Zinc-Oxide Arrester Design and Characteristics

Customer Service • 210 N. Allen St.•Centralia, MO 65240 • Phone 573-682-5521 • Fax 573-682-8714

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Brief History of Arrester Technology

The first commercially available lightning arrester was developed in the late 1890's by the Stanley Electric Manufacturing Company in Massachusetts. This arrester was rated 1,200 V and consisted of a simple rod-gap design. Although this device did perform the protective function, it did not have the capability to interrupt power follow current. Every arrester operation resulted in a system outage.

The early 1900s saw the development of the linear resistance-graded multigap arrester and the electrolytic arrester. The resistance-graded multigap arrester was the first to use nonarcing materials, such as copper and brass electrodes. As the kVA capacity of systems increased in the early 1900s, this multigap arrester design became inadequate.

Early Arrester Technological Developments

Simple Rod Gap - 1890's
Multigap with Linear Resistance - 1907
Electrolytic Arrester - 1908
Oxide-Film Arrester - 1918

The electrolytic arrester was introduced in 1908 and was the first design to use a nonlinear current-limiting resistance element to limit follow current and allow arc interruption. The design consisted of a sphere gap in series with a tank containing aluminum electrodes separated by a liquid electrolyte. The aluminum electrodes were formed into cells by electrolytically depositing a nonconducting film of aluminum hydroxide thick enough to withstand the applied voltage.

A lightning surge would momentarily puncture the nonconducting aluminum hydroxide film. However, the follow current from the system caused the punctured hole to heal itself by the same electrolytic mechanism used to initially coat the aluminum electrodes.

The main disadvantage of the electrolytic arrester was the electrolyte itself caused deterioration of the film. The electrolytic arrester, therefore, had to be recharged daily by connecting it to the power system.

The oxide-film arrester, introduced in 1918, was similar to the electrolytic design in its fundamental operation. It, too, required an external isolating gap. However, a dry grain lead dioxide or lead peroxide material replaced the electrolyte between metal electrodes. These oxide materials were pressed between electrodes. Characteristically, when connected to alternating current, they converted from a conductor to a nonconductor, forming an insulating film on the electrode. As with the electrolytic arrester, this film was punctured by overvoltage and the discharge current healed the puncture path, converting it to a nonconductive oxide.

Modern Era of Arrester Design

The introduction, in 1930, of the first silicon-carbide arrester marked the beginning of the modern era of lightning arrester design. The silicon-carbide arrester with a series multigap design is still in limited use today, exclusively on distribution class arresters.

The multigap silicon-carbide arrester design relied on the series gaps to spark over at a predetermined voltage level and then to interrupt system follow current, which was limited by the silicon-carbide material. A primary disadvantage of this design was the series gaps could not interrupt the flow of follow current until the system voltage made a zero crossing. As system voltages increased and lines lengthened in the 1940's and 1950's, the burden of energy absorption on the silicon-carbide blocks in an arrester became quite severe.

Modern Era of Arrester Technological Developments

Multigap with Silicon-Carbide Blocks - 1930
Current-Limiting Gaps with Silicon-Carbide Blocks - 1957
Metal-Oxide Arresters - 1976
Polymer Distribution Arrester - 1986
Polymer Intermediate Arrester - 1991
Polymer Station Arresters - 1993

The first current-limiting gap arrester design was introduced by Ohio Brass in 1957. It marked a historic breakthrough in arrester design. For the first time, the arrester series gaps were used for something more than sparkover and reseal duty. The current-limiting gap became an integral part of the energy absorbing system of the arrester. Because the gap was actually used to develop a back EMF during a power follow-current operation, the arrester did not have to wait for a system voltage-zero crossover to interrupt follow current. As soon as the back EMF of the silicon-carbide block and the gap exceeded the system voltage, follow-current interruption occurred. This significantly reduced the discharge duty of the silicon-carbide block.

The most important contribution of the current-limiting gap to system protection was it permitted a significant reduction in the arrester protective levels, with consequent reductions in system insulation levels. Figure 1 illustrates how system insulation levels have been reduced as a result of improved arrester technology.

The first current-limiting gaps were constructed with a nonporous mycalex material. Ohio Brass Type GP Series III intermediate class arresters, made from 1957 to 1983, were an example. An important improvement in the current-limiting gap design occurred in the mid 1960's with the development of porous alumina plate material. It enhanced the energy-absorbing capabilities of the current-limiting gap design and allowed additional reductions in system insulation levels. OB Type MP and Type MPR Series V station class arresters were examples of this design.

The late 1970's marked the introduction of zinc-oxide discs for surge arresters. The concept of zinc-oxide arrester design will be discussed during the remainder of this paper. Polymer housed surge arresters have been introduced by Ohio Brass since 1986 as the ultimate in surge protection.

Zinc-Oxide Varistors

Microstructure

Let's examine and compare microstructures of a zinc oxide disc and a silicon-carbide valve block. The most obvious difference between the two materials is the size of the grain particles. The silicon particles are a nominal 20 to 40 times larger than the zinc-oxide particles (see Figure 2).

The nonlinear characteristic of the sintered silicon-carbide block comes primarily from the nonlinear properties of the silicon-carbide particles, which average about 200 microns in diameter. A bonding agent, such as clay, bonds the silicon-carbide particles together during firing.

In contrast, the main component of the zinc-oxide disc is a 5- to 10-micron ZnO crystalline particle, surrounded by a 0.1-micron-thick highly resistive layer. This high-resistance layer forms the bonds between the ZnO particles of a fired ZnO disc.

Unlike the silicon-carbide element, whose nonlinear characteristic comes from the silicon-carbide particles, the resistivity of the ZnO particles is much lower than that of the boundary layers. Consequently, when high voltage is applied to a ZnO disc, the majority of the voltage develops across the boundary layers, producing the disc's nonlinear characteristic.

Boundary layers also determine the capacitance of the ZnO disc. A correlation exists between the discharge voltage and the capacitance characteristics of the disc as a result of the crystalline and boundary layer microstructure.

Voltage-Ampere and Exponent of Zinc-Oxide Disc

The voltage-ampere curve for a DynaVar 209-kV MCOV surge arrester is shown in Figure 3. Also shown is the voltage-ampere curve for an equivalently rated silicon-carbide MPR 258-kV rated surge arrester. Both have a protective level of about 2 p.u. 2(296 kV) peak phase-to-ground voltage at 10 kA impulse currents.

A heavy horizontal line is shown at 296 kV, which is the crest voltage line-to-ground for a nominal 345-kV system. Notice that the MOV V-I curve intersects the system voltage curve at less than one mA. The silicon-carbide V-I curve crosses the system voltage curve in the 200- to 500A range. This curve illustrates why the silicon-carbide arrester utilizes series gaps to take the voltage stress off the valve block elements. Without the series gaps, the silicon-carbide arrester would fail in a matter of cycles. In contrast, the MOV arrester, because of its high exponent, is capable of withstanding the small leakage currents at system operating voltage.

Compared to a silicon-carbide block, the outstanding characteristic of a zinc-oxide disc is its extreme nonlinearity. A 50 percent increase in voltage in the flat center portion of the V-I curve results in 10^6 current increase. In contrast, a silicon-carbide valve block current might increase only 5 to 10 times with a 50 percent voltage increase.

The voltage-ampere curve shows the zinc-oxide element has a varying exponent of nonlinearity. The high exponent region occurs in the medium current density region (on this curve, from 10 mA to 100 A). Over this range, the disc exponent is around 50. The actual exponent can be calculated from the curve by using the basic equation for nonlinear resistive elements:

$$\frac{I_2}{I_1} = \left(\frac{e_2}{e_1}\right)^x$$

Disc Low-Current Characteristic

The low-current end of the V-I curve (below 25 mA) has some unique characteristics. An understanding of these characteristics is very important in the design of the MOV arrester (see Figure 4).

The most obvious characteristic of this low-current region is the disc negative temperature coefficient of resistance. The series of curves shows how the resistive component of the disc current increases as the disc temperature rises. This decrease in disc resistance with temperature increase is prevalent only in the low-current region. The high-current discharge voltage characteristics of the disc are negligibly affected by variations in temperature.

The MCOV of a disc is the maximum continuous a-c operating voltage that can be applied to it. The lower horizontal line is the MCOV level for this disc. Notice that the resistive component of the disc current increases from less than 0.3 mA to almost 2 mA as the disc temperature increases from +25°C to +125°C.

The second important feature of the low-current end of the V-I curve is illustrated by the dashed line in Figure 4. This dashed line shows the capacitive component of current conducted by the disc. If you compare the magnitude of the capacitive current component and the resistive component (at 25°C) at MCOV, it becomes apparent the zinc-oxide disc at this voltage stress appears as a capacitor with mild loss. In fact, the dielectric constant of this disc is around 1000, which is the same order of magnitude of dielectric constant as the grading capacitors used in conventional silicon-carbide Ohio Brass MPR station class arresters.

Disc High-Current Characteristic

The high-current end of the V-I curve begins an upward trend above a few hundred amperes, resulting in a reduction in exponent to around 10. This voltage turnup at high-current density is a typical characteristic of the silicon-carbide valve blocks. However, the zinc-oxide disc exhibits significantly less voltage turnup as a result of high current than does a comparable silicon-carbide block.

MCOV

Unlike the conventional silicon-carbide arrester, a zinc-oxide arrester has voltage continuously applied across its very nonlinear zinc-oxide discs. Therefore, it is important to control the maximum continuous 60-Hz voltage applied to those arrester discs.

The MCOV level of a disc is the maximum continuous power frequency voltage that can be applied to the disc, where the disc will maintain thermal and electrical stability. For Figure 3, the disc MCOV level was 296-kV crest.

For an effectively grounded system, the MCOV typically corresponds to a system's maximum line-to-ground voltage.

Disc Discharging-Voltage Stability After High-Current and High-Energy Discharges

The zinc-oxide disc voltage-ampere characteristic is quite stable after being subjected to high-current discharges. The following chart shows the effect of two 100-kA, 4/8 discharges on the voltage-ampere characteristic of the disc.

ZnO Prorated Specimen Stability
After Discharging Two 100-kA High-Current Surges

	Before High Current Surges		**After High Current Surges**		**Percentage Change**	
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2
10-kA IR	6.25 kV	6.41 kV	6.31 kV	6.47 kV	+1.0	+1.0
Watts Loss at MCOV	0.86	0.81	0.92	0.88	+7.0	+8.0

In contrast to the slight increase in the zinc-oxide protective characteristic, the silicon-carbide valve block might exhibit an increase of as much as 10 percent in its discharge voltage characteristic after being subjected to high-current discharge duty.

Similarly, the zinc-oxide V-I disc characteristic is quite stable after being subjected to high energy long duration discharges. Figure 5 shows the oscillogram of a line discharge through a zinc-oxide disc. This operation causes the zinc-oxide disc to discharge its maximum energy capability.

A zinc-oxide disc was subjected to 10 consecutive maximum energy discharges at two-minute intervals.

The following chart shows the inherent stability of the prorated ZnO test specimen at both the high end and the low end of the disc volt-ampere characteristic.

ZnO Prorated Specimen Stability
After Discharging Maximum Energy

	Before Maximum Energy Discharges		After Maximum Energy Discharges		Percentage Change	
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2
10-kA IR	5.10 kV	4.94 kV	5.09 kV	4.97 kV	-.2	+.6
Watts Loss at MCOV	0.34	0.32	0.35	0.32	+2.9	0

Rate of Current Rise on Discharge Voltage

An area of much concern in recent years has been the effect of fast-front discharges on the protective characteristics of an arrester. For conventional silicon-carbide arresters, the concern has been primarily with the sparkover response of the arrester gaps.

However, another area of concern has been the voltage response of the nonlinear valve block as the rate of rise of the high-current discharge approaches times to current crest of less than one microsecond. This phenomenon has been examined on both the silicon-carbide and the metal-oxide discs.

The time of voltage response of a zinc-oxide disc to fast-front current discharges is similar to that exhibited by silicon-carbide discs. Both discs exhibit the characteristic of developing full disc voltage in about 70 percent of the time that the current reaches crest. For example, a silicon-carbide disc will develop full voltage in five to six microseconds while discharging an 8/20 current impulse. Similarly, a one microsecond to current discharge will develop full disc voltage in around 0.7 microsecond.

The curves on Figure 6 summarize the results of this examination. The 10-kA discharge voltage of both the Zn0 and the SiC discs was measured on a standard 8/20 current wave.

The time to crest for the 10-kA discharge was then reduced to 1.5 microseconds to crest. The data for each disc were normalized around the 8/20 discharge voltage level.

Notice that the silicon-carbide disc 10-kA IR increased by 23 percent over the 8/20 microseconds IR. In contrast, the zinc-oxide disc, 1-microsecond, 10-kA IR, increased by only 12 percent over the 8/20 IR. The 20-kA discharge voltage curves also exhibit a similar characteristic. The significantly improved response of the zinc-oxide disc over the silicon-carbide block assures improved protective margins for fast-front current discharges.

Thermal and Mechanical Properties

The energy capacity of a zinc-oxide disc is a function of the volume of the disc. A conservative energy capability figure is 200 J/cm^3 for a single operation. Exceeding the energy capability of the disc causes failure of the disc from thermal shock. A silicon-carbide disc fails due to electrical current tunneling with resulting block puncture. If its energy-absorbing capability is exceeded, a zinc-oxide disc mechanically fractures.

After a zinc-oxide disc has been allowed to equalize the temperature increase throughout its cross section, a second operation of equal energy content can be absorbed without damage. Generally, a one-minute interval between operations is adequate to ensure temperature equalization throughout the disc.

Disc Dimensional Considerations

As previously discussed, the energy-absorbing capability of a zinc-oxide disc is proportional to the volume of the disc. It is also well known that energy discharging requirements of arresters on lower-voltage systems generally are not as severe as those of arresters on high-voltage and EHV systems.

This knowledge allows smaller disc sizes to be used in applications requiring less energy discharging capabilities. This will be discussed later.

Discs of all diameters are designed to conduct approximately the same density of grading current at MCOV.

Gapless Zinc-Oxide Arresters

Zinc-oxide varistors with extreme nonlinearity (high exponent) and excellent stability are being produced today. It is possible to design a totally gapless surge arrester simply by using a series of zinc-oxide varistor elements that perform both the surge discharge and power frequency reseal functions. While the electrical characteristics of the gapless zinc-oxide arrester would seem to be determined solely by the characteristics of varistor elements, this is not quite the case. The design of the arrester housing, in particular the ability to transfer heat generated by the varistors to the housing (porcelain or polymer) and external atmosphere, determines the minimum amount of varistor that must be used in series and thus is a major factor in the gapless arrester protective levels.

The most important characteristic of the zinc-oxide varistor element is the volt-ampere curve. The typical normalized volt-ampere curve in Figure 7 shows voltage per length of varistor element (volts/mm) versus current per area (amperes/cm^2). Below a current density of 1 mA/cm^2, the characteristics are peak 60-Hz voltage versus the resulting peak resistive component of current. The higher current region of the characteristic is for 8/20 current waves.

The volt-ampere characteristic may be modified by changing either the basic material mix (zinc-oxide plus other metal-oxide additives), processing or the sintering cycle. For the purposes of this discussion, we will assume that the following desirable properties have been optimized by a combination of the above to give the volt-ampere curve shown:

1) High nonlinearity - large overall exponent from lightning discharge protective level to normal operating voltage.

2) High energy strength - single-shot joules/cm^3 switching surge energy without cracking due to thermal shock.

3) High current strength - maximum 4/10 two-shot strength without failures.

4) A-C stability - stability of low-current 60-Hz volt-ampere region with continuous a-c voltage stress, high energy discharges and high-current discharges.

Zinc-oxide varistor elements are pressed and fired in the shape of cylindrical sections similar to silicon-carbide valve blocks. The factors relevant to sizing the disc diameter for a given arrester class and size are the magnitudes of switching surge currents and associated energies, the maximum lightning surge currents and the desired protective levels. Disc diameter determines both the maximum energy capability and the temperature rise of the varistor for a fixed energy discharge. Manufacturing restrictions set an upper limit on disc diameter but varistor elements can be operated in parallel to obtain very large energy capability when needed.

For a given disc diameter, varistor length per kV of arrester size determines the protective levels of the arrester. The minimum protective levels obtainable are a function of both the zinc-oxide volt-ampere characteristic and the arrester thermal characteristics. Two areas must be examined to determine the maximum allowable continuous operating voltage on a varistor element.

First, the MCOV voltage must be low enough that aging due to continuous a-c voltage stress does not seriously shorten arrester life. At constant a-c voltage stresses, the varistor resistive current and watts may show a linear increase with the square root of time. The slope of increase in current versus square root of time is a function of the particular varistor mix and processing, sintering cycle, voltage level and temperature. Eventually, the increase in arrester heat generation at normal voltage could lead to a thermal runaway condition and arrester failure.

The second area of concern is thermal recovery from higher than ambient arrester temperatures. High energy surge duty or operation for dynamic overvoltages will cause an increase in varistor element temperature. Thermal runaway can occur because of the negative temperature coefficient of the varistor at low-current densities. Arrester design must allow for adequate heat transfer from the varistors at the maximum design temperature to ensure thermal stability.

Let's examine a specific example for 75-mm diameter station class zinc-oxide varistor elements. For varistor elements now being manufactured, the limiting factor for maximum MCOV and minimum protective levels is allowance for thermal recovery from high disc temperatures at MCOV and at the maximum ambient temperature.

The volt-ampere curve for a typical 75-mm diameter zinc-oxide varistor applied in a gapless surge arrester is shown in Figure 8. Voltage stress is in per unit of peak voltage. The 8/20 μs, 10-kA discharge voltage sets the lightning protective level at about 2.14 per unit of MCOV. (Note this is higher than the two per unit previously shown by Figure 3.) The 60-Hz resistive peak current increases from 0.25 mA to 1.8 mA at 1.0 per unit MCOV as the temperature increases from 25°C to 120°C.

The importance of this temperature dependence is demonstrated in Figure 9. Arrester watts generated at 1.0 per unit MCOV is plotted (as Curve No. 1) versus temperature along with the arrester heat dissipation characteristic. Curve No. 2 applies for a 60°C ambient temperature and shows the heat that a porcelain housing will dissipate versus disc temperature. The lower intersection of the curves for heat generated and heat dissipated is the stable operating point for a 60°C ambient temperature and a voltage of 1.0 per unit MCOV. The upper intersection is the varistor temperature above which thermal runaway will occur. At varistor temperatures below this level, the arrester housing will be capable of dissipating enough heat to cool the arrester varistors down to the stable operating point. A single high-energy discharge at the maximum kilojoule rating of the arrester would raise the zinc-oxide varistor temperature approximately 60°C.

The maximum temperature from which the arrester will thermally recover can be raised by improving the housing heat transfer, by using more zinc-oxide discs in series, or by improving the zinc-oxide nonlinear exponent to lower the watts generated curve.

Once MCOV per length of varistor is determined, the gapless arrester protective levels will be solely a function of the volt-ampere characteristic of the varistor elements. Figure 10 shows the discharge voltages for a zinc-oxide station class arrester. In the example, the ratio of peak MCOV to 8/20 μs 10-kA discharge voltage is 0.47. These curves indicate the general range of protective levels now obtainable for a zinc-oxide arrester with a heat transfer design.

The 60-Hz overvoltage capability for the gapless arrester will be determined by one of three considerations: 1) At high overvoltages, the energy capability of the varistors will be exceeded within cycles or seconds and the elements can crack due to the thermal shock to the ceramic varistor material; 2) at moderate overvoltages, a gradual temperature increase due to heat generated within the varistor will eventually exceed the maximum recoverable arrester temperature at normal voltage; and 3) a-c aging may be accelerated and become a factor for prolonged modest overvoltages. Figure 11 is a 60-Hz overvoltage capability curve for the gapless arrester of this discussion.

The zinc-oxide station class arrester just examined would have about a 10 percent higher 10-kA discharge voltage than a silicon-carbide arrester. A comparison of Figure 10 with current-limiting silicon-carbide arrester protective characteristics shows that the gapless zinc-oxide arrester would, however, provide better protection for front-of-wave and switching surge operations.

Intermediate class, riser pole, and distribution class gapless arresters have similar design constraints based upon block dimensions and thermal characteristics.

Mechanical Strength

The three primary sources of horizontal loading of DynaVar arresters are lead pull, wind or ice, and earthquake. The high strengths of the DynaVar designs meet most service requirements with generous factors of safety. The cantilever ratings of the DynaVar designs are as follows:

Type VL (Low-Voltage Station Class) - 70,000 in.-lbs.
Type VN (Gapless Station Class) - 150,000 in-lbs.

The maximum recommended continuous working base moment on these arresters is 40 percent of the above ratings.

Seismic Testing

Figure 12 shows the results of snapback testing performed on various Type VN Ratings of arresters. Tests were performed with the arresters mounted rigidly on the floor and also on number 272145 subbase. It is significant to note that the natural frequency and damping ratio measurements compare quite closely with comparably rated silicon-carbide arresters.

Pressure Relief

All DynaVar station class arresters have been designed with low- and high-current pressure relief mechanisms (see Figure 13).

The low-current pressure relief mechanism is identical to that previously used on conventional silicon-carbide station and intermediate class arresters; i.e., a thin tinned copper diaphragm designed in conjunction with a rupturing device to puncture the diaphragm if the arrester internal pressure exceeds the outdoor pressure by more than one atmosphere. This is to prevent the situation where an arrester may have internally failed and been thermally weakened by the low fault current arc. The ruptured diaphragm prevents any significant internal arrester pressure which could cause the thermally weakened housing to explode.

The high-current pressure relief design utilizes arc transfer chutes which direct the hot gases from the inside to the outside of the housing during a high-current failure. Transfer of the high-current arc to the outside takes only a few cycles and prevents the housing from exploding from internally-generated gases. Thermal fracture of the housing can occur if the housing is in contact with the high-current arc too long.

Figure 14 shows the results of high-current pressure relief tests performed on DynaVar arresters. In all cases, arc transfer external to the arrester occurred within a few cycles after fault current initiation.

Zinc-Oxide Disc Routine and Quality Control Testing

Because the zinc-oxide discs are so critical to the life and performance of the arrester, each station and intermediate class disc is subjected to an extensive series of routine tests outlined below:

Routine Tests

Ultrasonic (internal flaws)
Nine-shot Square-Wave Durability at High Energy
Measure Discharge Voltage (printed on block)
Measure Watts Loss
Measure Capacitance
Visual Examination

In addition, a sample from each batch of discs also is subjected to a series of quality control tests:

Quality Control Tests

Square-Wave Testing to Failure
Duty-Cycle Testing
65- and 100-kA High-Current Testing
Life Testing

Historical Review of Arrester Discharge Voltage Protective Levels Relative to Insulation BIL Levels

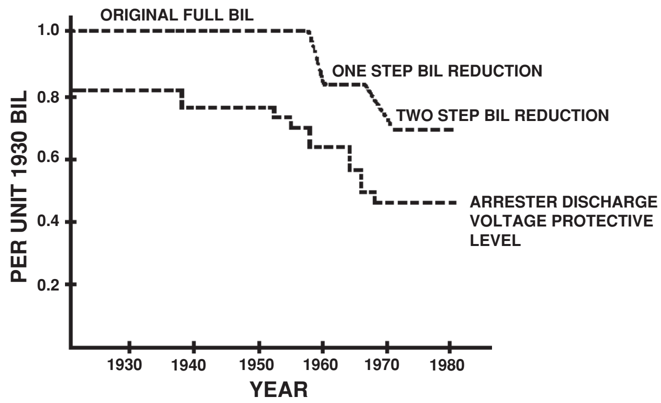


FIGURE 1

Comparison of SiC and ZnO Microstructures

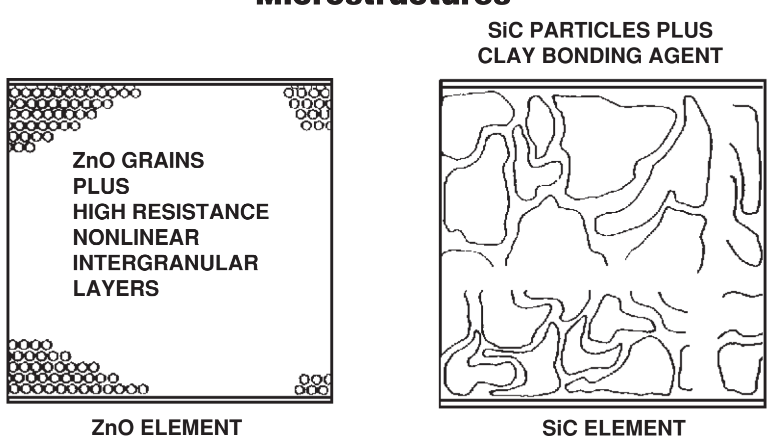


FIGURE 2

DynaVar VN209 Voltage-Current Curve Compared to MPR 258 and Linear Resistance

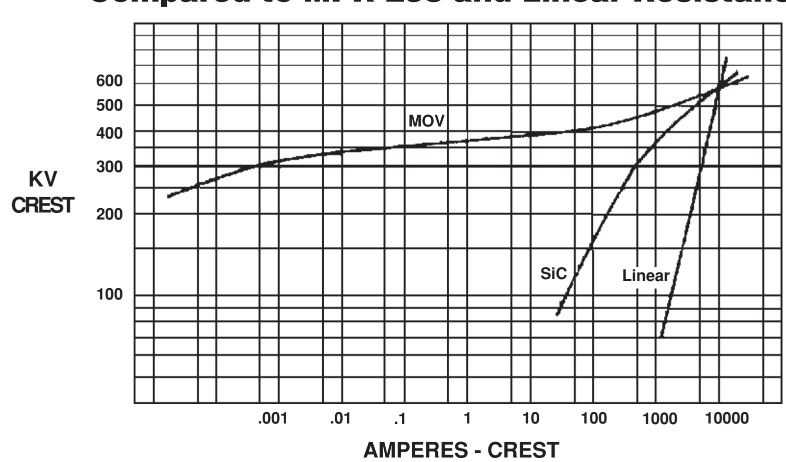


FIGURE 3

Temperature Effects on Voltage-Current Characteristics

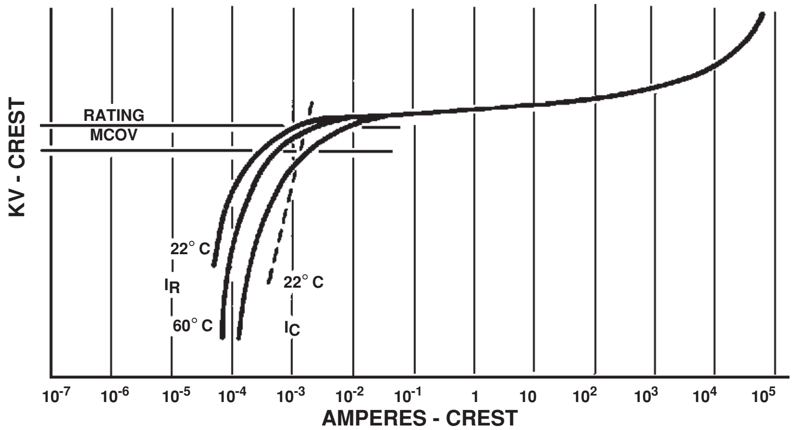
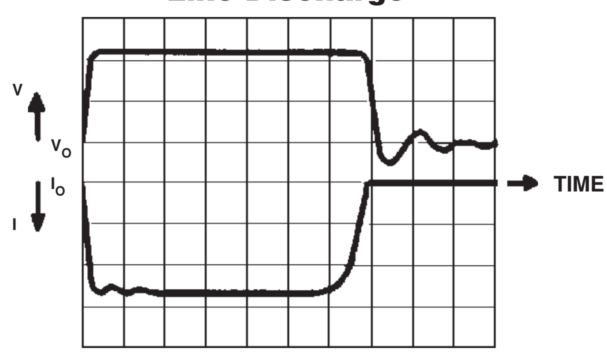


FIGURE 4

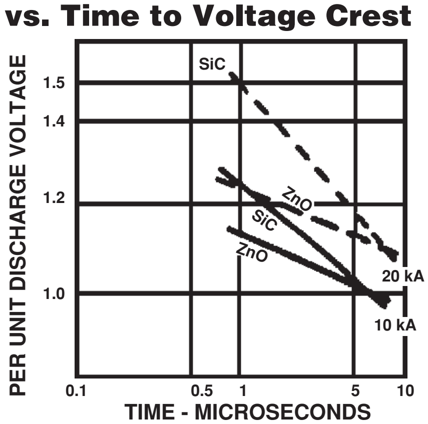
High Energy Transmission Line Discharge



UPPER VOLTAGE TRACE: 2 kV PER DIVISION
LOWER CURRENT TRACE: 500 AMPS PER DIVISION
TIME BASE: 500 MICROSECONDS PER DIVISION

FIGURE 5

Comparison of Discharge Voltage vs. Time to Voltage Crest



NOTE: 1.0 PER UNIT IS 10 kA DISCHARGE VOLTAGE FOR 8 x 20 μ SEC CURRENT

FIGURE 6

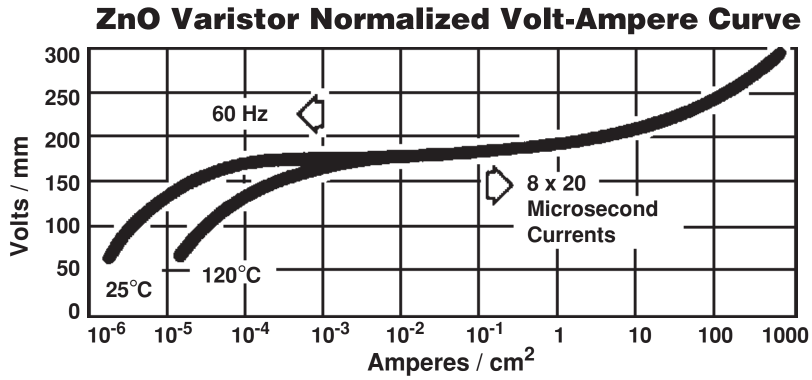


FIGURE 7

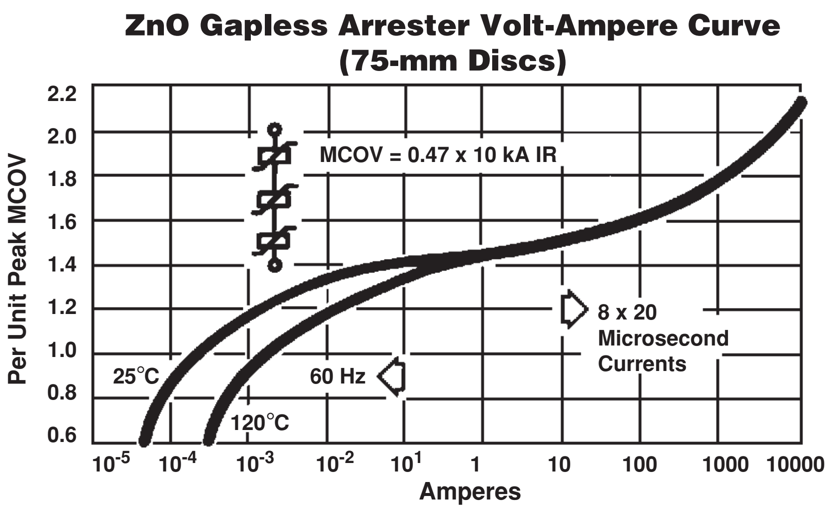


FIGURE 8

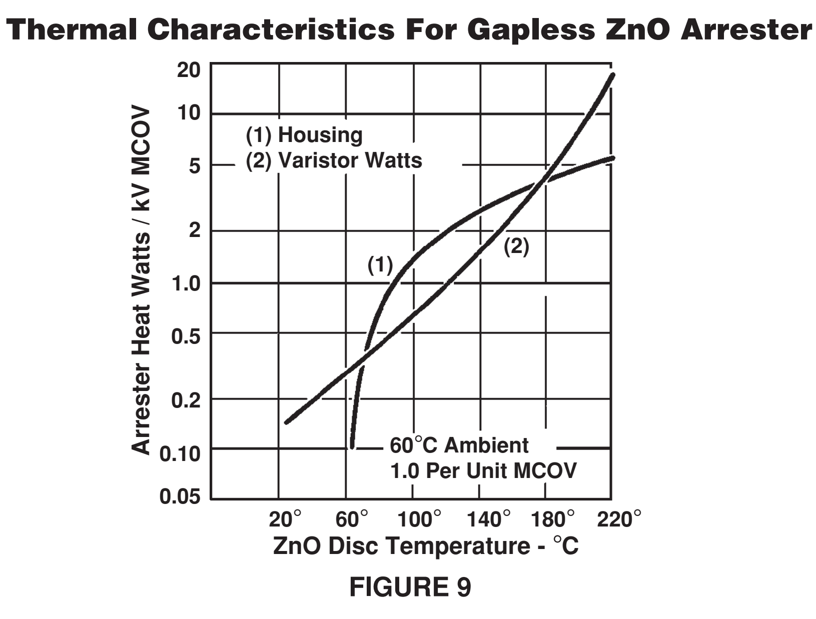


FIGURE 9

Volt-Time Protective Characteristic For Gapless ZnO Arrester

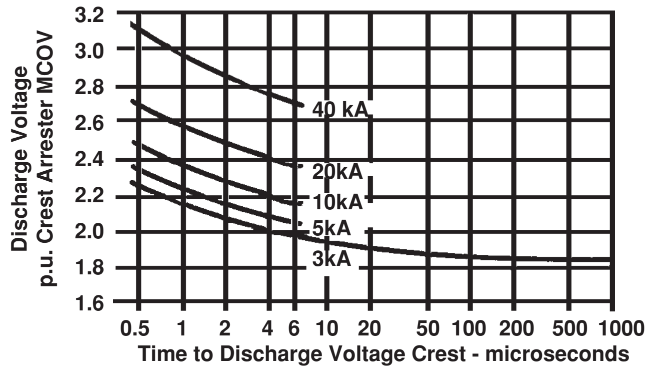


FIGURE 10

60-Hz Temporary Overvoltage Capability For Gapless ZnO Arrester DynaVar VL and VN

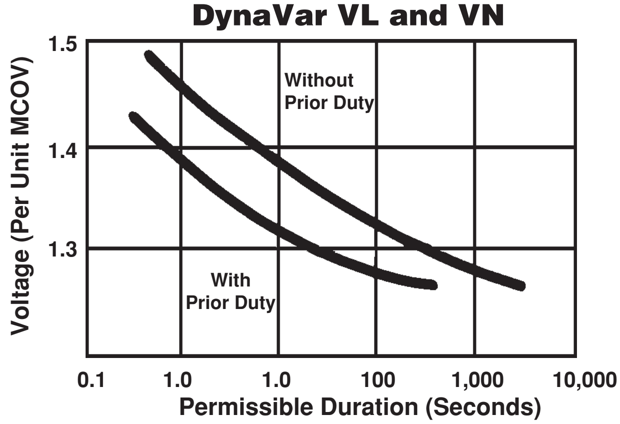


FIGURE 11

Snapback Testing Ohio Brass DynaVar Arresters

TYPE	MCOV	MOUNTING ARRANGEMENT	NATURAL FREQUENCY	DAMPING RATIO
VN	42	ON FLOOR	58	—
VN	42	ON SUBBASE	53.2	—
VN	140	ON FLOOR	11.5	>15%
VN	140	ON SUBBASE	10.7	>15%
VN	209	ON FLOOR	5.1	>15%
VN	209	ON SUBBASE	4.9	>15%

FIGURE 12

DynaVar Pressure Relief

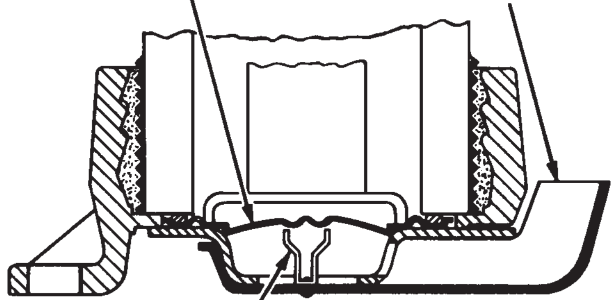


FIGURE 13

High-Current Pressure Relief Testing

Unit MCOV kV	Sym.	Asym.	Peak	Duration (Cycles)
VL-33	67.6	104.3	175.0	12.5

FIGURE 14