

WHITE PAPER



Solving partial vacuum effects with a vented bushing insert



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In the late 1980s, users of 25kV and 35kV loadbreak elbows and insulated caps began reporting incidents of flashover during switching operations.

Flashover occurs between the exposed conductive elements of the connector to the closest ground, which is typically the bushing, as the components are separated, usually in the first ½ inch of travel.

Study of the problem was difficult. Flashovers were not reproducible in the laboratory using the test methods described in IEEE Std. 386. The intermittent nature of the problem and concerns about interrupting utility customers' power for test purposes complicated field investigations.

Data from field flashovers was accumulated. Users and manufacturers analyzed circuits, failed parts, operating procedures and conditions. A number of common factors became apparent:

- Flashover occurred with connectors of all manufacturers
- Flashovers occurred on lightly loaded circuits or unloaded circuits. In the case of an insulated cap, the load current was zero
- The rate of flashover increased with increased voltage
- Flashover occurrences increased during cold weather
- A unique failure mode was common to most events: Flashover along the separating interfaces occurred early in the operation with an elbow or cap movement of less than ½ inch

Elastimold® resolved the flashover problem through analysis of these factors and the development of a new test method that duplicated the field flashover.

New insulated cap and bushing insert designs were developed that increase reliability and provide users with the system-operating benefits of live switching without concern for flashover.

Flashover mode

Flashovers

- Occur during break operation, not make
- Occur before contact separation
- Occur before cuff seal opens
- Show tell-tale arc pits on probe

Conclusion

- Cause not related to circuit-interruption phenomena
- The effect of decreased pressure reduces the dielectric strength of air along the opening connector interface and may result in a flashover
- A partial vacuum is the root cause of flashover, which cannot be eliminated, only controlled
- Affects all manufacturers and brands

Cause: Partial vacuum

Partial vacuum is a term used to describe a decrease in internal air pressure that occurs when an elbow or insulated cap is separated from a bushing insert.

To understand the cause and effect of partial vacuum, first consider the process of opening a connector.

Universal Gas Law

$$P_1 V_1 = P_2 V_2$$

$$T_1 \quad T_2$$

P = Pressure

V = Volume

T = Temperature

- As volume increases for a constant temperature, pressure decreases
- As temperature decreases for a constant volume, pressure decreases

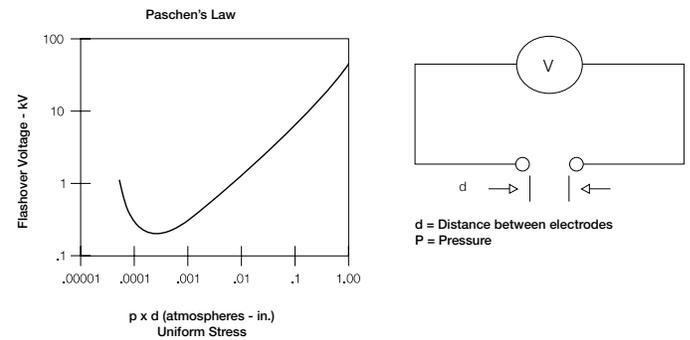
A decrease in pressure or partial vacuum occurs in an assembled connector when the ambient temperature decreases. Furthermore, the operation of opening the elbow causes a decrease in pressure.

Factors contributing to partial vacuum

- Cold temperatures
- Stiffens the rubber and increases internal/external temperature differential
- Increased voltages
- Higher potentials to break down reduced electrical resistance
- Break and not make operations
- Due to air expansion during the component separation
- Installation duration
- Lubricating grease bleed off creates a "sticky" interface

Effect: Paschen's Law

Paschen's Law explains the effect of decreased pressure on the dielectric strength of air, and is illustrated with the following curve:



To see the effect of pressure, let $d = 1$ inch. The horizontal axis then represents pressure only. Note that at 1.0 atmosphere, the flashover voltage for 1 inch is approximately 60kV, and at 0.1 atmosphere, the flashover voltage decreases to approximately 8kV.

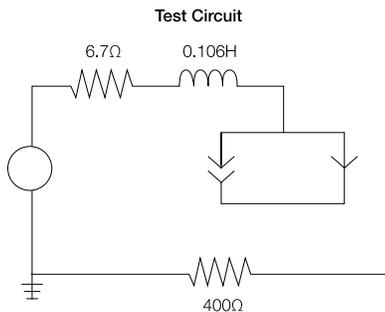
This curve illustrates the general relationship and does not represent true data. An accurate curve can be developed for small gaps under controlled pressure, temperature and humidity conditions. The principle applies to the complicated geometry of a connector.

Solution: Test method

To demonstrate the cause-and-effect relationship of partial vacuum to connector flashover, a test method was developed.

1. Circuit

Since voltage, and not current, is the critical parameter, a zero-current test circuit was set up.



The applied voltage was selected at 27.5kV, much in excess of normal line-to-ground voltage, to increase the failure rate. This allowed evaluation of test and design parameters with a limited number of samples.

2. Test sample conditioning

Test samples consisted of elbows, insulated caps and bushing inserts.

- Samples were assembled at room temperature without the use of grease. The absence of grease and the resulting high assembly force increased flashover rate.
- Assembled test samples were aged for 16 hours in a chamber at minus 20 C.

3. Operating procedure

Test samples were removed from the cold chamber and immediately assembled to a mounting plate, energized and separated using standard hot stick operating procedures.

4. Field failure mode was duplicated with this test method.

Solution: Vented bushing design

Various test scenarios were trialed to verify that the vented bushing ring solution works in all environments:

Case 1

Vented vs. non-vented bushing insert with elbow: No failures with the vented solution

Test results

	Non-vented insert with elbow	Vented insert with elbow
Tested	12	40
Pass	8	40
Fail	4	0
% Fail	33%	0%

Case 2

Vented vs. non-vented bushing insert with insulated cap: No failures with the vented solution

Test results

	Non-vented insert with elbow	Vented insert with elbow
Tested	14	16
Pass	4	16
Fail	10	0
% Fail	71%	0%

Case 3

Vented bushing insert with insulated cap or elbow and heavy grease applied to block vents: No failures with the vented solution

Test results

	Vented insert - heavy grease with elbow	Vented insert - heavy grease with insulated cap
Tested	16	16
Pass	16	16
Fail	0	0
% Fail	0%	0%

Case 4

Vented bushing insert with insulated cap or elbow and elevated voltage: No failures with the vented solution

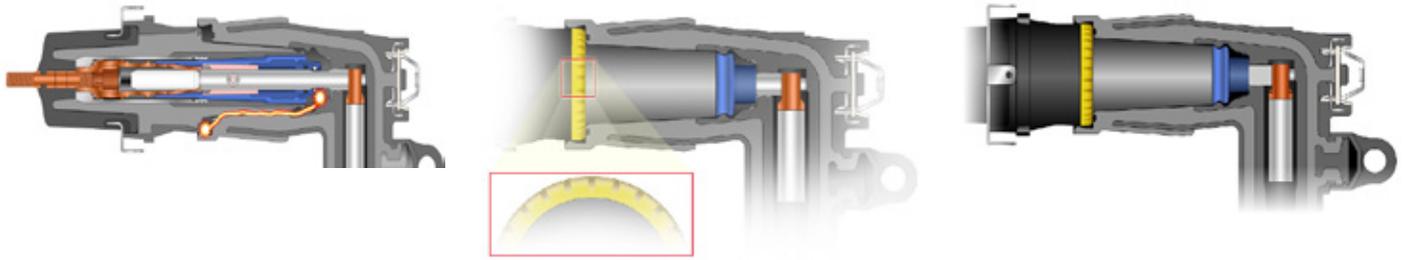
Test results

	Vented insert - 30 kV test with elbow	Vented insert - 30 kV test with insulated cap
Tested	12	12
Pass	12	12
Fail	0	0
% Fail	0%	0%

In four tests cases, even with extreme parameters, the Elastimold vented bushing solution resulted in no flashovers.

Evaluation of samples using the new test method showed that flashovers occurred at a rate of 33 percent for elbows and 71 percent for caps. With a new bushing insert design, which vents the trapped air and prevents a partial vacuum, flashover was eliminated.

It was also shown that the insulated cap design with the internal conductive parts (probe and internal shield) removed will provide flash-free operation.



Examples

- As the connector is removed from the bushing insert, shield separation causes high electric stress
- High Stress + Partial Vacuum = Partial Discharge and Ionized Gas
- Ionized gas is conductive, providing flashover path from probe to shield

Engineering vacuum prevention

- Vents in the bushing insert ring help equalize the pressure as the connector is removed and prevent (25 and 35kV Classes) flashover conditions
- Elastimold exclusive patented design is a universal solution for any 200A connector application

Vented bushing ring allows external air to enter, which equalizes pressure and prevents conditions that lead to flashover.

PBT interface shield

- Excellent dielectric mating surface for secure connections
- Rubber-to-rubber sticking eliminated
- Color-enhanced visibility for easy identification and proper installation verification
- Vented ring designed to prevent partial arc flash for enhanced safety



Since November 1997, when Elastimold began providing vented bushing interfaces, there have been no field reports of switching flashovers.

- The Elastimold solution is universal and will work with any attached components
- The Elastimold solution is designed to be cost effective and standard with the ideal there shouldn't be a price for safety
- Does not require adding a new connector which can result in time consuming and costly cable replacement and repair
- Conforms to all IEEE 386 interface standards
- Provides the added benefit of a non-stick interface when used with Elastimold 200A elbows for easier workability

Ordering information

		Cat. no.	
Voltage class	Voltage rating	Bushing insert	Insulated cap (disc color)
25 kV	15.2/26.3 kV	2701A4	273DRGA (blue)
28 kV	16.2/28 kV	2701A4-CS854	273DRGA-CS854 (blue)
35 kV	21.1 kV	3701A4	275DRGA (yellow)
35 kV	21.1/36.6 kV	3701A3	275DRGA (yellow)

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