Monitoring of Transmission Line Surge Arresters

Overview of Methods and Approaches

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Technical Update, November 2013

EPRI Project Manager

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PRODUCT DESCRIPTION

The transmission line surge arrester (TLSA) is gaining acceptance as a remedial option to improve the lightning performance of poorly performing lines. TLSAs are often used in areas with poor soil conditions where a low structure footing resistance cannot easily be obtained. There are two types of TLSAs: 1) non-gapped line arresters and 2) externally gapped line arresters.

One concern in managing existing TLSA populations is assessing their condition with a view to identifying end of life and replacement. Unlike other transmission line components, surge arresters contain active components that are vulnerable to electrical overstressing. Non-gapped line arresters may also be subject to aging because they are permanently energized.

This report provides a summary of the essential characteristics of metal oxide arresters and an explanation of how these arresters function during overvoltages. It provides an overview of the long-term performance of surge arresters and factors that may result in failures and describes some considerations for condition monitoring.

Background

This project is part of a larger program to provide member utilities with guidelines for the selection, installation, and management of equipment in the transmission network. This work complements the Electric Power Research Institute (EPRI) report *Overhead Transmission Line Lightning and Grounding Reference Book 2012* (1025451), an extensive guide on the application of TLSAs.

Objectives

This work serves as a first exploration of techniques that can be used to monitor and assess existing populations of TLSAs.

Approach

The results presented in this report are based on a literature search into techniques for monitoring metal oxide arresters. The applicability of each method is evaluated against the known constraints of using monitoring techniques on transmission line equipment.

Results

Seven possible arrester monitoring techniques are evaluated for their applicability to TLSAs.

Applications, Value, and Use

The results provide a first exploration of techniques that can be used to monitor and assess existing populations of TLSAs. The information and principles introduced can be used by utilities when making choices concerning the need and practicality of monitoring TLSAs.

Keywords

Aging performance
Monitoring techniques
Transmission line surge arresters (TLSAs)

ABSTRACT

This report provides an overview of gapless metal oxide arrester technology, its functioning, and its possible degradation and failure mechanisms. Against this background, a number of TLSA condition assessment methods are described and their suitability is evaluated. A distinction is made between non-gapped line arresters and externally gapped line arresters. Seven methods are described and evaluated for their applicability to TLSAs.

EXECUTIVE SUMMARY

Transmission line surge arresters (TLSA) are quickly gaining acceptance as a remedial option to improve the lightning performance of badly performing lines. There are two types of TLSAs: 1) non-gapped line arresters and 2) externally gapped line arresters. One concern in managing existing TLSA populations is to assess their condition with a view of identifying end of life and need for replacement.

For non-gapped line arresters, utilities have historically relied on the frangible lead connection as an indication that the arrester has failed. The primary purpose of this lead is to isolate the arrester from the active line if it fails, so that the line can be taken back into service with minimal interruption. A broken lead would, therefore, also serve as an indication of TLSA failure.

For externally gapped line arresters, specific measures must be taken to allow for the identification of failed arresters. In these applications, the surge arrester unit is not permanently energized, and the external series gap ensures that the presence of a failed arrester does not prohibit the line from being reenergized. Consequently, there is no clear, visible indication that could mark the presence of a failed TLSA. For this reason, suppliers of EGLAs offer a failure indicator as an optional accessory. These devices typically pop a flag to indicate arrester failure.

This report provides a summary of the essential characteristics of metal oxide arresters and an explanation of how these arresters function during overvoltages. It provides an overview of the long-term performance of surge arresters and factors that may result in failures and describes some considerations for condition monitoring. Seven possible arrester monitoring techniques are evaluated for their applicability to TLSAs.

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INTRODUCTION

Transmission line surge arresters (TLSA) are fast gaining acceptance as a remedial option to improve the lightning performance of poor performing lines. TLSAs are often used in areas with poor soil conditions where a low structure footing resistance cannot easily be obtained. Flashovers are avoided when installing TLSAs as they limit the overvoltages across the line insulation to values that it can withstand. EPRI has published an extensive guide on the application of TLSAs, which can be found as part of the EPRI Overhead Transmission Line Lightning and Grounding Reference Book (Gray book) [1].

There are two types of transmission line surge arresters: (1) Non-gapped line arresters (NGLA) and (2) Externally gapped line arresters (EGLA).

NGLA application is where the arrester is electrically connected between the energized phase conductor and the grounded support structures with leads. The arrester in this application is continuously energized. One of the leads contains a frangible link, called a disconnector, intended to sever the connection in case of arrester failure.

For EGLA applications an external air gap is included in series with the arrester circuit. This air gap flashes over under overvoltages to complete the circuit that allows the arrester to limit the overvoltage across the line insulation. In this application the arrester is only energized when it is fulfilling its overvoltage arresting function.

To date most applications in the US has been of the NGLA type, but in recent years the use of the EGLA technology has been promoted as a way of solving the poor mechanical reliability of the arrester connection leads in many installations.

One concern in managing existing TLSA populations is to assess their condition with a view of timeously identifying end of life and the need for replacement. Unlike other transmission line components surge arresters contain active components which are vulnerable to overstressing in line of duty. NGLAs may also be subjected to aging effects because they are permanently energized.

Historically with NGLA applications Utilities have relied on the frangible lead connection as an indication that the arrester has failed. The primary purpose of this lead is to isolate the arrester from the active line if it fails, so that the line can be taken back into service with minimal interruption. A broken lead would, therefore also serve as an indication of surge arrester failure.

On EGLA applications specific measures need to be taken to allow for the identification of failed arresters. In these applications the surge arrester unit is not permanently energized and the external series gap ensures that the presence of a failed arrester does not prohibit the re-energization of the line. Consequently there is no clear visible indication that could mark the presence of a failed arrester. Suppliers of EGLAs offer therefore a failure indicator as optional accessory. These devices typically pop a flag to indicate arrester failure.

The approach to condition monitoring on TLSAs is significantly different to that of surge arresters installed in substations. This is primarily because failures of surge arresters installed on overhead lines are less critical than those installed in substations. Substation arresters often are installed close to other equipment and they are not automatically disconnected on failure as is the case for line surge arresters.

This report explores techniques that can be used to monitor and assess existing populations of transmission line surge arresters. A summary of the essential characteristics of metal oxide arresters are given in Chapter 2 together with an explanation of how these arrester functions during overvoltages. Chapter 3 provides an overview of the long term performance of surge arresters and factors that may result in failures. Considerations for condition monitoring are discussed in Chapter 4 and the report closes with a list of conclusions in Chapter 5. Technical references are listed in Chapter 6.

2

METAL-OXIDE SURGE ARRESTER TECHNOLOGY

Functioning

In its simplest form, a metal-oxide arrester consists of a single column of zinc-oxide resistor blocks that have a nonlinear voltage-current characteristic. The zinc- oxide blocks (active part) of the arrester are housed using either porcelain or polymer materials. The majority of arresters installed today are polymer-housed.

The highly nonlinear behavior of the arrester blocks is due to the semi-conducting nature of zinc oxide (ZnO) base material when doped with small additives of other metal oxides. A typical voltage-current relationship of an arrester is shown in Figure 2-1. The extreme non-linearity properties of this material become evident from this figure in that a twofold voltage increase results in a threefold increase in current magnitude.

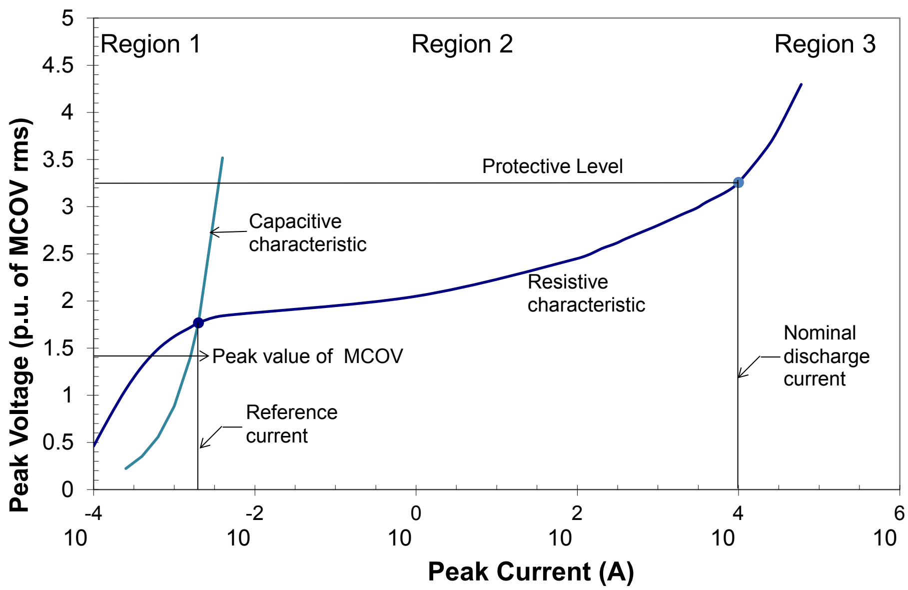


Figure 2-1
Nonlinear voltage-current relationship of a metal-oxide surge arrester.

The behavior of the blocks can best be described as three conduction regions depicted in Figure 2-1 [1]:

- **Region 1.** The surge arrester presents a high impedance to the power frequency voltage impressed on it. The current through the arrester is mainly capacitive with a very small (less than 1 mA) resistive component. The high impedance of the block is due to the insulating properties of the metal-oxide barrier that separates the individual zinc-oxide grains in the block. This behavior is demonstrated in Figure 2-2, which shows the current through the arrester when a voltage close to the maximum continuous operating voltage (MCOV) is applied.

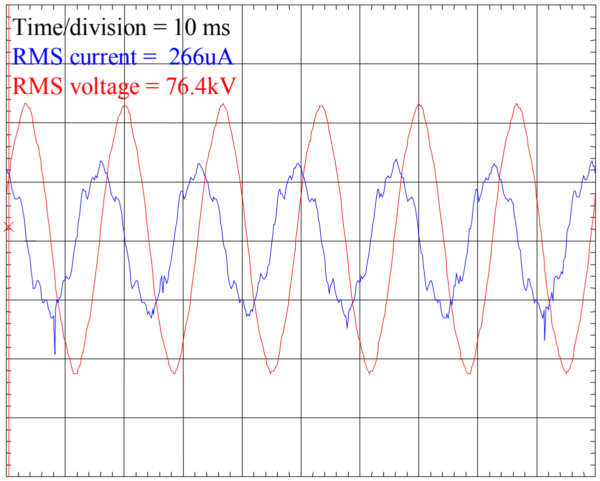


Figure 2-2
Typical voltage and currents across and through the arrester when operating in Region 1.

- **Region 2.** The surge arrester starts to go into conduction when the applied voltage exceeds the rated voltage of the arrester. In this region, the insulating properties of the inter-granular layers start breaking down, allowing electrons to tunnel through the insulating layer. This reduces the block resistance sharply as the voltage increases. This process is fully reversible, so the high resistance of the inter-granular layer will be fully restored if the applied voltage is lowered. Some manufacturers define the reference current as the point on the arrester voltage time characteristic when the resistive component of the current through the arrester is equal to the capacitive current. The current through the arrester in relation to the voltage across it is shown in Figure 2-3. An example of the voltage across the arrester and the current through it when operating fully in Region 2 is shown Figure 2-4.

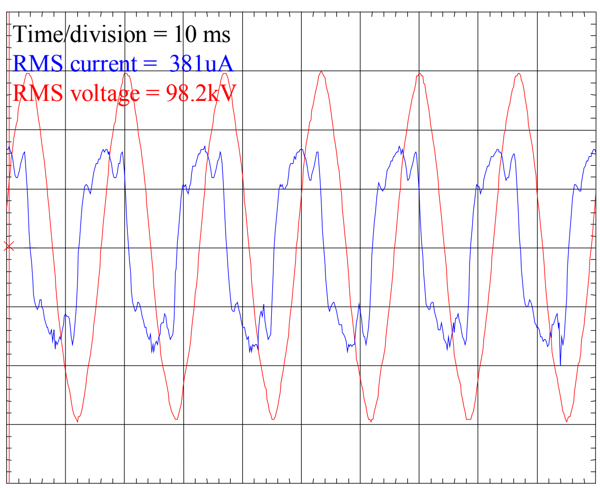


Figure 2-3
Typical voltage and currents over and through the arrester when operating on the border between Region 1 and Region 2.

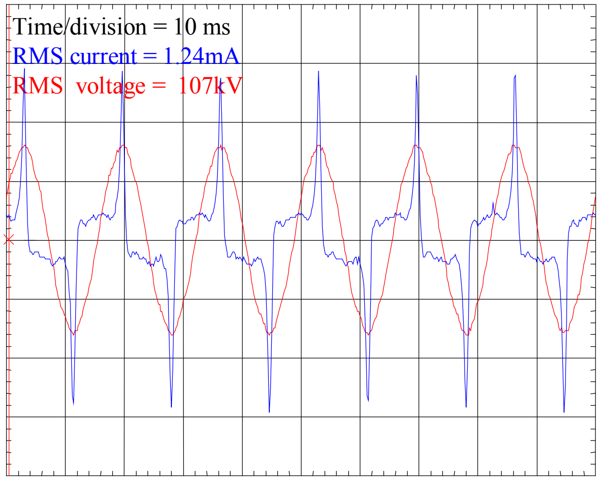


Figure 2-4:
Typical voltage and currents over and through the arrester when operating in Region 2.

- **Region 3.** The intergranular layer is fully broken down and the voltage current relationship is due to the zinc-oxide grains only. In this region, the arrester shows a linear current-voltage relationship.

Electrical Response of the MOV Blocks

The electrical response of a metal-oxide varistor (MOV) can be represented by a simple electrical circuit shown in Figure 2-5 [9].

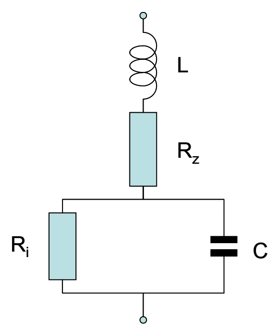


Figure 2-5
Equivalent circuit of a metal oxide varistor block

The components shown in Figure 2-5 represent the following aspects:

- "L" represents the inductance of the varistor and is determined by the current path. This inductance does not significantly contribute to the total impedance of the arrester column at power, or lower, frequencies and can be ignored in this domain. At high frequencies, however, this inductance becomes important and should be considered. A value of about 1 µH/m length is typically assumed..

- "R_z" represents the resistance of the metal-oxide grains, which has a resistivity of about 0.01 Ω-m. This resistance determines the voltage current relationship in the high current region, (Region 3) described earlier. In the low current region this resistor is small compared to the nonlinear resistance of the inter-granular layers (R_i) and is typically ignored for studies in Region 1.
- "R_i" is the highly non-linear resistance of the inter-granular layers in the metal oxide block. This resistance is very high for an applied voltage below the reference voltage, but it reduces rapidly as the voltage increases above U_{ref}. This high resistance is therefore dominant in determining the total resistance of the arrester when a normal power frequency supply voltage is applied across the surge arrester.
- "C" represents the capacitance associated with the inter-granular layers in the varistor block.

To describe the arrester behavior under normal operating voltage the arrester model can be simplified to the circuit shown in Figure 2-6.

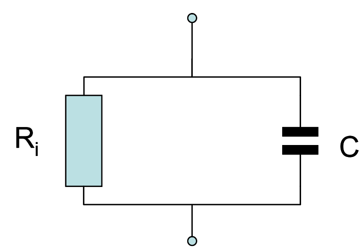


Figure 2-6
Simplified equivalent circuit of a metal oxide varistor block in the low current region

With reference to Figure 2-6, the low current behavior of the surge arrester can be described in terms of capacitive and resistive leakage current. Figure 2-7 provides important voltage and current characteristics for a typical arrester.

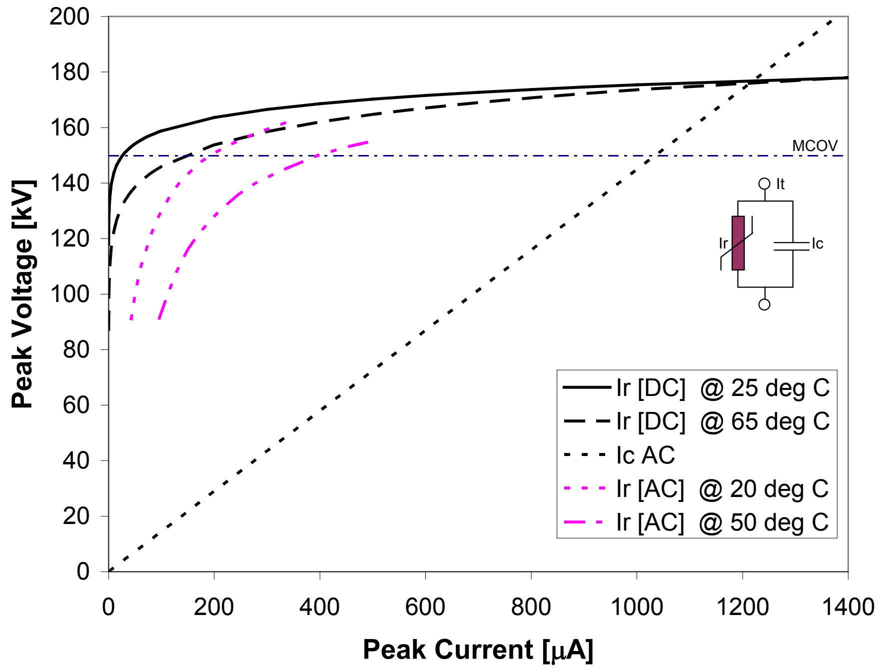


Figure 2-7
Typical voltage/current characteristics of a surge arrester

Arrester Capacitance:

The capacitance of a typical arrester, in pF, is approximately [9]:

$$C = 75\frac{\pi r^2}{U_{ref}} \text{ [pF]}$$

Where:

"r" is the radius of the block in cm

"U_{ref}" is the reference voltage of the block in kV.

An example of mainly capacitive current through the arrester at MCOV is shown in Figure 2-2. Note the high harmonic content of the current wave form. This is occurs because the block capacitance creates relatively low impedance for the harmonics present in the applied voltage.

Based on the capacitance equation above the calculated capacitive current through a typical arrester at MCOV should be between 1 mA to about a maximum of 5 mA depending on diameter of the zinc-oxide blocks. The expected total TLSA leakage current under normal service conditions should be below 1 mA, as shown by the example in Figure 2-2.

Under DC energization there is, obviously, no continuous capacitive current.

Arrester Resistance:

Figure 2-7 shows that the resistance of a metal oxide block in the low current region is strongly dependent on temperature and whether an AC or DC voltage is applied. The resistive current is higher under AC energization than under DC due to dielectric losses associated with the polarity reversals. In addition the resistance is dependent on the magnitude of the applied voltage. The voltage – current characteristic can be described as:

$$I_r = kU^{\alpha}$$

Where

"I_r" is the resistive current

"U" is the applied voltage.

"k" is an experimental constant, dependent on the number of blocks in series

"α" is the nonlinear coefficient which is a function of the temperature and voltage.

The resistive component of the arrester current under AC energization is typically 100-400 μA when the arrester is energized to its MCOV. Under DC energization, the (DC) current through the arrester is about 10 times lower if the applied DC voltage is equal to the peak value of the MCOV.

It isnot however possible to describe the full V-I characteristic with this expression because the exponent α may range from 3 to 50, depending on the operational region. . The higher values of α occur at the lower current range of Region 2, and the lower values of α describe the higher current region of the arrester. For modeling purposes, the exponent, α, is usually assumed to be constant—but the arrester characteristic is then only accurately representative of a narrow current range.

Response under surges:

The response of the arrester under surge conditions is illustrated in Figure 2-8. When a transient overvoltage is applied to the surge arrester, the nonlinear resistor blocks go into conduction smoothly and rapidly as the voltage increases, conducting the surge to the grounding system. The current through the arrester stops when the transient has passed, and the overvoltage is reduced. The breakdown process of the inter-granular material in the blocks occurs almost immediately, so there is no delay in the surge arrester operation. During the conduction process, the arrester absorbs many kilojoules of energy that raises the temperature of the blocks, which must be dissipated through the arrester housing as excess heat. After the surge current is discharged, the surge arrester—if applied correctly—will cool down, recover, and be able to repeat the protective function.

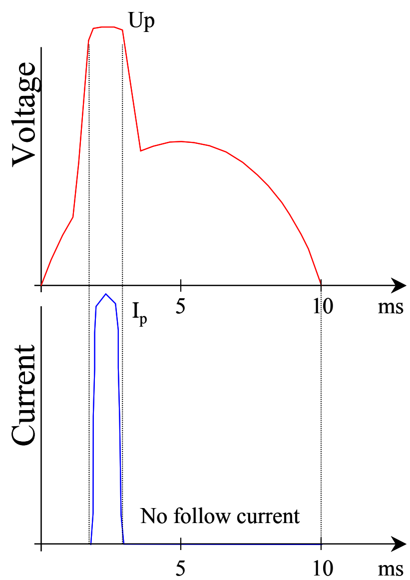


Figure 2-8
Schematic drawing of the voltage over and current through a gapless metal-oxide surge arrester during a transient.

The overall voltage rating of the arrester and the voltage discharge characteristic (voltage across the arrester corresponding to a particular discharge current) are directly proportional to the height of the metal-oxide blocks in the core. The diameter of the individual MOV blocks and total height of the stack determine the energy handling characteristics of the overall arrester.

Electrical Parameters

The parameters describing the arrester electrically are defined in Standard C62.11 [3] of the Institute of Electrical and Electronics Engineers (IEEE):

- *Maximum continuous operating voltage (MCOV)* is defined as the maximum power frequency voltage that an arrester is designed to withstand continuously before conduction or clamping starts. It is published as a line-to-ground voltage in rms.
- *Duty cycle voltage rating* (sometimes referred to simply as *rating*) is the voltage at which an arrester of a given MCOV passes a duty cycle test as defined by IEEE Standard C62.11. In the duty cycle test, the test sample that usually consists of a thermally pro-rated section of a full-size arrester is energized at duty cycle–rated voltage and subjected to 20 discharges of a classifying current (for example, 10 kA, 8/20 µs), spaced approximately 1 minute apart. The test sample is then heated to 60ºC and subjected to two additional duty cycle operations while energized at MCOV. After the second duty cycle operation, the sample remains energized at MCOV, and the sample temperature, resistive component of current, or power dissipation is monitored until thermal stability is demonstrated.
- *Protective level* of an arrester is defined as the voltage across the arrester when it is subjected to a current impulse of specified magnitude and waveshape. For example, the protective level at 10-kA, 8/20-µs waveshape for the arrester represented in Figure 2-1 is 3.2 per unit (pu) when expressed in terms of the rms value of the MCOV.

- *Energy capability* is defined in terms of how much surge energy can be absorbed by the arrester. For ANSI distribution class arresters, this is determined by applying two high-current impulses (4/10 µs, simulating lightning surge) following 20 impulses of 8/20 µs. For intermediate and station-class arresters, a long-duration current impulse test and a switching surge operating duty test are used to determine the arrester energy capability. The switching duty test comprises two current surges of a given magnitude and duration.

Arrester Standard C62.11 assigns a fixed duty cycle rating for each value of the MCOV. These values are listed in Table 2-1.

Table 2-1
Arrester duty cycle rating and MCOV as defined in IEEE Standard C62.11

MCOV (kV rms)	Duty Cycle Voltage (kV rms)		MCOV (kV rms)	Duty Cycle Voltage (kV rms)
22	27		84	108
29	36		98	120
36.5	45		115	144
39	48		131	168
42	54		140	172
48	60		152	192
57	72		209	258
70	90		245	312

Internal Construction

Metal-oxide arresters are manufactured with porcelain or polymer housings. Recently, polymer-housed surge arresters have gained in market share because they offer several advantages over porcelain housings. Polymer materials offer greater flexibility in construction, offering manufacturers more cost-effective designs options that provide reliable pressure relief if an arrester fails as well as a reduced risk for moisture ingress. Furthermore, polymer-housed arresters are lighter porcelain-housed arresters, and for this reason most TLSA installations utilize polymer housed arrester bodies.

Polymer Surge Arresters

The basic components of a polymer-housed surge arrester are shown in Figure 2-9.

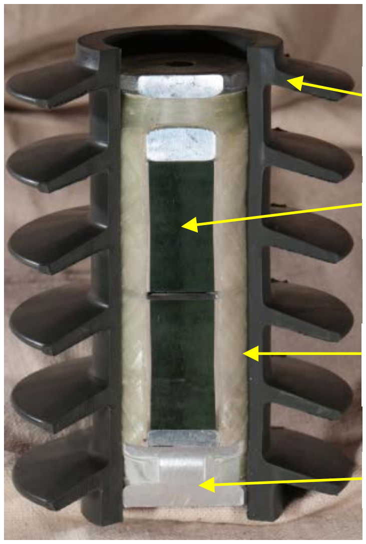


Figure 2-9
Disected polymer-housed gapless metal-oxide surge arrester.

In Figure 2-9, the following basic components are identified:

- At the heart of a Metal Oxide Surge Arrester is a stack, or column, of individual MOV blocks. This column may also contain metal spacers and springs. The column is fixed to connecting metal terminals at both ends and is under compression to ensure good electrical contact between the blocks.
- The central MOV block column is surrounded by a fiber-reinforced plastic (FRP) support structure, which provides the necessary mechanical support to withstand tensile and cantilever forces. The function of the FRP support is also to place the MOV column under compression. The housing design incorporates feature to allow internal arcs to propagate outwards to provide pressure relief in the event of arrester failure.
- The polymer housing provides insulating properties and protects the arrester column from weathering and moisture ingress, similar to polymer insulators.
- The metal end fittings at both ends of the arrester are used to connect external hardware to the arrester for mounting and to contain the arrester materials.

Polymer-housed surge arresters are available in several different designs, each optimized for the expected mechanical and electrical functionality required. An overview of these variations is given in Figure 2-10 [6].

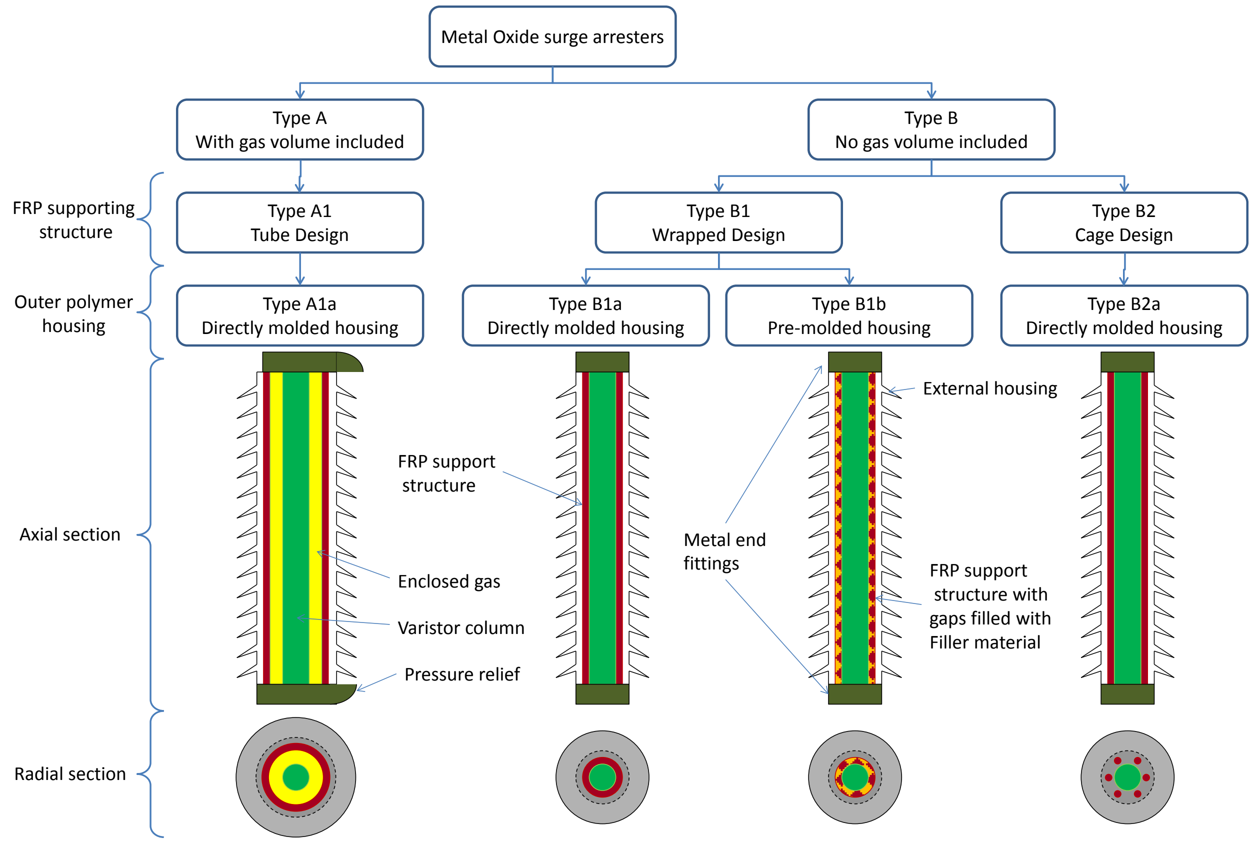


Figure 2-10
An overview of the design variants used in polymer-housed surge arresters (after [6]).

Briefly, they can be described as follows:

- **Tube design arresters** (Type A1) have a design similar to that of porcelain-housed arresters. The inclusion of gas inside the hollow insulator necessitates the use of end fittings with separate sealing and a sophisticated pressure relief system. This design, however, offers high mechanical cantilever strength [6]. This design variant is applied to station arresters with a high energy capability.
- In **wrapped design arresters** (Type B1), the FRP support structure is wrapped around the central column of MOV blocks. The enclosure structure may be open, completely closed, or closed with engineered weak parts to provide pressure relief (examples are shown in Figure 2-11). This design variant offers low weight but with limited mechanical strength [6]. The rubber external housing is either directly molded onto the FRP support structure or pre-molded and slipped over the internal components during assembly. In the latter case, silicone grease is used to fill any voids between the outer housing and internal components.
- **Cage design arresters** (Type B2) have an open construction in which the MOV block column is enclosed with FRP rods or loops. An example of this design variant is shown in Figure 2-12. The mechanical strength of this design may be further increased with additional wrapped bonding around the cage. This arrester design variant offers comparatively high mechanical strength and, because of its open design, good short-circuit performance [6]. The rubber housing is always directly molded onto the FRP cage.

The most frequently used polymeric housing materials are ethylene-propylene (EP) polymer and silicone rubber. Service experience with these polymeric housings has generally been good [8]. At high or medium voltage levels, the arrester unit can consist of multiple module units.

Closed Weave **Open weave** **Open**

Figure 2-11
Examples of surge arrester design variant B1: wrapped design.

Figure 2-12
An example of surge arrester design variant B2: cage design.

Porcelain housed Surge Arresters

The basic components of a porcelain-housed surge arrester are similar to that of the polymer housed arresters described earlier. It cosnsists of the following basic components [11]:

- The stack, or column, of individual MOV blocks forms the central active part of the arrester. This column might also contain metal spacers and springs. The column is fixed to connecting metal terminals at both ends and, importantly, is placed under compression to ensure good electrical contact between the blocks.
- The central MOV block column is housed in a porcelain hollow insulator. The insulator fulfills a number of important functions. It provides the necessary mechanical strength and is used to place the MOV column under compression. It also protects the arrester column from weathering and moisture ingress, and finally, the housing provides the necessary dielectric strength and external leakage distance.
- The metal end fittings at both ends of the arrester are used to connect external hardware to the arrester for mounting and to contain the arrester materials. The end fitting design should incorporate features to allow, in the case of arrester failure, for internal arcs to commutate to the outside to provide pressure relief. This can be in the form of a bursting disc or pressure relief vent.

The construction of porcelain housed surge arresters correspond to that of the Type A (tube design) described for polymer arresters – see Figure 2-10. The housing is usually filled with dry air or an inert gas. At high or medium voltage levels, the arrester unit can consist of multiple module units.

3

LONG TERM PERFORMANCE

The long-term performance of metal oxide arresters is measured against the ability to fulfill its intended function. A distinction can be made between functional deterioration – which means the non-linear resistive characteristic of the MOV blocks has undergone a permanent change and mechanical/insulation deterioration – where the mechanical or insulation characteristic of the arrester housing is affected.

It is important to know that all of the degradation and failure modes mentioned in this chapter are well-known and to a large extent addressed in the IEC and IEEE standards. Consequently modern day metal oxide arresters have a well-proven track record and are considered reliable devices.

Failure Modes

Thermal Runaway

The MOV blocks inside metal-oxide arresters are permanently under voltage since these arresters typically contain no series gaps. Consequently, under normal service conditions there is a permanent flow current through the blocks and the associated power loss may heat up the block material. The magnitude of the resistive component of the current through the arrester is strongly dependent on the temperature – see Figure 2-7. In this figure it can be seen that the block material has a negative temperature constant. This means that an increase in block temperature will result in a decrease of its resistance and that could, in turn, lead to a further increase in the current. Thermal runaway could therefore occur if the arrester housing is not able to effectively dissipate the heat generated in the blocks. The concept of thermal runaway can be explained with reference to Figure 3-1 [10, 11, 1].

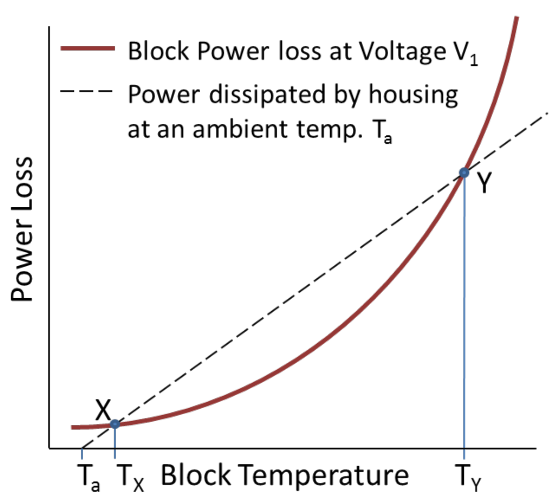
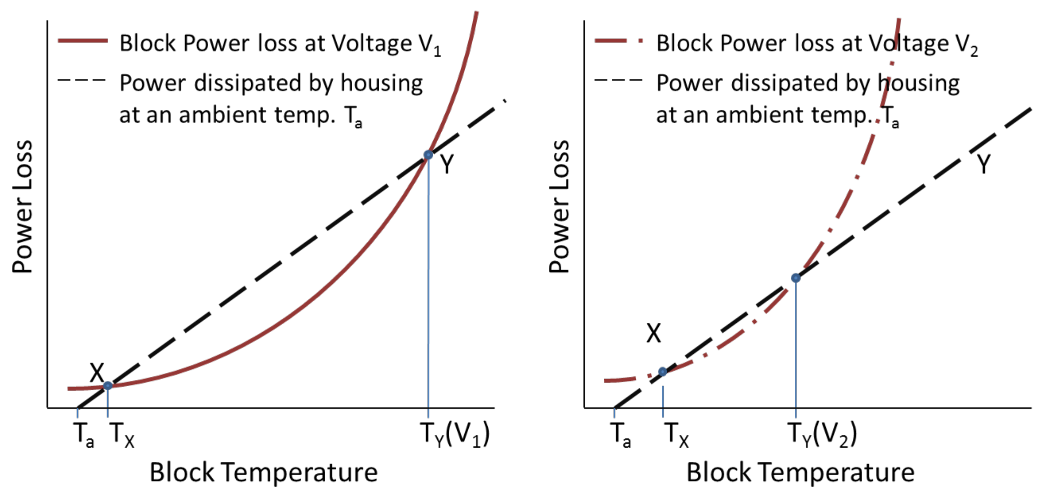


Figure 3-1
An schematic representation of a surge arrester thermal stability diagram.

The two curves in Figure 3-1 represent the power loss in the blocks as a function of block temperature when energized to a constant voltage (V_1), and the heat (power) dissipation through the housing at a constant ambient temperature T_a. For block temperatures between T_X and T_Y, the arrester power loss is below that of the housing curve. For these temperatures the arrester will cool down until a stable working point is reached at T_X where the heat dissipated though the housing equals the power loss of the blocks. Thermal runaway occurs above temperature T_Y since the heat loss through the housing is less than heat generated in the blocks. This results in a further temperature increase of the blocks, more current and eventually thermal breakdown of the block material and failure of the arrester. Factors that influence the arrester's sensitivity to thermal runaway are [1, 10, 11]:

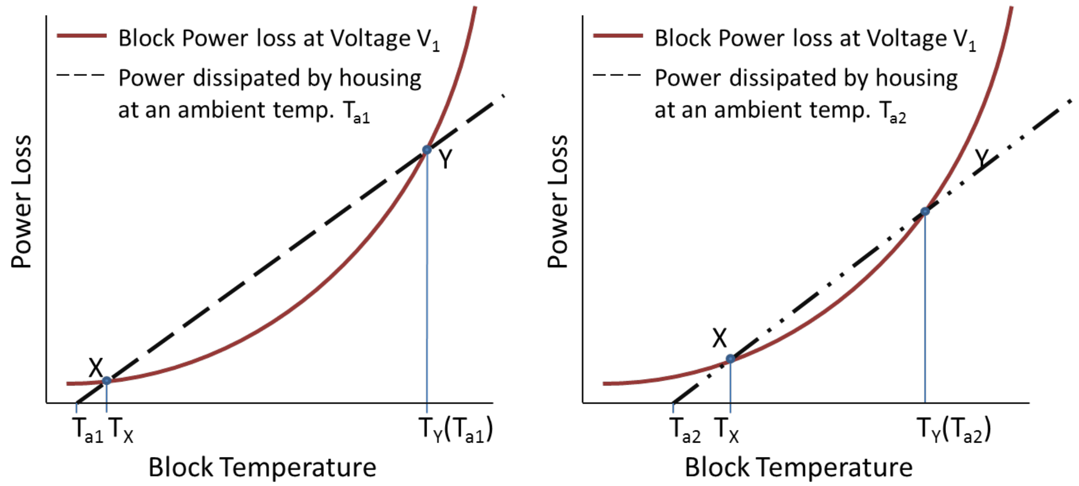
- **Applied Voltage:** An increase in the applied voltage across the arrester results in an increased level of leakage current through the arrester and, therefore a higher power loss. As shown in Figure 3-2 this results in a higher stable operating temperature (T_X) and a decrease in the maximum thermal stability temperature $\{T_Y(V_2)\}$. An increased applied voltage therefore increases the risk for thermal runaway.



Reference case **Elevated voltage (i.e. $V_2 > V_1$)**

Figure 3-2
An schematic representations of a surge arrester thermal stability diagram showing the effect of operating the blocks at a higher voltage.

- **Ambient temperature**: The effect of an increase in the ambient temperature is illustrated in Figure 3-3. A higher ambient temperature will lead to a smaller temperature difference across the arrester housing, thereby negatively impact the cooling effect of the housing. An increase in the ambient temperature will also result in a higher operating temperature (T_X) and a decrease in the maximum thermal stability temperature $\{T_Y(T_{a2})\}$. An increase in the ambient temperature increases therefore the risk for thermal runaway.



Reference case **Higher ambient temperature (i.e. $T_{a2} > T_{a1}$)**

Figure 3-3
An schematic representations of a surge arrester thermal stability diagram showing the effect of operating the blocks at a higher ambient temperature.

- **Aging of the block material:** Aging of the block material usually affects the high resistance inter-granular layer between the zinc oxide grains. This normally results in an increase in the resistive component of the leakage current. Also in this case the result is an increase in the operating temperature and a reduction of the maximum thermal stability temperature. Aged arresters are therefore more susceptible to thermal runaway.
- **Housing Design:** The ability of the housing to effectively dissipate the heat generated in the blocks also impacts the thermal stability of the arrester. Thermal runaway is less likely on housings that provide an efficient transfer of heat from the blocks to the environment.
- **Inadequate Electric Field grading:** On long arrester units grading rings may be needed to ensure an even voltage distribution across the blocks in the column. This ensures that all blocks are subjected to about the same voltage stress and that no hot spots develop along the arrester column.

System conditions that may initiate the process of thermal runaway:

- High or long duration temporary overvoltages as this increases the leakage current through the MOV blocks.
- Long duration surges with high energy content may heat the block sufficiently to push it over the thermal stability limit.
- In contaminated conditions dry-band arcing on the outside of the arrester and leakage current entering the MOV column on multi-stack arresters may heat the block sufficiently to cause thermal runaway.

Current overload

Localized heating of the block material during high-current surges may exaggerate non-uniformities in the current distribution through the block resulting in a concentration of the current density to a few narrow channels. The heating along these current paths may be sufficient to melt the zinc-oxide grains to form a “worm hole” through the block. For very fast rising current surges the mechanical stresses (due to thermal expansion forces) may be sufficient to crack the block. Examples of block failure due to high current surges are provided in Figure 3-4.

Figure 3-4
Examples of a MOV block failure due to a high current surge.

Housing Failure

One of the more common failure modes on surge arresters is an internal flashover of the arrester due to moisture ingress. This is specifically a problem on Type 1A (See Figure 2-10) arresters where the end fittings serve a dual purpose of sealing the internal components from the environment and provide a fast acting pressure relief in case of arrester failure. These conflicting demands force manufacturers to make compromises in the design, and which makes the end fitting seal– specifically for low cost arresters – the potential weak point of the arrester design.

The housing or internal components may also be damaged or broken during transport, installation or storage.

In contaminated locations polymeric housings may suffer erosion due to discharge activity associated for contamination of the external insulating surfaces.

Contamination on External Insulation Surfaces

Contamination on the external insulation surfaces of the surge arrester poses a particular threat to surge arresters [7, 1, 11]. During wet conditions, dry bands and dry band arcing cause a distortion in the electric field along the arrester. Under these conditions the MOV blocks may conduct high grading currents that could initiate thermal runaway. In addition, differences between the internal and external electric field grading may result in high radial fields and in extreme cases on type 1A arresters this may cause sparking across the air gap between the MOV column and the arrester housing. On multi-unit arresters external leakage current could enter the MOV column through the interconnecting flanges and heat the blocks. This could permanently damage the blocks, pollute the internal insulation surfaces and result in internal flashover.

Minimizing the effect of contamination on the surge arrester performance is to a large extent achieved by the design, dimensioning and choice of materials for housing. Important in this regard is to ensure that the leakage distance is sufficient for the environment where the arrester will be installed. The adequacy of the housing design may be verified with the pollution (contamination) test described in the IEC standard for metal oxide arresters [4]. Utilizing hydrophobic materials for the arrester housing, or treating porcelain housings with a hydrophobic coating, may also relieve the stresses on the blocks in contaminated areas [11].

Degradation Modes

Aging, or degradation, is considered a permanent change in the metal-oxide varistor (MOV) block characteristics. Degradation of blocks affects mainly the high resistance inter-granular layers of the zinc-oxide material. The following effects may contribute to ageing [1]:

- Chemical reactions between the block material and the surrounding environment. The block material may react and degrade if in contact with chemical radicals, such as the byproducts from partial discharges. Blocks are therefore provided with an external insulation layer to protect them from such chemical reactions.
- Constant energization may also result in ageing but this can be controlled to negligible levels through the block chemistry and uniformity. This aspect is also addressed in the standards through an accelerated aging test.
- During high current impulses some of the inter-granular layers may be damaged which contribute to the aging of the block material over time. From testing it is known that the amount of aging is more related to current amplitude than it is to the energy dissipated by the current surge [10]. Experimental results suggest that the residual voltage may be degreased with up to 6% after the blocks have been subjecting to 1000 high current impulses [10].

Arrester characteristics that may impact the aging process are [10]:

- Composition of blocks and the manufacturing process: The chemical composition of the block determines the quality of the inter-granular layer and its susceptibility to premature aging.
- Homogeneity of block material: More homogeneous block materials result in a more even current density throughout the block, thereby avoiding localized hotspots which could contribute to premature ageing.
- Working temperature of the arresters: The working temperature of the arresters is dependent on the continuous operating voltage, the ambient temperature and the heat transfer characteristics of the housing. Blocks running at high temperatures tend to age quicker.
- Working voltage: Arresters which are energized to higher voltages than the defined continuous operating voltage may be subject to accelerated aging.
- Linearity of the voltage distribution along the arrester column. This is related to the previous point. A highly non-linear voltage distribution along the arrester column may result in an over stress of the blocks located in high e-field regions. The higher operating voltage across these blocks may age them quicker and could result in corona from the edges of the blocks. This may, in turn, deteriorate the insulating collar around the block material.

- Chemical composition of the environment: The block material may react with the byproducts of internal arcing or corona which may result in significant premature aging. The block material may also be affected by other chemicals such as SF6, and oil immersed arresters may be affected if the insulating oil has a high temperature, such as in large power transformers.
- Contamination and dry band activity on the arrester housing: This aspect is discussed in the previous section.

Degradation of the housing:

- Erosion of polymer housing: External leakage current activity on the arrester housing may result in erosion of the polymer housing material.
- Corrosion of the end fitting and seals: In contaminated regions corrosion of the metal part of the arrester may occur if inappropriate or inferior materials are used.

Long term Performance of TLSAs

Aging of transmission line arresters is largely dependent on the type of installation. Non-gapped and externally gapped line arresters will be discussed separately.

Non-Gapped Line Arresters

For non-gapped line arresters (NGLA) the arresters are continuously energized and therefore subjected to the same stresses and aging phenomena than substation arresters. Thus all the aging and degradation effects described above apply. That is, aging due to both the continuous application of the P.F. voltage, temporary overvoltages and the conduction of overvoltage surges.

For NGLAs there is however an important mitigating condition. For line arresters it is not necessary to select arresters with a low protective level, as it only protects recoverable line insulation and not non-self-restoring insulation as is the case with substation arresters. This means that for the same system voltage, arresters with a higher MCOV or Rated voltage can be utilized. Consequently the normal day-to-day stress on TLSAs is generally lower than that on substation arresters and therefore also the aging stresses.

The arrester housing material may also be subject to aging as it may be exposed to high electric fields and corona or dry band discharges when wet.

Externally Gapped Line Arresters

Externally gapped line arresters (EGLA) the external gap isolate the arrester and it is accordingly not permanently energized. The active parts of the EGLA arrester bodies (i.e. MOV blocks) are therefore not subjected to aging due to P.F. voltages or temporary overvoltages. Block aging can only occur as a result of conducting lightning overvoltage surges.

Although the arrester body is not energized, it is situated in a high electric field and therefore it is possible that the housing material may be subjected to aging as a result of water induced corona discharges.

4

MONITORING OF LINE ARRESTERS

Introduction

Many techniques and methods have been developed in the past for monitoring of substation surge arresters. Even so, many utilities do not perform any structural monitoring on surge arresters at all, because in many respects surge arresters can be regarded as maintenance free. They contain no moving parts that could wear out and the non-linear characteristic is in principle the result of a fully reversible process. However there are a number of effects, as described in the previous chapter, that could result in permanent changes (or aging) of the arrester components. Monitoring on substation arresters are therefore only performed in situations where it is important to identify such changes at an early stage so that arresters can be replaced before failure. This is typically applicable to arresters installed to protect critically important equipment. Failures of a surge arrester and the subsequent fault on such locations in the system may have severe consequences. In addition arresters are usually installed very close to the equipment they are protecting. A failure of the arrester – especially porcelain housed ones – may cause consequential damage to nearby equipment if the housing fails explosively due to an internal arc.

These reasons for monitoring do not true true for TLSAs since these installations are already designed to limit the effect of failed arresters on the continued system operation. On NGLA installations disconnectors are used to isolate the arrester from the system in the event of failure. On EGLAs the same functionality is achieved by the series external gap which isolates the arrester unit from system voltages and system generated overvoltages.

Moreover the correct operation of the TLSA is less critical than for substation arresters. On transmission lines the TLSA is installed to protect self-restoring insulation so a failure of the arrester to protect the line insulation against a lightning overvoltage would only result in a transient fault. In substations, however, arresters protect substation primary equipment, e.g. power transformers or GIS, with non-self restoring insulation. A failure of a substation arrester to adequately protect the equipment insulation would result in a lengthy permanent fault.

Reasons for monitoring TLSAs are different to substation arresters. This may include:

- Monitoring the number of times it conducts a surge to confirma TLSA is installed in the correct location.. In order to optimize costs choices are typically made with regards to the placement of line arresters along a line. In many cases the total line performance of a badly performing line is determined by a few rogue structures, usually located on exposed rocky outcrops with poor grounding conditions. The arrester placement choices can then be confirmed by monitoring the number of arrester operations. A few operations without an improvement in the line performance may suggest the arresters are installed at the incorrect location.
- Identifying failed arresters. The series gap on EGLAs and the disconnector installed on NGLAs ensure that the arresters are disconnected quickly from the system on failure. In many cases this results in minimal visual signs of arrester failure because it is not subjected to multiple instances of power frequency fault current (e.g. during reclosing events). It can

therefore become challenging to identify failed arresters from ground based inspections. The same is true for NGLA installations, but on these a broken disconnector serves as an indication of a failed arrester. Service experience show, however, that in many cases disconnectors fail due to mechanical overload resulting in the unnecessary replacement of arresters still in good working order.

In principle it is relatively simple to do condition monitoring of surge arresters. They have a known voltage/current relationship and any significant deviation from this characteristic would indicate an aged or deteriorated arrester. In addition it is generally found that the deterioration of the blocks is generally a slow process which provides enough time to detect and identify failing arresters. Several diagnostic methods have been developed and most are described in detail in the IEC standard 60099-5 [5]. The following is a brief description of common condition monitoring methods:

- Visual inspection
- Temperature measurement
- Ultraviolet inspection
- Surge counting
- Leakage current monitoring
- Insulation resistance
- Characterization of the low current region (AC and DC tests)

Visual Inspection

Description of Technique

During a visual inspection the arrester is visually inspected for any signs of aging such as corrosion of the end fittings, deterioration of the pressure relief (if visible) and erosion of the housing in the case of polymeric housed arresters. Visual inspections may also serve to verify that the arrester is correctly installed and that the grading rings (if required) are positioned correctly. Examples of problems that can be detected with visual inspection are shown in Figure 4-1.

Visual inspection may also be used to identify failed arrester units. On polymer arresters this may be evident from damaged arrester housings – see Figure 4-2. On porcelain housed surge arresters an operation of the pressure relief is usually noticeable as a white deposit on the insulating surface, flash marks or cracks in the porcelain housing – see Figure 4-3.

Visual inspection cannot be used to detect internal damage or deterioration.

Erosion on a polymeric arrester housing

Incorrect installation, top and bottom units interchanged

Figure 4-1
Examples of arrester problems that can be detected with visual inspection.

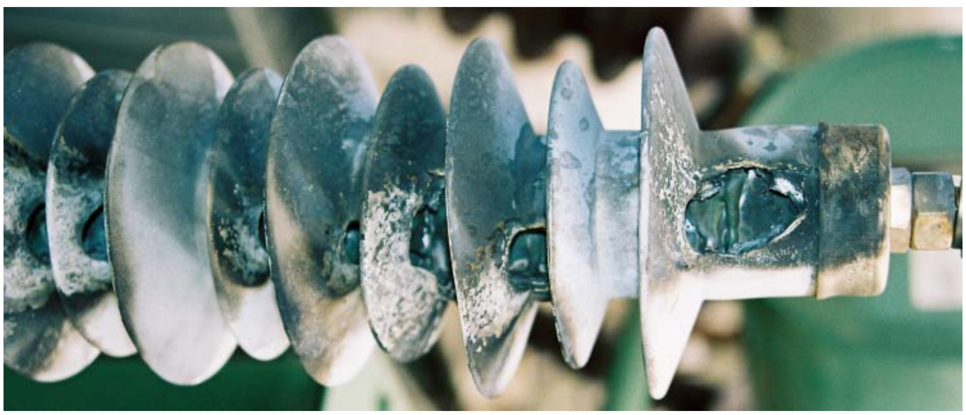


Figure 4-2
Example of a failed polymer housed arrester.

Figure 4-3
Example of a failed porcelain housed arrester.

Application to TLSA

Visual inspection is an effective means to identify NGLAs with broken disconnectors. With the use of binoculars it's relatively easy to see fault indicators (if installed) on EGLAs. Detecting damage to the arrester body may be difficult during ground based visual inspections because of the installation height, and because it may be difficult to see details such as housing deterioration against a bright background. Visual inspections on the arrester body are therefore best performed either from the structure or during a helicopter inspection.

Temperature Measurement

Description of Technique

Monitoring the operating temperature of arresters is an indirect method of identifying aged or deteriorated MOV blocks. As explained in the previous chapter, deterioration of the MOV block material causes an increase in the resistive component of the leakage current. This results in higher power losses and subsequently a higher operating temperature.

There are various methods by which the arrester temperature can be monitored:

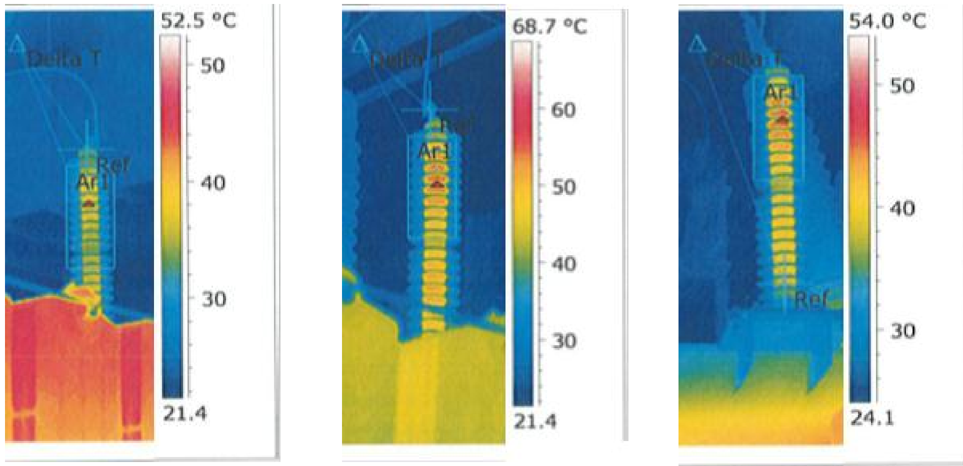
Built in wireless temperature sensor [13, 25]:

Although probably the most accurate method to monitor the temperature of MOV blocks, this method would require the temperature monitor to be built into the arrester when it is manufactured. This severely limits its applicability as a large scale monitoring method for in-service arresters.

Remote temperature measurement:

Remote temperature measurements can be made either by thermal vision equipment (Infra-red camera) or by a hand held infra-red thermometer.

Thermal vision cameras have been used in the past to successfully identify deteriorated surge arresters. Aged units are usually identified by comparing the temperature profiles of different arresters at the same location. An example of such comparative measurements is provided in Figure 4-4. From this figure Arresters B and C show higher operating temperatures than Arrester A which suggests that they have a higher degree of aging. This finding was later confirmed by measuring the block voltage current characteristic – see Figure 4-7.



Arrester A (max 38.0^{o}C) **Arrester B (Max 54.2^{o}C)** **Arrester C (Max 45.0^{o}C)**

Figure 4-4
An example of comparative Infra-Red images of three surge arresters installed at the same location. Laboratory tests confirmed that Arrester B was the most deteriorated, followed by Arrester C, and Arrester A, which was the least deteriorated.

Infra-red thermometers offer a less expensive option to thermal vision cameras, but it requires the user to take several measurements along the arrester to make sure the warmest part of the arrester is included in the measurement [28].

There is however some evidence that remote thermal sensing techniques may have some limitations in detecting aged arresters. On arresters with a type A1 design (Figure 2-10) the conduction of heat from the blocks to the outside of the housing is in many cases not very efficient. For such arresters a relatively large increase in block temperature is needed before the housing is heated sufficiently to detect the deterioration with a remote temperature measurement. For example; laboratory tests on porcelain housed arresters showed that a 15^{o}C rise in block temperature only produced a 4^{o}C increase in temperature on the outside of the arrester housing [15]. The temperature differences will however be smaller on arrester designs where housing material is in direct contact with the blocks thus ensuring a better thermal connection between the MOV blocks and the housing material. Most polymer housed arresters fall in this category which make them good candidates for condition monitoring by remote temperature measurement.

When performing remote thermal sensing inspections it is important to take account of factors that may influence the measurements. Typical environmental factors that may impact the results include:

- Whether the inspected object is exposed to direct sunlight or not,
- Differences in emissivity of the housing, contaminated versus uncontaminated external surface, porcelain versus polymer
- Exposure to wind.

Application to TLSA

Temperature measurement as diagnostic tool can only be applied to NGLAs as these arresters are continuously energized. The arrester bodies in EGLAs are isolated from the network voltage by the external series gap so there are no leakage current through the block and therefore no warming of the arrester.

The only practical temperature measurement option for NGLA installations are IR inspections, but this can be difficult to achieve due to the height of installation and awkward inspection angle from ground level. Furthermore it may not always be possible to do comparative measurements as in many cases only one arrester is installed at a structure.

As mentioned above, environmental conditions may play an important role in the success of the inspection and it is certainly good practice to utilize experienced inspectors for this task.

Ultraviolet Inspection

Description of Technique

Daylight UV cameras have been developed to detect electrical discharges such as corona and arcing activity on power equipment and installations. These cameras are sensitive to the part of the UV spectrum where there is no solar radiation so that electrical discharges can be detected even in broad daylight.

UV cameras can only detect external discharges and this makes it unsuitable for use as a condition monitoring tool on surge arresters. Deterioration of the blocks or moisture ingress into the housing generally does not result in external discharges.

Application to TLSA

Although UV inspections may not be very useful for detecting aged surge arrester units, it may still be a powerful tool to detect deficiencies with the TLSA installation. Spark discharges, indicating, poor electrical contacts could cause electromagnetic interference and should be eliminated.

Surge Counting

Description of Technique

A long standing method for condition monitoring on surge arresters is to count the number of discharges that the arrester has conducted. This is a carryover method that was frequently used on gapped arresters to obtain an indication of the deterioration of the series gap structure. On metal oxide arresters this method provides little information about the condition of the arrester as most modern metal-oxide arresters do not deteriorate much when conducting overvoltages [5]. Surge counters can only give indication of a deteriorated arrester if a sudden increase in surge counts is observed.

Surge counting is however useful to obtain an indication of the extent to which the arrester is exposed to overvoltages from the network. This may provide the justification for placing surge arresters at a particular location or it may indicate – if many surges are recorded – that additional overvoltage control measures may be necessary.

There are two basic types of surge counting devices:

- **Monitoring spark gap**. This is the simplest form of surge counting. A small plate gap is placed in the ground lead of the arrester. Every time the arrester operates, a sparkover occurs across this gap which leaves a mark on the gap electrode. At a specific interval the gap electrode may be visually inspected to count the number of spark overs and to get an indication of the magnitude and polarity of the discharges from the size of the markings [30].
- **Surge counter:** In this device a mechanical, or digital, counter is activated when the arrester conducts a surge above a certain magnitude. The threshold current necessary for counting is generally dependent on the type of overvoltage. Few manufacturers publish the thresholds for their surge counters. One manufacturer claims that their surge counter activates on all surges above 200 A[19]. Another manufacturer provides more details about the time response of their counter. For very short lightning impulses the threshold is in the order of 1 to 3 kA and for switching current surges about 500 A [16].

A prerequisite for the use of surge counting devices is that the arrester be installed on an insulating base – see Figure 4-5. It is then possible to install the device in series with the ground lead, thereby forcing the arrester current to pass though the counter. The counters are also only effective if they are installed close the arrester base. Counters installed at some distance from the surge arrester base are rendered ineffective because there will be a significant buildup of voltage on the lead which could result in flashover of the surge arrester insulating base. Also, there will be a significant coupling between the insulated lead and the arrester supporting structure so that a significant portion of the surge current would pass through the structure.

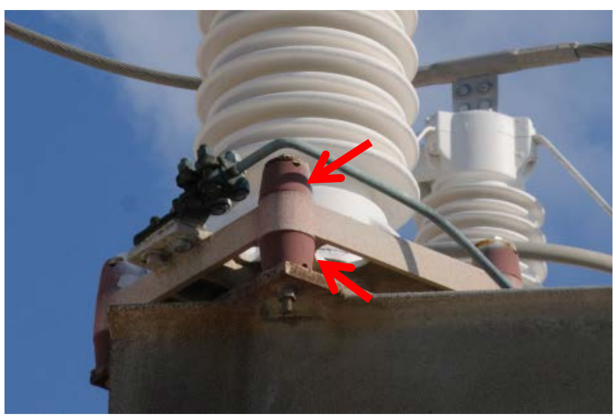


Figure 4-5
An example of a surge arrester installed on an insulating base.

Application to TLSA

Surge counting is applicable to both NGLA and EGLA installations, and can provide the necessary information on how often the TLSA is called on to conduct surges. This information can be used to evaluate the placement choices that have been made. Such data could also be used as part of the motivation for placement of TLSAs.

Due to the inaccessibility of the TLSA installation these types of devices will only be practical if they communicate their counts wirelessly, or if a flag – that is visible from ground level – is dropped on each arrester operation. In areas with a high lighting occurrence the only practical solution may be to install modern electronic counters with wireless data transfer. Such commercial units are available.

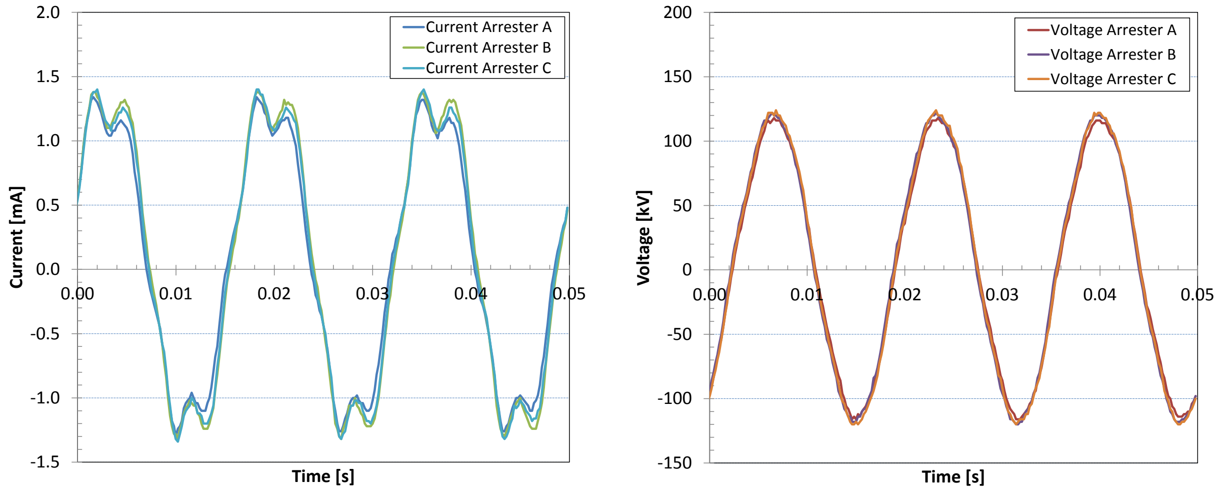
Leakage Current Monitoring

Description of Technique

Leakage current monitoring is the most direct way of determining the condition of a surge arrester. A device that measures the leakage current through the arrester is installed in arrester ground lead, which means this technique can only be used on surge arresters installed on an insulating base – see Figure 4-5.

Under normal service conditions the magnitude leakage current through the arrester is in the order of 0.2 to 3 mA [5] and it is almost purely capacitive – see Figure 2-2. The magnitude of this capacitive current is determined by the size of the blocks, the permittivity of the zinc-oxide material and any capacitive grading that may be present. The current also has a very small resistive component (i.e. 0.010 - 0.600 mA [5]) which is about an order of a magnitude lower than the capacitive part. The magnitude of the resistive current under normal service conditions is determined by the characteristics of the high resistivity, inter-granular layers of the zinc oxide material.

Experience has shown that the magnitude of the capacitive component of the leakage current is not significantly affected if the arrester blocks are deteriorated. Thus there is little benefit in utilizing the *capacitive* current as a parameter for condition monitoring [5]. This is illustrated in Figure 4-6 which shows a comparison of the leakage current through 3 arresters at different stages of deterioration. Arrester A is the least deteriorated and Arrester B the most. The deterioration of arrester C was between that of the other two. These arresters were taken out of service after it was noted that Arrester B was running warmer than the other two. The thermo-vision images of these surge arresters are shown in Figure 4-4. The leakage current graphs in Figure 4-6 show that the peak leakage current, which corresponds to the capacitive component, is very similar for the 3 arresters.



Leakage Current **Applied Voltage (MCOV)**

Figure 4-6
Examples of the leakage current through three arresters at various degrees of deterioration. Arrester B is the most deteriorated, and Arrester A the least deteriorated. The arresters were energized to their MCOV.

As discussed in Chapter 3, aging of the MOV blocks affect the inter-granular layers of the zinc-oxide material, which manifests itself usually as an increase in the *resistive* component of the leakage current through the arrester. This makes the resistive current a good candidate for condition monitoring of arresters. It is however not easy to extract the resistive current in real time applications since it is such a small component of the total leakage current. Additional factors that may complicate the utilization of the resistive current as a condition monitoring parameter are:

- The resistive component is strongly influenced by the applied voltage and block temperature. Consequently, on a healthy arrester there will be a significant variation in the level of resistive leakage current due to daily variations in the ambient temperature and applied voltage [5].
- The voltage distribution along the arrester column is not even. Usually the blocks closer to the HV side are stressed more than those on the grounded side of the arrester. This results in a higher level of leakage current through the upper part of the arrester column. This "additional" current feeds the stray capacitances along the arrester. This effect causes a phase shift in the measured leakage current with respect to the applied voltage. Because of this phase shift it is not sufficiently accurate to define the resistive component at the current through the arrester at the instant of the peak of the applied voltage [5].

- The capacitance of the surge arrester acts as a high-pass filter. Thus any harmonics present on the supply voltage will be amplified in the arrester current. These harmonic currents may be of the same magnitude than the harmonic current through the arrester because of its non-linear resistance [5].
- In contaminated conditions there may be a significant level of leakage current flowing over the external surface of the housing insulation. Dry band arcing normally initiates close to the peak of the voltage cycle and the contamination leakage current has a large resistive component. This current is also channeled through the ground lead to earth and would also pass through any leakage current monitoring device that may be installed [5]. During contamination events the accuracy of the condition monitoring could be severely impacted.

There are a number of ways to determine and monitor the resistive component of the leakage current through the arresters. These methods are classified as follows in IEC standard 60099-5 [5]:

Method A: Direct measurement of the resistive component of the arrester leakage current.

> **A1:** By utilizing the applied voltage as a reference signal, the magnitude of the resistive current can be determined measuring the current at the instant that the voltage reaches its peak value.
>
> **A2**: A HV bridge circuit is used to compensate (or neutralize) the capacitive component of the leakage on the basis of the applied voltage.
>
> **A3**: The capacitive current is compensated on the basis of an artificially generated reference voltage signal.
>
> **A4**: The capacitive current is compensated by combining the leakage current signals from arresters installed on the three phases.

Method B: An indirect measurement of the resistive component by performing a harmonic analysis of the leakage current.

> **B1**: The leakage current is filtered to extract the 3rd harmonic component. This method is based on the assumption that the harmonic content of the leakage current is solely because of the arrester non-linear characteristic [21].
>
> **B2**: The leakage current is filtered to extract the 3rd harmonic component and the result is compensated for any harmonics that may be present on the supply voltage [22].
>
> **B3**: The leakage current is filtered and analyzed to obtain the fundamental frequency component of the resistive leakage current through the arrester [20, 24].

Method C: Direct power loss measurement. The power loss, which is directly related to the resistive component of the current, can be calculated directly if both the voltage across and current through the arrester is known.

Method B2 has seen a number of successful implementations and there are a number of commercial devices available [16, 17, 18].

The interpretation of the leakage current data needs some consideration as the measured values tend to vary over time depending on temperature and applied voltage. Also the magnitude of the leakage current is dependent on the make and model of the arrester, and there may even be differences in leakage current between different arrester units of the same type. Some options for leakage current analysis are:

- Comparing the resistive current level from the arresters of the three phases.
- Trend the resistive leakage current over an appreciable period of time.
- Correct the arrester leakage current for the effects of temperature and applied voltage to enable a direct comparison with a reference value determined under "standard" conditions. Reference values may be obtained from the arrester manufacturers or can be measured on arresters under standard conditions, before they are installed [23].

When analyzing leakage current results it should be kept in mind that there are other factors which could cause high leakage current levels. Examples of conditions which may result in erroneous resistive leakage current estimations are:

- Contamination on the insulator surface may contribute significantly to the total leakage current under wet or damp conditions.
- Failure of the ground lead insulation may result in a ground loop which can pick up a significant current due to magnetic coupling [23].

It is therefore recommended practice to first verify the correctness of the leakage monitoring measurements before taking steps to remove suspect arresters.

Application to TLSA

Leakage current monitoring is only applicable to NGLA installations as the series gap in EGLA installations prevents any leakage current from flowing through the arrester.

Leakage current is used to determine the condition of the active part of the arrester. As for substation surge arresters leakage current is only useful as a diagnostic tool if the resistive component of the leakage current can be extracted. In addition it is also necessary to trend the development of leakage current over a considerable period of time (i.e. months) as there may be quite large variations over time because the resistive leakage current is very dependent on the temperature of the arrester blocks. Such trending is more suited in a substation environment where the leakage current data is frequently downloaded and monitored. For TLSAs the inspection frequency may be too low to allow for a reliable trending of the results. That is, of course, unless the monitoring device has sufficient memory onboard to capture leakage current data for extended periods of time.

Insulation Resistance

Description of Technique

A frequently used practice to assess the condition of arresters is to measure its insulation resistance or power factor [26, 27]. In the literature little to no details are given on the exact test method, voltages used, etc. These measurements can however only be performed if the arrester is de-energized and disconnected from the power system. It is therefore not considered as an on-line diagnostic tool. As for other methods, the best results are obtained when the external insulation surface is clean and dry to prevent external leakage current from interfering with the measurement.

The accuracy of this method is debatable as some authors suggest that the method is inaccurate [28] while the proponents of the method reports successful identification of aged units [27]. From EPRI laboratory test experience on arresters it is known that differences between good and bad arresters only become significant if the applied voltage is over 20 - 30 % of the MCOV. Others have suggested a minimum test value of 50% of the MCOV [28]. It seems therefore that this method can be used successfully provided that a sufficiently high voltage is used to do the measurement.

Application to TLSA

This technique is not applicable to in service TLSAs.

Characterization of the Low Current Region (AC and DC Tests)

Description of Technique

The condition of the arrester can also be determined by measuring the voltage-current characteristic of the surge arrester in the low current region (i.e. applied voltage smaller than the rated voltage). This can be done with a relatively small HV supply since the current burden is quite low. For such testing it is necessary to de-energize and disconnect the arrester from the system. Also the base of the arrester needs to be insulated in order to measure the current through the arrester. Another precaution needed for the test is to ensure that the arrester external surface is clean and dry to avoid external leakage current from interfering with the measurement.

The test can be performed with either AC or DC energization, although DC energization has a number of advantages as will be shown by way of an example. In Figure 4-7 the results are presented from tests to determine the AC and DC voltage current (V-I) characteristic of 3 identical surge arresters, but with varying degrees of ageing. All three arresters have a MCOV of 84 kV and an Ur of 104 kV. These arresters were identified as aged during a thermal vision inspection – see Figure 4-4.

Figure 4-7 shows that AC V-I characteristic is nearly identical for applied voltages below the MCOV (84 kV). This is because at these voltage levels the peak of the total arrester current is determined by the capacitive current. Above 90 kV, differences in the characteristic become apparent as the peak of the resistive current becomes dominant. In this region it was found that arrester B had the highest current and arrester A the lowest current.

When the same arresters are tested with DC energization larger differences between the V-I characteristics of the three arresters are observed. The reasons for this are twofold:

1. Under continuous DC energization magnitude of the capacitive current is insignificant.
2. The resistive current through the block is determined by the resistance of the block only, since there are no additional dielectric losses due to the polarity reversals as is the case under AC energization.

The DC tests show that lower currents were measured through Arrester A than through Arresters B and C at the same applied voltage.

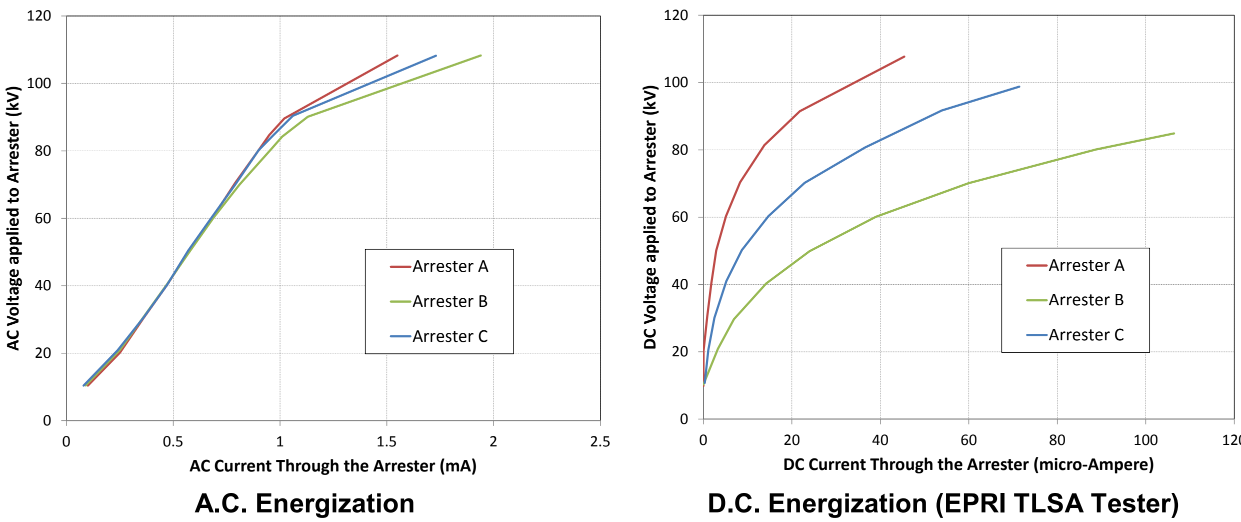
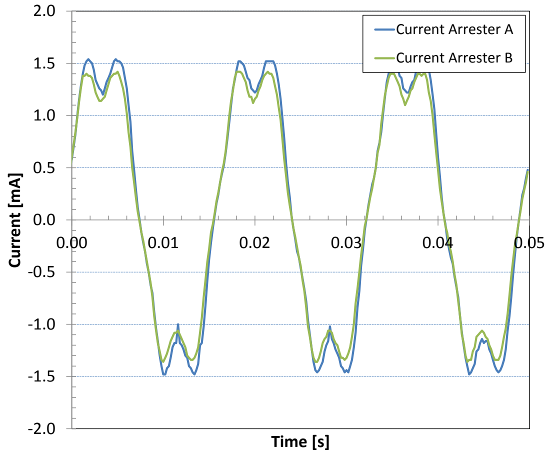


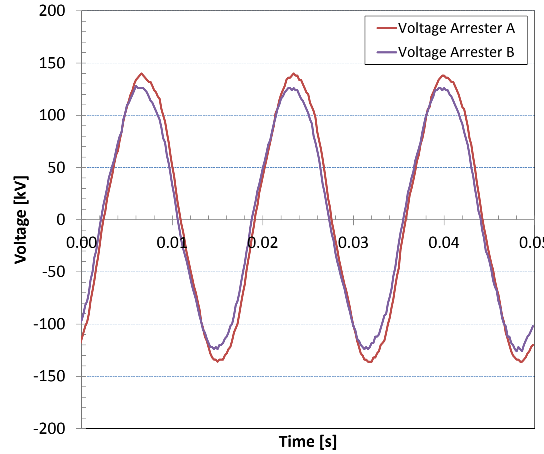
Figure 4-7
The voltage-current relationship of the 3 surge arresters as determined by EPRI.

From the results presented in Figure 4-7 it is clear that there is not much sense in obtaining the whole V-I characteristic under AC voltage as there is very little difference between characteristics of the aged and non-aged units. An alternative for the full AC test is to characterize the block characteristics with one reading at the “knee point” of the arrester. In this case the knee point is defined as the point on the V-I characteristic where the peaks of the resistive and capacitive current are the same. An oscilloscope needs to be used for this measurement and examples of the captured waveforms for arrester A and B are presented in Figure 4-8. For the three arresters (A, B and C) the knee-point voltages were respectively determined as 96 kV, 87.8 kV and 93.9 kV. A low knee-point voltage indicates an aged arrester.

This type of testing is preferably done in a laboratory environment, but it can also be done at substations if a small, transportable HV source is available. Due to the setup time and other practical considerations it is expected that site tests for arresters using this method is only feasible if there are a substantial number of arresters that needs to be tested.



Leakage Current



Applied Voltage (at knee point)

Figure 4-8
The voltage and current at the knee point of the arrester. The knee-point is defined as the voltage where the capacitive current peak equals the resistive current peak.

Application to TLSA

This technique is not applicable to in service TLSAs.

5

CONCLUSIONS

An overview of the gapless metal oxide arrester technology, its functioning and possible degradation and failure mechanisms were presented. Against this background a number of condition assessment methods were introduced, discussed and their suitability evaluated for transmission line surge arrester (TLSA) installations. A distinction is made between non-gapped line arresters (NGLA) and externally gapped line arresters (EGLA). Table 5-1 is a summary of inpection methods and their applicability TLSAs.

Table 5-1
A comparison of the important features of the various condition assessment methods discussed in this chapter.

		Applicability to	
Method	**On-line**	**NGLA**	**EGLA**
Visual inspection	Yes	Yes	Yes
Infra-red inspection	Yes	Yes	No
Ultraviolet inspection	Yes	Yes*	Yes*
Surge counting	Yes	Yes	Yes
Leakage current monitoring	Yes	Yes	No
DC insulation resistance	No	No	No
Characterization of the low current region (AC and DC tests)	No	No	No

Note: * Can only be used to ensure that the TLSA installation is corona and spark free

6
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