

**Application Considerations for Gapped Silicon-Carbide Arresters
Installed on Utility High Voltage Systems
Part II: Energy Consumption**

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Abstract: There has been increased global interest recently in identifying opportunities to conserve energy by reducing consumption, both in the residential and commercial areas. One such energy savings opportunity, in the utility environment, relates to the large number of gapped Station and Intermediate Class silicon-carbide (SiC) arresters still installed on utility high voltage systems. These gapped SiC arresters represented state-of-the-art protection during the 30+ years that they were installed (1950s thru 1980s). Application considerations regarding these gapped SiC arresters versus modern gapless metal oxide (MOV) arresters were presented previously in reference[1], which focused primarily on protection and durability concerns. The intent of this paper is to extend this initial effort and focus on energy consumption issues and energy savings opportunities associated with replacement of these high voltage gapped SiC with MOV arresters.

I. Introduction

In 2004, we participated in a joint venture with a US utility to evaluate a quantity of old style Station Class high

voltage gapped silicon-carbide (SiC) arresters recently removed from the utility's operating system. The utility was concerned about the electrical integrity and protective characteristics of these arresters. In total, 28 arresters were returned. Evaluation consisted of 60 HZ electrical testing and disassembly of a limited quantity of arresters, typically those with electrical test values different from the norm. 60 HZ testing included sparkover, Internal Ionization, grading current, and rated voltage watts.

This utilities interest in old style gapped silicon carbide (SiC) arresters, combined with continuing inquiries from other utilities, prompted writing reference [1]. This paper addressed technical considerations related to upgrading surge protection by replacing existing in-service gapped SiC arresters with new MOV arresters. Discussion focused on protective margin, pressure relief, and energy improvements provided by new MOV arresters versus design limitations associated with gapped SiC designs. This paper did not address energy consumption issues associated with the gapped SiC arrester's highly conductive grading structure.

The intent of this paper is to provide the utility with a quantifiable summary of potential energy savings that can be achieved by upgrading from gapped SiC to MOV arresters across their high voltage system.

While the energy savings estimates are based solely on one manufacturer's Intermediate and Station Class gapped SiC arresters, it is the author's opinion that all manufacturers of gapped SiC arresters during this era faced similar design issues, mainly control of the sparkover characteristic of these, sometimes quite tall, arresters. All manufacturers relied on grading components, oriented along the length of the gap stack, to counteract the influences of stray capacitance and external contamination affects. The amount of energy each design consumed is directly correlated to the conductivity of the individual manufacturer's arrester resistance grading circuits.

II. Discussion

While utilities understand that the new MOV arrester designs provide technical improvements in the form of improved protection and durability characteristics, many have not been able to economically justify updating surge protection, based solely on these improvements.

From this 2004 joint testing and disassembly effort, it became obvious that these older style gapped SiC Arresters were in good operating condition, even the early vintage (Series 3) arresters manufactured from 1957 thru 1966.

Electrical tests did indicate, however, that these gapped SiC arresters conducted high levels of grading current and dissipated significant watts when energized at their rated voltages. While the SiC arrester gap conducts no continuous current, the grading structure located in parallel with the gaps does

conduct continuous levels of grading current. The simple gap configuration of the early vintage Series 3 design required a highly conductive grading resistor structure, connected in parallel with the gaps. This "stiff" grading was necessary to control the sparkover characteristic of the long Series 3 arresters under all service conditions.

The design improvements incorporated in the later vintage Series 5 Station Class arrester (introduced in 1966) included the addition of external gap capacitors which allowed for the use of lower conductivity resistors. This redesign resulted in a marked improvement in the Series 5 protective characteristics (versus Series 3) and also provided more energy efficient performance in the form of lower watts dissipation.

In comparison to the gapped SiC arresters, the MOV gapless arresters, by design, conduct low levels of grading current continuously through the MOV disc column resulting in even lower levels of watts dissipation.

III. Purpose of Study

This analysis quantifies potential annual energy (KWHr) savings associated with the replacement of old style gapped high voltage SiC arresters with new gapless MOV designs. This analysis is based on measurements made during the joint test program and recent laboratory tests to characterize the non-linearity exponent of the Series 3 and Series 5 arrester grading resistors. This data was used to predict gapped SiC arrester watts loss as a function of applied voltage.

To make the analysis relevant to the utility, the watts loss calculations are

based on arresters applied at specific system voltages. Arrester watts loss values were estimated for both gapped SiC and proposed replacement gapless MOV designs. The difference between the gapped SiC and MOV arrester watts loss was converted to an annual KWHr savings.

IV. Results of Study

Tables 1, 2, and 3 summarize the results of this effort.

Table 1 estimates expected energy savings associated with replacement of Series 3 Intermediate Class arresters with equivalently rated gapless Intermediate Class MOV arresters. Note that the Series 3 gapped Intermediate SiC arrester was manufactured and installed on utility systems from 1957 thru 1982.

Table 1

Estimated Annual Energy Savings Associated with Replacement of Gapped Intermediate SiC Series 3 (1957-1982 Vintage) with Gapless MOV Intermediate Arresters

| Max Sys kV _{L-L} | Max Sys kV _{L-g} | MCOV Rating | | Gapped SiC Series 3 Arr Watts @ Max Sys kV _{L-g} | Nominal Estimated MOV Watts @ Max Sys kV _{L-g} | Watts Reduction by Replacing Gapped SiC with Gapless MOV | Estimated Annual KWHr Savings from Intermediate arrester replacement effort |
|------------------------------|------------------------------|-------------|------------|--|--|---|---|
| | | MCOV | Rating | | | | |
| 48.3 | 27.9 | 29 | 36 | 31.7 | 1.26 | 30.4 | 266 |
| | | 31.5 | 39 | 24.4 | 0.86 | 23.6 | 206 |
| | | 36.5 | 45 | 15.3 | 0.45 | 14.9 | 130 |
| 72.5 | 41.9 | 42 | 54 | 47.6 | 2.85 | 44.8 | 392 |
| | | 48 | 60 | 33.8 | 1.17 | 32.7 | 286 |
| | | 57 | 72 | 18.7 | 0.62 | 18.1 | 158 |
| 121 | 69.9 | 70 | 90 | 79.9 | 4.75 | 75.1 | 658 |
| | | 76 | 96 | 64.8 | 2.58 | 62.2 | 545 |
| 145 | 83.7 | 84 | 108 | 95.3 | 5.70 | 89.6 | 785 |
| | | 98 | 120 | 67.7 | 2.13 | 65.5 | 574 |
| 169 | 97.6 | 98 | 120 | 129.7 | 6.65 | 123.1 | 1078 |

Table 2 estimates expected energy savings associated with replacement of old Series 3 Station Class arresters with equivalently rated gapless MOV Station

arresters. Note that the Series 3 gapped Sic Station arresters were manufactured and installed from 1957 thru 1966.

Table 2

Estimated Annual Energy Savings Associated with Replacement of Gapped Station SiC Series 3 (1957-1966 Vintage) with Gapless MOV Station Arresters

| Max Sys kV _{L-L} | Max Sys kV _{L-g} | MCOV | Rating | Gapped SiC Series 3 Arr Watts @ Max Sys kV _{L-g} | Nominal Estimated MOV Watts @ Max Sys kV _{L-g} | Watts Reduction by Replacing Gapped SiC with Gapless MOV | Estimated Annual KWHr Savings from Station arrester replacement effort |
|---------------------------|---------------------------|------------|----------------|---|---|--|--|
| 48.3 | 27.9 | 29 | 36/37 | 31.7 | 2.52 | 29.2 | 255 |
| | | 31.5 | 39/40 | 24.4 | 2.52 | 21.9 | 192 |
| | | 36.5 | 45 | 15.3 | 2.52 | 12.8 | 112 |
| 72.5 | 41.9 | 42 | 54 | 47.6 | 3.94 | 43.7 | 383 |
| | | 48 | 60 | 33.8 | 3.90 | 29.9 | 262 |
| | | 57 | 72/73 | 18.7 | 3.86 | 14.8 | 130 |
| 121 | 69.9 | 70 | 90 | 79.9 | 6.6 | 73.3 | 642 |
| | | 76 | 96/97 | 64.8 | 3.8 | 61.0 | 534 |
| 145 | 83.7 | 84 | 108/109 | 95.3 | 7.9 | 87.4 | 766 |
| | | 98 | 120/121 | 67.7 | 3.4 | 64.3 | 563 |
| 169 | 97.6 | 98 | 120/121 | 129.7 | 8.9 | 120.8 | 1058 |
| | | 106 | 132/133 | 95.2 | 5.1 | 90.0 | 789 |
| | | 115 | 144/145 | 71.7 | 4.0 | 67.7 | 593 |
| 242 | 139.7 | 140 | 172 | 185.2 | 12.6 | 172.6 | 1512 |
| | | 144 | 180/182 | 159.7 | 10.5 | 149.2 | 1307 |
| | | 152 | 192/195 | 129.5 | 7.8 | 121.7 | 1066 |

Figure 1 illustrates the resistive grading structure used to control the Series 3 gap sparkover and stability characteristic.

Table 3 estimates expected energy savings associated with replacement of newer vintage Series 5 Station Class arresters with equivalently rated gapless MOV arresters. Note that the Series 5 gapped SiC Station arresters were manufactured and installed from 1966 thru 1982.

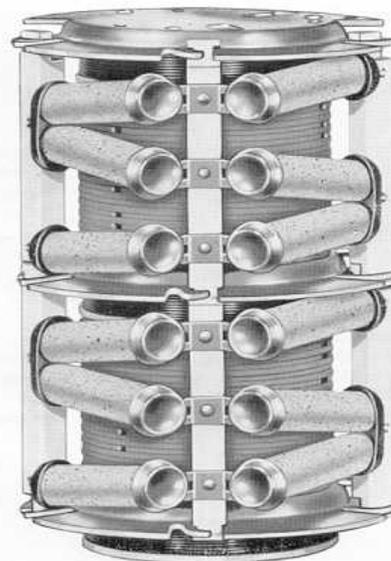


Figure 1

Table 3

Estimated Annual Energy Savings Associated with Replacement of Gapped Station SiC Series 5 (1967-1982 Vintage) with Gapless MOV Station Arresters

| Max Sys kV _{L-L} | Max Sys kV _{L-g} | MCOV | Rating | Gapped SiC | Nominal | Watts | Estimated Annual KWHr Savings from Station arrester replacement effort |
|------------------------------|------------------------------|-----------|------------|--|---|--|--|
| | | | | Series 5 Arr Watts @ Max Sys kV _{L-g} | Estimated MOV Watts @ Max Sys kV _{L-g} | Reduction by Replacing Gapped SiC with Gapless MOV | |
| 48.3 | 27.9 | 29 | 36 | 5.56 | 2.52 | 3.0 | 27 |
| | | 31.5 | 39 | 4.02 | 2.52 | 1.5 | 13 |
| | | 36.5 | 45 | 3.00 | 2.52 | 0.5 | 4 |
| 72.5 | 41.9 | 42 | 54 | 8.6 | 3.94 | 4.6 | 41 |
| | | 48 | 60 | 6.9 | 3.90 | 3.0 | 26 |
| 121 | 69.9 | 70 | 90 | 14.4 | 6.6 | 7.8 | 68 |
| | | 76 | 96 | 12.5 | 3.8 | 8.8 | 77 |
| 145 | 83.7 | 84 | 108 | 17.1 | 7.9 | 9.3 | 81 |
| | | 98 | 120 | 12.4 | 3.4 | 9.0 | 79 |
| 169 | 97.6 | 98 | 120 | 22.0 | 8.9 | 13.1 | 115 |
| | | 106 | 132 | 18.1 | 5.1 | 12.9 | 113 |
| | | 115 | 144 | 13.8 | 4.0 | 9.8 | 86 |
| 242 | 139.7 | 140 | 172 | 33.1 | 12.6 | 20.5 | 180 |
| | | 144 | 180 | 28.7 | 10.5 | 18.2 | 159 |
| | | 152 | 192 | 23.5 | 7.8 | 15.7 | 137 |

Examination of Tables 1 and 2 reveal that the utility can expect significant energy savings by replacing any in-service Series 3 Intermediate or Station Class arresters with similarly rated gapless MOV arrester. The energy savings is not as pronounced on Table 3 which summarizes energy dissipated by the Series 5 gapped Station Class arresters.

The minimal improvement in energy savings shown on Table 3 relates to the improved Series 5 gap/grading design when compared with the grading structure of the original Series 3 design.

Figure 2 shows the resistor and capacitor grading structure incorporated into the Series 5 arrester gap design



Figure 2

The manufacturing time frames associated with the reduction of arrester watts on (2) intermediate and (1) station arrester rating (bolded and highlighted in Tables 1 thru 3) are summarized in Figures 3 thru 5.

Figure 3

Estimated Arrester Watts Generated by 36 kV Gapped SiC Versus Gapless MOV Rated Intermediate Arrester Applied on 46 kV System 1957 thru 2009

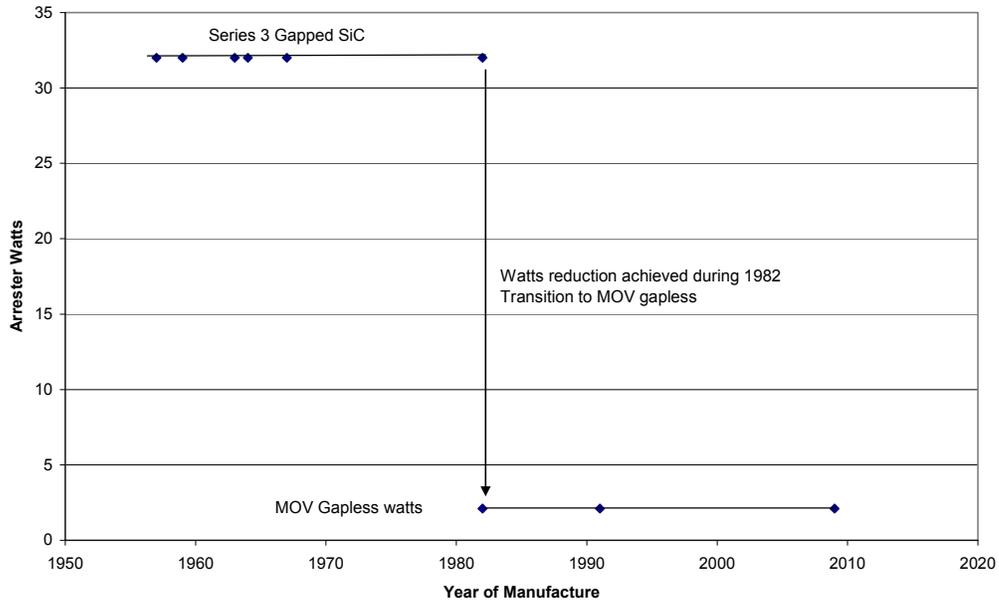


Figure 4

Estimated Arrester Watts Generated by 120 kV Gapped SiC Versus Gapless MOV 120 kV Rated Intermediate Arrester Applied on 161 kV System 1957 thru 2009

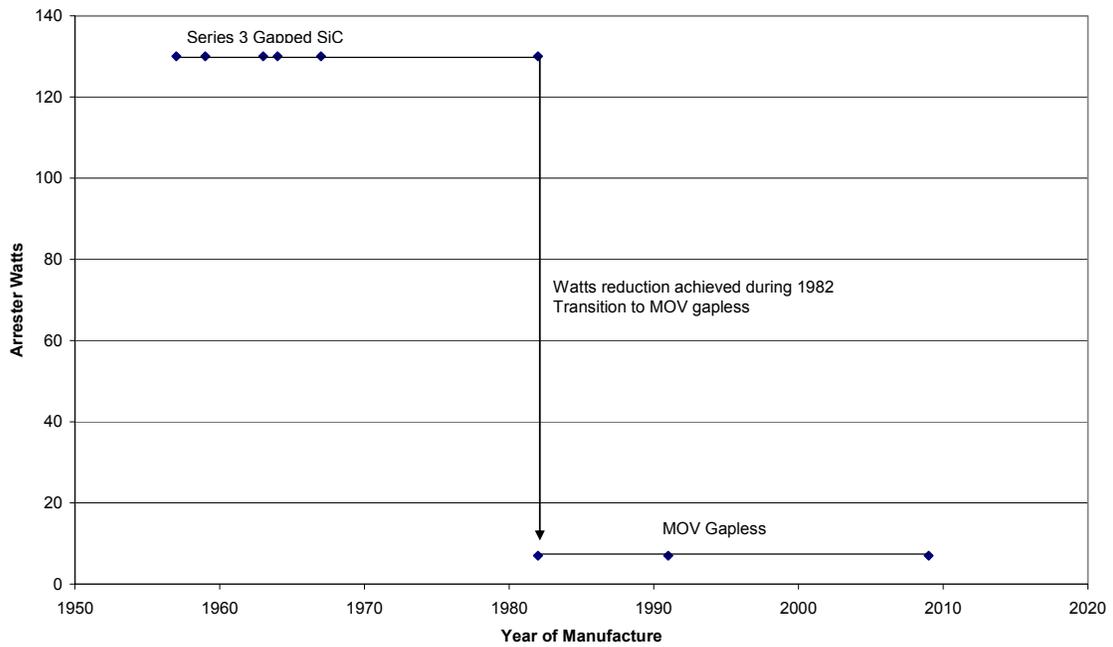
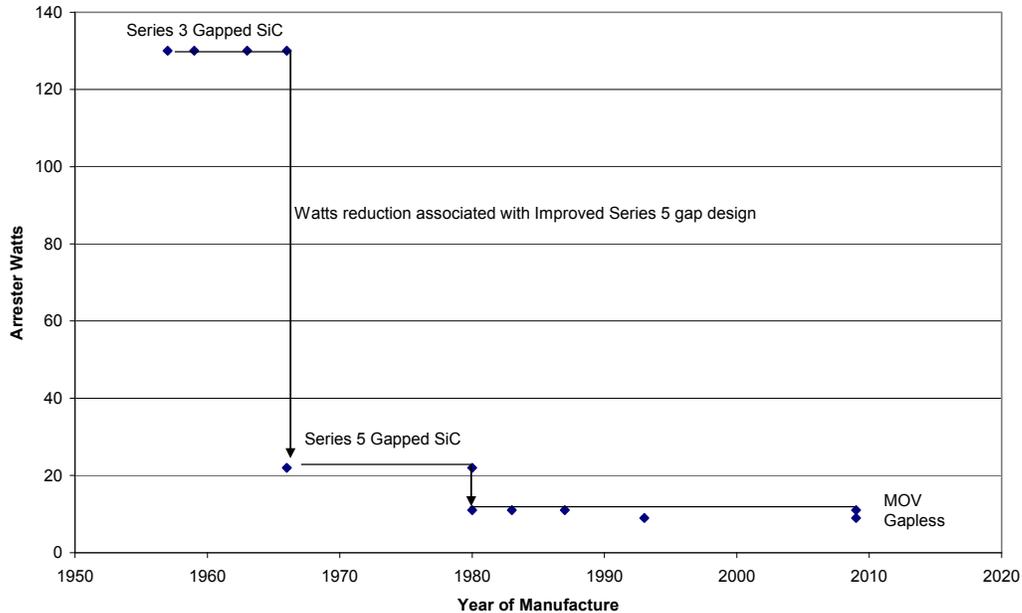


Figure 5

Estimated arrester watts Generated by 120 kV Gapped SiC versus Gapless MOV Station Arrester Applied on 161 kV System 1957 thru 2009



V. Conclusions

Figures 3 and 4 illustrate the watts profile versus manufacturing vintage for two ratings of Intermediate Class arresters. From Table 1 and Figure 3, 36 kV rated gapped SiC Intermediate arresters (manufactured from 1959 thru 1982) applied on a 46 kV system dissipate 31.7 watts. If this arrester is still in service, replacing it with a similarly rated Intermediate MOV gapless arrester would reduce energy losses at this location 266 KWHr per year. Similarly from Figure 4, replacement of a Series 3 120 kV rated gapped SiC Intermediate arrester (129.7 watts dissipation) with a gapless MOV Intermediate arrester would save 1078 KWHr per year. All calculations are based on single phase applications.

Figure 5 reveals that the Series 3 high watts characteristic design was also used to manufacture gapped SiC Station Class arresters manufactured from 1957 thru 1966. Specifically, examination of Figure 5 and Table 2 indicates 1058 KWHr annual energy savings achieved by replacing a 120 kV rated gapped SiC Series 3 arrester (applied on a 161 kV system) with an MOV Station Class gapless arrester. Similarly, the expected annual energy savings achieved by replacing a 192 kV rated gapped SiC Series 3 arrester (applied on a 230 kV system) with a similarly rated MOV Station arrester is 1066 KWHr.

As Figure 5 shows, the Station Class gapped SiC arresters were redesigned in 1966 with the introduction of the Series 5 family. This redesign was primarily motivated by a desire to improve the Station arrester’s protective

characteristic. This protective level improvement (reduction) translated into significantly improved insulation protective margins, ultimately allowing utilities to reduce required insulation levels for equipment installed on their system. Incorporation of gap grading capacitors into the Series 5 design allowed for a reduction in the conductivity of the arrester's gap resistive grading structure. The Series 5 gap grading design was manufactured from 1967 thru 1982, at which time MOV designs were introduced.

As Table 3 shows, an energy savings associated with replacement of Series 5 gapped SiC arresters with MOV designs can be achieved. However, the magnitude of the energy savings is low compared with Series 3. As shown, the projected annual energy savings associated with replacements of 120 kV

and 192 kV rated Series 5 arresters with MOVs are 115 and 137 KWHr, respectively.

As discussed in the reference [1], there were significant reductions in high voltage arrester protective levels associated with transition from Series 3 to Series 5, then ultimately to MOV arrester designs. The energy saving data presented in this paper demonstrates significant energy savings associated with replacement of early vintage Series 3 arresters. While energy savings are lower when converting from Series 5 to MOV, there is still an economic justification to make the change-out. Using this economic incentive, utilities can simultaneously take advantage of the MOV arrester's reduced protective and improved durability characteristics to improve reliability of equipment installed on these high voltage systems. .

VI. References

[1] Dennis Lenk, "Applications Considerations for Gapped Silicon-Carbide Arresters Installed on Utility High Voltage Systems", 2005/2006 IEEE PES Transmission and Distribution Conference and Exposition, Paper # TD 2005-000345.

VII. Biography

Dennis W. Lenk (F, 1999) has 40 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 30 years. Dennis is a member of the US Technical Advisory Group to IEC TC 37 and the NEMA 8LA Surge Arrester Section. 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.