High Voltage Fluidic Interface (HVFI) Test Report

Introduction

Since the late 1980s it has been standard practice in fluid rejuvenation to connect dielectric tubing, typically nylon or polyethylene, to energized cables with the unsustained pressure rejuvenation (UPR) paradigm. In fact, over 100 million feet have been injected in this way. In typical underground residential distribution UPR applications, tubing is connected to a feed end of a cable and an outlet end. These two tubes are connected to a feed bottle and receiving bottle respectively. Both bottles are primarily plastic dielectric with some metal fittings. The tubing and connected bottles are termed "potentially energized," as it is at least theoretically possible that they are not at ground potential. In practice they would almost always be very close to ground potential. On the inlet side, dielectric fluid flows into a dielectric tube and the possibility that the tubing/fluid system will conduct electricity is generally small. The exception is when a feed bottle is left connected for a long period of time, <u>while the outlet is plugged</u> in what is called a "soak period." During the soak period the flow of fluid into the cable is very close to zero and may flow backwards as the connected cable cycles in temperature from a cycling load. More problematic is the outlet side that begins the injection process as a course vacuum. Typically within 24 hours the vacuum decays and the gas phase transitions to a liquid. In the worst case the liquid could be water displaced from the strand interstices, but is more likely dielectric enhancement fluid or a desiccant fluid. The outlet fluids also transport conductive particles such as carbon black and ions. The tubing and the connected tanks are allowed to float electrically and for the sake of safety are handled by line personnel as though they are energized. With over two decades of experience the author is unaware of any incident where there were any injuries. None-the-less, Novinium has taken steps to further mitigate the risk of potentially energized equipment by introducing a new injection paradigm called sustained pressure rejuvenation (SPR), which entirely eliminates the risk for most URD-length cables and introducing an improved UPR approach, which eliminates the soak period. The later improvement eliminates the multi-month soak periods and hence reduces the exposure of the equipment over 60-fold.

The SPR process eliminates the issue by injecting normal length cables while they are deenergized. However, for cables with longer lengths, it is not always practical to leave a cable out of service during the entirety of the injection process. It is for this last case, that the HVFI was designed and the balance of this test report focuses. To learn more about the risks summarized above, the interested reader is referred to "A Comparison of Rejuvenation Hazards" for EDIST 2009, Markham, Ontario, January 15, 2009 available at:

http://www.novinium.com/pdf/papers/EDIST_Rejuvenation_Hazards_Analysis.pdf

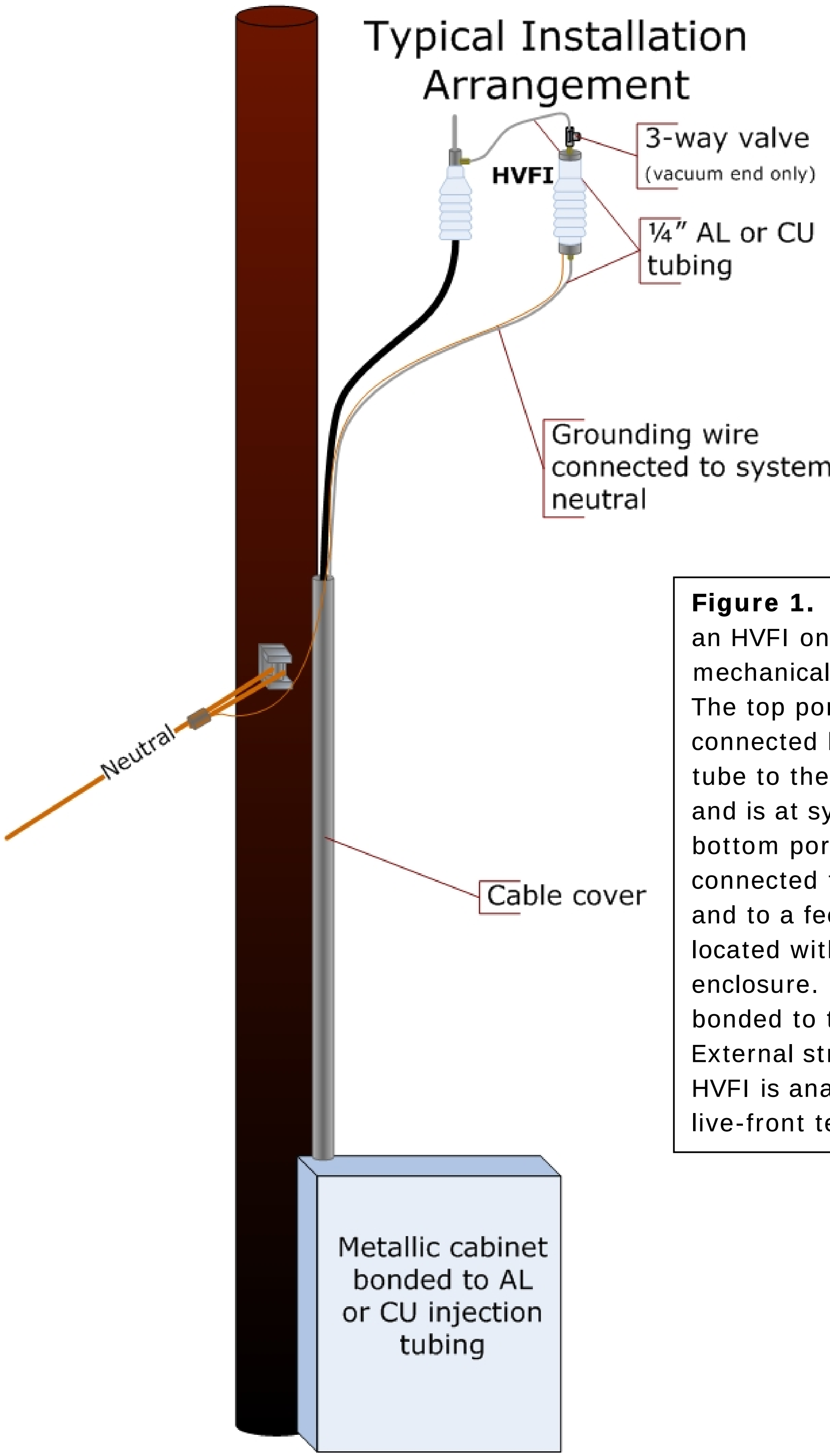


Figure 1. Typical arrangement of an HVFI on a pole excluding mechanical support hardware. The top portion of the HVFI is connected by a conductive metal tube to the cable injection adapter and is at system voltage. The bottom portion of the HVFI is connected to the system ground and to a feed or receiving tank located within a metallic enclosure. The enclosure is bonded to the system neutral. External stress control on the HVFI is analogous to that of a live-front termination.

A high voltage fluidic interface or HVFI is a component which electrically isolates the necessarily high voltage injection devices utilized with live-front terminations such as an injection adaptor, which must be in contact with the conductor, from those injection tanks and tubes which must be hydraulically connected. In other words the HVFI allows hydraulic communication, but interrupts electrical communication between the cable's injection interface and the bottles to which they are connected. Figure 1 is a schematic overview of a typical HVFI installation. Up-to-date instructions for the installation and operation of HVFI devices are available online at:

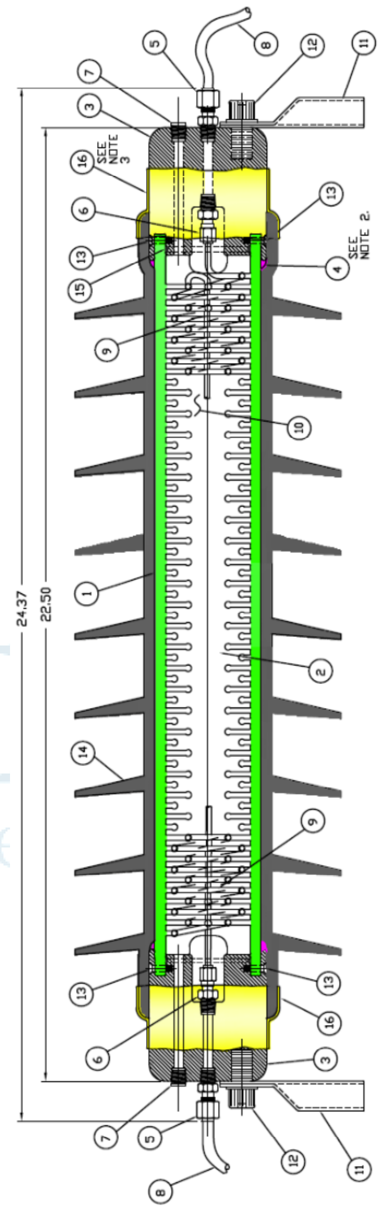
https://www.novinium.com/pdf/instructions/NRI69-N-Rex.pdf

Figure 2 provides HVFI design details. The external design is a 35kV life-front cable termination (3M QT-III-7686-S-8 skirted termination), which meets or exceeds the IEEE 48-2009 standards. The internal components begin with 6.7 meters (22 ft) of 1/8" OD nylon tubing and a 0.073" ID with a total volume of about 18.1 ml. The tubing enters the top of the HVFI, is wound in a descending outer helix, then an ascending inner helix, and finally down the axis to the bottom where it exits. The tubing is positioned on a polyethylene board with over 120 tube positioning cutouts alternating between the inner helix and the outer helix. The board is secured to the two aluminum end pieces and within a high density polyethylene tube. The volume outside of the 1/8" tubing and inside of the 2.5" body tube is filled with degassed dimethyl silicone RTV liquid, which sets to a permanent non-flowing dielectric gel. The aluminum end caps include dedicated electrical connections to the system voltage at the top and to the system ground at the bottom. The end caps include securing hardware so that the HVFI may be installed in a manner similar to a post insulator. Unlike a post insulator, the hardware needs only to support the HVFI. Hydraulic/pneumatic swage-type connections are also on each end cap and mate with ¼" aluminum or copper tubing. The tube at the top of the HVFI is connected to the injection adaptor. The tube at the bottom of the HVFI is attached to a feed bottle on the inlet cable end and to a receiving bottle on the outlet cable end. On the outlet cable end a three-way ball valve is attached to the top of the HVFI as shown in Figure 1, so that a side stream of fluid can be introduced into the HVFI.

During operation on the inlet cable end the fluid flow is initiated prior to the cable being re-energized. Because the outlet is never sealed in direct contrast to the legacy soaking approach not utilized by Novinium, flow is unidirectional into the cable for the entirety of the injection process. On the inlet side the tubing is filled with dielectric fluid 100% of the time. On the outlet cable end there are two stages of operation with the cable energized. Prior to the cable being energized a course vacuum (about 25 inches of Hg) is applied to the receiving tank, which is connected to the HVFI, associated tubing, and the cable. The majority of the air is removed from the system. At least 50 ml of low volatility, low viscosity, low surface energy, dielectric fluid (Ultrinium™ 732 fluid) is introduced into the top of the HVFI at the three-way valve shown in Figure 1. The fluid flushes through the 6.7 meters of tubing.

Figure 2. HVFI component assembly view.

1. HDPE tubing 2.5” OD (22’)
2. UHMWPE board (2”x ¼”x16.5”)
3. Aluminum end cap
4. Stress control compound (3M HiK)
5. ¼”-1/8” tube connector
6. 1/8”-1/8” tube connector
7. Pipe plug, brass
8. 1/8” nylon tubing, 6.7 m (22 ft)
9. ¼” AL or CU tubing
10. Silicone dielectric potting gel
11. 1-hole lug, 4/0
12. Cap screw
13. Set screw
14. Skirted termination, 3M QT-III, 35kV
15. O-ring, EPDM
16. Self-fusing silicone rubber tape (3M Scotch 70)



The majority of the 50 ml of fluid introduced flushes through the entire HVFI as the total volume within the tubing is about 18 ml. The HVFI traps several ml of the fluid in the tubing coils with two mechanisms. First, because of the low surface energy of the fluid it coats the tubing walls. Second, in the ascending inner coil fluid is drawn upward by weak shear forces as the low pressure air slowly flows toward the vacuum source, but gravity exerts a downward force on the fluid. An equilibrium is established where fluid flows upward in the coil near the tube axis, but flows downward in the coil near the inside diameter of the tube. The perpetual presence of the dielectric fluid blocks the path of any electrical field resisting ionization and repairs any microscopic damage that might occur if there were partial discharges. The shear length of tubing and thickness of the insulation layers including both the thickness of the nylon tubing and the surrounding dimethyl silicone gel make the HVFI tolerant of partial discharge.

The cable can now be energized and Stage I begins. In this stage the tubing is filled with a mixture of air at 25 in Hg vacuum and dielectric fluid. In the first ever application of a HVFI at Desolation Sound in British Columbia, Stage I lasted for about 100 days and the HVFI performed without issue. Stage II begins when dielectric fluid reaches the HVFI and the tubing becomes filled with dielectric fluid.

Standards

There are no industry standards for high voltage fluidic interfaces. Some guidance on qualification testing can be found by reviewing appropriate standards for devices that include similar functions as the HVFI. Appropriate engineering judgment is required for the application of these other standards as many dimensions of those standards will not be relevant to the design and operation of a HVFI.

IEEE 48 – IEEE Standard for Test procedures and Requirements for Alternating-Current Cable Terminations Used on Shielded Cables Having … Extruded Insulation Rated 2.5kV through 500 kV

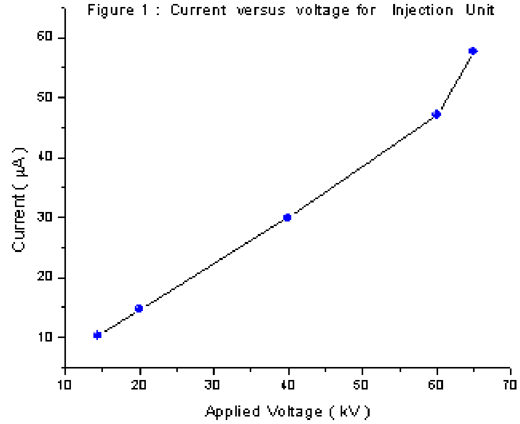
As implied by the title, the scope of IEEE 48 includes only cable terminations and hence does not apply to an HVFI, which does not terminate a cable. However, the performance of the exterior of the HVFI is analogous to the exterior of a termination. In fact the exterior of the HVFI is an IEEE 48 complaint terminator. It is a 3M QT-III-7686-S-8 and has passed all of the IEEE 48 requirements as per 3M's attached product data sheet, "3M™ Cold Shrink Silicone Rubber Termination Kit QT-III, 7620-S, 7680-S and 7690-S Series 5 - 34.5 kV. Test requirements include dielectric (7.1.1) and pressure leak tests (7.1.2).

Testing

In addition to the design testing performed for IEEE 48 of the HVFI external components, additional testing was undertaken at Powertech Laboratories by John Vandermaar (Manger, High Voltage Laboratory) and Kal Abdolall (Senior Research Physicist) at the behest of BC Hydro and in cooperation with Novinium on the HVFI assembly. The researchers concluded, "In our opinion this unit is suitable for this application." The results were transmitted by email on October 12, 2007. The email is attached to this test report. The measurements and tests undertaken were done in accordance with the requirements of IEEE Std. 48-1996 for 25 kV insulation class equipment are outlined below:

- The HVFI passed the AC dry withstand test at 65 kV for one minute.
- The HVFI passed the AC wet withstand test at 60 kV for 10 seconds.
- The HVFI passed the impulse withstand test at 150 kV (3 positive and 3 negative impulse waveforms).
- The HVFI was energized at 14.4 kV for 6.75 hours. There was no measurable increase in temperature above ambient on the surface of the HVFI.
- The HVFI tan delta is 3.75 and does not seem ect the performance of the unit, as reflected by the low leakage current (see figure nearby) and no measurable rise of tempera-ture after 6.75 hrs at 14.4 kV was observed.

Figure 1 : Current versus voltage for Injection Unit



Practice

Two HVFI units were placed in service on a crossing of Desolation Sound in British Columbia on October 15, 2007. Both terminations are within 100 meters of an ocean sound subject to high winds and salt spray. The “Pollution Severity Level” is “Heavy.” (i.e. Areas generally close to the coast and exposed to coastal spray or to strong winds carrying sand and salt, and subjected to regular condensation.) It took approximately 100 days for fluid to flow from the inlet side HVFI to the outlet side HVFI. The HVFI units have remained in continuous use to the day of this writing, December 10, 2013, which is over five years with perfect performance. The Desolation Sound crossing is a worst case scenario in that typical deployments of the HVFI would be of much shorter duration.

Summary

There are no industry standards for HVFI devices. The HVFI design incorporates an IEEE 48 35 kV standard termination, which is overdesigned for the application. Additional testing modeled after IEEE 48 was carried out on the HVFI assembly to confirm that internal components did not compromise the IEEE 48 performance. The testing confirmed that there was no performance degradation. Two HVFI devices have stood the rigorous test of time in a rugged field environment for over five years, which is much longer than typical deployments. The HVFI provides a safe and reliable fluid interface for fluid injection into energized live-front terminators.

Validation

This report was written by Glen Bertini, P.E. of Novinium. 3M provided the IEEE 48 test results for the termination kit, which is integral with the HVFI. Powertech has made measurements, which are a part of this test report. I have reviewed the HVFI design and the data and concur that the HVFI is suitable for the application of fluid injection into energized live-front terminators.

Signed: Glen J. Bertini, PE