HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-00
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

Michael G. Comber

M. G. Comber
Manager, Engineering

Date: March 15, 2011

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

Report No.	Description	Clause	Issue date
EU1575-H-01	Insulation Withstand Test on Arrester Housing	8.2.6, 8.2.7, 8.2.8	March 15, 2011
EU1575-H-02	Residual Voltage	8.3.1, 8.3.2, 8.3.3	March 15, 2011
EU1575-H-03	Long Duration Current Withstand	8.4	March 15, 2011
EU1575-H-04	Accelerated Aging Procedure	8.5.2	March 15, 2011
EU1575-H-05	Heat Dissipation Behavior of Test Section	8.5.3	March 15, 2011
EU1575-H-06	Switching Surge Operating Duty	8.5.4	March 15, 2011
EU1575-H-07	Short Circuit	8.7	March 15, 2011
EU1575-H-08	Internal Partial Discharge	8.8	March 15, 2011
EU1575-H-09	Bending Moment	8.9	March 15, 2011
EU1575-H-10	Environmental	8.10	March 15, 2011
EU1575-H-11	Seal Leak Rate	8.11	March 15, 2011
EU1575-H-12	RIV	8.12	March 15, 2011
EU1575-H-13	Power Frequency Voltage Versus Time	Annex D	March 15, 2011
EU1575-H-14	Artificial Pollution	Annex F	March 15, 2011

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-01
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Insulation Withstand Test on Arrester Housing

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

Michael G. Comber

M. G. Comber
Manager, Engineering

Date: March 15, 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 MH4 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	°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. EU1575-H-02
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Residual Voltage

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M. G. Comber
Manager, Engineering

Date: March 15, 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 clauses 8.3.1, 8.3.2 and 8.3.3 of IEC 60099-4, to determine steep current impulse residual voltages at 20 kA, lightning impulse residual voltages at 10 kA, 20 kA and 40 kA, and switching impulse residual voltages at 0.5 kA and 2 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 (20 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 (20 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	20	1/2	15.83	1.122	28
Lightning impulse	10	8/20	13.24	0.938	4
	20		14.11	1.000	7
	40		15.54	1.100	10
Switching impulse	0.5	38/84	10.89	0.771	16
	2		11.60	0.822	22

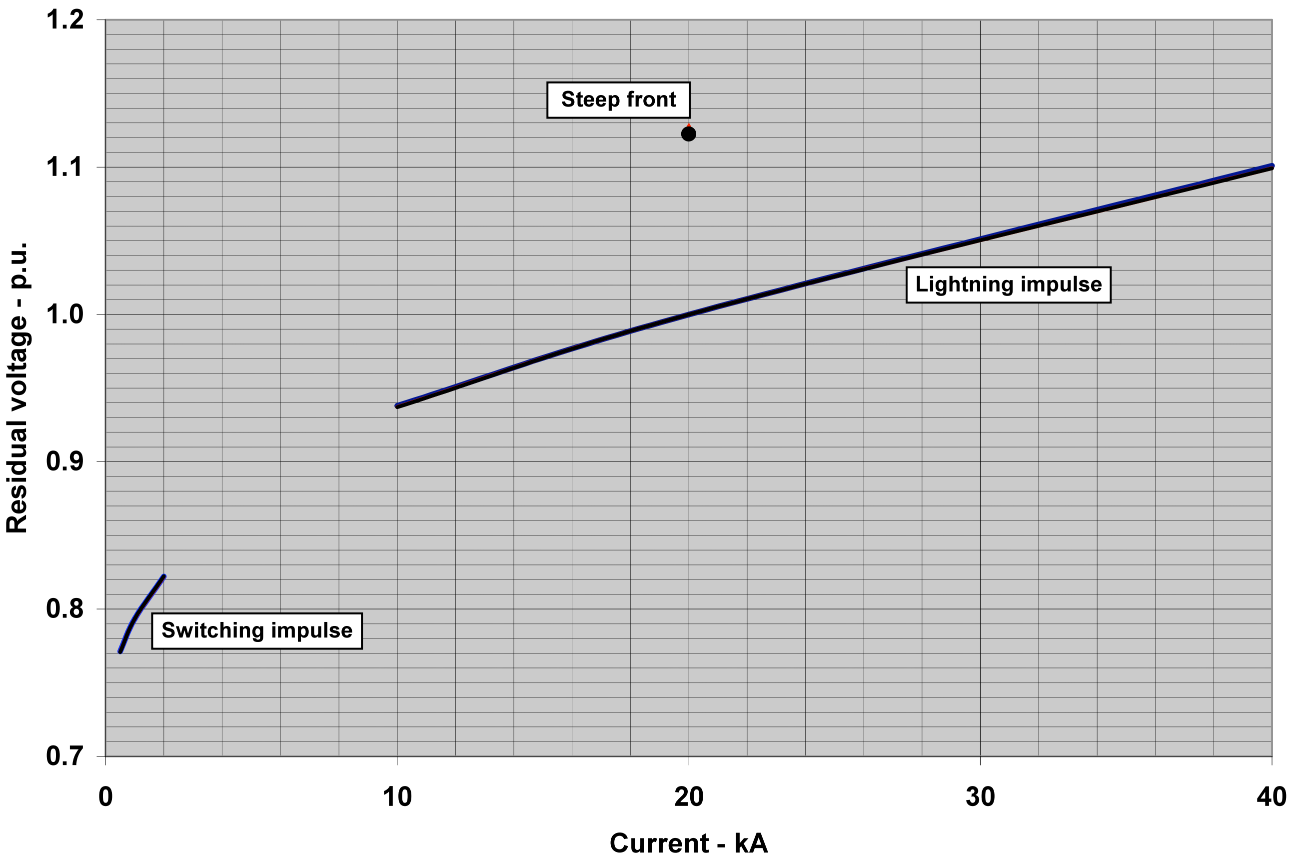
Table 2. Measurements made on test sample 2

Test wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	µs	kV	p.u.	number
Steep current	20	1/2	15.93	1.126	29
Lightning impulse	10	8/20	13.26	0.937	5
	20		14.15	1.000	8
	40		15.56	1.099	11
Switching impulse	0.5	38/84	10.91	0.771	17
	2		11.63	0.822	23

Table 3. Measurements made on test sample 3

Test wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	µs	kV	p.u.	number
Steep current	20	1/2	15.91	1.122	30
Lightning impulse	10	8/20	13.28	0.937	6
	20		14.17	1.000	9
	40		15.58	1.099	12
Switching impulse	0.5	38/84	10.92	0.771	18
	2		11.65	0.822	24

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 (20 kA). These values (*Per-unit* $U_{res\text{-}chart}$) are used to calculate the residual voltage characteristics ($U_{res\text{-}arrester}$) of assembled MH4 series arresters. For the cases of switching impulse and lightning impulse residual voltages, the arrester residual voltages are calculated as follows:

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

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:

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

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 (= 20 kA)
T_f is the front time of the steep current impulse (= 1µs)

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-03
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Long Duration Current Impulse Withstand Tests

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 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 in series. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with clause 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 below lists the measured residual voltage and reference voltage for each sample, and lists the corresponding transmission line parameters used for the test. U_c for the MH4 series of arresters has been established as 0.768 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 0.768 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, 0.78 x U_{ref}), thereby making the test more onerous.

The minimum energy required for each line discharge for Class 4 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 500 A.

Table 1. Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Switching impulse residual voltage (kV) U_{res}	20.69	20.69	20.63
Initial Residual Voltage (kV) @ 20 kA, 8/20	27.10	26.98	26.98
Reference Current (mA) I_{ref}	17	17	17
Reference Voltage (kV_c) V_{ref}	16.48	16.48	16.47
COV (kV rms) U_c	9.09	9.09	9.08
Rating (kV rms) U_r	11.36	11.36	11.35
Arrester Classification (kA)	20	20	20
Line Discharge Class	4	4	4
Virtual Duration of Peak (μs, 90-90%) - min	2800	2800	2800
Surge Impedance (Ω) Z_g - max (0.8 U_r)	9.08	9.08	9.08
Charging Voltage (kV) U_L – min (2.6 U_r)	29.54	29.54	29.51
Energy required (kJ) - min	56.4	56.4	56.5

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

$$Z_g = 7456\text{ V} / 828.7\text{ A} = 8.997\ \Omega \qquad \text{Virtual Duration of Peak } = 2992\ \mu\text{s}$$

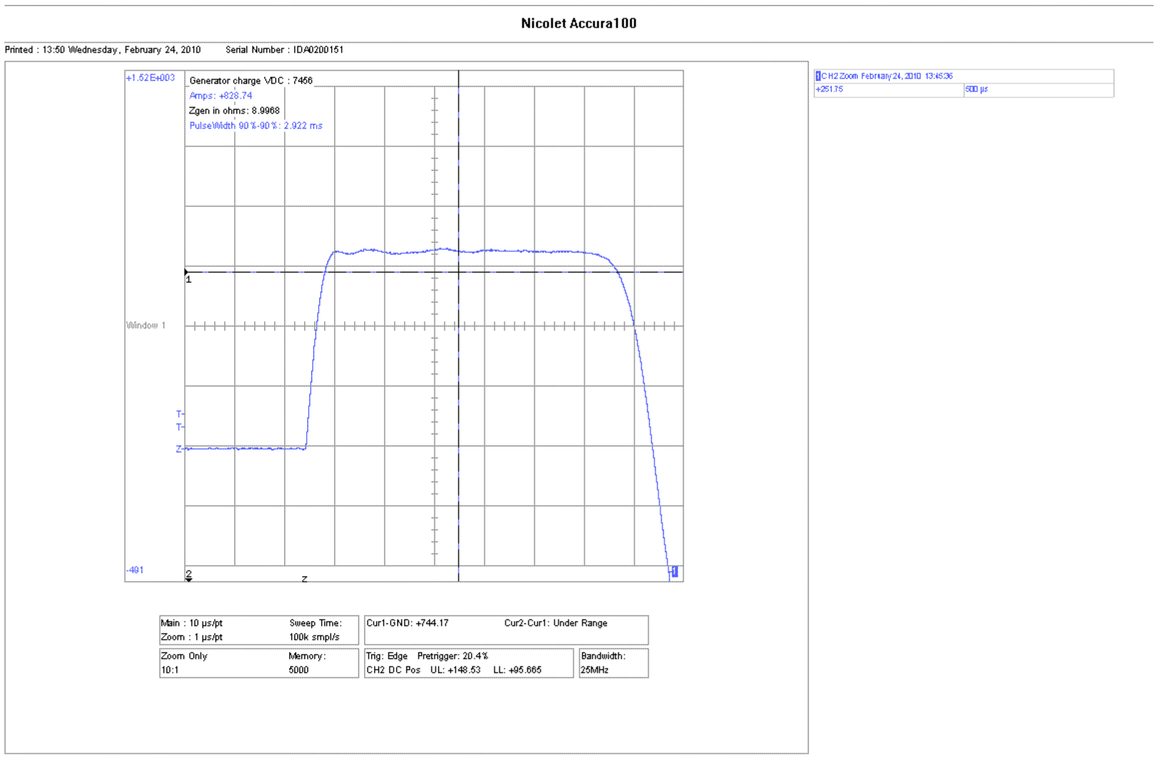


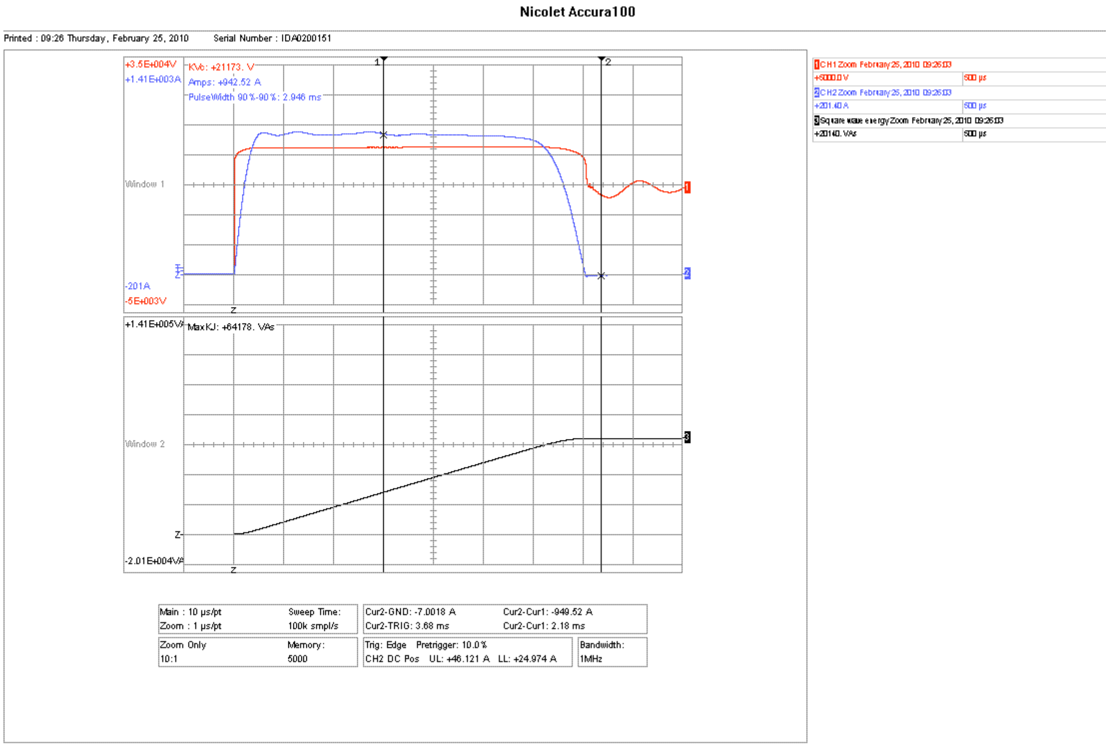
Figure 1. Oscillogram of discharge current for generator short circuit set up test

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.

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	943	21.17	64.2	834	21.54	57.9	n/a	21.02	60.44
2	890	21.37	61.2	865	21.25	59.3	845	21.21	58.0
3	834	21.54	57.9	835	21.41	57.2	818	21.35	56.6
4	830	21.64	57.8	867	21.07	59.0	870	21.03	58.2
5	829	21.30	56.8	839	21.26	57.6	849	21.24	58.0
6	821	21.49	57.0	820	21.41	56.7	841	21.46	59.0
7	869	21.13	59.2	868	21.09	59.0	869	21.05	58.1
8	840	21.32	57.7	843	21.30	57.9	848	21.27	56.9
9	823	21.51	57.0	825	21.45	57.1	823	21.44	57.8
10	851	21.10	57.9	849	21.06	57.6	852	21.03	57.7
11	840	21.33	57.7	843	21.27	57.8	843	21.24	57.7
12	814	21.49	56.5	832	21.45	57.5	830	21.42	57.4
13	845	21.11	57.5	851	21.08	57.8	849	21.05	57.6
14	837	21.34	57.6	842	21.28	57.7	839	21.25	57.4
15	823	21.53	57.1	828	21.45	57.3	826	21.42	57.0
16	848	21.11	57.8	852	21.07	57.9	848	21.05	57.6
17	840	21.34	57.8	841	21.29	57.8	840	21.27	57.6
18	825	21.53	57.2	825	21.44	57.1	822	21.43	56.9

Sample 1, Discharge 3



Sample 1, Discharge 18

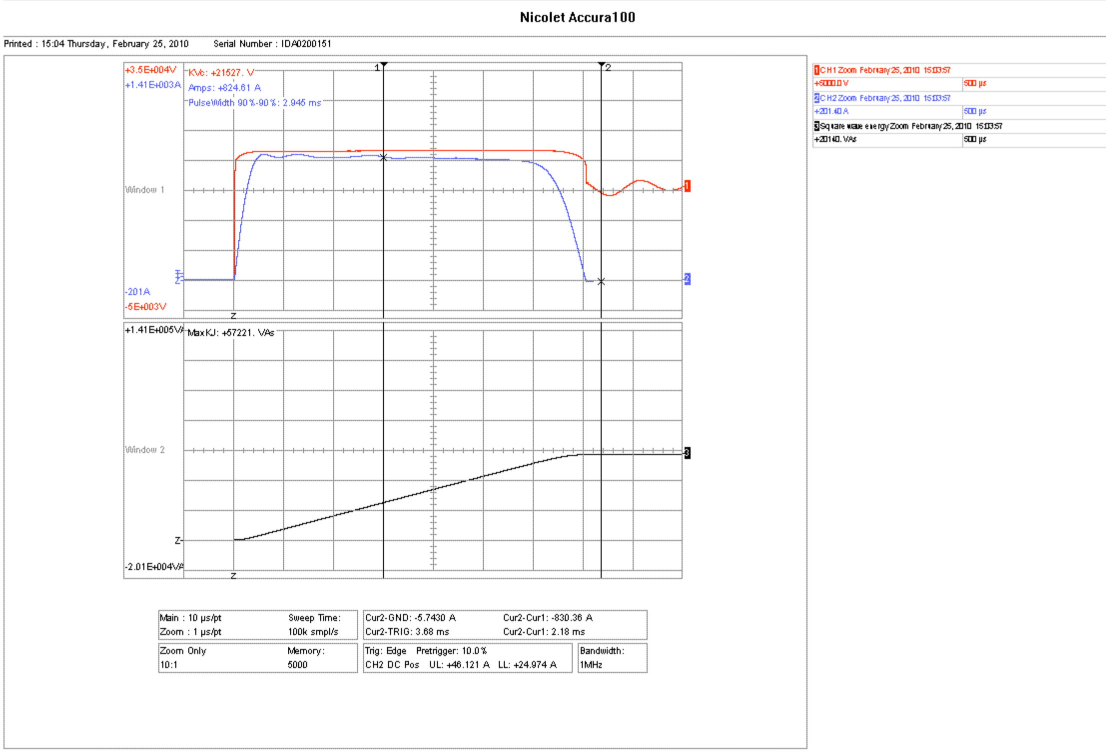


Figure 2. Oscillograms of line discharges for sample 1

Sample 2, Discharge 1

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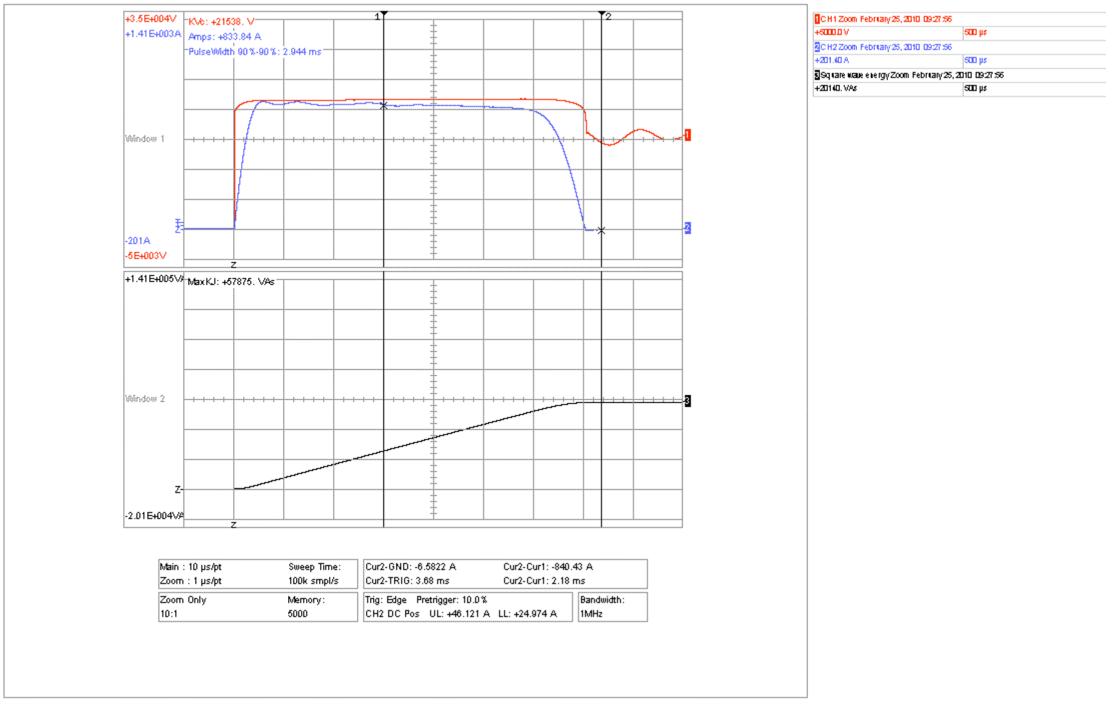

Sample 2, Discharge 18

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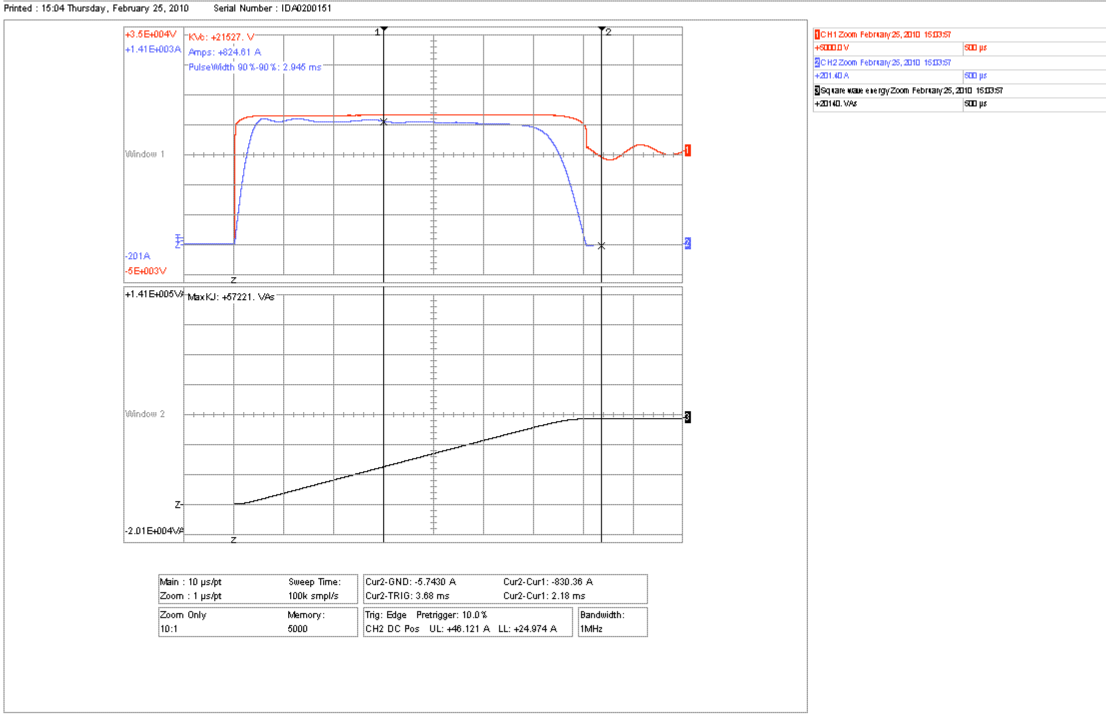

Figure 3. Oscillograms of line discharges for sample 2

Sample 3, Discharge 1

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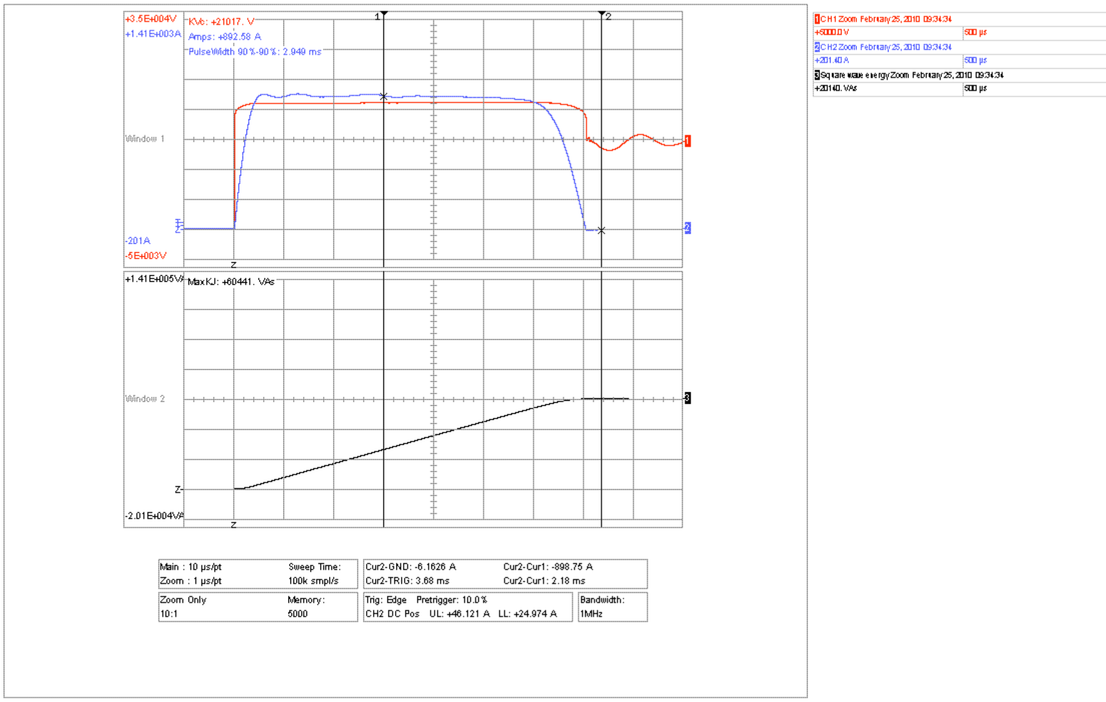

Sample 3, Discharge 18

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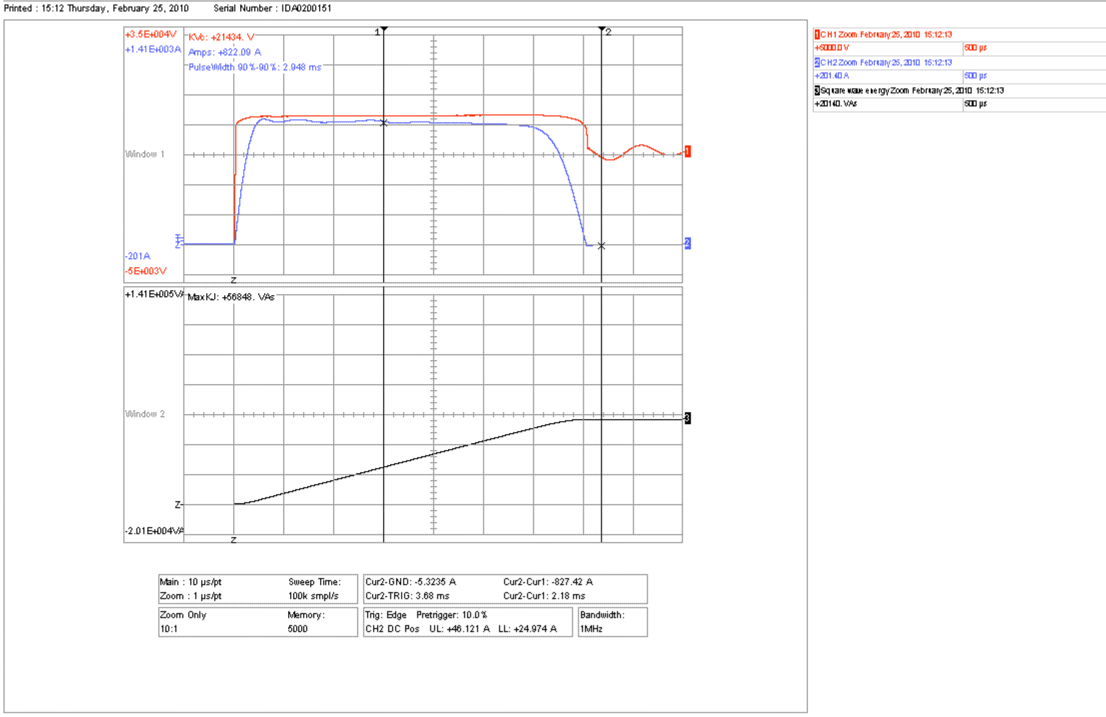


Figure 4. Oscillograms of line discharges for sample 3

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	27.10	27.13	+ 0.1 %
2	26.98	27.02	+ 0.1 %
3	26.98	27.02	+ 0.1 %

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

IEC Type Test Report
Report No. EU1575-H-04
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Accelerated Aging Procedure

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Accelerated Aging Procedure

TESTS PERFORMED:
Accelerated aging tests were performed on two resistor elements. The tests were conducted in accordance with Clause 8.5.2 of IEC 60099-4. 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. 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:
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 both 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	5.20	2.82	2.82
2	5.97	2.91	2.91

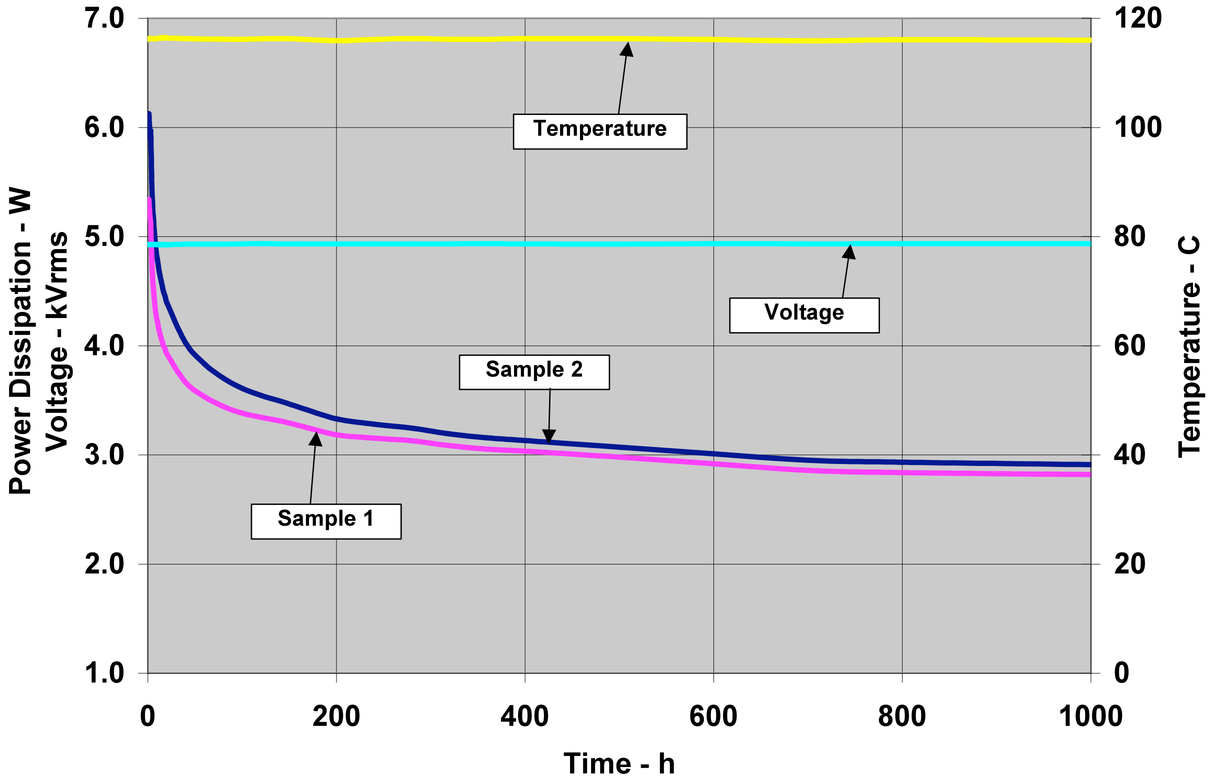


Figure 1. Power dissipation, voltage and temperature measurements during 1000 h test period

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-05
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Heat Dissipation Behaviour of Test Section

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

Michael G. Comber
M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Heat Dissipation Behaviour of Test Section

TESTS PERFORMED:
Tests were performed as described in Clause 8.5.3 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 = 144 kV unit and a test section with U_r = 10.6 kV were prepared. The 144 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 a thermocouple located between one-third and one-half of the unit length from the top of the resistor stack. The test section was comprised of two resistor elements 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 hours.

With both samples starting from the same initial temperature of 120^{o}C, the temperature of the resistors in the test section remain at or 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.

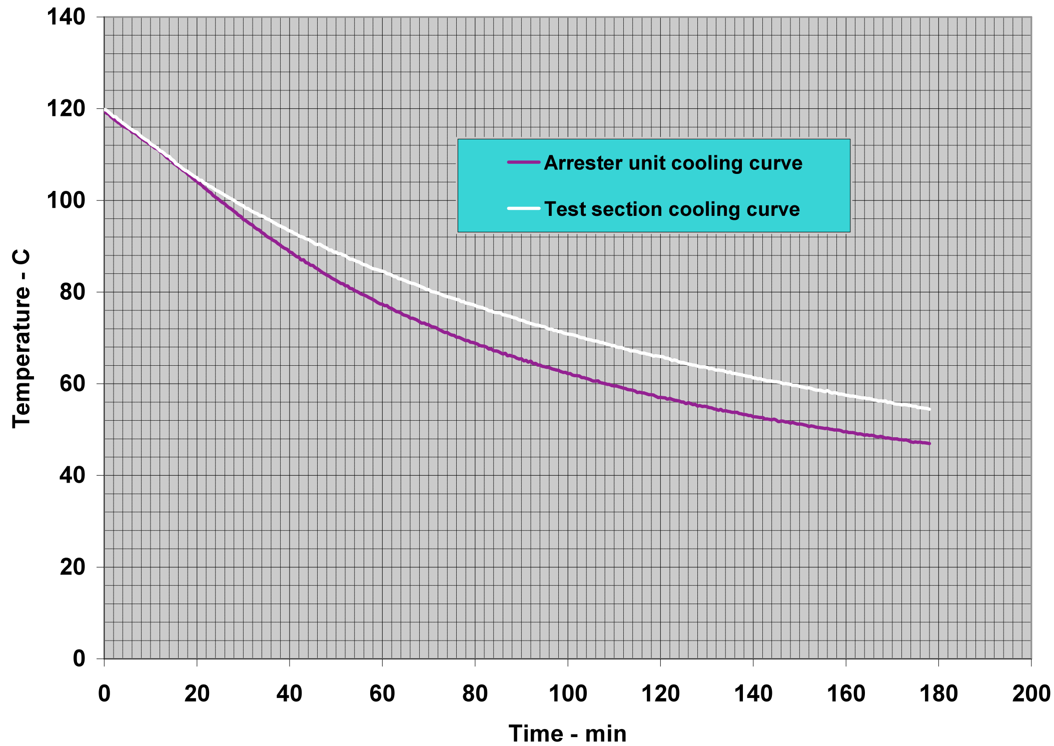


Figure 1. Cooling curves of fully assembled unit and test section

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-06
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Switching Surge Operating Duty Test

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Switching Surge Operating Duty Test

TESTS PERFORMED:
Switching surge operating duty tests were performed on three prorated test sections prepared based on the results of the tests to verify heat dissipation behaviour of test sample. Each section consisted of two resistors in series and had U_r of approximately 11.3kV. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with Clause 8.5.5 of IEC 60099-4. 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 were 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 initial measurements of residual voltage and reference voltage for each section, and lists the corresponding transmission line parameters used for the test.

U_c for the MH4 series of arresters has been established as 0.768 times the lowest acceptable reference voltage in routine tests, and U_r has been established as 1.25 times U_c.

The minimum energy required for each line discharge for Class 4 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 500 A.

Table 1. Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Switching impulse residual voltage (kV) U_{res}	20.65	20.60	20.64
Initial Residual Voltage (kV) @ 20 kA, 8/20	26.98	26.98	27.01
Reference Current (mA) I_{ref}	17	17	17
Reference Voltage (kV_c) V_{ref}	16.46	16.46	16.46
COV (kV rms) U_c	8.94	8.94	8.94
Rating (kV rms) U_r	11.17	11.17	11.17
Arrester Classification (kA)	20	20	20
Line Discharge Class	4	4	4
Virtual Duration of Peak (µs, 90-90%) - min	2800	2800	2800
Surge Impedance (Ω) Z_g - max (0.8 U_r)	8.94	8.94	8.94
Charging Voltage (kV) U_L – min (2.6 U_r)	29.04	29.04	29.04
Energy required (kJ) - min	54.3	54.5	54.3

RESULTS:

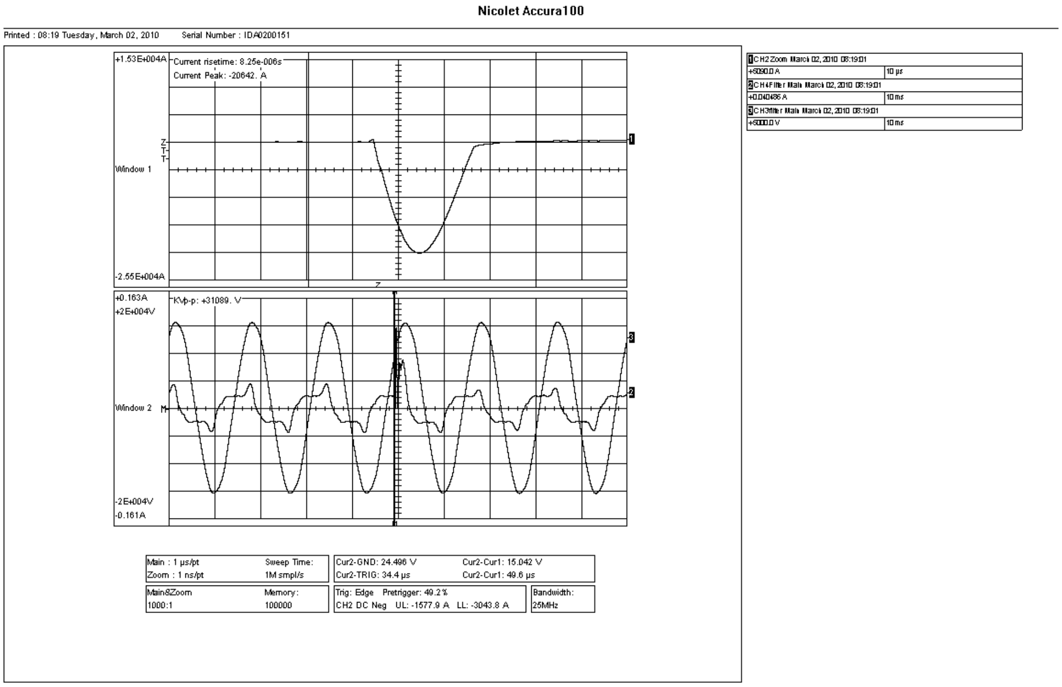
Representative voltage and current waveforms for lightning impulse conditioning discharges and high current conditioning impulses are shown in Figures 1 and 2, respectively.

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 3 shows

$Z_g = 7456 \text{ V} / 828.7 \text{ A} = 8.997\ \Omega$ Virtual Duration of Peak = 2992 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.

Section 1: 1st conditioning impulse



Section 1: 20th conditioning impulse

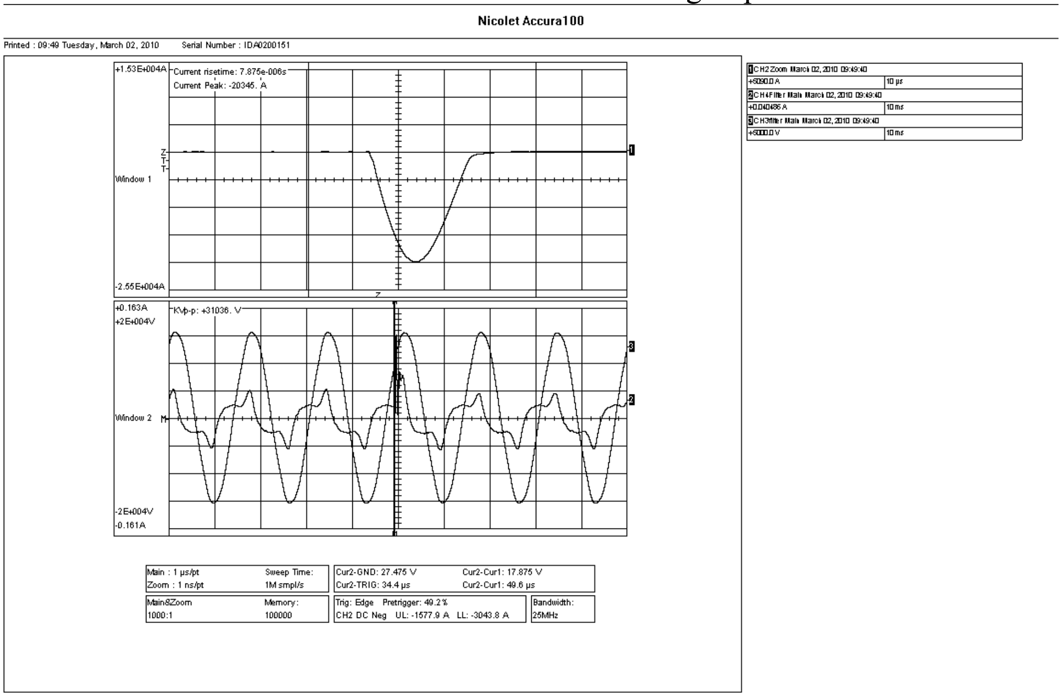


Figure 1. Representative oscillograms of 20kA 8/20 conditioning impulses

Section 1: 2nd conditioning impulse

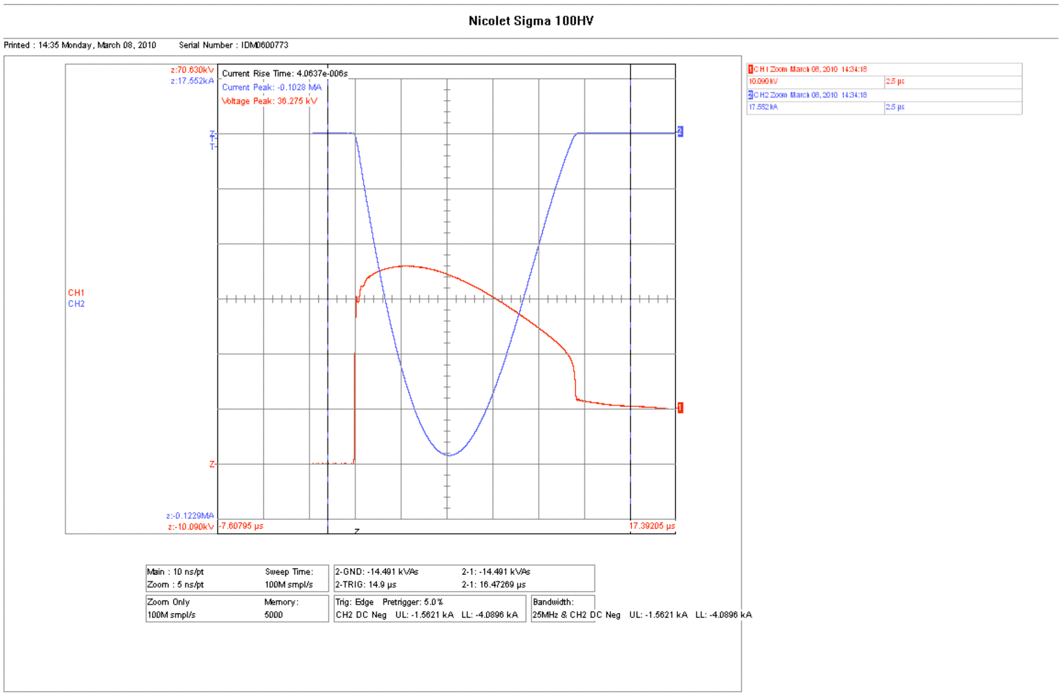


Figure 2. Representative oscillograms of 100kA conditioning impulse

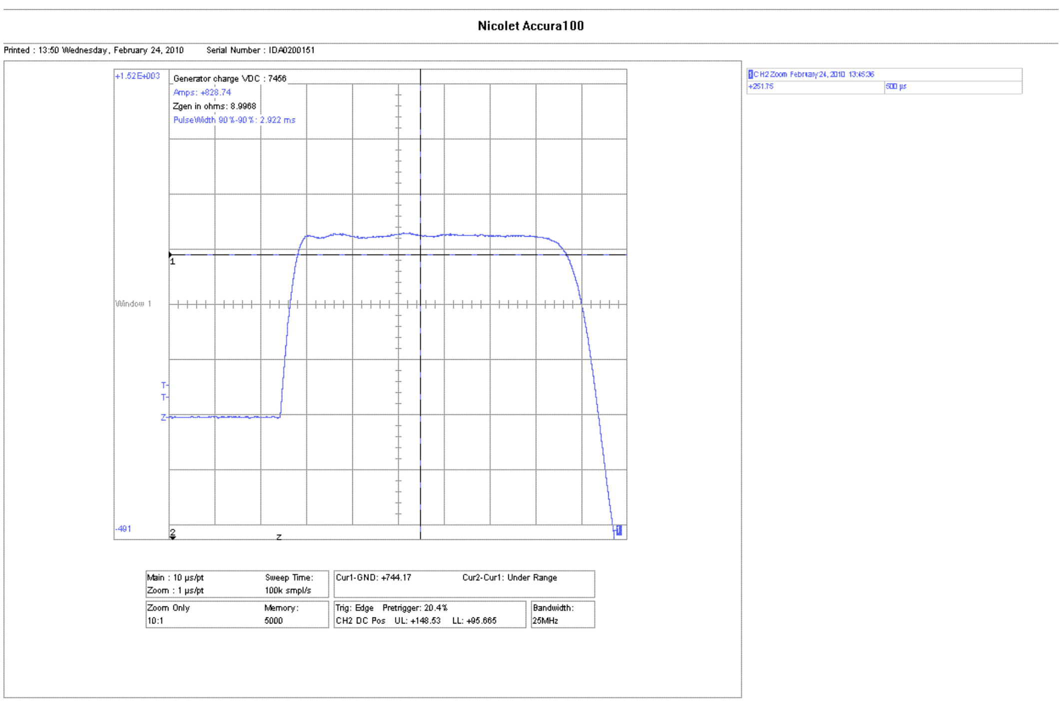


Figure 3. Oscillogram of discharge current for generator short circuit set up test

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	804	21.28	55.3	819	21.20	56.1	810	21.28	55.6
2	787	21.44	54.6	800	21.43	55.2	792	21.44	54.8

Representative waveforms of voltage and current during the line discharges and the 10 s application of U_r are shown in Figure 4. Ambient air temperature at the time of the test was 22 °C. Table 3 lists measurements made during this period. The actual voltage applied during the 10 s period was approximately 2.4% higher than the U_r established for the sample, making the test slightly more onerous than required.

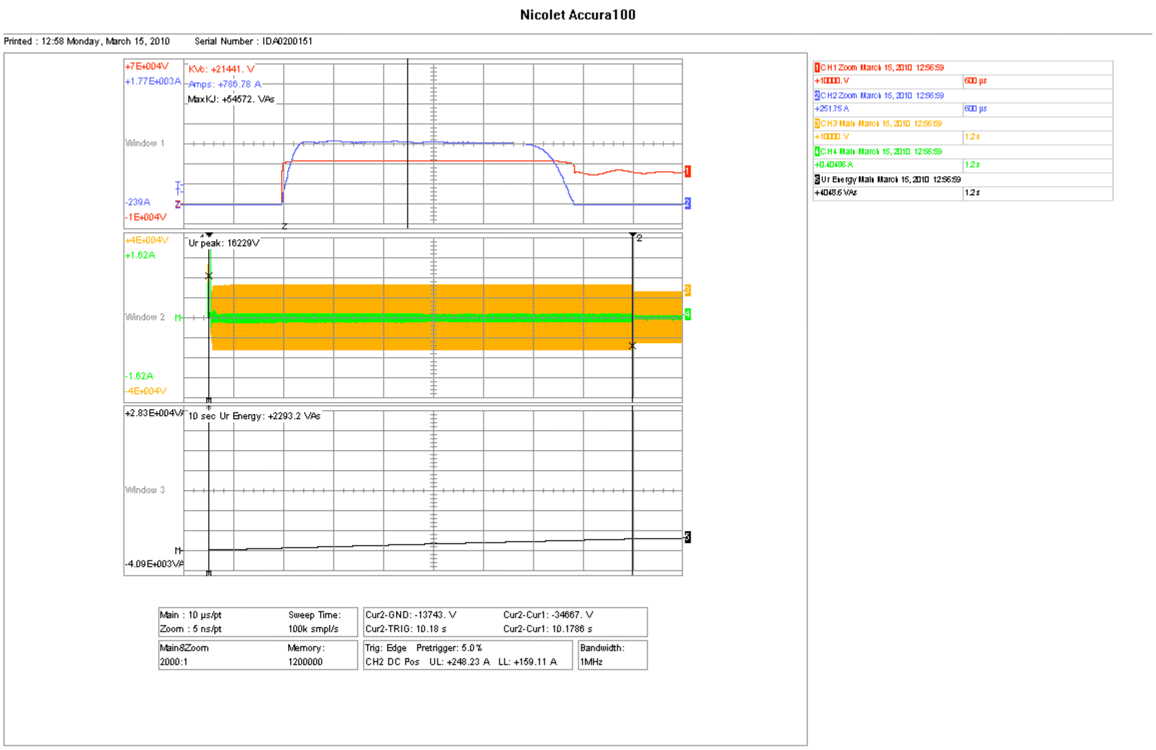


Figure 4. Oscillogram of second line discharge and application of U_r for section 1

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)
0.06	16.08	116	0.06	16.08	96	0.06	16.00	87
1	16.20	85	1	16.19	97	1	16.15	89
2	16.24	86	2	16.20	95	2	16.19	89
4	16.24	84	4	16.22	96	4	16.19	89
6	16.24	71	6	16.25	100	6	16.20	90
8	16.24	70	8	16.23	98	8	16.19	90
10.2	16.25	73	10.2	16.24	100	10.2	16.19	91
Avg rms voltage during 10s	11.47 kV		Avg rms voltage during 10s	11.46 kV		Avg rms voltage during 10s	11.43 kV	

Figure 5 shows representative oscillograms of voltage and current at the beginning and end of the 30 min application of U_c. 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	19.1	23.0	22.8
0.5	18.1	21.8	21.9
1	17.5	21.3	21.4
2	17.6	21.0	20.9
5	16.7	20.4	19.7
10	16.1	19.5	19.4
20	14.9	17.5	18.4
30	13.6	16.9	17.2

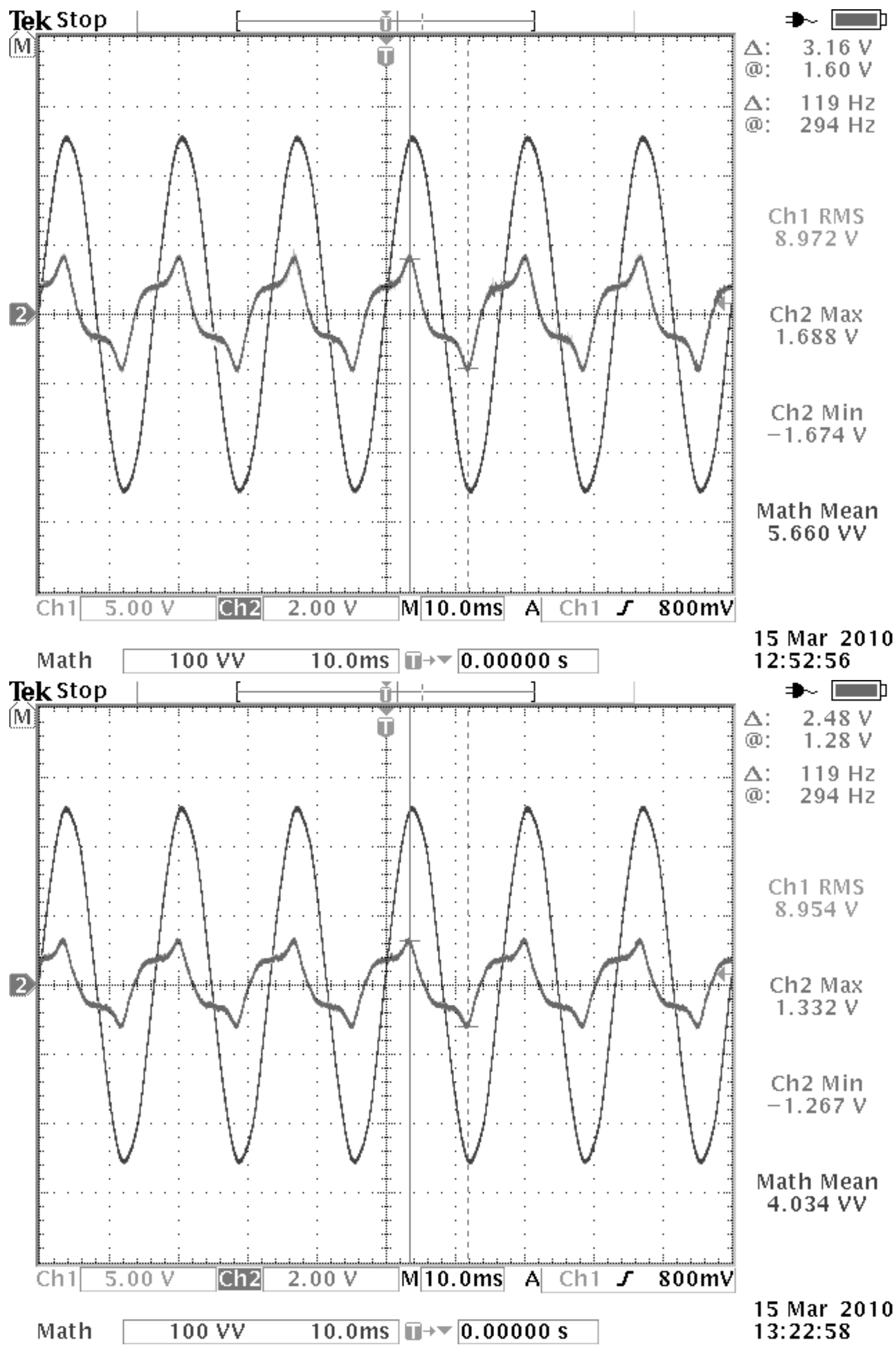


Figure 5. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c for section 1

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	26.98	27.11	+ 0.5 %
2	26.98	27.05	+ 0.3 %
3	27.01	27.10	+ 0.3 %

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

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-07
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Short Circuit

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Short Circuit

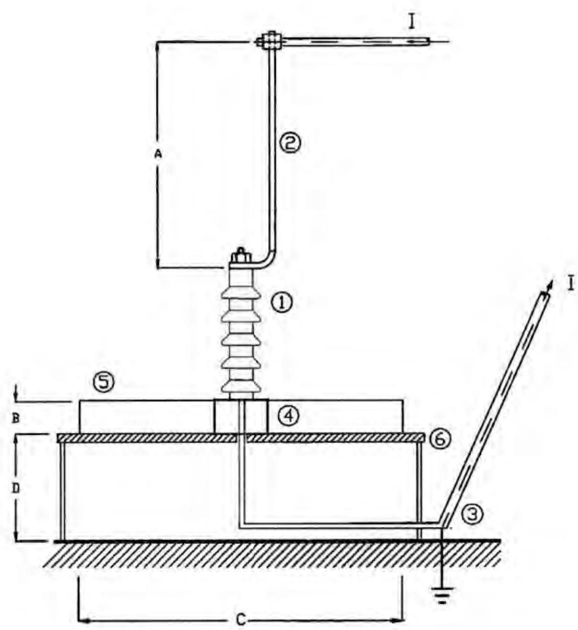
TESTS PERFORMED:
High current short circuit tests were performed at the CESI high power laboratory in Milan, Italy according to the procedures described in Clause 8.7 of IEC 60099-4. The MH4 series of arresters has a rated short circuit capability of 63000 A symmetrical. Verification of capability requires 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 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 unit used in the MH4 series of arresters. The tests were performed in 2004, in accordance with IEC 60099-4 Ed. 2.0-2004. However, since the short circuit test procedure for porcelain-housed arresters in IEC 60099-4 Ed. 2.2-2009 remains the same as in Ed. 2.0-2004, the tests performed to Ed. 2.0-2004 also qualify the design to Ed. 2.2-2009.can be used to qualify the design to this edition of the standard.

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 1308 mm. 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 porcelain housing (in the case of the 12000 A and 63000 A tests, a small amount of breakage of weathersheds occurred, but the porcelain pieces did not fall outside the enclosure). Actual prospective rms values of test currents were 12600 A, 25500 A and 67000 A. For the rated current test, the peak of the first half cycle of test current was 169000 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 : 3,50 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 3,50 m in diameter. The circular enclosure was positioned on an insulating wood platform. The pressure relief device was directed toward the power supply conductors (inside 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

D1232IG

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

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

Test arrangement : See D8045 and photo No.1
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
2	1	12,6	35,0

Condition of the apparatus before the tests: new, see photo No.2.

Date: June 23, 2004

Test	Oscillogram		Sample 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.
1	6	2	2	0,21	29,0	29,3	12,6	6,20	-	-

Condition of the apparatus after the tests: see photos No.3 and 4.

The arrester structure remained almost intact with light damages to the porcelain housing.
The arrester remained connected to the supply and return circuits.
No pieces were projected inside or outside the circular enclosure.

Figure 3. Data sheet for 12000 A test

D1232IG

High-current short-circuit test with 25,5 kA for 0,21 s

Test circuit : See D0046 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
7	1	25,5	70,7

Condition of the apparatus before the tests: new, see photo No.5.

Date: June 23, 2004

Test	Oscillogram		Sample 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.
2	10	2	3	0,21	23,0	54,3	25,5	5,20	-	-

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

The upper cap was pulled off from the arrester body so that some resistor blocks and metal parts were projected inside and outside the circular enclosure.
Light damages to the porcelain housing of the arrester.
The arrester remained connected to the supply and return circuits.

Figure 4. Data sheet for 25000 A test

D1232IG

High-current short-circuit test with 67,0 kA for 0,21 s

Test circuit : See D0046 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	67,0	199

Condition of the apparatus before the tests: new, see photo No.9 (The surge-arrester unit under test was fitted on the top with a suitable device simulating the upper unit in multi-unit arresters).

Date: June 25, 2004

Test	Oscillogram		Sample 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.
3	18	2	4	0,21	15,0	169	63,0	3,90	-	-

Condition of the apparatus after the tests: see photos No.10 and 11.

The arrester structure remained almost intact with light damages to the porcelain housing.
The arrester remained connected to the supply and return circuits.
No pieces were projected inside or outside the circular enclosure.

Figure 5. Data sheet for 63000 A test

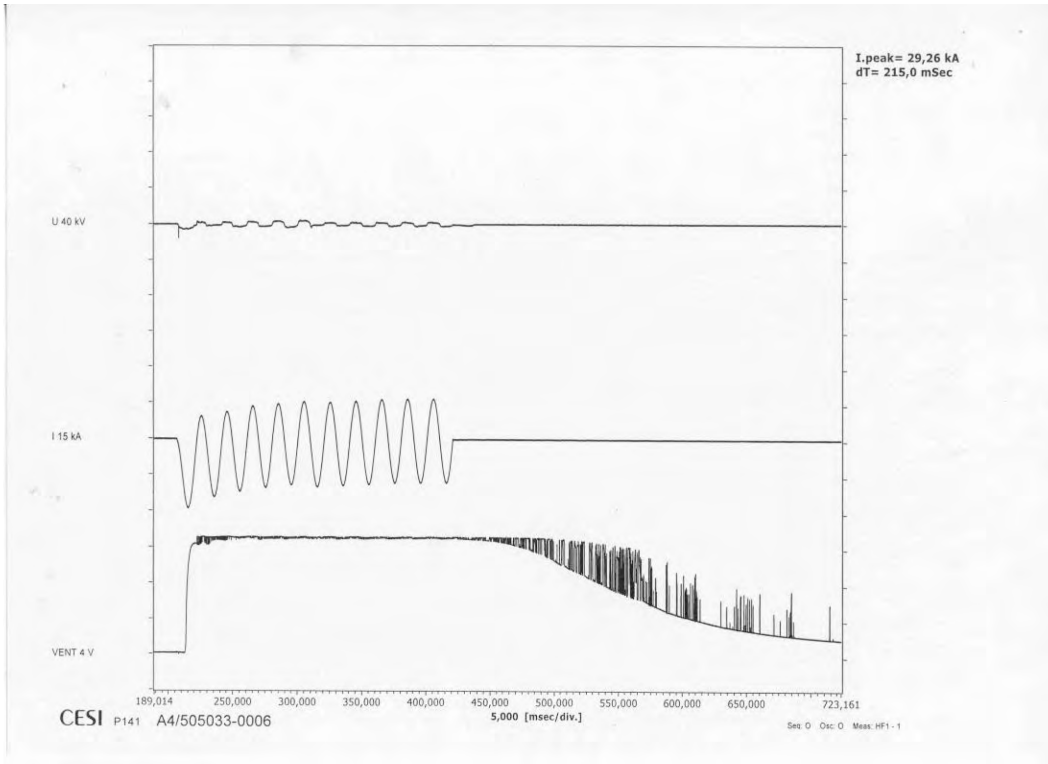


Figure 6. Oscillograms for 12000A test

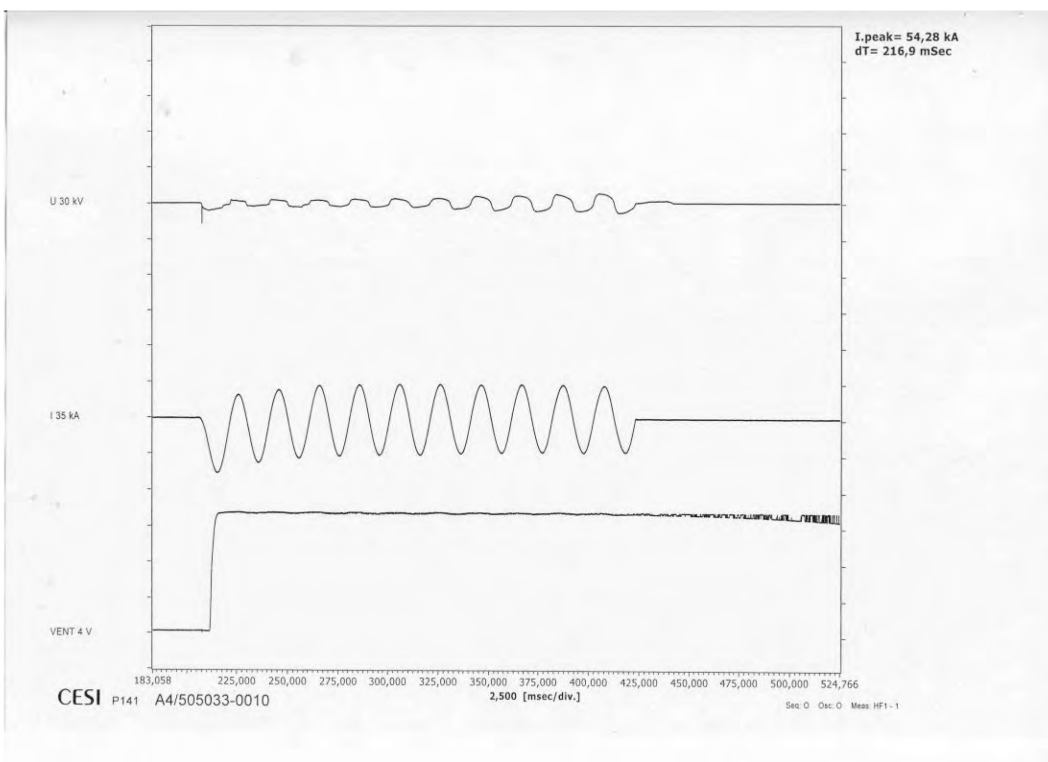


Figure 7. Oscillograms for 25000A test

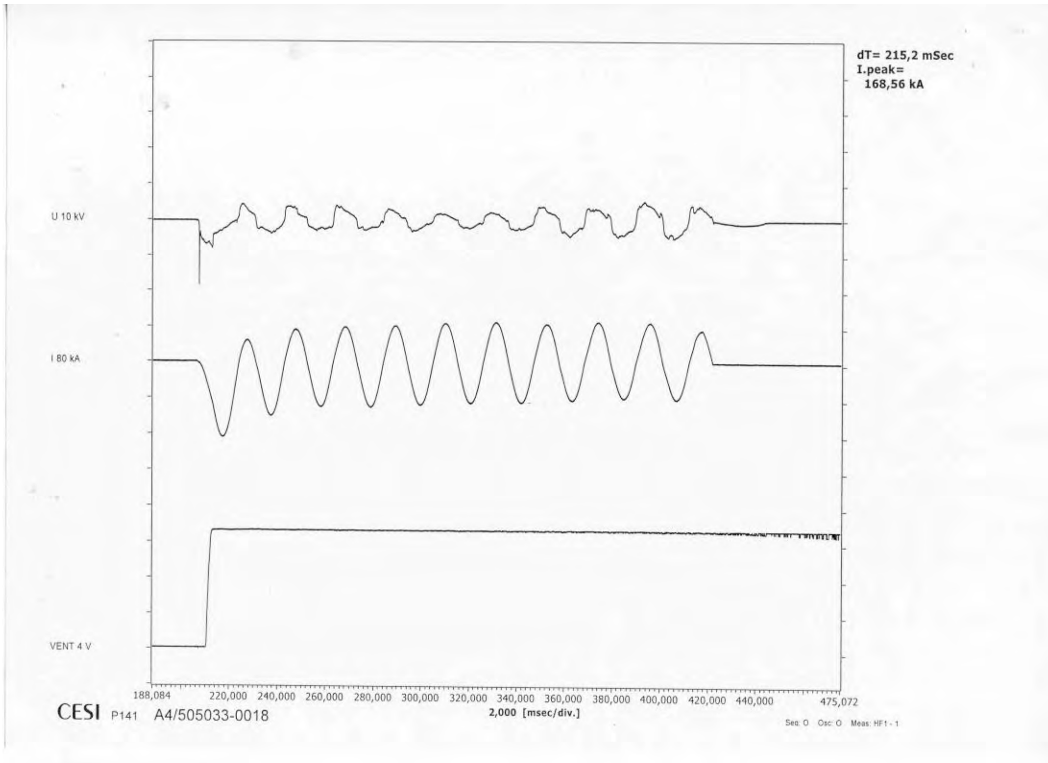


Figure 8. Oscillograms for 63000A test

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-08
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Internal Partial Discharge

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

Michael G. Comber

M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Internal Partial Discharge

Clause 8.8 of IEC 60099-4 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. EU1575-H-09
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Bending Moment

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 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 MH4 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 MH4 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 MH4 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 MH4 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 in tact 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 <u>at least</u> 1.2 times SSL, and therefore meets the requirement of IEC 60099-4.

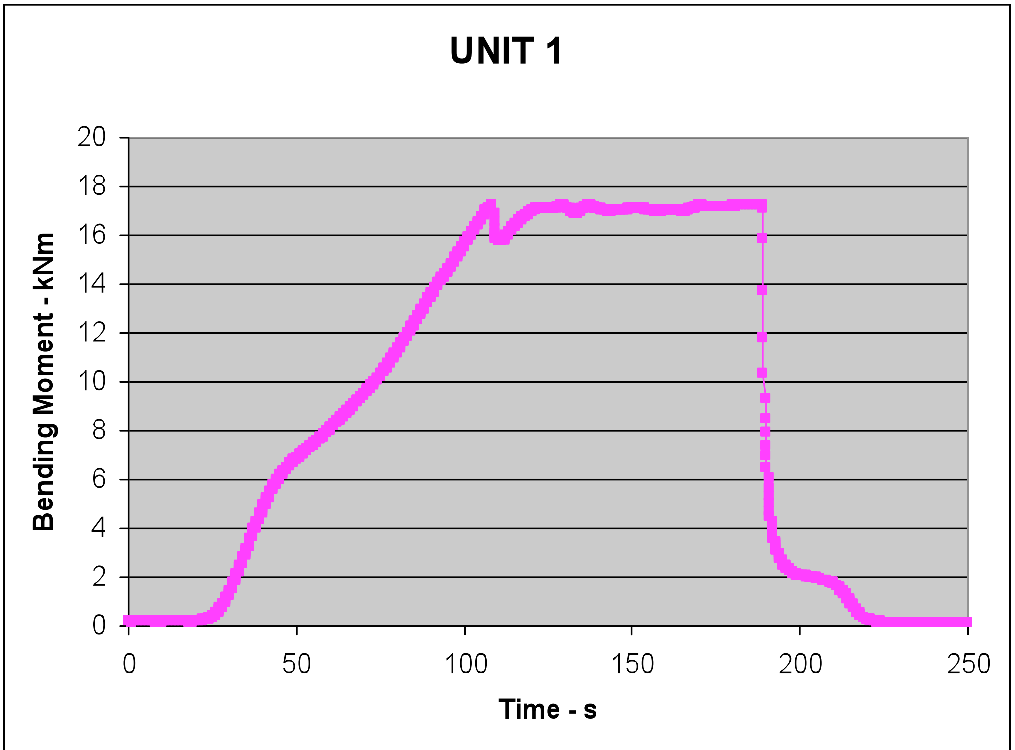


Figure 1. Loading curve to SSL for Unit 1

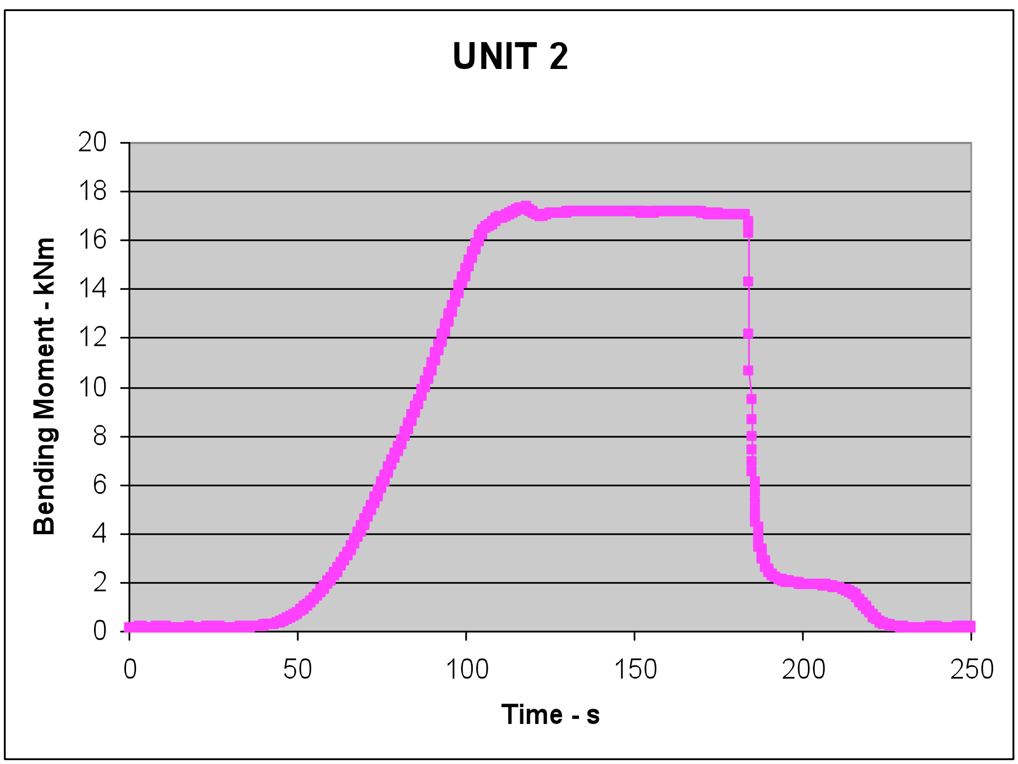


Figure 2. Loading curve to SSL for Unit 2

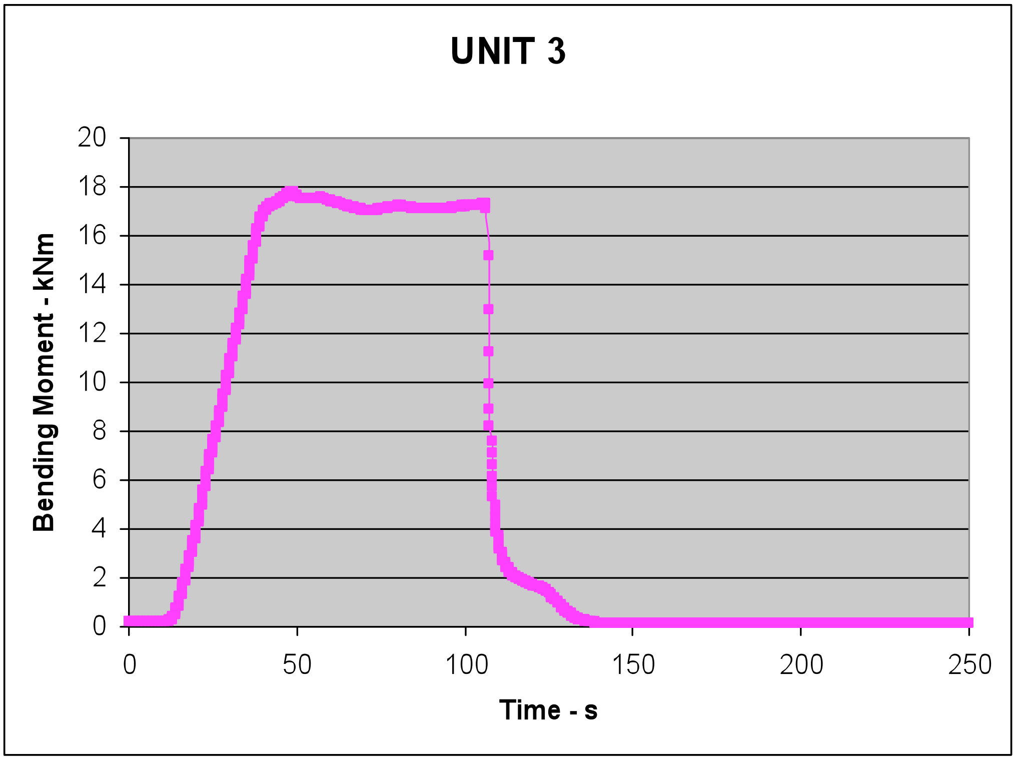


Figure 3. Loading curve to SSL for Unit 3

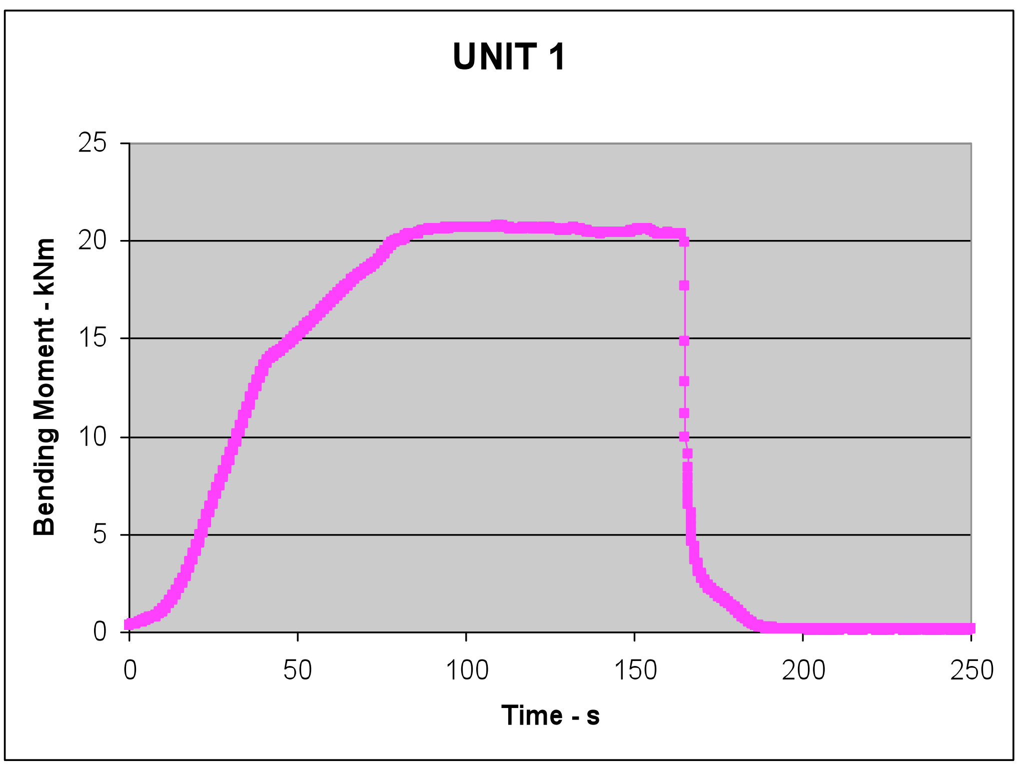


Figure 4. Loading curve to 1.2 times SSL for Unit 1

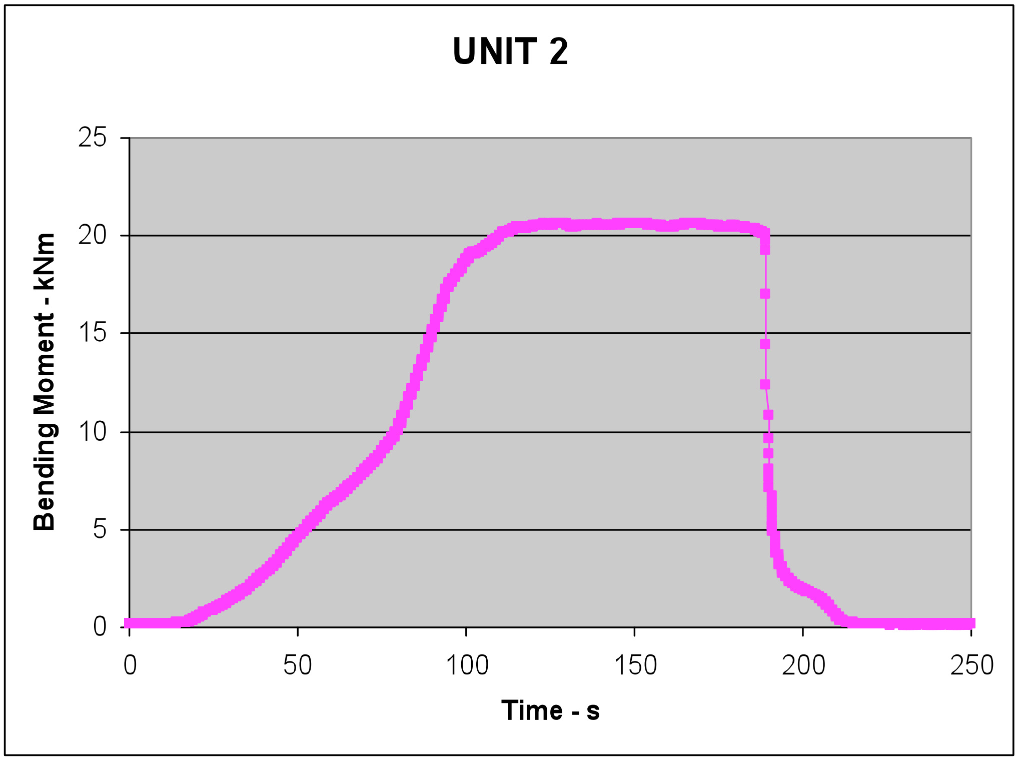


Figure 5. Loading curve to 1.2 times SSL for Unit 2

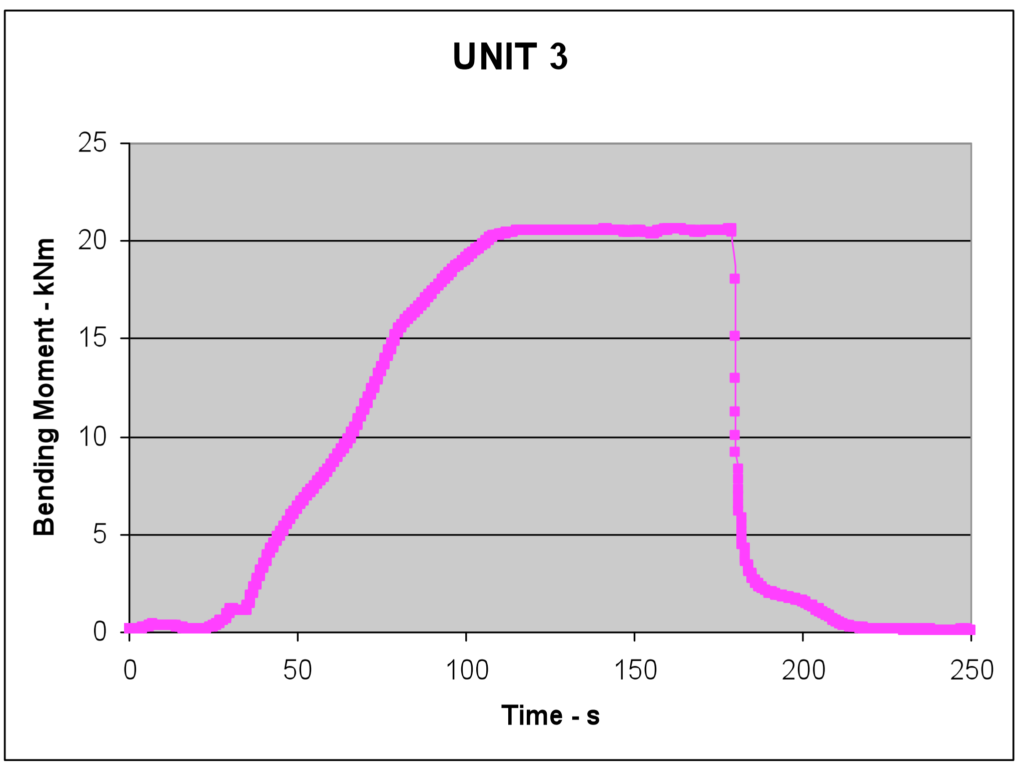


Figure 6. Loading curve to 1.2 times SSL for Unit 3

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-10
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Environmental Test

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

Michael G. Comber
M. G. Comber
Manager, Engineering

Date: March 15, 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 MH4 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 1×10^{-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 1×10^{-6} $Pa.m^3.s^{-1}$, thereby meeting the requirements of IEC 60099-4.

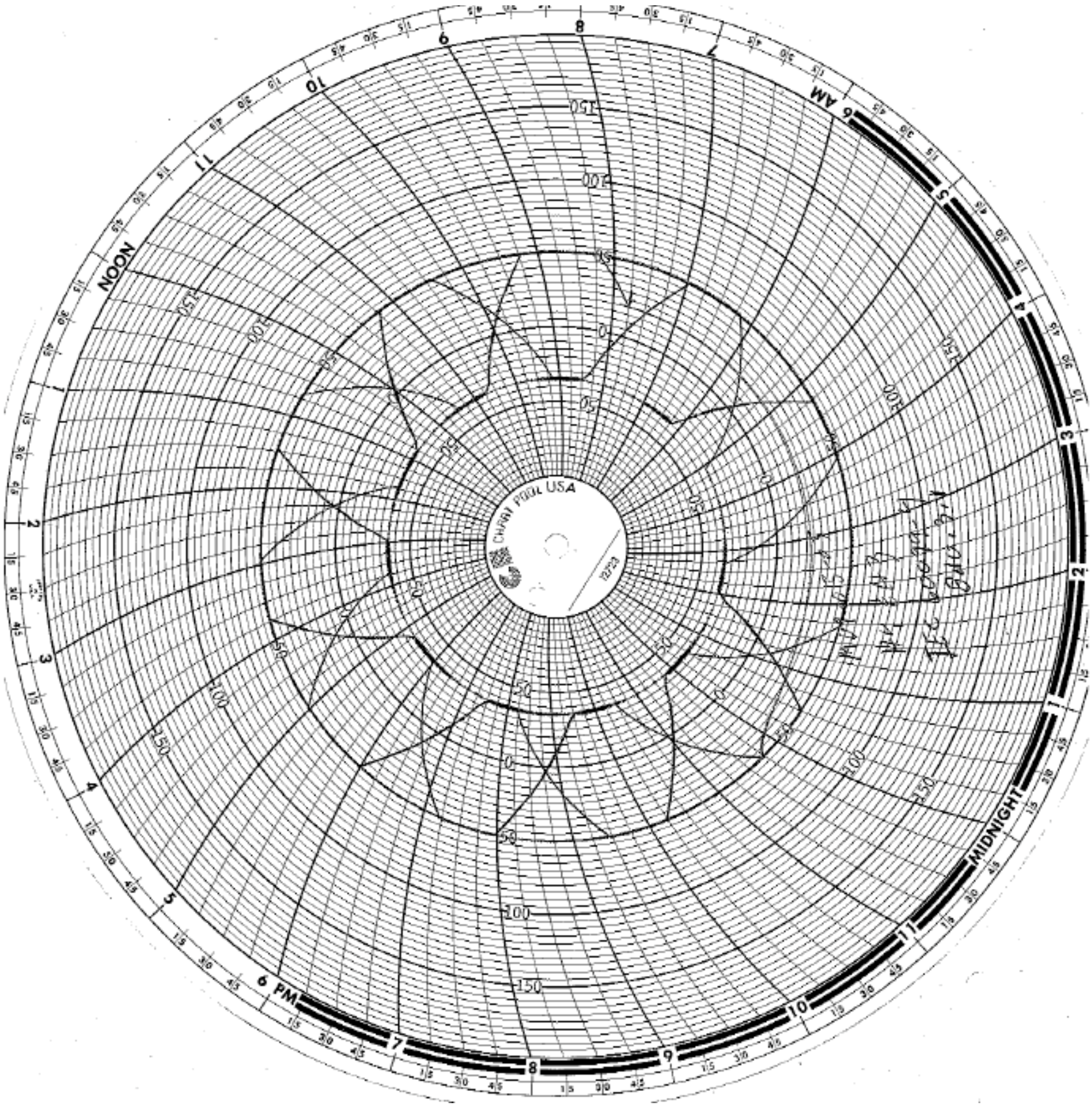


Figure 1. Copy of temperature profile recorded during the temperature cycling portion of the test.

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

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-11
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Seal Leak Rate

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Seal Leak Rate

Clause 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 MH4 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 MH4 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 8.11 are automatically met.

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-12
H4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Radio Influence Voltage (RIV)

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Radio Influence Voltage (RIV)

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	40-100	40-100
Arrester installed	376	400	20
Arrester installed	352	300	20
Arrester installed	336	28	16
Arrester installed	302	20	14
Arrester installed	269	2	10
Arrester installed	235	2	1
Arrester installed	202	<1	<1
Arrester installed	176	<1	<1
Arrester installed	202	<1	<1
Arrester installed	235	1	2
Arrester installed	269	2	10
Arrester installed	302	22	14
Arrester installed	336	20	14
Arrester installed	352	200	20
Arrester installed	336	20	18
Arrester installed	302	16	14
Arrester installed	269	1	10
Arrester installed	235	<1	1
Arrester installed	202	<1	<1
Arrester installed	176	<1	<1

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-13
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Power Frequency Voltage Versus Time

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Power Frequency Voltage Versus Time

TESTS PERFORMED:
Power frequency voltage versus time tests were performed on prorated test sections prepared based on the results of the tests to verify heat dissipation behavior of test sample. Each section consisted of two resistors in series, and with U_r of approximately 11.3kV . 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 of the reference voltage of the section to determine its rated voltage U_r and continuous operating voltage U_c.

Tests were made for three different time durations 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 4 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_r) was applied for a measured period of time, following which the voltage was reduced to U_c for 30 min. During the 30 min period at U_c the power dissipation was monitored to verify thermal stability.

The tests used the same samples as used for the Operating Duty tests, and the same transmission line generator set up as used for the Operating. The relevant test parameters are listed in Table 1.

Table 1. Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Reference Current (mA) I_{ref}	17	17	17
Reference Voltage (kV_c) V_{ref}	16.46	16.46	16.46
COV (kV rms) U_c	8.94	8.94	8.94
Rating (kV rms) U_r	11.17	11.17	11.17
Arrester Classification (kA)	20	20	20
Line Discharge Class	4	4	4
Virtual Duration of Peak (µs, 90-90%) - min	2800	2800	2800
Surge Impedance (Ω) Z_g - max (0.8 U_r)	8.94	8.94	8.94
Charging Voltage (kV) U_L – min (2.6 U_r)	29.04	29.04	29.04
Energy required (kJ) - min	54.3	54.5	54.3

RESULTS:
The transmission line generator used for this test was set up as for the Operating Duty test.

Table 2 lists measurements made during the three phases of the test, namely: application of long duration impulse, application of elevated voltage, and application of Uc for thermal recovery.

Table 2. Measurements of long duration impulse, elevated voltage and thermal recovery phases of the test

Sample 1				Sample 2				Sample 3			
LONG DURATION IMPULSES				LONG DURATION IMPULSES				LONG DURATION IMPULSES			
Impulse No.	Voltage ((kV)	Current (A)	Energy (kJ)	Impulse No.	Voltage ((kV)	Current (A)	Energy (kJ)	Impulse No.	Voltage ((kV)	Current (A)	Energy (kJ)
1	21.289	802.1	55.13	1	21.215	803.2	56.29	1	21.254	798.8	55.18
2	21.518	779.9	54.32	2	21.421	785.4	54.72	2	21.462	793.5	54.82
APPLICATION OF OVERVOLTAGE				APPLICATION OF OVERVOLTAGE				APPLICATION OF OVERVOLTAGE			
Elapsed time	Power frequency voltage		Current	Elapsed time	Power frequency voltage		Current	Elapsed time	Power frequency voltage		Current
(s)	(kVrms)	pu Ur	(mAc)	(s)	(kVrms)	pu Ur	(mAc)	(s)	(kVrms)	pu Ur	(mAc)
0.00	12.57	1.125	1.32	0	11.207	1.003	19.2	0	10.67	0.96	22.2
0.04	12.57	1.125	1.29	5	11.235	1.005	17.6	20	10.71	0.96	19.8
0.09	12.57	1.125	1.25	7	11.239	1.006	16.0	40	10.71	0.96	18.9
0.14	12.56	1.124	1.18	13	11.259	1.008	16.0	60	10.74	0.96	18.7
0.19	12.58	1.126	1.24	16	11.230	1.005	16.0	80	10.70	0.96	18.0
0.24	12.58	1.126	1.22	19	11.249	1.007	15.2	100	10.74	0.96	18.6
0.29	12.57	1.125	1.23	21	11.223	1.004	16.0	120	10.65	0.95	18.2
0.34	12.58	1.126	1.20	25	11.200	1.002	16.0	150	10.74	0.96	19.0
0.39	12.59	1.127	1.25	27	11.215	1.004	17.6	180	10.71	0.96	20.3
0.44	12.57	1.125	1.21	29	11.254	1.007	20.8	220	10.67	0.95	22.4
0.49	12.60	1.127	1.22								
0.54	12.58	1.126	1.25								
Avg	12.58	1.125		Avg	11.23	1.005		Avg	10.70	0.958	
APPLICATION OF RECOVERY VOLTAGE				APPLICATION OF RECOVERY VOLTAGE				APPLICATION OF RECOVERY VOLTAGE			
Elapsed time	Power frequency voltage		Power Loss	Elapsed time	Power frequency voltage		Power Loss	Elapsed time	Power frequency voltage		Power Loss
(min)	(kVrms)	pu Ur	(W)	(min)	(kVrms)	pu Ur	(W)	(min)	(kVrms)	pu Ur	(W)
0	8.99	1.01	20.31	0	9.19	1.03	18.25	0	8.94	1.00	19.55
0.5	9.00	1.01	19.42	0.5	8.93	1.00	19.35	0.5	8.95	1.00	19.82
1	9.00	1.01	18.89	1	8.94	1.00	19.02	1	8.97	1.00	20.02
2	8.99	1.01	18.04	2	8.95	1.00	18.63	2	8.98	1.00	19.82
5	8.99	1.01	16.87	5	8.96	1.00	17.83	5	8.97	1.00	18.97
10	9.00	1.01	15.98	10	8.94	1.00	16.76	10	8.95	1.00	18.02
20	8.98	1.00	14.74	20	8.95	1.00	16.05	20	8.96	1.00	17.08
30	8.97	1.00	13.87	30	8.97	1.00	15.76	30	8.98	1.00	16.53

Figure 1 shows the three test points (elevated voltages for 0.54 s, 29 s and 220 s) superimposed on the characteristic of power frequency voltage vs. time for MH4 series of arresters.

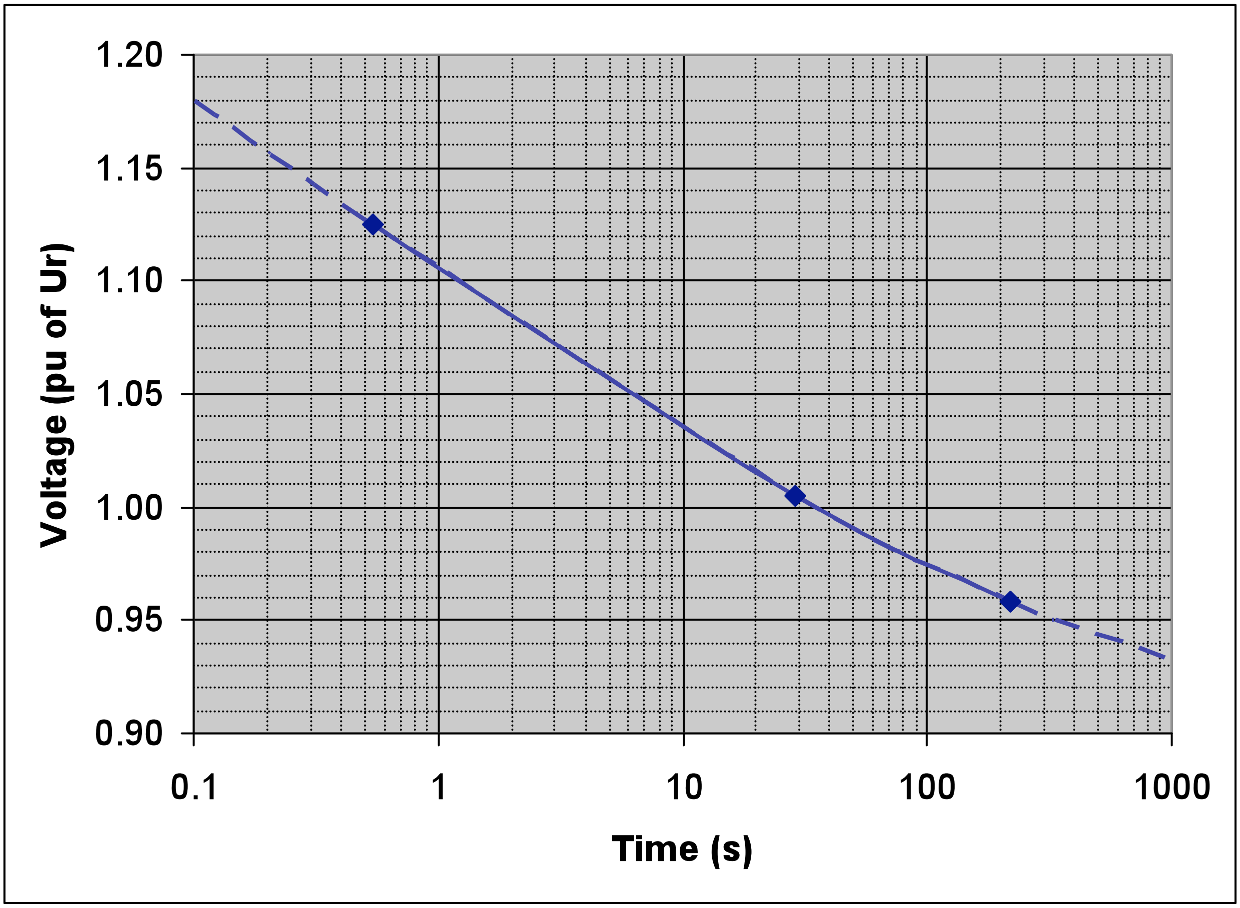


Figure 1. Power frequency voltage vs. time curve for MH4 series of arresters

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1575-H-14
MH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Artificial Pollution

This report records the results of type tests made on MH4 series 20 kA Line Discharge Class 4 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.

M.G. Comber
Manager, Engineering

Date: March 15, 2011

IEC TYPE TEST REPORT
Artificial Pollution

INTODUCTION:
The MH4 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 MH4 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 MH4 "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 °C
- 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:

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

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 MH4 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.

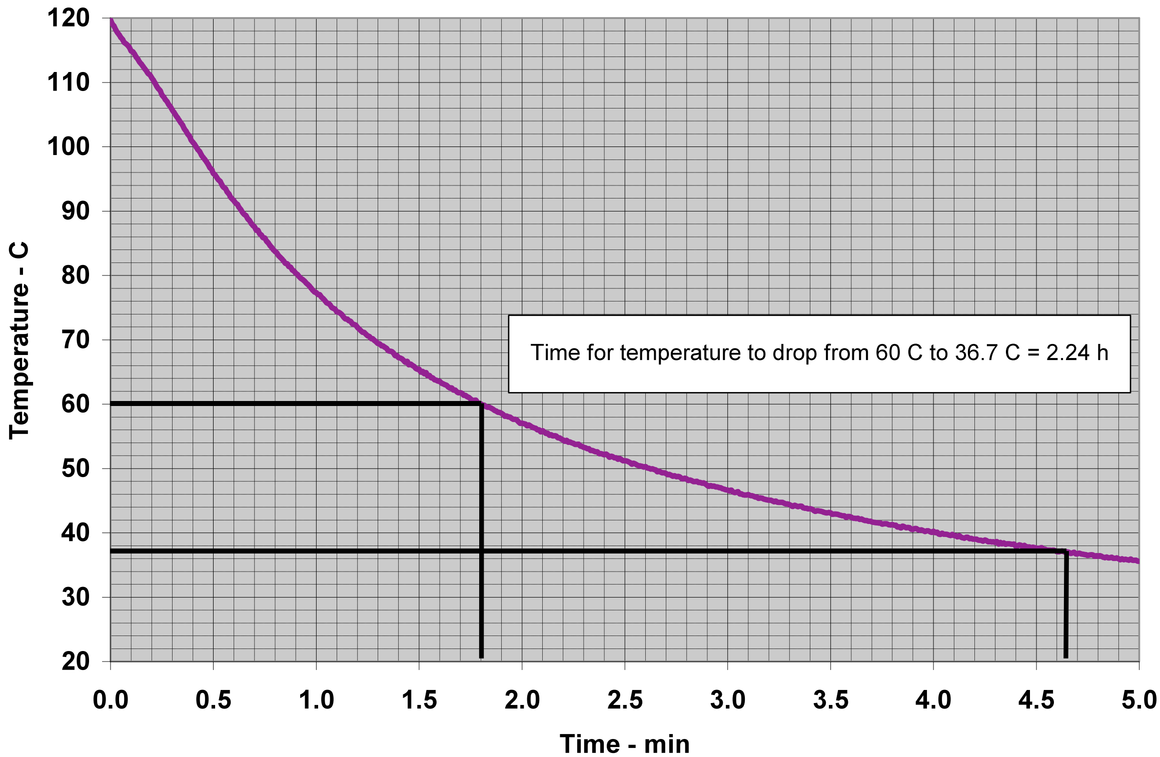


Figure 1. Resistor temperature vs. time after heating to 120°C