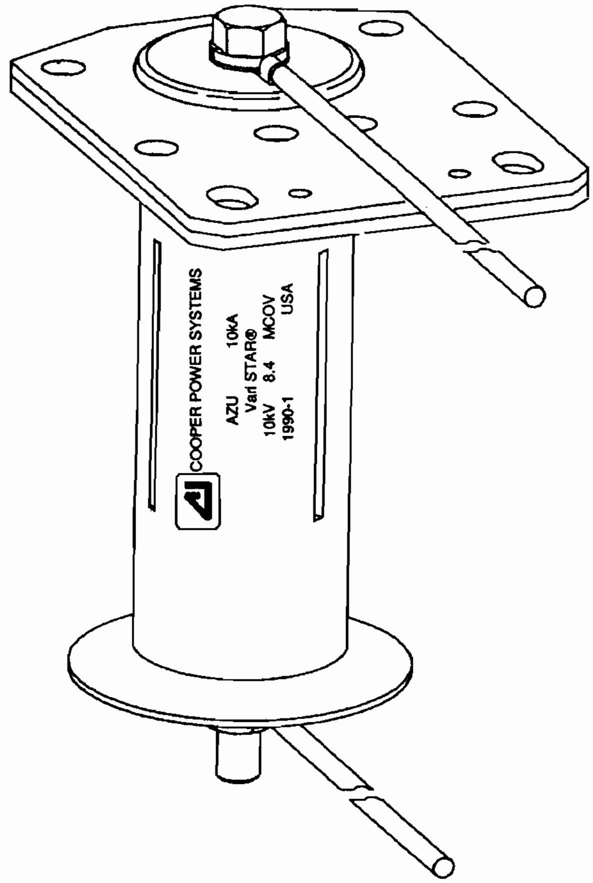
Surge Arresters

COOPER POWER SYSTEMS

VariSTAR® Type AZU Heavy Duty Distribution Class Underoil Surge Arrester Certified Design Test Report



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SECTION 1 - GENERAL INFORMATION

1.1 Purpose and Objectives Statement

The purpose of this document is to present certified design test data and a summary of physical and electrical characteristics of the McGraw-Edison VariSTAR® Type AZU Heavy Duty Distribution Class Underoil Surge Arrester.

1.2 Certification Statement

The design tests conducted and the data recorded in this document are presented in accordance with the sections of ANSI/IEEE Standard C62.11-1987 relevant to Heavy Duty Distribution Class Metal Oxide Surge Arresters.

The McGraw-Edison VariSTAR® Type AZU Heavy Duty Distribution Class underoil surge arresters rated 3 kV to 36 kV meet or exceed all applicable requirements of the above referenced standard as reported in the following sections of this document.

1.3 Summary Data

Tabulated below are summaries of the electrical and physical characteristics of the McGraw-Edison VariSTAR® Type AZU Heavy Duty Distribution Class underoil surge arresters rated 3 kV to 36 kV

TABLE 1
Protective Characteristics

Arrester Rating	MCOV	Front-of-Wave Protective Level*	Maximum Discharge Voltage 8/20 μs Current Wave						Switching Surge**
kV rms	kV rms	kV crest	1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA	kV crest
3	2.55	10.7	8.2	8.7	9.2	10.0	11.3	13.6	7.4
6	5.10	21.4	16.4	17.4	18.4	20.0	22.5	27.1	14.7
9	7.65	32.1	24.5	26.1	27.5	30.0	33.8	40.7	22.1
10	8.40	35.3	27.0	28.7	30.3	33.0	37.2	44.7	24.3
12	10.2	42.8	32.7	34.7	36.7	40.0	45.0	54.2	29.4
15	12.7	53.5	40.9	43.4	45.9	50.0	56.3	67.8	36.8
18	15.3	64.2	49.1	52.1	55.1	60.0	67.6	81.4	44.1
21	17.0	74.9	57.3	60.8	64.3	70.0	78.8	94.9	51.5
24	19.5	84.3	64.4	68.4	72.3	78.8	88.7	106.8	57.9
27	22.0	95.2	72.8	77.3	81.7	89.0	100.2	120.7	65.5
30	24.4	105.9	81.0	86.0	90.9	99.0	111.5	134.2	72.8
36	30.4	124.8	95.4	101.3	107.0	116.6	131.3	158.1	85.8

*Based on a 10 kA current impulse that results in a discharge voltage cresting in 0.5 μs
**45-60 μs rise time 500 A surge

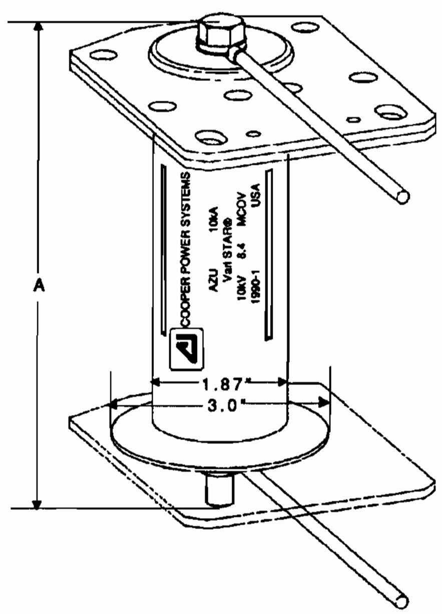

Figure 1
Arrester Diagram for Table 2

Table 2
Arrester Heights

Arrester Rating	Dimension A
kV rms	In
3	4.6
6	5.8
9	7.0
10	7.0
12	8.1
15	9.3
18	10.3
21	11.6
24	11.6
27	12.7
30	13.9
36	16.2

SECTION 2 - DESIGN TEST DATA

2.0 Definition of Terms

Surge Arrester - A protective device for limiting surge voltages on equipment by diverting surge current and returning the device to its original status. It is capable of repeating these functions as specified.

Metal-Oxide Surge Arrester (MOSA) - A surge arrester utilizing valve elements fabricated from nonlinear resistance metal oxide materials.

Duty-cycle Voltage Rating -The designated maximum permissible voltage between terminals at which the arrester is designed to perform its duty cycle.

Maximum Continuous Operating Voltage (MCOV) -The maximum designated root-mean-square (rms) value of power frequency voltage that may be applied continuously between the terminals of the arrester.

Prorated Section - A complete, suitably housed part of an arrester, comprising all necessary components, including gaseous medium, in such a proportion as to accurately represent, for a particular test, the characteristics of a complete arrester.

Arrester Disconnector - A means for disconnecting an arrester in anticipation of, or after a failure in order to prevent a permanent fault on the circuit.

Design Tests - Tests made on each design to establish the performance characteristics and to demonstrate compliance with the appropriate standards of the industry. Once made they need not be repeated unless the design is changed so as to modify performance.

Certification Tests - Tests run on a regular periodic basis to verify that selected, key performance characteristics of a product or representative samples thereof have remained within performance specifications.

Routine Tests - Tests made by the manufacturer on every device or representative samples, or on parts or materials, as required, to verify that the product meets the design specifications.

Waveshape Designation - (1) The wave shape of an impulse (other than rectangular) of a current or voltage is designated by a combination of two numbers. The first, an index of the wave front, is the virtual duration of the wave front in microseconds. The second, an index of the wave tail, is the time in microseconds from the virtual zero to the instant at which one-half of the crest value is reached on the wave tail. Examples are 1.2/50 and 8/20 μs waves.

- (2) The wave shape of a rectangular impulse of current or voltage is designated by two numbers. The first designates the minimum value of the current or voltage that is sustained for the time in microseconds designated by the second number. An example is 75 A 2000 μs wave.

Reference Current -The reference current (Iref) of an arrester is the peak value of the resistive component of the power frequency current used to determine the reference voltage (Vref) of an arrester. The reference current is high enough to make the effects of stray capacitance on the measured voltage negligible.

Reference Voltage - The reference voltage of an arrester is the highest peak value of the power frequency voltage, independent of polarity, divided by the square root of two, measured at the reference current of the arrester.

Temporary Overvoltage - A temporary overvoltage is defined as an excursion of power frequency voltage above the normal line-to-ground value. Such excursions are of variable magnitude and duration.

2.1 Arrester Insulation Withstand Tests ANSI/IEEE C62.11-1987; Section 8.1

2.1.1 INSULATION WITHSTAND TEST DESCRIPTION

The voltage withstand tests of arrester insulation demonstrate that the insulation of the arrester is above the minimum specified levels given in Table 2 of the referenced section of the ANSI/IEEE C62.11-1987 standard.

2.1.2 INSULATION WITHSTAND TEST PROCEDURE

New, clean arresters of each rating, with internal parts removed, were mounted underoil in a distribution transformer and subjected to positive and negative 1.2/50 µs withstand tests. 60 Hz wet and dry withstand tests are not applicable to the underoil arrester.

2.1.3 INSULATION WITHSTAND TEST EVALUATION

Table 3 lists the actual withstand voltage values determined from testing. The measured insulation withstand voltages meet or exceed the standard specified values for all arrester ratings when arresters are mounted at least 0.9 inches from the nearest ground plane in the transformer tank.

TABLE 3
Insulation Withstand Voltages

Arrester Rating	Insulation Withstand Voltage 1.2/50 µs
kV rms	kV crest
3	170
6	170
9	170
10	170
12	170
15	170
18	170
21	170
24	170
27	170
30	170
36	170

2.2 Discharge Voltage Characteristics ANSI/IEEE C62.11-1987; Section 8.3

2.2.1 DISCHARGE VOLTAGE TEST DESCRIPTION

The discharge voltage tests serve to establish the relation between the voltage across the arrester terminals and the discharge current at several values of discharge current of specified waveshape.

2.2.2 DISCHARGE VOLTAGE TEST PROCEDURES

Discharge voltage measurements were made on new 9 kV arresters randomly selected and subjected to an 8/20 current wave at 1.5, 3, 5, 10, 20 and 40 kA. Each test was performed in compliance with the referenced section of the ANSI/IEEE C62.11-1987 standard.

Front-of-wave protective level tests were performed on new 9 kV, randomly selected, arresters. Each arrester was subjected to 8/20, 2/4 and 1/2 µs current waves at 10 kA. A front-of-wave protective level corresponding to a discharge voltage cresting at 0.5 µs was extrapolated from this data.

2.2.3 DISCHARGE VOLTAGE TEST EVALUATION

Figures 2 & 3 show typical test current and measured voltage oscillograms for discharge voltage tests at 10 and 20 kA.
Figure 4 shows a typical curve for determining the the front-of-wave protective level from discharge voltage versus time to voltage crest tests.

The curves in Figures 5 and 6 show the minimum and maximum discharge voltage versus impulse current for 10, 18 and 27 kV arrester ratings.
Tables 4 and 5 present the tabulated values for the minimum and maximum discharge voltage respectively and the front-of-wave protective level for each arrester rating.

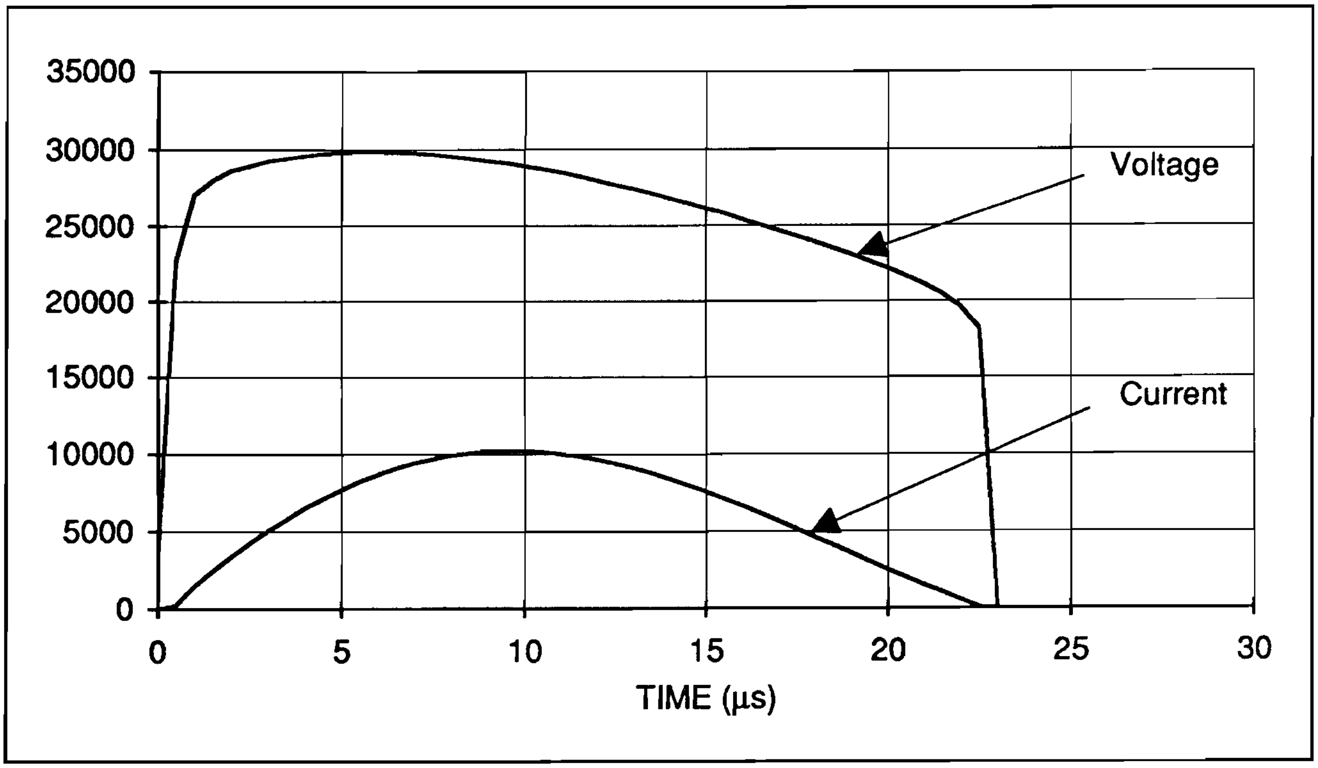

Figure 2
10 kA, 8/20 µs Discharge Voltage for AZU

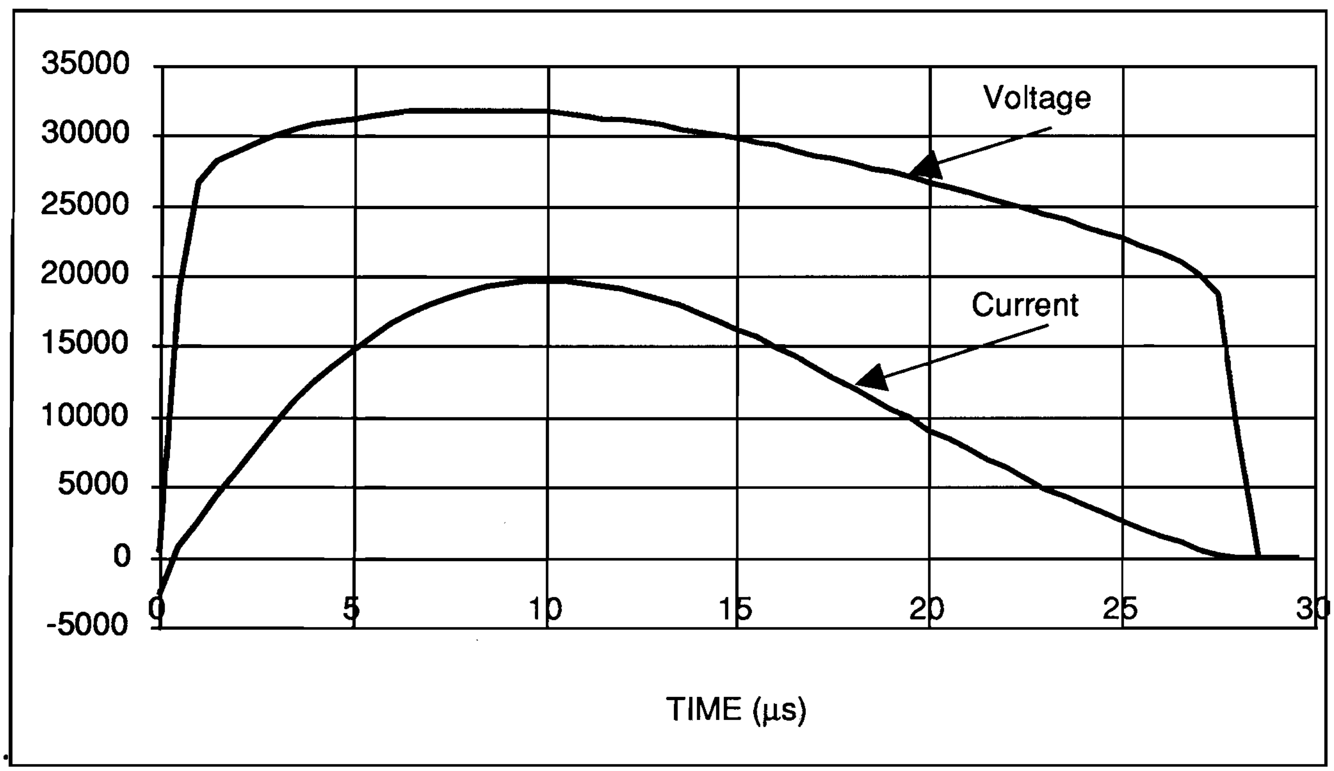

Figure 3
20 kA, 8/20 µs Discharge Voltage for AZU

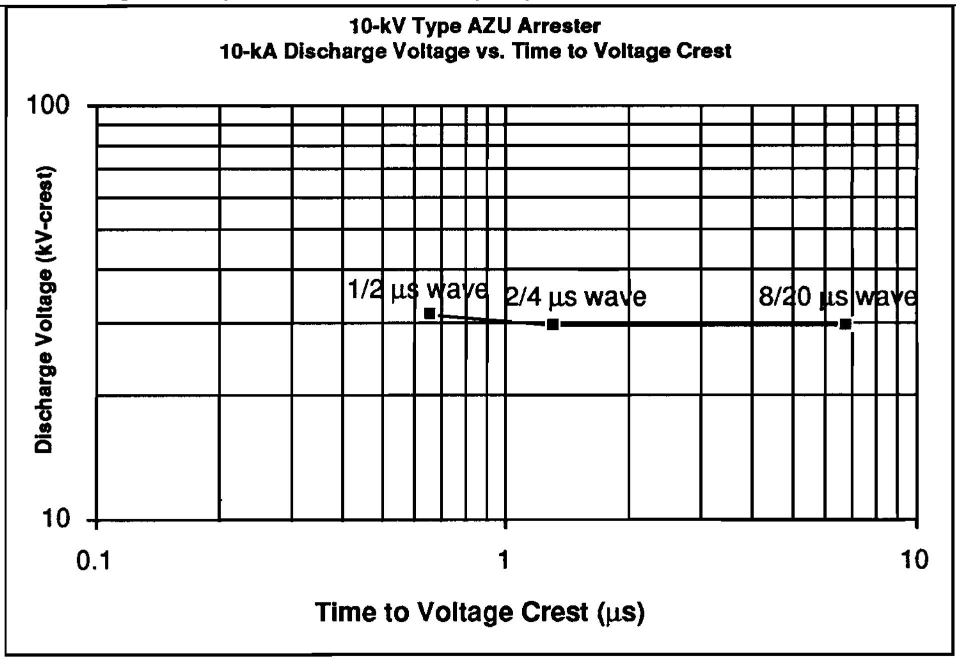

Figure 4
Fast Front Discharge Voltages

TABLE 4
Protective Characteristics-Minimum values

Arrester Rating	MCOV	Front-of-Wave Protective Level*	Minimum Discharge Voltage 8/20 µs Current Wave						Switching Surge**
kV rms	kV rms	kV crest	1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA	kV crest
3	2.55	9.7	7.3	7.8	8.2	9.0	10.0	12.1	6.6
6	5.10	19.3	14.7	15.6	16.5	18.1	20.0	24.3	13.2
9	7.65	29.0	22.0	23.3	24.7	27.1	30.0	36.4	19.8
10	8.40	32.2	24.4	25.9	27.4	30.1	33.3	40.4	22.0
12	10.2	38.7	29.3	31.1	32.9	36.1	40.0	48.5	26.5
15	12.7	48.3	36.7	38.9	41.2	45.2	50.0	60.7	33.1
18	15.3	58.0	44.0	46.7	49.4	54.2	60.0	72.8	39.7
21	17.0	67.7	51.3	54.4	57.7	63.3	70.0	84.9	46.3
24	19.5	77.9	59.1	62.7	66.4	72.8	80.5	97.8	53.3
27	22.0	87.4	66.3	70.3	74.5	81.7	90.4	109.7	59.8
30	24.4	96.6	73.3	77.7	82.3	90.3	99.8	121.2	66.1
36	30.4	115.3	87.5	92.8	98.2	107.8	119.2	144.7	78.9

* Based on a 10 kA current impulse that results in a discharge voltage cresting in 0.5 µs
**45-60 µs rise time 500 A current surge.

TABLE 5
Protective Characteristics-Maximum values

Arrester Rating	MCOV	Front-of-Wave Protective Level*	Maximum Discharge Voltage 8/20 µs Current Wave						Switching Surge**
kV rms	kV rms	kV crest	1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA	kV crest
3	2.55	10.7	8.2	8.7	9.2	10.0	11.3	13.6	7.4
6	5.10	21.4	16.4	17.4	18.4	20.0	22.5	27.1	14.7
9	7.65	32.1	24.5	26.1	27.5	30.0	33.8	40.7	22.1
10	8.40	35.3	27.0	28.7	30.3	33.0	37.2	44.7	24.3
12	10.2	42.8	32.7	34.7	36.7	40.0	45.0	54.2	29.4
15	12.7	53.5	40.9	43.4	45.9	50.0	56.3	67.8	36.8
18	15.3	64.2	49.1	52.1	55.1	60.0	67.6	81.4	44.1
21	17.0	74.9	57.3	60.8	64.3	70.0	78.8	94.9	51.5
24	19.5	84.3	64.4	68.4	72.3	78.8	88.7	106.8	57.9
27	22.0	95.2	72.8	77.3	81.7	89.0	100.2	120.7	65.5
30	24.4	105.9	81.0	86.0	90.9	99.0	111.5	134.2	72.8
36	30.4	124.8	95.4	101.3	107.0	116.6	131.3	158.1	85.8

* Based on a 10 kA current impulse that results in a discharge voltage cresting in 0.5 µs
**45-60 µs rise time 500 A current surge.

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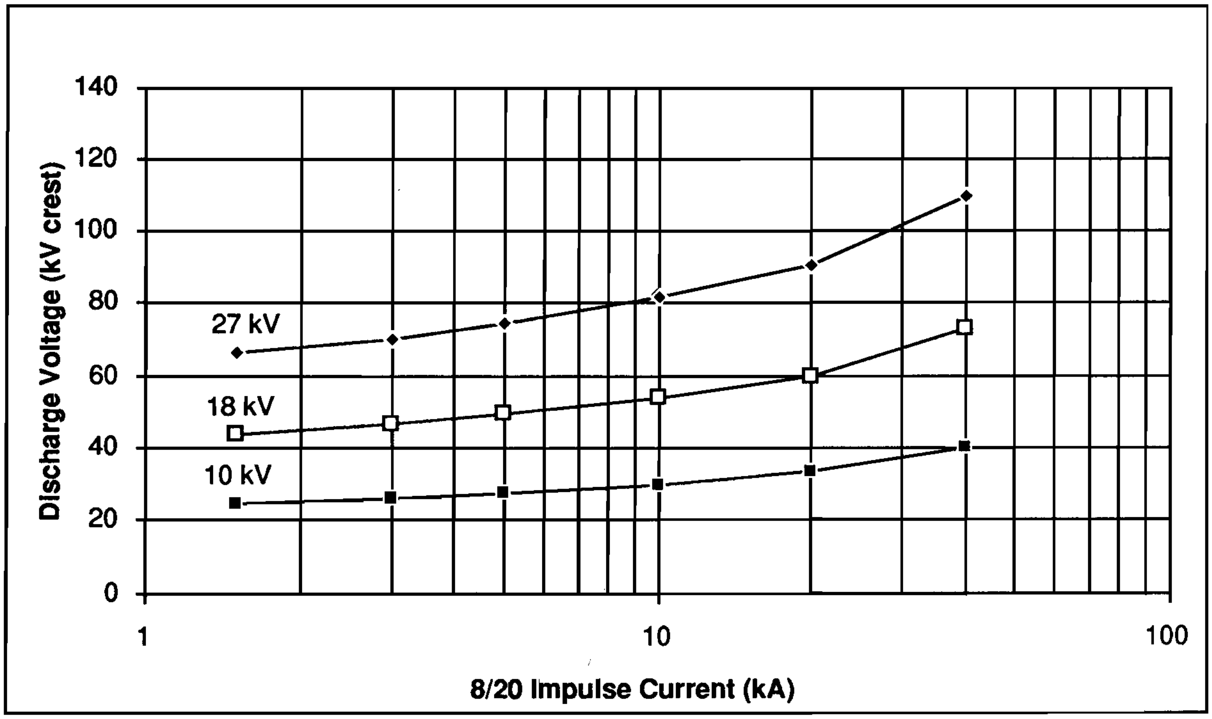


Figure 5
Minimum Discharge Voltage vs 8/20 Impulse Currents

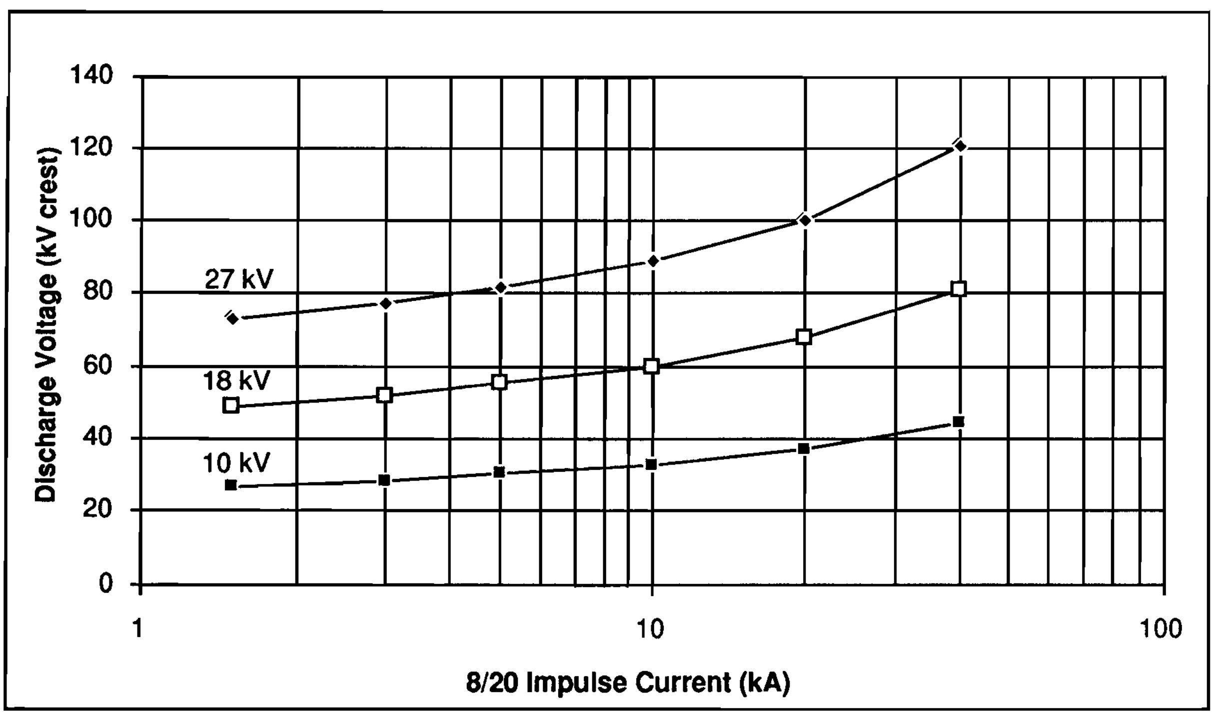


Figure 6
Maximum Discharge Voltage vs 8/20 Impulse Currents

2.3 Accelerated Aging Procedure

ANSI/IEEE C62.11-1987; Section 8.5

2.3.1 ACCELERATED AGING TEST DESCRIPTION

The accelerated aging test procedure provides a method to simulate the long-term effect of voltage and temperature on design parameters significant to the arrester performance. It is not a test in itself and has no evaluation procedure. It is an aging procedure from which voltage ratios are obtained for use in duty-cycle and discharge current withstand tests to simulate the performance of arresters as if they had been in service for an extended period. Standards currently requires a test period of 1000 hrs. at 115 °C, but due to the operating conditions of the AZU, the test in this case has been lengthened to 7000 hrs and samples were all submerged in transformer oil for the entire test sequence.

2.3.2 ACCELERATED AGING TEST PROCEDURE

Three typical AZU MOV elements were submerged in 115 °C transformer oil and energized at their MCOV. The maximum watts loss of each specimen was measured at MCOV and rated voltage during the first two to five hours of the test and at the conclusion of 7000 hours of continuous testing.

2.3.3 ACCELERATED AGING TEST EVALUATION

If the voltage ratios determined during this test are greater than 1.0, then the voltages used for duty-cycle and discharge current withstand tests must be adjusted accordingly.

Since all final watts loss values were lower than the initial watts loss values the voltage ratios (Kc & Kr) are equal to 1.0, therefore no test voltage adjustments need to be made for duty-cycle or discharge current withstand tests.

Figure 7 illustrates the watts loss curves for the three AZU MOV elements at MCOV for the 7000 hour duration of the test. The data is also tabulated in Table 6.

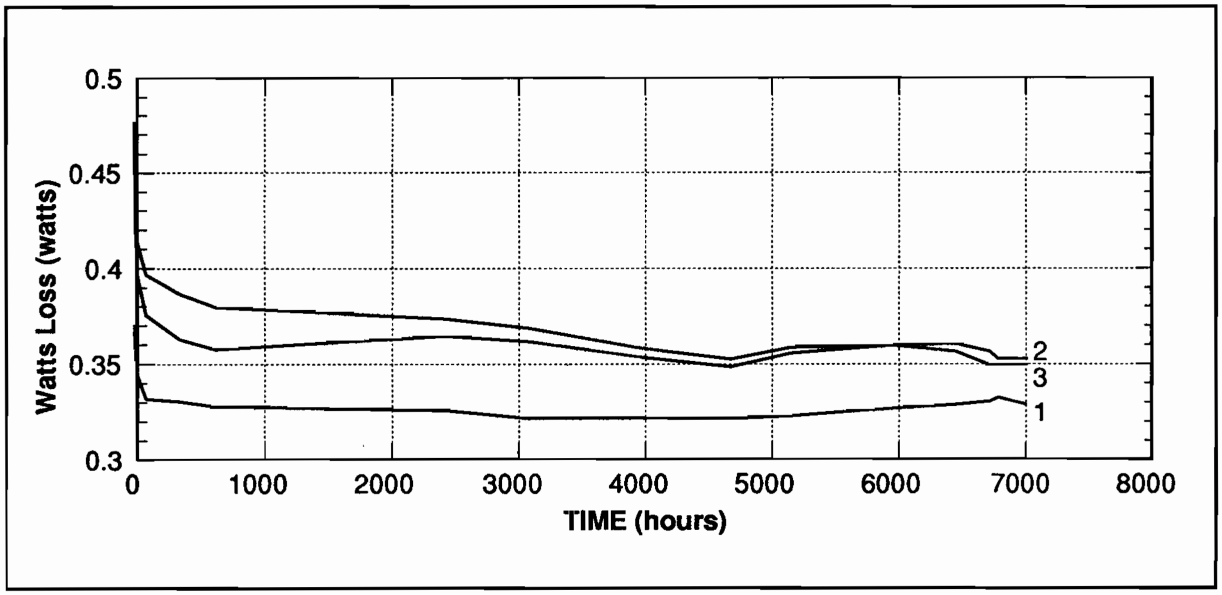


Figure 7 - Typical Accelerated Aging Test at MCOV - Watts Loss vs. Time at 115 °C

TABLE 6
Accelerated Aging Test Summary at 115 °C

Test Voltage	MCOV			Rated		
Disk Number	1	2	3	1	2	3
Watts @ 2.5 hr.	.37	.45	.48	.85	1.2	1.2
Watts @ 7000hr.	.33	.36	.35	.77	.95	.95
K Value	Kc=1			Kr=1		

Section 2.4 Discharge-Current Withstand Tests ANSI/IEEE C62.11-1987; Section 8.6

2.4.1 DISCHARGE-CURRENT WITHSTAND TEST DESCRIPTION

The discharge current withstand tests, consisting of high-current, short-duration and low-current, long-duration tests, serve to demonstrate the adequacy of the electrical, mechanical and thermal design of the arrester.

2.4.2 DISCHARGE-CURRENT WITHSTAND TEST PROCEDURES

2.4.2.1 High-Current, Short-Duration

Three 9 kV AZU arresters submerged in 80 °C transformer oil were subjected to two 4/10 µs impulse current waves having 100 kA-crest amplitude. Within five minutes of the second discharge each arrester was energized at MCOV and the power monitored for thirty (30) minutes as prescribed in Section 8.6.1.2 of the referenced standard. An applied voltage greater than MCOV was not necessary since the voltage ratios determined in the accelerated aging tests were less than 1.0.

The discharge voltage of each arrester measured with a 10 kA-crest, 8/20 µs current wave was determined before and after the high-current, short-duration current withstand test.

2.4.2.2 Low-Current, Long-Duration

Three 9 kV AZU arresters submerged in 80 °C transformer oil were subjected to a minimum 250 A 2000 µs rectangular current wave. The test current waves were applied in three groups of six operations followed by one group of two operations for a total of twenty (20) operations with a one minute interval between successive operations throughout the test. Specimens were allowed to cool to ambient temperature between the groups of operations. Prior to the 19th operation the arrester temperature was equilibrated at 120 °C. Within five minutes of the 20th operation the arrester was energized at MCOV and the power monitored for thirty (30) minutes as prescribed in Section 8.6.2.1.3 of the referenced standard. An applied voltage greater than MCOV was not necessary since the voltage ratios determined in the accelerated aging tests were less than 1.0.

The discharge voltage of each arrester measured with a 10 kA-crest, 8/20 µs current wave was determined before and after the low-current, long-duration withstand test.

2.4.3 DISCHARGE-CURRENT WITHSTAND TEST EVALUATION

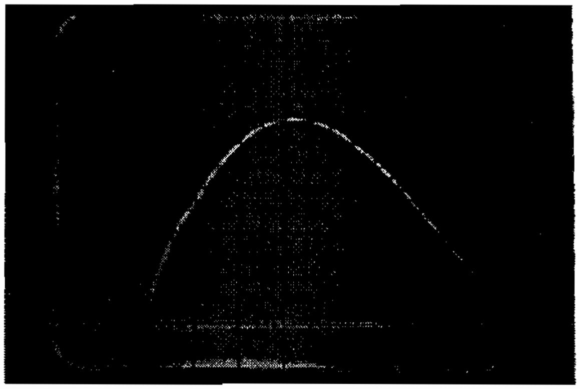
2.4.3.1 High-Current, Short-Duration

The oscilligrams in Figures 8 and 9 show the typical pairs of current and voltage traces for the first and second high current, short-duration operations for a 9 kV AZU surge arrester.

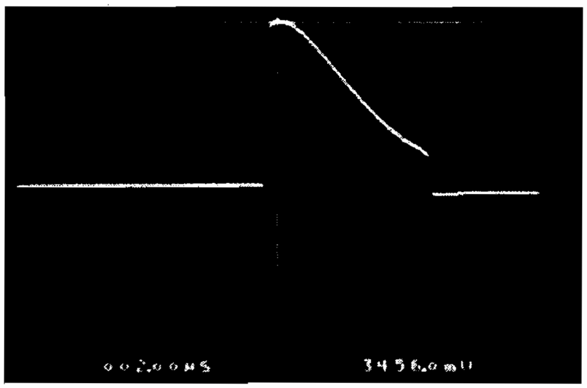
The arresters pass this design test based on the fact that each arrester exhibited thermal recovery by demonstrating continuously decreasing power values over the thirty (30) minute monitoring after the current withstand test. This is illustrated in Table 7.

TABLE 7
High-Current, Short-Duration Test Summary

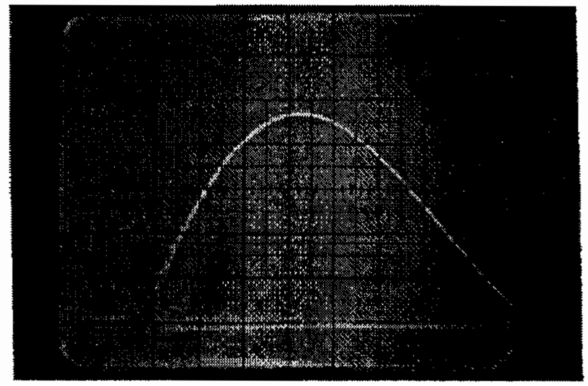
Arester	100 kA Discharge Voltage(4/10 µs)		10 kA Discharge Voltage(8/20 µs)		Watts Loss @ MCOV	
Rating	1st shot	2nd shot	Before 100 kA	After 100 kA	Initial	30 Min.
kV rms	kV crest	kV crest	kV crest	kV crest	Watts	Watts
9	68.5	70.8	29.6	29.4	5.4	2.0
9	70.8	68.8	29.3	28.5	4.2	1.9
9	69.6	73.4	29.2	28.8	4.5	3.6



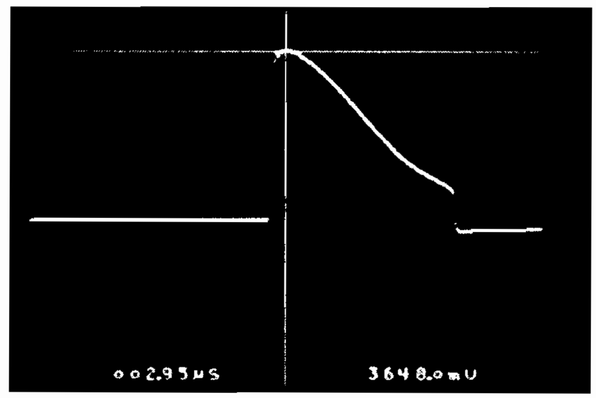
4/10 Current Wave



Voltage Wave (69.7 kV)



4/10 Current Wave



Voltage Wave (73.4 kV)

Figure 8
1st High Current Short Duration (100 kA) operation

Figure 9
2nd High-Current, Short Duration (100kA) operation

2.4.3.2 Low-Current, Long-Duration

Typical oscilligrams in Figures 10 and 11 show the corresponding pairs of current and voltage traces for the first and twentieth low-current, long-duration operations for a 9 kV AZU surge arrester.

The arresters pass this design test based on the performance criteria listed below:

1. Each arrester exhibited thermal recovery by demonstrating continuously decreasing power values over the thirty (30) minute monitoring after the current withstand test. This is illustrated in Table 8.

2. There was no evidence of physical or electrical deterioration caused by the current withstand tests.

3. The 10 kA (8/20 μs) discharge voltages measured after the low-current, long-duration test remained essentially unchanged from the initial values as shown in Table 8.

TABLE 8
Low-Current, Long-Duration Test Summary

Arrester Rating	250 A 2000 μs			10 kA Discharge Voltage (8/20 μs)		Watts Loss @ MCOV	
	1st Discharge	19th * Discharge	20th Discharge	Before LCLD	After LCLD	Initial	30 Min.
kV rms	kV crest	kV crest	kV crest	kV Crest	kV Crest	Watts	Watts
9	20.8	21.0	21.1	29.2	28.8	2.4	1.4
9	20.7	20.9	21.0	29.3	28.8	2.0	1.1
9	20.9	21.0	21.2	29.3	28.8	2.3	1.3

* - Temperature was equilibrated at 120 °C before the 19th discharge

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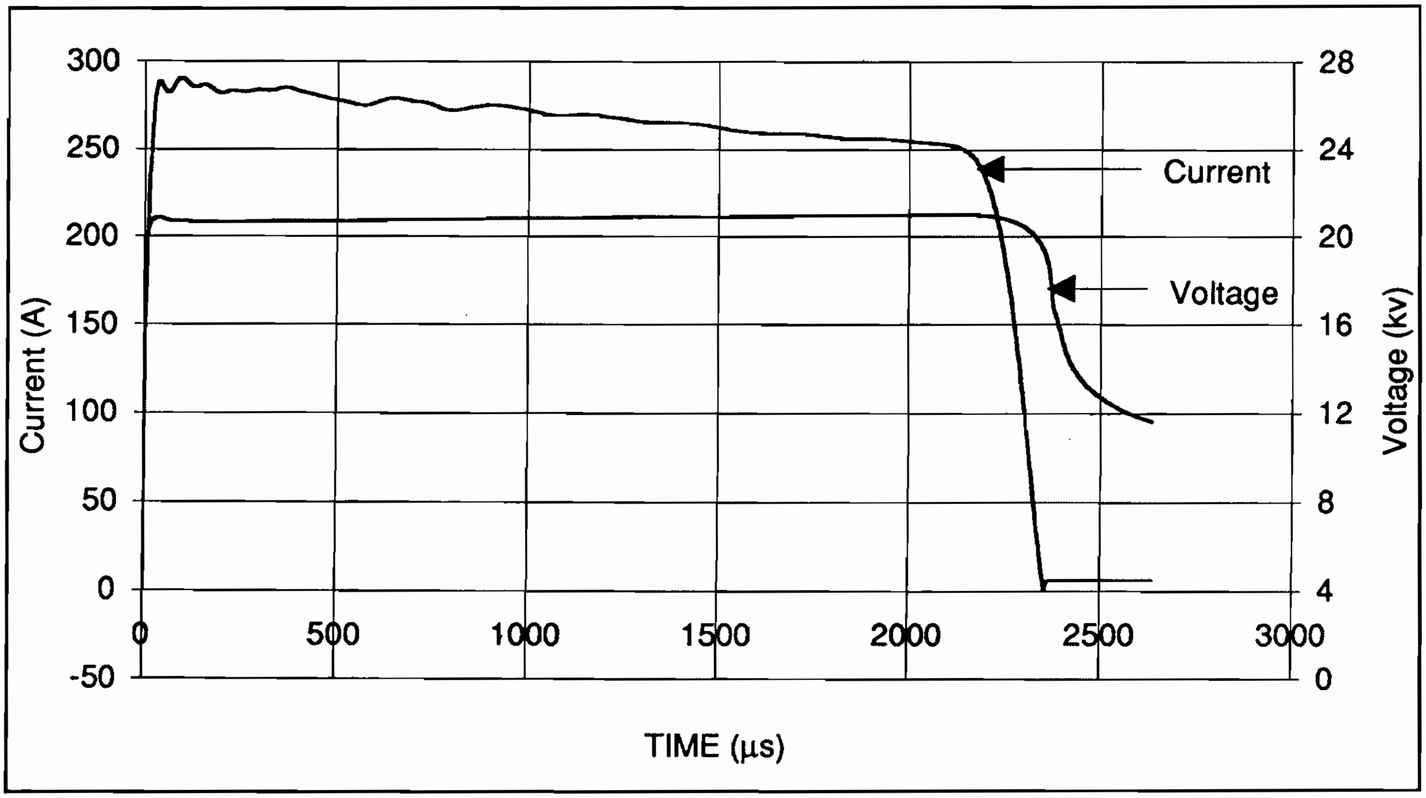

Figure 10
1st Low-Current, Long Duration Operation (250 A 2000 µs)

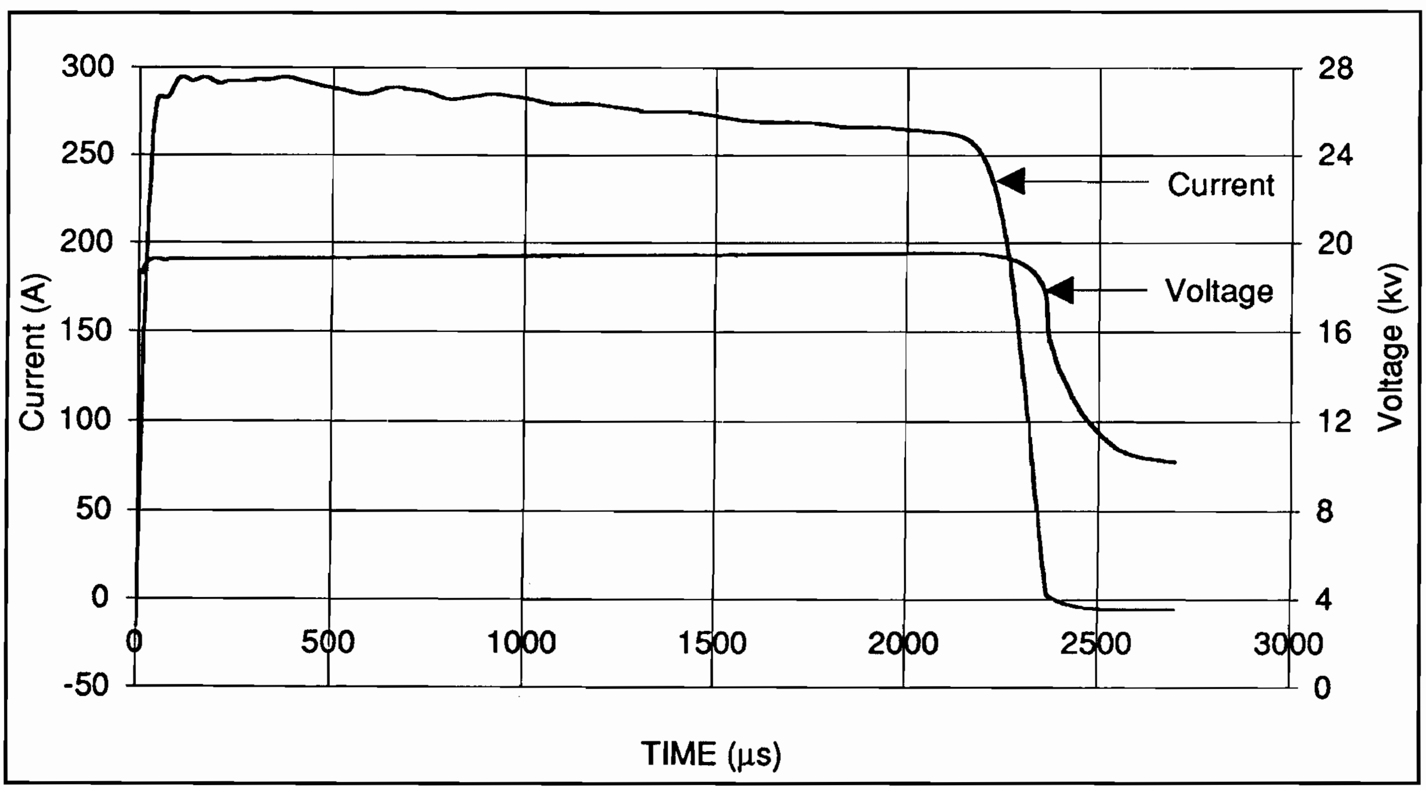

Figure 11
20th Low-Current, Long Duration Operation (250 A 2000 µs)

2.5 Duty-Cycle Test

ANSI/IEEE C62.11-1987; Section 8.7

2.5.1 DUTY-CYCLE TEST DESCRIPTION

The duty-cycle test serves to establish the ability of the arrester to discharge impulse current repeatedly while energized at duty-cycle voltage and thermally recover at MCOV.

2.5.2 DUTY-CYCLE TEST PROCEDURE

Three 9 kV AZU arresters submerged in 80°C transformer oil were subjected to twenty (20) operations of a 10 kA 8/20 µs current wave while being continuously energized at rated power frequency voltage. The current wave crest, initiation was approximately 60 degrees before the crest of the power frequency voltage and was applied at one minute intervals.

Following the twentieth operation the oil temperature was raised to 120°C and each arrester was energized at MCOV and further subjected to two 40 kA, 8/20 µs current waves with a one minute interval between operations. After the 40 kA operations the arrester remained energized at MCOV and the power monitored for thirty (30) minutes.

The 10 kA-crest, 8/20 µs discharge voltage was measured before the operating duty-cycle test and again when the arresters had returned to ambient temperature subsequent to the operating duty-cycle test.

2.5.3 DUTY-CYCLE TEST EVALUATION

Figures 12 and 13 show typical oscillograms of the corresponding pairs of the current and voltage traces after the first and twentieth 10 kA duty-cycle operations respectively.

Figures 14 and 15 present similar data for after each of the 40 kA duty-cycle operations.

The data presented in the above figures is also in Table 9 for both the 10 kA and 40 kA duty-cycle tests.

The arresters pass this design test based on the performance criteria listed below:

1. Each arrester exhibited thermal recovery by demonstrating continuously decreasing power values over the thirty (30) minute monitoring after the operating duty-cycle test. This is illustrated in Table 9.

2. There was no evidence of physical or electrical deterioration caused by the operating duty-cycle test.

3. The 10 kA (8/20 µs) discharge voltages measured after the duty-cycle test remained essentially unchanged from the initial values as shown in Table 9.

TABLE 9
Operating Duty-Cycle Test Summary

Arrester Rating	20, 10kA Discharges at ODC Rating Watts Loss			2, 40 kA Discharges at MCOV Watts Loss			10 kA Discharge Voltage (8/20 µs)	
kV rms	Initial	1st Discharge	20th Discharge	21st Discharge	22nd Discharge	After 30 min.	Before ODC kV crest	After ODC kV crest
9	3.2	3.9	8.6	.63	5.5	.84	28.9	29.1
9	1.1	1.6	10.7	1.5	10.5	.81	28.8	28.8
9	1.2	2.1	10.4	2.9	13.7	.63	28.9	28.8

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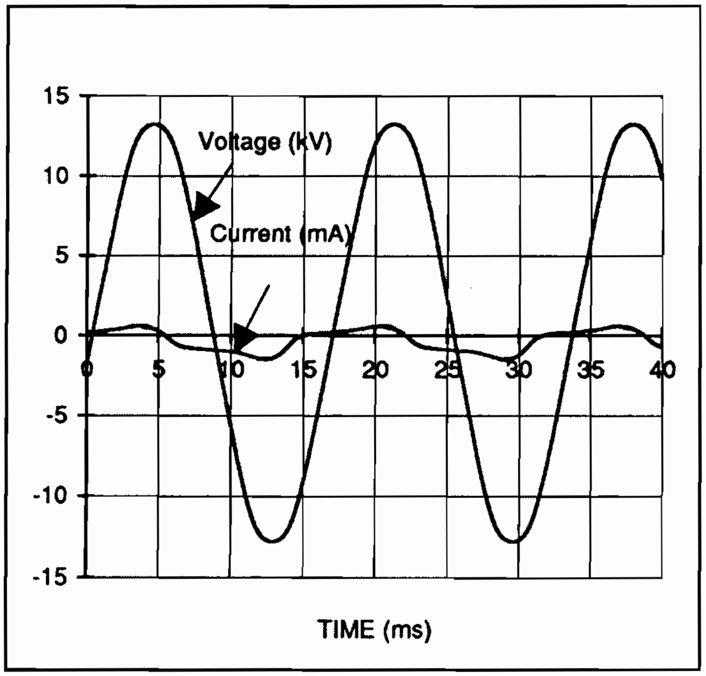

Figure 12
1st Operating Duty-Cycle Operation

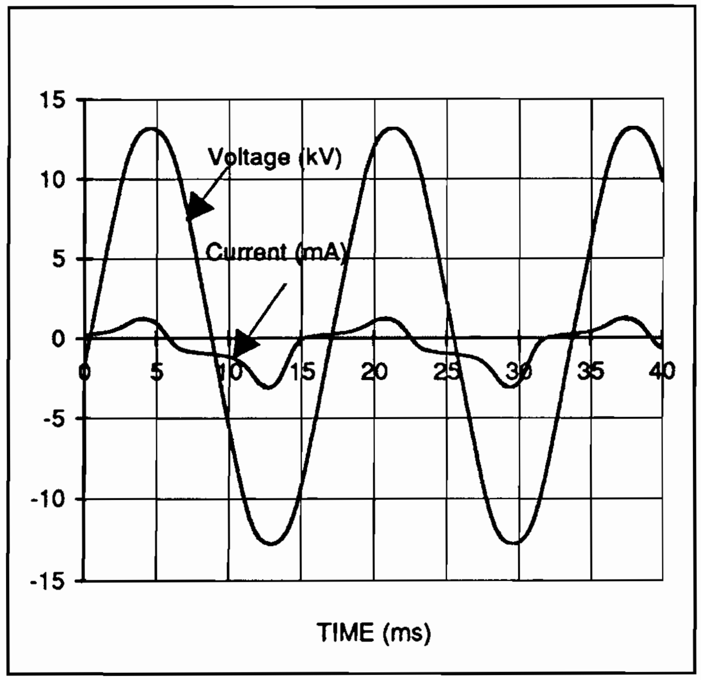

Figure 13
20th Operating Duty-Cycle Operation

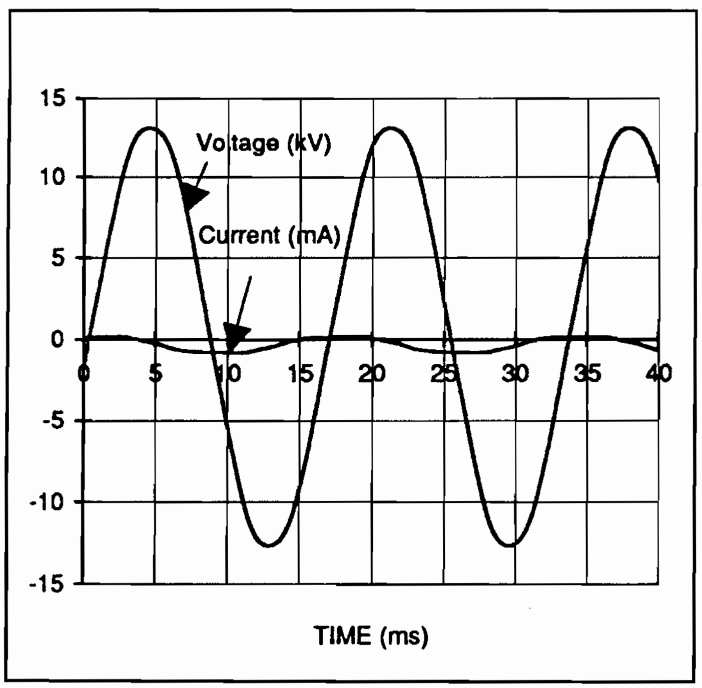

Figure 14
21st Operating Duty-Cycle Operation

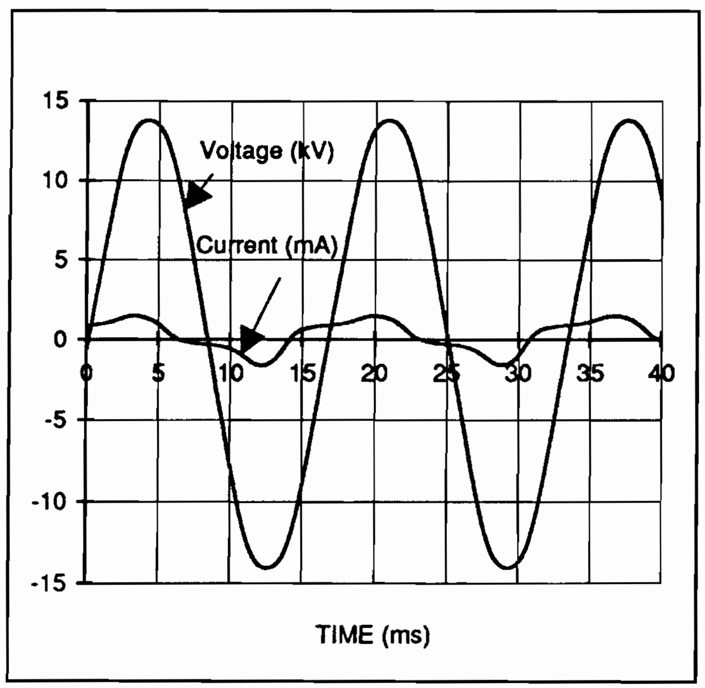

Figure 15
22nd Operating Duty-Cycle Operation

2.6 Internal-Ionization Voltage and Radio-Influence Voltage

ANSI/IEEE C62.11-1987; Section 8.8 and NEMA LA-1-1986

2.6.1 INTERNAL-IONIZATION VOLTAGE AND RADIO-INFLUENCE VOLTAGE TEST DESCRIPTION

The internal-ionization voltage test provides a measure of ionization current present within an arrester design. This may cause deterioration of internal arrester parts. The radio-influence voltage (RIV) test provides a measure of externally generated "noise" which would be a nuisance to communication equipment.

2.6.2 INTERNAL-IONIZATION VOLTAGE AND RADIO-INFLUENCE VOLTAGE TEST PROCEDURES

Arresters of each rating were selected and energized at the specified voltage and the internal-ionization voltage and RIV measured.

2.6.3 INTERNAL-IONIZATION VOLTAGE AND RADIO-INFLUENCE VOLTAGE TEST EVALUATION

The measured internal-ionization voltage and RIV values do not normally exceed ambient background values and therefore are less than the maximum specified values listed in Table 12.

TABLE 12
Internal-Ionization and Radio-Influence Voltages

Arrester Rating	Test Voltage	Max. Spec. Internal Ionization	Max. Spec. RIV
kV rms	kV rms	μV	μV
3	3.54	50	250
6	7.07	50	250
9	10.6	50	250
10	11.8	50	250
12	14.1	50	250
15	17.7	50	250
18	21.2	50	250
21	24.7	50	250
24	28.3	50	250
27	31.8	50	250
30	35.3	50	250
36	42.4	50	250

The AZU arrester is 100% tested at the prescribed voltage. The total RIV for a typical arrester does not normally exceed ambient background values.

2.7 Temporary Overvoltage Tests

2.7.1 TEMPORARY OVERVOLTAGE TEST DESCRIPTION

Although this is not a test prescribed or described by the ANSI/IEEE standard, it is none the less an important test to establish a power frequency voltage-time curve that demonstrates an arresters ability to successfully discharge current, while experiencing an overvoltage excursion in power frequency voltage, without thermal run away.

2.7.2 TEMPORARY OVERVOLTAGE TEST PROCEDURES

The temporary overvoltage capability of the Type AZU Distribution Arrester is shown by the curve in Figure 16. The curve was established by applying power frequency voltages to preheated (to 100 °C) test samples, above their duty cycle rating, for various times between 0.1 and 10,000 seconds. The test overvoltage was reduced to the sample MCOV, within 200 ms, prior to thermal run-away failure. The area under the curve is the voltage-time characteristic in which the samples demonstrated thermal stability during a thirty (30) minute monitoring period, with a final watts-loss equal to or less than their original value.

2.7.3 TEMPORARY OVERVOLTAGE TEST EVALUATION

Figure 16 illustrates the temporary overvoltage capability of the McGraw-Edison VariSTAR® Type AZU Arrester.

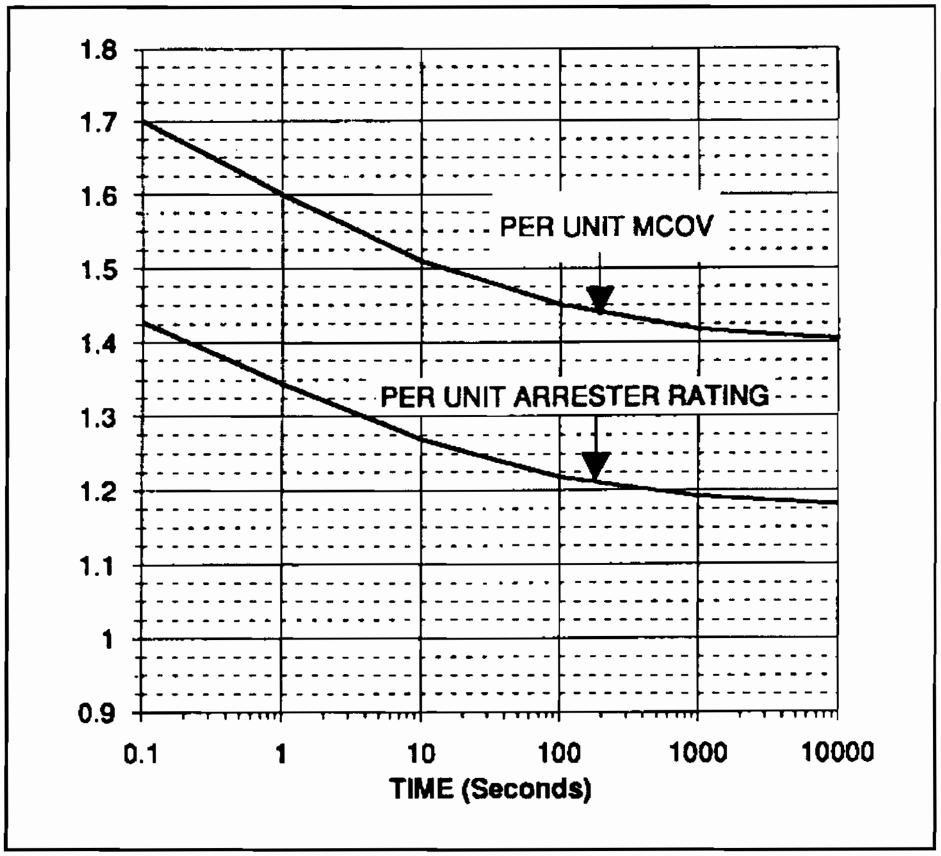

Figure 16
Temporary Overvoltage Capability of McGraw-Edison VariSTAR® Type AZU Arrester.