

New Distribution Class Arrester Ground Lead Disconnecter Design Enhances Detonation Reliability and Improves Arrester Performance

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Abstract-- This paper examines performance characteristics of existing distribution class arrester ground lead disconnecting devices. The paper also introduces a new Distribution Class ground lead disconnecter design that not only extends the claimable detonation range well below the 20 amps specified in industry standards, but is very durable when exposed to severe arrester durability tests. Finally, this paper shows how this next generation disconnecter interacts with the connected arrester to improve the overvoltage withstand capability of the arrester assembly.

I. Introduction

Electric utility operating system reliability has been identified as a critical parameter of the utility performance. For distribution systems, one factor that can affect system reliability is the failure rate of surge arresters. A related factor is the consistency of operation of the arrester ground lead disconnecter in the unlikely event of an arrester failure. This paper examines performance characteristics of existing distribution class arrester ground lead disconnecting devices. In particular, it will focus on how the detonator performs after the series connected arrester fails, under various system conditions. The paper also introduces a new disconnecter design that not only extends the claimable

detonation range well below the 20 amps specified in industry standards, but is very durable when exposed to severe arrester durability tests. It will also be shown how this device interacts with the connected arrester to improve the overvoltage withstand capability of the arrester assembly.

II. Background

It has been standard practice of North American utilities to protect distribution class equipment, particularly pole top transformers, with distribution class arresters. Protection of the dielectric integrity of the transformer is provided by the closely connected arrester. Approximately twenty years ago, the traditional gapped-silicon carbide distribution class arrester design was replaced by the improved gapless arrester, based on metal oxide varistor (MOV) technology. In addition to performance improvements associated with this new MOV technology, the traditional porcelain-housed arresters were replaced during this same time period by polymer-housed arresters.

Conversion to MOV resulted in lowering of the protective levels of the arrester, particularly under fast front rate of rise surges, providing improved protection to the internal insulation of the transformer. Implementation of polymer housings significantly improved the performance of the arrester in the unlikely event of arrester failure. Specifically, the polymer housed arrester removed the concern of violent porcelain fragmentation associated with porcelain-housed distribution class arresters. To validate

this characteristic, the IEEE C62.11 Standard instituted a short circuit test for polymer-housed arresters. The predecessor porcelain-housed distribution class arrester had no required short circuit performance requirement.

Conversion from porcelain to polymer-housed distribution class arresters allowed manufacturers to reduce the active element length of their arrester designs. The porcelain designs traditionally had a ground lead disconnecter attached to the base end of the arrester and the arrester was supported by a grounded metal “bellyband” bracket, typically attached around the porcelain housing approximately one-third the distance from the bottom end of the arrester housing. The distance from the top edge of the metal bellyband to the arrester top end cap provided the required line to ground insulation clearance as specified for each arrester rating in the C62.11 Standard. The distance from the bottom of the grounded bellyband to the ground lead disconnecter provided the necessary clearance to prevent the intact, failed porcelain arrester from locking out the system if the arrester should fail but remain intact.

For the polymer-housed designs, this “lockout prevention” clearance was relocated to the supporting bracket, which typically attaches to the base end of the polymer-housed arrester. Because this member now has the added requirement of voltage withstand after arrester failure, its composition changed from metal to an insulating plastic material. Should the polymer-housed arrester fail and remain intact (typical), the ground lead disconnecter, connected between the base of the arrester and the arrester ground lead, will detonate.

Disconnection of the ground lead causes the base end of the failed (intact) arrester to assume system line potential. The composition and shed design of the insulated bracket allows the arrester location to remain energized until the utility operating personnel replace the failed arrester.

The above description is valid, assuming that the ground lead disconnecter reliably detonates during arrester failure. Should the disconnecter fail to operate, the base end of the failed arrester will remain connected to system ground and the line will lock out until upstream protection operates and the failed arrester is replaced.

III. Ground Lead Disconnecter Standards Requirements

Industry standards (1, 2) define the performance requirements of the ground lead disconnecter. The performance requirements are divided into two areas of concern. The first addresses the detonation characteristic of the disconnecter, essentially the current-time curve. This test specifies that the disconnecter is subjected to 60 Hz power frequency currents of 20, 80, 200, and 800 Amps rms and the time to detonation at each current level is measured. From this test series, the disconnecter detonation curve is established. A knowledgeable application engineer can use the arrester detonation curve to develop proper coordination with upstream protection, e.g., fuses (3).

The second aspect of performance is that the disconnecter will not detonate when subjected to required arrester durability tests, including high current-short duration, low current-long duration, and duty cycle tests. Another test

requirement is that the disconnecter will not detonate as a result of arrester surface currents when the arrester assembly is subjected to contamination testing. Essentially, the disconnecter is designed to withstand (without detonating) the same durability tests that the arrester must withstand; however, it must detonate, disconnecting the arrester ground lead, when the arrester fails and conducts system fault current.

The above standards requirements have assured that distribution class arrester disconnecters meet a minimum performance requirement.

IV. Disconnector Designs

There are two basic detonator designs used in disconnecters currently being manufactured in the US. As noted earlier, virtually all designs attach the isolator to the ground end of the arrester. One design mounts the arrester base end on an insulating bracket and holds the arrester to the bracket by attaching a disconnecter to the underside of the assembly. This design was a carryover from porcelain arresters. The second design, targeted specifically to polymer arresters, integrates the disconnecter into the body of the insulating bracket. This integrated design attaches to the base end of the arrester.

Regardless of which approach is utilized, both designs use the same basic internal design approach. An unprimed cartridge is used to promote separation of the disconnecter. This cartridge is typically located in the vicinity of a sparkgap, which is oriented in parallel with some type of electrical grading component.

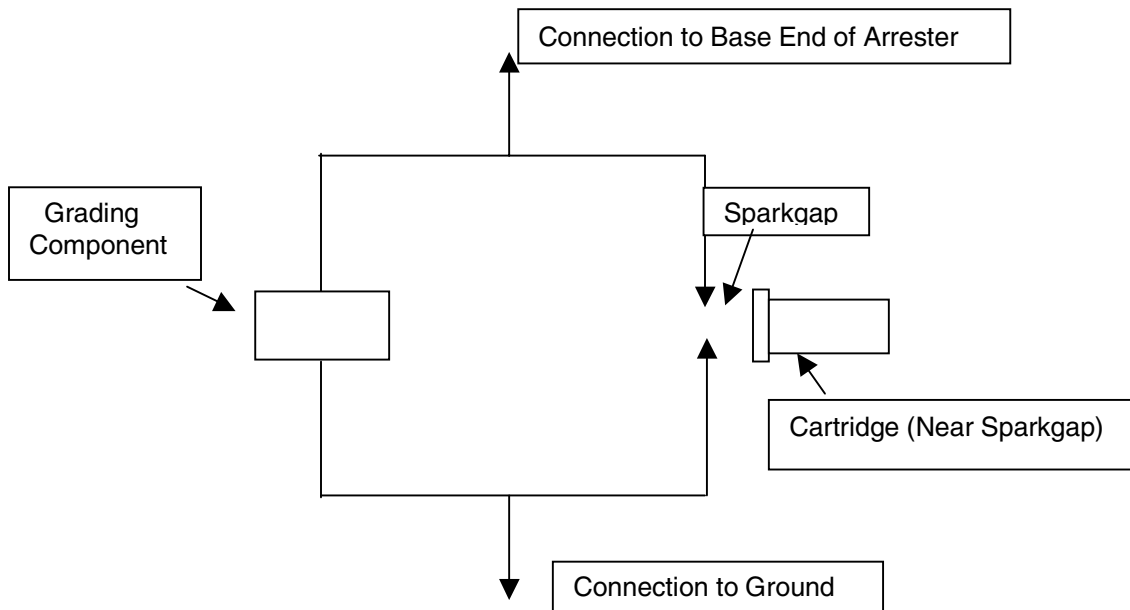
Manufacturers have utilized a variety of grading components, including electronic capacitors, electronic resistors, conductive polymers, and higher wattage resistors. Figure 1 shows an electrical schematic of a typical ground lead disconnecter.

The grading component, typically a molded resistor in currently manufactured US designs, provides a path for normal arrester internal grading and external leakage currents to flow from the base of the arrester to ground. The sparkgap, located electrically in parallel with the resistor, provides a bypass function when the arrester assembly is subjected to abnormal surge duty. Voltage drop across the grading component during this abnormal surge duty causes the bypass gap to sparkover.

For required arrester durability tests defined in the standard, the arrester is expected to withstand the duty without failing and the detonator is expected to withstand the duty without detonating. The thermal design of the disconnecter is such that there is not sufficient coulomb content in the sparkgap region to cause the adjacent cartridge to detonate during arrester durability tests. However, if the surge duty is sufficient to cause the arrester to fail, the subsequent flow of system fault current available at the arrester location is intended to provide sufficient heating of the cartridge to cause it to detonate. The design of the disconnecter is such that this detonation then causes the ground lead to be separated from the base end of the arrester.

Figure 1

Electrical Schematic of Ground Lead Disconnecter



V. Disconnecter Detonation Curve

As noted, the disconnecter current detonation range specified in the standard is 20 to 800 amps. The standard does not specify the shape of the current-time detonation curve. It merely defines the procedure for performing the test on new disconnecters. Above 800 amps, all designs should detonate very quickly from the high heat associated with the high 60 Hz fault current. Problems can be encountered on arresters applied to non-effectively grounded systems or on arresters located on weak feeders where only low fault currents are available (< 20amps). Specifically, the cartridge relies on heating from the system 60 Hz fault current to cause detonation. Inherent in these weak source current locations is the possibility that the cartridge is not heated sufficiently by the available 60 Hz current to detonate before upstream protection triggers.

Reliable detonation of the disconnecter under this weak source condition is an issue of concern. Figure 2 shows disconnectors tested per the current ANSI standard.

VI. Capacitor-Graded Disconnecter

To address the detonation reliability concerns of the ground lead disconnecter, the molded resistance grading component of the disconnecter was replaced with a high voltage ceramic capacitor. Figure 3 shows a cross-sectional view of a capacitively graded disconnecter designed as an integral part of the insulating bracket.

A primary advantage of the high voltage capacitor grading is that the capacitor will not fail from thermal runaway when the arrester assembly is subjected to a prolonged overvoltage condition. Unlike the grading resistor, which can heat up and fail from I^2R loss, the capacitor

design will withstand the capacitance portion of the total overvoltage. Ultimate arrester failure will occur when the arrester metal oxide discs fail from

thermal runaway or when voltage across the capacitance-graded sparkgap becomes high enough to cause the gap to spark over.

Figure 2

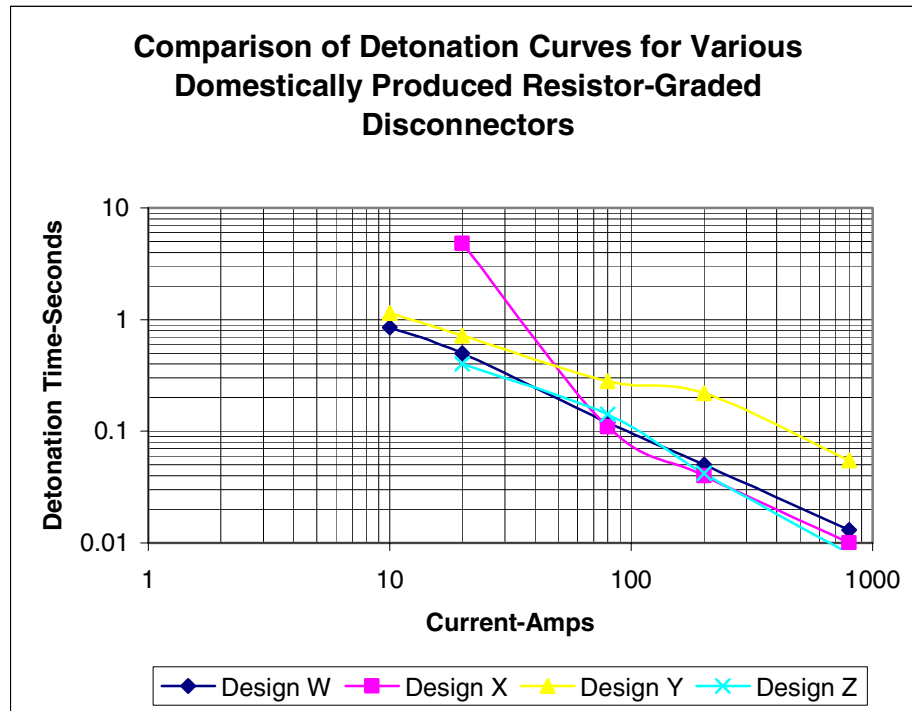
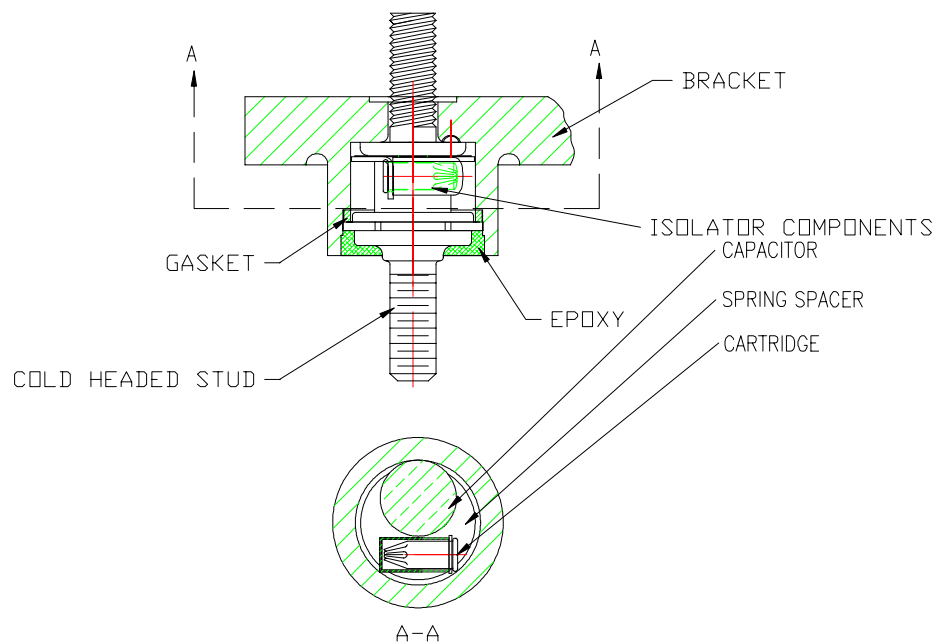


Figure 3

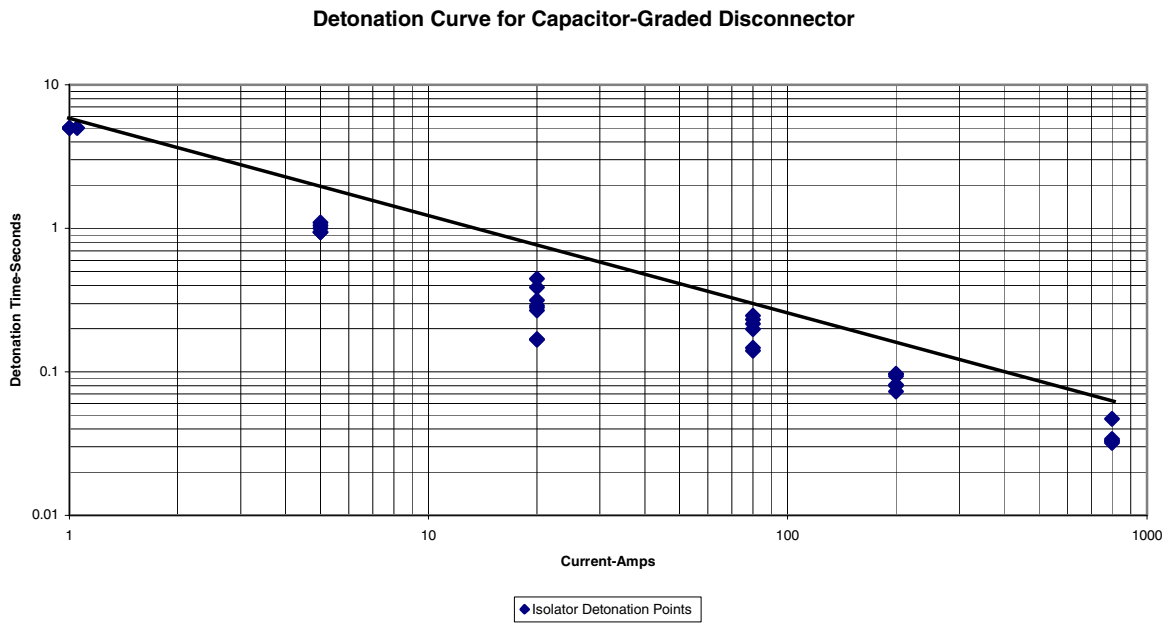


Under these conditions, the arrester 60 Hz fault current will, as designed, cause the disconnecter gap to sparkover, placing the internal arc at the cartridge location, resulting in detonation and ground lead disconnection. This assumes that protection upstream does not disconnect the arrester from system voltage before the cartridge is heated sufficiently to cause detonation. Since the capacitor-graded disconnecter removes failure concerns associated with the resistor-graded disconnecter, time to detonation for low fault current applications becomes strictly an issue

related to the thermal design of the disconnecter sparkgap.

To validate the detonation curve for the capacitor-graded design, tests were performed per Section 8.18.2.3 of IEEE C62.11-1999 Standard, except the detonating current range was extended to 5 and 1 amp fault current levels. Figure 4 shows the resultant detonation curve. Note that all (5) samples tested at 1 and 5 amp current levels detonated. There was no damage to the grading capacitor other than the external arcing damage associated with the fault current arc.

Figure 4



VII. Durability of Capacitor-Graded Disconnecter

As shown above, the new capacitor-graded disconnecter will detonate down to 1 ampere. As the design becomes more sensitive to low current detonation, there is a concern that the disconnecter might become too sensitive and detonate on required arrester durability tests. Section 8.18.2 of IEEE C62.11-1999 standard defines required design tests. To address this concern, the following durability tests were performed.

Five arresters with capacitor-graded insulating brackets were subjected to (18) shots of 400 amp, 2ms duration, exceeding the 18 shot, 250 amp test requirement for Heavy Duty Distribution Class arresters. While not detonating as a result of the repetitive duty, all five disconnectors detonated when subjected to a 1 amp fault current.

Six capacitor-graded disconnectors were also subjected to (2) 100 kA 5.5/12 discharges with no detonation occurring. In addition, the measured capacitance changed less than 5% and there was no partial discharge measured as a result of this severe duty.

As a final confirmation of the electrical integrity, three disconnectors that successfully passed the (2) 100 kA shots were tested for detonation in a 6-amp test circuit. Time to detonation on these three samples was .983, 1.0, and 1.43 seconds, well within the claimed detonation curve for the new disconnecter.

VIII. Examination of Performance of Resistor-Graded Disconnecter Designs in the Domestic Marketplace After Exposure to Arrester Durability Tests

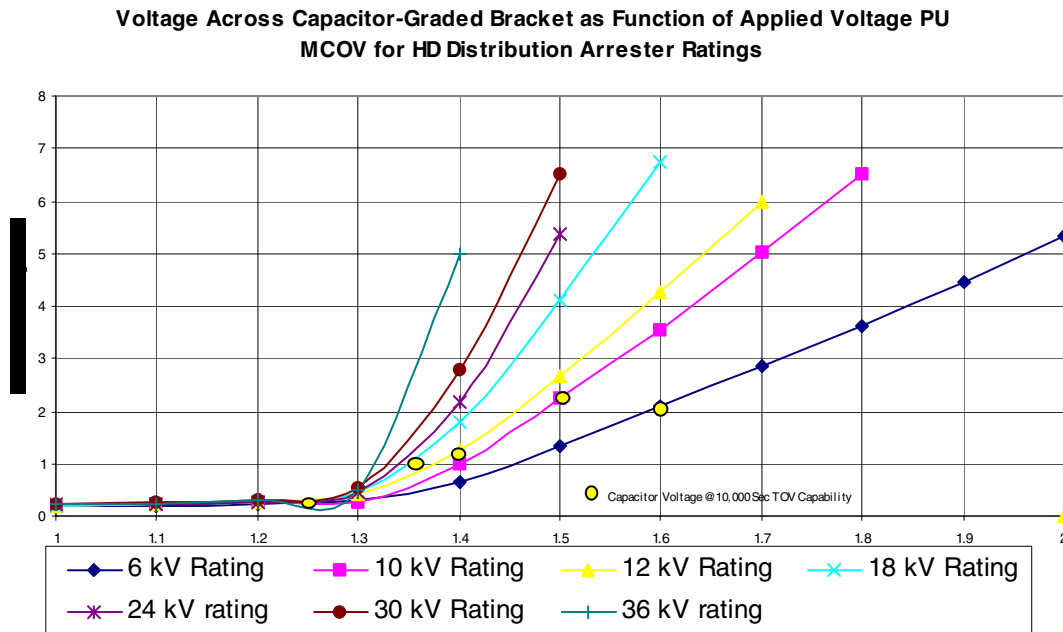
A limited number of disconnecter designs currently in the marketplace were subjected to (2) 100 kA 4/10 current discharges. Design A successfully withstood the (2) shot test without detonating. Design B had the disconnecter detonate on the first 100 kA surge on both samples tested. A third sample withstood two discharges without detonation. Three disconnectors of design C and design D successfully withstood (2) 100 kA discharges without detonation.

Design A disconnectors were then subjected to a 20-amp and a 5-amp detonation tests. At 20-amp, detonation occurred. At 5-amp, there was no detonation. The third sample of design B did not detonate at 20-amp. One of the design C disconnectors detonated at 20-amps while two did not detonate at 5-amps. Design D detonated at both 5 and 20 amps.

IX. Arrester-Disconnecter Interaction Issues

The impedance of the capacitor-graded isolator is significantly higher than that of the existing domestic resistor-graded disconnecter designs. This has a significant impact on the voltage sharing that exists between the connected arrester metal oxide disc elements and the series connected disconnecter. Figure 5 displays the 60 Hz voltage measured across the disconnecter as a function of total voltage applied to the arrester-disconnector combination. Note that below 1.25 per unit MCOV, the disconnecter develops less than 1 kV across the grading capacitor, well below the continuous AC capability of the device.

Figure 5



X. Arrestor Temporary Overvoltage Improvement Associated With Capacitor-Graded Disconnecter

It should be pointed out that most manufacturers publish only one TOV curve for their distribution arrester designs. This curve is typically based on the TOV capability of the arrester only, since Distribution Class arresters can be

installed without insulating brackets and ground lead disconnectors. The actual arrester assembly (including disconnector) TOV capability may exceed that claimed for the arrester alone. Figure 6 shows a typical gapless distribution class arrester temporary overvoltage curve.

Figure 6

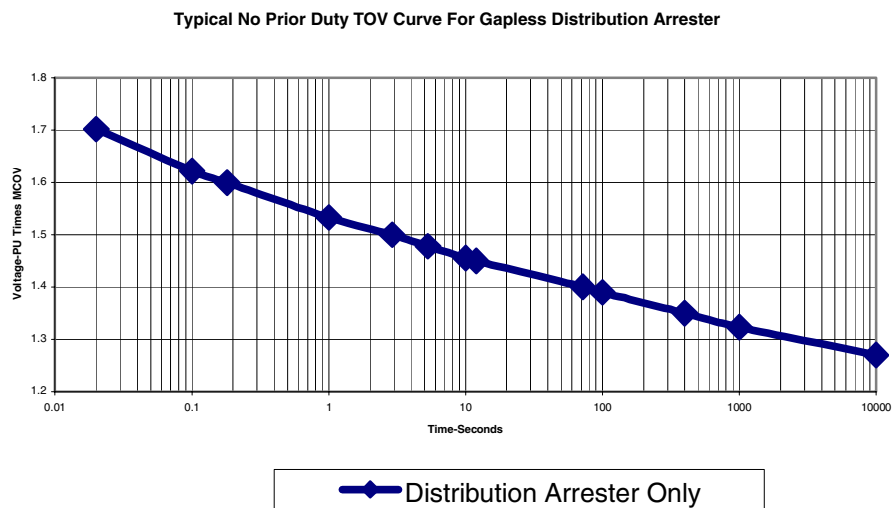
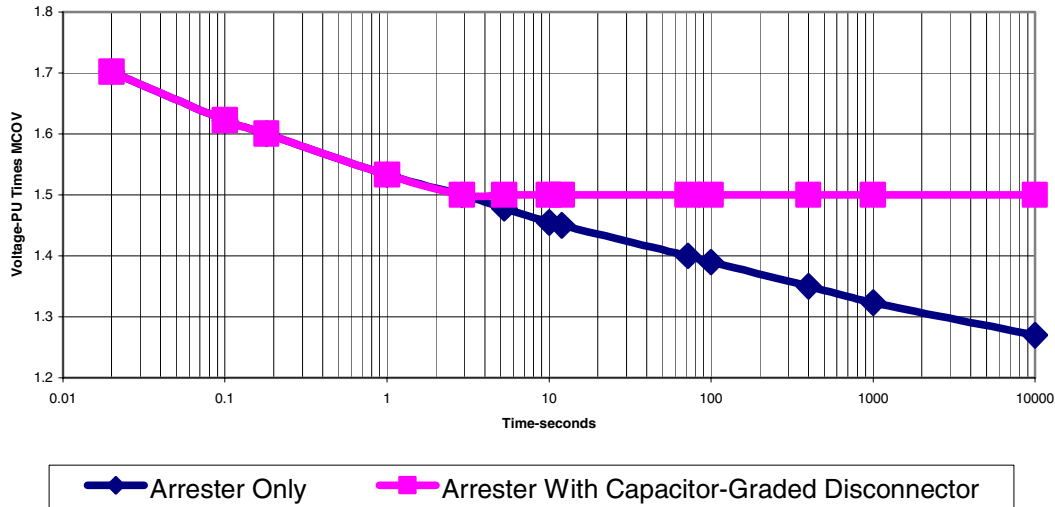


Figure 7

No Prior Duty TOV Curves for 9 and 10 kV Rated HD Distribution Arresters With and Without Capacitor-Graded Disconnecter



As noted previously, the significantly higher impedance of the capacitor-graded disconnector electrically interacts with the capacitive and non-linear resistance characteristic of the metal oxide discs. At system operating voltage levels, the voltage across the capacitively graded disconnector is typically a few hundred volts, compared with tens of volts for the resistively graded disconnector. As applied voltage increases above operating levels, the parallel combination of the disconnector capacitor and its sparkgap assume a higher percentage of total voltage than does the resistively graded disconnector. Because the capacitor does not experience I^2R loss, in contrast to the resistance graded design, the disconnector can withstand overvoltages for extended periods of time, as long as the capacitor voltage does not exceed the bypass gap sparkover level. Unlike an arrester with a resistively graded disconnector, which has a claimed TOV capability that is independent of arrester voltage rating, arresters with

capacitively graded disconnectors have a rating-dependent TOV curve. Figure 7 shows the TOV curve for 9 and 10 kV rated HD Distribution Class arresters.

XI. Conclusion

Introduction of a high voltage capacitor-graded arrester ground lead disconnector addresses utility concerns regarding reliable detonation of the Distribution Class arrester disconnector. Test data confirms the detonation integrity of the disconnector is maintained even after the arrester is subjected to high current surge duty prevalent in the distribution system environment. Even under weak source temporary overvoltage conditions, which can damage the resistance-graded design affecting detonation reliability, the capacitor-graded design performs properly. The detonation range of this design has also been reliably extended to 1 amp, below the 20 amps required by the C62.11 arrester design standard. Finally, the interaction of the disconnector grading capacitor with the

series-connected arrester metal oxide disc elements actually improves the arrester assembly temporary overvoltage withstand capability, making the design less vulnerable to TOV failures. Since the vast majority of distribution class arresters are sold domestically with ground lead disconnectors, this design improvement in the disconnector to improve detonation reliability also translates into a significantly improved distribution class arrester design.

XII. References

Standards:

- (1) IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV) IEEE Std C62.11-1999
- (2) CEI IEC 60099-4 (2001-12) Ed. 1.2 Consolidated Edition: Surge Arresters-Part 4: Metal Oxide Surge arresters Without Gaps for AC Systems

- (3) IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems IEEE Std C62.22-1997

XIII. Bibliography

Dennis W. Lenk (F, 1999) has 35 years of experience in the design and testing of surge arresters. He has been actively involved in the IEEE PES Surge Protective Devices Committee for 25 years, most recently serving as Past Chair of the committee. Dennis is also a member of the US TAG to IEC TC 37. He is the SPDC Editor to the IEEE Transactions on Power Delivery. He is a Registered Professional Engineer in Ohio and currently a Principal Engineer for Hubbell Power Systems.