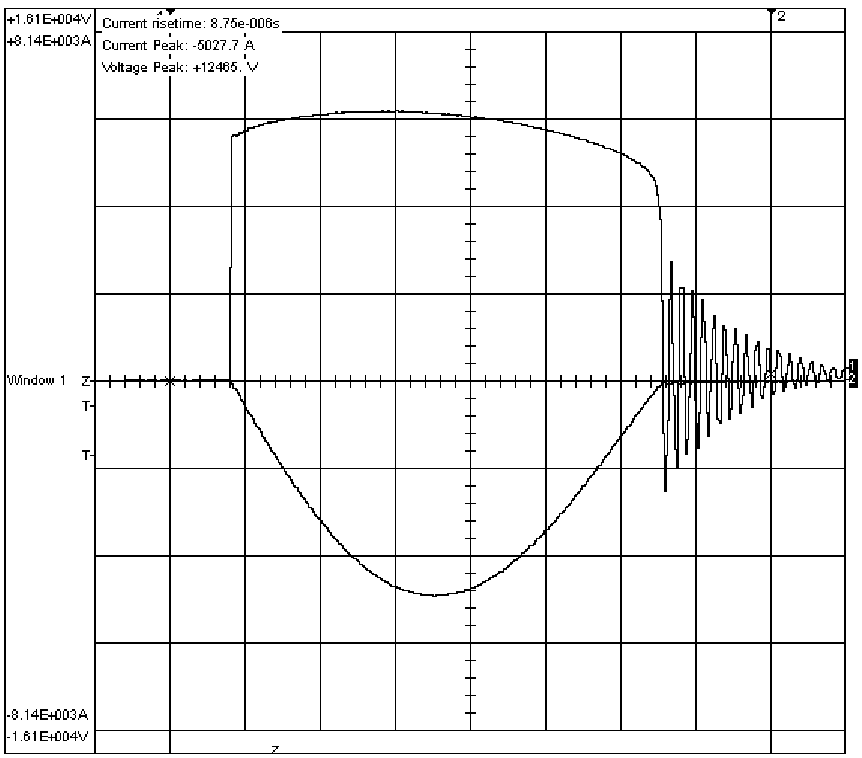
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -570.08 A LL: -1700.1 A	4.4MHz

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
Zoom Only	Memory:
5:1	2000

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

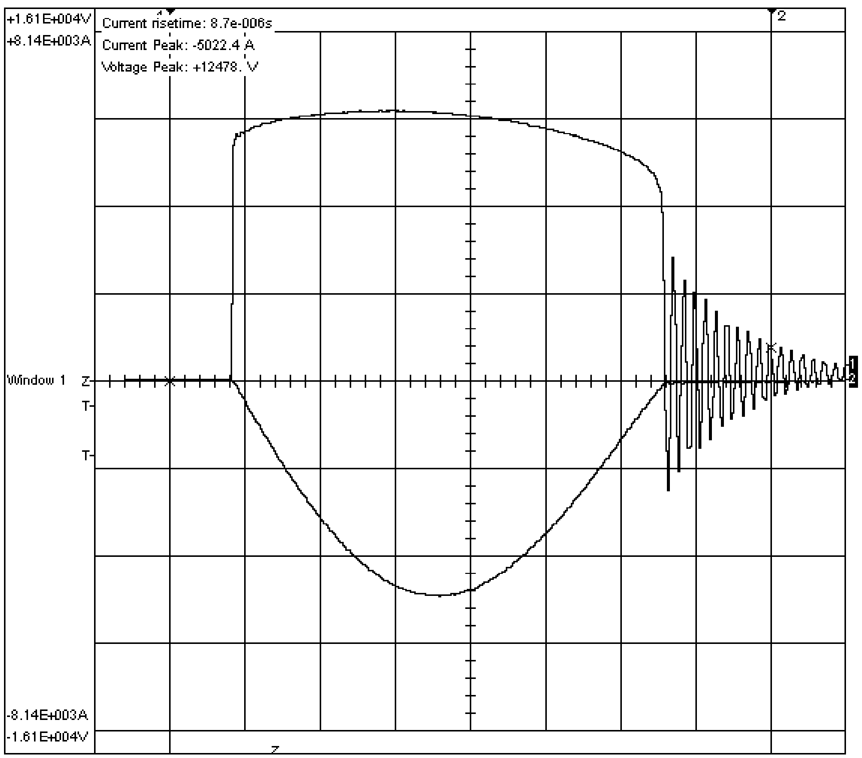
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -570.08 A LL: -1700.1 A	4.4MHz

1 CH1 Zoom July 20, 2006 14:10:51	
+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
Zoom Only	Memory:
5:1	2000

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

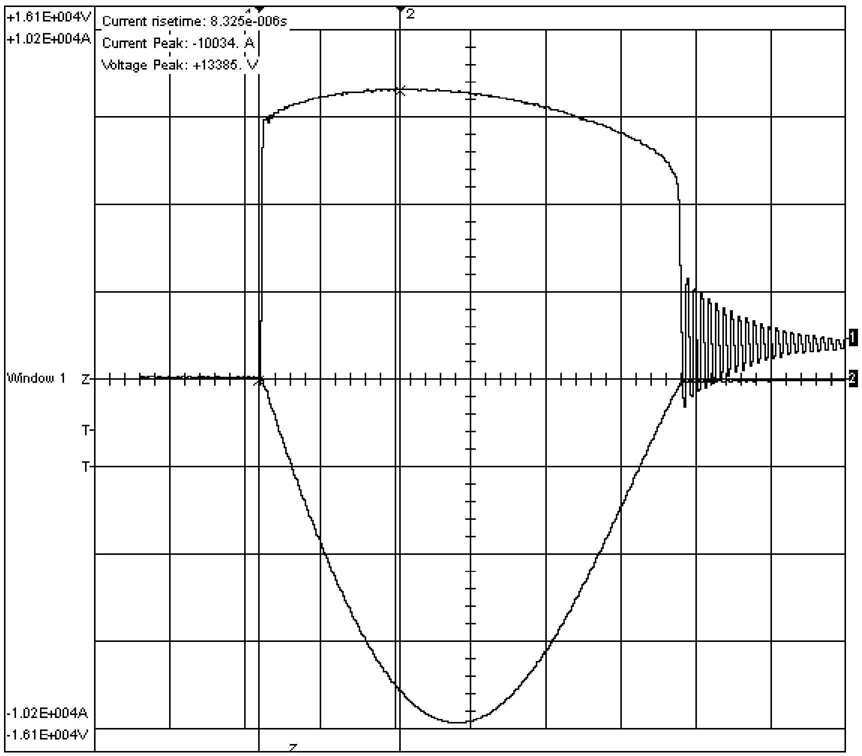
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -570.08 A LL: -1700.1 A	4.4MHz

1 CH1 Zoom July 20, 2006 14:18:57	
+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
Zoom Only	Memory:
5:1	2000

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

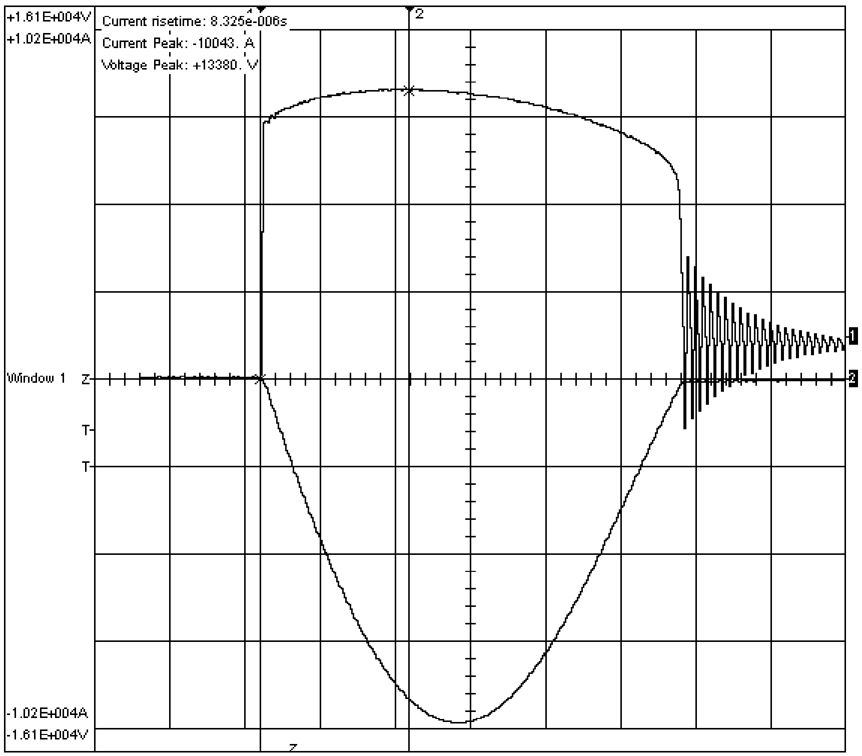
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -1460.8 A LL: -2529.7 A	4.4MHz

1 CH1 Zoom July 20, 2006 15:39:29	
+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 %
CH2 DC Neg UL: -1460.8 A LL: -2529.7 A

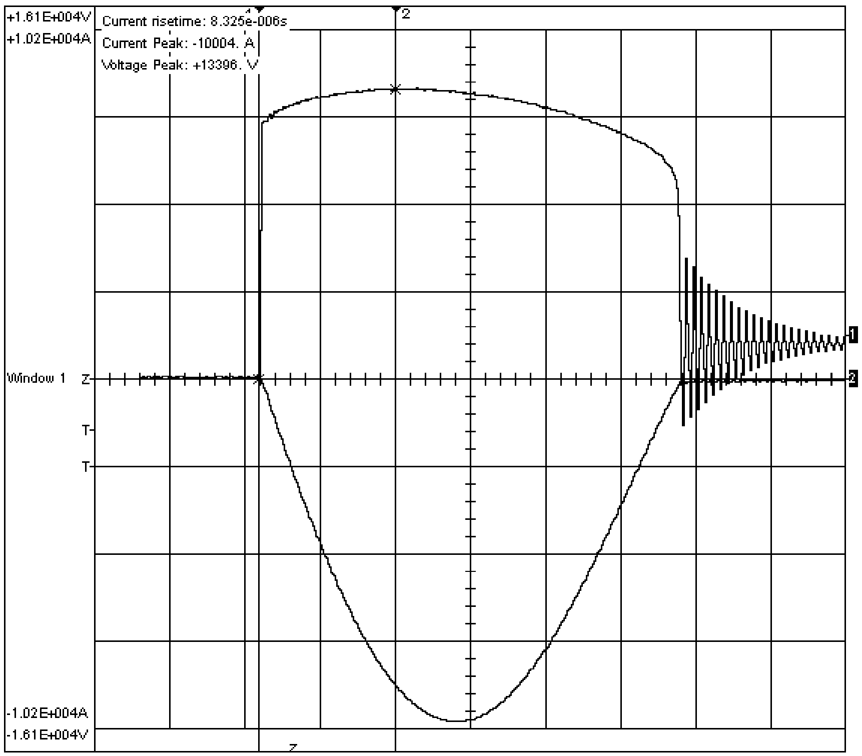
Bandwidth:
4.4MHz

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:
Zoom : 20 ns/pt	10M smpl/s

Cur2-GND: +13396. V	Cur2-Cur1: +13332. V
Cur2-TRIG: 5.5 µs	Cur2-Cur1: 7.34 µs

Zoom Only	Memory:
5:1	2000

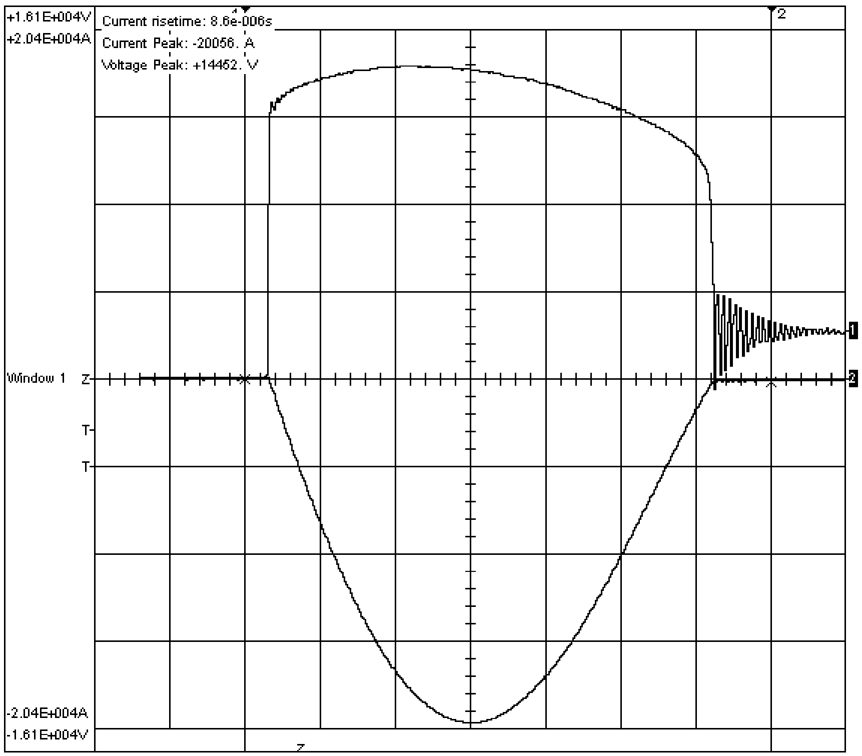
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -1460.8 A LL: -2529.7 A	4.4MHz

1 CH1 Zoom July 20, 2006 15:27:04	
+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

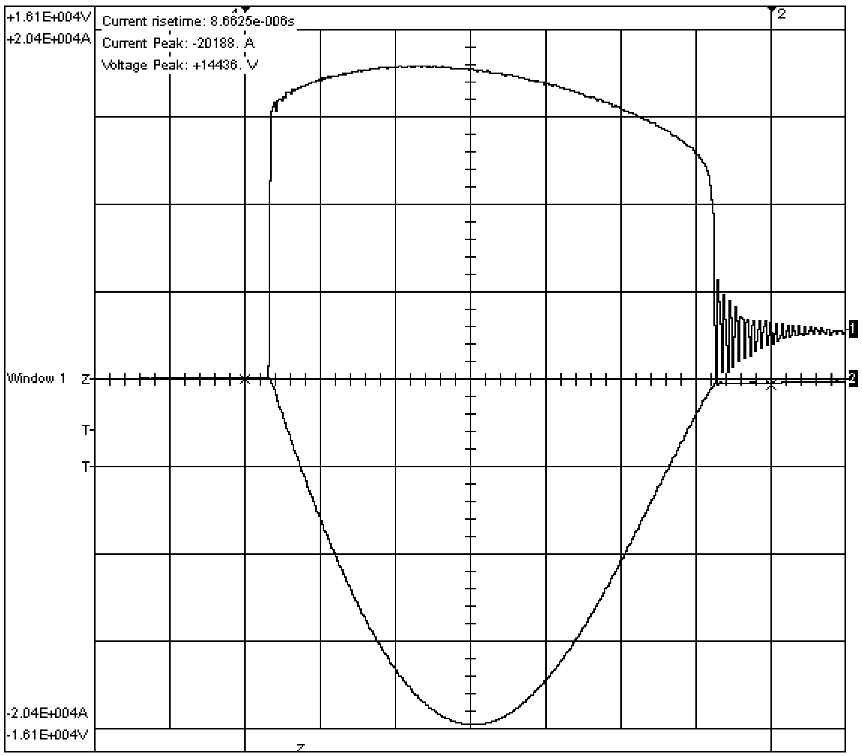
Trig: Edge Pretrigger: 4.2 %	Bandwidth:
CH2 DC Neg UL: -2921.7 A LL: -5059.5 A	4.4MHz

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



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

Cur1-GND: +9.2786 A	Cur2-Cur1: -271.73 A
Cur1-TRIG: -2.9518 µs	Cur2-Cur1: 27.9918 µs

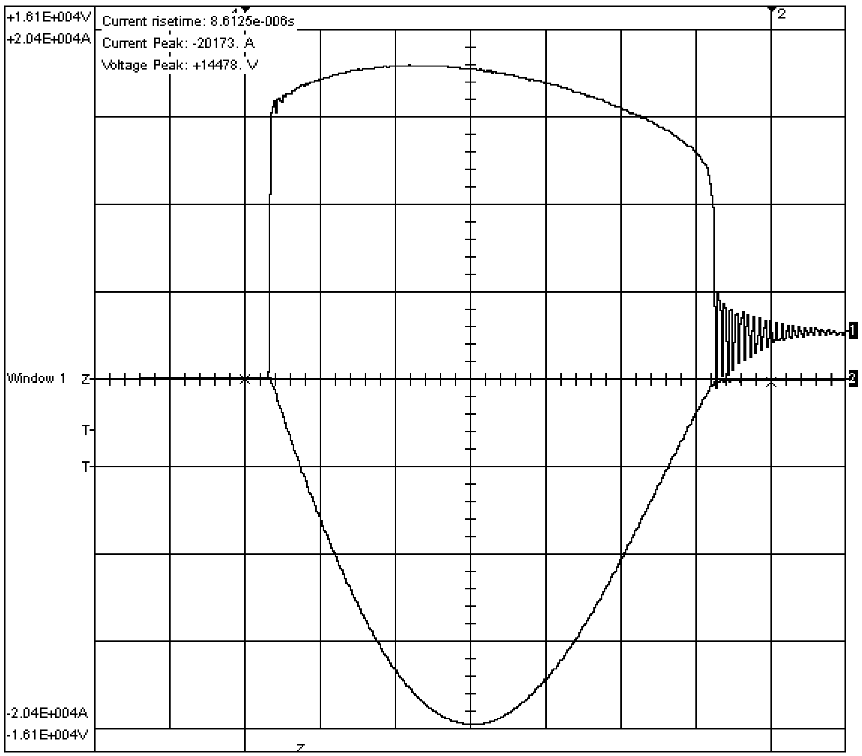
Trig: Edge Pretrigger: 4.2 %	Bandwidth:
CH2 DC Neg UL: -2921.7 A LL: -5059.5 A	4.4MHz

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

Oscillogram 15
Sample 3

Nicolet Accura100

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



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

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

Cur1-GND: +10.604 A	Cur2-Cur1: -136.53 A
Cur1-TRIG: -2.9518 µs	Cur2-Cur1: 27.9918 µs

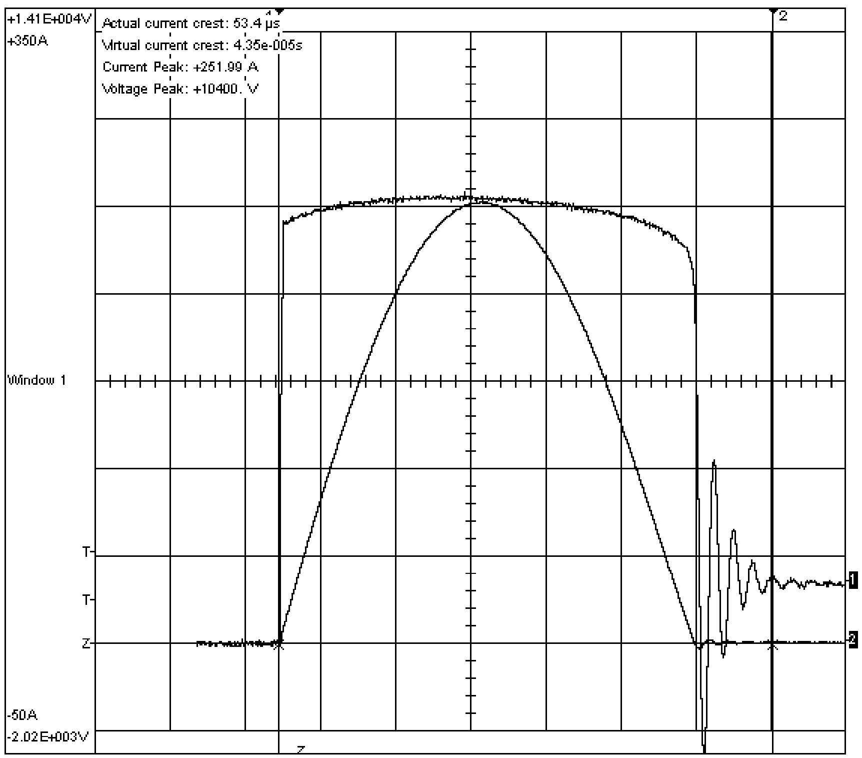
Zoom Only	Memory:
5:1	2000

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

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

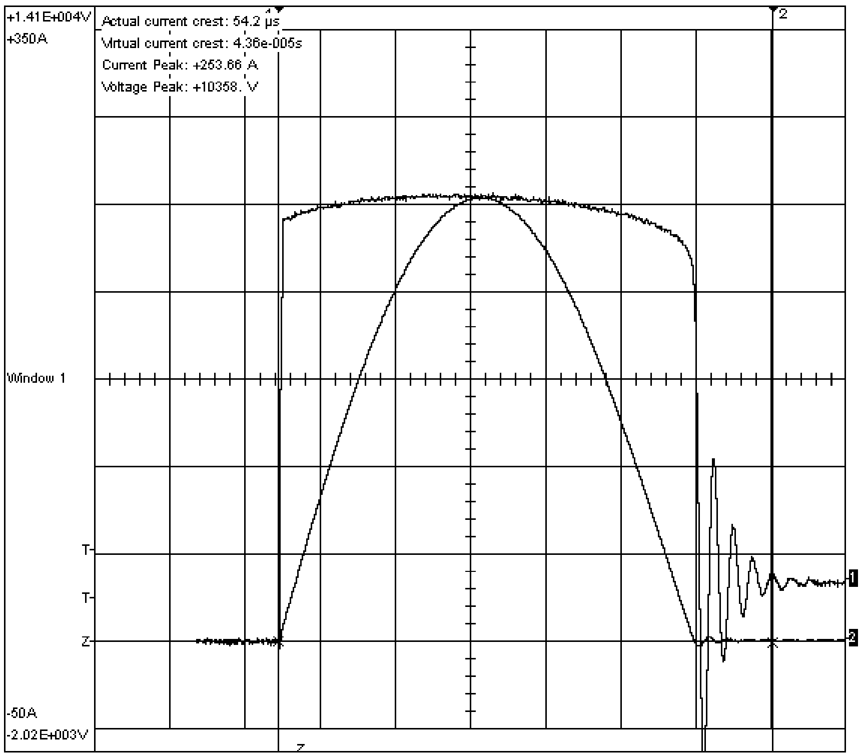
Trig: Edge Pretrigger: 7.0 %	Bandwidth:
CH2 DC Pos UL: +52.600 A LL: +25.000 A	25MHz

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

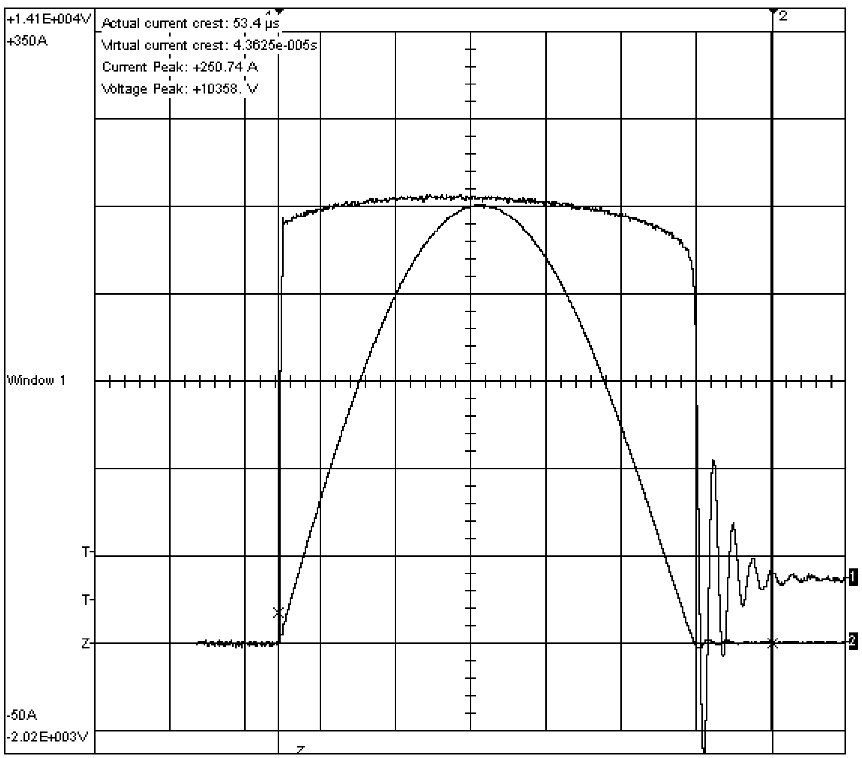
Trig: Edge Pretrigger: 7.0 %	Bandwidth:
CH2 DC Pos UL: +52.600 A LL: +25.000 A	25MHz

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



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

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

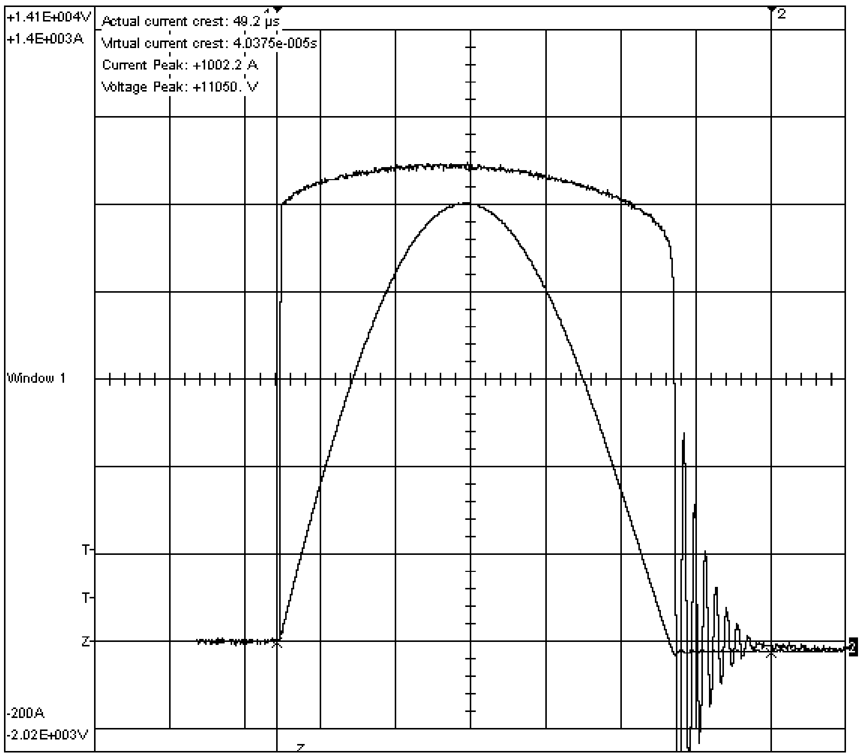
Zoom Only	Memory:
2:1	2000

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

Oscillogram 25
Sample 1

Nicolet Accura100

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



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

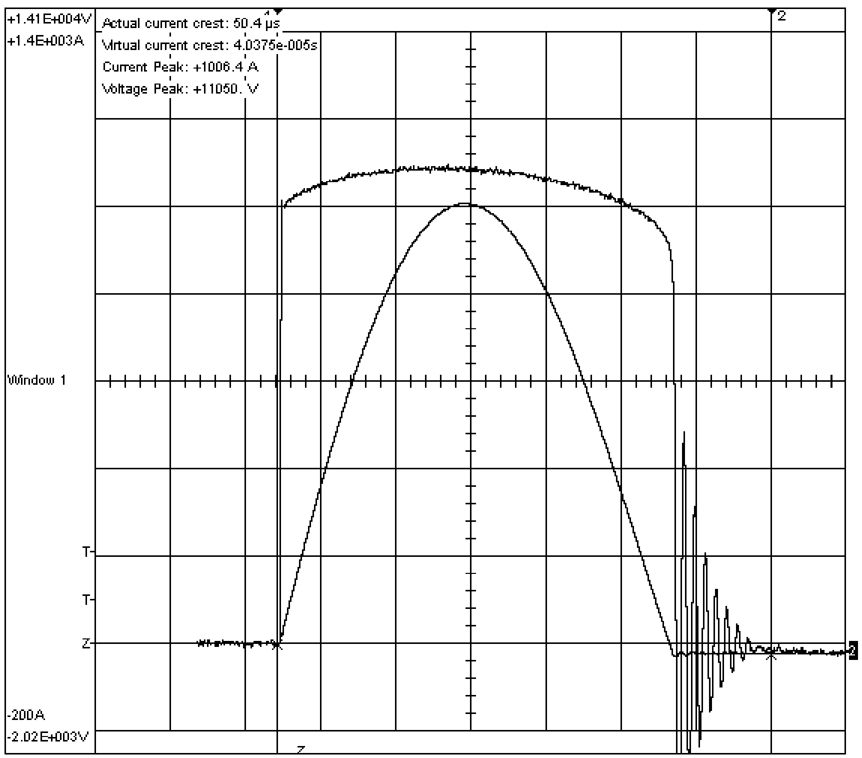
Zoom Only	Memory:	Trig: Edge Pretrigger: 7.0 %	Bandwidth:
2:1	2000	CH2 DC Pos UL: +210.40 A LL: +100.00 A	25MHz

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

Oscillogram 26
Sample 2

Nicolet Accura100

Printed : 14:27 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: -23.333 A
Cur1-TRIG: -6.4 µs	Cur2-Cur1: 131.6 µs

Zoom Only	Memory:
2:1	2000

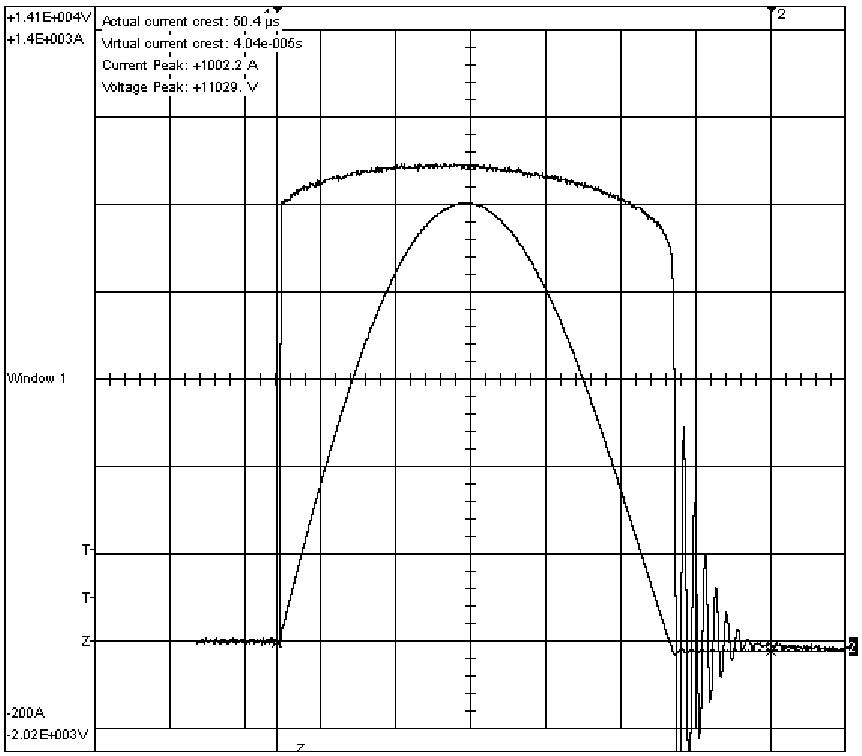
Trig: Edge Pretrigger: 7.0 %	Bandwidth:
CH2 DC Pos UL: +210.40 A LL: +100.00 A	25MHz

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

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

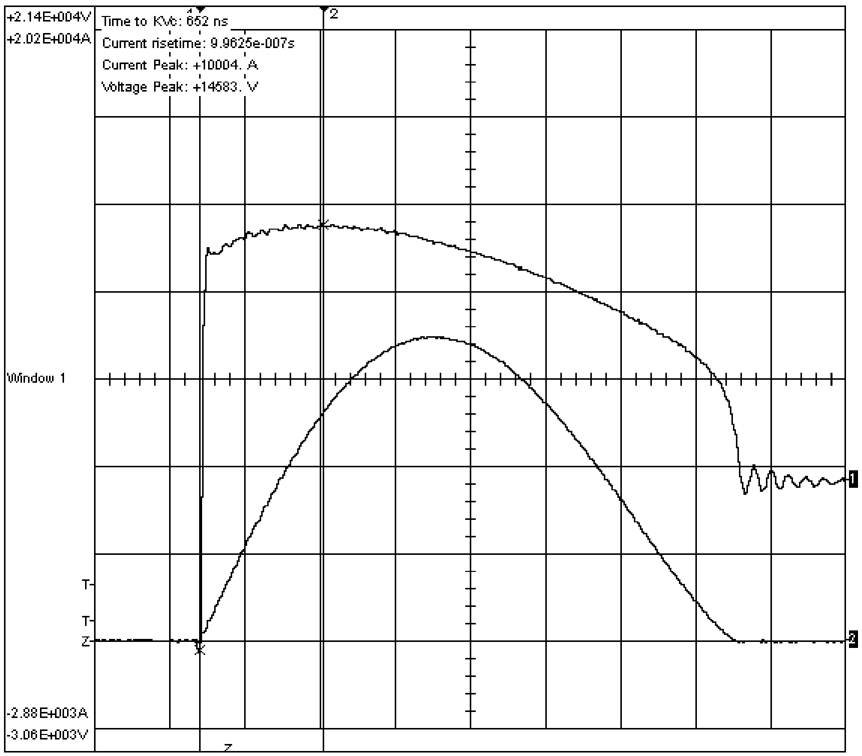
Trig: Edge Pretrigger: 7.0 %	Bandwidth:
CH2 DC Pos UL: +210.40 A LL: +100.00 A	25MHz

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

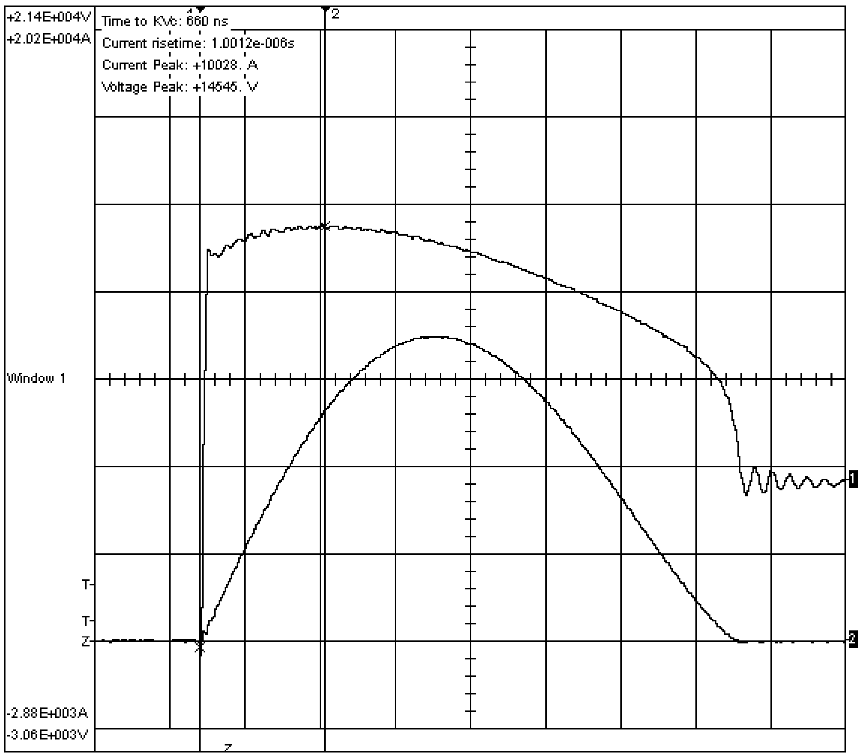
Trig: Edge Pretrigger: 10.4%	Bandwidth:
CH2 DC Pos UL: +1889.3 A LL: +679.68 A	25MHz

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:
Zoom : 2 ns/pt	100M smpl/s

Cur2-GND: +14532. V	Cur2-Cur1: +14687. V
Cur2-TRIG: 512 ns	Cur2-Cur1: 660 ns

Zoom Only	Memory:
5:1	2000

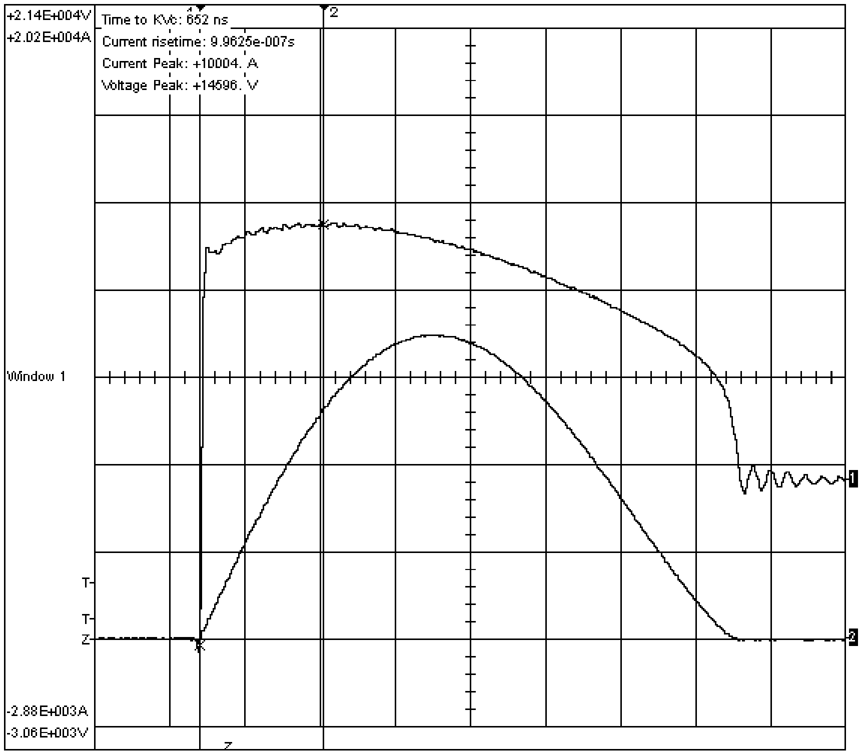
Trig: Edge Pretrigger: 10.4%	Bandwidth:
CH2 DC Pos UL: +1889.3 A LL: +679.68 A	25MHz

1 CH1 Zoom July 24, 2006 11:37:37	
+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



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

Cur2-GND: +14551. V	Cur2-Cur1: +14746. 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 11:40:17	
+3058.3 V	400 ns
2 CH2 Zoom July 24, 2006 11:40:17	
+2880.0 A	400 ns

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-03
PH3 Series Polymer-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 PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

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 (75 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 4 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 PH3 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

$$Z_g = 13\ 221\ \text{V} / 876.38\ \text{A} = 15.086\ \Omega \qquad \text{Virtual Duration of Peak} = 2\ 453\ \mu\text{s}$$

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.

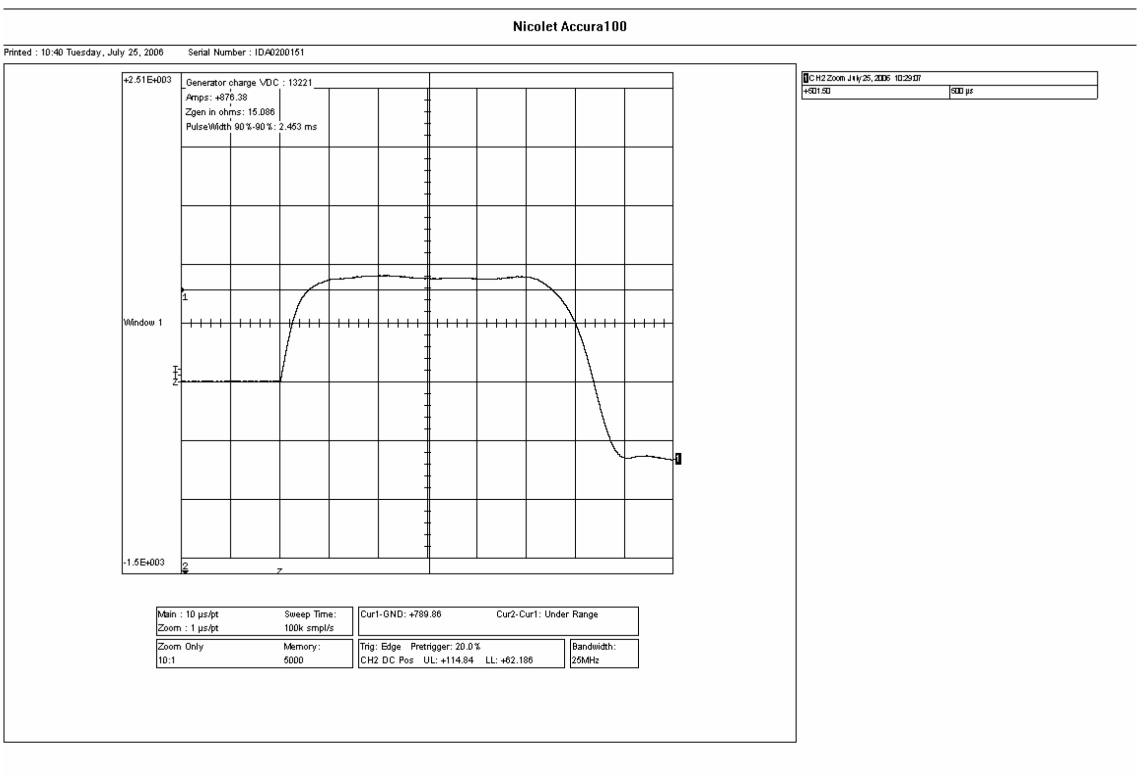


Figure 1. Oscillogram of discharge current for generator short circuit set up test

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

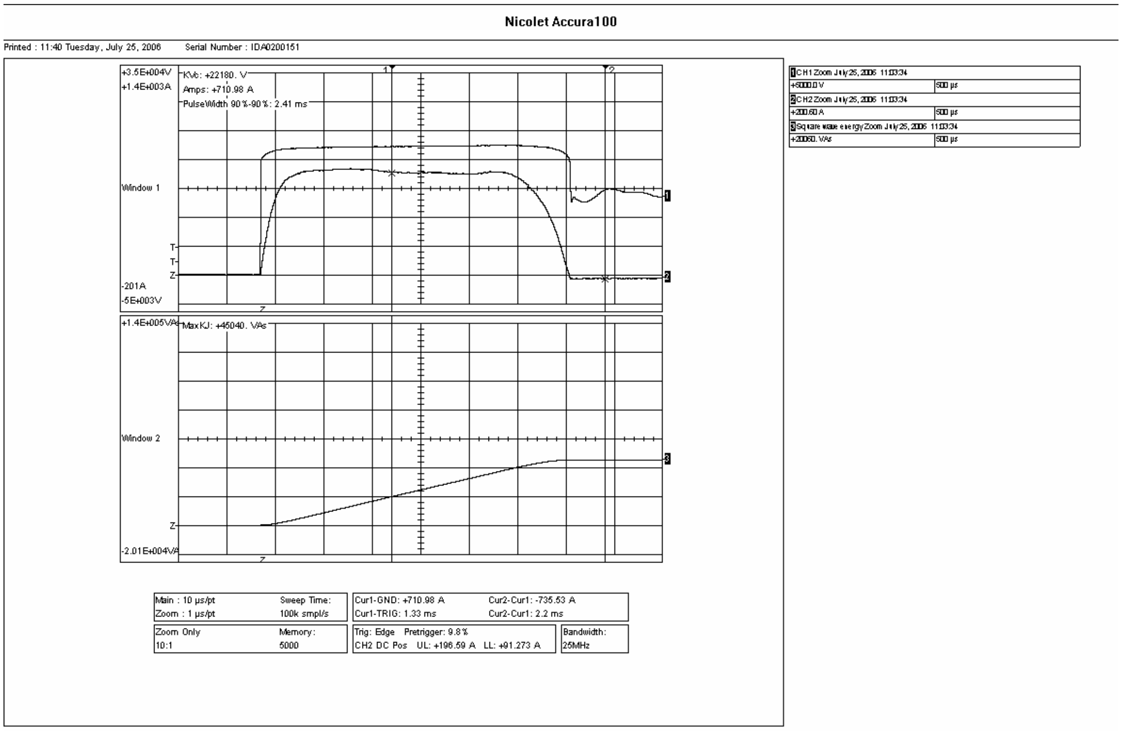
Subsequent to the completion of the transmission line discharges, the residual voltage at nominal discharge current was re-measured and compared to the initial values for each test sample. Results are summarized in Table 3. The maximum change of residual voltage of the three samples is less than the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

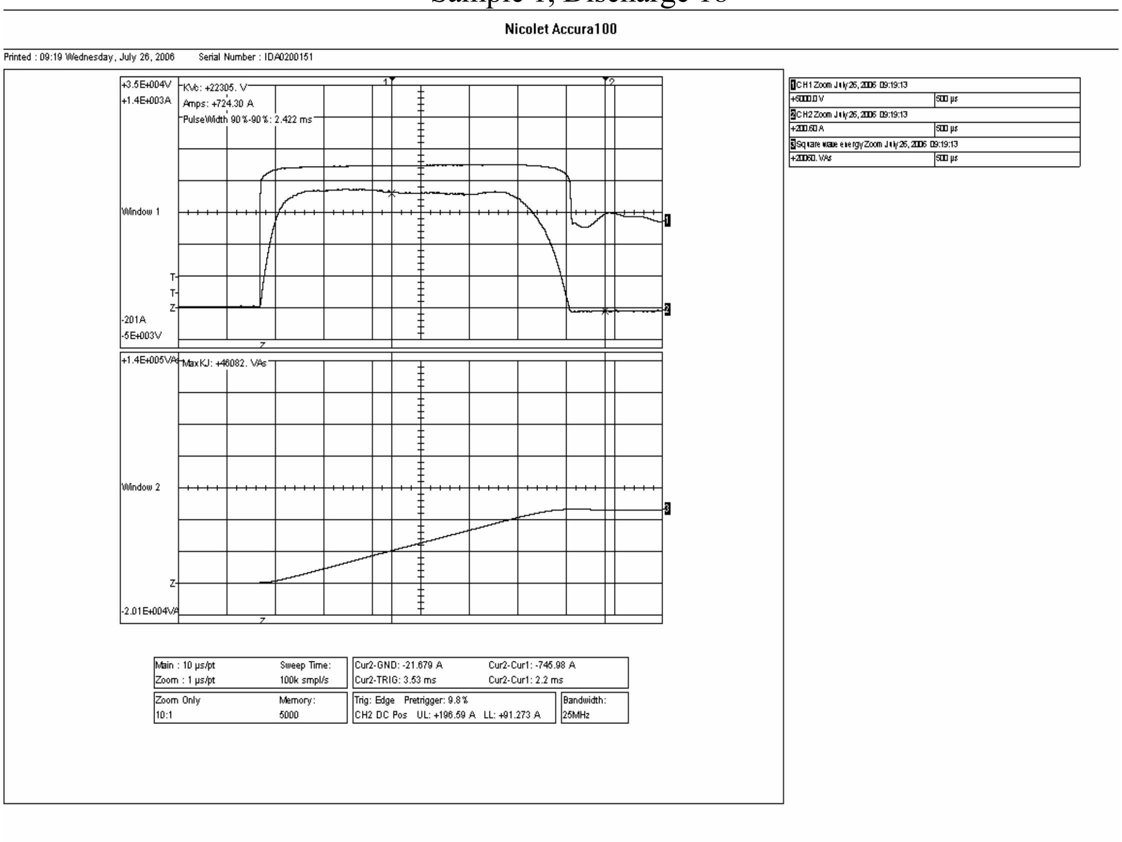
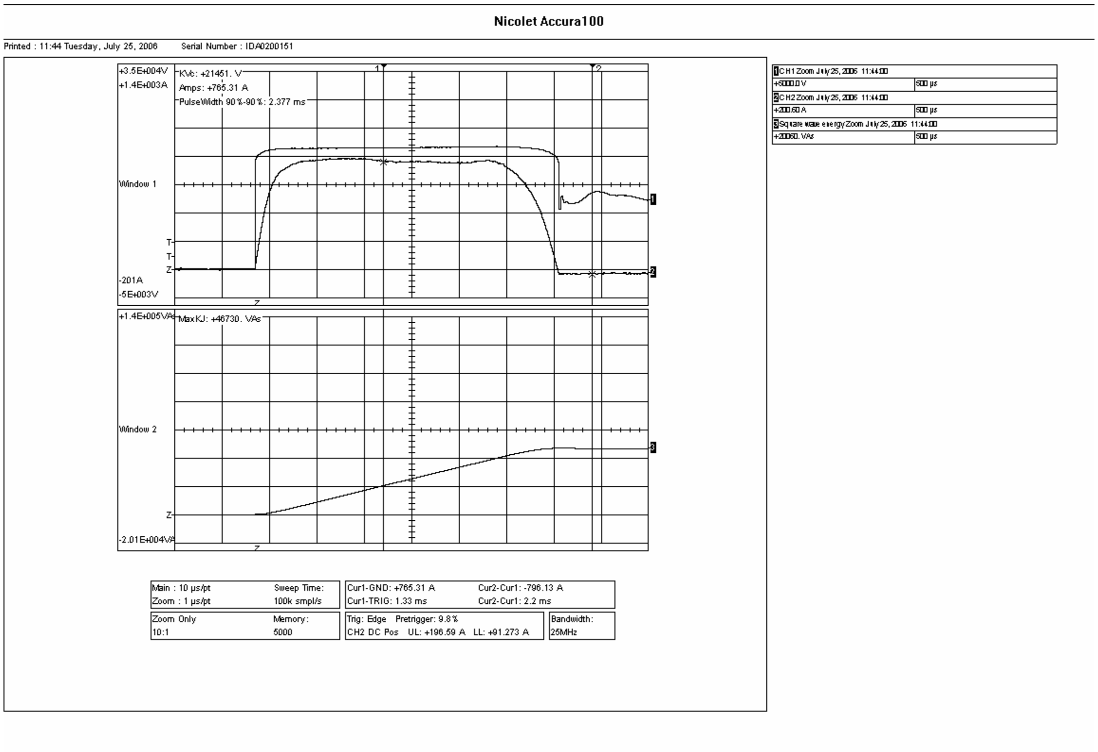


Figure 2. Oscillograms of line discharges for sample 1

Sample 2, Discharge 1



Sample 2, Discharge 18

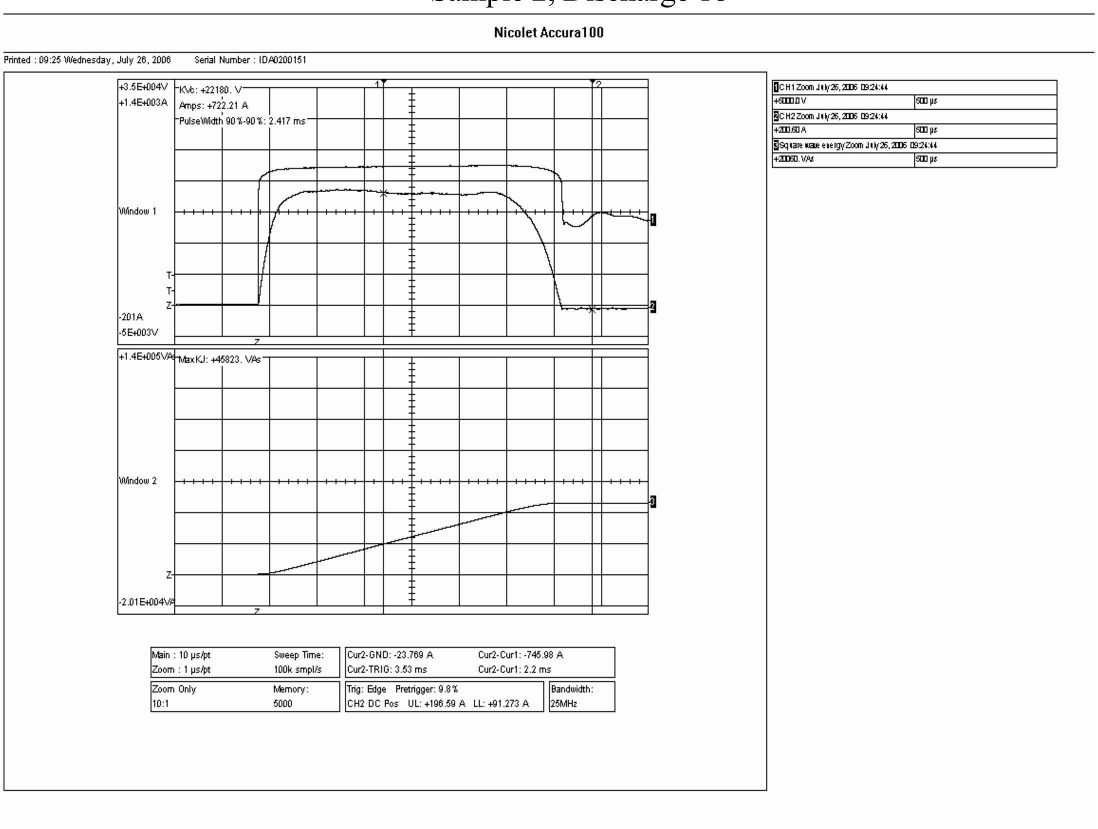
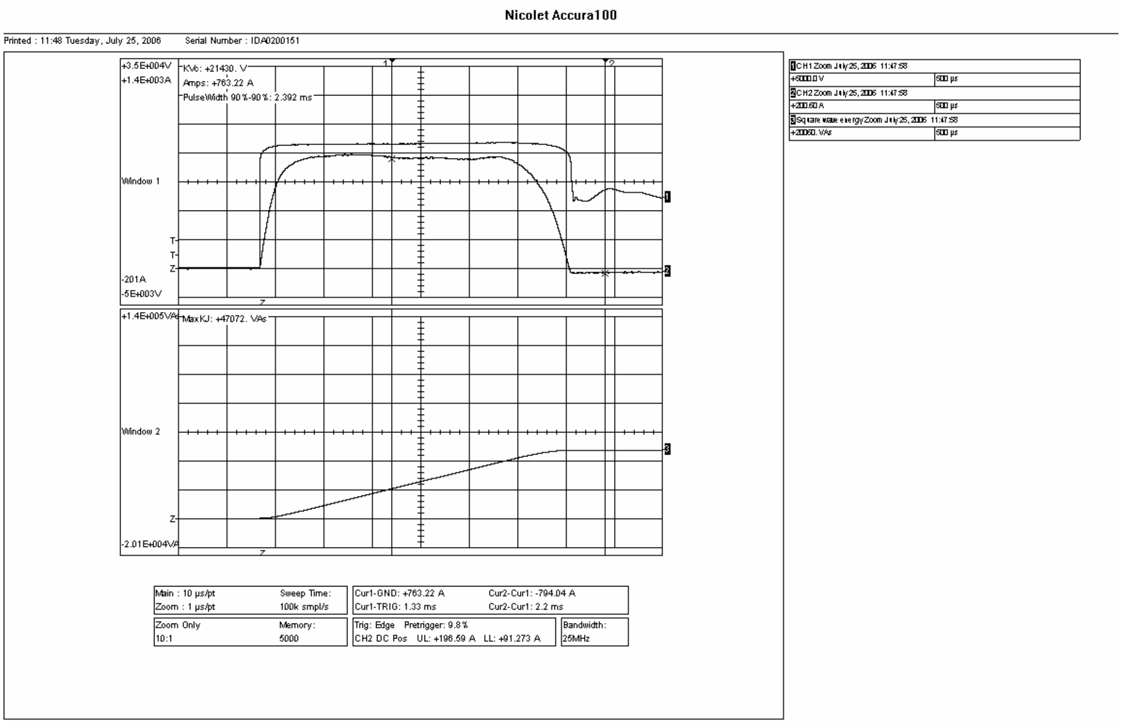


Figure 3. Oscillograms of line discharges for sample 2

Sample 3, Discharge 3



Sample 3, Discharge 18

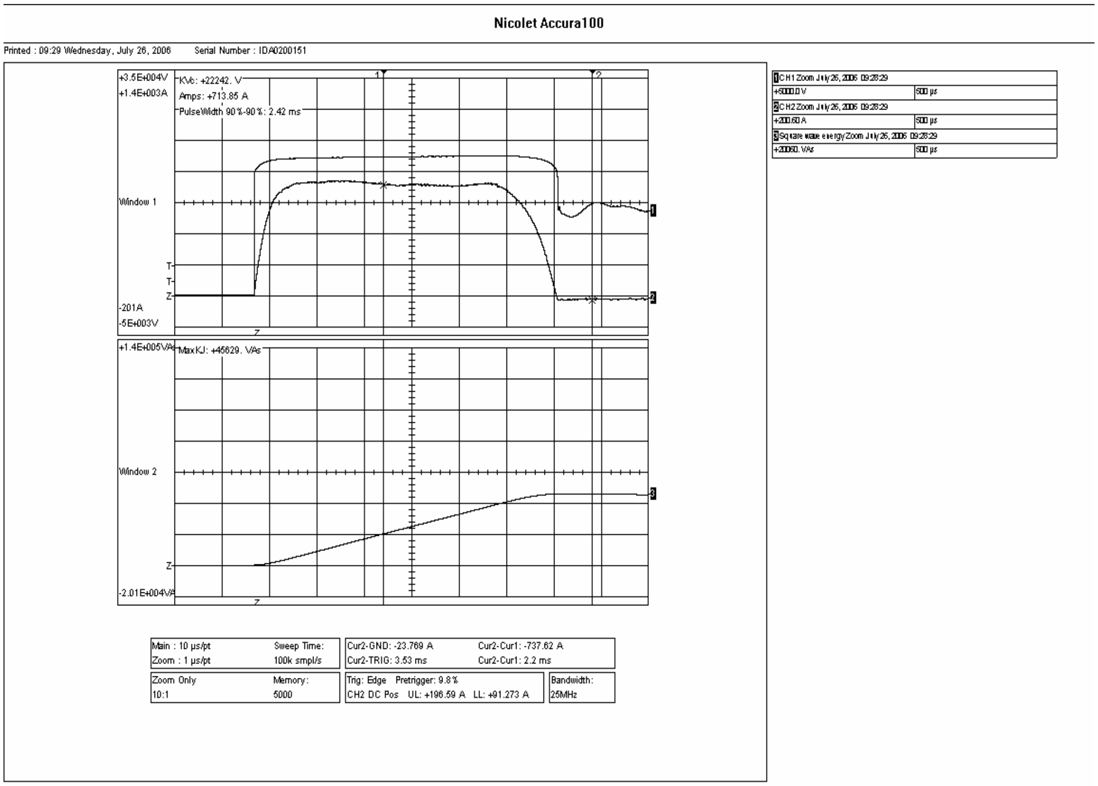


Figure 4. Oscillograms of line discharges for sample 3

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-04
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Accelerated Aging Procedure

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

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. PH3 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

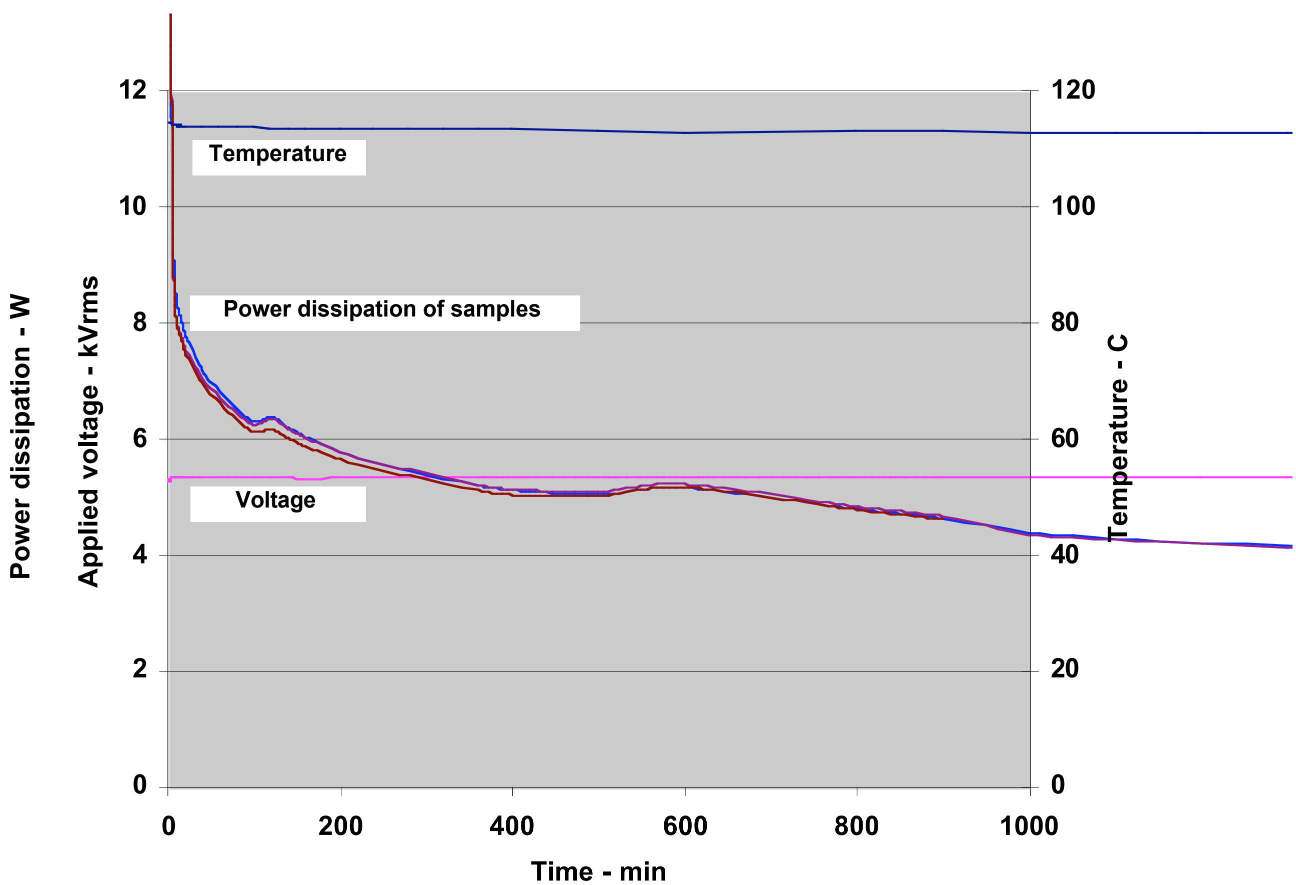


Figure 1. Power dissipation, voltage and temperature measurements during 1000 h test period

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-05
PH3 Series Polymer-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 PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

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 polymeric 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°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°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°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.

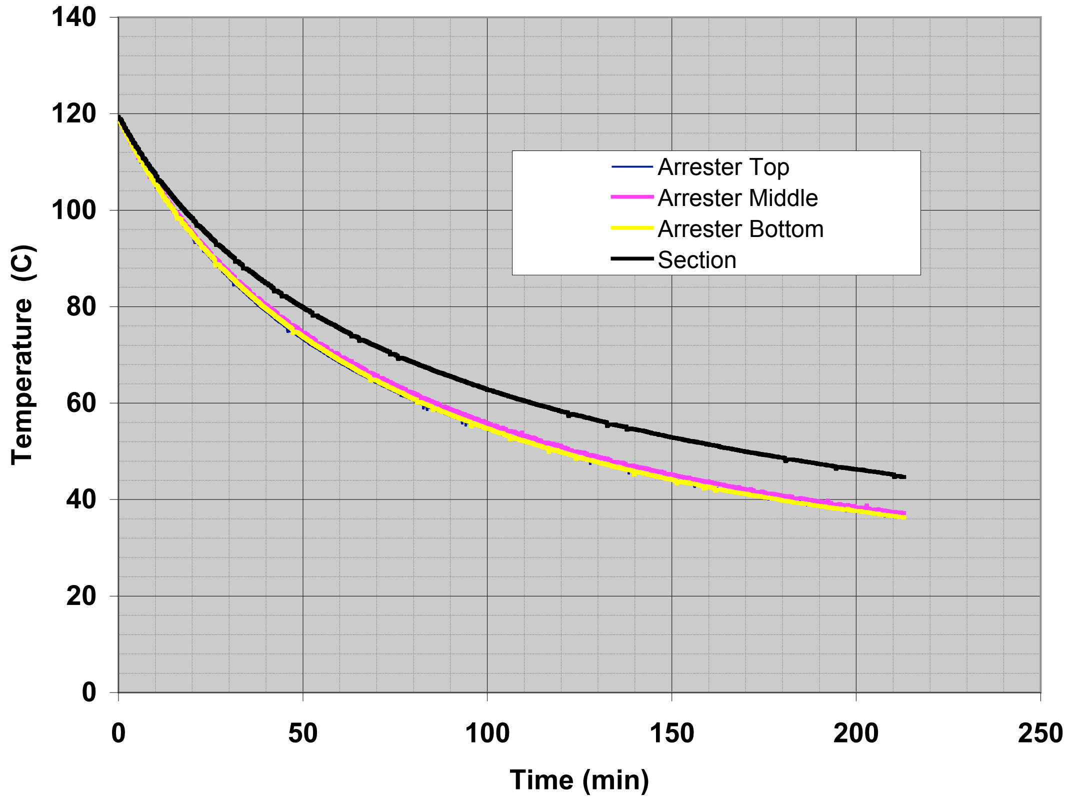


Figure 1. Cooling curves of fully assembled arrester unit and test section

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-06
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Switching Surge Operating Duty Test

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

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 EU1527-H-05 section of PH3 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 PH3 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

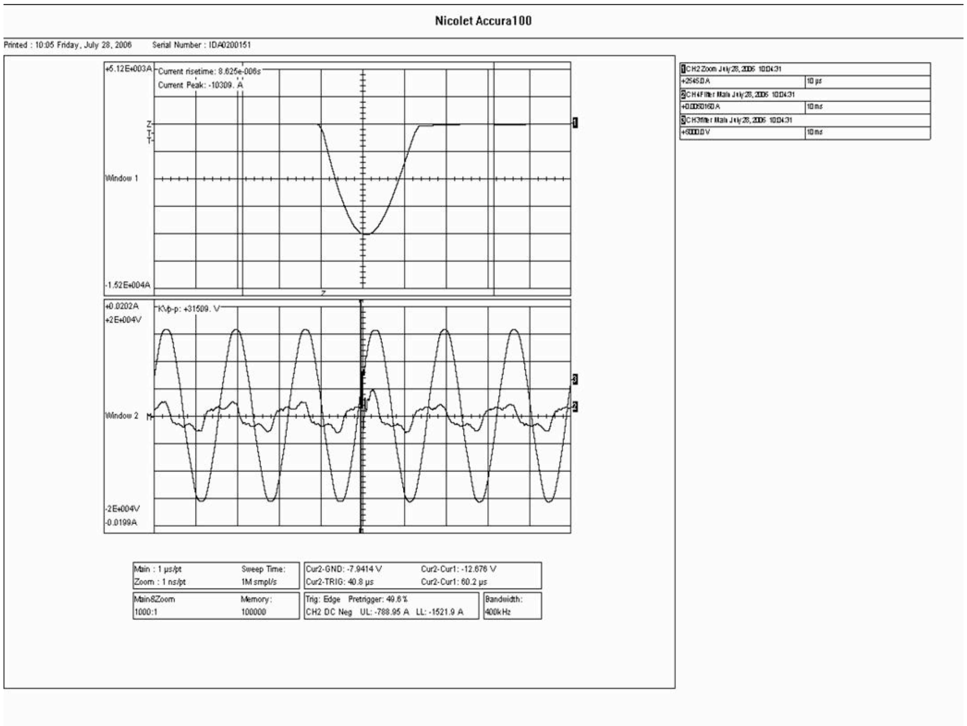
$$Z_g = 10\,708 \text{ V} / 728.09 \text{ A} = 14.707\ \Omega \qquad \text{Virtual Duration of Peak} = 2\,457\ \mu s$$

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

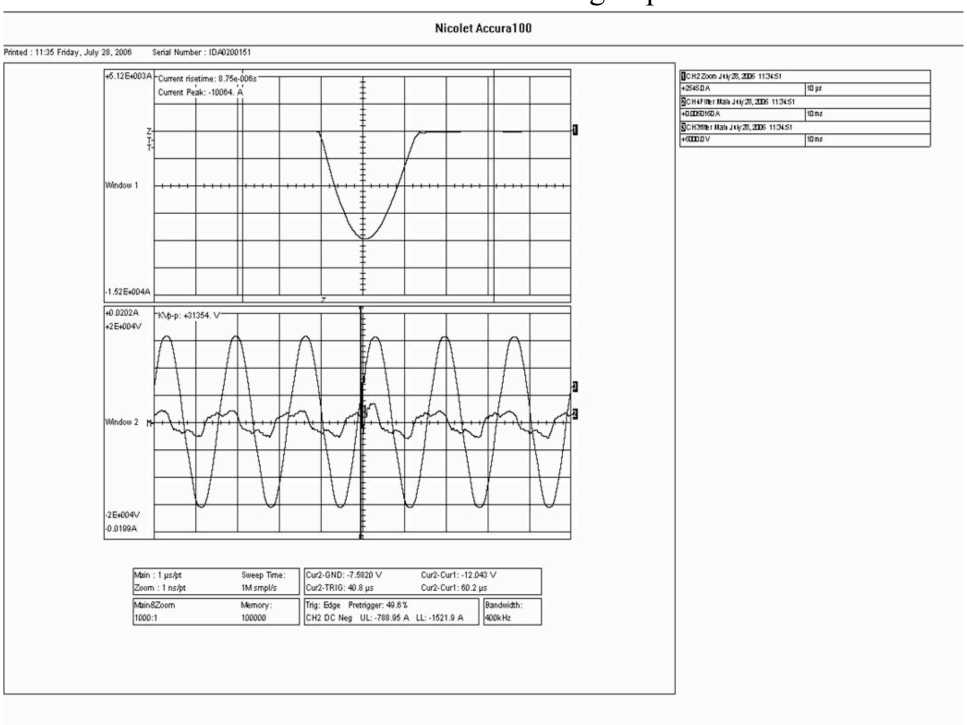
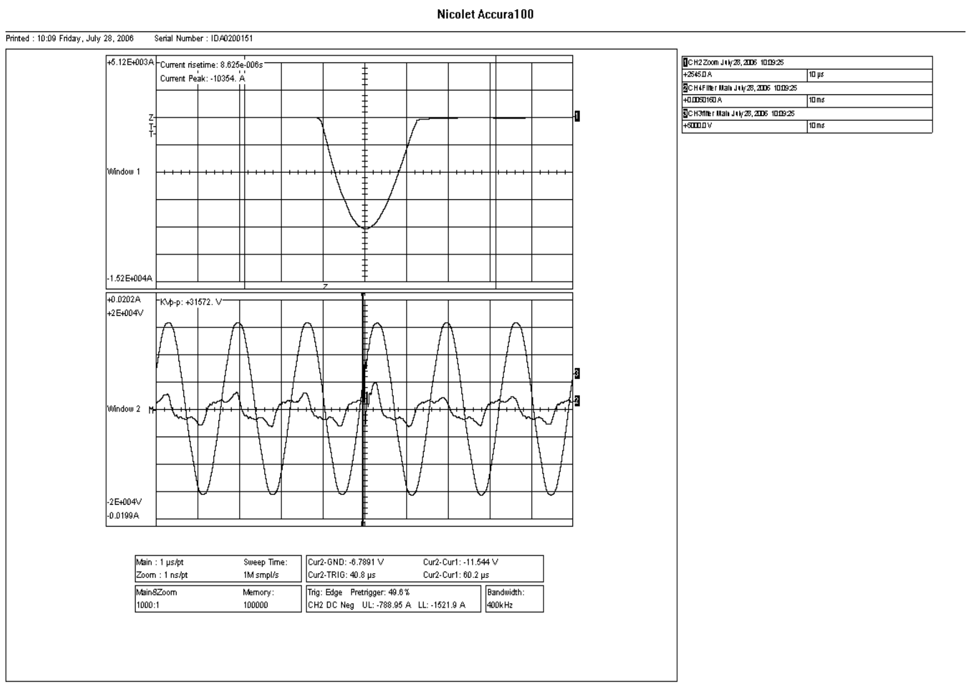


Figure 1. Oscillograms of 10kA 8/20 conditioning impulses for section 1

Section 2: 1st conditioning impulse



Section 2: 20th conditioning impulse

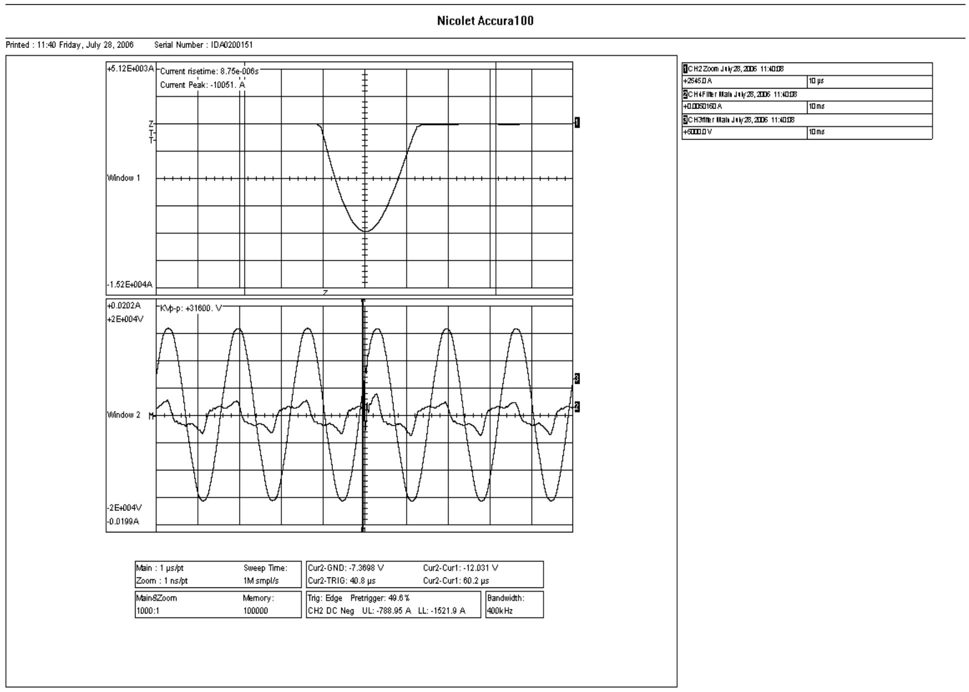
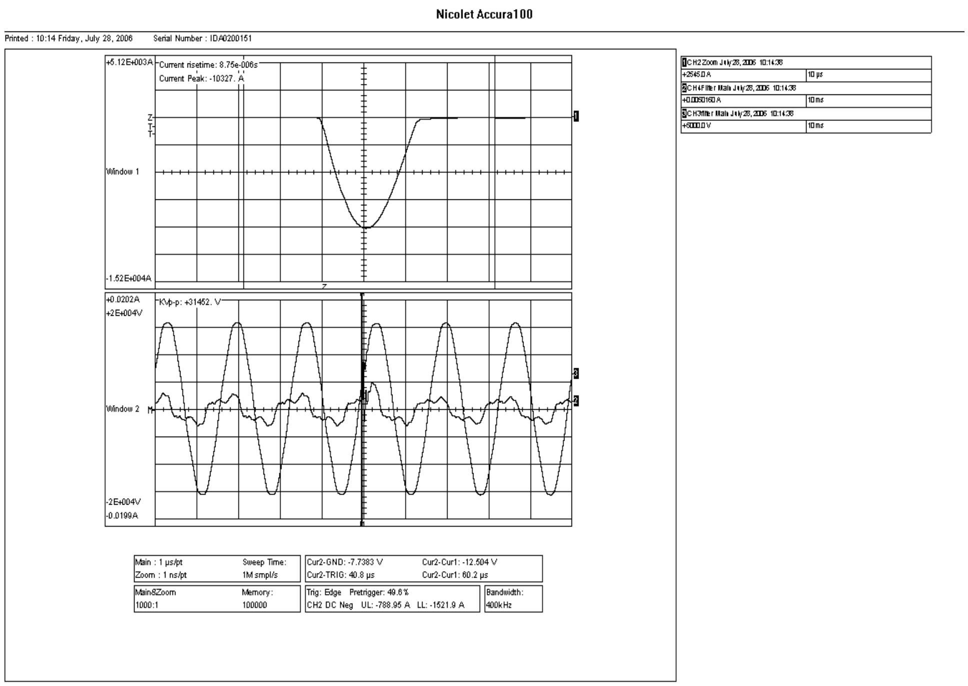


Figure 2. Oscillograms of 10kA 8/20 conditioning impulses for section 2

Section 3: 1st conditioning impulse



Section 3: 20th conditioning impulse

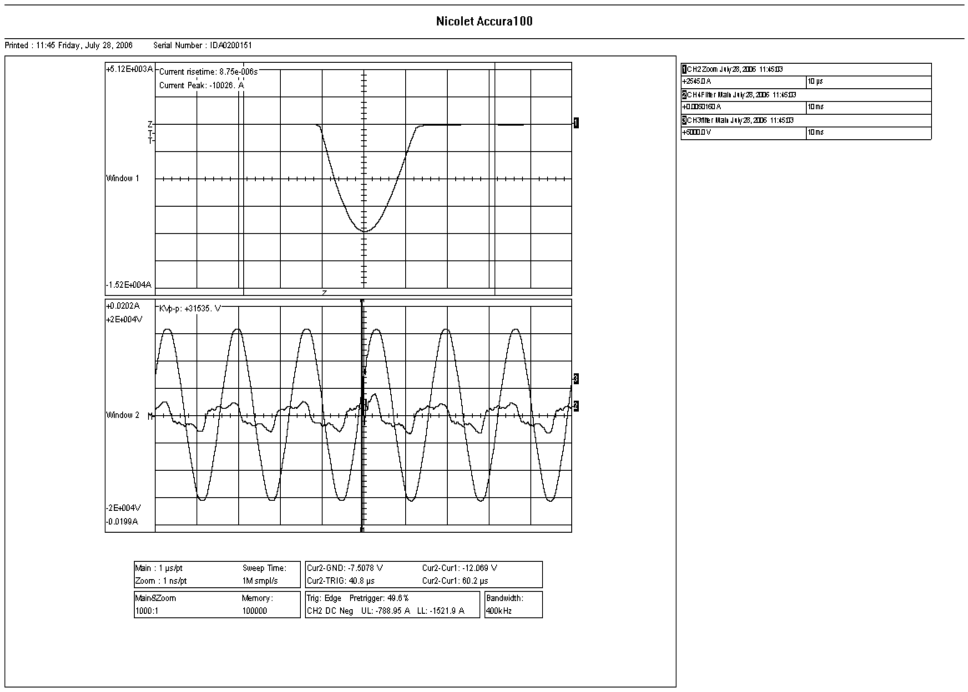
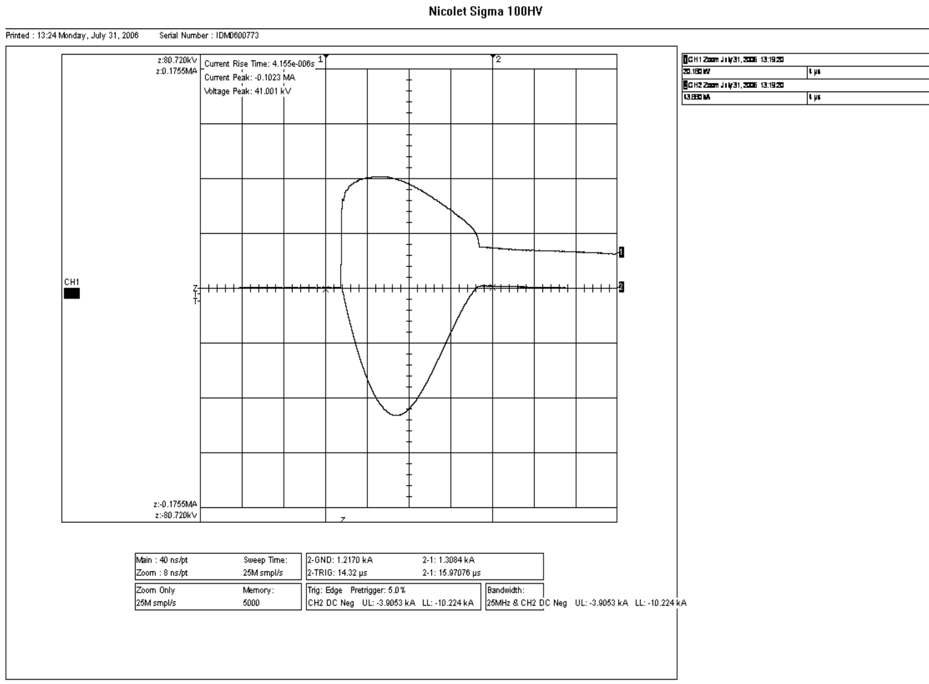


Figure 3. Oscillograms of 10kA 8/20 conditioning impulses for section 3

Section 1: 1st conditioning impulse



Section 1: 2nd conditioning impulse

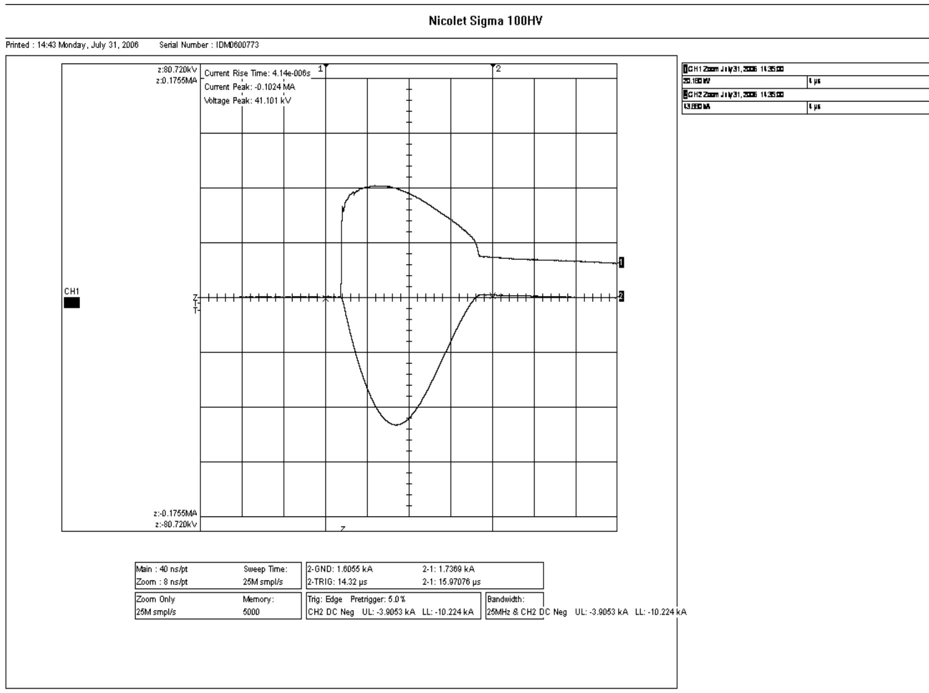
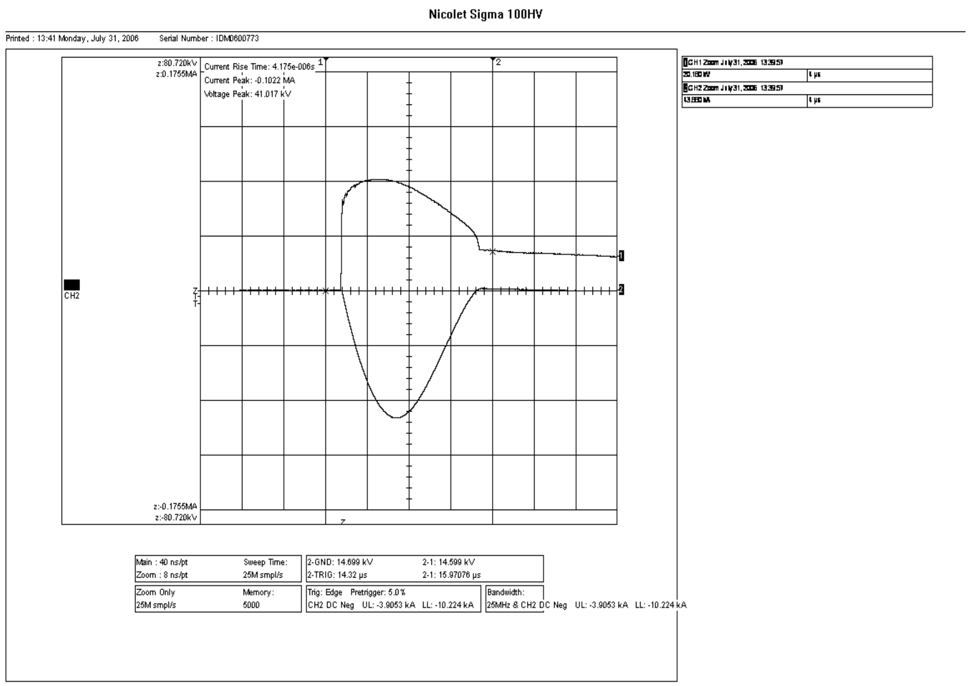


Figure 4. Oscillograms of 100kA conditioning impulses for section 1

Section 2: 1st conditioning impulse



Section 2: 2nd conditioning impulse

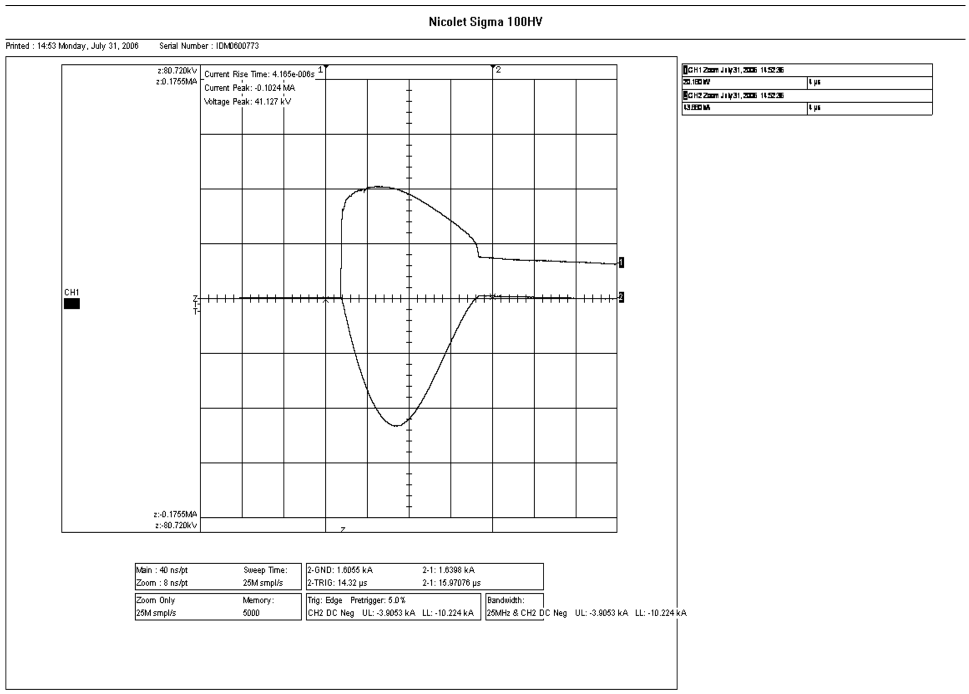
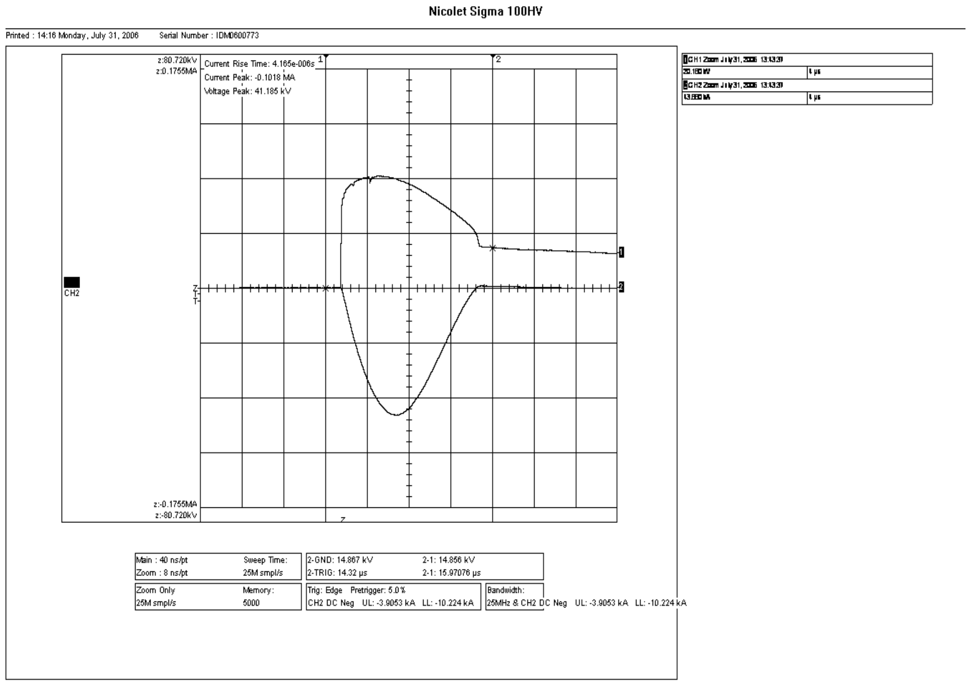


Figure 5. Oscillograms of 100kA conditioning impulses for section 2

Section 3: 1st conditioning impulse



Section 3: 2nd conditioning impulse

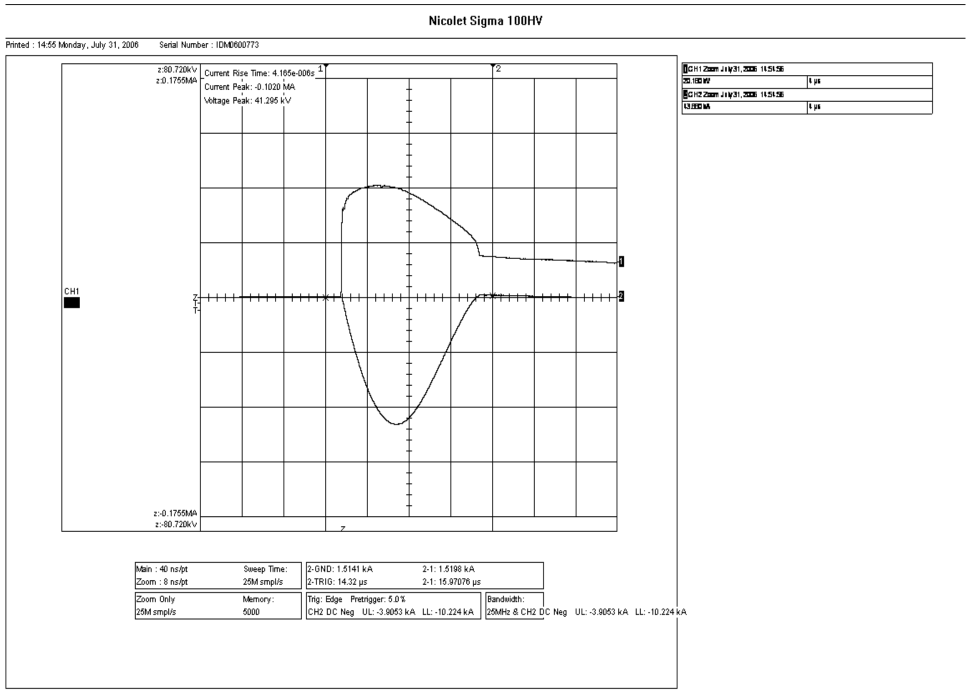


Figure 6. Oscillograms of 100kA conditioning impulses for section 3

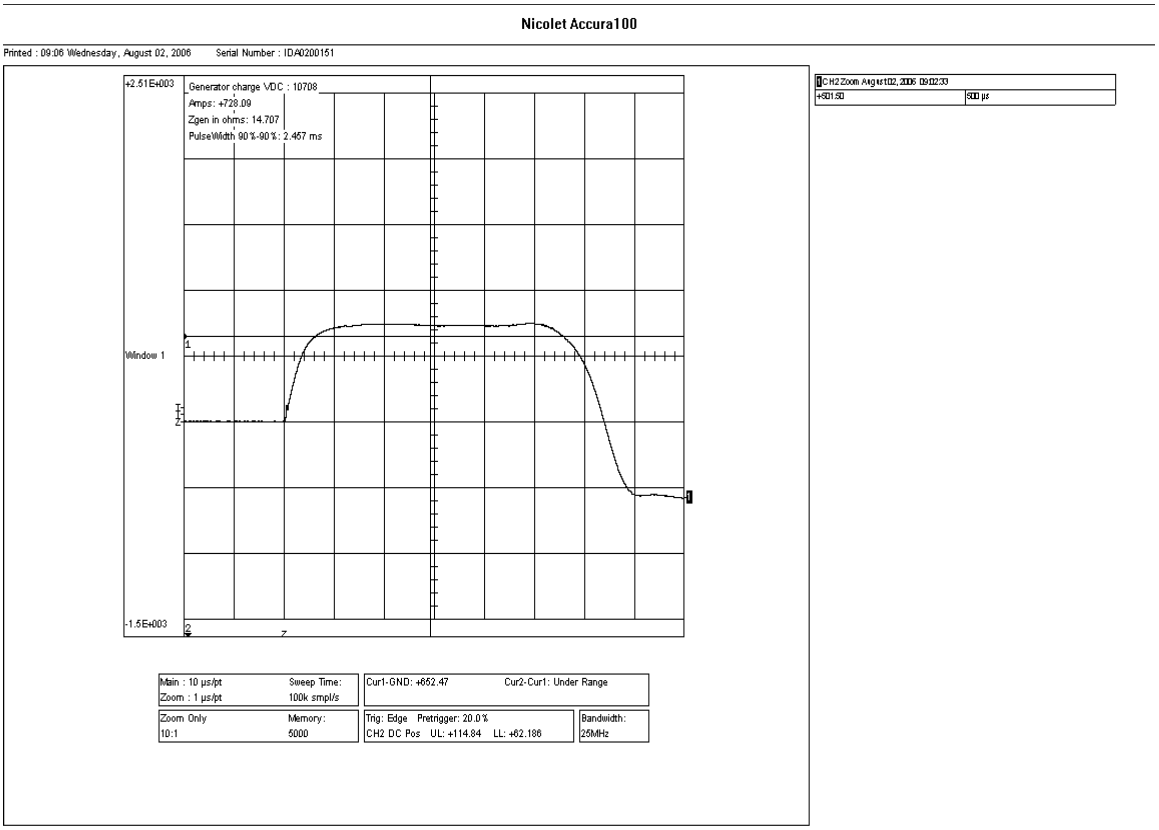


Figure 7. Oscillogram of discharge current for generator short circuit set up test

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	

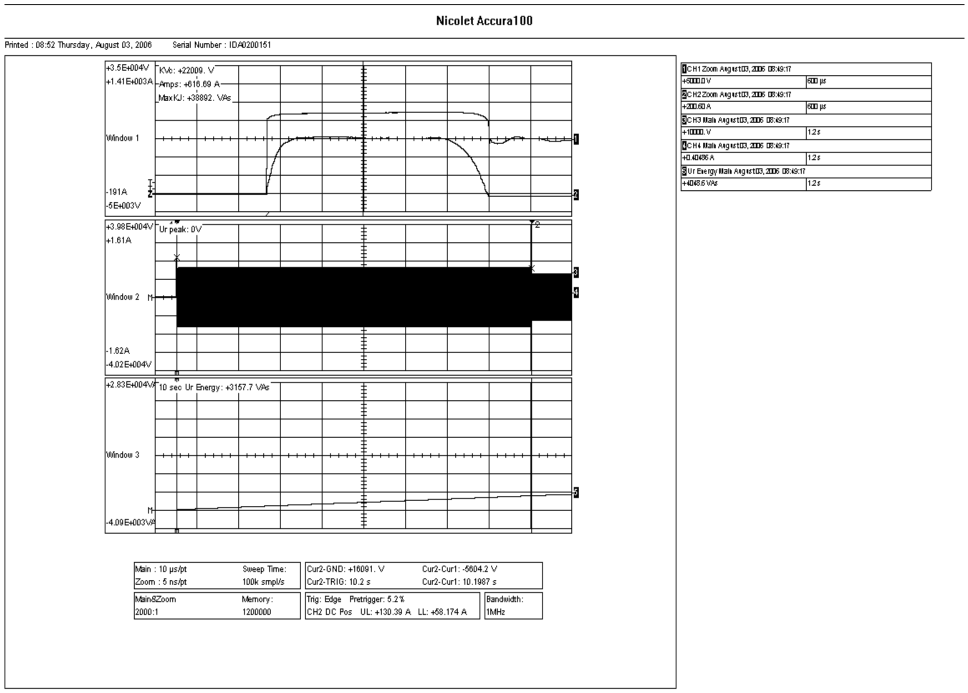


Figure 8. Oscillogram of second line discharge for section 1

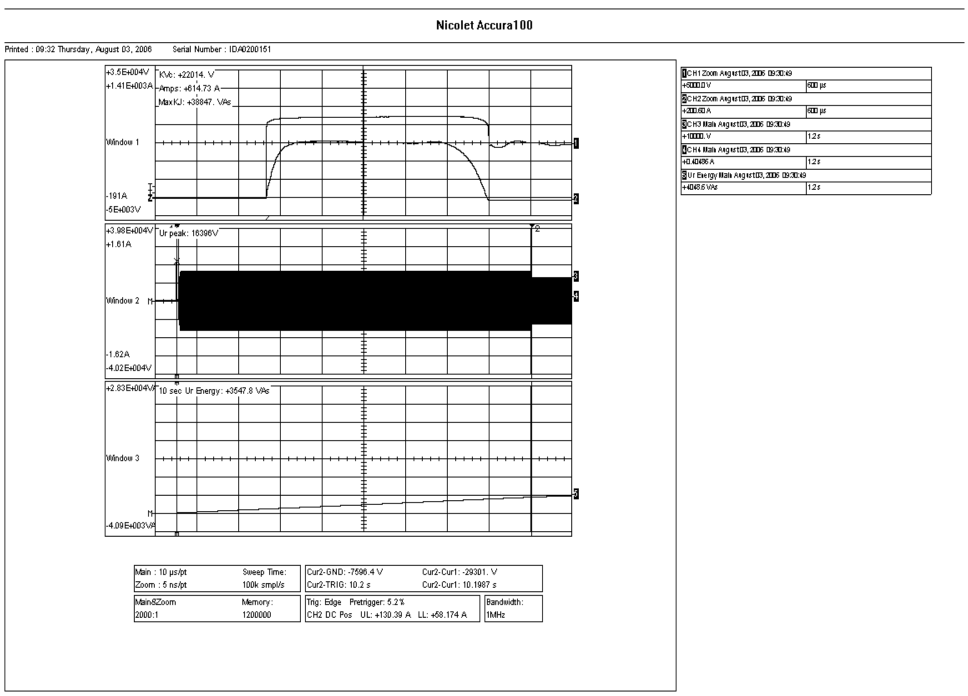


Figure 9. Oscillogram of second line discharge for section 2

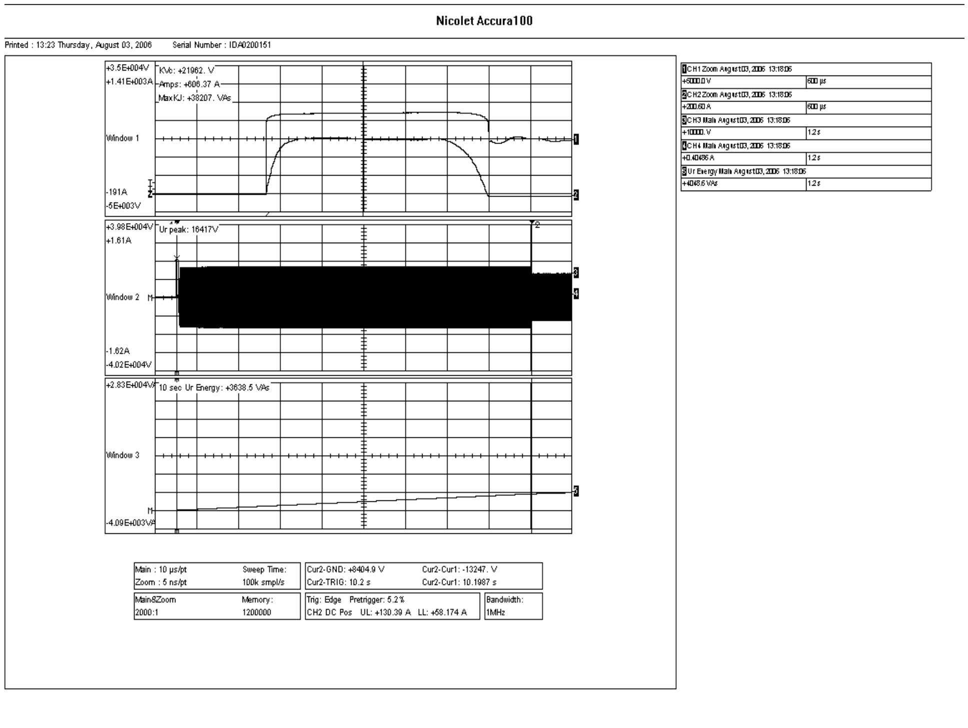
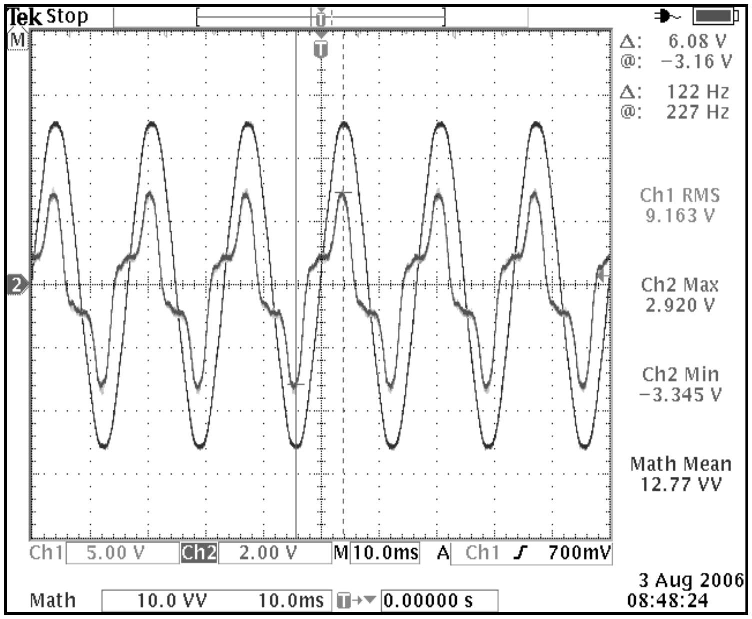


Figure 10. Oscillogram of second line discharge for section 3

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



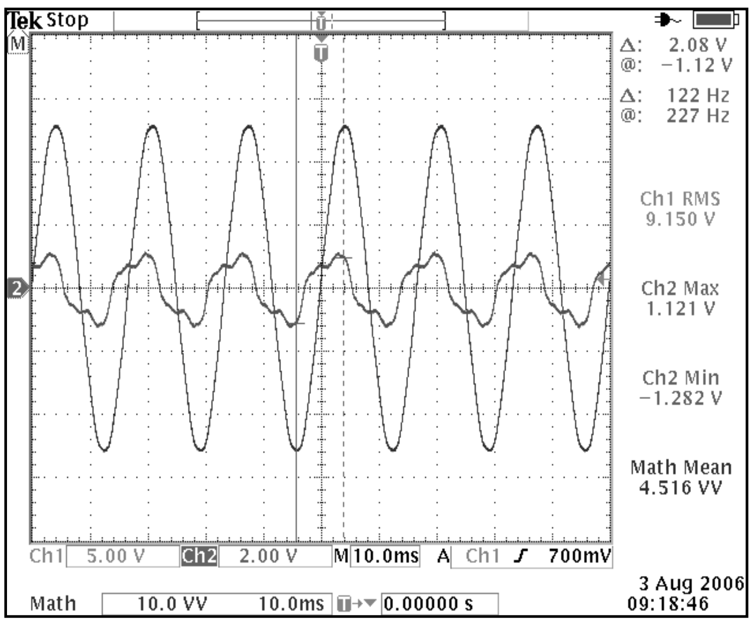
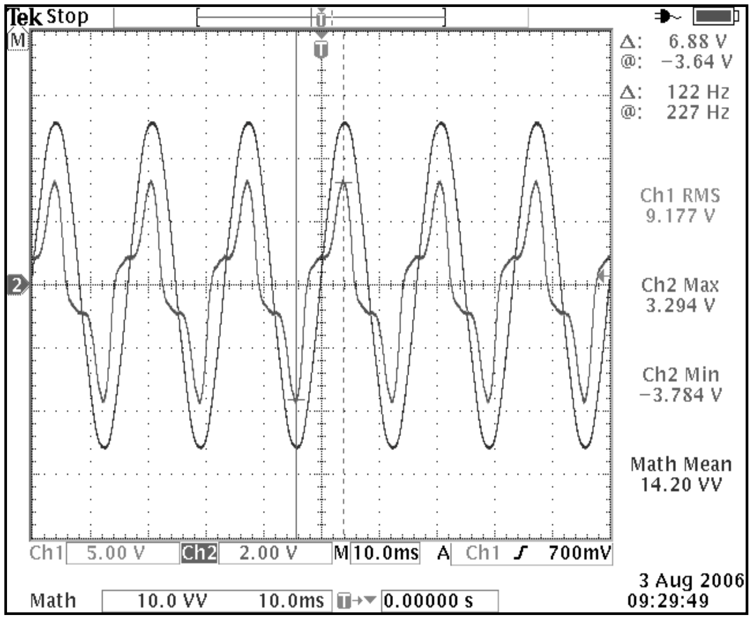


Figure 11. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c for section 1



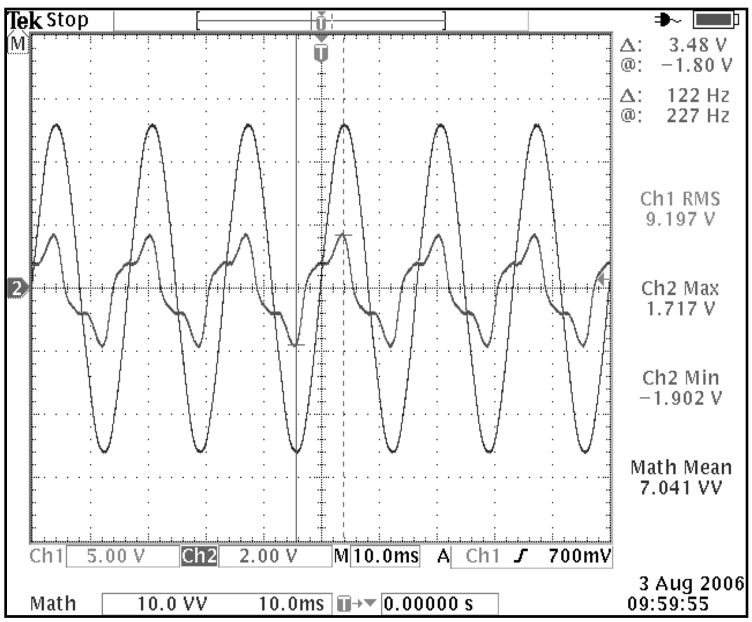
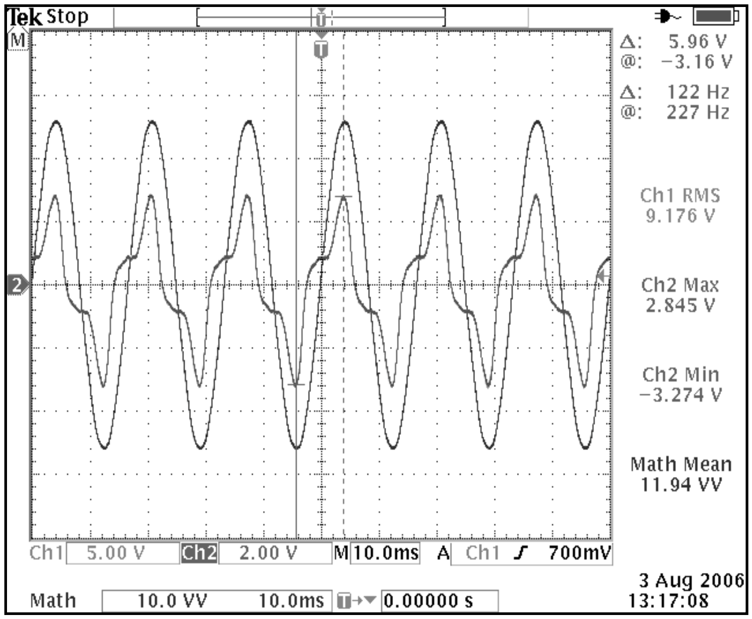


Figure 12. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c for section 2



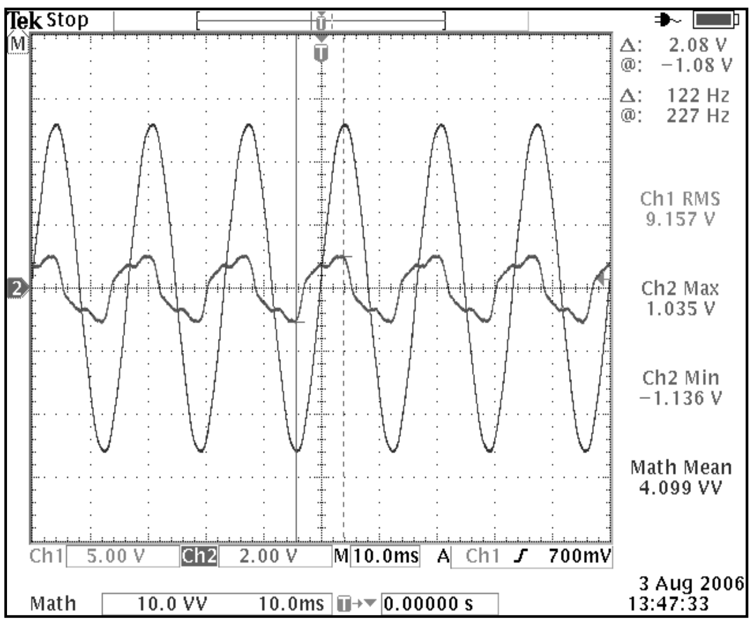


Figure 13. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c for section 3

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.

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-07
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Short Circuit

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

IEC TYPE TEST REPORT
Short Circuit

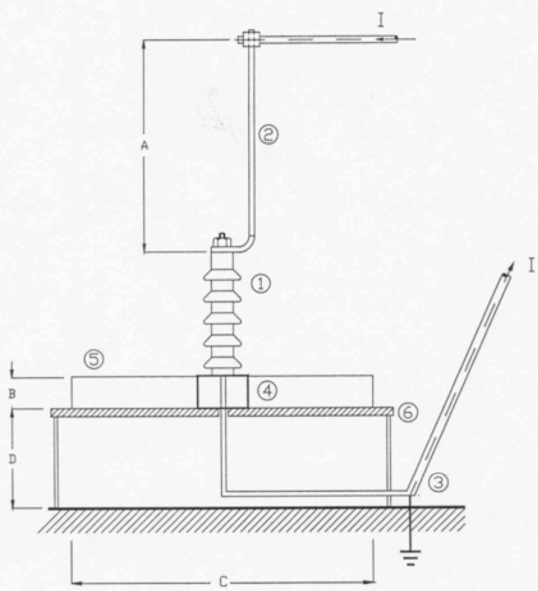
TESTS PERFORMED:
The PH3 series of arresters has a rated short circuit capability of 63 000 A symmetrical. The physical design of the PH3 arresters is identical to that of PH4 arresters in all respects except for the diameter of the resistor elements. The PH3 arrester uses 56mm diameter resistors, compared to 75mm diameter resistors for PH4. High current short circuit tests were performed at the CESI high power laboratory in Milan, Italy on PH4 arrester units. These tests are sufficient to qualify also the PH3 arrester, because the reduced amount of internal air space in the PH4 design makes the test of PH4 more severe. Tests were made according to the procedures described in Amendment 1, Clause 10.8.7, of IEC 60099-4. . Verification of capability requires three high current tests, performed with rated short circuit current (63 000 A) and two reduced short circuit currents (25 000 A and 12 000 A). For these tests, fully assembled test units were prepared, each containing as many resistor 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 elements. The units tested represented the longest mechanical unit used in the PH3 and PH4 series of arresters.

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 were of the longest individual unit length used in PH3 and PH4 arresters (1352 mm without terminal cap, 1495 mm with terminal cap). The test samples contained as many resistor elements as good be assembled into the unit. Figure 1 shows the general arrangement of the test set up. Figure 2 shows one of the units in the test chamber.

All three samples successfully withstood their respective short circuit current tests with no fracturing of the polymer housing. Actual prospective rms values of test currents were 14 400 A, 28 000 A and 68 500 A. For the rated current test, the peak of the first half cycle of test current was 162 500 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– 5, and associated oscillograms are shown in Figures 6 - 9.

D8045 - Test arrangement



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

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

The arrester to be tested was fixed on a support at 1,40 m to ground in the middle of a circular enclosure of 2,9 m in diameter. The circular enclosure was positioned on an insulating wood platform. The pressure relief device was positioned 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.

D8045IG

Figure 1. Test circuit arrangement

Figure 2. Test sample mounted in test chamber

D12321G

High-current short-circuit tests with 13,7 kA for 0,20 s

Test circuit : See D046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
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 resistor was used as detector of the opening time of the explosion vent.

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
16	1	14,4	41,1

Condition of the apparatus before the tests: new

Date: October 20, 2005

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Opening time of the explosion vent		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms		No.
6	17	1	PR1	0,21	26	30,5	13,7	5,10		

Condition of the apparatus after the tests:
The arrester remained connected to the supply and return circuits
No pieces were projected inside and outside the circular enclosure
The arrester structure remained almost intact

Figure 3. Data sheet for 12 000 A test

D1232IG

High-current short-circuit tests with 26,8 kA for 0,20 s

Test circuit : See D046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045

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 resistor was used as detector of the opening time of the explosion vent.

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
14	1	28,0	76,1

Condition of the apparatus before the tests: new

Date: October 20, 2005

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Opening time of the explosion vent		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms		No.
5	15	1	PR4	0,21	26	58,3	26,8	4,50		

Condition of the apparatus after the tests:

The arrester remained connected to the supply and return circuits
No pieces were projected inside and outside the circular enclosure
The arrester structure remained almost intact

Figure 4. Data sheet for 25 000 A test

D1232IG

High-current short-circuit tests with 65,0 kA for 0,20 s

Test circuit : See D046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
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 resistor was used as detector of the opening time of the explosion vent.

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
-	-	68,5	-

Condition of the apparatus before the tests: new

Date: October 20, 2005

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Opening time of the explosion vent		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms		No.
4	11	1	PR5	0,21	15	162,5	65,0	3,60		

Condition of the apparatus after the tests:
The arrester remained connected to the supply and return circuits
No pieces were projected inside and outside the circular enclosure
The arrester structure remained almost intact

Figure 5. Data sheet for 63 000 A test

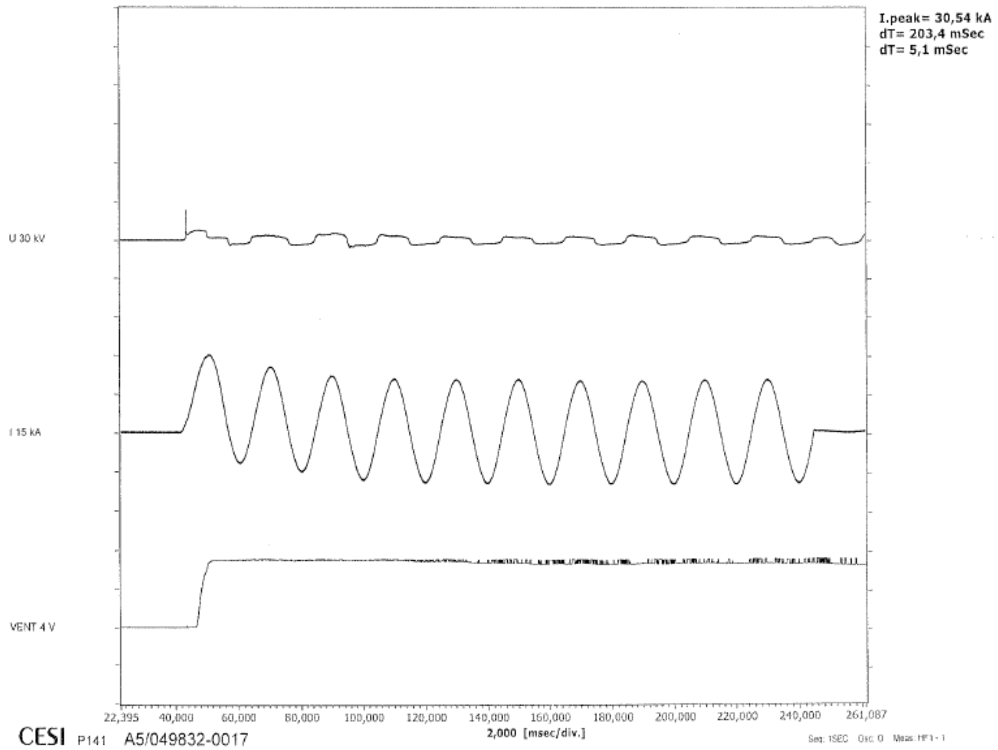


Figure 6. Oscillograms for 12 000A test

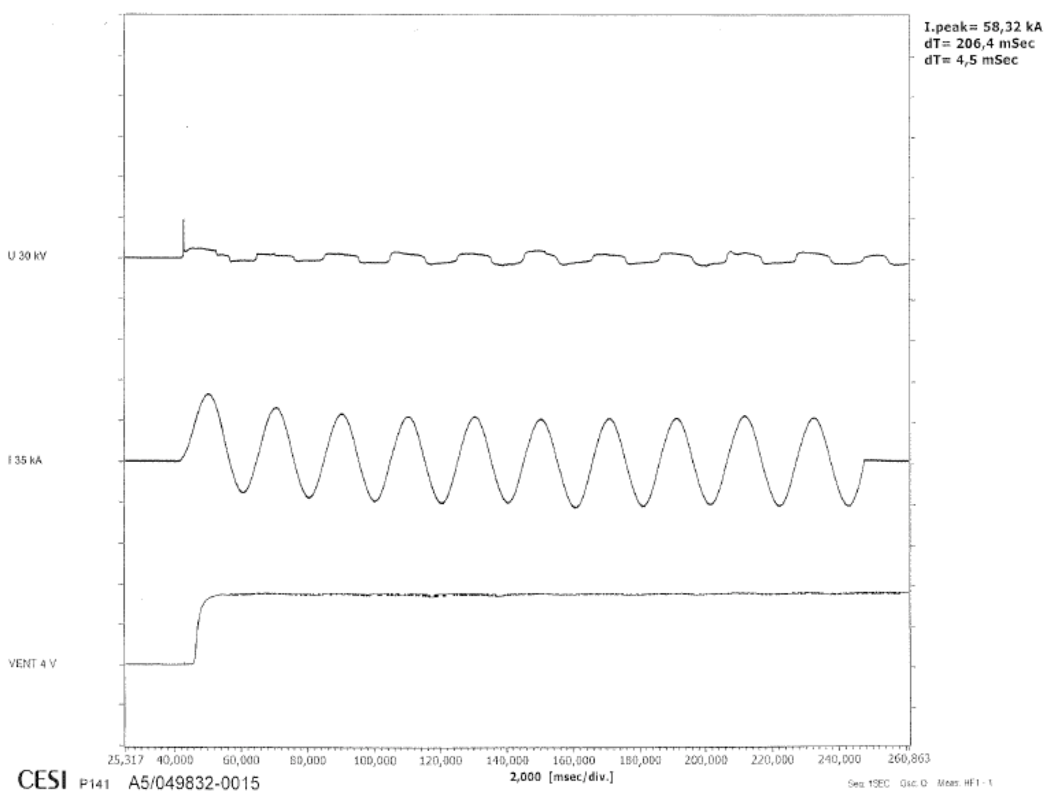


Figure 7. Oscillograms for 25 000A test

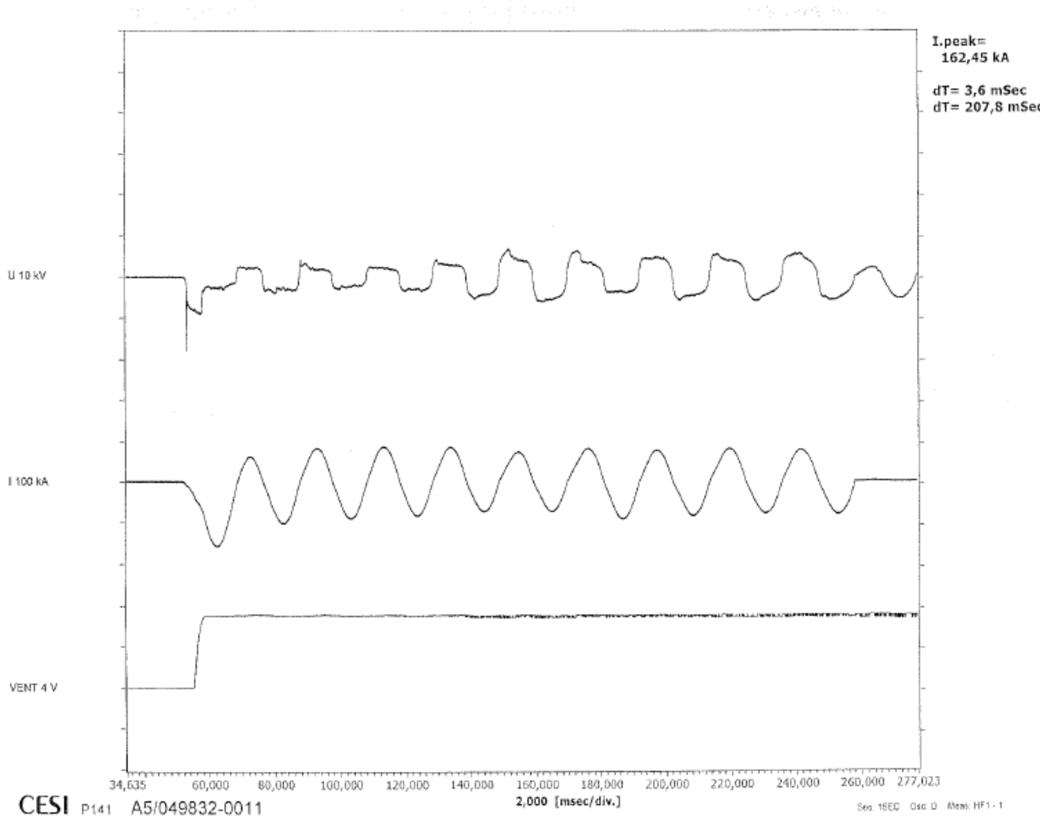


Figure 8. Oscillograms for 63 000A test

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-08
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Internal Partial Discharge

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

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.

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-09
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Bending Moment

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

IEC TYPE TEST REPORT
Bending Moment

TESTS PERFORMED:
A bending moment test was performed as described in Clause 10.8.9 of IEC 60099-4, for polymer-housed arresters with enclosed gas volume and a separate sealing system, on a fully assembled arrester unit that had been seal leak tested according to 9.1 d) of the standard. Prior to the mechanical testing, the unit was subjected to tests to determine watts loss, partial discharge, and residual voltage.

The test unit was securely mounted to the horizontal base of the test equipment and lateral (horizontal) loading was applied to the free end of the unit, in a direction perpendicular to the axis of the unit, at a rate necessary to reach the bending moment corresponding to the maximum permissible service load (MPSL) in approximately 50 s. The load was then maintained at not less than this level for about 90 s. Deflection was measured prior to release of the load. After release of load, the test sample was inspected to verify that no mechanical damage had occurred, and the load-deflection curve was examined to verify that there was no discontinuity, and that the strain condition after release of load was within allowed limits.

The sample was then subjected to the complete Moisture Ingress test described in 10.8.13 of the standard). At the conclusion of the Moisture Ingress test, the electrical and seal leak tests were repeated to verify that any changes were within allowed limits, and a visual inspection was made to verify that no mechanical damage had occurred.

RESULTS:
The PH3 series of arresters uses one, two or three units (depending on voltage rating and overall creepage distance requirements), with all units using one general polymer housing type (all housings have the same diameter and weathershed profile, differing only in height) and only one design of end fitting. The greatest bending stress is always at the bottom end of the bottom unit of the arrester, and according to the requirements of IEC 60099-4, it is therefore necessary only to perform a test on one unit.

The tested unit was the longest electrical section used in PH3 arresters, with U_r = 150 kV and U_c = 120 kV. Results of initial tests are shown in Table 1.

Table 1. Results of initial measurements

Test Parameter	Result
Watts loss at U_c	13.8 W
Residual voltage at 10 kA 8/20	340.4 kV
Internal partial discharge at 1.05 x U_c	< 10 pC
Seal leak	$< 1x\ 10^{-7}$ $Pa.m^3s^{-1}$

The MPSL declared for PH3 arresters is 8000 Nm. A loading curve for the bending test is shown in Figure 1. Examination of the loading curve shows no discontinuity during the load application.

Maximum deflection of the top end of the unit during application of MPSL was 57 mm, and after the load was released the residual deflection was zero.

The unit was then subjected to the Moisture Ingress test (see EU1527-H-12 section of the PH3 arrester type test report for details and results of this test). At the conclusion of the Moisture Ingress test, initial tests conducted on the unit (watts loss, partial discharge, residual voltage and seal leak) were repeated, with results shown in Table 2.

Table 2. Results of final measurements

Test Parameter	Result	Change from initial test
Watts loss at U_c	15.0 W	+ 8.7%
Residual voltage at 10 kA 8/20	338.5 kV	- 0.6 %
Internal partial discharge at 1.05 x U_c	< 10 pC	--
Seal leak	$< 1x\ 10^{-7}$ $Pa.m^3s^{-1}$	--

The change in watts loss and residual voltage from the values initially measured were well within the maximum allowed change of 20% and 5%, respectively. Additionally, partial discharge and seal leak rate were found to be below the allowed limits of 10 pC and $1x\ 10^{-7}$ $Pa.m^3s^{-1}$, respectively.

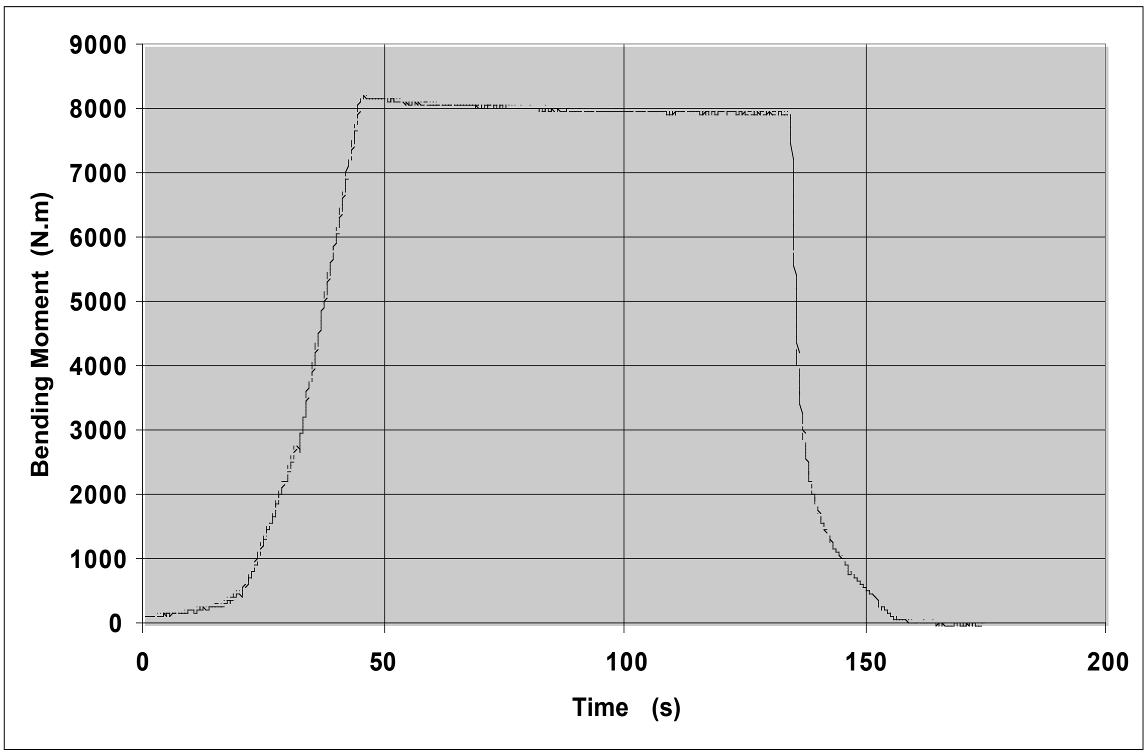


Figure 1. Bending moment at bottom end of unit
Max design moment at MPSL: 8000 Nm

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-10
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Seal Leak Rate

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

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 PH3 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 PH3 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.

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-11
PH3 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 PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

IEC TYPE TEST REPORT
Radio Influence Voltage (RIV)

TESTS PERFORMED:
A fully-assembled arrester, with voltage rating U_r of 312 kV and continuous operating voltage U_c of 249.6 kV, was subjected to the RIV test as prescribed in Clause 10.11 of IEC 60099-4. This sample represents an arrester of the longest length and highest voltage stress in the PH3 series of arresters. The voltage application was as follows:

- raised to 287 kV (1.15 U_c)
- lowered to 262 kV (1.05 U_c)
- held at 262 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 262 kV (1.05 U_c)
- held at 262 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 1 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. Figure 1 shows the arrester installed for test. Results of the RIV measurements are shown in Table 1.

At all test voltage levels, the RIV was only marginally above the background noise level. IEC 60099-4 allows a maximum RIV level of 2500 µV.

Figure 1. 312 kV rated arrester

Table 1. Measured RIV values

Test condition	Test voltage (kV rms)	RIV (µV)
Open circuit		2-4
Arrester installed	287	6-20
Arrester installed	262 (0 min)	4-10
Arrester installed	262 (5 min)	4-10
Arrester installed	235	4-10
Arrester installed	208	2-4
Arrester installed	181	2-4
Arrester installed	154	2-4
Arrester installed	125	2-4
Arrester installed	154	2-4
Arrester installed	181	2-4
Arrester installed	208	4-10
Arrester installed	235	4-10
Arrester installed	262 (0 min)	4-10
Arrester installed	262 (5 min)	4-10
Arrester installed	235	4-10
Arrester installed	208	2-10
Arrester installed	181	2-4
Arrester installed	154	2-4
Arrester installed	125	2-4

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-12
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Moisture Ingress

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

IEC TYPE TEST REPORT
Moisture Ingress

TESTS PERFORMED:
A fully-assembled arrester unit, with voltage rating U_r of 150 kV and continuous operating voltage U_c of 120 kV, was subjected to the Moisture Ingress test as prescribed in Clause 10.8.13 of IEC 60099-4. The overall height of the unit was 1352 mm, representing the longest mechanical unit used in the PH3 series of arresters.

Initial measurements were made of watts loss at U_c, partial discharge at 1.05 times U_c after 10 s at U_r, and residual voltage at 10 kA. The sample was then subjected to a bending moment test at MPSL of 8000 N.m (as part of the Bending Moment test described in the EU1527-H-09 section of the PH3 type test report), and was subsequently subjected to thermomechanical preconditioning, consisting four 24 h periods at, respectively, +60°C, -25°C, +45°C and –40°C. During each of the 24 h periods, cantilever load was applied to the top end of the sample to produce a bending moment at the bottom end of at least 4 kNm, the maximum continuous bending moment defined for PH3 arresters. The load was applied in a different direction, designated respectively as 0°, 180°, 270°, and 90°, for each of the four periods.

The sample was then immersed in boiling water, with initial salt concentration of 1 kg/m^3, for 42 h. At the end of this period, the sample remained immersed until the water had cooled to 50°C, after which time the initial measurements of watts loss, partial discharge and residual voltage were repeated.

RESULTS:
Table 1 shows the results of initial measurements. Table 2 shows the deflections measured during each of the four 24 h periods of preconditioning. Table 3 shows the results of the electrical measurements conducted after removal of the sample from the water.

Table 1. Results of initial measurements

Test Parameter	Result
Watts loss at U_c	13.8 W
Residual voltage at 10 kA 8/20	340.4 kV
Internal partial discharge at 1.05 x U_c	< 10 pC

Table 2. Deflections measured during 24 h periods

Period	Temperature	Load direction	Beginning of period		End of period		
			Bending moment (Nm)	Maximum deflection (mm)	Bending moment (Nm)	Maximum deflection (mm)	Residual deflection (mm)
1	+ 65 °C	0°	4531	23.4	4483	25.4	0
2	- 25 °C	270°	4629	24.2	4671	25.1	4.4
3	+ 45 °C	180°	4552	24.1	4465	27.6	5.4
4	- 40 °C	90°	4629	24.1	4647	26.3	4.3

Table 3. Results of final measurements

Test Parameter	Result	Change from initial test
Watts loss at U_c	15.0 W	+ 8.7%
Residual voltage at 10 kA 8/20	338.5 kV	- 0.6 %
Internal partial discharge at 1.05 x U_c	< 10 pC	--

The change in watts loss and residual voltage from the values initially measured were well within the maximum allowed change of 20% and 5%, respectively.

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-13
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Weather Ageing

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 9/29/2006

IEC TYPE TEST REPORT
Weather Ageing

TESTS PERFORMED:

A fully-assembled arrester unit, with voltage rating U_r of 144 kV and continuous operating voltage U_c of 115.2 kV, was subjected to the Weather Ageing test series A (1000 h salt fog) as prescribed in Clause 10.8.14 of IEC 60099-4. The test was performed at the CESI high voltage laboratory in Milan, Italy.

Initial measurements were made of reference voltage, at reference current of 17 mA_{pk}, and internal partial discharge at 1.05 times U_c after 10 s at U_r.

The test sample, was energized at U_c = 115.2 kV_{rms} for a total of 1000 h in the test room filled with salt fog having the following characteristics:

- Salinity of water solution: 10 kg/m^3
- Water flow rate: 0.4 ± 0.1 l/h*m^3

The salt fog was not directly spayed on the test sample. A schematic of the test arrangement is shown in Figure 1 (two other arrester units were tested at the same time).

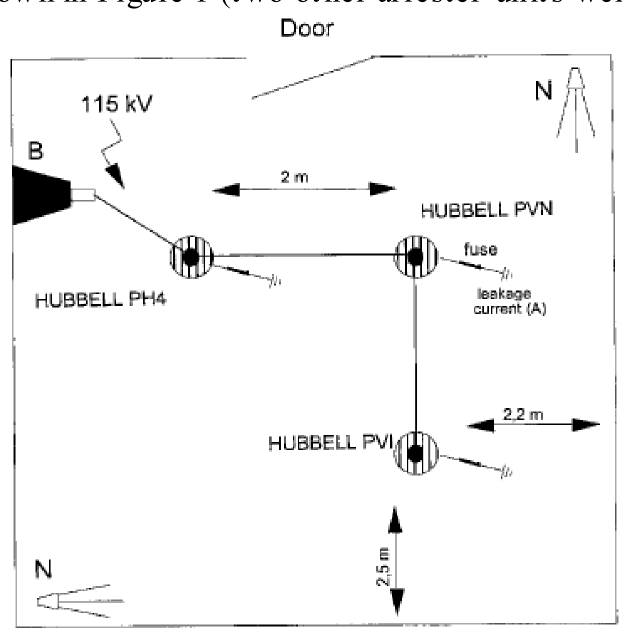


Figure 1. Test chamber layout

Visual observations of the condition of the silicone rubber housing were made after 500 h and at 1000 h. Measurements of reference voltage and internal partial discharge were repeated at the conclusion of the 1000 h test period.

RESULTS :

Tests were performed on a PH4 arrester that uses an identical housing to the PH3 arrester of the same voltage rating, and the tests on the PH4 housing qualify also the PH3 design. 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.

No tracking or shed puncture, and only very light erosion occurred in the first 500 h. No tracking or shed puncture, and only light erosion occurred during the remaining 500 h. No flashovers occurred during the 1000 h test period.

Table 1 shows the initial and final values of reference voltage and internal partial discharge. The requirements of not more than 5% change in reference voltage and partial discharge levels of less than 10 pC were met.

Table 1. Initial and final electrical measurements

Measured quantity	Initial	Final	Result
Reference voltage	147.6 kV	151.5 kV	+ 2.6% change
Partial discharge	1.2 pC	1.6 pC	< 10 pC

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1527-H-14.1
PH3 Series Polymer-housed Arrester
10,000 A Line Discharge Class 3

Power Frequency Voltage Versus Time

This report records the results of type tests made on PH3 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.

M.G. Comber
Manager, Engineering

Date: 8/24/2007

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 PH3 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} Reference	20.62
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

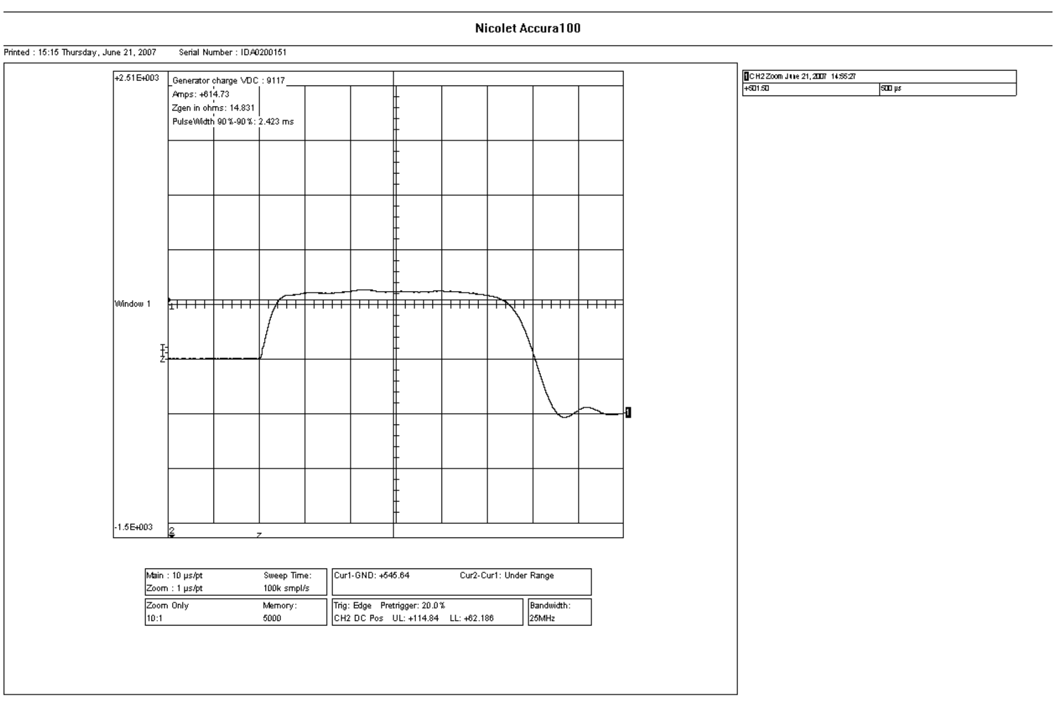


Figure 1. Oscillogram of discharge current for generator short circuit set up test

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 PH3 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

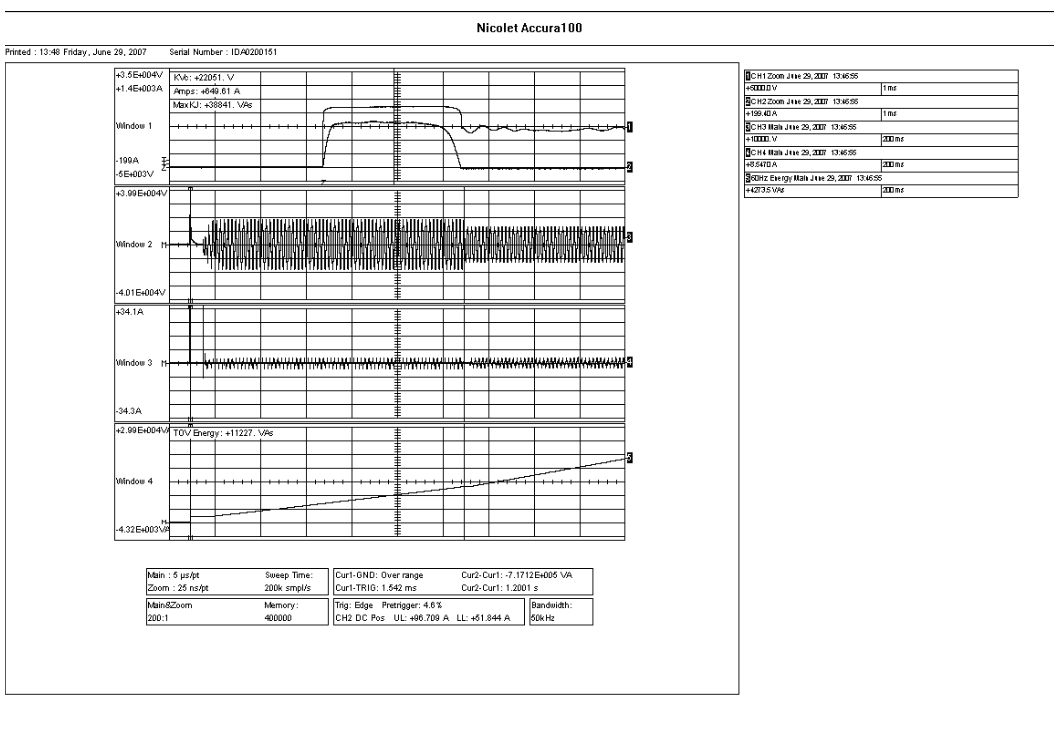


Figure 2. Oscillograms of line discharge and 1.1 s application of elevated voltage

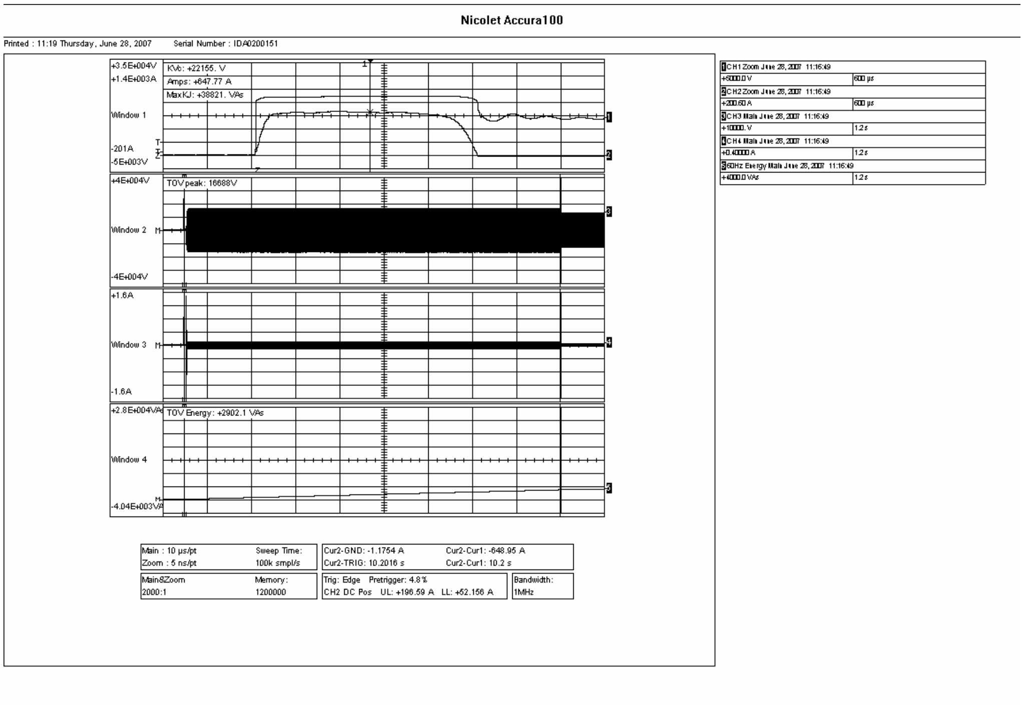


Figure 3. Oscillograms of line discharge and 10 s application of elevated voltage

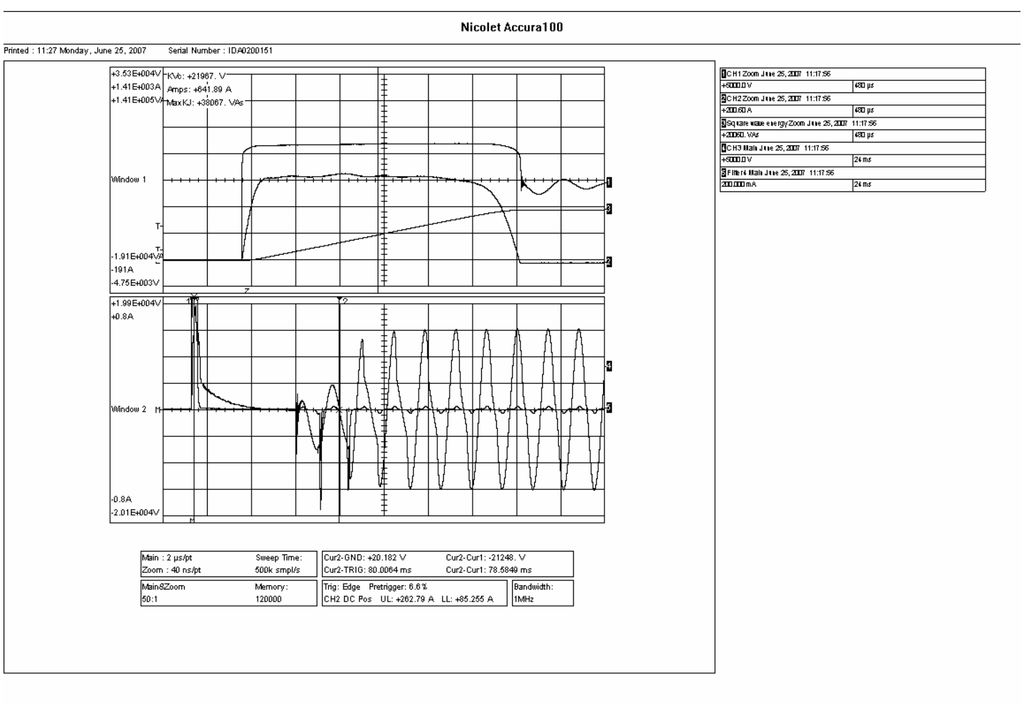


Figure 4. Oscillograms of line discharge and first several cycles of 210 s application of elevated voltage

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

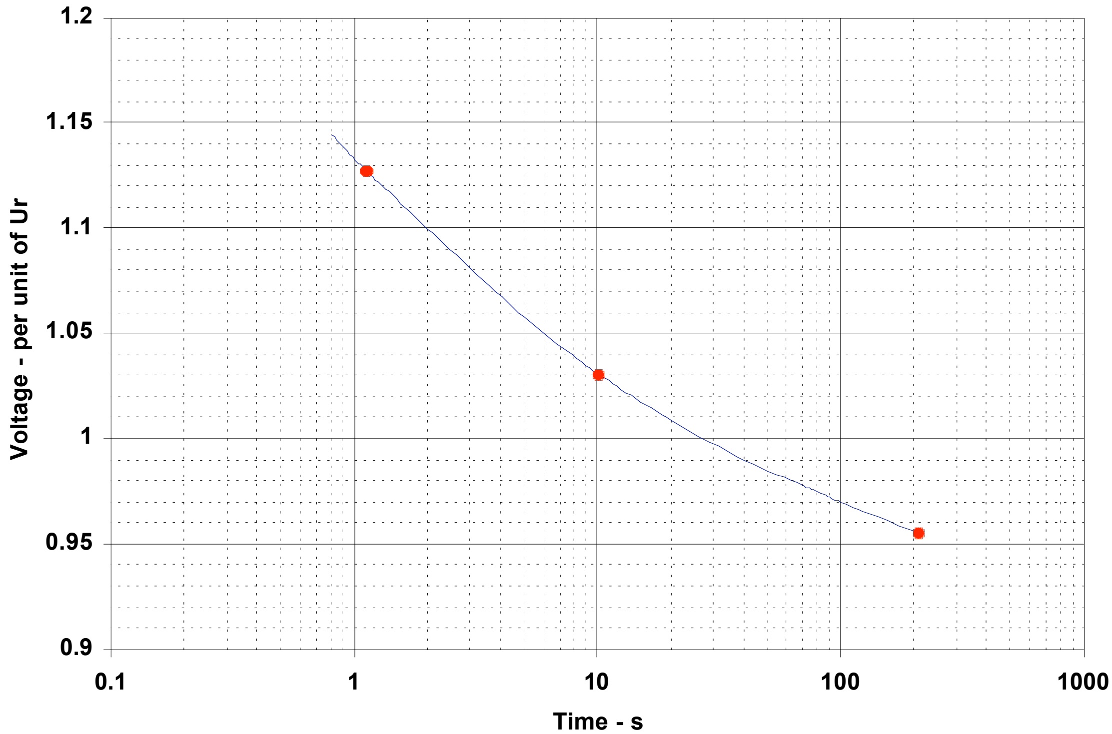


Figure 5. Power frequency voltage vs. time characterstic for PH3 series arresters, with test points for 1.1 s, 10 s and 210 s