New Testing Requirements for Medium-Voltage Cables

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Abstract

For many years, the traditional DC High Potential (Hipot) test has been the method of choice for both maintenance and acceptance testing of medium voltage cables in the field. Premature failures of the "new" solid dielectric cables (like HMWPE and XLPE) that occurred in the late sixties, seventies, and early eighties led worldwide efforts to establish the causes and effects of the aging mechanisms associated with these cables. Case studies and research from all over the world was conducted and identified the presence of, as yet, unknown "water trees" that were weakening the cable's insulation medium. Subsequently it was also found that DC high potential testing was not only very limited in its effectiveness as a cable testing tool, it was also shown to potentially further deteriorate the insulation of these aged solid dielectric cables resulting in their premature in-service failure.

This paper highlights some of the developments that led to the new IEEE cable acceptance and maintenance "Hipot" testing standards, the application of these testing standards in the field and a look at some of the features and specifications of the equipment that can be used to meet these standards.

Keywords: Solid Dielectric Cable (also called Extruded cable e.g. HMWPE, XLPE), Very Low Frequency (VLF), Paper Insulated Lead Covered (PILC), Water Trees, Electrical Trees, Space Charge, Direct Voltage (DC), Alternating Voltage (AC), Stress Enhancement.

Introduction

A great number of changes and new developments have occurred in the world of medium voltage cables over the last 10 to 15 years. A gradual dissemination of new information about cable aging mechanisms associated with premature failures of some cables and the applicability of DC or the "DC Hipot" as a still viable and effective testing method has made its way through the electrical industry. As this new information has spread through the various levels within the industry, the facts have often become distorted, resulting in misunderstanding and misinterpretation.

The National and International Standards societies like IEEE and IEC, generally take several years to adapt to new developments and adopt new guidelines. This has largely been the case with respect to drawing up a new set of guidelines for the field testing of shielded medium voltage cables. This void, created by the long time constants between what is established by research and case studies and the creation of a solid set of nationally accepted guidelines for the industry often creates a vacuum where anything can, and sometimes does, go. As a result, various "home grown testing procedures" were, and in many cases still are being used. These "procedures" can vary haphazardly from one company to another; some continue to maintain the old IEEE400-1991 test standard that specified elevated DC levels; others reduced these voltage levels and/or applied shorter test durations; others performed re-energized cable "soak" tests; while others perform repetitive reclosing onto a cable circuit and sectionalizing to identify the faulted cable segment - performing no offline testing and merely re-energizing the line at full system voltage and fault level. Cable failures that do occur under these conditions often result in collateral damage and unnecessary wear to adjacent circuits and electrical apparatus.

The recently released new testing guidelines IEEE400 revised in 2001 "IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems" and IEEE400.2 "Guide for Testing of Shielded Power Cable Systems using Very Low Frequency (VLF)" now provide the long awaited solid reference for the electrical testing industry. It is therefore no longer required, recommended or advised to use or apply the old IEEE 400 (1991) guidelines or any mutated variation thereof.

Why is DC testing no longer recommended for solid dielectric cables?

Why has DC testing of medium voltage cables been under so much scrutiny and received so much negative press, sometimes unfairly so, during the last few years?

For an ideal cable with homogenous, uniform insulation, as typically found in new cables, the steady state electric stress distribution in the cable insulation is similar under both AC and DC high voltage applied conditions. For this reason DC testing is not harmful to new solid dielectric cables. In addition it should be noted that DC Hipot maintenance and acceptance testing is still acceptable for use on laminated insulated paper cables like PILC.

However, as these cables age, their insulation is no longer homogeneous and defects form in or around the insulation. The electric stresses that now result in the cable insulation vary under the different waveforms of AC and DC. This can result in an accumulation of space charges at defect sites within the cable insulation, particularly for solid dielectric cables such as XLPE. These defect sites can be water trees, voids or other imperfections in the cable insulation. Under elevated voltage DC conditions, localized stress enhancements may be produced at these defect sites, resulting in a localized discharge or breakdown in that part of the insulation when the cable is returned to normal 50/60Hz AC service conditions. These partial discharges can form and grow into what is known as an electrical tree. Electrical trees that form and grow at operating voltages within solid dielectric cables such as XLPE, rapidly increase in length and size, with the inevitable result usually being a complete cable insulation failure.

The second disadvantage of using elevated DC voltages, applicable to all cable insulation types, is its inability to effectively find certain existing and often serious cable insulation defects. Since the main objective of any high voltage acceptance or maintenance test is the successful detection of any critical pending insulation defects in the cable system. This is obviously a serious drawback.

Unlike AC, DC by its very nature does not change either its voltage level or its polarity with time during a test (ignoring obviously the initial charging of a cable's capacitance when the DC is initially applied). As there is no changing applied electric field, no inception of partial discharge activity can take place at the defect sites within the insulation. Without the presence of partial discharge activity, the chances of detecting some serious insulation defects during a DC Hipot test are very small.

An example of this is a test that was performed on a 10kV XLPE cable. A needle was pierced from the outside through the insulation of the cable, leaving less than 1/25" (1mm) of XLPE insulation remaining between the end of the needle's pointed head and the cable conductor. The cable was then energized with DC to check its ability to locate the defect. No breakdown or detection of this serious defect occurred up to the maximum voltage of the test set of 100kV. In addition, increasing the duration of the applied DC test voltage also did not help detect this serious insulation defect. Ref [2].

This results in questionable tests results. *Is the cable really free of serious insulation defects after passing a DC Hipot test*?

Potentially damaging space charges can however still be injected into the aged solid dielectric cable during the DC Hipot test. A cable with several severe defects in its insulation can therefore "pass" the traditional DC Hipot test, while increasing the likelihood of a failure when the cable is returned to service. DC Hipot testing of solid dielectric cables can therefore "*make aged cables weaker without having the ability of detecting weak cables!*"

Unlike DC, the intrinsic nature of AC with its continuous polarity changes, does not allow dangerous space charges to develop inside the cable insulation.

It should be noted that DC is still effective for detecting certain types of insulation defects, particularly those that involve the cable accessories, interfacial and surface leakage problems where conduction and / or thermal factors are involved. However the negative side effects of DC and the availability of alternative AC options has resulted in most standards around the world no longer recommending DC for field testing of installed solid dielectric cables in the field, particularly those that are older than 5 years.

Water Trees and DC

The primary source of insulation aging and subsequent failures in solid dielectric cables (like XLPE) is water trees. These are tree-like structures that take many years to grow and mature in the cable's insulation. They can form both "bow tie" and/or "vented" trees and can grow from the inside conductor out or from the outside conductor (ground) in towards the main conductor of a cable. These water-filled micro cavities often occur in the hundreds and thousands within the insulation of a cable and their presence is not normally localized to only one point within the cable. See Figure 1.

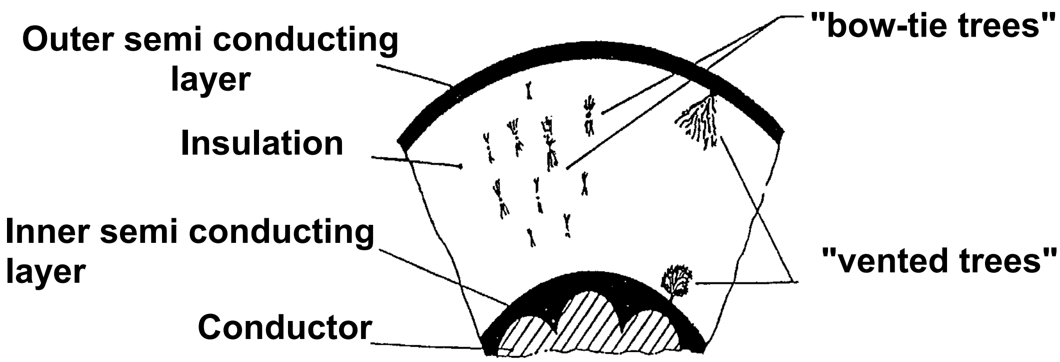

Figure 1: Cross Section of a Solid Dielectric Cable showing various possible Water Tree Formations.

Testing of the these service aged cables at elevated DC "Hipot" voltage levels may cause the cable to fail prematurely after the cable has been returned to service. The cable failures would not have occurred at that time if the cable had not been tested with DC. Ref [1]. The injection of space charges that can occur under elevated DC voltages at the sites of these water trees can result in localized stress enhancements. With the reapplication of normal AC power to the cable, these localized stress enhanced areas at the water tree sites can ultimately lead to an electrical tree or trees. Compared to water trees, the channel growth rate of electrical trees is very fast, particularly for PE and XLPE insulations. Once an electrical tree has been initiated, complete cable failure is normally imminent and inevitable. See Figure 2. However it should be noted that of the many thousands of water trees that may exist in a cable, only one has convert to an electrical tree to cause a cable to fail.

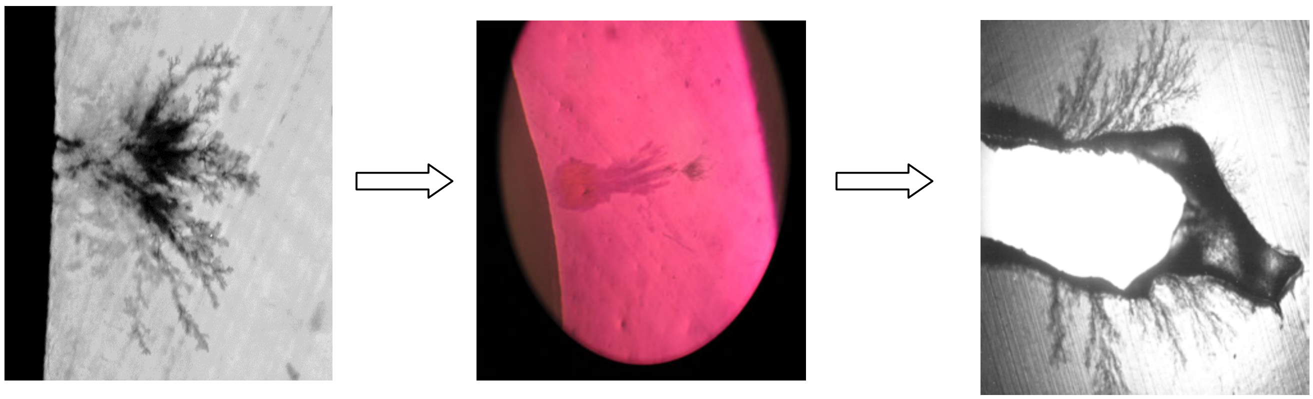

Figure 2: The progression of a Water Tree in a solid dielectric cable insulation: A water tree can "convert" to an Electrical Tree and then finally to complete cable insulation failure. Note the clear distinction between the water tree and the electrical tree in the second frame above.

The Recommended Alternative to DC: AC

As a result of the above developments, AC is now recommended by most cable testing standards throughout the world, particularly for solid dielectric cables. Although DC is still recommended and used for laminated cables such as PILC, AC still tends to be more effective. It should be noted however that even though AC does not have the same negative side effects as DC, a cable that is severely aged or has a severe pending defect, will still fail under an AC test. It must be remembered that this is the whole purpose of a "Hipot" test – to find severe insulation defects. Insulation in good and even reasonable condition will not be affected by an AC Hipot test at the recommended voltage levels.

There are essentially two choices when considering AC test equipment for field cable testing - either to use AC at power frequency (i.e. 60 / 50 Hz) or at Very Low Frequency (VLF). AC power frequency test sets are available in a variety of configurations that include standard, resonant (series and parallel) and other variations thereof. AC power frequency HV test systems all produce applied voltages at frequencies approximately equal to 60 Hz (or 50Hz). On the other hand, Very Low Frequency systems produce applied voltages at frequencies that typically range from 0.01 to 1Hz. The "standard" VLF frequency is 0.1Hz. That is, one cycle every 10 seconds.

From a technical perspective, there are small differences between the two frequencies as to their efficacy as a Cable testing "Hipot" frequency. However there are large differences in affordability and practicality.

AC power frequency test sets are relatively large, heavy, and expensive and they require large impractical amounts of power in the field to energize cables. The reason why cables require so much power to energize at power frequency is because they are essentially seen as "capacitors" to an AC power source. The longer the cable, the larger the capacitance becomes. The cable capacitance is mainly dependent upon the geometry and dielectric constant of the insulation. For most cables, a rough guide for a cable capacitance is 100pF per ft of cable.
Even with AC resonant type test systems, the power required to energize, even relatively short sections of cable, at relatively low test voltages, will soon overload a standard 110V AC power supply.

The Apparent Power required to feed a capacitive load like a cable is given by the equation:

$$S = 2\pi fCV^2 \quad \text{Equation 1.}$$

where S is the apparent power required (VA).
V is the applied rms voltage (kV phase to ground).
f is the applied frequency (Hz).
C is the cable capacitance (μF).

For example: If we apply a test voltage of 16kV (60Hz) on a 15kV rated cable that is 1000 ft long, we would require a 10kVA power supply. If this AC high voltage power supply was fed from an 110V AC source, it would draw 90 amps! Even with resonant techniques, the power demand remains high; the equipment remains costly and the weight remains heavy.

Very Low Frequency AC

As can be seen from equation 1, the only practical component that can be adjusted to reduce the power requirement is that of the applied frequency. The reactive power required by an applied test voltage level at 0.1Hz is 600 times lower than that at 60Hz. This was originally the main driving force behind the development and use of VLF for testing capacitive loads such as cables, generators etc.

It is important to note that VLF is still AC (Alternating Current/Voltage) – it is as one cable engineer said "slow moving AC".

Although AC VLF test sets are small and lightweight compared to their AC power frequency counterparts, they are slightly larger and heavier than their DC cousins, which only have to supply the normally very low resistive losses of the cable being tested.

There are several VLF waveforms available; however they all operate at frequencies close to the "standard" 0.1Hz.

- VLF Sinewave: A sinusoidal voltage, like that found in AC power systems.
- VLF Squarewave: A bipolar rectangular or Squarewave
- VLF Cosine-Rectangular or Trapezoidal

All three VLF waveform types above can be used for performing high voltage AC Hipot tests under the new IEEE guidelines. However research has shown that if an electrical tree exists in a cable, the faster electrical tree growth rate of the Sinewave waveform (for the same applied rms test voltage) results in shorter testing times to detect insulation defects compared to the other two waveforms above. The sinusoidal waveform can also be used as an excitation source to perform diagnostic tests such as leakage current, dissipation factor, partial discharge and dielectric spectroscopy. Diagnostic testing using VLF is a complete subject on its own and is not covered in this paper.

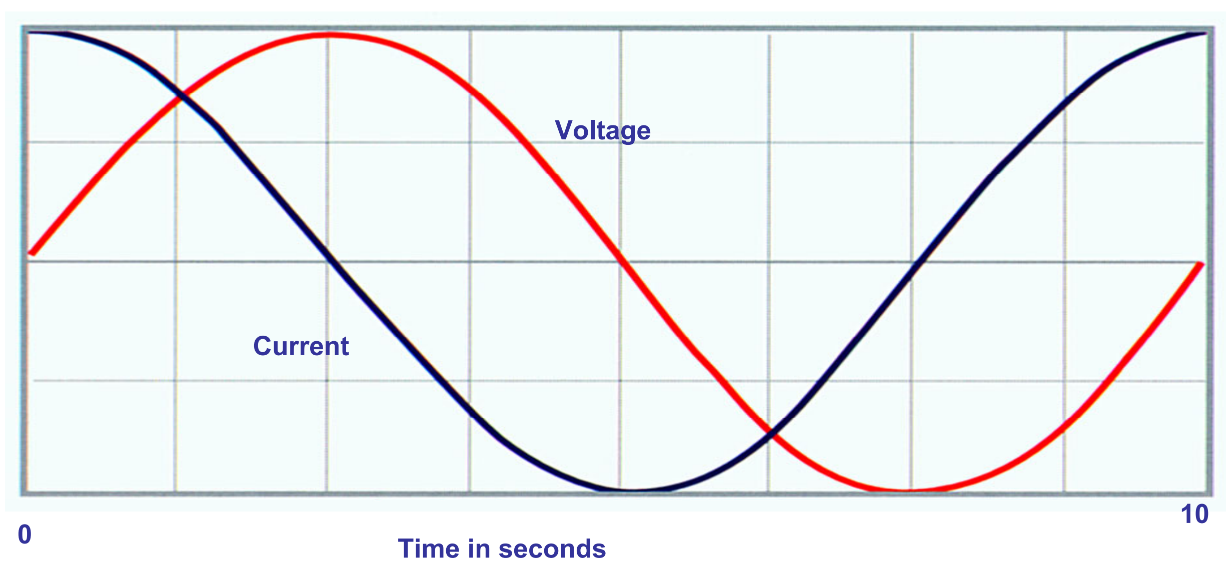

Figure 3: A Sinewave Very Low Frequency Voltage and Current Waveform. Note the almost 90º phase shift between current and voltage.

The New IEEE400.2 Guide for Field Testing Cables using VLF

The new VLF testing guide IEEE400.2 is a point or sub-document of the main omnibus document IEEE400 and it covers both cable testing and cable diagnostics.

The IEEE400 defines 3 types of field tests that can be performed.

Installation Test: This test is conducted after the installation of the cable but before the installation of accessories like the splices and terminations. Its purpose is to detect any transport, manufacturing, storage or installation defects.

Acceptance Test: This test is performed after the installation of the accessories, but before energization of the cable. It checks for installation defects of the complete cable system, as well as defects as a result of shipping, manufacturing or storage.

Maintenance Test: This test is made during the operating life of the cable. Its main function is to assess aging and /or serviceability of the cable system i.e. is it fit for normal system operating conditions?

The most important application part of the new IEEE400.2 cable testing guide is the Table 1 below that shows the recommended VLF Hipot voltage testing levels for the various medium voltage cable ratings for both new (Acceptance and Installation Testing) and old (Maintenance Testing) cable installations. This is essentially a Pass/Fail type test, the cable either withstands the specified test voltage or it does not.

The rationale behind the values in the table is to use a test voltage that will suitably and adequately test the cable insulation to a level that the cable could conceivably "see" during normal operation. Normal operation will include for example, operation transients from switching or lightning. At the same time, testing at elevated levels that could overstress an aged cable that still has some useful remaining life, should be avoided. Likewise one does not want to make the testing almost meaningless by under stressing the cable by applying voltages below the normal operating voltage. As a result the voltage levels in the table are approximately 2 to 3 times rated phase to ground. The maintenance levels are typically about 80% of the acceptance voltage levels.

The IEEE looks at the test levels for the Squarewave / Cosine-Rectangular and the Sinewave by looking at the maximum electrical stress levels created by the two waveforms. Therefore the peak value of the Sinewave waveform (RMS x $\sqrt{2}$) is equivalent to the peak or flat section of the Squarewave which also happens to be its approximate RMS value (assuming no distortion). The IEEE correctly equalizes these voltage points. Since we very seldom refer to the peak voltage of a Sinewave but rather the RMS value in the electrical industry, the table shows the RMS ratings. The peak values are also shown in brackets for the Squarewave which also happen to be the peak of the Sinewave waveform. The bottom line is that the same maximum amplitude of either of the waveforms is applied to the cable under this new standard. *Operators of the equipment should therefore be careful to note which type of waveform they are applying and the voltage measuring method used (RMS or peak), to correctly select the recommended test voltage from the table.*

Cable Rating phase to phase (RMS)	Installation Test phase to ground	Acceptance Test phase to ground	Maintenance Test phase to ground
kV rms	**kV rms (or peak)**	**kV rms (or peak)**	**kV rms (or peak)**
5	**9 (13)**	**10 (14)**	**7 (10)**
8	**11 (16)**	**13 (18)**	**10 (14)**
15	**18 (25)**	**20 (28)**	**16 (22)**
25	**27 (38)**	**31 (44)**	**23 (33)**
35	**39 (55)**	**44 (62)**	**33 (47)**

Table 1: IEEE400.2 VLF Test Voltage Levels for Sinusoidal, Cosine-Rectangular. Voltage Peak values are shown in brackets for Cosine-Rectangular and Squarewave.

Test Duration. The current IEEE recommendation for the duration of a VLF test is from 15 to 60 minutes. In reality, an open time window like this often results in the operator selecting the shortest possible testing time of 15 minutes. However as evidence from the field has shown, it is important to note that although most of the serious defects may present themselves and be detected during this short time frame, there will also be some that would require additional testing time to “manifest” themselves. The risk of terminating a cable test too early is that there may be defects that are on now on the verge of causing complete insulation breakdown. When this cable is returned to service, an uncontrolled cable failure is likely to occur. The author therefore recommends a testing time of at least 30 minutes. In Europe for example, it is recommended that a testing time of one hour be used.

Should a cable fail during a test sequence, it is recommended to restart the test from “scratch” once suitable repairs have been made. This means that the full test sequence (i.e. the specified test voltage and full test duration) should again be applied to the cable.

Test Frequency: The “standard” most commonly used VLF test frequency is 0.1Hz. However even though this frequency allows the testing of highly capacitive loads, it may still be necessary to decrease the frequency of the applied voltage to below 0.1Hz to increase the load capability even further. This may be required for example when testing very long cable runs. It should be noted that a substantial reduction in the applied test frequency away from the VLF "standard" of 0.1 Hz, diminishes the effectiveness of the VLF test. In these cases, the testing time should be increased to counteract the effect of the decreased frequency. It is therefore advised to keep the test frequency as close to 0.1Hz as possible. Some commercially available VLF units now use automatic frequency optimization techniques to keep this test frequency as close to 0.1Hz as the load will allow. Other less sophisticated units allow the operator to manually set the required frequency after checking the capacitance of the load.

Connecting a VLF Test Instrument to a Cable

All cable testing is to take place offline, i.e. the cable to be tested must be safely disconnected from the system voltage and solidly grounded. The connection of a VLF test instrument to a cable is very similar to that used for DC Hipot testing and cable fault location.

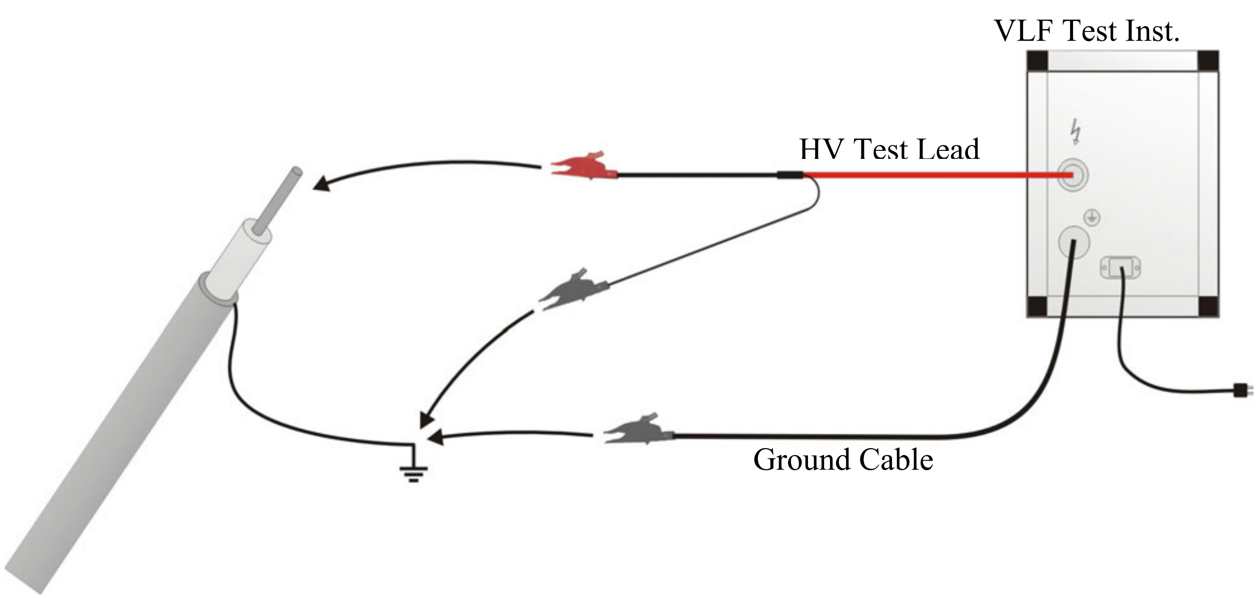

Figure 4: Connection Setup for a VLF Cable

The VLF test instrument should be solidly grounded before connecting up any cables. The HV test lead is typically a coaxial cable with an outside shield conductor that should be grounded by

connecting it to the concentric neutral ground point of the cable to be tested. The main conductor of the HV test lead is then to be connected to the conductor of the cable under test.
It is important to ground other phases that are not being tested. It is possible to reduce the testing time by connecting all three phases together, however this is not advised if you have a belted cable, or if the individual phases are not shielded. In such cases, each individual phase should be tested independently, grounding the other two phases. This avoids the possibility of not detecting a phase to phase fault on such a cable construction.

Figure 5: A typical connection setup for a VLF cable test. Note the grounding of the other two phases, while the third phase is being tested.

Care should also be taken to maintain sufficient clearances around all high voltage parts. Environmental conditions and contamination of terminations can substantially increase leakage currents and cause possible flashovers. Terminations should also be checked and cleaned prior to testing.

Applications using VLF

There are several applications in the field of medium voltage cables, where VLF can be effectively used.

As discussed above, VLF is very effective and the recommended choice for performing ***acceptance and maintenance*** testing of medium voltage cables in the field. Installation and manufacturing defects can be effectively detected on new cables and their connected accessories. Corrective action can be taken before putting the cable into service, thus avoiding the costly and often untimely consequences of a cable fault.
Maintenance testing can be performed after a cable outage, making sure that the complete cable system, including any new accessories, workmanship associated with these new accessories and the remaining insulation sections of the cable are all "fit for service".

Another useful maintenance program that is and has been implemented by several electrical utilities is the ***proactive VLF maintenance strategy*** of "weeding out" those weak sections of a cable system during a planned VLF testing outage. This prevents a potential future unplanned outage under service conditions, by proactively finding those severe defects in a controlled voltage stress test and then repairing them. This may sound like an aggressive approach of finding pending cable defects, taking a cable that is operating in service and removing it for testing, only to potentially fail that cable. Cable diagnostics is often the preferred alternative and normally less destructive approach of evaluating the condition of a cable, however there are many cases where diagnostic testing is not viable, either commercially and / or technically. Cases that lend themselves to proactive cable testing include hybrid combinations of different insulation types connected together in a single cable run; very long lengths of cable; network cables with multiple taps etc.

Results from those utilities that have performed these proactive VLF tests are very promising. A utility in Malaysia that performed this type of testing on over 15000 of their aged cables (representing 35% of their total cable network) over a 20 month period, found that about 12% of the cables failed during the testing. The total number of faults that have subsequently occurred on these cables, after passing the VLF proactive tests, is only 3.71% of the total number of faults that they have had on their system. Ref [3]. A large utility in the USA which has also implemented a similar program is beginning to see similar positive results.

Fault Conditioning*:* The only viable method of finding most cable faults in medium voltage cables is to use a DC thumper. Applying elevated DC to an installed aged cable is not recommended as discussed above, so how does one practically find the fault without further damaging the insulation. Firstly, the flashover voltage of the fault should be reduced before applying a thumper by first conditioning the fault. Secondly, the duration of the "thumping"

action should be minimized. This can be effectively achieved by using a VLF tester, applying an alternating voltage to the cable and allowing the fault to continuously arc over. The energy supplied by the VLF test instrument and the capacitance of the cable then conditions the area by ionizing and carbonizing the area to reduce the flashover voltage or fault impedance.
The thumper can then be applied using lower less destructive voltages. In some cases the fault resistance may now be so low that a standard TDR, which normally operates with completely harmless output voltages, will be able to pre-locate the fault.

What features and specifications to look for in VLF test equipment?

There has been a great deal of improvements in VLF test equipment over the last few years. Prices have come down and specifications and features have gone up. As with any test instrument, certain features and specifications may be important for some users, while others may have other considerations to be met. Below, is a list of some of the questions and features that potential users of VLF equipment should ask before purchasing a test instrument. As with many things, you typically get what you pay for.

"What is the maximum length of cable that can be tested with the VLF test instrument?"
This is a very common question. The answer depends on the capacitance of the cable. Not the answer that the average person wants to hear, but it is technically the correct answer. If a VLF test instrument has a specified maximum output load capability of say 1µF (1 micro farad), then a cable that has a per unit capacitance of say 100pF per foot (found in cable manufacture's data sheet), the test instrument will be able to test up to a maximum of 10 000 ft of this cable.

Does the VLF instrument have sufficient voltage output for my requirements?
This is a relatively easy question to answer. Look at the IEEE recommended voltage levels (see Table 1) and based on the cable systems you plan to test, and the type of tests you plan to perform (acceptance/maintenance etc), select the maximum voltage required that best meets your requirements. In addition you need to look how the voltage output is defined. This is particularly important for the Sinewave output models. Is it stated in conventional RMS or as peak? A data sheet for a VLF instrument with a 20kV rms rated output, has exactly the same output voltage as an instrument with a more impressive sounding 28kV rated peak output. It's just a matter of mathematics. For example, some VLF units will say 60kV output. Carefully check if this is referring to RMS or Peak!

Does the VLF instrument have sufficient voltage and power to energize some of the longer cables you plan to test?
As can be seen by Equation 1 above, one can trade frequency, power and voltage. VLF equipment data sheets can be very misleading. Equipment venders will state that their equipment has a load rating of 5uF for example. But checking the data sheet closely will show that this load capability is only available at 0.01Hz and not the “standard” and normally preferred test frequency of 0.1Hz. To define and compare the true output capability of an instrument, consider the output load capability (in µF), frequency (Hz) and voltage (rms) all specified in the same line.

Is the VLF test instrument capable of detecting and measuring the cable capacitance load?
A cable load that is too large for a VLF test instrument output rating will either trip out the instrument or the voltage will uncontrollably collapse. It is then difficult for the operator to determine if this is due to a cable failure or an overloaded test instrument. Some instruments automatically measure and display the cable capacitive load after “hooking” up the cable and initializing the test, while others do not have this feature and rely on the operator to either measure it with another instrument or hope it’s within the capabilities of the equipment. Other instruments have a separate capacitance checker within the VLF instrument. It normally requires an additional connection hookup to the cable to be tested, before the final test connections and voltage can be applied.

Modern VLF Test Instruments

Portable 30kV, 2.5uF, less than 45 lbs!

Larger Van Mounted, 80kV, 20uF, 300 lbs with integrated Dissipation Factor and Partial Discharge Diagnostics

Does the VLF test instrument have the ability to reduce its output frequency in small increments from 0.1Hz?
As discussed earlier, case studies indicate that the most effective output frequency of a VLF test instrument is the "standard" 0.1Hz. The efficacy of the VLF test tends to decrease the more this frequency is reduced. For that reason it is best to keep the output frequency as close to 0.1Hz as possible. Therefore having the ability to decrease the frequency of the output in small steps (like 0.01Hz) instead of large steps is an important feature. Why decrease the frequency to 0.05Hz, if your instrument could energize the cable with 0.08Hz?

Is the voltage output, symmetrical and load independent?
This is very important feature that can vary substantially from one equipment supplier to the next. The output should ideally be load independent across the full load range of the equipment. What happens to the output voltage at low and / or at high loads? Is the output voltage symmetrical? Is there significant distortion of the waveform?

Can the instrument measure leakage current and / or resistance of the load?
As used in traditional DC testing, the insulation resistance and leakage current that occurs during a VLF test can often indicate a pending insulation weakness in a cable. Possible interfacial, moisture and surface tracking can, for example, be detected. Make sure the current measuring accuracy and resolution is sufficient to measure the small leakage values. Likewise, insulation resistance measurements should be able to measure in the Giga Ohm range.

Does the VLF instrument have a fault burning and a trip out function?
Some VLF test instruments will "trip out" on overcurrent when a cable fault occurs. This is acceptable when performing a Hipot test and to establish if the cable has failed. However during testing and fault burning/conditioning this can often cause nuisance tripping of the VLF unit. Other instruments have user selectable "burn" and "trip" modes that allow the operator to select either a "Burn" or "Trip" in the event of a cable failure during the VLF test. If the VLF user wants to investigate the cause of the insulation failure without any burning action taking place that will destroy the area of the original failure mechanism, then a fast Overcurrent tripping function is an important feature. Some VLF units will also record and indicate the actual fault flashover voltage, allowing the operator to know if the fault resistance is at a level that is then suitable for thumping at less potentially destructive levels.

Can the VLF test instrument perform an Automatic Test Sequence?
The IEEE VLF Testing Table (See Table 1 above) specifies various settings such as applied voltage levels, for various cable ratings, for various testing modes (acceptance / maintenance / installation) for recommended testing durations. Manual VLF instruments require the operator to know the correct settings to apply during the test. Automatic VLF test instruments are programmed to apply the correct settings as defined in the IEEE standards. This ensures that the correct voltage, and test duration are applied for the correct type cable test. These automatic VLF

units also normally have built in timers that automatically terminate the test voltage after the correct testing time has elapsed. Automatic test sequences often help reduce operator errors when performing electrical tests in the field that may otherwise result in over-stressing or ineffective testing of the cable system.

Does the VLF instrument automatically discharge and ground the cable before and after testing?
As found on many DC Hipots and thumpers, it is useful and advisable to have an integrated discharge resistor in a VLF test instrument to continue to ground the cable before testing and to softly discharge the cable after testing. However it should never be assumed that the VLF instrument has grounded the cable and is therefore safe to handle. Strict adherence to all safety, isolation and grounding procedures should always be followed.

Is it possible to upgrade the VLF system to include TD and PD?
The ability to connect to, or upgrade a VLF test instrument to include well known cable diagnostic measurements such as Dissipation Factor (or Tan Delta TD) and /or Partial Discharge (PD) diagnostics may be a useful feature if users want to start performing diagnostic tests on cables.

What is the Weight of the VLF unit?
Weight and power output capability are often at odds with one another. Some new VLF units weigh as little as 45 lbs, almost as light as traditional DC Hipots. Other units weight several hundred pounds. If size, weight and general portability of the instrument are important, then it may be necessary to sacrifice some output power and use lower frequencies to avoid carrying a 300 lb monster around.

Does the VLF unit have the ability to automatically record and store Cable Test Reports?
Some VLF units have built in memory to record cable test results from the field. The reports can include information about the test such as testing time (or time to failure), resistance, capacitance current, voltage and user specific data like date, time etc. The ability to then download this data to a computer for archiving, trending and analysis is often a very useful feature.

Does the VLF instrument also have DC output capability?
Some of the VLF test instruments available have both VLF and DC output voltage capability. As there are still many applications that require high voltage DC, the universal output capability of a test instrument may make the difference between taking one instrument to site instead of two.

Conclusion:

The many new discoveries, changes and developments that have occurred in the area of medium voltage cables in recent years, has finally resulted in a firm set of testing standards that have once again clarified the recommended and most effective methods of cable testing. These new standards have been met with new equipment, developed to meet these new requirements. Electrical testing methods and procedures of these medium voltage cables should no longer be a matter of choice, but a well defined and effective means of proving if a cable is fit for service or not.

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