Design Test Report
Report No. EU1526-H-00.2
SVN Series Polymer-housed Arrester

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)".

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

Mike Kelley

Sr. Technology Manager,
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Date: -11/15/2013

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

Report No.	Description	Clause	Issue date
EU1526-H-01.1	Arrester Insulation withstand	8.1.2.4	11/15/2013
EU1526-H-02.1	Discharge voltage characteristics	8.2	11/15/2013
EU1526-H-03.1	Accelerated aging of MOV blocks	8.5	11/15/2013
EU1526-H-04.1	Accelerated aging of polymer housing with exposure to salt fog	8.7	11/15/2013
EU1526-H-05.1	Contamination	8.8	11/15/2013
EU1526-H-06.1	Radio-influence voltage (RIV)	8.10	11/15/2013
EU1526-H-07.1	Partial discharge (PD)	8.11	11/15/2013
EU1526-H-14	Switching surge energy rating	8.14	11/15/2013
EU1526-H-15	Single-impulse withstand rating	8.15	11/15/2013
EU1526-H-10.1	Duty cycle	8.16	11/15/2013
EU1526-H-11.1	Temporary overvoltage (TOV)	8.15	11/15/2013
EU1526-H-12.2	Short Circuit	8 .18	11/15/2013
EU1526-H-13.2	Maximum design cantilever load (MDCL) and moisture ingress	8.20*	11/15/2013

* Clause number as modified by C62.11a-2008 amendment to C62.11-2005

Design Test Report
Report No. EU1526-H-01.1
SVN Series Polymer-housed Arrester

Arrester Insulation Withstand Test

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley

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Date: 11/15/2013

DESIGN TEST REPORT
Arrester Insulation Withstand Test

TESTS PERFORMED:
Insulation withstand tests were made on one arrester unit of each length used in SVN arresters, in accordance with the requirements of Clause 8.1.2.4 of IEEE C62.11-2012. The internal components of the units were removed for these tests. It is required that the external insulation withstand of the arrester housing conforms to the following:

- The 1.2/50 impulse withstand voltage in dry conditions shall not be less than the maximum discharge voltage for a 20 kA 8/20 discharge current multiplied by 1.42.
- The 10 s wet power frequency withstand voltage (rms value) shall not be less than the maximum switching impulse discharge voltage multiplied by 0.82.

For purposes of evaluation, the highest unit MCOV used for each of the four unit lengths will be used as the basis for the discharge voltages. These are as listed in Table 1.

Table 1. Parameters of tested housing units

Housing number	Overall unit length (with fittings)	Dry arc distance	Leakage distance	Highest MCOV used in housing	Max. 20kA 8/20 discharge voltage	Max. switching impulse discharge voltage
	in	in	in	kVrms	kVcr	kVcr
1	32.5	23.5	83.1	64	199	159
2	38.8	31.0	112.6	81	252	201
3	46.5	37.5	141.7	101	315	251
4	53.2	44.5	171.3	120	374	298

RESULTS:
1.2/50 impulse
The 1.2/50 impulse test was performed under dry conditions by applying 15 positive and 15 negative full-wave lightning-impulse voltages to the test samples, according to the requirements of Clause 7.8.2.2 of IEEE 4-1995. 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 samples experienced not more than two disruptive discharges in the self-restoring insulation (air) with no indication of failure of the non-self restoring insulation (polymer housing). The withstand voltages obtained were corrected to standard atmospheric conditions in accordance with IEEE 4. In all cases, the positive polarity impulses resulted in the lower withstand voltage. The corrected positive withstand values are reported in Table 1.

Table 1. 1.2/50 impulse withstand results

Housing number	Measured withstand voltage	Ambient temperature	Barometric pressure	Relative air density	Absolute humidity	Voltage correction factor, K	Corrected withstand voltage	
	kVpk	^{o}C	kPa	p.u.	g.m^{-3}	p.u.	kVcr	p.u. of 20kA 8/20 discharge voltage
1	355	27.2	97.75	0.9463	0.946	1.054	374	1.88
2	431	24.4	97.54	0.9485	0.949	1.078	464	1.84
3	554	21.5	98.22	0.9645	0.965	1.046	579	1.84
4	631	24.4	97.54	0.9485	0.949	1.078	680	1.77

Power frequency

The power frequency test was performed under wet conditions by applying a 60 Hz voltage for a duration of 10 s. The precipitation conditions and resistivity of the water were in accordance with the requirements of Clause 14.2 of IEEE 4, Conventional procedure – practice in USA. Water resistivity was within the range 151-205 Ω.m, and the rain rate was within the range 4.5-5.5 mm/min. Ambient temperature was within the range 23-25 ^{o}C. The test sample withstood the applied voltage without disruptive discharge. The withstand values are reported in Table 2.

Table 2. Power frequency withstand results

Housing number	Withstand voltage	
	kVrms	p.u of 2kA 36/90 discharge voltage
1	186	1.16
2	249	1.24
3	310	1.24
4	349	1.17

EVALUATION:

The design meets the arrester insulation withstand test requirements of IEEE C62.11-2012. The voltage withstand for 1.2/50 impulse under dry conditions and for power frequency voltage under wet conditions exceed the minimum requirements by approximately 25% and 41%, respectively.

Design Test Report
Report No. EU1526-H-02.1
SVN Series Polymer-housed Arrester

Discharge Voltage Characteristics

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

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Date: 11/15/2013

DESIGN TEST REPORT
Discharge Voltage Characteristics

TESTS PERFORMED:
Discharge voltage measurements were made on three single MOV blocks of the longest length of the type used in SVN arresters. Tests were conducted in accordance with Clause 8.3 of IEEE C62.11-2012, to determine discharge voltage-current and voltage-time characteristics. Lightning impulse discharge voltages were determined for 8/20 impulse currents of 1500 A, 3000 A, 5000 A, 10 000 A, 20 000 A and 40 000 A. Switching impulse discharge voltages were determined for 0.25, 0.5, 1, 2, and 3kA with impulse wave shape of 36/90. Front-of-wave (FOW) discharge voltages were determined for 10 kA and 20 kA impulses with virtual front time of 1 μs.

All discharge voltages measured during the design tests have been normalized to the voltage measured for the current used for routine tests on production SVN arresters, namely 10kA 8/20.

RESULTS:
Lightning impulse discharge voltage
Table 1 shows the discharge voltages measured at different currents on the three test samples. For each test sample, the measured discharge voltages have been normalized to the voltage measured at 10 kA, 8/20,the current magnitude and wave shape used for routine tests on production SVN arresters.

Table 1. Discharge voltage-current measurements for 8/20 current wave shape (lightning impulse)

Current	Sample 1		Sample 2		Sample 3	
kAcr	kVcr	Normalized p.u.	kVcr	Normalized p.u.	kVcr	Normalized p.u.
1.5	11.935	0.873	11.935	0.871	11.944	0.873
3	12.446	0.910	12.455	0.909	12.455	0.910
5	12.936	0.946	12.936	0.945	12.915	0.944
10	13.679	1.000	13.696	1.000	13.687	1.000
20	14.672	1.073	14.664	1.071	14.638	1.069
40	16.207	1.185	16.102	1.176	16.144	1.180

Switching impulse discharge voltage
Table 2 shows the discharge voltages measured for 0.25, 0.5, 1, 2 and 3 kA impulses with 36/90 waveshape. For each test sample, the measured discharge voltages have been normalized to the voltage measured at 10 kA, 8/20, , the current magnitude and waveshape used for routine tests on production MVN arresters.

Table 2. Discharge voltages for 36/90 waveshape (switching impulse)

Current	Sample 1		Sample 2		Sample 3	
kAcr	kVcr	Normalized p.u.	kVcr	Normalized p.u.	kVcr	Normalized p.u.
0.25	11.031	0.806	11.023	0.805	11.023	0.805
0.5	11.284	0.825	11.292	0.824	11.309	0.826
1	11.628	0.850	11.620	0.848	11.637	0.850
1.5	11.821	0.864	11.837	0.864	11.854	0.866
2	12.077	0.883	12.044	0.879	12.065	0.881
3	12.325	0.901	12.325	0.900	12.346	0.902

Front-of wave (FOW) discharge voltage

Table 3 shows the discharge voltages measured for 10 kA and 20 kA impulses with virtual front time of 1 μs. For each test sample, the measured discharge voltages have been normalized to the voltage measured at 10 kA, 8/20, , the current magnitude and waveshape used for routine tests on production MVN arresters.

Table 3. Discharge voltages for 1/2 waveshape (front-of-wave)

Current	Sample 1		Sample 2		Sample 3	
kAcr	kVcr	p.u.	kVcr	p.u.	kVcr	p.u.
10	14.609	1.068	14.609	1.067	14.597	1.066
20	15.814	1.156	15.827	1.156	15.852	1.158

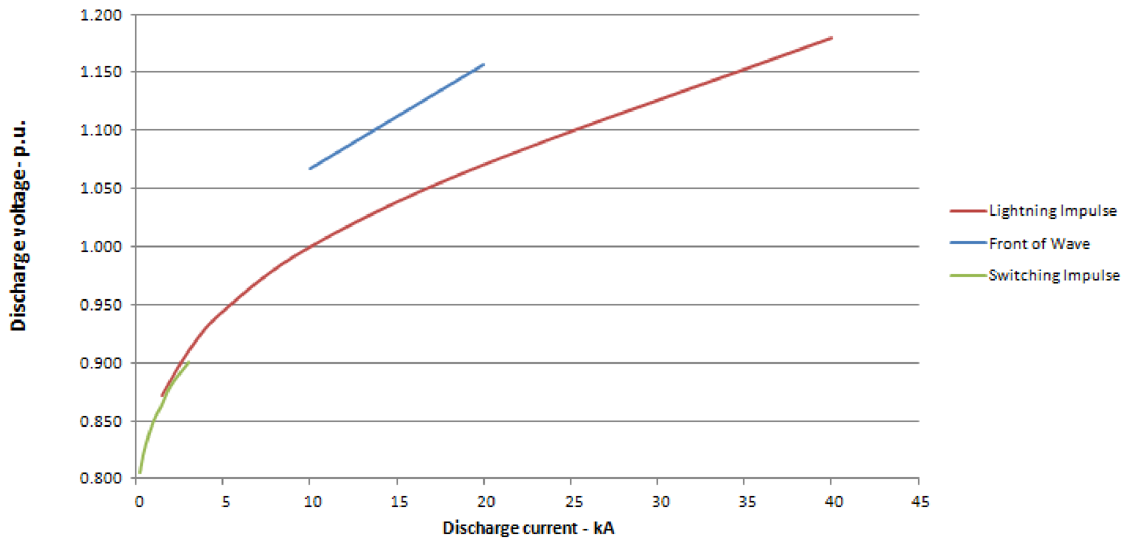

Figure 1. Measured discharge voltage-current characteristics normalized to discharge current of 10kA 8/20

Evaluation

In the routine tests of production SVN arresters, discharge voltages are performed at 10 kA, 8/20. If the maximum permitted value for this voltage for a given rating of arrester is represented by $\textit{discharge-voltage}_{routinetestmax}$, and the maximum published discharge value for any given magnitude and waveshape of current is represented by $\textit{discharge-voltager}_{publishedtmax}$ then the "production test ratio" for that discharge current magnitude and waveshape is given by

$$\textit{production-test ratio} = \textit{discharge-voltage}_{publishedmax} / \textit{discharge-voltage}_{routinetestmax}$$

For all arresters in the SVN family, the normalized discharge voltages determined from design tests (given in Tables 1 – 3) are less than the *production-test ratio* for each of the corresponding currents. As an example,_Table 4 shows the evaluation for an SVN with 98 kV MCOV (120 kV duty cycle rated voltage). In all instances, the normalized design test values are less than the *production-test ratio*, thereby meeting the requirements specified in IEEE C62.11-2012.

Table 4 – Evaluation of discharge voltage design tests for 98 kV MCOV SVN arrester

98kVrms MCOV	FOW	Switching Surge	Lightning Impulse					
Discharge Current	10kA	1kA	1.5kA	3kA	5kA	10kA	20kA	40kA
discharge-voltage published max (kVc)	308	241	252	262	271	284	304	334
discharge-voltage routine max @10kA IR 8/20 kVc	281.50	281.50	281.50	281.50	281.50	281.50	281.50	281.50
Production-test ratio	1.094	0.856	0.895	0.931	0.963	1.009	1.080	1.186
Maximum normalized discharge voltage from design tests	1.067	0.850	0.872	0.910	0.945	1.000	1.071	1.180

$$discharge\text{-}voltage_{routinetestmax} = 281.5 \text{ kV}$$

The normalized values presented in Tables 1 -3 are shown graphically in Figure 1. These values (*per-unit discharge-voltage*$_{chart}$) are used to calculate the discharge voltage characteristics (*discharge-voltage*$_{arrester}$) of assembled SVN arresters, as follows:

$$discharge\text{-}voltage_{arrester} = per\text{-}unit\ discharge\text{-}voltage_{chart} \times discharge\text{-}voltage_{10kA\ pub}$$

where *discharge-voltage*$_{10kA\ pub}$ is the published maximum discharge voltage of the arrester for 10kA 8/20, as verified by routine test at time of arrester manufacture.

Design Test Report
Report No. EU1526-H-03.1
SVN Series Polymer-housed Arrester

Accelerated Aging Procedure

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
Sr. Technology Manager,
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Sr. Design Engineer

DATE: 11/15/13

DESIGN TEST REPORT
Accelerated Aging Procedure

TESTS PERFORMED:

Accelerated aging tests were performed at 15% above MCOV on six MOV blocks, three of the longest length and three of the shortest length of the type used in SVN arresters The tests were conducted in accordance with the requirements of Clause 8.5 of IEEE C62.11-2012. The test samples were placed in an air oven and energized at a voltage equal to an adjusted MCOV that accounts for the maximum non-uniformity of voltage distribution in arrester application. 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 at the adjusted MCOV and at duty-cycle voltage 2 h after the start of the 1000 h test period, and again at the end of the period.

RESULTS:

Power dissipation measured after two hours and after 1000 hours on the six MOV block samples are reported in Table 1.

Table 1. Accelerated aging test data

MOV block	Sample number	Power dissipation at adjusted MCOV (W)		Power dissipation at duty-cycle voltage (W)	
		After 2 h	After 1000 h	After 2 h	After 1000 h
shortest	1	2.39	2.09	3.80	3.38
	2	2.71	2.24	4.64	4.43
	3	2.47	2.00	4.43	3.68
longest	1	4.03	3.43	7.23	6.39
	2	3.73	3.10	7.18	6.07
	3	3.42	2.94	6.19	5.19

EVALUATION:

The values of power dissipation at the end of the 1000-hour test period were, in all cases, less than the values at 2 hours. Consequently, no adjustment to test sample MCOV and duty-cycle voltage is required for low-current long-duration, high-current short-duration, duty cycle, and TOV tests (i.e. accelerated aging adjustment factors k_C and k_R are both equal to 1.00).

Design Test Report
Report No. EU1526-H-04.1
SVN Series Polymer-housed Arrester

Accelerated Aging of Polymer Housing with Exposure to Salt Fog

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
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Date: 11/15/2013

DESIGN TEST REPORT
Accelerated Aging of Polymer Housing with Exposure to Salt Fog

TESTS PERFORMED:

A fully-assembled PH4 arrester unit (of same construction as SVN arresters), with duty-cycle voltage of 144 kV and MCOV of 115.2 kV , was subjected to the accelerated aging test as prescribed in Clause 8.7 of IEEE C62.11-2012 (identical to requirements of IEC 60099-4: 2004, Clause 10.8.14, Test series A). 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 partial discharge at 1.05 times MCOV.

The test sample, was energized at MCOV 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).

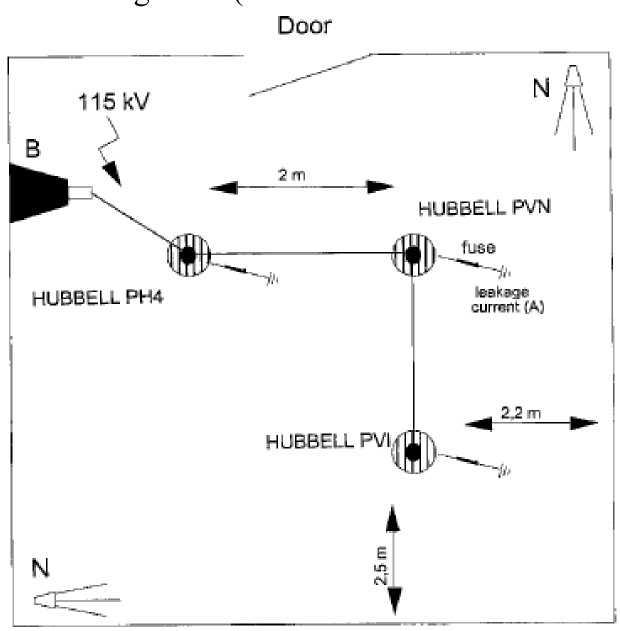

Figure 1. Test chamber layout

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

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.

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 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

EVALUATION:
The design meets the IEEE C62.11-2012 requirements for accelerated aging of polymer housing exposed to salt fog. No external flashovers, punctures, or internal breakdown occurred during the 1000 hours exposure to the salt fog. No surface tracking was evidenced. Reference voltage changed by less than 5%, and partial discharge measured before and after the test were less than 10 pC.

Design Test Report
Report No. EU1526-H-05.1
SVN Series Polymer-housed Arrester

Contamination Test

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
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Date: 11/15/2013

DESIGN TEST REPORT
Contamination Test

TESTS PERFORMED:

A fully-assembled arrester, with MCOV of 353 kV was subjected to the contamination test as prescribed in Clause 8.8 of IEEE C62.11-2012.

The arrester was energized at MCOV for 1 hour, at which time the power loss was measured. The arrester was de-energized for application of the contaminant slurry. The contaminant consisted of water, bentonite (at concentration of 5g/L of water), a non-ionic detergent (at concentration of 1 g /L of water), and sodium chloride sufficient to bring the resistivity of the slurry to 425 Ω.cm. The slurry was flowed as uniformly as possible over all housing surfaces of the lower 50% of the arrester (the complete bottom unit and half-way up the second unit). The contaminant application and re-energization at MCOV was accomplished within 5 minutes from the time of the de-energization. Power losses were measured at time of re-energization and at times 1, 5, 10 and 15 minutes thereafter.

At the 15 minute mark, the arrester was de-energized, upon which the process of contaminant application and subsequent re-energization at MCOV for 15 minutes, and power loss measurement during the 15 minute period was repeated. At the end of this second cycle, MCOV was maintained for an additional 30 minutes, during which time power loss was measured.

RESULTS:

Figure 1 shows the arrester installed for test.

Figure 1. Arrester installed for RIV test

The following table lists the power loss measurements made at each stage of the test.

Stage	Time of day	Elapsed time in stage	Power loss
	hh:mm	min	W
Initial energization	10:20	0	23
	10:35	15	20
	10:50	30	20
	11:05	45	20
	11:20	60	20
First contaminant application	11:25	0	21
	11:26	1	21
	11:30	5	21
	11:35	10	20
	11:40	15	20
Second contaminant application	11:45	0	23
	11:46	1	22
	11:50	5	22
	11:55	10	22
	12:00	15	22
Recovery	12:00	0	22
	12:05	5	21
	12:10	10	21
	12:15	15	21
	12:20	20	21
	12:25	25	21
	12:30	30	21

EVALUATION

The design meets the contamination test requirements of IEEE C62.11-2012. The power loss was affected very little by the contamination process. At the end of the test, the power loss was below the initial level, and was at an essentially steady-state stable condition.

Design Test Report
Report No. EU1526-H-06.1
SVN Series Polymer-housed Arrester

Radio Influence Voltage (RIV)

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
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Date: 11/15/2013

DESIGN TEST REPORT
Radio Influence Voltage (RIV)

TESTS PERFORMED:
A fully-assembled arrester, with MCOV of 353 kV (longest length and highest voltage) was subjected to the RIV test according to Clause 8.10 of IEEE C62.11-2012. The equipment used and general methods were in accordance with Annex A of NEMA CC-1.

Figure 1. Arrester installed for RIV test

Ambient temperature was recorded to be 24.5°C. The variable-frequency RIV meter was tuned to 1 MHz for the measurements.

The test voltage was increased to 1.15 MCOV and then lowered to 1.05 MCOV , where it was maintained for 5 minutes. The voltage was then decreased in steps (each step being 0.1 MCOV) to 0.5 MCOV, raised again by steps to 1.05 MCOV for 5 minutes and finally decreased by steps to 0.5 MCOV. At each step the RIV was measured and the levels, during the last series of voltage reductions, were then plotted versus the applied voltage.

RESULTS:

Prior to installing the arrester in the test circuit, an open circuit test was run to determine the background noise of the circuit, measured at 8 – 10 µV.

EVALUATION

IEEE C62.11-2012 specifies 2500 µV as the maximum limit for arresters with MCOV ≥ 245kV. The SVN series of arresters meet, by a very wide margin, the requirements of this standard.

Design Test Report
Report No. EU1526-H-07.1
SVN Series Polymer-housed Arrester

Partial Discharge

This report records the results of type tests made on SVN series arresters, rated up to 440 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

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Date: 11/15/2013

DESIGN TEST REPORT
Partial Discharge

Clause 8.11 of IEEE C62.11-2012 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 applied voltage is raised to an adjusted duty cycle voltage rating for at least 2 seconds, and then reduced to 1.05 times the adjusted MCOV for measurement of partial discharge. The adjusted duty-cycle voltage rating and MCOV are to represent, by test or calculation, the most highly stressed varistor of the complete arrester. This determination takes account of non-uniform voltage distribution.

TESTS PERFORMED:

For the SVN product family the worst case voltage stress, by calculation, occurs on the SVN172GA140AA from evaluation of the electromagnetic field plot of the arrester and accompanying grading ring. This worst case value amounts to 133 V/mm. This translates to a 27.8% (133/104) increase above nominal design stress for the duty-cycle and MCOV voltage and accounts for the most highly stressed case. The longest electrical unit of the SVN product family is the 120 kV MCOV unit, which was selected and tested. Adjusted Duty-cycle and PD test voltages were determined as follows:

Adjusted Duty-cycle voltage = 144 kV x 1.278 = 184 kV
PD test voltage = Adjusted MCOV voltage x 1.05 = 140.8 x 1.05 = 147.8 kV

RESULT AND EVALUATION:

In order to pass the test the partial discharge should be less than 10pC. The measured partial discharge was 5.4 pC.

The design requirements for partial discharge were met.

HUBBELL
Power Systems

Design Test Report
Report No. EU1526-H-14
SVN Series Polymer-housed Arrester

Switching Surge Energy Rating Test

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
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Date: 11/15/2013

DESIGN TEST REPORT
Switching Surge Energy Rating Test

TESTS PERFORMED:
A switching surge energy rating test was performed on three prorated test samples using a stack of two MOV blocks of the type used in SVN arresters. The blocks for the test samples were selected to represent the lowest pro-rated volume of blocks used in the arrester. The test was conducted in accordance with Clause 8.14 of IEEE C62.11-2012 with an energy class of F. The samples were conditioned with 6 groups of three long-duration impulses of 11kJ/kV MCOV, two 65kA 4/10 impulses, and heated to 61°C. The samples then had 2 long-duration impulses followed by 10 s at rated voltage and 30 minutes of adjusted voltage.

RESULTS:
For the SVN series of arresters, MCOV is set at 0.5 times the max allowable 10kA IR. and the maximum ratio between duty-cycle voltage rating and MCOV is 1.286. The MCOV and duty-cycle voltage rating (DCVR) of the test sample are then determined from

MCOVsample = 0.5 x max allowable 10 kA IR V/mm x sample height
DCVRsample = 1.286 x MCOVsample

In this case,
Maximum allowable 10kA IR = 303 V/mm
10kA IR for sample ≤ 26.9 kVc
MCOVsample ≥ 9.51 kVrms
DCVRsample ≥ 12.23 kVrms

MCOV of the samples tested were 9.56, 9.642, and 9.642 kVrms.

18 conditioning pulses were applied to the sample followed by two high current energy discharges. An example of the applied conditioning pulse is shown in Figure 1 and Figure 2 shows an example of the high current pulse. The sample was then heated and upon removal from the oven was subjected to 10 seconds of rated voltage. The rated voltages are shown in Tables 4-6. Thermal recovery was then demonstrated and shown in Table 7 - Table 9 for the three tested samples. No physical damage was observed and the 2kA switching surge discharge voltage did not change by more than 5% from the initial measurement as shown in Table 10.

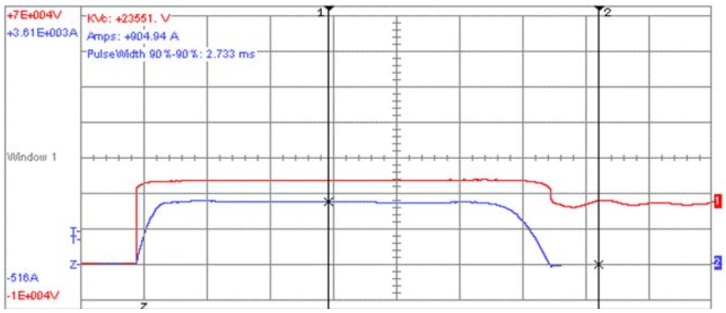

Figure 1: Example of low current long duration impulses used for 18 conditioning impulses and 2 impulses after sample heated to 61°C

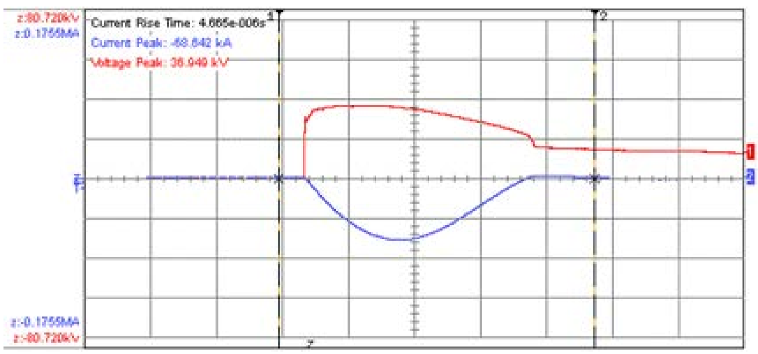

Figure 2: Example of 65kA impulses used for conditioning

Table 1: 10 s Duty - Sample 1

Time (sec)	Ur (KVC)	60Hz (mA)
0.060	17.500	95.8
1.008	17.594	94.6
2.04	17.625	95.0
3.024	17.625	92.9
4.056	17.635	93.8
5.04	17.625	92.1
6.024	17.615	91.7
7.08	17.635	92.5
8.136	17.625	91.7
9.24	17.635	93.8
10.20	17.635	92.1

Table 2: 10 s Duty - Sample 2

Time (sec)	Ur (KVC)	60Hz (mA)
0.060	17.594	110.0
1.032	17.688	112.5
2.04	17.719	110.8
3	17.708	109.2
4.056	17.719	109.2
5.04	17.698	107.9
6.048	17.708	108.3
7.008	17.719	109.6
8.064	17.708	108.8
9.24	17.708	109.6
10.20	17.698	109.2

Table 3: 10s Duty - Sample 3

Time (sec)	Ur (KVC)	60Hz (mA)
0.060	17.427	76.3
1.056	17.552	78.8
2.016	17.594	79.2
3	17.573	77.1
4.008	17.552	75.4
5.088	17.563	75.4
6.12	17.573	75.4
7.056	17.583	77.5
8.016	17.583	75.8
9.00	17.573	74.6
10.20	17.604	77.9

Table 7: Sample 1 Thermal Recovery Data

Elapsed Time	Recovery (KV_{RMS})	It (mA_C)	Ir (mA_C)	Watts
0:00:00	9.70	-5.98	-5.13	20.57
0:00:30	9.73	-5.98	-5.13	20.03
0:01:00	9.76	-5.69	-4.91	19.98
0:02:00	9.73	-5.86	-4.46	19.18
0:05:00	9.76	-5.31	-4.24	18.95
0:10:00	9.77	-5.40	-4.24	18.37
0:20:00	9.76	-4.75	-4.28	18.22
0:30:00	9.70	-4.76	-4.19	17.47

Table 8: Sample 2 Thermal Recovery Data

Elapsed Time	Recovery (KV_{RMS})	It (mA_C)	Ir (mA_C)	Watts
0:00:00	9.71	-6.75	-6.24	25.00
0:00:30	9.73	-6.67	-6.06	24.01
0:01:00	9.69	-6.31	-5.98	22.72
0:02:00	9.68	-5.99	-5.53	21.76
0:05:00	9.72	-6.12	-5.53	21.52
0:10:00	9.71	-5.90	-5.44	20.84
0:20:00	9.70	-5.70	-5.11	20.56
0:30:00	9.69	-5.70	-5.17	20.51

Table 9: Sample 3 Thermal Recovery Data

Elapsed Time	Recovery (KV_{RMS})	It (mA_C)	Ir (mA_C)	Watts
0:00:00	9.71	-5.47	-5.80	20.79
0:00:30	9.71	-5.41	-4.55	19.94
0:01:00	9.71	-5.34	-4.55	19.72
0:02:00	9.74	5.22	4.10	19.46
0:05:00	9.69	4.81	4.10	18.00
0:10:00	9.72	4.76	3.84	17.83
0:20:00	9.72	-4.75	-3.84	17.31
0:30:00	9.70	4.64	3.92	16.78

Table 10: Pre-test and Post-test 2000A Discharge Voltages

Sample	Pre-test	Post-test	% Change
1	24.044	24.341	1.2
2	24.023	24.196	0.72
3	24.002	24.196	0.81

EVALUATION:

The design meets the switching surge energy rating test requirements of IEEE C62.11-2012. Thermal recovery after the 22nd impulse was demonstrated by a declining level of watts, no physical damage was evident, and discharge voltage changed by less than 5%.

Design Test Report
Report No. EU1526-H-15
SVN Series Polymer-housed Arrester

Single-impulse withstand rating test

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
Sr. Technology Manager,
Engineering

Fayaz Khatri
F.Khatri
Sr. Design Engineer

Date: 11/15/2013

DESIGN TEST REPORT
Single-impulse withstand rating test

TESTS PERFORMED:

Tests were performed on 10 of the longest MOV blocks used in SVN arresters. The discharge voltage (at 15 kA 8/20) and reference voltage (at 17mApk) were determined for each block. Each sample was then subjected to ten groups of two long-duration current impulses of 3.9 ms duration and 6.5 C charge content. The samples were allowed to cool after the last group of impulses and the initial discharge tests and reference voltage tests were repeated. The test was conducted in accordance with Clause 8.15 of IEEE C62.11-2012.

RESULTS:

All 10 samples survived the 10 groups of two discharges with no damage. Subsequent measurements of discharge voltage and reference voltage indicated that the change in these quantities from the initial values was less than 5% for each sample.

Table 1: Before and After Discharge Voltages and Reference Voltages

	IR (KVc)			Uref (kVc)		
Sample	Before	After	% change	Before	After	% change
B1	14.25	14.22	-0.2%	8.90	8.94	0.5%
B2	14.25	14.21	-0.3%	8.91	8.94	0.3%
B3	14.26	14.23	-0.2%	8.92	8.93	0.1%
B4	14.24	14.21	-0.2%	8.91	8.92	0.1%
B5	14.15	14.13	-0.1%	8.92	8.93	0.1%
B6	14.19	14.17	-0.1%	8.92	8.93	0.1%
B8	14.26	14.24	-0.1%	8.92	8.91	-0.1%
B9	14.21	14.17	-0.3%	8.92	8.92	0.0%
B10	14.23	14.20	-0.2%	8.92	8.92	0.0%

EVALUATION:

The design meets the single-impulse withstand rating test requirements of IEEE C62.11-2012. The rating claimed is 5.6C. This was determined as follows:

Claimed single impulse rating (steps of 0.4C) ≤ Test Charge / 1.1

In this case, the test charge was 6.5C and the claimed rating is 5.6C.

HUBBELL
HUBBELL Power Systems

Design Test Report
Report No. EU1526-H-10.1
SVN Series Polymer-housed Arrester

Duty Cycle Test

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
Sr. Technology Manager,
Engineering

Fayaz Khatri
F.Khatri
Sr. Design Engineer

Date: 10/15/2013

DESIGN TEST REPORT
Duty Cycle Test

TESTS PERFORMED:
A duty cycle test was performed on a prorated test sample using a stack of two MOV blocks of the type used in SVN arresters. The blocks for the test sample were selected to represent the lowest pro-rated volume of blocks used in the arrester. The test was conducted in accordance with Clause 8.16 of IEEE C62.11-2012. The test was conducted in still air at 22^{o}C.

Prior to the application of impulses, the discharge voltage was measured at 15 kA 8/20. The sample was then energized at its duty-cycle voltage rating and subjected to twenty 8/20 current impulses of at least 15 kA each, with 50-60 seconds between impulses. The impulses were timed to occur at approximately 60 electrical degrees before the crest of the applied voltage having the same polarity as the impulse. After the 20th impulse, the test sample was heated in an oven and stabilized overnight to 60^{o}C ± 5^{o}C. After removal from the oven, the sample was subjected to two additional impulses of at 15 kA, separated by 50-60 seconds, while energized at an adjusted MCOV recovery voltage (MCOV of the sample increased by a factor to represent MOV watts loss equal to the maximum allowed in manufacture). This voltage was maintained for 30 minutes after the second additional impulse to allow demonstration of thermal recovery of the samples.

The discharge voltage at 15 kA 8/20 was measured at the end of the test, and compared to initial; values. The test sample was then disassembled for visual inspection of its components.

RESULTS:
For the SVN series of arresters, MCOV is set at 0.5 times the maximum allowable 10kA IR and the maximum ratio between duty-cycle voltage rating and MCOV is 1.286. The MCOV and duty-cycle voltage rating (DCVR) of the test sample are then determined from

The MCOV of the test sample are then determined from

MCOVsample = 0.5 x max allowable 10 kA IR V/mm x sample height
DCVRsample = 1.286 x MCOVsample

In this case,
Maximum allowable 10kA IR = 303 V/mm
10kA IR for sample ≤ 26.9 kVc
MCOVsample ≥ 9.51 kVrms
DCVRsample ≥ 12.23 kVrms

To determine the adjusted MCOV to be applied on the heated sample (for the 21st and 22nd impulses, and for the subsequent 30 minute recovery period), initial measurements were made on the blocks used in the test sample, whereby the applied voltage was increased above $MCOV_{sample}$ until the watts loss matched the maximum limit allowed in manufacturing, resulting in an adjusted MCOV of 9.80 kVrms

Table 1 lists the times of application of the impulses, and the values of applied voltage, power dissipation, test sample current and impulse magnitude recorded at the time of each impulse.

Table 1. Voltage, watts and current measured during duty cycle test

	Time of day	Applied voltage	Power dissipation	Test sample current	Impulse current
Impulse no.	hh:mm:ss	kVrms	Watts	mAcr	kAcr
1	10:33:55	12.54	30.21	-18.14	15.8
2	10:34:50	12.50	31.18	-29.72	15.5
3	10:35:44	12.53	32.00	-14.08	15.3
4	10:36:39	12.53	34.94	-15.96	15.2
5	10:37:33	12.51	36.32	-16.63	15.1
6	10:38:28	12.49	39.24	-16.61	15.1
7	10:39:23	12.48	42.53	-18.96	15.2
8	10:40:17	12.52	48.83	-21.39	15.2
9	10:41:12	12.49	52.52	-22.21	15.3
10	10:42:07	12.49	62.29	-25.65	15.0
11	10:43:01	12.52	71.25	-28.67	15.1
12	10:43:56	12.49	84.39	-33.04	15.2
13	10:44:51	12.50	108.25	-41.05	15.3
14	10:45:45	12.51	126.22	-47.74	15.2
15	10:46:40	12.52	154.90	-56.52	15.1
16	10:47:34	12.51	202.75	-71.72	15.0
17	10:48:29	12.47	273.56	-94.98	15.2
18	10:49:24	12.49	424.84	-139.23	15.1
19	10:50:18	12.51	731.84	-229.26	15.0
20	10:51:13	12.51	3139.84	-804.44	15.0
Specimen preheated to 61.1 °C overnight					
21	14:32:28	9.787	3.66	-2.60	15.2
22	14:33:21	9.782	3.81	4.74	15.2

The adjusted MCOV was maintained for an additional 30 minutes, during which time measurements were made of power dissipation and current. Recorded values are shown in Table 2.

Table 2. Voltage, watts and current measured during 30 minute recovery period

Elapsed time	Applied voltage	Power dissipation	Current
hh:mm:ss	kVrms	Watts	mAcr
0:00:00	9.8	3.87	-2.57
0:00:30	9.9	4.14	-2.48
0:01:00	9.9	4.12	-2.65
0:02:00	9.9	4.05	-2.58
0:05:00	9.9	4.02	-2.56
0:10:00	9.9	4.02	-2.41
0:20:00	9.9	3.96	-2.60
0:30:00	9.8	3.91	-2.49
0:31:00	9.8	3.89	-2.39

After the sample had cooled to ambient temperature, its discharge voltage was measured at 20 kA 8/20, and the value compared to the value measured prior to the test. Results are shown in Table 3.

Table 3. Initial and final discharge voltage measurements

Discharge voltage (kV)		Change
Before	After	
28.179	28.482	1.07%

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

EVALUATION:

The design meets the duty cycle test requirements of IEEE C62.11-2012. T hermal recovery after the 22nd impulse was demonstrated by a declining level of watts, no physical damage was evident, and discharge voltage changed by less than 10%.

Design Test Report
Report No. EU1526-H-11.1
SVN Series Polymer-housed Arrester

Temporary Overvoltage (TOV) Test

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
Sr. Technology Manager,
Engineering

Fayaz Khatri
F.Khatri
Sr. Design Engineer

Date: 11/15/2013

DESIGN TEST REPORT
Temporary Overvoltage (TOV) Test

TESTS PERFORMED:
TOV tests were performed on four prorated test samples, each consisting of two MOV blocks in series. The blocks for the test samples were selected to represent the lowest volume of blocks used in the arrester. The test was conducted in accordance with Clause 8.17 of IEEE C62.11-2012.

<u>No Prior Duty Test:</u>
Initial measurements were made of the discharge voltage of the samples at 15 kA.

Samples were then heated in an oven and stabilized overnight to 60°C ± 5°C. Upon removal from the oven into ambient air of 22°C , each sample was subjected to a temporary overvoltage lasting for a time within one of the time ranges specified in Clause 8.15.3 of the standard, followed by application of an adjusted MCOV recovery voltage (MCOV of the sample increased by a factor to represent MOV watts loss equal to the maximum allowed in manufacture). This voltage was maintained for 30 minutes after the second additional impulse to allow demonstration of thermal recovery of the samples. This process was repeated, including heating of samples to 60°C ± 5°C, for temporary overvoltages in four other time ranges prescribed in the standard.

After all samples had cooled to ambient temperature, discharge voltages at 15 kA 8/20 was measured and compared to initial values. The test samples were then disassembled for visual inspection of their components.

<u>Prior Duty Test</u>
Initial measurements were made of the discharge voltage of the samples at 15 kA.

Samples were then heated in an oven and stabilized overnight to 60°C ± 5°C. Upon removal from the oven into ambient air of 22°C , each sample was subjected to two long-duration impulses of 11 kJ/kV MCOV to verify switching surge energy capability followed by a temporary overvoltage lasting for a time within one of the time ranges specified in Clause 8.15.3 of the standard, followed by application of an adjusted MCOV recovery voltage (MCOV of the sample increased by a factor to represent MOV watts loss equal to the maximum allowed in manufacture). This voltage was maintained for 30 minutes after the second additional impulse to allow demonstration of thermal recovery of the samples. This process was repeated, including heating of samples to 60°C ± 5°C, for temporary overvoltages in four other time ranges prescribed in the standard.

After all samples had cooled to ambient temperature, discharge voltages at 15 kA 8/20 was measured and compared to initial values. The test samples were then disassembled for visual inspection of their components.

RESULTS:

For the SVN series of arresters, MCOV is set at 0.5 times the maximum allowable 10kA IR and the maximum ratio between duty-cycle voltage rating and MCOV is 1.28. The MCOV of the test sample are then determined from

MCOVsample = 0.5 x max allowable 10 kA IR V/mm x sample height
DCVRsample = 1.286 x MCOVsample

In this case,
Maximum allowable 10kA IR = 303 V/mm
10kA IR for sample ≤ 26.9 kVc
MCOVsample ≥ 9.51 kVrms
DCVRsample ≥ 12.23 kVrms

To determine the adjusted MCOV to be applied after the TOV application, initial measurements were made on the blocks used in the test sample, whereby the applied voltage was increased above $MCOV_{sample}$ until the watts loss matched the maximum limit allowed in manufacturing. Table 1 shows the values determined for the four test samples.

Time ranges selected for the four sets of TOV tests were:

A	0.01 – 0.1 s
C	1.1 – 10 s
D	10.1 – 100 s
F	1001 – 10 000 s

The applied TOV and time of application is listed in Tables 1 & 2 for each of the four time periods and four test samples. Representative oscillograms taken during the TOV application and during the recovery period are shown at the end of this report.

After all samples had cooled to ambient temperature, discharge voltages were measured at 15 kA 8/20. The measured values, compared to the initial values, are shown in Table 3.

Table 1: MCOV and adjusted MCOV recovery voltages for four test samples

Sample number	Reference voltage	MCOV	Max watts adjustment factor	Adjusted MCOV
	kVrms	kVrms	p.u.	kVrms
1[1]	9.11	6.9	1.006	6.925
2	12.61	9.537	1.008	9.610
3	12.61	9.537	1.002	9.560
4	12.61	9.532	1.003	9.560

.

[1] A smaller sized block was used for the 0.1 second test. 10kA IR for this sample was 9.82kV. MCOV = 6.9kVrms

Table 2: TOVs and applied durations for four test samples – No Prior Duty

Sample number	Time (s)	P.U. MCOV
1	0.1	1.607
2	1.2	1.519
3	10.2	1.459
4	1400	1.304

Table 3: TOVs and applied durations for four test samples – Prior Duty

Sample number	Time (s)	P.U. MCOV
1	0.1	1.509
2	1.2	1.441
3	10.2	1.351
4	1400	1.141

Table 4:Discharge voltage measurements at 20 kA 8/20

Sample	Initial measurement	Final measurement	Change
	kVcr	kVcr	%
1	20.285	20.565	1
2	28.133	28.511	1
3	28.164	28.490	1
4	28.178	28.616	2

Figure 1 shows a plot of the points from Table 2 after normalization to the MCOV of each sample. The solid curve constructed to envelope the lower limit of all points represents the "no prior energy" TOV characteristic for the design. The "no prior energy" curve is reproduced in Figure 2, which also shows the "prior duty" curve.

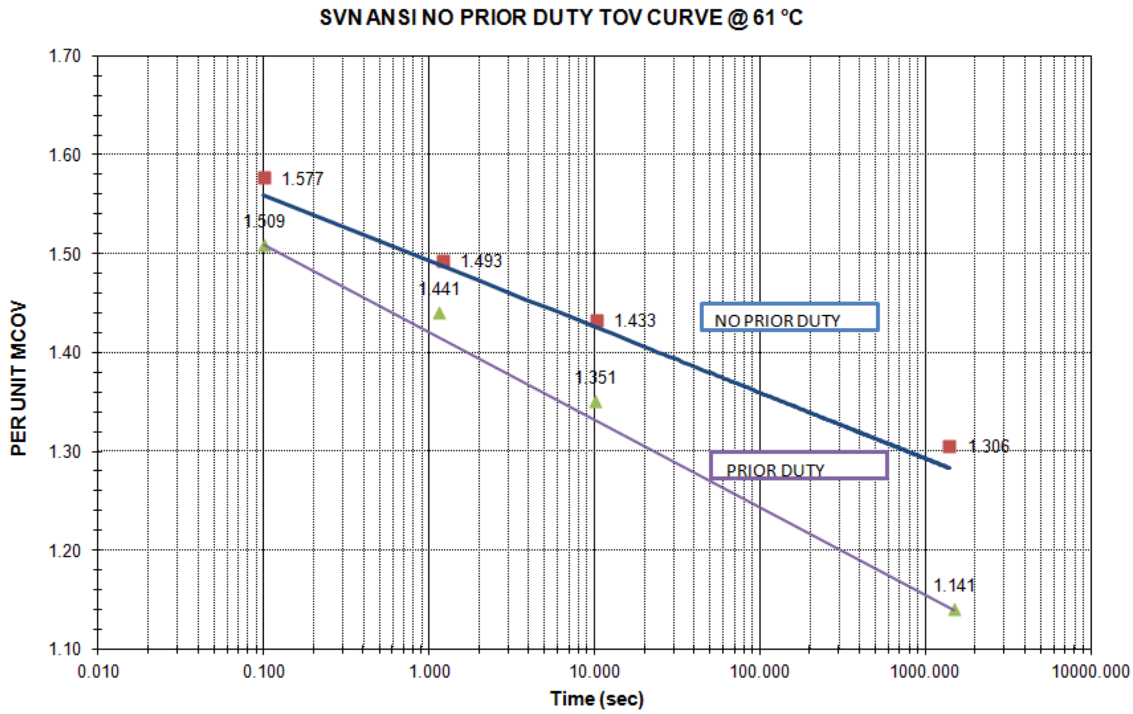

Figure 2. TOV characteristics for both “no prior duty” (upper curve) and “prior duty” (lower curve)

EVALUATION

The design meets the TOV test requirements of IEEE C62.11-2012. Change of discharge voltage from beginning to end of the test was well within the 10% allowed by the standard, and no physical damage was evident on any of the samples.

OSCILLOGRAMS

The following pages contain oscillograms taken for one of the four test samples tested in each of the TOV time ranges. For each time range, osciilograms are presented for the period of application of the TOV, and for the beginning and ending of the 30 minute recovery perid.

Oscillograms for No Prior Duty

TOV application for Time Range A

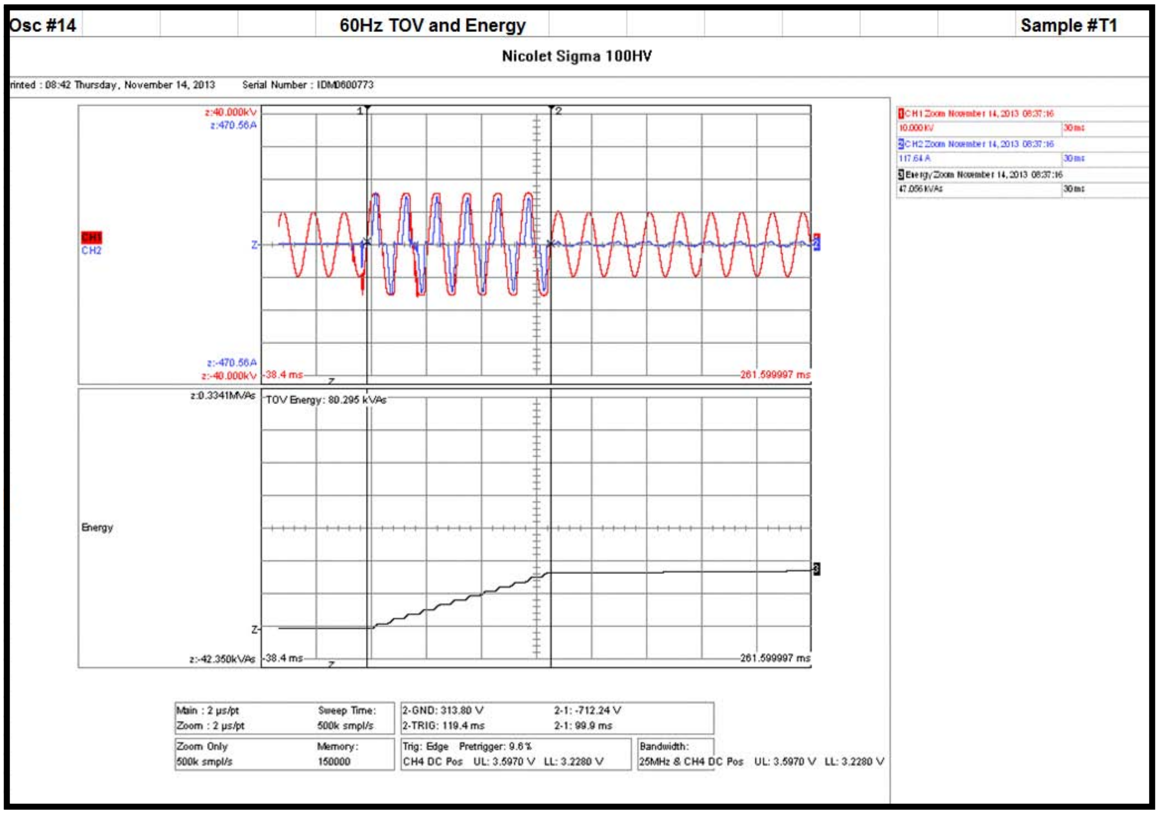

Figure 1: TOV Application for 0.1s

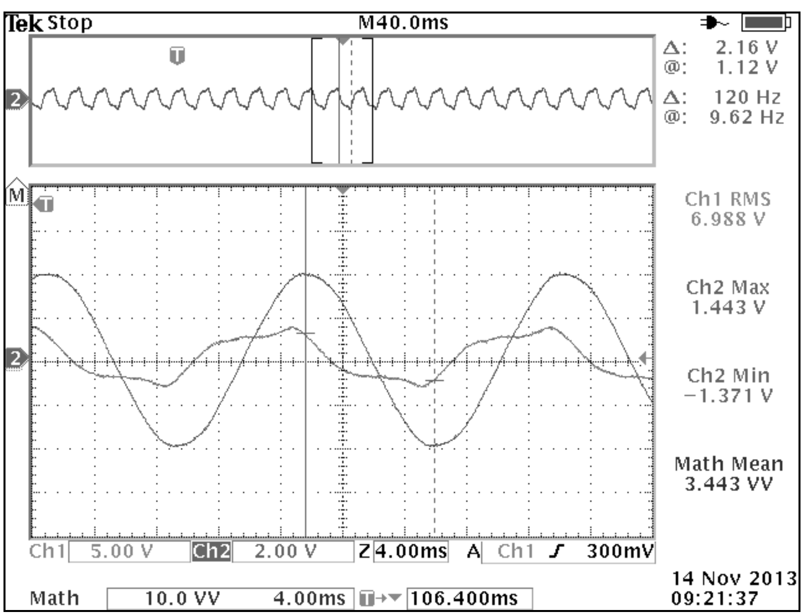

Figure 2: Recovery after 1 minute

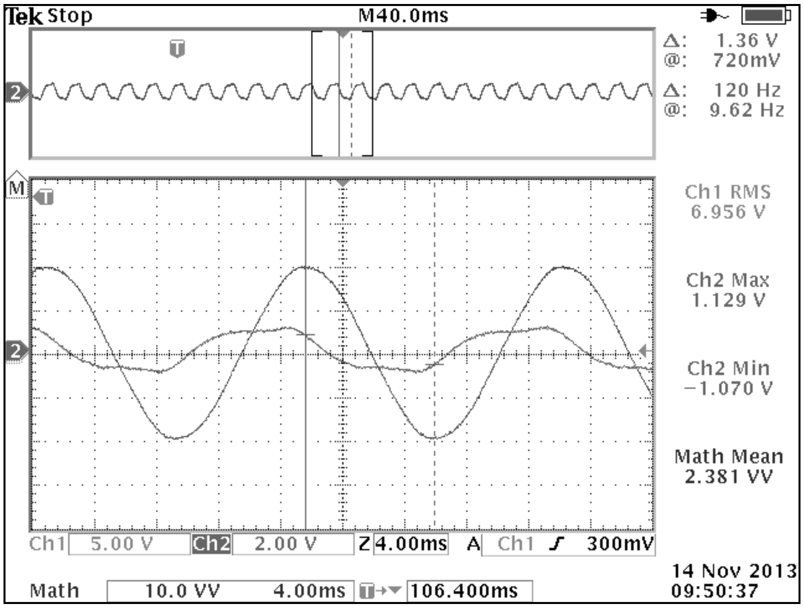

Figure 3: Recovery after 30 minutes

Oscillograms for time range C

TOV application

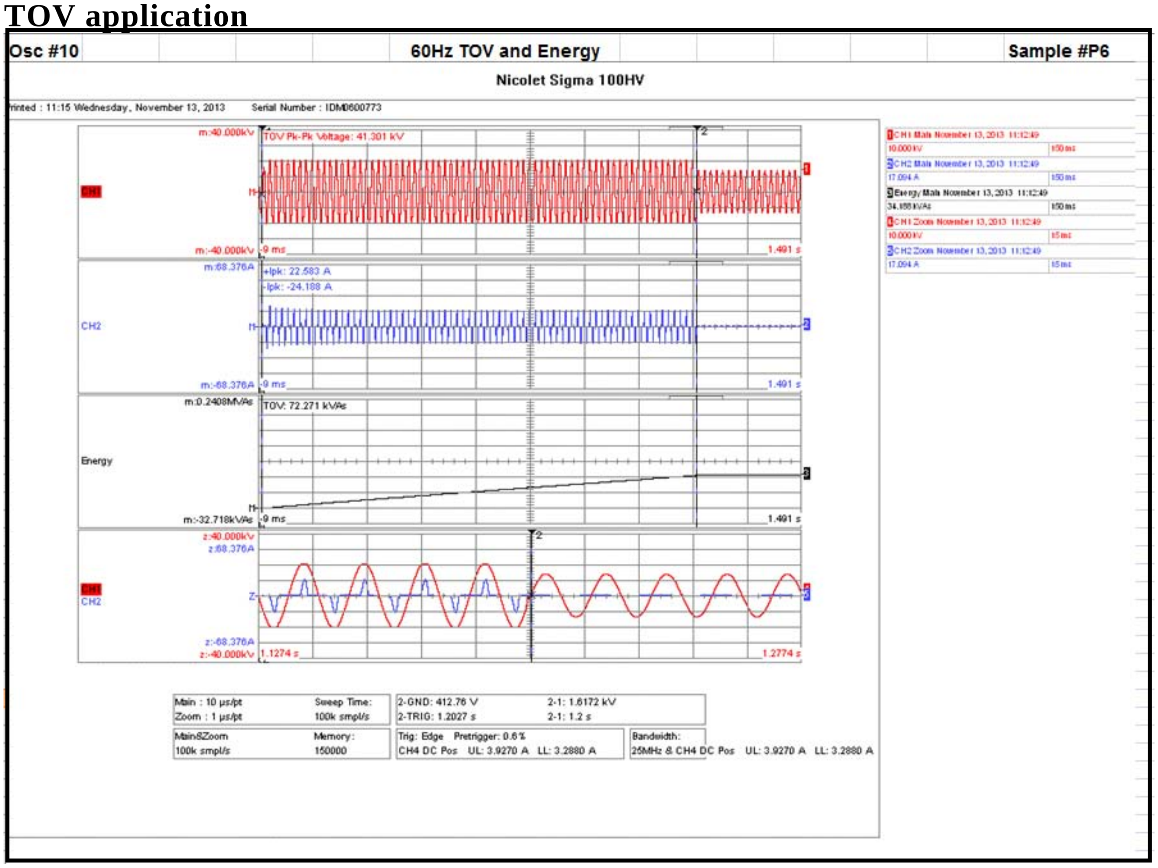

Figure 4: TOV application for 1.2 s

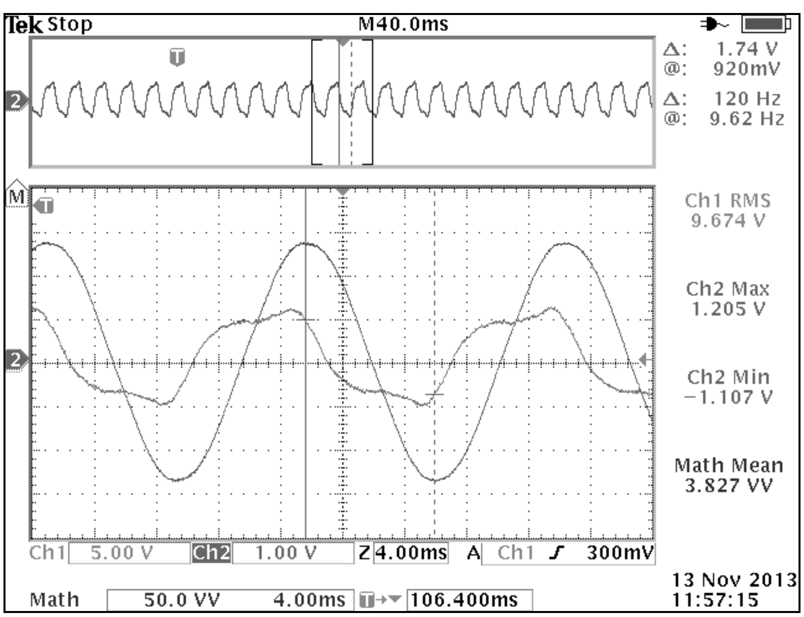

Figure 5: Recovery after 1 min

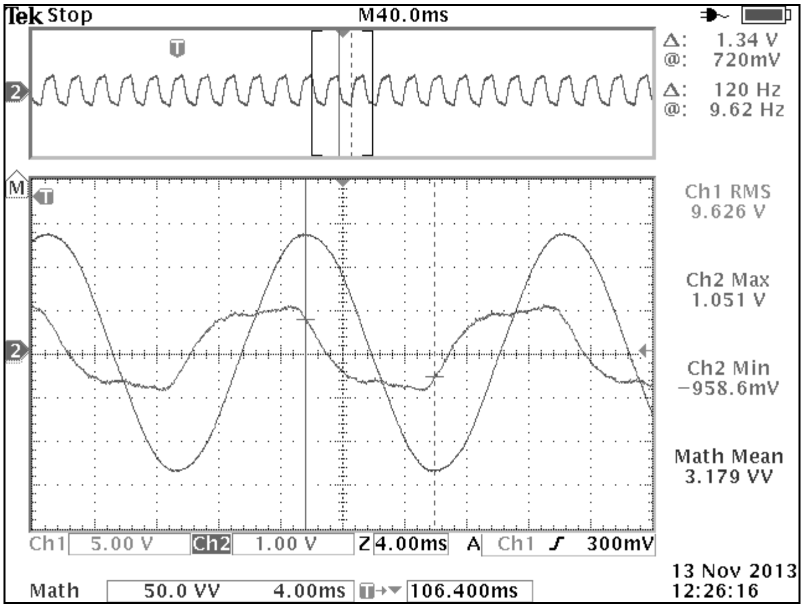

Figure 6: Recovery after 30 min

Oscillograms for time range D

TOV application

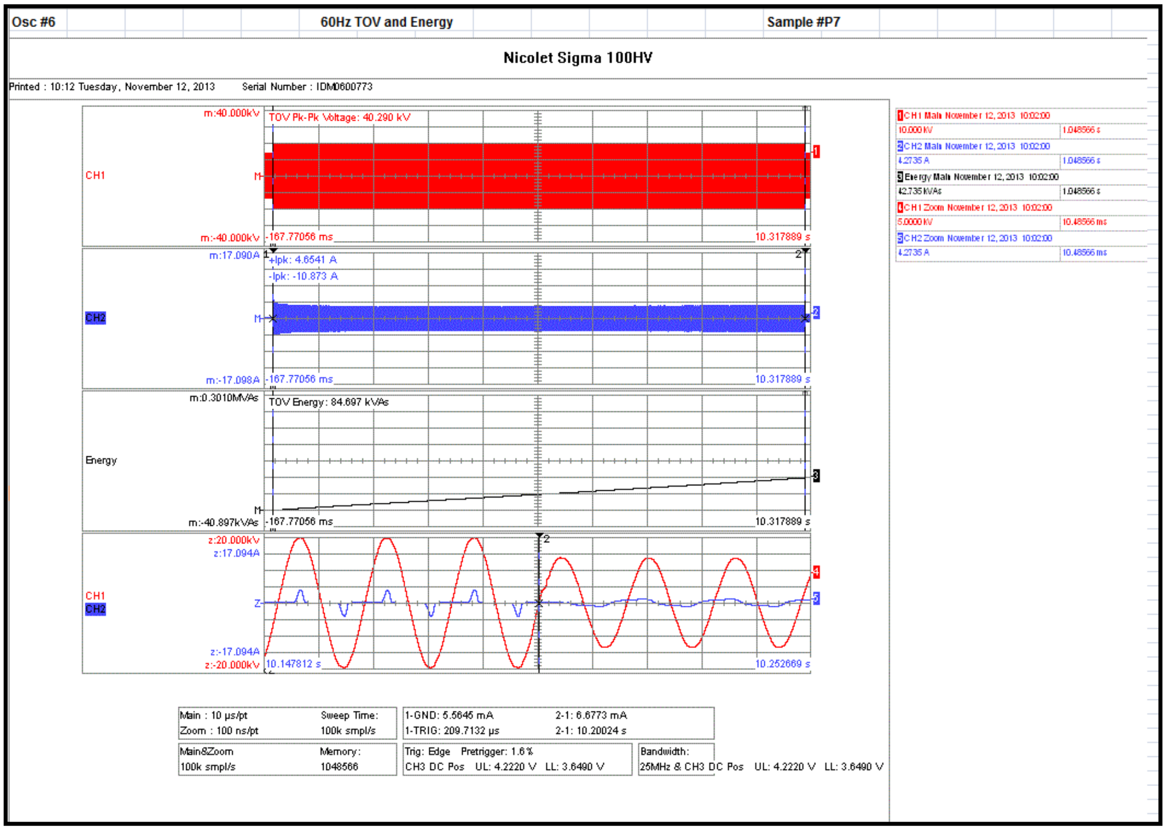

Figure 7: TOV application for 10.2 sec

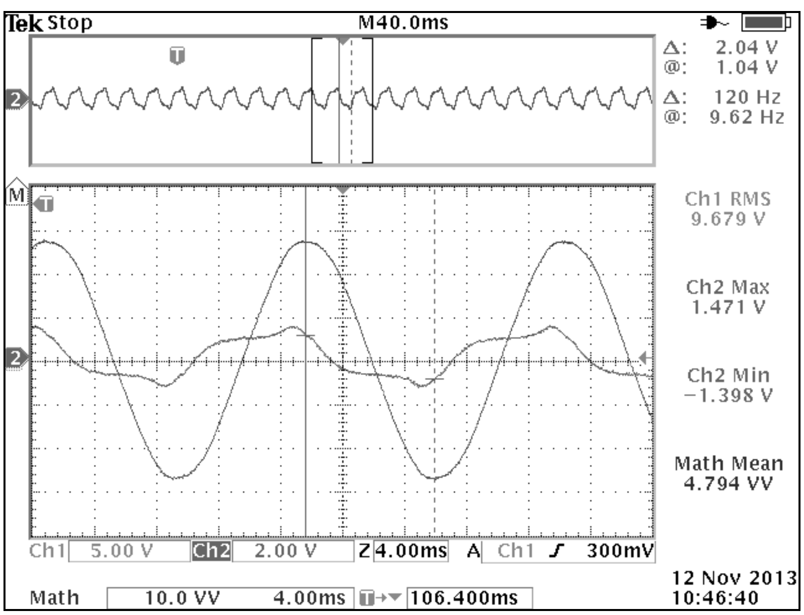

Figure 8: Recovery after 1 min

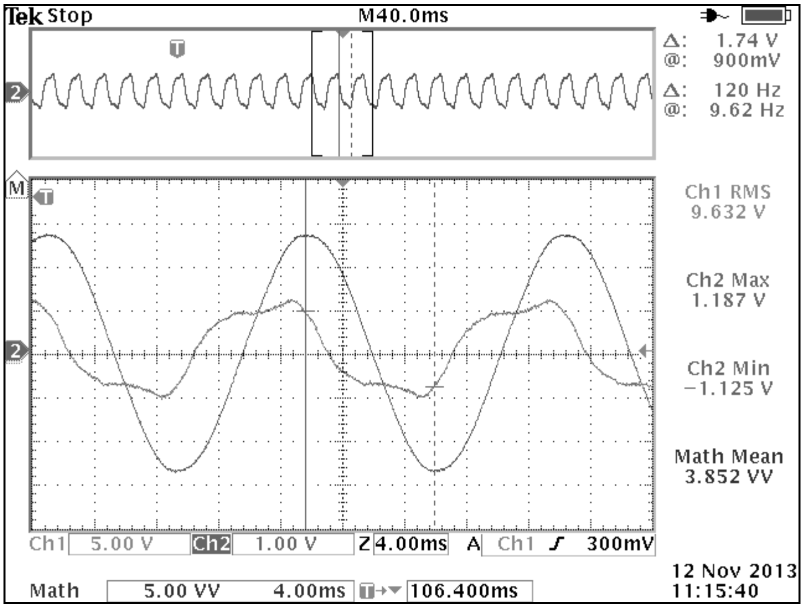

Figure 9: Recovery after 30 minutes

Oscillograms for time range F

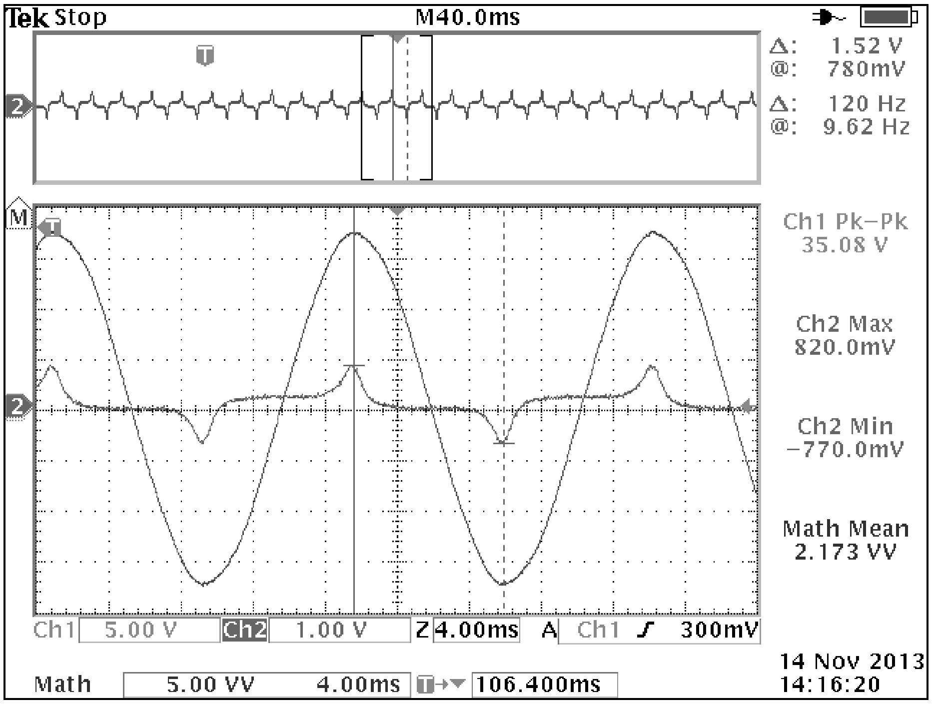

Figure 10: TOV after 1 minute

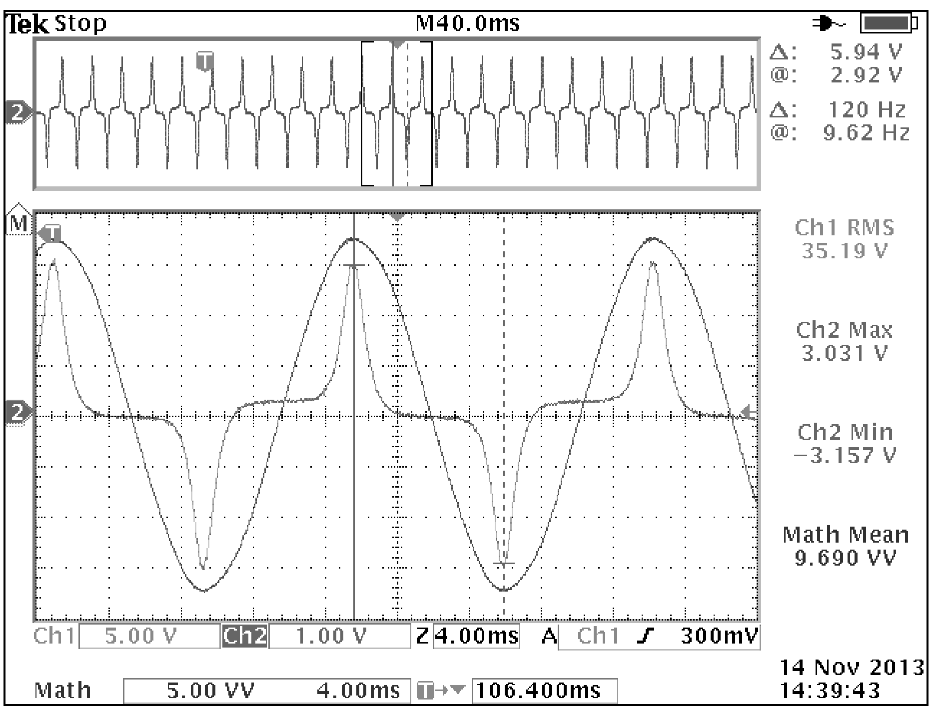

Figure 11: TOV at 1400 seconds

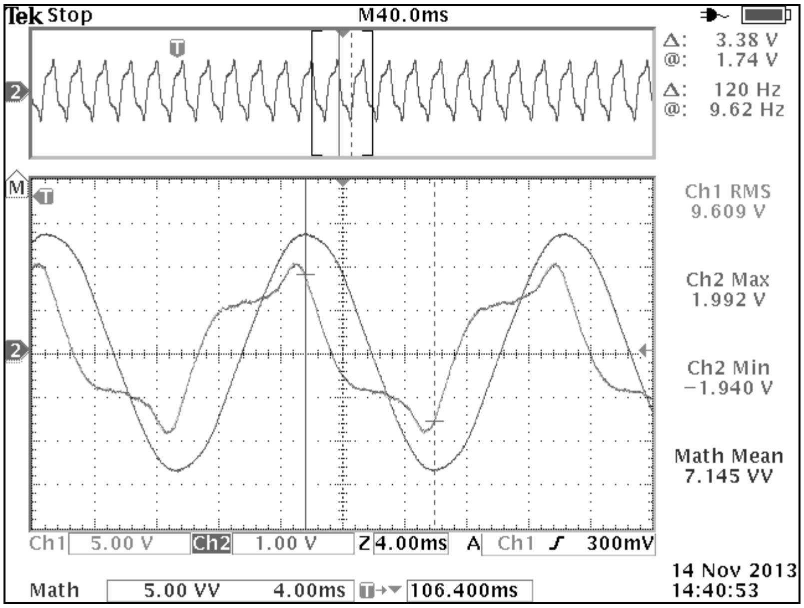

Figure 12: Recovery at 1 min

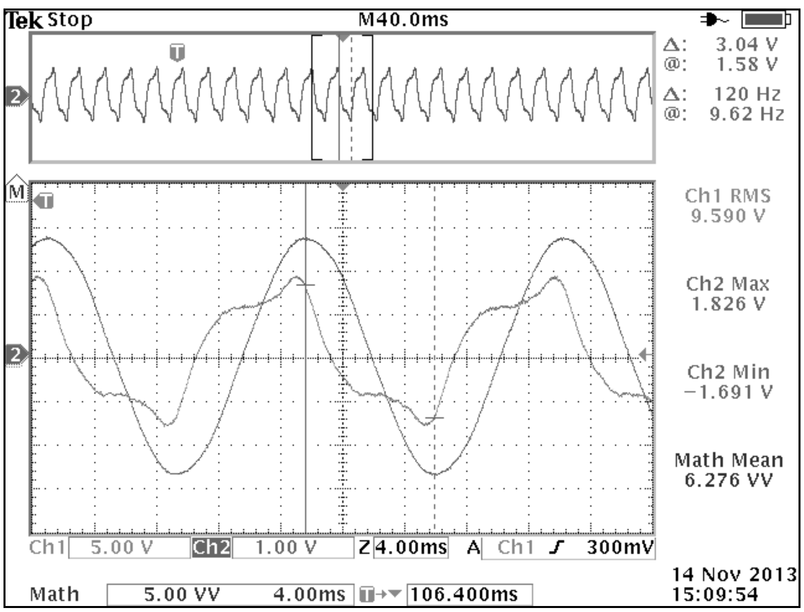

Figure 13: Recovery at 30 min

Design Test Report
Report No. EU1526-H-12.2
SVN Series Polymer-housed Arrester

Short Circuit Test

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
Sr. Technology Manager,
Engineering

Fayaz Khatri
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Date: 11/15/2013

DESIGN TEST REPORT
Short Circuit Test

TESTS PERFORMED:

High current short pressure relief tests were performed on a PH4 arrester (same construction as SVN arresters) at the CESI high power laboratory in Milan, Italy according to the procedures described in 8.18 of IEEE C62.11-2012 (identical to requirements of IEC 60099-4 Ed 2.1: 2006, Clause 8.7 and Annex N of IEC 60099-4 Ed. 2.0:2004). The SVN series of arresters has a rated short circuit capability of 65,000 A symmetrical. Verification of capability requires three high current tests, performed with rated short circuit current (65000 A) and two reduced short circuit currents (25000 A and 12000 A) Three fully assembled test units were prepared, each containing as many non-linear 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 with the highest rated voltage used in the SVN 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.

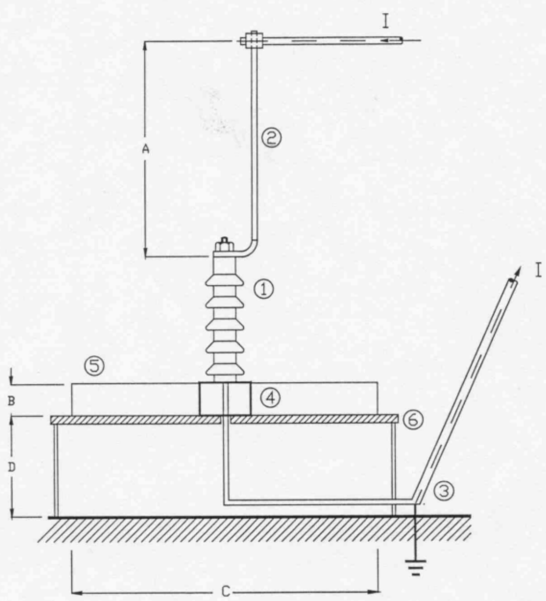
The test sample was rated 144 kV and had a unit length of 53.2 in (58.9 in with terminal cap). Figure 1 shows the general arrangement of the test set up. Figure 2 shows one of the units in the test chamber.

All three samples successfully withstood their respective short circuit current tests with no rupturing of their housings, and with no release of components. Actual prospective rms values of test currents were 14400 A, 28000 A and 68500 A. For the rated current test, the peak of the first half cycle of test current was 162500 A, meeting the requirement that this be at least 2.5 times the rms value of the rated short circuit current (2.5 x 65000 = 162500 A). Data sheets for the tests are shown in Figures 3 - 5, and associated oscillograms are shown in Figures 6 - 9.

EVALUATION:

The design meets the high-current pressure relief test requirements of IEEE C62.11-2012. The test sample successfully withstood the rated short circuit current test and the two reduced high current tests with no rupturing of the polymer housing, and no release of internal components.

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

D1232IG

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 12000 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 25000 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 65000 A test

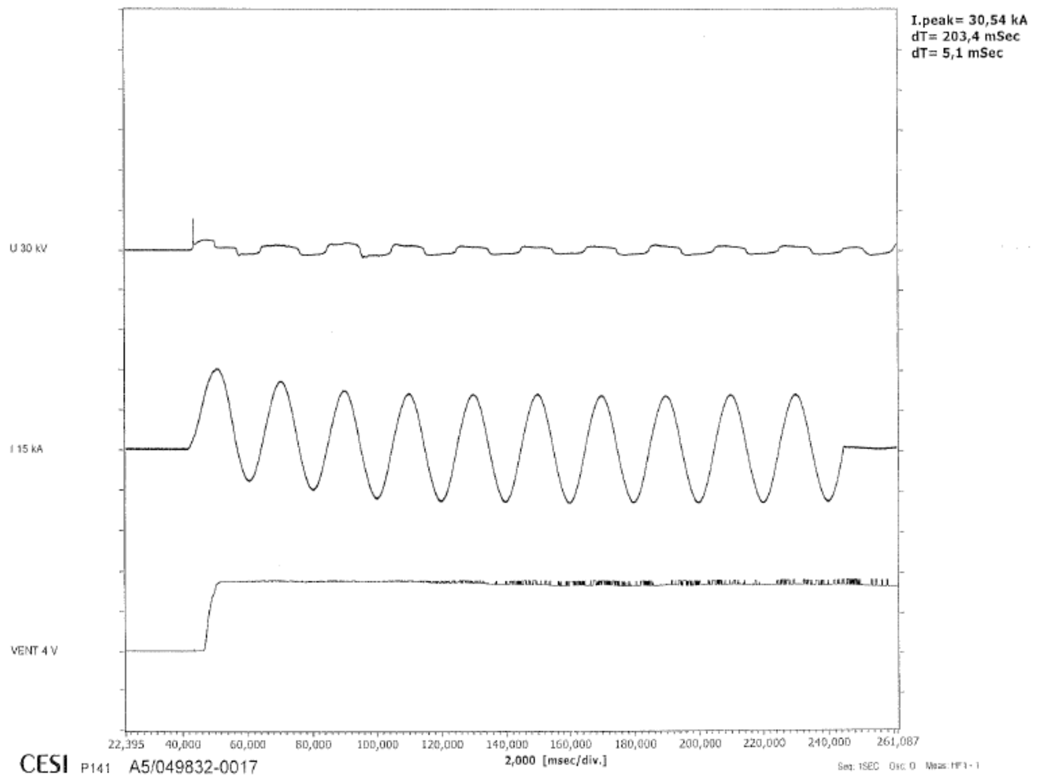


Figure 6. Oscillograms for 12000A test

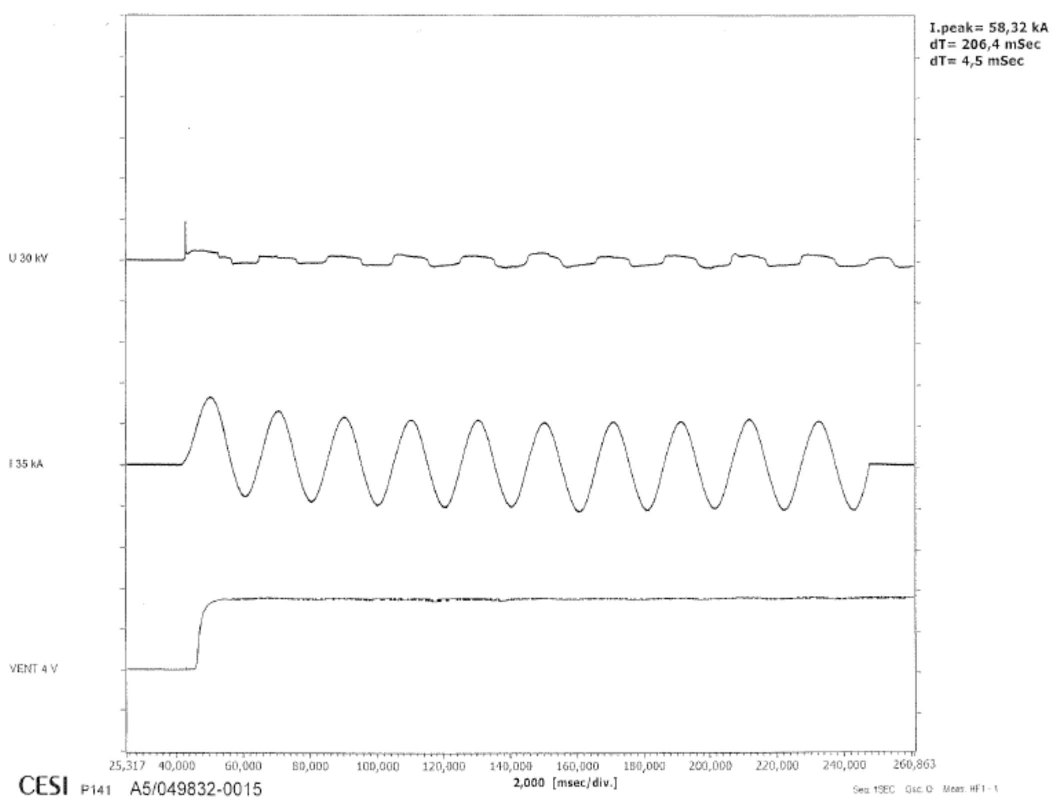


Figure 7. Oscillograms for 25000A test

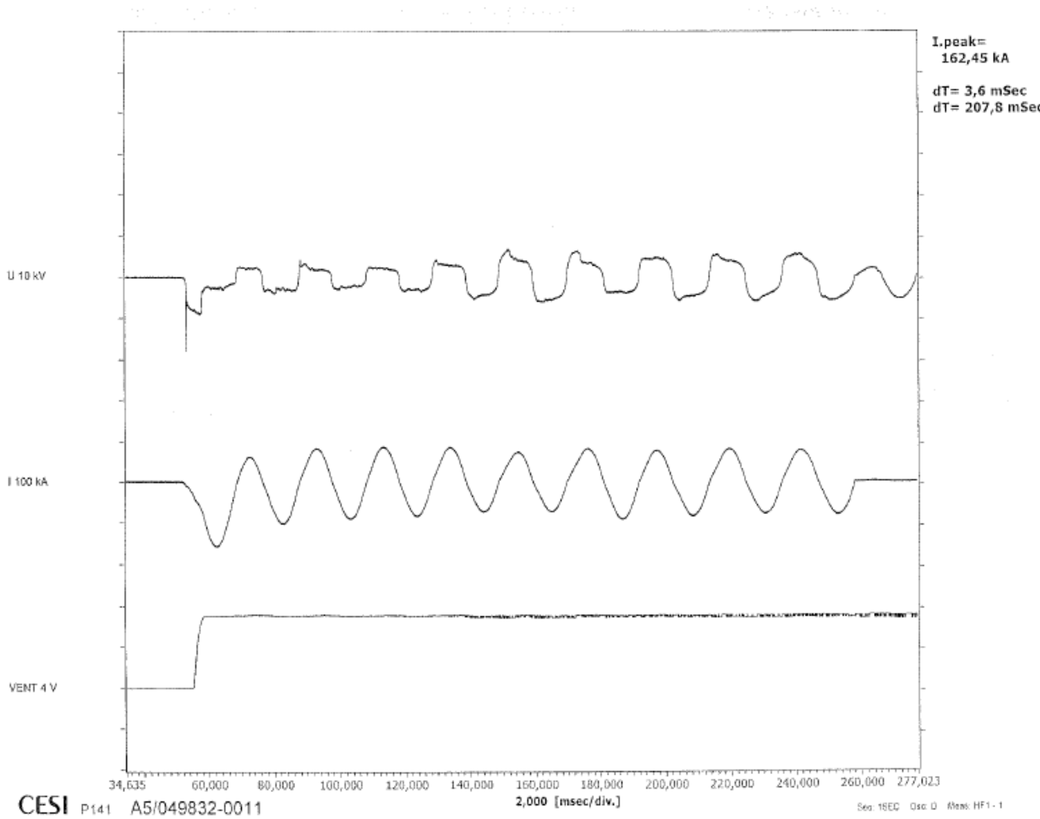


Figure 8. Oscillograms for 65000A test

Design Test Report
Report No. EU1526-H-13.2
SVN Series Polymer-housed Arrester

Maximum design cantilever load (MDCL) and moisture ingress test

This report records the results of type tests made on SVN series arresters, rated up to 444 kV (353 kV MCOV). Tests were performed in accordance with procedures of IEEE Std C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)"

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

Mike Kelley
Sr. Technology Manager,
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Sr. Design Engineer

Date: 11/15/2013

DESIGN TEST REPORT
Maximum design cantilever load (MDCL) and moisture ingress test

TESTS PERFORMED:
A maximum design cantilever load (MDCL) and moisture ingress test was performed on the longest mechanical unit used in the SVN series of arresters. Tests were performed according to Clause 8.22 of IEEE C62.11-2012 Prior to the mechanical testing, the unit was subjected to tests to determine watts loss at MCOV and discharge voltage at 10kA 8/20.

The test unit was subjected to thermomechanical preconditioning, consisting of four 24 h periods at, respectively, +60^{o}C, -25^{o}C, +45^{o}C and –40^{o}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 35,000 in-lbf, the maximum continuous bending moment defined for SVN arresters. The load was applied in a different direction, designated respectively as 0^{o}, 180^{o}, 270^{o}, and 90^{o}, for each of the four periods. At the end of each loading, the deflection of the top of the unit from its original location was measured, and after removal of the load the residual deflection from the original location was recorded.

Within 24 hours of the completion of the four 24-hour cycles, with the unit having cooled to ambient temperature, cantilever load was successively applied in the four directions described above.

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^{o}C, after which time the initial measurements of watts loss, and discharge voltage were repeated, and partial discharge was measured.

RESULTS:
The SVN 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 IEEE C62.11-2012, it is therefore necessary only to perform a test on one unit.

The tested unit was the longest mechanical unit used in SVN arresters, with MCOV of 120 kVrms. Results of initial tests are shown in Table 1.

Table 1. Results of initial measurements

Test Parameter	Result
Watts loss at MCOV	13.8 W
Discharge voltage at 10 kA 8/20	340.4 kV

The maximum continuous bending moment declared for SVN arresters is 35,000 in-lbf. Table 2 reports the average bending moment maintained during each 24-hour period, the deflections measured at the end of each of period, and the residual deflection after removal of the load.

Table 2. Loads and deflections measured during 24-hour periods

Period	Temperature	Load direction	Average bending moment (in-lbf)	Maximum deflection (in)	Residual deflection (in)
1	+ 65 ^{o}C	0^{o}	36,358	1.00	0
2	- 25 ^{o}C	270^{o}	37,510	0.99	0.17
3	+ 45 ^{o}C	180^{o}	35,966	1.09	0.21
4	- 40 ^{o}C	90^{o}	37,412	1.04	0.17

The unit was then subjected to 42 hours of immersion in boiling water, after which the initial tests conducted on the unit (watts loss and discharge voltage) were repeated, and partial discharge was measured at 1.05 times MCOV. Results are shown in Table 3.

Table 3. Results of final measurements

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

EVALUATION:
The design meets the MDCL and moisture ingress test requirements of IEEE C62.11-2012. The changes 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 was found to be below the allowed limit of 10 pC.