Application Considerations for Gapped Silicon-Carbide Arresters Currently Installed on Utility High Voltage Installations

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Abstract— Utilities have expressed concern recently about the electrical integrity and performance capability of the large number of gapped silicon-carbide arresters that they currently have installed on their operating system. These arresters, manufactured from the early 1950s thru the late 1970s, were the state-of-the-art overvoltage protection device at the time they were installed. While these gapped silicon-carbide arresters have a good service history, current state-of-the-art metal oxide arresters provide an opportunity to upgrade arrester performance and improve service reliability. This paper discusses some of the issues that should be addressed in evaluating these arrester installations.

I. Introduction

From the mid 1950s through the late 1970s, gapped silicon-carbide arresters represented the state of the art overvoltage surge protection used on distribution through high voltage transmission systems. With the development of metal oxide disc technology in the mid-late 1970s, manufacturers replaced the traditional silicon-carbide gap design with a gapless MOV arrester having improved performance characteristics.

While the gapped silicon-carbide technology relied on both the gap and the silicon-carbide valve block to operate properly, the high exponent characteristic of the metal oxide varistor disc negated the need for a series connected gap.

Design improvements were incorporated into gapped-silicon carbide (SiC) arresters over the 25+ years that they were manufactured, but the basic technology did not change. This paper discusses some of the significant performance characteristics of conventional gapped SiC Intermediate and Station Class arresters and comparably rated gapless metal oxide (MOV) arresters.

While gapped SiC arresters have, in general, had a good service history, utilities continue to evaluate their overvoltage protection needs, in particular at critical locations that are currently protected by gapped silicon-carbide arresters. This paper discusses some of the issues that should be addressed in evaluating these applications, including:

- Arrester Integrity
- Protection/Margin
- Pressure Relief capability
- TLD/Energy absorbing capability

II. Brief History

Surge arresters are applied on power systems to protect equipment insulation

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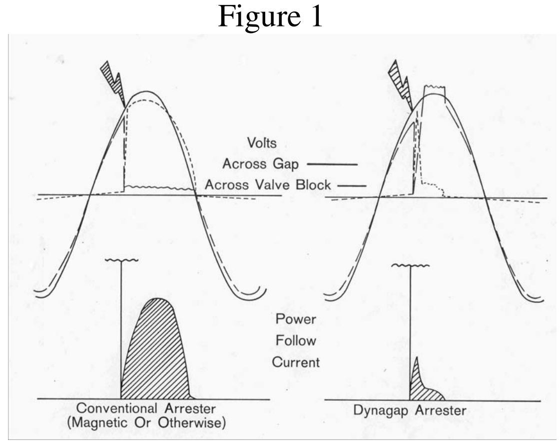
from damage associated with overvoltage surges on the power lines. These surges can take many forms, ranging from lightning to capacitor bank to line switching surges.

The design of the earliest SiC arresters consisted of a simple multigap configured in series with non-linear silicon carbide valve blocks. A common characteristic of all SiC designs was that the gap design, under normal operating conditions, withstood total line-to-ground system voltage. In the simple multigap configuration, the gap was the brains of the design. It responded to an overvoltage condition on the line and sparked over preventing damage to line/equipment insulation. Once the gap sparked over, 60 Hz power follow current flowed through the series gap-valve block combination. The non-linear valve block limited the magnitude of the follow current to a level that the series gap could interrupt. Power follow current interruption on a properly functioning arrester, designed with a simple multigap, typically occurred on the first voltage crossing of the power frequency voltage following the overvoltage surge. This gap "reseal" completed the arrester operation and the system voltage again appeared across the gap.

The multigap design worked quite well at distribution voltages but, for higher system voltages, resulted in very tall arresters. In addition, since all the energy absorbing during the arrester operation was done by the valve blocks, a large quantity of valve blocks were required for the arresters to function properly.The large quantity of valve blocks resulted in very high discharge voltages, accompanying the already high sparkover levels for these multigap SiC arresters.

During the late 1950s, the first current limiting (CL) gap arrester was introduced. Unlike the simple gap design which basically provided a sparkover and reseal function, the CL gap was designed to help limit system follow current by developing a "back EMF". This "back EMF", in combination with the valve block current limiting, actually caused follow current interruption prior to zero voltage crossing. Figure 1 shows a comparison between the duty cycle oscillogram of the simple SiC multigap design versus the SiC CL design.

Figure 1



Implementation of the current limiting gap significantly reduced the energy absorbed during the duty cycle operation, ultimately allowing arrester designers to reduce the quantity of valve elements inside the arrester. This ultimately resulted in shorter arresters with reduced discharge voltage levels. These stepped reductions in discharge voltage resulted in stepped reductions in BIL/BSL margins.

III. Protection/Insulation Coordination

For gapped SiC arresters, the protective margin between equipment insulation and arrester protective levels is a function of the highest of either the arrester discharge voltage or the arrester sparkover voltage (2).

In the switching surge region, the BSL margin of protection is determined by the magnitude of the arrester switching surge sparkover. The BIL margin, however, is determined by the highest of either the arrester 1.2 x 50 impulse sparkover or the discharge voltage level for an 8/10 discharge current waveshape of 10 or 20 kA. The FOW/chopped wave margin is determined by the arrester FOW sparkover characteristic.

It was previously noted that the introduction of the CL gap allowed arresters to be designed with reduced discharge voltages. To take advantage of the discharge voltage reductions, extensive design work was performed to reduce sparkover levels of these arresters. These evolutionary reductions resulted in the lowering of equipment insulation levels, while still maintaining acceptable protective margins.

During the 25+ year manufacturing period of gapped SiC arresters, there were significant reductions in the discharge voltage and sparkover levels for these arresters. As the Table 1 for one manufacturer demonstrates, the sparkover levels for gapped SiC arresters progressively decreased as newer/ improved designs evolved. While the values in the table are for one manufacturer, they represent typical sparkover improvements for all manufacturers during the manufacturing period. Note the significant sparkover level reductions associated with the more recently manufactured arresters.

Table 1

Arrester Vintage	FOW Protective Level (1) kVc	Impulse Protective Level (1) kVc	Switching Surge Protective Level (1) kVc
1957-1963 Series 3 195 kV Rating	656	545	560
1963-1966 Series 4 195 kV Rating	560	448	490
1966-1978 Series 5 192 kV Rating	560	426	435
2005 MOV 192 kV Rating	476	440	377

(1) For the three SiC vintages (1957 thru 1978), the protective level shown is the guaranteed maximum arrester sparkover for the designated waveshape. For the MOV arrester, the protective levels are the 10 kA IR for .5 microsecond FOW and 8/20 waveshapes, and the 1.5 kA switching surge IR for the gapless arrester.

IV. Pressure Relief

Gapped SiC arresters were designed to meet the specified fault current performance requirements of ANSI C62.1 Standard. Table 2 specifies the fault current requirements for SiC Station and Intermediate Class arresters per C62.1 Standard.

The above pressure relief requirements applied only to Station and Intermediate Class arresters designed with metal castings on both ends, allowing venting of internal gases through both ends in the unlikely event of arrester failure. Low voltage Station or Intermediate Class arresters with porcelain tops, designed typically for applications with restricted clearances, did not have a standardized pressure relief requirement. While these designs did have a tested pressure relief capability, it was typically lower than that claimed for the standard design with two end castings because these designs could only vent through the bottom casting.

While this paper is dealing with high voltage Station and Intermediate Class gapped SiC arresters, it is worth remembering that C62.1 Standard did not have a pressure relief testing requirement for gapped SiC Distribution Class arresters.

Table 2

Arrester Description	High Current- kA_{rms}	Low current-Amps
3-15 kV Rated Station	25 kA or 65 kA	400-600
21-684 kV Rated Station	25 kA or 40 kA	400-600
3-120 kV Rated Intermediate	16.1 kA	400-600

V. Transmission Line Discharge/Energy Absorbing Capability

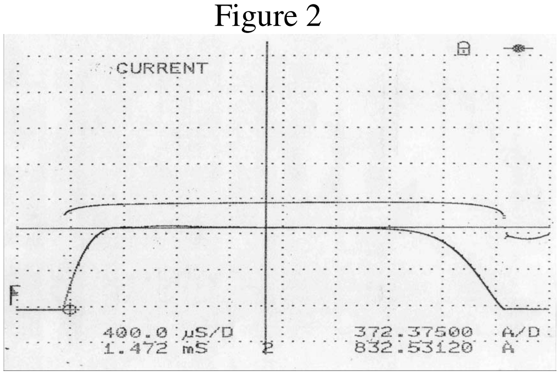
The introduction of gapped and gapless MOV arresters into the domestic marketplace was accompanied by a new design test standard C62.11(3). This standard included a number of tests required in the C62.1 Standard but also added new tests specific to MOV arresters. This standard has evolved over several years to include polymer housed arrester special requirements.

One of the tests that was carried over from SiC was the transmission line discharge (TLD) test. This test verifies that SiC arresters applied at various system voltages (with defined surge impedance, line length, and charge voltage) will successfully pass (20) TLD discharges without failure. This same test was incorporated into C62.11 standard for MOV arresters, except at the conclusion of the 20 shots, the MOV sample is subjected to two additional discharges (spaced 1 minute apart) followed by the application of recovery voltage. This recovery portion of the new test was not required on the gapped SiC arresters because there is no danger of thermal runaway on the gapped designs.

A characteristic of interest to users is the claimable energy capability of the gapless MOV arresters in the marketplace. Over the years, manufacturers have adopted the TLD waveshape for determining the claimable energy capability for a specific design. Typically, at least two energy claims are made for an arrester design. One is the "single shot" capability; the second is the "2-shot within a minute" capability. The single shot claim defines the maximum energy the arrester can discharge without failing when subjected to a single TLD discharge. The 2-shot claim , higher than the single shot, not only demonstrates the arrester's higher energy absorbing capability, but also includes a validation that the arrester will not thermally runaway after the second shot.

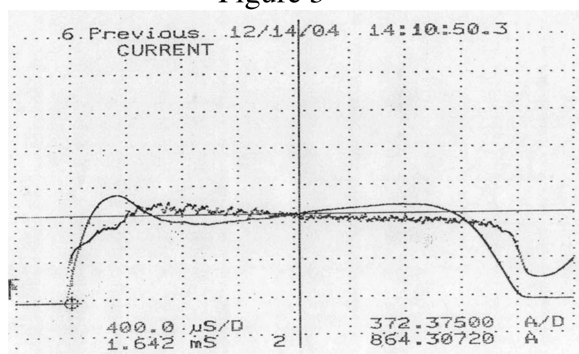
Questions have arisen regarding how the MOV arrester energy absorbing capability compares with that of the gapped SiC arrester designs. Quantification of the gapless MOV arrester's TLD energy capability is a simple integration of TLD current/ voltage/time oscillograms. Figure 2 shows a typical oscillogram for a Station Class MOV arrester applied on a 345 kV system.

Figure 2



The task of quantifying energy capability is not nearly so simple for gapped SiC arresters utilizing current limiting gaps. The voltage developed across (and the energy absorbed by) the gap-SiC block combination is the sum of the IR drop across the block and the arc voltage developed inside the gap arc chambers. As Figure 3 shows, the smooth TLD current wave crests in 200-300 microseconds, similar to MOV TLD. As the gap does not immediately develop voltage, the initial TLD current limiting is performed by the SiC block. After about 400 microseconds, the current arcs begin extending within the individual gap arcing chambers, resulting in the slow buildup of gap arc voltage. As gap voltage increases, the resulting TLD current is forced lower in magnitude.

Figure 3



The measured energy integration for the gapped SiC design will vary from discharge to discharge depending upon the consistency of the current limiting performed by the gaps. Both of the above examples were simulations of the typical performance of each type of arrester when applied to a 345 kV system. The line impedance, charge, and length characteristics were specified in Table 4 of IEEE C62.11.

VI. Discussion of Issues

From the early 1950s though the late 1970s, utilities typically selected gapped SiC Station Class arresters for applications requiring the best available (lowest) arrester protective levels. These arresters provided the largest margin of protection for equipment insulation. High fault current locations might also have necessitated the higher pressure relief capability of Station versus Intermediate Class arresters.

While the gapped silicon-carbide arrester designs have had a good service history, utilities are continuing to evaluate their overvoltage protection needs, in particular at locations that are currently protected by gapped silicon-carbide arresters. Once they identify locations and types of SiC arresters, they need to identify the manufacturer, arrester type, and catalog number (vintage) stamped on the arrester nameplate. This is the first step in determining the performance characteristic of the arrester.

VII. SiC Arrester Integrity Issue

Determination of the operating condition of a gapped SiC arrester can involve various methodologies. If the arrester is in service and cannot easily be removed, infrared imaging techniques can be used to assure that the arrester is not operating hot, a sign of degradation. Since larger arresters may not be perfectly graded due to external capacitive upset, hot spots at the top end might represent a normal arrester.

Typically, gapped SiC station and intermediate arresters were constructed with a resistive or resistive/capacitive grading circuit. This grading circuit, external to the gap-block stack, improved the arrester sparkover characteristic and performance under contaminated environmental conditions. At system operating voltage, these arresters typically conducted up to a few milliamperes of grading current. Since arrester grading current at operating voltage does not flow through the gap-block structure, grading current measurements only confirm the electrical integrity of the grading circuit. An arrester mounted on an insulating subbase with a grading current meter attached to the ground connection would allow grading current monitoring while the arrester is in service.

Another option for an arrester that is installed, but not energized, is to use a Meggar or Doble test set to measure the arrester's resistance or watts loss, respectively. These reduced voltage test set have traditionally proved to be effective in detecting arresters with moisture ingress problems.

While the above described techniques are effective at identifying an arrester in service that might have damage to its grading circuit or possibly moisture ingress concerns, they do not allow an evaluation of the condition of the arrester gaps or blocks. This can best be accomplished by removing the arrester from its service location and sending to a high voltage laboratory. Performing routine power frequency sparkover, grading current, and IIV/PD tests are a very good first step toward determining the condition of the entire arrester. IEEE Standard C62.1-1984 required that SiC station arrester rated 60 kV and above had a minimum allowed 60 Hz sparkover of 1.35 times rating. Similarly, for SiC station and intermediate designs below 60 kV rating, a minimum allowed 1.5 times rating was acceptable. Sparkover levels below these required minimums could identify an arrester with a degraded sparkover characteristic.

VIII. SiC Protection Issue

A utility with early vintage gapped SiC arresters could be afforded significantly improved protection by replacing them with MOV designs. The replacement of late model gapped SiC designs (see Table 1) will also provide measurable margin improvements. As the primary function of the arrester is to protect system equipment insulation from being damaged by overvoltages occurring on the line, it is critical that the utility understand that margin improvements can be achieved by conversion to MOV arrester designs. Armed with SiC arrester nameplate information, the utility has the opportunity to obtain catalog protection data on the subject arresters from the manufacturers. Comparison of these values with the catalog discharge voltage data on comparably rated MOV arresters, margin improvements can be determined. Combined with information on the dielectric integrity and criticality of equipment adjacent to these arresters, the utility can make an informed decision regarding the merits of replacing these SiC with MOV type arresters.

IX. Short Circuit Issue

Over the last 50 years, utilities have continued to upgrade their quality and level of service. Grids have been interconnected and fault current levels have significantly increased over what was originally expected at various locations. While SiC arresters may have had adequate pressure relief capability for the locations where the arresters were installed, system upgrades may have caused the available fault currents at some arrester locations to a level that exceeds the designed capability of the originally installed SiC arresters. In the unlikely event that one of these arresters would fail, the excessive fault current could result in a violent failure of the arrester.

The Duquesne Light Company had such a situation several years ago at a substation originally equipped with Intermediate Class SiC arresters, which at the time they were installed, had a short circuit capability sufficient to the location. Multiple circuit upgrades and interconnections resulted in available line-to-ground fault currents at this substation above 40 kA, well exceeding the original 16 kA capability of the SiC intermediate arresters. While the customer was tolerant of the high protective levels of the intermediate SiC arresters, he ultimately replaced these with new MOV arresters with pressure relief capability adequate to the location (4).

X. TLD/Energy Capability Issue

The TLD energy absorbing capability of gapped SiC arresters assembled with CL gaps is a function of the design of the valve block and gap assembly. The SiC valve block, by design, limits the magnitude of the TLD surge current that will flow through the arrester to a "critical" level. This "critical" current should not exceed the "critical" current capability of the series connected gap. If the magnitude exceeds this "critical" level, the gap may not be able to successfully develop arc voltage, ultimately resulting in valve block and arrester failure.

TLD tests performed on a 258 kV rated Station Class gapped SiC arrester, applied on a 345 kV system, indicate that the arrester discharges approximately 4.4-4.6 kV/kV rating per shot at an initial current level of about 1 kA. Similar tests were performed on a gapless 258 kV rated metal oxide arrester. The resultant energy absorbed per shot on this design was also about 4.6 kJ/kV rating at about 830 amps. For the TLD testing required by the C62.1 and C62.11 Standards, both arresters met the 20 shot durability requirement while discharging similar energy levels.

The energy capability difference between the two designs shows up at higher current levels than are required on the standard TLD test. Because the gap critical current is close to that occurring in the TLD test, the gapped SiC arrester energy discharge capability, at the defined waveshape, is, in reality, limited to that shown on the TLD test. In contrast, the gapless MOV arrester's capability is strictly a function of the energy absorbing capability of the metal oxide discs. Domestically produced HV station class MOV arresters typically claim energy capabilities exceeding twice those demonstrated by the SiC arresters on the TLD test.

XI. Conclusion

This paper presents some critical performance characteristics of gapped SiC high voltage arresters and compares them with MOV gapless arresters. It discusses issues that utilities should consider in their evaluation of the integrity and performance capabilities of gapped SiC surge arresters presently installed on their systems. It is intended that this paper provide technical assistance to utilities concerned with assessing their HV gapped SiC surge arrester application issues.

XII. References

(1) IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems ANSI/IEEE Std C62.22-1987.
(2) American National Standard Surge Arresters for Alternating-Current Power Circuits IEEE Std 28-1974/ANSI C62.1-1975.
(3) IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV) IEEE Std C62.11-1999
(4) Proceedings of the 1991 IEEE Power Engineering Society Transmission and Distribution Conference , Sept 22-27, 1991, in Dallas, Texas. Pages 424-431, entitled "Utilization of Polymer Enclosed Intermediate Class Arresters to Improve the Performance of Modern Power Systems", authored by Dennis W. Lenk, Joseph L. Koepfinger, and John D. Sakich.

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. Dennis is 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.