Analysis of Short-Circuit Testing Methods for Distribution-Class Surge Arresters

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1. Research Background

Distribution-class surge arresters play a critical role in power systems, primarily protecting equipment from overvoltage caused by lightning strikes. When a surge arrester fails, it may generate short-circuit currents and explode, posing risks to nearby equipment and personnel. To ensure the arrester's safety during failure and the system's stable operation, it is essential to conduct short-circuit testing during the type test phase of surge arresters.

International standards such as IEEE C62.11 and IEC 60099-4 clearly define short-circuit testing for surge arresters under different conditions. Our distribution system widely employs Design B polymer-housed surge arresters (Material Specification Code: $C045_{(105\text{-}01)}$). To validate the safety of these arresters in case of failure, it is crucial to perform short-circuit testing according to IEEE and IEC standards(fig.1-3).

This research aims to analyze the short-circuit testing methods outlined in current standards and assess the feasibility of conducting such tests in our research institute's short-circuit testing laboratory.

2. Research Findings

This research primarily focuses on analyzing short-circuit tests in accordance with the following standards: IEEE C62.11 (2020) Section 8.1 and IEC 60099-4 (2014) Sections 8.10 and 10.8.10.

(1) Testing Standards' Requirements for the Test Setup:

A. Installation Requirements: The arrester installation should closely replicate actual service conditions, and the wiring layout should account for the effects of Lorentz forces on the test specimen.

B. Fence Material: The fence must be made of non-metallic materials and can be circular or square. The diameter or side length (in meters) of the fence should be:

(A) For IEC arresters: Max(1.8, 1.2 × (2 × H + Darr))

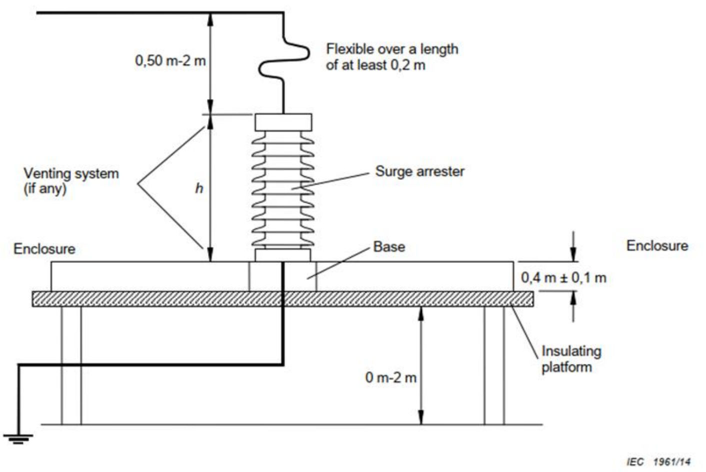
(B) For IEEE arresters: Max(1.8, 2 × H + Darr)

D is the fence diameter or side length, H is the arrester's height (in meters), and Darr is the arrester's diameter (in meters).

(2) IEEE Standards' Requirements for Surge Arrester Short-Circuit Test Currents:

A. Rated Short-Circuit Current and Reduced Short-Circuit Current: The test current's total duration should equal or exceed 0.2 seconds.

B. Low Short-Circuit Current Test: The current is measured approximately 0.1 seconds after it starts flowing through the arrester. After the fuse blows, the current should continue for at least 1 second.



Source: According to IEC 60099-4

Figure 1. The surge arrester short-circuit test wiring configuration

Table 14—Short-circuit symmetrical test currents for station, intermediate and distribution arresters

Arrester class	Rated short-circuit current (I_s)	Reduced short-circuit current [a]		Low short-circuit current with a duration of 1 s
	A rms	A rms		A rms
No. of test samples	1	1	1	1
Station	80 000	50 000	25 000	600 ± 200
Station	63 000	25 000	12 000	600 ± 200
Station and intermediate	50 000	25 000	12 000	600 ± 200
Station and intermediate	40 000	25 000	12 000	600 ± 200
Intermediate	31 500	12 000	6 000	600 ± 200
Intermediate	20 000	12 000	6 000	600 ± 200
Intermediate	16 100	6 000	3 000	600 ± 200
Distribution	Not less than maximum claimed	0.5 ± 0.05 times maximum claimed	0.25 ± 0.05 times maximum claimed	600 ± 200

NOTE 1—Test values for arresters with porcelain tops have not been standardized.
NOTE 2—If an existing arrester is qualified for one of the rated short-circuit currents in this table, it is deemed to have passed the test for any value of rated current lower than this one.

Source: Defined by IEEE C62.11

Figure 2. The surge arrester short-circuit test current

Table 13—Test requirements

	Required number of test samples	Initiation of short-circuit current	Ratio of first current peak value to rms value of required short-circuit current taken from Table 14					
			Test voltage: MCOV or higher			Test voltage: below MCOV		
			Rated short-circuit current	Reduced short-circuit current	Low short-circuit current	Rated short-circuit current	Reduced short-circuit current	Low short-circuit current
"Design A" Porcelain	4	Fuse wire along surface of metal-oxide disks; within or as close as possible to the gas channel	Prospective: ≥ 2.5 Actual: no requirement	Prospective: ≥ $\sqrt{2}$ Actual: no requirement	Actual: ≥ $\sqrt{2}$	Actual: ≥ 2.5	Actual: ≥ $\sqrt{2}$	Actual: ≥ $\sqrt{2}$
"Design A" Polymer-housed	4 *or* 5	Fuse wire along surface of metal-oxide disks; within or as close as possible to the gas channel	Prospective: ≥ 2.5 Actual: no requirement	Prospective: ≥ $\sqrt{2}$ Actual: no requirement	Actual: ≥ $\sqrt{2}$	Actual: ≥ 2.5 *or:* Actual: ≥ $\sqrt{2}$ on longest unit plus Actual: ≥ 2.5 on unit of MCOV ≥ 120 kV	Actual: ≥ $\sqrt{2}$	Actual: ≥ $\sqrt{2}$
"Design B" Porcelain-housed	4	Fuse wire along surface of metal-oxide disks ; located as far away as possible from the gas channel	Prospective: ≥ 2.5 Actual: no requirement	Prospective: ≥ $\sqrt{2}$ Actual: no requirement	Actual: ≥ $\sqrt{2}$	Actual: ≥ 2.5	Actual: ≥ $\sqrt{2}$	Actual: ≥ $\sqrt{2}$
"Design B" Polymer-housed	2	Pre-failing by constant voltage or constant current source	Prospective: ≥ $\sqrt{2}$ Actual: no requirement	N/A	Actual: ≥ $\sqrt{2}$	Actual: ≥ $\sqrt{2}$	N/A	Actual: ≥ $\sqrt{2}$

NOTE—For tests at full voltage (at or above MCOV), it is necessary only that the requirements for prospective currents are met. Any current limitation caused by the arrester during the short-circuit test is acceptable, as this limitation would also occur on the electrical system.

Source: Defined by IEEE C62.11

Figure 3. The peak short-circuit current

(3) Short-Circuit Testing of Design B Polymer-Housed Surge Arresters:

A. Test Method 1:

Applicable Standards: IEEE C62.11 (2020) and IEC 60099-4 (2014) (fig. 4)

Pre-Breakdown Testing:

(A) Overvoltage Condition: The overvoltage specified by the manufacturer should exceed 1.15 times the rated voltage, and within 5 minutes ± 3 minutes, the arrester should fail. Failure is considered to occur when the voltage across the metal oxide varistor (MOV) discs drops below 10% of the original applied voltage.

(B) Constant Voltage Method: During this test, a constant voltage is applied, typically with an initial current between 5 mA/cm^2 and 10 mA/cm^2, and the short-circuit current ranges from 1A to 30A. The voltage is adjusted as needed to ensure the failure of the MOV discs within a given time range.

(C) Constant Current Method: Voltage is adjusted to maintain a constant current, typically with a current density of approximately 15 mA/cm^2, varying ±50%, to cause failure of the MOV discs. The short-circuit current typically ranges from 10A to 30A.

(D) Pre-Breakdown Condition: Before applying a large short-circuit current, a pre-breakdown test is conducted, with a current not exceeding 300A for no more than 2 seconds. This step ensures that the arrester's impedance is extremely low.

(E) Operational Steps:

a. Close SW 1, open SW 2, and apply pre-fault current (maximum 30A).

b. Within 2 seconds, close SW 2 to cause a short-circuit current to flow through the test specimen.

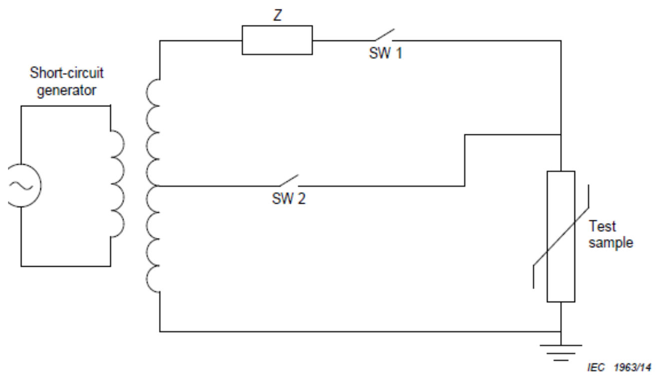


Figure 4. Design B polymer-housed surge arrester short-circuit test circuit diagram (from IEC 60099-4)

B. Test Method 2:

Applicable Standard: IEEE C62.11 (2020) only, applicable in our research institute's short-circuit test lab.

(A) Drilling Method:

As an alternative to pre-breakdown testing, manufacturers may choose to drill a hole in the MOV disc and insert a fuse for short-circuit testing. The hole should be 5mm ± 2mm in diameter.

(B) Fuse Conditions:

The fuse material and size should be appropriately selected to ensure it melts within 30 electrical degrees after the test current begins.

(C) Documentation:

Manufacturers should provide detailed photos or diagrams to specify the fuse's location and size.

(4) Criteria for Test Result Evaluation

The test is considered successful if the following conditions are met:

A. No violent explosion occurs.

B. Apart from zinc oxide components weighing less than 60g, pressure release caps, explosion membranes, or soft polymer materials, no parts of the arrester are expelled beyond the test fence.

C. The arrester should self-extinguish any flames within 2 minutes after the test, and expelled components (inside or outside the fence) should self-extinguish within 2 minutes.

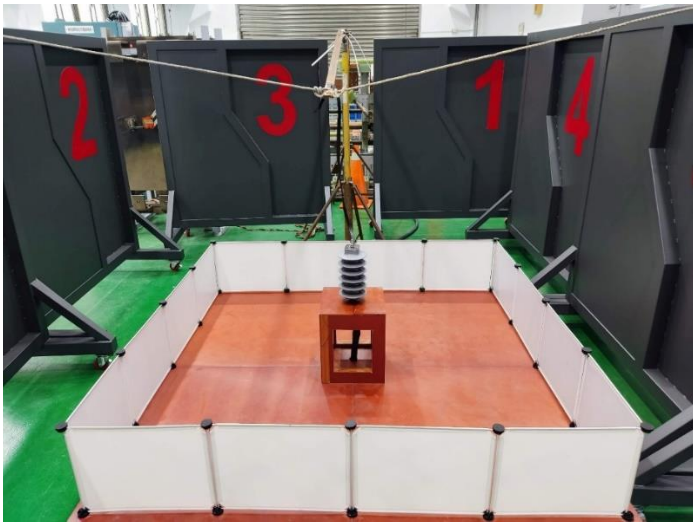


Figure 5. The short-circuit test setup at Taiwan Power Research Institute's short-circuit testing lab

Our supplier currently conducts short-circuit testing of polymer-housed surge arresters in mainland China. The test does not involve the fuse-insert drilling method; instead, the arrester undergoes pre-breakdown before large short-circuit currents are applied. Although C045(105-01) only requires a 10kA short-circuit test, some manufacturers also conduct a 600A short-circuit test.

Our research institute has explored the feasibility of conducting polymer-housed arrester short-circuit tests in its short-circuit test lab. The findings are as follows:

1. The low-voltage test area (~500V) cannot generate arcs after the fuse melts, thus failing to produce a short-circuit current of at least 0.2 seconds.
2. The medium-voltage test area (≧3.6kV) can perform 10kA short-circuit tests based on IEEE standards. However, since no pre-breakdown equipment exists, the test must use the fuse-insert drilling method.

3. Conclusion

Due to the absence of pre-breakdown equipment, the short-circuit test lab at our research institute cannot conduct Design B polymer-housed arrester short-circuit tests according to IEC standards. However, it can perform tests based on IEEE standards using the fuse-insert drilling method. To minimize the impact on the power system, the test voltage will be set below 4kV.