

High-Voltage Direct Current Live Line and Insulator Testing

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Technical Update, December 2011

EPRI Project Manager

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ABSTRACT

This report has two main parts. The focus of the first part is on live work in overhead high-voltage direct current (HVDC) lines operating above 100 kV dc. It does not address issues related to lines for electric transport that typically operate below 60 kV dc worldwide. In addition, this first part of the report is not a detailed treatise on live work but, rather, addresses the main issues related to dc live work. More detailed information on the general topic of live work can be found in the references cited throughout this report and summarized in Section 11, References.

The first part of the report contains sections that describe the basic principles of design testing and use of live working (LW) tools on ac and dc overhead lines, and it identifies important differences—from the LW viewpoint—in worksite conditions between ac and dc applications. These topics have been previously studied and investigated. One of the significant differences that has not been studied in detail relates to the possible detrimental effects of corona-generated space charge that occupies a large amount of space around dc lines. This report aims to address this issue through reduced-scale tests. The following two aspects are investigated:

- The possible deposition of space charge (ions resulting from corona on energized electrodes) on the surface of an LW tool (fiberglass-reinforced plastic rod)
- The possible detrimental effect of the deposited charge on flashover/withstand characteristics of an LW tool with deposited charge

The second part of the report is about HVDC insulators. A questionnaire was developed and sent to five insulator manufacturers. The questionnaire was aimed at determining the differences, if any, that exist in the material and manufacturing processes of their ac and dc insulators. The results of this questionnaire are presented in this report.

Preliminary insulator tests were carried out to determine corona inception levels under wet and dry conditions for an insulator under ac, positive dc, and negative dc voltages. The results of these tests are included in this report.

Keywords

Corona rings

HVDC

Insulator

Live line

Live line tool

Water droplet

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1

HVDC LIVE LINE TESTING

The focus of this report is on live work in overhead HVDC lines operating above 100 kV DC. It does not address issues related to lines for electric transport that operate typically below 60 kV DC worldwide (in North America, electric transport systems operate at voltages typically below 1.2 kV DC [1]).

Also, this report is not a detailed treatise on live work, but addresses the main issues related to DC live work. More detailed information on live work in general can be found in the references cited throughout this report and summarized in the References section.

Introduction

Live work is sometimes considered a recent development in the electric power industry. However, forerunners of modern insulating tools made their appearance in the USA as far back as 1913. These initial tools were homemade, crude, and bulky; still, they launched the development of the efficient and refined tools that are used by utilities today. The tools were developed for use on AC lines.

Historical Notes on LW in the USA

In 1916, a tool known as an “electrical hook” was introduced in Atlanta, Georgia. This was essentially a spring-type clamp mounted on an insulating wooden stick that was used to tap energized circuits. Its use identified the need for live working tools for other applications, and tools were soon developed for applying parallel-groove clamps, handling conductors, pulling insulator cotter pins, and manipulating tie wires. Soon to come were a hacksaw, a live work come-a-long, and saddles that could be attached to structures (usually wood poles) to support other tools. Figure 1-1 shows an example of a vintage live line maintenance truck.

Live work tools were first accepted for work on lines up to 34 kV AC; however, many linemen were hesitant to perform live work at this voltage. Because of this reluctance, many companies initially restricted live work to 22 kV AC or less. Linemen began to acquire confidence in the safety of live work when they realized that the tools always kept them at a safe distance from energized parts. Restrictions were gradually relaxed, and by 1930 several utilities were permitting live work on 66 kV AC lines. The voltage limit for live work soon rose to 110 kVAC, and in the late 1930s news circulated that a 220 kV AC line on the West Coast had been successfully worked energized (“hot”). Another milestone was passed in March 1948, when linemen changed suspension insulators on a 287 kV AC Hoover Dam-Los Angeles transmission line with live work tools specifically designed for the job.

Live work tools with fiberglass sticks were introduced in 1959. The fiberglass sticks consisted of layers of resin-coated glass fibers wound around and laid lengthwise over a plastic foam core. They were formed into a single unit by curing in an oven maintained at a constant temperature. It was the introduction of these fiberglass sticks, which were highly resistant to moisture absorption and damage, that allowed electric utilities to develop the live work maintenance practices they currently employ on 345 kV AC, 500 kV AC, and 765 kV AC transmission lines.



Figure 1-1
Live Line Maintenance Truck, circa 1920s.

First Barehand Work

In the late 1960s, Harold L. Rorden, a high-voltage practices engineer for the American Electric Power Service Corporation, conceived the live work barehand method, which was further developed and perfected in extensive field and laboratory tests at Ohio Brass Company's high-voltage laboratory. Rorden was assisted by a co-developer of the new method, Dr. Charles J. Miller, Jr., an Ohio Brass high-voltage research engineer. Ohio Brass Company's Holan Division designed and produced the insulated aerial device and other equipment used during the development of barehand work.

Since that time, live work tools have become considerably more sophisticated. Today, aerial devices with insulating boom segments have become integral parts of many live work procedures, and insulating tools, such as sticks and non-conductive rope, are required components of most barehand procedures.

The development of barehand work required tight control of overvoltages at the worksite. Switching impulses (SI) in AC lines were controlled (reduced) by blocking the reclosing features of the breakers of the line to be worked; however, this did not provide sufficient control of temporary (transient) overvoltages (TOV). With the construction of both 500 kV AC transmission lines and more compact line designs, control of TOV became an urgent necessity. In 1965, the first portable protective air gap (PPAG) was developed and tested for use on 500 kV

AC lines. At present the use of PPAGs at 500 kV AC is becoming more common, and PPAGs have been developed for all transmission voltages between 69 kV AC and 550 kV AC. Also, EPRI is developing a “next generation” PPAG that alleviates the most important disadvantages of the tradition PPAG [2].

The terms “liveline work” and “liveline tools” were natural selections for use in connection with work on energized facilities because for a long time transmission lines were the only application for live work. However, because today’s market forces place a premium on transmission grid reliability and stability as well as revenues, more and more maintenance is being performed on energized substation circuits as well. As such, the term “liveline” is evolving into the more general term “live work” because it is more descriptive of today’s work practices. The term “live work” is consistent with international standards such as those developed by International Electrotechnical Commission (IEC). Furthermore, since the term “hotstick” has been used as a trade name, it is now being replaced by the term “insulating tool” in national and international standards.

Principles of Live and Live Working Tool Design for DC Lines

Live work (LW) on DC lines was derived from AC live work, and in general the two employ the same work methods and tools. However, different phenomena are associated with the two types of systems, and some work requires special procedures.

The principles of DC LW and tool design are based on the best available technical information and experience. The design principles are based on the following fundamental assumptions:

- Nominal pole—ground or earth DC voltage, V_{p-G} , is equal to the AC phase—ground or earth peak voltage:

$$V_{p-gDC} = V_{\phi-gACpeak} \quad \text{Equation 1-1}$$

- Maximum transient overvoltages on DC lines are not higher than p.u.= 1.8

Live Working Methods and Practices for DC Voltages

The basic work methods used on AC systems can be employed on DC systems as well:

- The insulating tool method is universal for all voltage levels
- The barehand method in work locations where sufficient clearances exist to other energized parts and ground

The two most prominent LW methods, insulating tool and barehanding, should have wide acceptance on DC systems, as they do for AC work.

Air Insulation Considerations for DC LW

To ensure personal safety and operational security during LW, one must first consider the insulation properties of air. The second consideration, which deals with the insulating properties of materials and tools used in LW, is discussed later in this report.

Similarities and Differences between AC and DC Lines from Live Working Viewpoint

Main Similarities

Although experience with LW on DC lines is very limited, the general consensus is that the nominal pole-earth DC voltage is equal to the nominal AC phase-earth peak voltage, as shown in Equation 1-1.

Based on this principle, one follows the same steps to calculate minimum approach distance (MAD) for either AC or DC LW. Work practices for both AC and DC LW are also based on the same principles.

Main Differences

The major difference in the calculation of AC distances and DC distances is in the value of the maximum p.u. factor. For AC applications, the maximum factors for various system voltage levels are listed in Table 1-1 based on Reference [3]. For DC applications, the maximum p.u. factor of 1.8 is used.

Table 1-1
Industry-Accepted Values of the p.u. Overvoltage Factor for Live Work on AC Lines [3]

AC Line-to-Line Voltage	p.u. Factor for AC Live Work
Above 72.5 kV and below 362 kV	3.0
363 to 550 kV	2.4
551 to 800 kV	2.0

Reference [3] also contains a caution statement regarding the industry-accepted values of the p.u. factor, without an explicit explanation whether it applies only to AC or to both AC and DC LW. A slightly modified version of the caution statement is listed below.

CAUTION An engineering evaluation should be performed to determine the p.u. factor. It is possible to obtain values of the p.u. factor greater than the industry-accepted values of the p.u. factor listed in Table 1-1.

This difference in the p.u. factors for AC (Table 1-1) and DC LW (1.8 p.u.) results in larger Minimum Approach Distance (MAD) values for AC LW than for DC LW.

Special Worksite Considerations

In addition to the fundamental issue of MAD, LW on DC systems differs from that on AC systems in several other important ways. Some of the issues utilities must consider prior to undertaking AC LW include:

- Electric field effects (capacitive coupling)
- Magnetic field effects (induction)
- Step, touch and transferred potentials (associated with system faults)

Some of the issues utilities must consider prior to undertaking DC LW include:

- Corona effects
- Space charge effects
- Step, touch and transferred potentials (associated with system faults)

The first two effects are related to static (DC) electric fields. There have been no known concerns regarding DC magnetic field issues. While the effects of system faults (that is, step, touch and transferred potentials) are included in this discussion, no related problems have been reported to date during DC LW.

One can also include additional special considerations that arise in hybrid situations, that is, on transmission corridors that contain both AC and DC lines (there are no operating examples of hybrid structures, that is, situations where both AC and DC lines are on a common structure).

Table 1-2 summarizes the important differences between AC and DC systems that could have an effect on LW.

Table 1-2
Differences between HVDC and HVAC Overhead Transmission Lines

Item	Difference	Impact
Electric field at ground	HVDC electric field depends on space charge, it could be much greater than that for crest values of ac electric field of HVAC lines, dc electric field does not induce currents in bodies of workers.	No potential biological effects for HVDC due to induced currents. Greater possibility of corona on earthed objects under HVDC lines.
Air ions at ground	Air ion concentration near HVDC lines can be significantly above ambient levels.	Potential constraint on HVDC line design at maintenance at high DC voltages.
Currents coupled to vehicles	Potential for human perception and shock for HVAC. Below threshold of perception for HVDC.	For HVAC, can govern minimum heights above roads and requires proper grounding during LW. No impact on HVDC line design or maintenance.
Spark discharges	Common occurrence under EHV and UHV AC lines. Seldom occurring under EHV or UHV DC lines.	Can be a source of annoyance in right-of-way of HVAC lines. No impact on HVDC lines.
Magnetic field	Field of HVAC lines has been the subject to intense research efforts to determine potential for biological effects. Field of HVDC lines is generally similar to Earth's magnetic field.	Magnetic field may impose restrictions on HVAC line design and maintenance. No restrictions anticipated for HVDC.

Additional precautions may also be required on DC and low-frequency circuits since a considerably larger switch gap is required to break the arc when opening a circuit.

Weather Conditions

Live work should not be performed when the following adverse conditions exist [3]:

- Lightning activity in the worksite area (this applies to both AC and DC LW)
- Relative humidity at or near 100% (this applies to both AC and DC LW)
- Relative humidity at or above 85% for high-voltage DC work above 72.5 kV
- Rain or snow (this applies to both AC and DC LW)

2

MINIMUM APPROACH DISTANCE (MAD) FOR DC LIVE WORK

As mentioned earlier, the basis for determination of the required Minimum Approach Distance (MAD) for DC LW is the assumption of direct equivalence between the DC pole-to-ground voltage and the AC line-to-ground peak voltage, as expressed in Equation 1-1. The overvoltage (p.u.) factors used in the calculation of MAD are, however, significantly different for live work on AC systems than on DC systems, see Table 1-2.

Calculation of MAD

There are two generally accepted methods for calculation of the Minimum Approach Distance:

- IEEE method, described in IEEE Std 516-2009 [3]
- IEC method, described in the IEC Publication 61472 [4]

The IEC document [4] does not provide guidance for calculation of MAD for work on DC systems.

IEEE Std 516-2009 Calculation Method

The IEEE Std 516-2009 document defines live work as [3]:

live work: Work on or near energized or potentially energized lines (that is, grounding, insulating tool work, gloving, barehand work). *Syn:* **live-line work; hot stick work.**

It also defines several distances that need to be considered for live work:

minimum air insulation distance (MAID): The shortest distance in air between an energized electrical apparatus and/or a line worker's body at different potential. This distance, with a floating electrode in the gap, is equal to or greater than the sum of the individual minimum approach distances (MADs). This is the electrical component and does not include any factor for inadvertent movement. *Syn:* **electrical distance.**

NOTE—For the definition of electrical distance, see IEC 61472[4].

minimum tool insulation distance (MTID): The minimum length of insulation distance required, measured using the shortest distance between the conducting part at the live end and the closest point at ground potential. This term applies to tools that are not subject to inadvertent movement.

minimum approach distance (MAD): The minimum air insulation distance (MAID) plus a factor for inadvertent movement.

minimum approach distance for tools (MAD for Tools): The minimum length of insulation distance required, measured using the shortest distance between the conducting part at the live end and the closest point at ground potential. This term applies to tools that are subject to inadvertent movement.

minimum helicopter approach distance (MHAD): The shortest distance in air between an energized conductor and the closest point of helicopter.

The above definitions are general, that is, they do not distinguish between AC LW and DC LW. The equations for calculation of the various quantities (MAID, MTID, MAD, MAD for Tools and MHAD) are:

$$D_{MAID} = (C_1 + a) \times V_{L-G} \times T \times A \quad \text{Equation 2-1}$$

$$D_{MTID} = (C_1 \times C_2 + a) \times V_{L-G} \times T \times A \quad \text{Equation 2-2}$$

$$D_{MAD} = (C_1 + a) \times V_{L-G} \times T \times A + M \quad \text{Equation 2-3}$$

$$D_{MADforTools} = (C_1 \times C_2 + a) \times V_{L-G} \times T \times A + M \quad \text{Equation 2-4}$$

$$D_{MHAD} = [(C_1 + a) \times V_{L-G} \times T \times A + M] \times H \quad \text{Equation 2-5}$$

where:

- D is the distance (MAID, MTID, MAD, MAD for Tools, MHAD), in feet, since C_1 is in feet/kilovolts
- C_1 is 0.01 ft/kVrms (60 Hz rod gap withstand) (100 kVrms/ft)
- a is the adjustment ratio to compensate for air saturation expressed as a ratio of distance to kilovolts
- C_2 is the used in calculation of D_{MTID} and $D_{MADforTools}$, an accounts for additional 6% for the effect of the insulating tools in the air gap plus additional 4% for intangibles, that is, typically $C_2 = 1.1$. However, the 6% factor may range from 2% to 20% depending upon the structure and electrode configuration and the surface condition of the tool. Also, the factor C_2 is used only for calculations of AC line-to-ground and DC pole-to-ground, MAD, that is, $D_{MADfor\ tools, L-G}$ and $D_{MADfor\ tools, P-G}$. Until test data are available, guidance for line-to-line for AC and pole-to-ground for DC MAD, that is, $D_{MADfor\ Tools, L-L}$ and $D_{MADfor\ Tools, P-L}$ is not provided in IEEE Std 516.
- V is the nominal voltage across the air gap, which may be V_{L-G} or V_{L-L}
- V_{L-G} is the line-to-ground rms voltage, in kilovolts
- V_{L-L} is the line-to-line rms voltage, in kilovolts
- T is the maximum anticipated p.u. factor, which can occur across the air gap
- A is the altitude correction factor
- H is the helicopter factor for calculations in this guide (H is 110% of D_{MAD})
- M is the inadvertent movement factor

CAUTION

If the overvoltage, that is, the quantity $(V_{L-G}) \times (T)$ is greater than 449 kV rms, determine the air saturation ratio, a , first to use in these equations.

Also, the maximum system operating voltage, V_M , should be used in Equations 2-1 through 2-5. The maximum system operating voltage is defined as:

maximum power frequency operating voltage (V_M): The maximum system operating root-mean-square (rms) line-to-line (or line-to-ground for single phase or pole-to-ground for DC) voltage, which is also equal to the 1 per-unit (p.u.) base.

NOTE—Normally, the maximum operating voltage is 5% higher than the rated (nominal) system voltage: $1.05 \times$ rated (nominal) system voltage.

For pole-to-pole Mad on DC lines, IEEE Std 516 provides the following further guidance:

$$MAID_{p-p} = MAID_{p1-G} + MAID_{p2-G} \quad \text{Equation 2-6}$$

$$MTID_{p-p} = MTID_{p1-G} + MTID_{p2-G} \quad \text{Equation 2-7}$$

$$MAD_{p-p} = MAID_{p-p} + M \quad \text{Equation 2-8}$$

$$MAD_{forTools_{p-p}} = MTID_{p-p} + M \quad \text{Equation 2-9}$$

$$MHAD_{p-p} = MAD_{p-p} \times H \quad \text{Equation 2-10}$$

where:

$MAID_{p-p}$, $MTID_{p-p}$, MAD_{p-p} , $MAD_{forTools_{p-p}}$, $MHAD_{p-p}$ are pole-to-pole distances

$MAID_{p1-G}$ and $MAID_{p2-G}$, are pole1-to-ground and pole2-to-ground distances, respectively

H and M are factors defined earlier.

Details on the altitude correction factor, A , the inadvertent movement factor, M , and computational examples are beyond the scope of this report, and can be found in References [2 and 3].

3

PRINCIPLES OF TOOL DESIGN AND TESTING FOR LW ON DC LINES

As for ac, insulating materials used in LW equipment and tools are characterized in terms of their dielectric strength, which is defined as the maximum electric field that the material can withstand without flashover or puncture. The electrical performance of insulating materials depends on several factors, including:

- Purity of the material
- Aging
- Characteristics of the applied voltage
- Electrodes (shape, dimensions, separation)
- Atmospheric conditions (air density, humidity)
- Contamination

Surface contamination of the insulating material is one of the principal causes of insulating tool failures. Under normal conditions it is assumed that all LW tools are clean and dry. Impurities of the material and aging also degrade the dielectric strength of the insulating materials.

As with ac systems, the insulating materials used in LW equipment and tools provide insulation essentially in two ways:

- The thickness of the insulating material – cover-up and protective equipment
- The length of the insulating material – insulating tools

In the first case, the electric stresses are applied across the thickness of the material. Examples of insulating tools that use materials in this manner are:

- Flexible protective cover-up: gloves, sleeves, line hose, blankets, overshoes, sheeting, mats.
- Rigid protective equipment: hand tools, line guards, insulation covers, pole guards.

In the second case, the electric stresses are applied along the length of the insulating material. Examples of insulating tools that use the materials in this way are:

- “Hotsticks” (solid and hollow)
- Aerial lift booms
- Work platforms
- Ladders
- Ropes and chains

For the purposes of this report, which focuses on DC LW on lines above 100 kV, attention is directed to the second case only, that is, tools and equipment where electric stresses are applied along the length of the insulating material. Specifically, this report covers insulating tools use for live work on overhead transmission lines.

Tools for Live Work on HVDC Lines

Transmission line tools, such as hotsticks, strain poles, ladders, cradles, etc. for LW on DC lines are essentially the same as for LW on AC lines. This is primarily due to a rather small number of utilities that perform LW on DC lines, and absence of research that would identify DC tool design parameters and guide development of appropriate tools.

Available Industry Standards for Live Working Tools

There are several industry standards that contain performance requirements for transmission live working tools:

- IEEE Std 516-2009
- IEC 60855 for insulating foam-filled tubes and solid rods
- ASTM F711-02
- IEC 60832-1:2010
- IEC 60832-2:2010
- IEC 60855-1:2009
- IEC 61235:1993

It must be noted that only IEEE Std 516 contains clauses that refer to DC applications such as testing of tools using DC voltage, and use of tools on DC lines. This is discussed next.

IEEE Std 516-2009

Testing of Fiberglass-Reinforced Plastic (FRP) Live Work Tools

For historical reasons and for completeness, IEEE Std 516-2009 still contains references to wooden tools that were developed and used in the first half of the 20th century. Such tools are no longer in common use and they have been replaced in late 1950s with FRP tools.

IEEE Std 516-2009 recommends the use of AC voltage for testing of FRP tools, however, it also allows DC testing that can be done at the discretion of the user [3]. There are several reasons that some users opt to test tools with DC, irrespective of the tool application:

- DC testing is less sensitive to slight changes in the geometry of the test equipment
- DC equipment is much lighter, more compact, and is sufficiently portable to perform testing at different locations.

However, IEEE Std 516-2009 recommends using AC to test tools that are used on AC lines, and DC to test tools that are used on DC.

For AC tests, the specified test voltage stress for post-production (that is, in-service) testing is 75 kV AC_{rms} across 30 cm (1ft) of the tool (new tools are tests with 100 kV AC_{rms} across 30 cm). There are also limits on the measured tool (leakage) current for AC tests [3].

There are no specific guidelines for DC test voltage or maximum measured DC current. However, based on the assumption of equivalence of AC peak voltage and DC voltage, see Equation 1-1, the commonly used DC test voltage stress is 106 kV DC ($= 75 \text{ kV AC}_{\text{rms}} \times \sqrt{2}$). Is it also acceptable and common to test sorter section of the tools with an appropriately adjusted stress:

- 37.5 kV AC_{rms} across 15 cm (6 in)
- 53 kV DC across 15 cm (6 in)

4

WORKSITE CONDITIONS ON HVAC AND HVDC LINES

Section 1 listed some essential differences between HVAC and HVDC lines. These differences and their potential impact on LW are discussed next.

Electric Field Effects

AC Electric Field Effects

One manifestation of AC electric field effects that is of concern to LW is the “electric shock”. A worker who is not electrically bonded to energized or grounded objects assumes a potential other than that of the adjacent conductive object and can receive a shock when approaching or touching the object. The magnitude or severity of the shock depends on several factors, including the strength of the electric field and the position of the worker relative to the object (that is, capacitive coupling). The effects of the shocks can be mitigated by bonding the worker to adjacent objects or adequately shielding the worker from the electric field.

Another manifestation of AC electric field effects is the steady-state current induced in the worker's body. Very small induced currents (less than about 1 mA) are not perceptible, but currents on the order of 10 to 16 mA result in undesirable muscle reaction (spasm). For example, if the current exceeds the so-called “let-go level”, the worker may not be able to move or open his fingers to release his or her hold on an energized conductor. Table 4-1 gives the perception and let-go levels for AC and DC for various situations.

Table 4-1
Thresholds for Body Currents

Effect	60 Hz AC (mA)		DC (mA)	
	Men	Women	Men	Women
No sensation on hand	0.4	0.3	1.0	0.6
Slight tingling “Threshold of Perception” level	1.1	0.7	5.2	3.5
Shock: uncomfortable, but not painful; muscular control not lost	1.8	1.2	9.0	6.0
Painful shock: muscular control not lost “Safe Let Go” level for 99.5 percent of persons tested	9.0	6.0	62	41

DC Electric Field Effects

DC electric field effects, which are different from those on AC lines, are related to a combination of electrostatic field and space charge and occur in two zones:

- The ionization zone
- The interelectrode or space-charge zone

It should also be noted that capacitive coupling does not exist in DC fields.

DC Ionization Zone – Corona Effects

The basic ionization processes of DC lines are the same as those for AC lines. In simplified terms, the ionization zone near an energized conductor contains particles (ions) that are charged with the same polarity at the conductor. However, with AC lines nearly all of the ions created during one-half of the sinusoidal AC voltage cycle are recaptured and neutralized by the conductor during the subsequent opposite polarity half-cycle. Hence, the resulting ionization is very thin and confined to the immediate vicinity of the energized conductor. On the other hand, with DC lines no polarity reversal occurs and the ions created near the conductor are continually repelled away from it. Theoretically, then, the space between the conductor and ground is filled with ions. In the case of bipolar DC lines, the space on the side of the positive pole contains positive ions (that is, positive space charge), while the side on the negative pole contains negative space charge.

From the perspective of LW tools used on DC lines, a part of the tool may reside in the space filled with the space charge (ions) for various period of time. There is, therefore, the possibility of space charge deposition on the tool surface, which may degrade the insulating properties of the tool to an unknown extent. This effect is explored in a later section.

DC Interelectrode Zone – Space Charge Effects

The interelectrode zone extends beyond the ionization zone and includes the space between the pole conductors and the space between the conductors and ground. No ionization processes take place in this zone. However, the space charge created in the ionization zone near the conductor drifts away, disperses, and is eventually deposited on objects and/or neutralized.

If the object, such as a worker performing LW is earthed, charge neutralization results in steady current flow in the object. This current is normally much lower than the perception levels listed in Table 4-1.

If the object is electrically floating, it will become charged by the deposited space charge and will acquire a certain voltage. No current will flow until contact is made with earth or other objects at different potentials. In this case, a discharge will occur that will produce an electric shock. The released energy is proportional to the capacitance of the object and the square of the voltage acquired by the object.

With relatively small objects such as human beings this shock is normally insignificant. In the case of large objects such as trucks or helicopters, the shock can be noticeable, but it is usually no greater than a “carpet type” shock of 5-10 mJ [5]. Nevertheless, it is advisable to make contact carefully using a metallic wand before touching objects with hands or other parts of the body.

From the perspective of LW tools used on DC lines, the tool may reside in the space filled with the space charge (ions) for various period of time, while the rest of the tool may reside in the charge drift (the interelectrode) zone. There is, therefore, also the possibility of space charge deposition on the tool surface, which may degrade the insulating properties of the tool to an unknown extent. This effect is explored in a later section.

Magnetic Field Effects

AC Magnetic Field Effects

It needs to be noted that accepted shielding methods employed to mitigate the effects of electric fields are not effective in shielding a worker from magnetic fields. While researchers have been investigating the possible long-term effects of magnetic fields on people, results continue to be inconclusive, and no definitive evidence of health risk has been found to date among utility workers performing LW.

DC Magnetic Field Effects

Magnetic field of HVDC lines is generally similar to Earth's magnetic field. No concerns have been voiced on this issues from the LW viewpoint.

Step, Touch and Transferred Potentials

AC Step, Touch and Transferred Potentials

When a fault to ground occurs on an AC transmission line, the power frequency current entering the earth through the grounding system of a structure produces a difference in potential between the structure and the remote earth. This current also produces potential differences along the earth's surface near the structure. A worker walking near the structure may be exposed to this potential difference. Also, a vehicle that is electrically bonded to the structure may develop a potential difference relative to the local earth. These potentials present hazards to workers performing LW. The degree of the hazard depends on several factors, including the magnitude of the fault current, the resistivity of the earth at the worksite, and the fault duration. The following steps can be taken to reduce the step, touch, and transferred potential hazard:

- During LW, workers on the ground should wear insulating protective overshoes while assisting workers on structures.
- Aerial lifts and other similar equipment should be bonded to the line's neutral or ground conductor.
- Equipotential grids (metallic grids) designed for the specific soil resistivity and fault conditions can be installed at remote disconnect switches or other similar locations.
- Use of physical restraints such as barricades and barriers to prevent access to areas and equipment that could result a hazardous exposure if approached or touched.

The last method, use of physical restraints, is also used to protect the public from step, touch, and transferred potentials.

DC Step, Touch, and Transferred Potentials

The concern with DC step, touch, and transferred potential is similar to that with AC systems. However, when a fault to earth occurs on a DC line, the control systems usually react very quickly, and the resulting fault current is less than that for an equivalent AC system. Further research is needed to quantify the concerns for DC systems, in particular for DC systems that operate in monopolar mode.

There are no known reports of LW incidents associated with step, touch, and transferred potentials on DC systems.

5

STUDY OF POSSIBLE DEPOSITION OF DC SPACE CHARGE ON TOOL SURFACE

The previous sections discussed the basic principles of design testing and use of live working tools on AC and DC overhead lines, and identified important differences, from the live working viewpoint, in worksite conditions between AC and DC applications. One of the significant differences that has not been studied in detail relates to the possible detrimental effects of corona-generated space charge that occupies a large amount of space around DC lines. This Section aims to address this issue through reduced-scale tests. Two aspects are investigated:

- Possible deposition of space charge (ions resulting from corona on energized electrodes) on the surface of a LW tool (FRP rod).
- Possible detrimental effect of the deposited charge on flashover/withstand characteristics of a LW tool with deposited charge.

The overall test plan is listed in Appendix A for reference. The test setup is described in Appendix B.

The first aspect is discussed in detail next.

Investigation of the second aspect did not produce desired or conclusive results because of the limitations of the test circuitry. However, it did produce other important and unexpected results, which are discussed later.

Possible Deposition of Space Charge on Tool Surface

A large volume of literature [6–15] exists on the subject of corona-generated space charge on HVDC lines and methods of calculating the amount and distribution of the charge in space. There is also anecdotal evidence that the corona-generated ions can be deposited on surfaces of insulating tools used for live work, however, extensive scientific treatment of this topics has been lacking. In this project, various methods were tried to detect the presence of charge deposited on the surface of a dielectric section of a live working tool. Tests, and results from those tests, performed to detect charge deposition on dielectric surfaces of LW tools are described next.

Tests to Detect the Presence of Deposited Charge

The procedure to try to detect charge deposition on the surface of an FRP rod consisted of energizing a 6” section of a fiberglass rod (section of a live working tool) up to 53 kVDC and observing the behavior of a small strip of aluminum foil positioned close to the test sample. This was repeated several times with various foil locations and configurations, and HVDC polarities.

A general view of the test setup for DC and AC tests is shown in Figure 5-1, with a close-up of the test section in Figure 5-2.



Figure 5-1
General View of the Test Setup for DC and AC Tests



Figure 5-2
Close-up View of a Sample of a LW Tool under Test

Space Charge Detection Tests

In initial tests, the sample was energized with either positive DC or negative DC, with a foil leaf suspended, from an overhead support, and located about 2" laterally from the surface of the sample and about 2" longitudinally from the energized electrode (a hose clamp). Fine wires were used on the hose clamp to produce corona, which was evidenced by sound (hissing or crackling), the odor of ozone (O_3), and a faint glow. Figure 5-3 and 5-4 show two views of the foil leaf. The fine wires (a section of a braided ground strap) are visible at the left energized electrode.

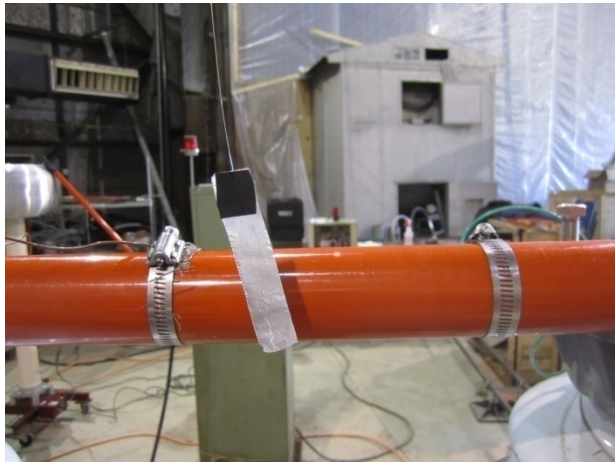


Figure 5-3
Side View of the Foil Leaf Setup.



Figure 5-4
End View of the Foil Leaf Setup.

In other tests, a Leyden jar concept was used to see whether the ends of a folded foil strip would separate as voltage was increased and corona set in, see Figure 5-5. This approach did not produce reliable results. The folded foil was also suspended from a wire loop placed on the FRP rod, as shown in Figure 5-6.



Figure 5-5
Side View of the Foil Leaf Setup.

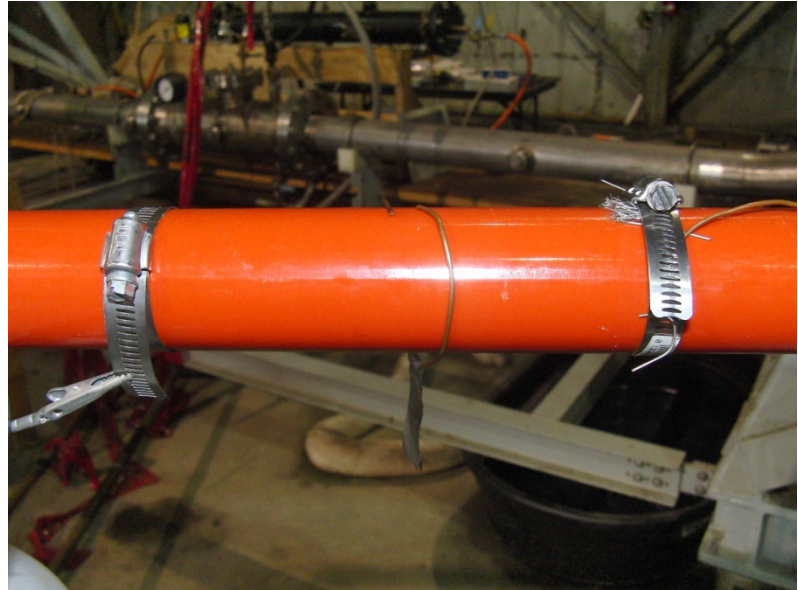
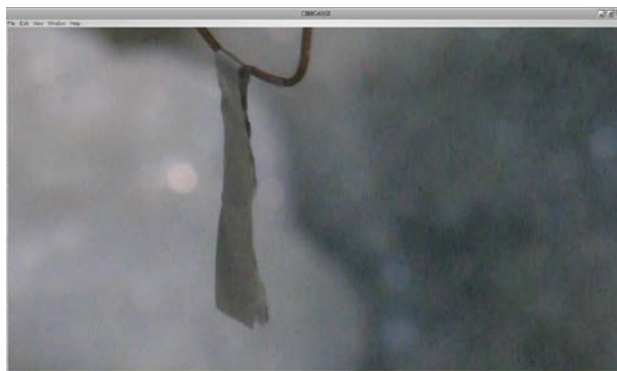


Figure 5-6
End View of the Foil Leaf Setup.

Findings

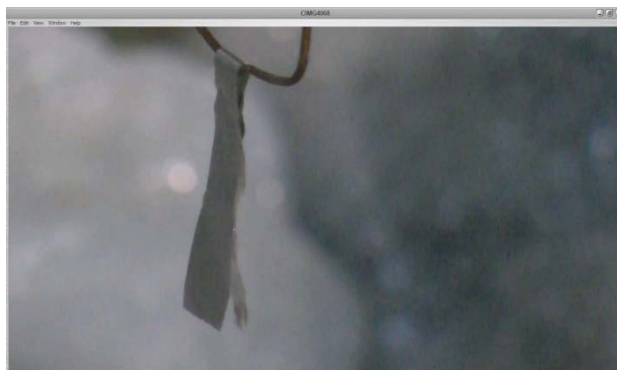
In the tests with the folded foil suspended from a wire loop placed on the FRP rod, the two opposing parts of the foil strip did separate, however, the behavior was not very consistent. Nevertheless, these tests show that separation of the foil parts is due to and a function of charge that has been deposited on the foil and/or on the tool surface. Figure 5-7 shows selected stills from video CIMG4068 taken during the test with the folded foil.



(a)



(c)



(b)



(d)

Figure 5-7
Sequence of Stills from Video CIMG4068 Showing Separation of the Two Parts of the Folded Foil as the Applied Voltage and Corona Intensity Was Increased.

The most consistent and telling results were obtained with the foil strip suspended near the FRP rod, as shown in Figures 5-3 and 5-4. In its neutral position, the foil strip would hang very close to the rod surface without actually touching it. Several variations of the test procedure were tried:

1. The foil strip was suspended as shown in Figures 5-3 and 5-4, and **positive**-polarity voltage was raised to the target value of 53 kVDC, then lowered. The **objective** of this test was to find whether the foil strip would move at all, that is, it was not too heavy.
2. The foil strip was suspended as shown in Figures 5-3 and 5-4, and **negative**-polarity voltage was raised to the target value of 53 kVDC, then lowered. The **objective** of this test was to find whether the foil strip would move at all, that is, it was not too heavy.
3. The foil strip was suspended as shown in Figures 5-3 and 5-4, and a ground lead was touched to the foil to remove residual charge, if any. **Positive**-polarity voltage was then raised to the target value of 53 kVDC, then lowered. The **objective** of this test was to find whether the foil strip, assured to have zero net charge by contacting the foil with the grounded lead, would acquire a positive charge due to positive corona on the energized electrode, and move away from the tool surface (like charged repel). This in turn would also imply that some charge was deposited on the tool surface as well.

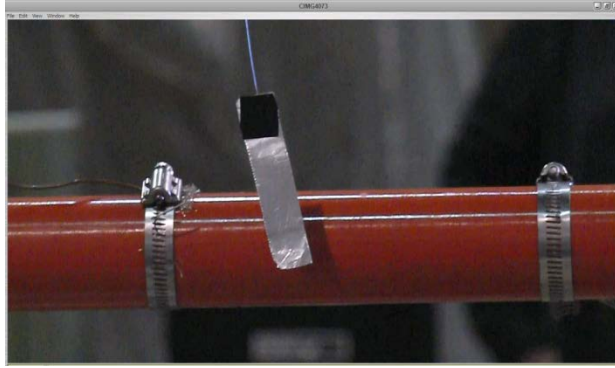
4. The foil strip was suspended as shown in Figures 5-3 and 5-4, and a ground lead was touched to the foil to remove residual charge, if any. **Negative**-polarity voltage was then raised to the target value of 53 kVDC, then lowered. The **objective** of this test was to find whether the foil strip, assured to have zero net charge by contacting the foil with the grounded lead, would acquire a negative charge due to negative corona on the energized electrode, and move away from the tool surface (like charged repel). This in turn would also imply that some charge was deposited on the tool surface as well.
5. The foil strip was suspended as shown in Figures 5-3 and 5-4, and a ground lead was touched to the foil to remove residual charge, if any. **Positive**-polarity voltage was then raised to the target value of 53 kVDC, then lowered. Without contacting the foil, positive-voltage was again raised to the target value of 53 kVDC, then lowered. The **objective** of this test was to find whether the positive charge acquired by the foil strip due to positive corona would move away from the tool surface upon the second energization, indicating that the charge remains on the foil strip and on the tool surface for at least a short length of time.
6. The foil strip was suspended as shown in Figures 5-3 and 5-4, and a ground lead was touched to the foil to remove residual charge, if any. **Negative**-polarity voltage was then raised to the target value of 53 kVDC, then lowered. Without contacting the foil, negative-voltage was again raised to the target value of 53 kVDC, then lowered. The **objective** of this test was to find whether the negative charge acquired by the foil strip due to negative corona would move away from tool surface upon the second energization, indicating that the charge remains on the foil strip and on the tool surface for at least a short length of time.
7. The foil strip was suspended as shown in Figures 5-3 and 5-4, and a ground lead was touched to the foil to remove residual charge, if any. **Positive**-polarity voltage was then raised to the target value of 53 kVDC, then lowered. Without contacting the foil, voltage polarity was reversed quickly (see Appendix B for the procedure), and **negative**-polarity voltage was raised to the target value of 53 kVDC, then lowered. The **objective** of this test was to find whether the foil strip, assured to have initially zero net charge by contacting the foil with the grounded lead, would acquire a positive charge due to positive corona on the energized electrode, and move away from tool surface (like charged repel). Then, following reversal of the source voltage polarity, the (presumably) positively-charged foil strip should move towards the tool surface (opposite charges attract).
8. The foil strip was suspended as shown in Figures 5-3 and 5-4, and a ground lead was touched to the foil to remove residual charge, if any. **Negative**-polarity voltage was then raised to the target value of 53 kVDC, then lowered. Without contacting the foil, voltage polarity was reversed quickly (see Appendix B for the procedure), and **positive**-polarity voltage was raised to the target value of 53 kVDC, then lowered. The **objective** of this test was to find whether the foil strip, assured to have initially zero net charge by contacting the foil with the grounded lead, would acquire a negative charge due to negative corona on the energized electrode, and move away from the tool surface (like charged repel). Then, following reversal of the source voltage polarity, the (presumably) negatively-charged foil strip should move towards the tool surface (opposite charges attract).

In all tests listed above, the behavior of the foil strip was observed. The observed behavior is described in Table 5-1.

Figure 5-8 shows selected stills from video CIMG4073 taken during test #7 described above and in Table 5-1. The movement of the foil strip relative to the electrodes is clearly visible in the sequence of still. The movement of the strip relative to the rod surface is difficult to discern from the camera angles used in this test. Figure 5-9 shows several selected clips from another test (MOV0303) in which the high-speed camera was positioned for a view along the tool sample. The foil strip is to the left of the tool sample.

Table 5-1
Results of the Charge Deposition Tests

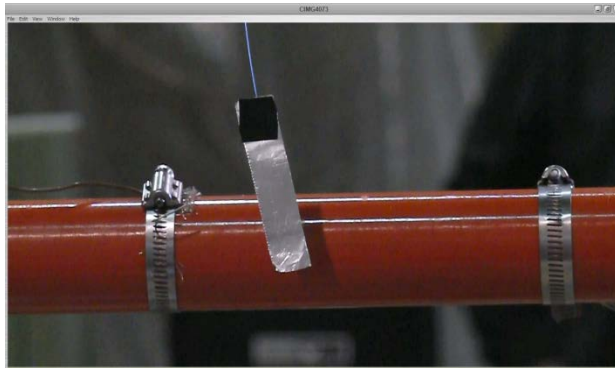
Test #	Essential Steps	Observed behavior of the Foil Strip
1	Apply positive -polarity voltage.	The foil was observed to move.
2	Apply negative -polarity voltage.	The foil was observed to move.
3	Discharge the foil before test. Apply positive -polarity voltage.	The foil was observed to move away from the energized electrode and the tool surface.
4	Discharge the foil before test. Apply negative -polarity voltage.	The foil was observed to move away from the energized electrode and the tool surface.
5	Apply positive -polarity voltage. Apply positive -polarity voltage again.	The foil was observed to move away from the energized electrode following first energization. The foil was observed to move away from the tool surface after second application of voltage.
6	Apply negative -polarity voltage. Apply negative -polarity voltage again.	The foil was observed to move away from the energized electrode following first energization. The foil was observed to move away from the tool surface after second application of voltage.
7	Discharge the foil before test. Apply positive -polarity voltage. Without touch the foil, reverse polarity. Apply negative -polarity voltage.	Upon application of voltage, the foil initially moved away from the tool surface and the energized electrode. When voltage was reduced, the foil returned to nearly original location. After polarity reversal and application of the opposite-polarity voltage, the foil moved towards the tool surface and the energized electrode. After contacting the electrode energized at the opposite polarity, the foil was repelled from it and the tools surface, and tended to move toward the opposite electrode.
8	Discharge the foil before test. Apply negative -polarity voltage. Without touch the foil, reverse polarity. Apply positive -polarity voltage.	Upon application of voltage, the foil initially moved away from the tool surface and the energized electrode. When voltage was reduced, the foil returned to nearly original location. After polarity reversal and application of the opposite-polarity voltage, the foil moved towards the tools surface and the energized electrode. After contacting the electrode energized at the opposite polarity, the foil was repelled from it and tended to move toward the opposite electrode.



(a)



(d)



(b)



(e)

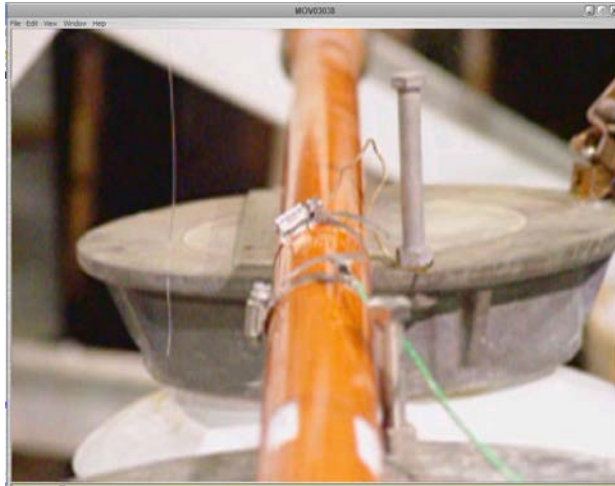


(c)

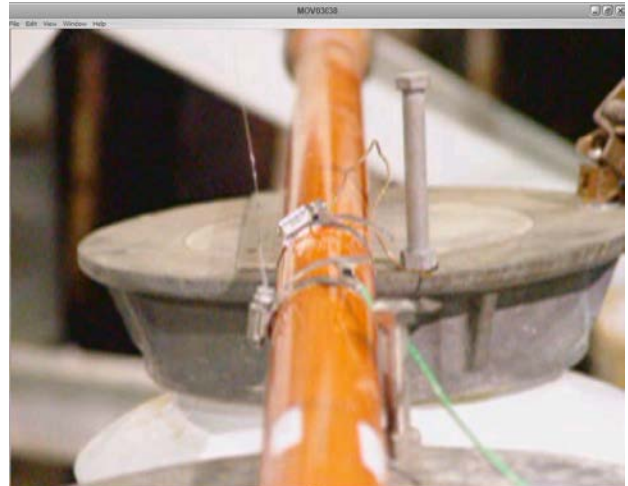


(f)

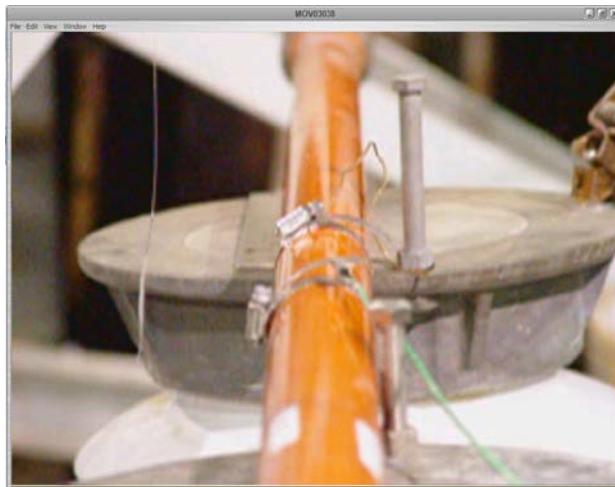
Figure 5-8
Selected Stills from Video CIMG4073 Taken During Test #7 Described in Table 5-1.



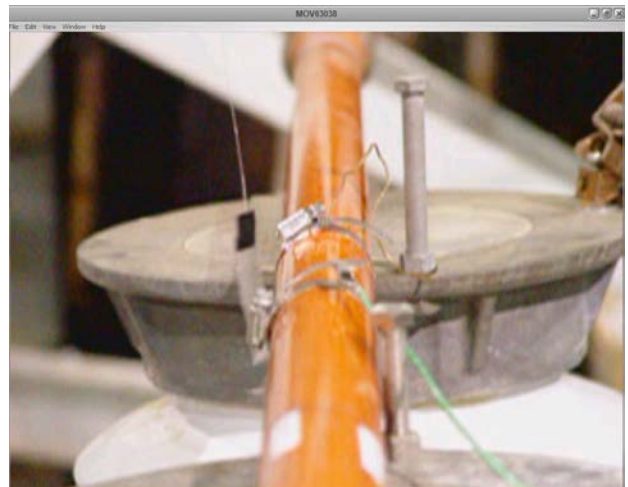
(a)



(c)



(b)



(d)

Figure 5-9
Selected Clips from a Test (MOV0303) with the High-Speed Looking along the Test Sample.

Discussion

The tests clearly indicate movement of the foil positioned next to an FRP rod with two electrodes energized with DC voltage. The obvious question is whether this motion is caused by charge deposition, or by some other factors such as wind, air currents, etc.

As all tests were performed indoors and care was taken to minimize movement of personnel, wind as the cause of foil movement can be eliminated. Other factors, such as air currents, are also eliminated because of the repeatability of observed results on various days. Also, tests did not produce reliable results on humid days, that is, when charge can more easily bleed off from the foil and tool surface along insulating supports.

For these reasons, the tests seem to indicate that corona-generated charge can be deposited both on metal parts (foil) and on insulating portion of live working tools (the FRP rod).

Possible Effects of Deposited Charge on Tool Flashover

Based on the results from tests with the aluminum foil, there is strong evidence that corona-generated space charge can be deposited on surfaces of live working tools. The possible effects of the deposited charge on flashover characteristics of live working tools have not been investigated thus far in any detail. In this project, an attempt was made to determine whether charge deposited on the tool affects (that is, reduces) the surface flashover voltage of the tool. Tests were initially performed on short samples in a setup similar to that described in Reference [3], which is used for in-service testing of tools with AC voltage (the “Hi-pot” test in Reference [3]). The distance between electrodes (hose clamps) was set at 6”, and the normal test voltage for this setup is 35 kVAC or 53 kVDC. Guard electrodes were not used and additional corona sources were added to produce copious corona (space charge). Tests were performed under dry and wet conditions. Wetting was performed by spraying de-ionized water on the entire surface of the sample.

Figure 5-10 shows a close-up of the test setup, and Figure 5-11 shows the sample wetted with de-ionized water.

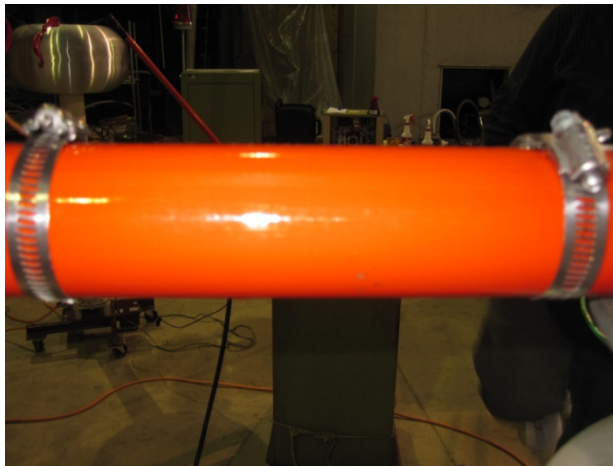


Figure 5-10
Close-Up of the Test Setup for Flashover Tests.

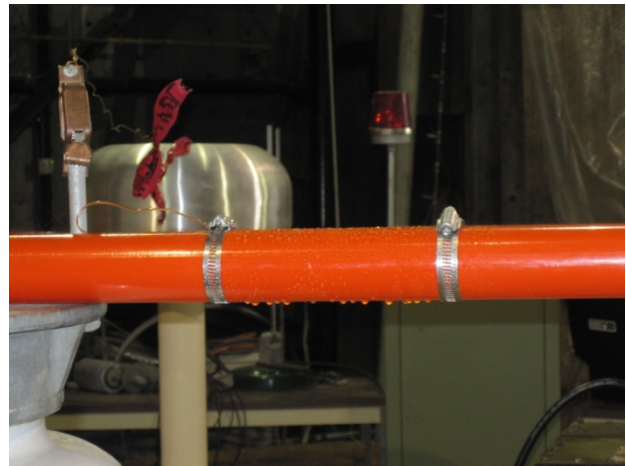


Figure 5-11
Sample Wetted with De-Ionized Water.

Flashover of LW tools tends to damage the tools surface. For this reason, initial tests used short samples that were part of previous research [16, 17]. These samples were exposed to up to 2500 hours of ultraviolet radiation that simulates sunlight to which tools can be subjected in normal service.

An interesting observation was made. While exposure to UV during the aging tests did not appear to degrade the tool surface, exposure of the aged samples to water and test voltage resulted in de-lamination of a surface layer (the UV protection later). Figure 5-11 shows local de-lamination occurring after one wet energized test. Figure 5-12 shows de-lamination over the entire surface after repeated wet energized tests. In Figure 5-12, de-lamination extends even beyond energized (right-hand-side) and the grounded (left-hand-side) electrodes. While this observation may be important from the viewpoint of tools aging (and exposure to sunlight), further detailed investigation would be outside the scope of this project and was not conducted.

Rather, tools that were not exposed to the UV aging tests were used for further flashover tests. It should be noted, however, that flashover voltage of the UV-aged samples with surface de-lamination was very low.



Figure 5-12
Local De-Lamination after One Wet Energized Test.

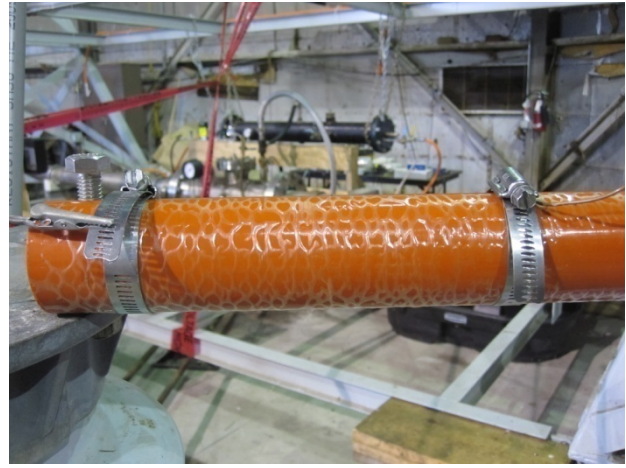


Figure 5-13
De-Lamination over the Entire Surface after Repeated Wet Energized Tests.

The remainder of the research was conducted using actual full-length tools that were provided by participating utilities. The service history of these tools is not known, however, they did not exhibit surface de-lamination. Figure 5-14 shows the entire test setup and Figure 5-15 shows a close-up of the wetted section of the tool.

To achieve flashover, the applied voltage was raised until flashover occurred or the DC source breaker tripped on overcurrent. Due to current limitations of the DC power supply, the DC source breaker tripped in most cases before flashover occurred. In tests with dry samples, flashover voltage varied somewhat from tests to test, but on average the value was around 100 kVDC. It must be recalled, however, that the test setup used deviates from the recommended setup in Reference [3], that is, guard electrodes were not used, and means of generating copious corona were deliberately implemented. While guard electrodes are recommended for AC tests to minimize the capacitive current (capacitive current is not present in DC tests) component of the measured current, the guard electrodes also grade (reduce) the electric field and thus may affect flashover voltage. In the test setup in Figure 5-14, electric field at the energized electrode was deliberately enhanced to increase corona activity and generation of space charge. Hence, comparison of results from these tests with those from typical in-service “Hi-pot” tests is not meaningful.



Figure 5-14
View of the Test Setup for Flashover Tests.

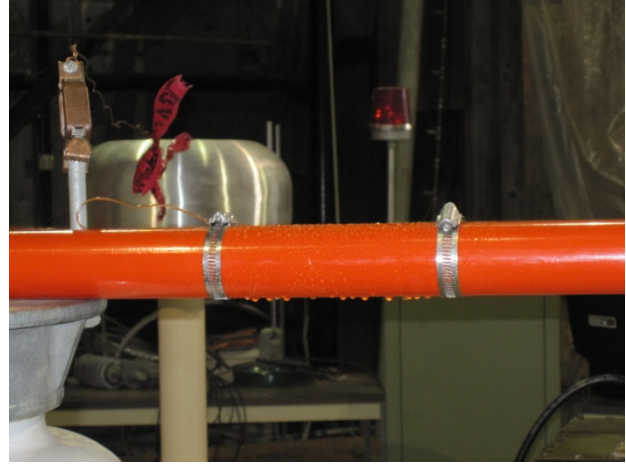


Figure 5-15
Close-Up of the Wetted Section of the Tool.

It should also be recognized that short-sample tests were performed to develop the test procedure and gain some preliminary data, but they are not necessarily representative of exposure to voltage stresses to which tools are subjected in actual service [18]. Full-scale tests, with corona-generated space charge are recommended as the next step in this study.

6

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER LIVE LINE RESEARCH

Background

Live work (LW) on DC lines was derived from AC live work, and in general the two employ the same work methods and tools. However, different phenomena are associated with the two types of systems, and some work requires special procedures.

The principles of DC LW and tool design are based on the best available technical information and experience. The design principles are based on the following fundamental assumptions:

- Nominal pole—ground or earth DC voltage, V_{P-G} , is equal to the AC phase—ground or earth peak voltage.
- Maximum transient overvoltages on DC lines are not higher than p.u.= 1.8.

Based on this principle, one follows the same steps to calculate minimum approach distance (MAD) for either AC or DC LW. Work practices for both AC and DC LW are also based on the same principles.

However, there are significant differences in the worksite conditions on AC and DC lines. Specifically, worksite and LW tools on DC lines are subjected to corona-generated space charge. Study of the possible effects of this space charge on the performance of tools is the goal of this research.

Conclusions

Tests on short tool samples performed with DC energization as part of this research indicate that corona-generated space charge can be deposited on tool surfaces. No attempt was made to determine the amount of the deposited charge, and such measurements are known to be very difficult to perform. However, a more important question to address from the live working point of view is the possible effect of the deposited charge on tool performance, specifically flashover voltage.

Flashover tests on short samples of tools did not provide conclusive results because the test setup was deliberately modified from the typically used setups for in-service testing [3]. The modifications were done to increase the amount of corona. Although dry flashover voltages obtained in this research tend to be lower than in more typical tests, it is difficult to discern whether the decrease is related to effects of any deposited charge or to the deliberately modified test setup. Further investigation of this important issue should be performed on full-scale HVDC transmission structures.

Recommendations

The results of this research indicate that corona-generated charge can be deposited on surfaces of LW tools, however, possible detrimental effects of this charge could not be evaluated. It is recommended that investigation of this important issue should be performed on full-scale HVDC transmission structures.

7

HVDC INSULATOR MANUFACTURER QUESTIONNAIRE

Introduction

The questions contained in the questionnaire were developed with input from the EPRI insulator specialists. The questionnaire consisted of a brief introduction, which included the aim of the questionnaire. It also included the contact details of the EPRI project manager. The main body of the questionnaire consisted of 14 questions. The entire questionnaire is shown below.

Start of Survey

The aim of the questionnaire is to gain an understanding and gather information on the differences if any between HVDC and HVAC insulators which you manufacture.

Any information you supply will be made available to project funders however no mention will be made of the name of your company. Reference will be made to Manufacturer 1, Manufacturer 2, Manufacturer 3, etc.

If you have any questions, do not hesitate to contact me via email gsibilant@epri.com or by telephone at +1-704-595-2598.

Thank you for participating in this survey.

Yours sincerely

Gary Sibilant

Manufacturer Information

Name:

Email

Telephone number:

Company:

Survey Questions

Question 1: Does your company manufacture AC and DC insulators?

If you answered “yes” to question one, please proceed to question 3.

Question 2: Why do you not manufacture DC insulators?

Question 3: Of which material(s) are your AC insulators made (glass, composite or porcelain)?

Question 4: Of which material(s) are your DC insulators made (glass, composite or porcelain)?

Question 5: If there is a difference in materials listed in the answers to question 4 and 5, please explain why?

Question 6: If the same material is used for your AC and DC insulators, is there any difference in the formulation of the materials used?

Question 7: If the same materials are used for your AC and DC insulators is there any difference in the way they are manufactured?

Question 8: If you answered yes to either or both of questions 6 and 7, Could you explain why there is a difference in the formulation and/or the manufacturing process between your AC and DC insulators?

Question 9: If you answered yes to either or both of questions 6 and 7, can you explain what the difference is between the AC and DC insulators which you manufacture?

Question 10: If you answered no to either or both of questions 6 and 7, could you explain why there is no difference?

Question 11: Do you recommend using corona rings on your composite AC and DC insulators?

Question 12: At what voltage do you recommend that corona rings be used on your AC and DC insulators?

Question 13: Are corona rings recommended for both ends of the insulator for AC and DC?

Question 14: Could you please send us a catalog of your AC and DC insulators?

8

SUMMARY OF MANUFACTURER RESPONSES

All five the manufacturers that received the questionnaire sent their responses. The responses are summarized below.

Question 1

Does your company manufacture AC and DC insulators?

All 5 manufacturers reported that they manufacture both AC and DC insulators.

Question 2

Why do you not manufacture DC insulators?

Since all the manufacturers manufacture DC insulator this question was not applicable.

Question 3

Of which material(s) are your AC insulators made (glass, composite or porcelain)?

2 Manufacturers only make AC composite insulators.

2 Manufacturers make AC composite and porcelain insulators.

1 Manufacturer makes AC composite, porcelain and glass insulators.

Question 4

Of which material(s) are your DC insulators made (glass, composite or porcelain)?

2 Manufacturers only make DC composite insulators.

2 Manufacturers make DC composite and porcelain insulators.

1 Manufacturer makes DC composite, porcelain and glass insulators.

Question 5

If there is a difference in materials listed in the answers to question 4 and 5, please explain why?

All manufacturers used the same materials (glass, composite or porcelain) for both their AC and DC insulators.

Question 6

If the same material is used for your AC and DC insulators, is there any difference in the formulation of the materials used?

3 of the manufacturers state that there is no difference in the material formulation used for their AC or DC insulators (although one states that they use a sacrificial zinc sleeve on the HV end metal fitting).

1 Manufacturer states that the porcelain used for their DC insulators are of a much higher purity than the AC insulators.

1 Manufacturer states that while no difference exists between the AC and DC polymer insulators, their polymer has been designed to a much higher standard from the outset—therefore allowing it to be used for AC and DC applications.

Question 7

If the same materials are used for your AC and DC insulators is there any difference in the way they are manufactured?

4 of the manufacturers state that there is no difference in the way that their AC and DC insulators are manufactured.

1 manufacturer states that there are differences in the melting processes of AC and DC glass insulators and that the levels of potassium are changed. The exact details are proprietary.

Question 8

If you answered yes to either or both of questions 6 and 7, Could you explain why there is a difference in the formulation and/or the manufacturing process between your AC and DC insulators?

One manufacturer answered that for toughened glass like for porcelain cap and pin insulators there is a necessity to manage ionic effects between cap and pin fittings. This is done with a high resistivity formulation of glass.

Another manufacturer stated that they use a zinc sleeve for DC insulators on the HV end and not for AC insulators.

All other manufacturers had no differences.

Question 9

If you answered yes to either or both of questions 6 and 7, can you explain what the difference is between the AC and DC insulators which you manufacture?

One manufacturer indicated the following: the body resistance is higher for DC. Caps are fitted with a zinc collar to prevent electrochemical corrosion of the cap under steady activity as encountered in DC. Also a zinc sleeve is adherent to the pin as per IEC 61325. For composite insulators the fittings used in DC are fitted with a zinc protection sleeve like for glass insulators for the same reasons.

Another manufacturer stated the use of a zinc sleeve for certain end fitting on the HV end of their DC polymer insulators.

The other three manufacturers had no differences.

Question 10

If you answered no to either or both of questions 6 and 7, could you explain why there is no difference?

One manufacturer indicated that while there was no difference in the material or the manufacturing process of their AC and DC insulators—they do recommend higher creepage distances for the DC insulators.

Another manufacturer stated that long term experience has led to the design of the AC and DC insulators being the same.

A third manufacturer indicated that while the material and manufacturing process was the same, there were differences in the AC and DC insulator designs.

A fourth manufacturer indicated that for their composite insulators, there is no difference in rod or housing material for AC or DC insulators.

Question 11

Do you recommend using corona rings on your composite AC and DC insulators?

All the manufacturers responded that they recommend using corona rings on their composite AC and DC insulators.

Three answered that the application depended upon the magnitude of the applied voltage.

One replied further that they have a special corona ring recommendation for DC insulators compared to their AC insulators.

Question 12

At what voltage do you recommend that corona rings be used on your AC and DC insulators?

One manufacturer responded that they recommend corona rings for AC voltages above 161 kV. They have only supplied DC insulators at voltages of 400 kV or above and therefore have always recommended corona rings for the DC insulators.

One manufacturer recommends corona rings for AC insulators at 240 kV or above. The application of corona rings at voltages of 230 kV or below is determined by modeling. The use of corona rings on DC insulators is determined by the customer specification and or the voltage class.

A third manufacturer indicates that they recommend corona rings be used for AC insulators being used at voltages of 123kV and above, and sometimes for voltages as low as 72.5 kV too. They always recommend corona rings for DC insulators (150 kV up to 800 kV).

The fourth manufacturer states that for AC voltages they recommend the use of corona rings for 115 kV system voltages and above on polymer suspension type insulators. While their DC insulators is generally only employed at ± 250 kV or higher and so they recommend corona rings.

The fifth manufacturer recommends corona rings for AC voltages of or above 230 kV. Since their insulators have been applied to DC lines at 350 kV or above, they always recommend corona rings.

Question 13

Are corona rings recommended for both ends of the insulator for AC and DC?

Manufacturer 1 indicated that corona rings are always specified at both ends of their insulators.

Manufacturer 2 indicated that on AC insulators the application of corona rings on both sides of the insulator is voltage dependent, while they always specify the use of corona rings on both ends of DC insulators.

Manufacturer 3 indicated that the application of corona rings on both sides of their insulators depends on the voltage level.

Manufacturer 4 indicated that they recommend corona rings at both ends for 345 kV AC and higher and for all DC applications.

Manufacturer 5 indicated that the application of corona rings on both ends is dependent on the voltage class.

Table 8-1 summarizes the results on the application of corona rings.

Table 8-1
Summary of Insulator Corona Ring Application

Manufacturer	AC Corona Ring Application	DC Corona Ring Application	Corona Rings Applied to Both Ends of Insulator
1	$V \geq 161 \text{ kV}$	$V \geq 400 \text{ kV} *$	Yes
2	$V \geq 240 \text{ kV}$	Customer specification and or voltage class	Yes (For DC), AC – voltage dependent
3	$V \geq 123 \text{ kV}$ (sometimes as low as 72.5 kV)	$V \geq 150 \text{ kV} **$	Yes (voltage dependent)
4	$V \geq 115 \text{ kV}$	$V \geq 250 \text{ kV} ***$	Yes (For DC), AC – voltage dependent
5	$V \geq 230 \text{ kV}$	$V \geq 350 \text{ kV} ****$	Voltage dependent

* Only supplied insulators to DC systems of 400 kV or above

** DC systems are between 150 kV and 800 kV – recommends corona rings for all applications

*** DC systems are only employed at 250 kV or above

**** DC systems only used at 350 kV or above

9

INITIAL HVDC INSULATOR TESTING

Introduction

Initial tests were undertaken in the EPRI Charlotte laboratory to determine the effects of water droplets on the corona activity which occurs at the end fittings of polymer insulators.

Negative and Positive DC voltages were studied as well as AC. The tests conducted were of an exploratory nature and will be used as a basis for future testing.

Test Setup

Tests were done in the high voltage area of the Charlotte PDU laboratory. A ± 125 kV DC supply and a 120 kV AC supply was used for the tests. A 25000lb NGK insulator was used for these tests.

Tests were conducted in a corona cage. The corona cage was used to ensure that the electric field generated on the end fitting would be high enough to generate corona activity. The corona cage is shown in Figure 9-1. The DC supply control panel is shown in Figure 9-2.



Figure 9-1
Corona Cage used for Tests



Figure 9-2
DC Test Supply used for Tests

Test Procedure

Dry Tests:

The end fitting of the insulator was placed in the corona cage as shown in Figure 9-3. A voltage was then applied to the end fitting until it was continuously in corona—this was recorded as the inception voltage. The voltage was reduced until no further corona activity was noticed—this was recorded as the extinction voltage.



Figure 9-3
Insulator end fitting in Corona Cage

Wet Tests:

The same procedure as for the dry tests was followed, except that before a voltage was applied to the end fitting, a water droplet was placed on it.

Test Results

Negative Polarity Tests

Figure 9-4 shows the results for the negative DC tests conducted. As expected the inception gradient under wet conditions (average = 85.5 kV) is lower than that under dry conditions (average = 96.6 kV). What is interesting to note is that the extinction voltage is similar for the wet and dry tests (average = 82.4 kV in both cases).

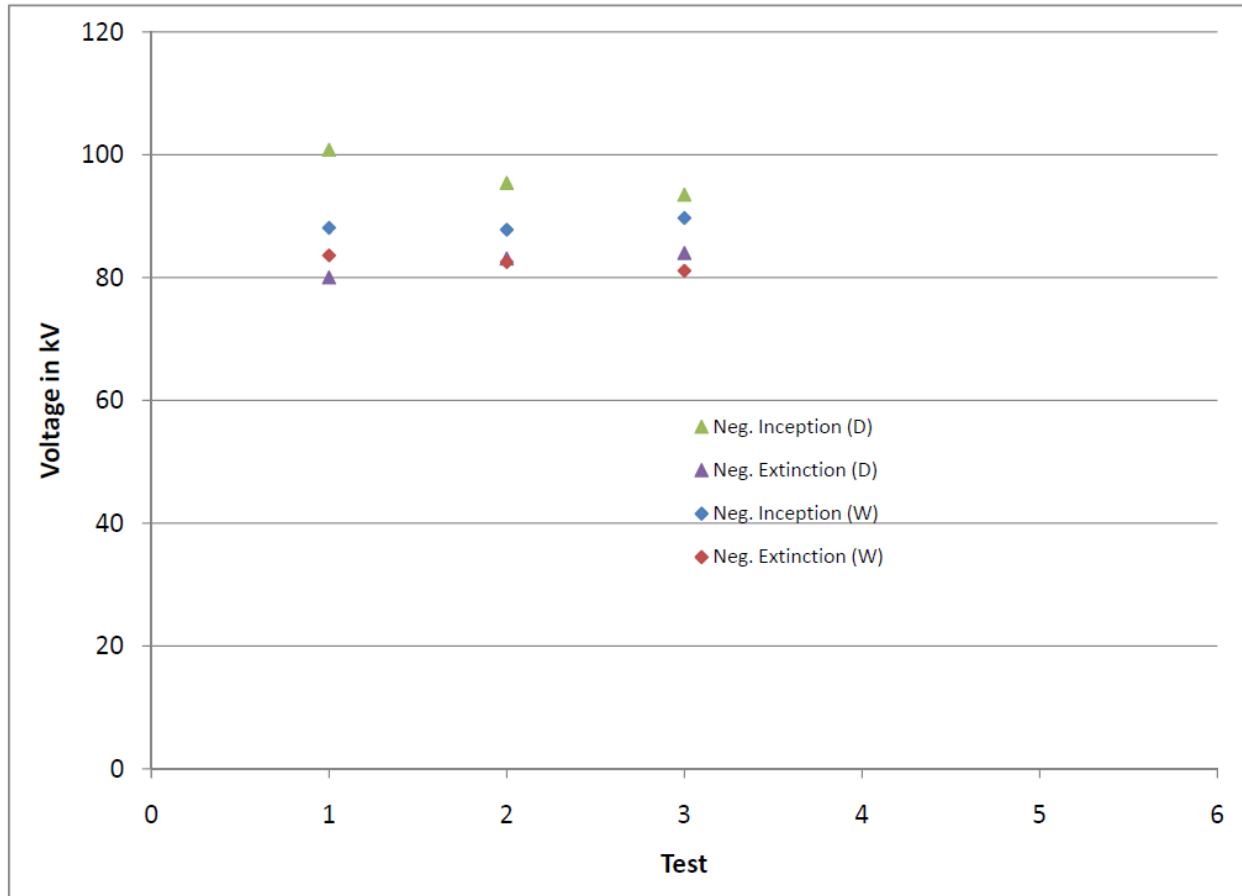


Figure 9-4
Wet and Dry Negative DC results

Positive Polarity Tests

Figure 9-5 shows the results for the positive polarity tests. Similar to the negative DC results, the wet test inception levels (average = 74.4 kV) were lower than the dry test inception levels (average = 91.0 kV).

Compared to the inception levels, the extinction levels for the wet (average = 68.8 kV) and dry (average = 65.7 kV) were similar.

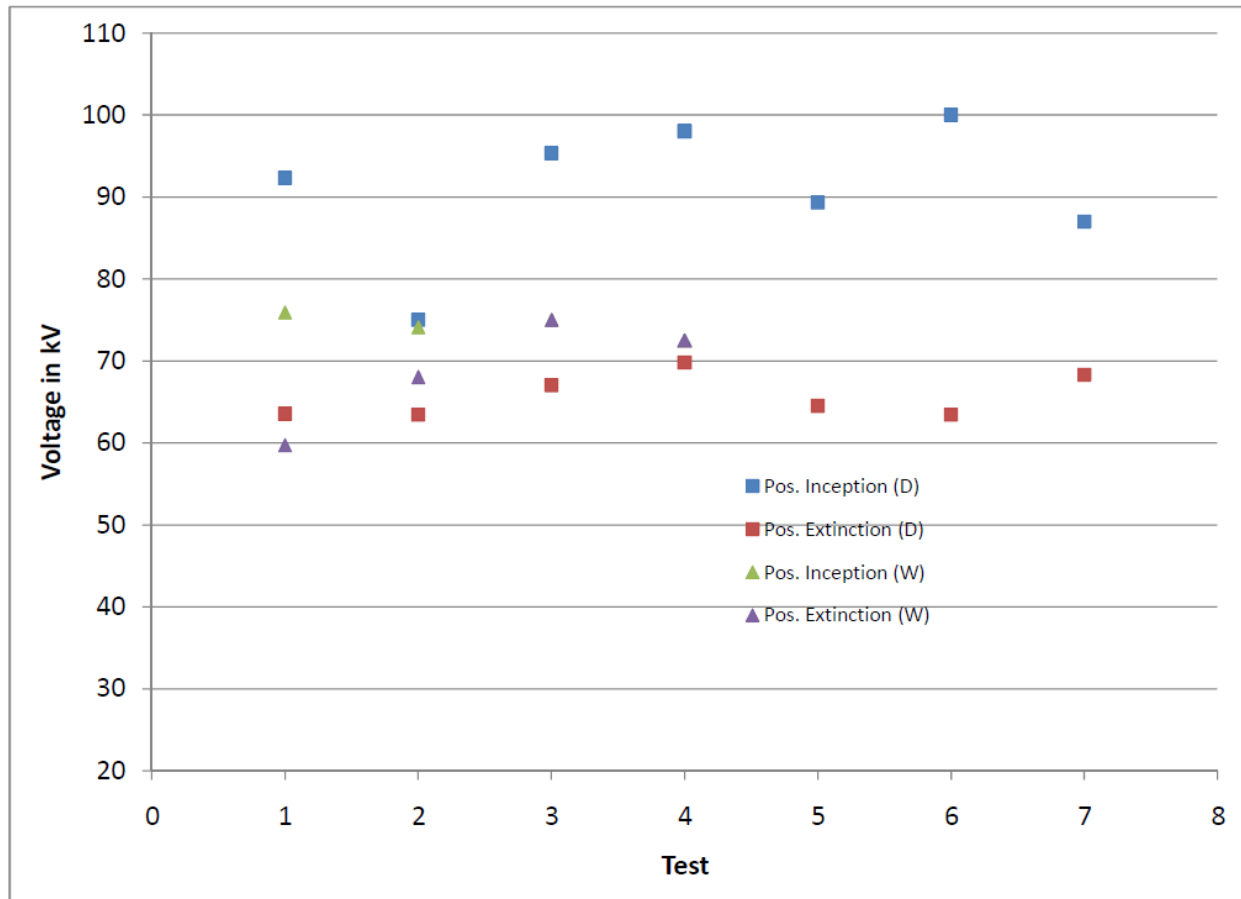


Figure 9-5
Wet and Dry Positive DC results

AC Test Results

Figure 9-6 shows the AC test results. AS with the DC test results, the wet tests (average = 57.5 kV) results in lower inception voltages when compared to the dry tests (average = 91.4 kV). The average extinction voltage for the wet tests was 51.4 kV, while for the dry tests it was 85.0 kV.

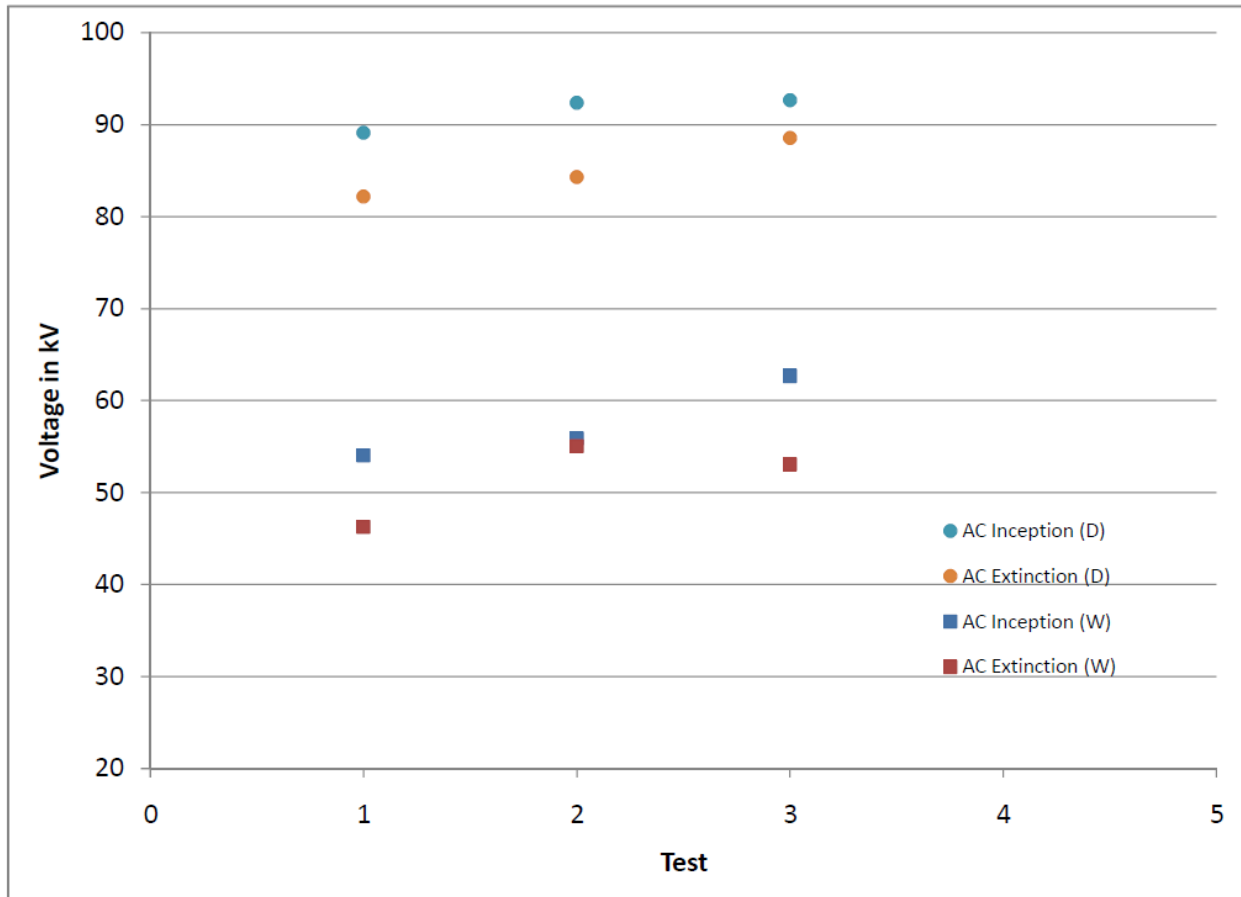


Figure 9-6
Wet and Dry AC Results

Discussion

The positive polarity tests resulted in corona inception levels which were lower than that of the negative polarity for both the dry and wet tests. Similarly, the positive polarity extinction levels were lower than that of the negative polarity.

For both the wet and dry tests, the extinction voltages were similar in magnitude, this applied to the positive and as well as the negative polarity tests. This implies that the extinction voltage was not affected by the water droplet (it should be noted that once the droplet went into corona it was dispersed, this could be the reason why the wet and dry extinction levels are similar).

For the dry AC tests, the corona inception voltage was slightly higher than the positive Dry DC polarity test result, while the extinction voltage was higher than the negative Dry DC polarity test result. The corona activity on the test object would become extinct on the negative half cycle—since the negative polarity has the higher extinction voltage.

Figure 9-7 shows the region of Dry AC corona activity in relation to the Positive and Negative DC inception and extinction voltages. This graph indicates that the AC corona activity voltages lay within the negative DC corona activity voltages (this is expected as empirical tests have shown similar results [19]).

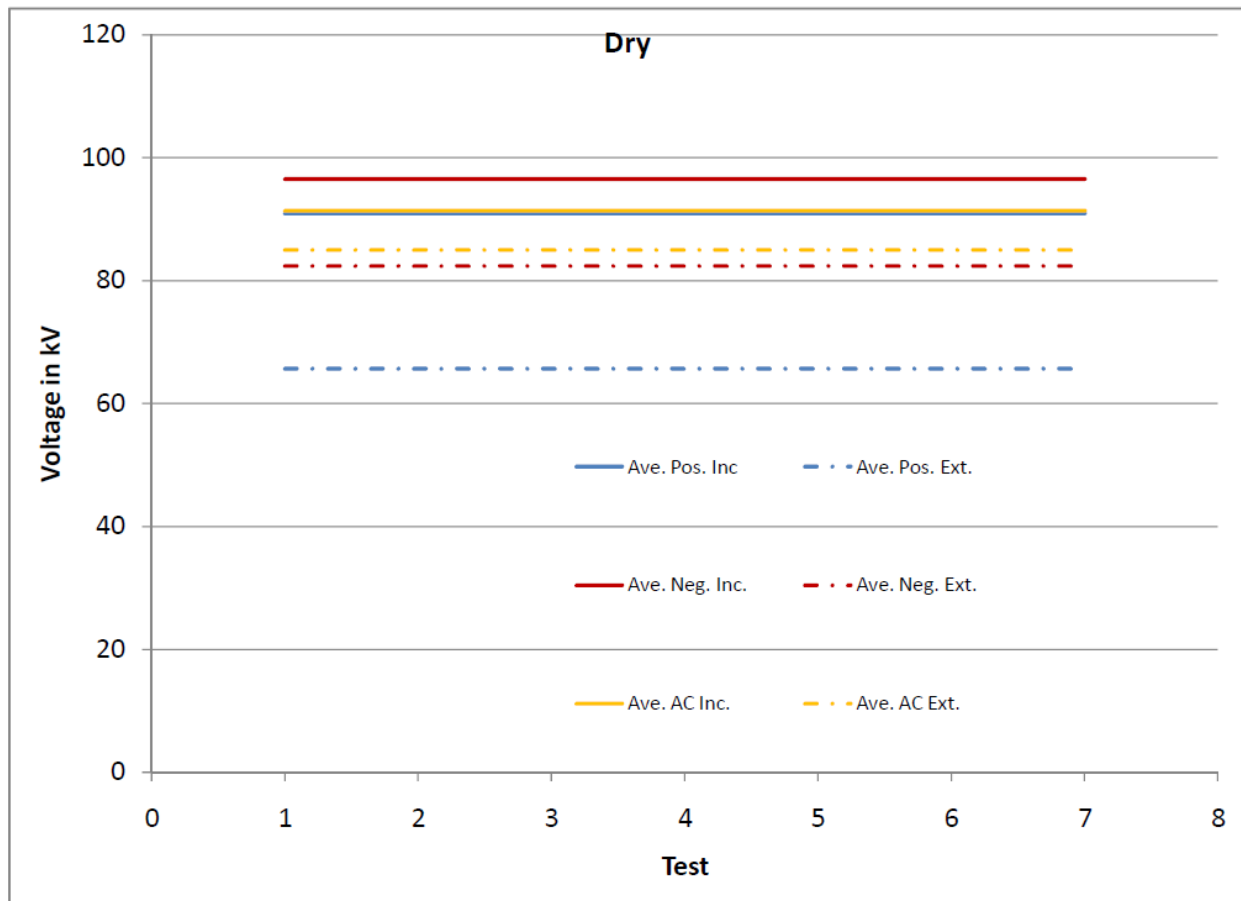


Figure 9-7
Measured dry corona inception and extinction levels

What was not expected was that the positive tests would result in lower inception voltages than the negative tests for both the wet and dry tests. A possible explanation for this anomaly is that as the positive and negative tests were done several weeks apart—this could have resulted in the positioning of the test object as well as the orientation of the test object and the location of the water droplets to be slightly different. Further tests will need to be conducted in order to clarify the results.

The results of the wet AC tests however do not correlate as well with the inception and extinction levels from the DC tests. The reason for this could be due to the fact that under DC conditions, the water droplet changes shape more drastically than under AC conditions. It was noted that during the DC tests, the water droplet would elongate and flatten substantially, compared to the AC case. As a result of this, the field intensification caused by the water droplet shape is lower for DC than for the AC case. Therefore the inception voltage needed to get the water droplet into corona under AC conditions is lower. Similarly the AC extinction voltage is lower than the DC test extinction voltage.

10

CONCLUSIONS OF HVDC INSULATOR SURVEY AND TESTING

Questionnaire

A questionnaire was drawn up to obtain some basic information from insulator manufacturers on their practices of manufacturing DC insulators.

All five of the manufacturers surveyed made AC and DC composite insulators. However of the five only three made DC insulators of other materials (two made DC insulators out of porcelain and one made DC insulators out of glass and porcelain as well).

Three of the manufacturers indicate that the same materials and processes are used for both AC and DC insulators. One manufacturer uses a higher purity porcelain for their DC insulators compared to their AC insulators, while another uses a special glass formulation for their DC insulators.

The recommendation on the application of corona rings varied by the manufacturer, the most common response was that the application was voltage dependent.

Corona Tests

Initial tests were conducted to determine the corona inception levels of an insulator end fitting under wet and dry conditions for AC, positive DC as well as negative DC applied voltages. Initial results have shown that the AC wet and dry end fitting corona results lay, as expected within the DC negative test results. An anomalous finding was that the DC positive tests resulted in lower inception voltages than the DC negative tests. This anomaly could be attributed to the test setup and will need to be clarified in future testing which could include the long term aging effects of DC voltages on polymer insulator materials.

11

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A

TOOLS FOR HVDC LW - TEST PROCEDURE

Task 1: AC versus DC

Objective

Evaluate performance of traditional FRP LW tool in HVDC environment.

General Approach

1. Clean and wipe selected tool sample. Test sample with AC per IEEE 516 Clause 5.8.3 modified (wire in place of spiral electrodes, separation 6", no guard electrode) and 5.8.5. Measure AC current per IEEE 516 Clause 5.8.4.
2. Clean and wipe the same tool sample. Test tool sample with +DC using procedure in Step 1. Measure DC current per IEEE 516 Clause 5.8.4.
3. Clean and wipe the same tool sample. Test tool sample with -DC using procedure in Step 1. Measure DC current per IEEE 516 Clause 5.8.4.
4. Clean and wipe the same tool sample. Test tool sample with AC using procedure in Step 1. Measure AC current per IEEE 516 Clause 5.8.4.
5. Repeat Steps 1 through 4.
6. Again repeat Steps 1 through 4.
7. Clean and wipe selected tool sample. Wet the sample per IEEE 516 Clause 5.8.5. Test sample with AC per IEEE 516 Clause 5.8.3 modified (wire in place of spiral electrodes, no guard electrode) and 5.8.5. Measure AC current per IEEE 516 Clause 5.8.4.
8. Clean and wipe the same tool sample. Wet the sample per IEEE 516 Clause 5.8.5. Test tool sample with +DC using procedure in Step 1. Measure DC current per IEEE 516 Clause 5.8.4.
9. Clean and wipe the same tool sample. Wet the sample per IEEE 516 Clause 5.8.5. Test tool sample with -DC using procedure in Step 1. Measure DC current per IEEE 516 Clause 5.8.4.
10. Clean and wipe the same tool sample. Wet the sample per IEEE 516 Clause 5.8.5. Test tool sample with AC using procedure in Step 1. Measure AC current per IEEE 516 Clause 5.8.4.
11. Repeat Steps 7 through 10.
12. Again repeat Steps 7 through 10.

Task 2: DC space charge deposition on tool

Objective

Evaluate space charge deposition on tool.

General Approach

1. Set up DC test electrodes to produce copious amounts of corona.
2. Set up aluminum foil leaf suspended from fishing line.
3. Clean and wipe selected tool sample. Test sample with +DC per IEEE 516 Clause 5.8.3 modified (wire in place of spiral electrodes, separation 6", no guard electrode). Measure DC current per IEEE 516 Clause 5.8.4. Observe foil leaf for movement.
4. Repeat Step 3.
5. Again repeat Step 3.
6. Clean and wipe selected tool sample. Test tool sample with -DC using procedure in Step 1. Measure DC current per IEEE 516 Clause 5.8.4. Observe foil leaf for movement.
7. Repeat Step 6.
8. Again repeat Step 6.

Task 3: AC versus DC flashover

Objective

Evaluate flashover performance of traditional FRP LW tools with AC and DC.

General Approach

1. Clean and wipe selected tool sample. Test sample with AC per IEEE 516 Clause 5.8.3 modified (wire in place of spiral electrodes, separation 6", no guard electrode) and 5.8.5. Raise voltage to flashover.
2. Clean and wipe the same tool sample (if not damaged, else use new sample). Test tool sample with +DC using procedure in Step 1. Raise voltage to flashover.
3. Clean and wipe the same tool sample (if not damaged, else use new sample). Test tool sample with -DC using procedure in Step 1. Raise voltage to flashover.
4. Clean and wipe the same tool sample (if not damaged, else use new sample). Test tool sample with AC using procedure in Step 1. Measure AC current per IEEE 516 Clause 5.8.4.
5. Repeat Steps 1 through 4.
6. Again repeat Steps 1 through 4.
7. Clean and wipe selected tool sample. Wet the sample per IEEE 516 Clause 5.8.5. Test sample with AC per IEEE 516 Clause 5.8.3 modified (wire in place of spiral electrodes, no guard electrode) and 5.8.5. Measure AC current per IEEE 516 Clause 5.8.4.
8. Clean and wipe the same tool sample (if not damaged, else use new sample). Wet the sample per IEEE 516 Clause 5.8.5. Test tool sample with +DC using procedure in Step 1. Measure DC current per IEEE 516 Clause 5.8.4.

9. Clean and wipe the same tool sample (if not damaged, else use new sample). Wet the sample per IEEE 516 Clause 5.8.5. Test tool sample with -DC using procedure in Step 1. Measure DC current per IEEE 516 Clause 5.8.4.
10. Clean and wipe the same tool sample (if not damaged, else use new sample). Wet the sample per IEEE 516 Clause 5.8.5. Test tool sample with AC using procedure in Step 1. Measure AC current per IEEE 516 Clause 5.8.4.
11. Repeat Steps 7 through 10.
12. Again repeat Steps 7 through 10.

B

TOOLS FOR HVDC LW - TEST SETUP

The test setup was located in the Lenox UHV building and included both AC and DC voltage sources. Extensive safety controls were implemented.

The test setup included the following equipment:

1. 2 Fluke Digital Multimeters (see Figure B1).
2. A Leakage Current Shunt Box and cabling (see Figure B-2).
3. The Phenix 10,000:1 300kV Divider (serial number 08-4725) and meter (see Figure B-3).
4. The Hipotronics 200kV Divider and meter (serial number M9606285) (see Figure B-3).
5. The Hipotronics HVDC Source (7200-10, serial number 72998) and control box (see Figures B-4 and B-5).
6. The Hipotronics HVAC 150 kV Source (see Figure B-6) and control box (see Figure B-7).
7. 2 Stacks of 2 insulators each, with the test piece mounted on top (see Figure B-9).
8. Associated cables, gate circuits, and grounding equipment (see Figure B-9).

All high voltage sources were placed with a minimum of 3 feet clearance around the output. The transformers, supplies, shunt box, and dividers were grounded with 4AWG jacketed welding cable. These ground cables were connected in a star configuration to the central point at the base of the Phenix divider. The star point was connected to the building ground at the South wall of the UHV building, see Figures B-10 and B11.

Before each test, atmospheric conditions (temperature, humidity, pressure) were recorded. If testing continued for more than 4 hours, atmospheric conditions were recorded again.



Figure B-1
Two Fluke Digital
Multimeters.



Figure B-2
Leakage Current Shunt
Box.



Figure B-3
Phenix 300kV Divider (Left) and Hipotronics 200kV Divider (Right).

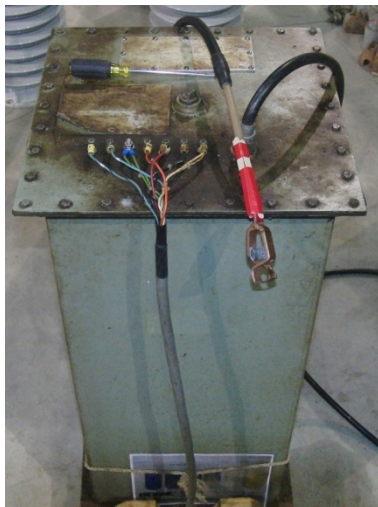


Figure B-4
Hipotronics HVDC Source.



Figure B-5
Hipotronics HVDC Control Box.



Figure B-6
Hipotronics HVAC Transformer.



Figure B-7
Hipotronics HVAC Control Box.



Figure B-8
**2 Stacks of 2 Insulators Each,
with a Test Piece Mounted on
Top.**



Figure B-9
Associated Cables, Gate Circuits, and Grounding Equipment.

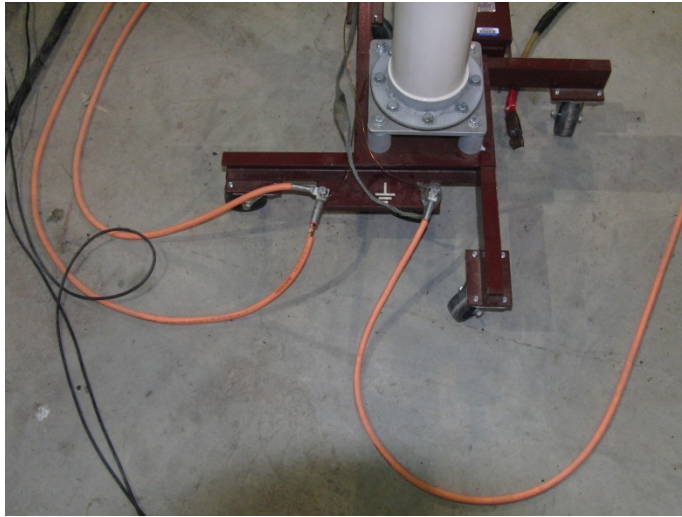


Figure B-10
Ground Cables Connect in a Star Configuration to the Central Point at the Base of the Phenix Divider.

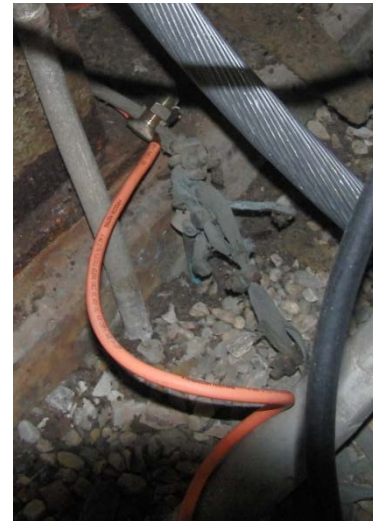


Figure B-11
Star Point Connected to Building Ground at the South Wall of the UHV Building.

To energize the AC source, the breaker on the South wall of the building (see Figure B-12) has to be closed.

Procedure for Changing DC Polarity:

1. Ensure that both of the Hipotronics power supplies are OFF.
2. Ground the test setup.
3. Remove the 12 screws from the small access plate on top of the HVDC tank (see Figure B-12).
4. Remove the plate.
5. Slowly and carefully remove (by pulling upward) the diode card from the HVDC tank
6. Avoid dripping oil on floor.
7. Rotate the diode card 180°, keeping the same side facing you.
8. Avoid dripping oil on floor.
9. Slowly and carefully insert the diode card into the appropriate grooves in the HVDC tank.
10. Avoid dripping oil on floor.
11. Replace the cover and 12 screws.



Figure B-12
Breaker on the South Wall of the
Building for Energizing the Test
Setup with HVAC.

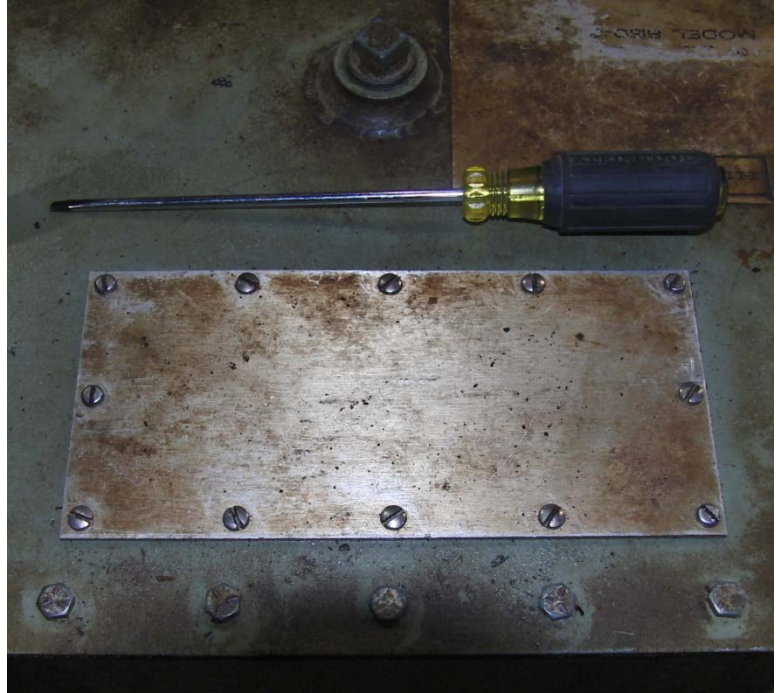


Figure B-13
Small Access Plate on Top of the HVDC Tank for Changing
the Polarity of the HVDC Source.

C

INSULATOR MANUFACTURER RESPONSES

Response from Manufacturer 1

Question 1: Does your company manufacture AC and DC insulators?

Answer 1: Yes.

If you answered “yes” to question one, please proceed to question 3.

Question 2: Why do you not manufacture DC insulators?

Question 3: Of which material(s) are your AC insulators made (glass, composite or porcelain)?

Answer 3: Composite.

Question 4: Of which material(s) are your DC insulators made (glass, composite or porcelain)?

Answer 4: Composite

Question 5: If there is a difference in materials listed in the answers to question 4 and 5, please explain why?

Question 6: If the same material is used for your AC and DC insulators, is there any difference in the formulation of the materials used?

Answer 6: No.

Question 7: If the same materials are used for your AC and DC insulators is there any difference in the way they are manufactured?

Answer 7: No.

Question 8: If you answered yes to either or both of questions 6 and 7, Could you explain why there is a difference in the formulation and/or the manufacturing process between your AC and DC insulators?

Question 9: If you answered yes to either or both of questions 6 and 7, can you explain what the difference is between the AC and DC insulators which you manufacture?

Question 10: If you answered no to either or both of questions 6 and 7, could you explain why there is no difference?

Answer 10: The construction of the insulators is the same. However, we do recommend higher leakage distances for DC units than for equivalent nominal voltage AC units.

Question 11: Do you recommend using corona rings on your composite AC and DC insulators?

Answer 11: Yes.

Question 12: At what voltage do you recommend that corona rings be used on your AC and DC insulators?

Answer 12: AC is currently >161 kV. We've never supplied DC insulators for less than 400 kV, and we do supply them at that level.

Question 13: Are corona rings recommended for both ends of the insulator for AC and DC?

Answer 13: Yes.

Question 14: Could you please send us a catalog of your AC and DC insulators?

Answer 14: We don't have a DC Catalog.

Response from Manufacturer 2

Question 1: Does your company manufacture AC and DC insulators?

Answer 1: Yes

If you answered “yes” to question one, please proceed to question 3.

Question 2: Why do you not manufacture DC insulators?

Question 3: Of which material(s) are your AC insulators made (glass, composite or porcelain)?

Answer 3: Composite, Porcelain

Question 4: Of which material(s) are your DC insulators made (glass, composite or porcelain)?

Answer 4: Composite, Porcelain

Question 5: If there is a difference in materials listed in the answers to question 4 and 5, please explain why?

Question 6: If the same material is used for your AC and DC insulators, is there any difference in the formulation of the materials used?

Answer 6: No differences (except sacrificial Zinc sleeve applied on the HV end metal fitting of DC types)

Question 7: If the same materials are used for your AC and DC insulators is there any difference in the way they are manufactured?

Answer 7: No differences in manufacturing process

Question 8: If you answered yes to either or both of questions 6 and 7, Could you explain why there is a difference in the formulation and/or the manufacturing process between your AC and DC insulators?

Answer 8: Sacrificial Zinc sleeve is applied in order to avoid electrolytical corrosion under DC stress of some types of end fittings, e.g. ball fittings if at HV end

Question 9: If you answered yes to either or both of questions 6 and 7, can you explain what the difference is between the AC and DC insulators which you manufacture?

Answer 9: Only Zinc sleeve for critical end fitting types (e.g. ball fittings at HV end)

Question 10: If you answered no to either or both of questions 6 and 7, could you explain why there is no difference?

Answer 10: Evaluation of long-term experience, application of lessons learned / best practice procedures

Question 11: Do you recommend using corona rings on your composite AC and DC insulators?

Answer 11: Yes, this is a very important point. We have a special corona ring recommendation also for DC type insulators.

Question 12: At what voltage do you recommend that corona rings be used on your AC and DC insulators?

Answer 12: For AC $\geq 123\text{kV}$ (for some type also $\geq 72.5\text{kV}$)

For DC at all voltages (which are typically $\geq 150\text{kV} \dots 800\text{kV}$)

Question 13: Are corona rings recommended for both ends of the insulator for AC and DC?

Answer 13: AC: depending on voltage, see attached file

DC: yes, always on both sides

Question 14: Could you please send us a catalog of your AC and DC insulators?

Answer 14: Attached (also publications of types in service long-term)

Response from Manufacturer 3

Question 1: Does your company manufacture AC and DC insulators?

Answer 1: Yes

If you answered “yes” to question one, please proceed to question 3.

Question 2: Why do you not manufacture DC insulators?

Question 3: Of which material(s) are your AC insulators made (glass, composite or porcelain)?

Answer 3: Composite

Question 4: Of which material(s) are your DC insulators made (glass, composite or porcelain)?

Answer 4: Composite

Question 5: If there is a difference in materials listed in the answers to question 4 and 5, please explain why?

Question 6: If the same material is used for your AC and DC insulators, is there any difference in the formulation of the materials used?

Answer 6: No

Question 7: If the same materials are used for your AC and DC insulators is there any difference in the way they are manufactured?

Answer 7: No

Question 8: If you answered yes to either or both of questions 6 and 7, Could you explain why there is a difference in the formulation and/or the manufacturing process between your AC and DC insulators?

Question 9: If you answered yes to either or both of questions 6 and 7, can you explain what the difference is between the AC and DC insulators which you manufacture?

Question 10: If you answered no to either or both of questions 6 and 7, could you explain why there is no difference?

Answer 10: It is the same process and materials with different designs.

Question 11: Do you recommend using corona rings on your composite AC and DC insulators?

Answer 11: Yes, depending on voltage

Question 12: At what voltage do you recommend that corona rings be used on your AC and DC insulators?

Answer 12: AC – We recommend the use of corona rings on all applications 240kV and above. The application of rings below 230kV is determined by modeling.
DC – The Corona Rings are applied by voltage class and/or customer specification.

Question 13: Are corona rings recommended for both ends of the insulator for AC and DC?

Answer 13: Yes but it depends on the voltage.

Question 14: Could you please send us a catalog of your AC and DC insulators?

Answer 14: DC applications are special applications, typically driven by specific customer specifications therefore there is no catalog. Catalog numbers and drawings are available upon request.

Response from Manufacturer 4

Question 1: Does your company manufacture AC and DC insulators?

Answer 1: Yes.

If you answered “yes” to question one, please proceed to question 3.

Question 2: Why do you not manufacture DC insulators?

Question 3: Of which material(s) are your AC insulators made (glass, composite or porcelain)?

Answer 3: Composite or porcelain.

Question 4: Of which material(s) are your DC insulators made (glass, composite or porcelain)?

Answer 4: Composite or porcelain.

Question 5: If there is a difference in materials listed in the answers to question 4 and 5, please explain why?

Answer 5: That depends on the application. There is no difference in polymer composite materials when employed for either AC or DC. For porcelain, there is no difference in the material used for post insulators, but for suspension type insulators made of porcelain there is a difference. Porcelain has a glassy phase that contains sodium ions. These ions will migrate under a very high unidirectional (DC) electrical stress.

Question 6: If the same material is used for your AC and DC insulators, is there any difference in the formulation of the materials used?

Answer 6: The porcelain for suspension type insulators used for DC applications must be made from raw materials of a much higher purity than is required for porcelain used for AC applications.

Question 7: If the same materials are used for your AC and DC insulators is there any difference in the way they are manufactured?

Answer 7: The manufacturing operations do not change, but the profile of the porcelain is different for DC than for AC.

Question 8: If you answered yes to either or both of questions 6 and 7, Could you explain why there is a difference in the formulation and/or the manufacturing process between your AC and DC insulators?

Answer 8: See the answer to question 5 above.

Question 9: If you answered yes to either or both of questions 6 and 7, can you explain what the difference is between the AC and DC insulators which you manufacture?

Answer 9: See the answer to question 7 above.

Question 10: If you answered no to either or both of questions 6 and 7, could you explain why there is no difference?

Question 11: Do you recommend using corona rings on your composite AC and DC insulators?

Answer 11: That depends on the magnitude of the applied voltage.

Question 12: At what voltage do you recommend that corona rings be used on your AC and DC insulators?

Answer 12: For AC voltages we recommend the use of corona rings for 115 kV system voltages and above on polymer suspension type insulators. DC is generally only employed at ± 250 kV or higher and so we recommend corona rings.

Question 13: Are corona rings recommended for both ends of the insulator for AC and DC?

Answer 13: We recommend corona rings at both ends for 345 kV AC and higher and for all DC applications.

Question 14: Could you please send us a catalog of your AC and DC insulators?

Response from Manufacturer 5

Question 1: Does your company manufacture AC and DC insulators?

Answer 1: Yes we manufacture both AC and DC in both glass and polymers

If you answered “yes” to question one, please proceed to question 3.

Question 2: Why do you not manufacture DC insulators?

Question 3: Of which material(s) are your AC insulators made (glass, composite or porcelain)?

Answer 3: Glass, composite, and porcelain for substation

Question 4: Of which material(s) are your DC insulators made (glass, composite or porcelain)?

Answer 4: Glass, composite, and porcelain for substation

Question 5: If there is a difference in materials listed in the answers to question 4 and 5, please explain why?

Answer 5: Yes, for glass there is a special glass chemistry called HRTG (high resistivity toughened glass) which body resistance is much higher than for AC. This is basically made using a bi alkali effect, known through higher amounts of K. As a consequence, the higher resistivity will reduce/eliminate the risk of ionic migration, thermal runaway and therefore shattering of the glass.

For composite, our strategy more than 20 years ago was to qualify composite materials fit for both AC and DC applications, unlike some other manufacturers.

Question 6: If the same material is used for your AC and DC insulators, is there any difference in the formulation of the materials used?

Answer 6: See above for composite for which we are using the same material. Basically, for our composite, the rubber housing was formulated according to much higher standards than existing requirements to prevent possible erosion of rubber under DC stress. For instance, our ATH level is among the highest in the industry

Question 7: If the same materials are used for your AC and DC insulators is there any difference in the way they are manufactured?

Answer 7: For glass, production of DC glass is different from AC in the way that melting characteristics are adapted to the glass formulations. There are several settings which differ when using a high K recipe of glass. Details are proprietary.

Question 8: If you answered yes to either or both of questions 6 and 7, Could you explain why there is a difference in the formulation and/or the manufacturing process between your AC and DC insulators?

Answer 8: For toughened glass like for porcelain cap and pin there is a necessity to manage ionic effects between cap and pin fittings. This is done with a high resistivity formulation of glass as explained earlier.

Question 9: If you answered yes to either or both of questions 6 and 7, can you explain what the difference is between the AC and DC insulators which you manufacture?

Answer 9: Body resistance is higher for DC. Caps are fit with a zinc collar to prevent electrochemical corrosion of the cap under steady activity as the one encountered in DC. Also zinc sleeve is adherent to pin as per IEC 61325.

For composite the fittings used in DC are fit with a zinc protection sleeve like for glass caps for the same reasons.

Question 10: If you answered no to either or both of questions 6 and 7, could you explain why there is no difference?

Answer 10: For composites no difference in rubber or rod

Question 11: Do you recommend using corona rings on your composite AC and DC insulators?

Answer 11: Yes, all depending upon voltage level.

DC lines are always lines for voltage levels high enough to not even think of not having a ring.

Question 12: At what voltage do you recommend that corona rings be used on your AC and DC insulators?

Answer 12: 230kV for AC

DC : there is no such question, since all lines so far are at least in the 350kV range and above. There is always a ring (at least)

Question 13: Are corona rings recommended for both ends of the insulator for AC and DC?

Answer 13: Depends upon voltage class

Question 14: Could you please send us a catalog of your AC and DC insulators?

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