IEEE Design Test Report
Report Number: EU1603-H-00
SVNH IEEE Station Class Arrester
10 kA Discharge Current

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard C62.11-2012, "IEEE Standard for Metal-Oxide Surge arresters for AC Power Circuits (>1 kV)."

SVNH Station Class Arresters are assembled at an ISO 9001 certified Hubbell location. 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.

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

Report Number	Description	Clause
EU1603-H-01	Arrester Insulation Withstand	8.1.2.4
EU1603-H-02	Discharge-voltage Characteristics	8.2
EU1603-H-03	Accelerated Aging Test of Varistors	8.5
EU1603-H-04	Accelerated Aging Test of Polymer-housed Arresters with Exposure to Salt Fog	8.7
EU1603-H-05	Contamination	8.8
EU1603-H-06	Radio-influence Voltage (RIV)	8.10
EU1603-H-07	Partial Discharge (PD)	8.11
EU1603-H-08	Switching Surge Energy Rating	8.14
EU1603-H-09	Single-impulse Withstand Rating	8.15
EU1603-H-10	Duty-cycle	8.16
EU1603-H-11	Temporary Overvoltage (TOV)	8.17
EU1603-H-12	Short Circuit	8.18
EU1603-H-13	Maximum Design Cantilever Load (MDCL) and Moisture Ingress Test for Polymer-housed Arresters	8.22

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE Design Test Report
Report Number: EU1603-H-01
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Arrester Insulation Withstand
IEEE Clause 8.1

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Arrester Insulation Withstand
IEEE Clause 8.1

INTRODUCTION

The insulation withstand tests demonstrate the arrester housing will not flash over during usual system conditions under defined impulse, switching and power-frequency conditions.

PROCEDURE

Insulation withstand tests were made on one arrester unit of each length used in SVNH arresters. Testing was performed in accordance with the requirements of Clause 8.1.2.4 of IEEE Standard 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 requirements:

- 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 second wet power frequency withstand voltage (rms value) shall not be less than the maximum switching impulse discharge voltage multiplied by 0.82.

The highest unit MCOV of each housing length was used for the discharge voltages. Values are 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 2kA switching impulse discharge voltage
	in	in	in	kVrms	kV	kV
1	53.5	50.0	142.3	113	350	288
2	63.5	60.0	184.5	140	433	356
3	73.3	69.8	224.6	166	514	423

RESULTS

Tests were conducted with both positive and negative polarities. The lower of the two withstands is reported for each housing and have been used to determine the claimable insulation withstand voltage. Results are reported in Table 2. The per unit (p.u.) impulse ratios are displayed in Table 3.

Table 2: 1.2/50 impulse withstand results

Housing number	Measured withstand voltage	Ambient temperature	Barometric pressure	Relative air density	Absolute humidity	Air density correction factor (k_d)	Humidity correction factor (k_h)
	kVpeak	^oC	kPa	p.u.	$g.m^{-3}$	p.u.	p.u.
1	575	26.7	97.8	0.944	8.73	0.944	1.019
2	579	26.7	97.8	0.944	8.73	0.944	1.019
3	688	26.7	97.8	0.944	8.73	0.944	1.019

Table 3: 1.2/50 impulse withstand ratios

Housing number	Overall correction factor ($K = k_d/k_h$)	Corrected withstand voltage (test voltage/K)	p.u. of 20kA 8/20 impulse discharge voltage
	p.u.	kVpeak	p.u.
1	0.927	620	1.77
2	0.927	625	1.44
3	0.927	742	1.44

The withstand values for the power frequency withstand tests are reported in Table 4. The power frequency ratios are displayed in Table 5.

Table 4: 10 s Wet Power frequency withstand results

Housing number	Measured withstand voltage	Ambient temperature	Barometric pressure	Relative air density	Absolute humidity	Air density correction factor (k_d)	Humidity correction factor (k_h)
	kVrms	°C	kPa	p.u.	$g.m^{-3}$	p.u.	p.u.
1	228	23.3	97.6	0.953	13.09	0.957	1.000
2	282	23.3	97.6	0.953	13.09	0.957	1.000
3	336	23.3	97.6	0.953	13.09	0.957	1.000

Table 5: 10 s Wet Power frequency withstand ratios

Housing number	Overall correction factor ($K = k_d/k_h$)	Corrected withstand voltage (test voltage/K)	p.u. of 2kA switching impulse discharge voltage
	p.u.	kVrms	p.u.
1	0.957	238	0.83
2	0.957	294	0.83
3	0.957	351	0.83

CONCLUSION

The p.u. 20 kA ratio was found to exceed the minimum requirement of 1.42. The p.u. 2 kA switching impulse ratio was found to exceed the minimum requirement of 0.82. Insulation withstand tests performed on all three SVNH unit housings meet the requirements of Clause 8.1.2.4 of IEEE Standard C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-02
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Discharge-voltage Characteristics
IEEE Clause 8.2

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Discharge-voltage Characteristics
IEEE Clause 8.2

INTRODUCTION

The discharge-voltage characteristics test demonstrates the arrester discharge voltages for defined surge conditions, do not exceed values published in manufacturers' literature.

PROCEDURE

Discharge voltage measurements were made on three metal oxide varistor (MOV) discs of the longest length used in SVNH arresters. Tests were conducted in accordance with Clause 8.2 of IEEE Standard C62.11-2012. For each test sample, all measured voltages have been normalized to the lightning impulse discharge voltage of that sample at a classifying current of 10 kA.

RESULTS

Table 1 shows the lightning impulse discharge voltages measured at 1.5 kA, 3 kA, 5 kA, 10 kA, 20 kA and 40 kA. The impulses have a 8/20 microsecond waveshape. The normalized per unit (p.u.) values are also included.

Table 1: Lightning impulse discharge voltage measurements

Current magnitude	Sample 1		Sample 2		Sample 3	
kA	kV	p.u.	kV	p.u.	kV	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

Table 2 shows the switching impulse discharge voltages measured for 0.25 kA, 0.5 kA, 1 kA, 1.5 kA, 2 kA and 3 kA. The impulses have a 36/90 microsecond waveshape.

Table 2: Switching impulse discharge voltage measurements

Current magnitude	Sample 1		Sample 2		Sample 3	
kA	kV	p.u.	kV	p.u.	kV	p.u.
0.25	11.031	0.806	11.023	0.852	11.023	0.853
0.5	11.284	0.825	11.292	0.873	11.309	0.876
1	11.628	0.850	11.620	0.898	11.637	0.901
1.5	11.821	0.864	11.837	0.915	11.854	0.918
2	12.077	0.883	12.044	0.931	12.065	0.934
3	12.325	0.901	12.325	0.953	12.346	0.956

Table 3 shows the front-of-wave (FOW) discharge voltages for 10 kA and 20 kA. The impulses have a virtual front time of 1 microsecond.

Table 3: FOW impulse discharge voltage measurements

Current magnitude	Sample 1		Sample 2		Sample 3	
kA	kV	p.u.	kV	p.u.	kV	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

The maximum p.u. values from Tables 1 – 3 are plotted in Figure 1.

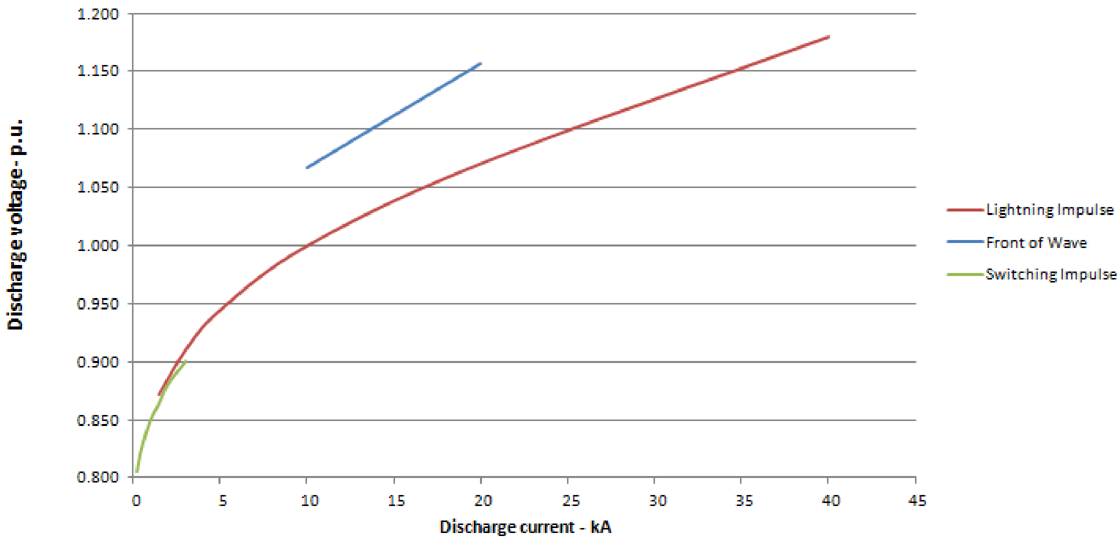

Figure 1: Discharge voltage measurements normalized to arrester discharge current of 10kA 8/20

CONCLUSION

In the case of routine production tests on complete SVNH 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 discharge-voltage$_{routinetestmax}$, and the maximum published discharge value for any given magnitude and waveshape of current is represented by discharge-voltage$_{publishedmax}$ then the “production test ratio” for that discharge current magnitude and waveshape is given by:

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

For all arresters in the SVNH 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. 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.

IEEE Design Test Report
Report Number: EU1603-H-03
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Accelerated Aging Test of Varistors
IEEE Clause 8.5

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

INTRODUCTION

The accelerated aging test verifies the varistors remain stable and do not increase in power dissipation at MCOV during their expected lifetime.

PROCEDURE

Accelerated aging tests were performed at 15% above MCOV on six MOV discs. The tested discs represent three of the shortest and three of the longest used in SVNH arresters. Tests were conducted in accordance with the requirements of Clause 8.5 of IEEE C62.11-2012. The MOV discs were placed in an air oven and energized at a voltage equal to an adjusted MCOV. The adjusted voltage accounts for the maximum non-uniformity of voltage distribution in arrester application. The temperature of the MOV discs was maintained at 115 °C ± 2 °C for the duration of the test.

Power dissipation was measured on each MOV disc at adjusted MCOV and at duty-cycle voltage two hours after the start of the one thousand hour test, and again at the end of the period.

RESULTS

Power dissipation measured after two hours and after one thousand hours on the six MOV discs are reported in Table 1.

Table 1: Accelerated aging test data

MOV disc length	MOV disc number	Power dissipation at adjusted MCOV (W)		Power dissipation at duty-cycle voltage (W)	
		After 2 hours	After 1000 hours	After 2 hours	After 1000 hours
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	4	4.03	3.43	7.23	6.39
	5	3.73	3.10	7.18	6.07
	6	3.42	2.94	6.19	5.19

CONCLUSION

Power dissipation measurements at the end of the each one thousand hour test period were less than the values at two hours. The SVNH design meets the requirements of Clause 8.5 of IEEE C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-04
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Accelerated Aging Test of Polymer-housed Arresters with Exposure to Salt Fog
IEEE Clause 8.7

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Accelerated Aging Test of Polymer-housed Arresters with Exposure to Salt Fog
IEEE Clause 8.7

INTRODUCTION

The purpose of the accelerated aging test verifies the external housing and internal components of polymer-housed arresters will remain functional for the design level when exposed to specific levels of salt fog.

PROCEDURE

A 124 kV MCOV SVNX arrester was subjected to the accelerated aging test as prescribed in Clause 8.7 of IEEE Standard C62.11-2012. SVNX arresters are constructed using the same polymer housings and end castings used in SVNH arresters. Due to design similarities, salt fog testing performed on an SVNX arrester is sufficient to qualify SVNH arresters.

Initial measurements were made of reference voltage and partial discharge. The arrester was energized at MCOV for 1000 hours with the salt fog having a starting salinity of 10 kg/m3. The salt fog was not directly sprayed on the test sample.
Visual observations of the condition of the silicone rubber housing were made periodically during the 1000 hour test. Measurements of reference voltage and partial discharge were repeated after 1000 hours.

RESULTS

Visual inspection of the arrester after test showed no evidence of polymer housing tracking or weathershed puncture. Table 1 shows the initial and final values of reference voltage and partial discharge.

Table 1: Initial and final electrical measurements

Parameter	Initial	Final	Change
Reference voltage	164.2 kV	163.4 kV	- 0.5%
Partial discharge	< 10 pC	< 10 pC	N/A

CONCLUSION

No housing tracking, weathershed punctures or internal breakdown occurred during the 1000 hour test Reference voltage changed by less than 5%, and partial discharge values measured before and after the test were less than 10 pC. The SVNH design meets the requirements of Clause 8.7 of IEEE Standard C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-05
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Contamination Test
IEEE Clause 8.8

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Contamination Test
IEEE Clause 8.8

INTRODUCTION

The contamination test demonstrates the ability of the arrester to withstand electrical stresses on the arrester housing, caused by contamination. The test is only applicable for multi-unit station or intermediate arresters.

PROCEDURE

A fully assembled SVNH arrester, with MCOV of 353 kV was subjected to the contamination test per Clause 8.8 of IEEE Standard C62.11-2012. The arrester was energized at MCOV for one hour, at which time power loss was measured. The arrester was de-energized for application of the contaminant slurry. The contaminant consisted of water, bentonite (at concentration of 5 g/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 applied as uniformly as possible over all housing surfaces of the lower 50% of the arrester. Power losses were measured at the start and the end of 15 minutes of energization.

At the 15 minute mark, the arrester was de-energized, upon which the process of contaminant application and subsequent re-energization at MCOV was repeated. Power losses were monitored for 30 minutes to verify that they were continuing to decrease.

RESULTS

Table 1 lists the power loss measurements made at each stage of the test.

Table 1: Power loss measurements during contamination test

Stage	Time (min)	Voltage (kVrms)	Power loss (W)
Initial energization	0	353	44.83
	5	353	44.08
	10	353	42.01
	30	353	43.91
	60	353	43.46
Elapsed Time = 6 min			
First contaminant application	0	353	48.45
	15	353	46.87
Elapsed Time = 5 min			
Second contaminant application	0	353	55.55
	5	353	53.18
	10	353	51.70
	15	353	50.00
Energize at MCOV	0	353	50.00
	15	353	50.50
	30	353	51.50

CONCLUSION

At the end of the test, the arrester power loss was below the initial level. The SVNH design meets the requirements of Clause 8.8 of IEEE Standard C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-06
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Radio-influence Voltage (RIV)
IEEE Clause 8.10

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Radio-influence Voltage (RIV)
IEEE Clause 8.10

INTRODUCTION

The RIV test verifies that under normal operating conditions, the arrester does not generate partial discharges that produce excessive RIV. The test applies to open-air surge arrester having MCOV of 70 kV and above.

PROCEDURE

One fully assembled SVNH arrester with an MCOV of 353 kV was subjected to an RIV test in accordance with Clause 8.10 of IEEE Standard C62.11-2012. The equipment used and general methods were in accordance with Annex A of NEMA CC-1.

Ambient temperature during the test was 22°C. The variable-frequency RIV meter was tuned to 1 MHz for the measurements. Prior to installing the arrester in the test circuit, an open circuit test was run to determine the background noise of the circuit. The background noise measured to be less than 10 µV.

The test voltage was increased to 1.15 times MCOV and then lowered to 1.05 times MCOV, where it was maintained for five minutes. The voltage was then decreased in steps (each step being approximately 0.1 times MCOV) to 0.5 times MCOV, raised again by steps to 1.05 times MCOV for five minutes and finally decreased by steps to 0.5 times MCOV. At each step the RIV was measured and recorded.

RESULTS

Results of the measurements are given in Table 1.

Table 1: RIV levels for 353 kV MCOV SVNH arrester

Applied voltage (kVrms)	RIV (µV)
405	2.4
370	1.7
335	2.0
300	1.7
264	2.2
229	2.1
194	2.0
176	1.5
158	1.8

CONCLUSION

The RIV level at 1.05 times MCOV and all lower voltages were below the maximum allowed level of 2500 µV. The SVNH design meets the requirements of Clause 8.10 of IEEE Standard C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-07
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Partial Discharge (PD)
IEEE Clause 8.11

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Partial Discharge (PD)
IEEE Clause 8.11

INTRODUCTION

The PD test assures the arrester design does not include materials, parts, or internal assemblies stressed beyond their PD inception limit under normal operating conditions.

PROCEDURE

The PD test was performed according to Clause 8.11 of IEEE Standard C62.11-2012 on a 168 kV MCOV SVNH arrester. The standard specifies the test voltage be raised to the adjusted duty cycle voltage rating for a minimum of two seconds, and then reduced to 1.05 times the adjusted MCOV. The PD measurement is made at the adjusted MCOV. PD must be below 10 pC.

RESULTS

PD measured at the adjusted MCOV was 5.1 pC.

CONCLUSION

The SVNH design meets the requirements of Clause 8.11 of IEEE Standard C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-08
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Switching Surge Energy Rating Test
IEEE Clause 8.14

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Switching Surge Energy Rating Test
IEEE Clause 8.14

INTRODUCTION

The switching surge energy rating test demonstrates the multiple-discharge switching surge energy capability claimed for station and intermediate arresters.

PROCEDURE

A switching surge energy rating test was performed on three prorated test samples consisting of two MOV discs in series. The MOV discs for the test sample were selected to represent the lowest volume of discs used in the arrester. The test was conducted in accordance with Clause 8.14 of IEEE C62.11-2012 with energy class F (11 kJ/kV MCOV). The test was conducted in still air at 22^{o}C.

The samples were conditioned with 6 groups of three long-duration impulses of at least 5.5 kJ/kV MCOV, followed by two 65kA 4/10 impulses. The test samples were then heated in an oven and stabilized overnight to a temperature of 72^{o}C. After removal from the oven, each sample was subjected to two long duration impulses of at least 5.5 kJ/kV MCOV. Within 100 ms of the second impulse, the sample was energized at duty cycle rated voltage for 10 seconds, immediately followed by an adjusted MCOV recovery voltage. This voltage was maintained for 30 minutes after the second additional impulse to allow demonstration of sample thermal recovery.

The switching impulse discharge voltage at 2 kA 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 SVNH series of arresters, MCOV is set at 0.5 times the 10kA discharge voltage. The maximum ratio between duty-cycle voltage rating (DCVR) and MCOV is 1.282. The MCOV and DCVR for each sample are shown in Table 1.

Table 1: MCOV and duty cycle voltage rating for test samples

Sample Number	10kA IR	Reference voltage	Minimum $MCOV_{sample}$	Minimum $DCVR_{sample}$
	kVpk	kVpk	kVrms	kVrms
1	19.87	13.17	7.025	9.006
2	19.89	13.21	7.032	9.015
3	19.93	13.24	7.046	9.033

Table 2 shows voltage and current during the 10 seconds period energized at DCVR for each sample. Table 3 shows voltage, current and power dissipation for the subsequent 30 minute period.

Table 2: Voltage and current during 10 second period following last long duration impulse

Sample 1			Sample 2			Sample 3		
Time	Applied voltage	Sample current	Time	Applied voltage	Sample current	Time	Applied voltage	Sample current
second	kVrms	mAcr	second	kVrms	mAcr	second	kVrms	mAcr
0.06	9.19	135.4	0.07	9.09	84.6	0.07	9.07	77.9
1.03	9.19	129.6	1.08	9.07	81.3	1.08	9.08	75.0
2.04	9.19	127.9	2.04	9.09	80.0	2.04	9.10	75.0
3.10	9.19	126.3	3.00	9.07	78.8	3.00	9.09	73.8
4.03	9.20	127.5	4.01	9.08	78.8	4.01	9.07	72.1
5.04	9.21	127.1	5.02	9.08	77.5	5.02	9.07	70.8
6.10	9.19	125.4	6.05	9.08	76.7	6.05	9.09	74.6
7.06	9.20	125.4	7.03	9.08	76.3	7.03	9.09	73.8
8.11	9.20	125.8	8.06	9.07	75.0	8.06	9.10	73.3
9.22	9.19	123.3	9.24	9.09	75.8	9.24	9.10	72.9
10.2	9.19	122.5	10.2	9.08	76.3	10.2	9.10	73.8

Table 3: Voltage and current during subsequent 30 minute period

Elapsed time	Sample 1			Sample 2			Sample 3		
	Applied voltage	Sample current	Power dissipation	Applied voltage	Sample current	Power dissipation	Applied voltage	Sample current	Power dissipation
minute	kVrms	mAcr	W	kVrms	mAcr	W	kVrms	mAcr	W
0	7.72	-10.8	31.09	7.69	-9.00	23.73	7.68	-8.81	22.96
0.5	7.74	-10.0	28.97	7.69	-8.30	22.22	7.68	-8.39	21.68
1	7.69	-9.38	27.75	7.70	-8.02	21.33	7.69	-8.13	21.07
2	7.63	-8.71	24.60	7.71	-7.81	20.38	7.68	-7.69	20.10
5	7.63	-7.94	22.49	7.67	-6.59	18.04	7.69	-7.23	18.90
10	7.63	-6.92	21.00	7.68	-6.12	16.75	7.64	-6.48	16.81
20	7.58	-6.37	18.78	7.70	-6.18	15.83	7.63	-6.13	15.64
30	7.59	-6.21	18.10	7.66	-5.71	14.66	7.62	-6.00	15.10

After the sample had cooled to ambient temperature, its switching impulse discharge voltage was measured at 2 kA. The value was compared to the initial measurement. Results are shown in Table 4. Disassembly of each test sample at the end of testing revealed no evidence of physical damage.

Table 4: Initial and final discharge voltage measurements

Sample Number	Discharge voltage		% Change
	Before	After	
1	17.463	17.570	0.61%
2	17.544	17.651	0.61%
3	17.544	17.678	0.76%

CONCLUSION

Thermal recovery was demonstrated by a declining level of watts, no physical damage was evident, and the 2 kA switching impulse discharge voltage changed by less than 5%. Each long duration impulse applied in the test exceeded 11.1 kJ/kV MCOV. This is sufficient to claim a switching surge energy rating of Class F (11 kJ/kV MCOV). The SVNH design meets the evaluation criteria of Clause 8.14.5 of IEEE C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-09
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Single-impulse Withstand Rating
IEEE Clause 8.15

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Single-impulse Withstand Rating
IEEE Clause 8.15

INTRODUCTION

The single-impulse withstand rating test verifies the arrester withstand capability. The capability represents the maximum charge of a single current impulse that the arrester can withstand multiple times without causing physical or electrical damage to the varistors of the arrester. The test only applies to intermediate and station class arresters.

PROCEDURE

Tests were performed in accordance with Clause 8.15 of IEEE Standard C62.11-2012 on ten of the longest metal-oxide varistor (MOV) discs used in SVNH arresters. The discharge voltage at 15 kA and reference voltage at 17 mA were determined for each sample. The samples were then subjected to ten groups of two long-duration current impulses. Each impulse had a rectangular waveshape with 3.9 millisecond duration and 6.5 C charge content. The samples were allowed to cool after the last group of impulses. After cooling, discharge voltage and reference voltage measurements were repeated.

RESULTS

All ten MOV discs survived the ten groups of two discharges with no damage. Table 1 summarizes the minimum, maximum and average charge for the 20 discharges applied to each sample. Table 2 compares the initial and final discharge voltage and reference voltage measured on each sample.

Table 1: Summary of charge content of discharges for each sample

	Charge (C)		
Sample	Minimum	Maximum	Average
1	6.33	6.57	6.40
2	6.29	6.49	6.35
3	6.29	6.38	6.32
4	6.31	6.42	6.34
5	6.29	6.50	6.33
6	6.32	6.50	6.38
7	6.31	6.52	6.37
8	6.28	6.45	6.34
9	6.31	6.44	6.37
10	6.33	6.51	6.37

Table 2: Initial and final discharge and reference voltages

	Discharge voltage			Reference voltage		
Sample	Initial kV	Final kV	Percent change	Initial kVrms	Final kVrms	Percent change
1	13.86	13.92	0.43%	9.23	9.25	0.22%
2	13.91	13.98	0.50%	9.26	9.29	0.32%
3	13.96	14.04	0.57%	9.31	9.34	0.32%
4	13.91	13.99	0.58%	9.27	9.31	0.43%
5	13.94	14.02	0.57%	9.31	9.34	0.32%
6	13.87	13.98	0.79%	9.24	9.26	0.22%
7	13.90	14.04	1.01%	9.24	9.27	0.32%
8	13.92	14.01	0.65%	9.26	9.29	0.32%
9	13.87	13.99	0.87%	9.21	9.24	0.33%
10	13.89	14.02	0.94%	9.24	9.26	0.22%

The minimum charge content of the 200 discharges summarized in Table 1 was 6.28 C. This value will be used to establish the single-impulse withstand rating. Measurements of discharge voltage and reference voltage after the impulses showed that these characteristics changed by less than 5%. The test charge level must be at least 10% above the claimable charge rating, it would be possible to claim a capability not more than 6.28/1.1 = 5.7 C.

CONCLUSION

Per Clause 8.15 of IEEE Standard C62.11-2012, the claimable single-impulse withstand rating must be a multiple of 0.4 C in the range 4.0 to 8 C. The SVNH design passed the single-impulse withstand rating test with a claimable rating of 5.6 C.

IEEE Design Test Report
Report Number: EU1603-H-10
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Duty-cycle
IEEE Clause 8.16

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Duty-cycle
IEEE Clause 8.16

INTRODUCTION

The duty-cycle test verifies the arrester can withstand multiple lightning type impulses without causing thermal instability or dielectric failure.

PROCEDURE

A duty cycle test was performed on a prorated test sample consisting of two MOV discs in series. The discs for the test sample were selected to represent the lowest volume of discs used in the arrester. The test was conducted in accordance with Clause 8.16 of IEEE Standard C62.11-2012. The test was conducted in still air at 22°C.

Prior to the application of impulses, the discharge voltage was measured at 15 kA 8/20. The sample was then energized at duty-cycle voltage rating and subjected to twenty 8/20 current impulses of at least 15 kA each, with 50-60 seconds between impulses. After the twentieth impulse, the test sample was heated in an oven and stabilized overnight to a temperature of 72°C. After removal from the oven, the sample was subjected to two additional impulses of 15 kA, separated by 50-60 seconds, while energized at an adjusted MCOV recovery voltage. This voltage was maintained for 30 minutes after the second impulse to allow demonstration of sample thermal recovery.

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

To determine the adjusted MCOV to be applied on the heated sample, initial measurements were made on the MOV discs used in the test sample. The applied voltage was increased above $MCOV_{sample}$ until the watts loss matched the maximum limit allowed in manufacturing. The resulting adjusted MCOV was 7.55 kVrms. Measurements of power dissipation and current were recorded during the overvoltage. Recorded values are shown in Table 1.

Table 1: Voltage, watts and current measured during 30 minute recovery period

Elapsed time	Applied voltage	Power dissipation	Current
hours:minutes:seconds	kVrms	W	mAcr
0:00:00	7.69	3.92	2.29
0:00:30	7.71	3.95	2.27
0:01:00	7.71	4.00	2.25
0:02:00	7.62	3.48	2.14
0:05:00	7.60	3.47	2.18
0:10:00	7.61	3.47	2.21
0:20:00	7.60	3.46	2.19
0:30:00	7.57	3.41	2.16

After the sample had cooled to ambient temperature, its discharge voltage was measured at 15 kA. The resulting value was compared to the value measured prior to the test. Results are shown in Table 2.

Table 2: Initial and final discharge voltage measurements

Discharge Voltage (kVcr)		Percent change (%)
Before	After	
20.934	20.853	0.39

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

CONCLUSION

Thermal recovery after the twenty second impulse was demonstrated by a declining level of watts, no physical damage was evident, and discharge voltage changed by less than 10%. The SVNH design meets the requirements of Clause 8.16 of IEEE Standard C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-11
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Temporary Overvoltage (TOV)
IEEE Clause 8.17

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Temporary Overvoltage (TOV)
IEEE Clause 8.17

INTRODUCTION

The TOV test verifies the TOV capability of the arrester. The test is a power-frequency overvoltage for time periods 0.01 second to 10,000 seconds.

PROCEDURE

A TOV test was performed on SVNH prorated test samples consisting of two metal-oxide varistor (MOV) discs in series. The discs for the test sample were selected to represent the lowest volume of discs used in the arrester. The test was conducted in accordance with Clause 8.17 of IEEE Standard C62.11-2012. The ambient temperature at the time of the test was 22°C. No prior duty and prior duty tests were conducted on four samples. Discharge voltage for each sample was measured at 15 kA 8/20.

The no prior duty samples were heated in an oven and stabilized overnight to a temperature in excess of 72°C. Each sample was subjected to a power-frequency overvoltage for a specific duration. Adjusted MCOV recovery voltage was applied for 30 minutes to allow demonstration of sample thermal recovery. This process was repeated for all four samples.

The prior duty test was performed on four samples as described for the no prior duty test except for the application of two switching impulses, prior to the application of the overvoltage. Each of the two impulses were of the same form and magnitude as used in the switching surge energy rating test. Each impulse had an energy content of at least 5.5 kJ/kV of MCOV. The two impulses were separated by 50-60 seconds.

After all samples had cooled to ambient temperature, discharge voltage was measured at 15 kA 8/20. The test samples were then disassembled for visual inspection.

RESULTS

Table 1 shows the claimed per unit (p.u.) TOV capability for both the no prior duty and prior duty TOV test. Initial and final discharge voltage measurements are shown in Table 2. Disassembly of the test samples at the end of the electrical tests revealed no evidence of physical damage.

Table 1: Claimed TOV points for no prior duty curve

Time (seconds)	Per unit (p.u.) MCOV
No prior duty	
0.1	1.538
1	1.478
10	1.418
100	1.355
1000	1.295
Prior duty	
0.1	1.490
1	1.405
10	1.319
100	1.230
1000	1.140

Table 2: Initial and final discharge voltage measurements

Sample	Initial measurement	Final measurement	Change
	kV	kV	%
No prior duty			
1	21.068	21.135	0.3
2	20.934	21.215	1.3
3	21.001	21.161	0.8
4	21.001	21.349	1.7
Prior duty			
5	20.934	20.947	0.1
6	21.135	21.161	0.1
7	21.269	21.269	0
8	21.336	21.322	0.1

Demonstrated TOV capability is also shown in Figure 1.

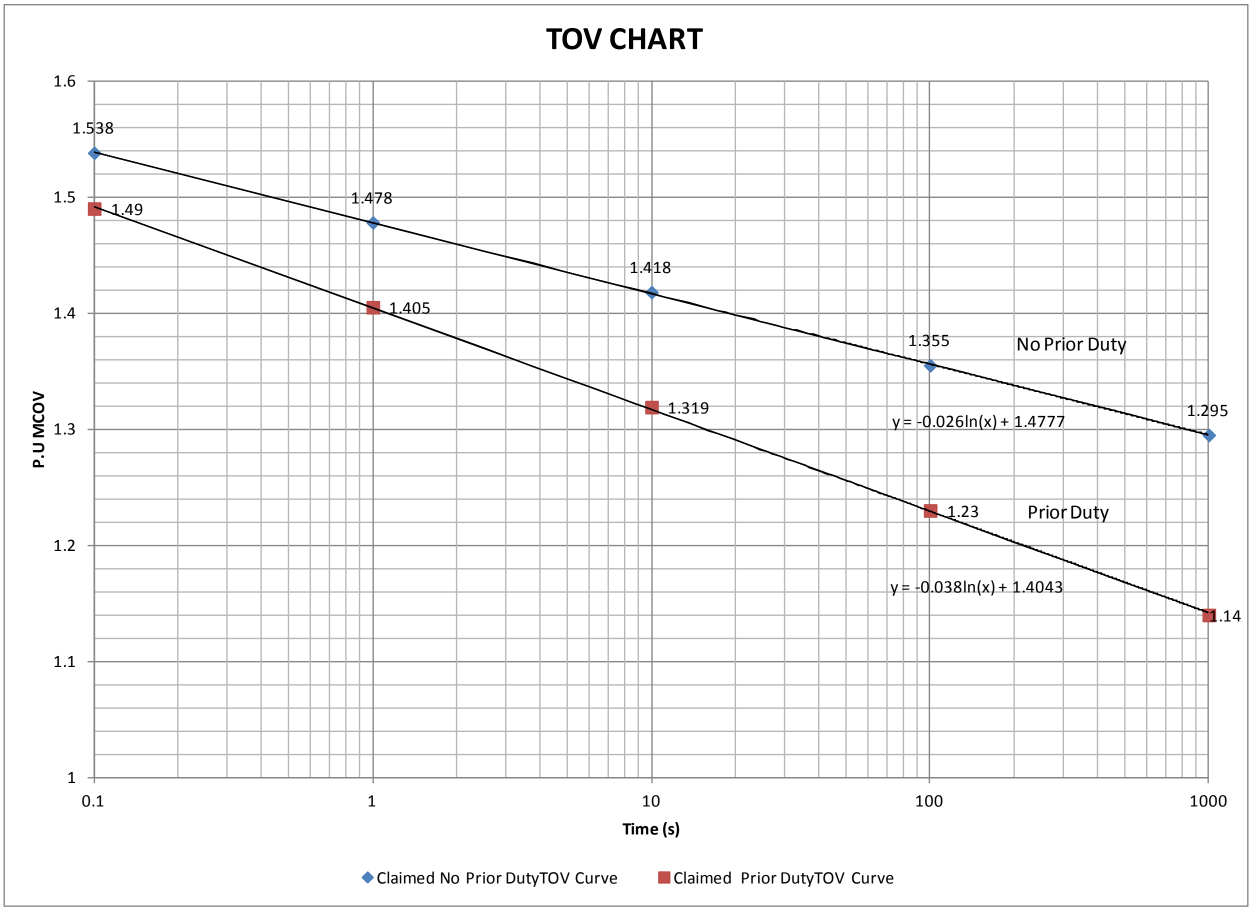

Figure 1: SVNH no prior duty and prior duty TOV capability

CONCLUSION

Each sample demonstrated thermal recovery, no physical damage was evident and the switching impulse discharge voltage changed by less than 10%. The SVNH design meets the criteria of Clause 8.17 of IEEE C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-12
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Short Circuit
IEEE Clause 8.18

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Short Circuit
IEEE Clause 8.18

INTRODUCTION

The short circuit test is performed to show an arrester failure does not result in a violent shattering of the arrester housing.

PROCEDURE

Short circuit tests were performed on SVNX arresters according to the procedure in Clause 8.18 of IEEE Standard C62.11-2012. SVNX arresters are constructed using the same polymer housings, end castings and pressure relief mechanisms used in SVNH arresters. SVNH arresters are constructed with a single column of MOV discs, as opposed to the SVNX family which uses two parallel columns of MOV discs. The reduced amount of internal air space in the SVNX design makes the test of SVNX more severe. Tests performed on SVNX arresters are sufficient to qualify SVNH arresters.

Verification of rated short circuit capability requires three high current tests, performed with rated short circuit current (63 kA), two reduced short circuit currents (25 kA and 12 kA) and a low current test (600 A). Four fully assembled test units were prepared. The internal MOV discs of each unit were shorted by a fuse wire running along the outside of the stack of MOV discs.

RESULTS

All four samples successfully withstood their respective short circuit current tests without housing rupture or release of components. For the rated high current test, the peak of the first half cycle of test current was 160 kA, meeting the requirement that this be at least 2.5 times the rms value of the rated short circuit current (2.5 x 63 kA = 157.5 kA).

CONCLUSION

The test samples successfully withstood the rated short circuit current test (63 kA), the two reduced high current tests (25 kA and 12 kA) and the low current test (600 A). The SVNH design meets the requirements of Clause 8.18 of IEEE Standard C62.11-2012.

IEEE Design Test Report
Report Number: EU1603-H-13
SVNH IEEE Station Class Arrester
10 kA Discharge Current

Maximum Design Cantilever Load (MDCL) and Moisture
Ingress Test for Polymer-housed Arresters
IEEE Clause 8.22

This report presents the results of design tests made on SVNH IEEE Station Class Arrester, rated up to 444kV. Tests were performed in accordance with IEEE Standard 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.

Approved by:
Christopher B. Kulig – Staff Design Engineer
Fayaz Khatri – Engineering Manager, Arresters

IEEE DESIGN TEST REPORT
Maximum Design Cantilever Load (MDCL) and Moisture
Ingress Test for Polymer-housed Arresters
IEEE Clause 8.22

INTRODUCTION

The MDCL and moisture ingress test verifies the electrical and mechanical integrity of polymer-housed arresters is not compromised under significant thermal, mechanical and environmental stresses.

PROCEDURE

The MDCL and moisture ingress test was performed on a 98 kV MCOV SVNH arrester as described in Clause 8.22 of IEEE Standard C62.11-2012. Prior to mechanical testing, the arrester was subjected to electrical tests to determine watts loss at MCOV, partial discharge and discharge voltage at 10kA 8/20.

The test unit was subjected to thermomechanical preconditioning at the arresters MDCL of 178,500 in-lb (20.2 kNm). At the end of each period, the deflection at 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 measured.

The unit was immersed in boiling water for 42 hours. Electrical tests were repeated on the unit. The increase in watts loss cannot change more than 20% and discharge voltage cannot change more than 5%. Additionally, the internal partial discharge cannot exceed 10 pC.

RESULTS

Preliminary electrical tests were performed on one SVNH 98 kV MCOV arrester. Table 1 summarizes the results of those preliminary electrical tests.

Table 1: Results of initial measurements

Test Parameter	Result
Watts Loss at MCOV (W)	31.5
Discharge Voltage at 10 kA (kV_{peak})	258.9
Partial Discharge (pC) at 1.05*MCOV	<10

The unit was subjected to thermomechanical preconditioning at an MDCL of 178,500 in-lb (20.2 kNm). The maximum deflection under load was 0.844" and the residual deflection was 0.188". The unit was then subjected to 42 hours of immersion in boiling water. After 42 hour exposure the test samples were dried off and electrical tests were repeated. Results are shown in Table 2.

Table 2: Results of final measurements

Test Parameter	Result	Change from initial test
Watts loss at MCOV	34.8 W	+ 10.4%
Discharge voltage at 10 kA 8/20	258.9 kV	0 %
Partial discharge at 1.05 x MCOV	< 10 pC	N/A

CONCLUSION

The change in watts loss and residual voltage from the values initially measured were within the maximum allowed change of 20% and 5%, respectively. Additionally, partial discharge was found to be below the allowed limit of 10 pC. The SVNH design successfully passed the MDCL test, both mechanically and for moisture ingress, at an MDCL of 178,500 in-lb (20.2 kNm) according to Clause 8.22 of IEEE Standard C62.11-2012.