Leak Location in Fluid Filled Cables Using the PFT Method

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Abstract: A new method of pinpointing dielectric fluid leaks on pipe-type and self-contained cables using perfluorocarbon tracer (PFT) is presented. The method has successfully been used on the Con Edison transmission system to locate leaks of dielectric fluid on both types of cables. Application of the PFT technique does not require feeder deenergization and provides major advantages over the conventional method of freeze and pressure testing. Description of the method and results of field application are presented in the paper.

Keywords: pipe-type, self-contained, leak location, dielectric fluid leaks, fluid-filled cable.

Introduction

High Pressure Fluid Filled (HPFF), pipe-type cable has been widely used in the United States and accounts for more than 80% of the total in-service length of the underground transmission cable in the country. An HPFF cable system is comprised of a steel pipe, which encloses three cables. The pipe is filled with dielectric fluid (DF) and is pressurized at a nominal operating pressure of 200 psig. HPFF cable systems have proven to be very reliable. However, in some cases due to various causes such as corrosion, contractor damage, effects of stray currents, and localized pipe wear due to vibrations, a pipe's integrity might be compromised, resulting in the pressurized leaking of DF to the surrounding environment. Self-contained, low and medium-pressure, fluid filled cables which have an oil channel in the middle of the conductor and an outer jacket, such as lead, have also been found to develop leaks. Cable leaks need to be detected, pinpointed and repaired as fast as possible.

Development of a new method which would quickly locate a leak, without requiring feeder de-energization, is of prime importance to the utility industry and has been the subject of research in the past few years. References [1] and [2] present results of studies performed for the Electric Power Research Institute (EPRI) to address the problem of leak detection and location. Reference [3] describes a method of locating leaks in gas-filled underground cables. In addition to the referenced studies, Con Edison has pursued several methods for locating leaks including acoustic method, subsurface radar, and flow direction indicators. Reference [4] is a description of one of the methods pursued by Con Edison using the hydrocarbon-sensor wire approach. To date, limited practical success has been achieved from aforementioned studies. On the other hand, the Perfluorocarbon Tracer (PFT) method has proven to be a very successful technique for pinpointing leaks. The PFT method and results of field application are described in this paper.

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PFT Technology

The tracer technology applied to dielectric fluid, DF, leak locating was originally developed and applied in verifying the ability of atmosphere transport and dispersion models to predict air-born concentrations on large transport scales of 500 to 3000 km [5,6] for early warnings of impacts from incidents such as occurred in Chernobyl and Bopal. The first major test of the new PFT technology occurred more than 20 years ago [7] in an intentional multi-tracer release in Idaho; the technology and its tools well established today.

The essential need for tracer measurements aloft [8] during atmospheric model-validation experiments lead to the development and use of a real-time PFT analyzer, the dual-trap analyzer or DTA [9]. That instrument, and its subsequent commercial version, is the key component used in a van to find the general location of a DF leak.

Leak Locating Overview

To find a subsurface DF leak, a very small amount of a PFT liquid-- which is itself an excellent dielectric fluid, is dissolved uniformly into the existing DF in the cable along its entire length (see next section). The PFT liquids are environmentally and biologically benign, and are compatible with cable system. When a leak occurs, the leaking cable DF wets an area of subsurface soil which then allows a portion of the dissolved PFT dielectric fluid to evaporate into the soil air. The PFT is then transported by conventional driving forces (barometric pumping, wind-induced pressure gradients, etc.), ultimately venting into the air above the street. This venting generally occurs not too far from the subsurface leak location. Usually the emissions of PFT vapors into the air reach steady state in less than 24 hours.

Based on the tagging levels used, the magnitude of the leak, the prevailing meteorology, and a number of other site conditions (e.g., depth to the feeder and the street/above-ground interface conditions), the typical PFT concentrations in the air above the street at a leak site are in the few to several hundred parts-per-quadrillion (ppq or 10^{-15}) range. Unlike conventional DFs, the resulting PFT vapors are extremely sensitive to measurement by electron capture detection (ECD), the type of detector used in the DTA. PFTs have extremely low ambient background levels (the two currently used cable tracers both have background near 1 ppq), allowing signals of less than 1 ppq above that background to be used to locate even very small leaks (~ 1gallon per day).

While one DTA trap is sampling the air above the street as the van drives along feeder route, the other adsorption trap is being thermally desorbed to recover the PFT vapor just collected in the previous instrument cycle; those vapors are processed within the DTA (physical and chemical steps) for subsequent ECD measurements on concentration—all within a two-minute cycle time covering, typically, about two city blocks per analysis. At the end of the two-minute cycle, the traps switch positions. This continuing process provides an integrated PFT signal along the feeder route; the magnitude everywhere should be at the ambient background of the cable tracer unless a leak site has been passed. Details of further localizing via aboveground air sampling in the "hot spot" area and subsequent pinpointing of the leak via subsurface air sampling are described in the following section. Figure 1 is representing the dual trap analyzer used for sampling.

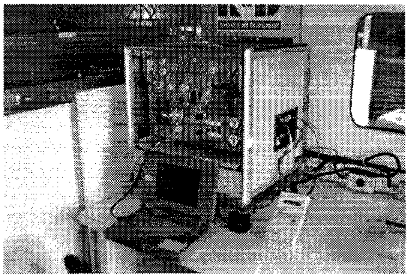

Figure 1: Dual trap analyzer

PFT Leak Location Steps

Application of the PFT technology to leak locating on pipe-type cables is summarized in figure 2 and consists of the following steps:

- Preparation of PFT / DF primary mixture (tagging fluid)
- Injection of primary mixture with circulation
- Survey of the feeder route: general localization
- Barhole sampling: pinpointing

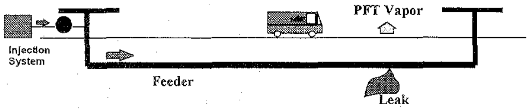

Figure 2: Schematic diagram of leak location

Preparation of tagging fluid: Since PFT dielectric liquid is heavier than conventional dielectric fluid, with only limited solubility, it does not easily mix with DF. Starting with degassed DF, care is taken during the mixing to preclude gases; this is especially important for self-contained systems. A small mixer is used to produce a uniform mixture of primary tagging fluid in the oil to o.1-to-1% range; subsequently this is diluted 2-to-3 order of magnitude to the final concentration required in the feeder.

Injection and circulation: The tagging fluid is diluted into the pipe using an injection system that was specifically designed and developed for this application. Injection is made at one or more points along the feeder having access via valves and is carried out with the feeder remaining in service. On-line dilution is readily achievable for feeders with high-rate circulation (force-cooled feeders); however, for static feeders, other methods, such as removing the dielectric fluid from the far end to create circulation or returning DF along a parallel feeder need to be implemented to ascertain that tagged fluid has reached the point of the leak.

Survey of feeder route: After allowing time for the PFT tagged fluid to reach to the leak area and diffuse through the soil to the surface, the route of the feeder is traversed with the leakmobile and air samples automatically tested for traces of PFT. With this, a general location of the leak, within few blocks, is identified. Alternatively, for short distances (1to2 miles) and very small leaks, passive PFT sampling can be deployed (about 20 per mile) for a period of few days and subsequently recovered and analyzed. Figure 3 is a representative map of PFT concentrations from passive sampling around the leak area.

Barhole sampling: After the general area of the leak is localized, to narrow down that area, about 7 or 8 barholes at about 40 foot intervals are made in the surface of the street and air samples from the soil tested. Further barholing at shorter intervals will finally pinpoint the location of the leak. Figure 4 is a representative concentration chart from the barholes. The barhole with the highest concentration is over the leak site.

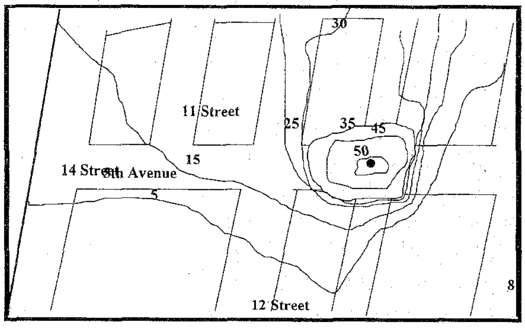

Figure 3: PFT concentration map

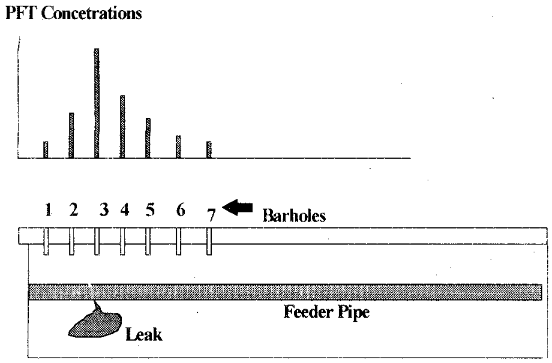

Figure 4: Pinpointing process

Field Trial Results

As part of the development of this application, and prior to transferring the technology to Con Edison, BNL successfully demonstrated the method in locating a number of simulated and actual leaks. Subsequently, Con Edison has successfully employed the method in locating several leaks on pipe-type as well as low and medium pressure feeders. The leak rates have ranged from a small one-gallon per day rate up to 50 gallon per hour. In some cases the entire feeder run (about 15 miles) had to be covered, and other cases, a smaller section of the feeder route needed inspection because the area of the leak had been narrowed down, using other conventional methods.

Conclusions

A new technique for pinpointing leaks on fluid-filled cables has been developed and successfully demonstrated under actual field conditions. Conventional method of locating leaks is based on freezing the dielectric fluid and pressure testing the sections of the pipe to successively sectionalize the location of the leak. This is time consuming, requires feeder deenergization and a number of street excavations. The new PFT method does not require feeder deenergization or street excavations, providing a faster, cheaper, and less disruptive alternative.

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Biographies

Reza Ghafurian (Senior Member IEEE) received his M.S. and Ph.D. degrees from the University of London, Imperial College of Science and Technology. During 1983 to 1985 he was Associate Professor of Electrical Engineering at the Iowa State University, Ames, Iowa. In January 1985 he joined Consolidated Edison Company of New York. He is currently Project Manager responsible for the Transmission Research Program in the Research and Development Department of Con Edison.

Russell Dietz received his B.S and Ph.D. degrees in chemical engineering from the Polytechnic Institute of Brooklyn, in 1960 and 1964, respectively. He was Fellow of National Science Foundation, 1960-1964. He holds seven patents and is the author of several technical papers. His research activities include instrumentation for sub-part-per-quadrillion detection atmospheric tracers, study of indoor ventilation and subsurface applications in oil and gas reservoir studies and leak pinpointing. He is currently head of the Tracer Technology Center at the BNL.

Thomas Rodenbaugh is a Senior Member of IEEE, PES, LEOS and EM. He is a past Member of the Board for the North American Society of Trenchless Technology, NASTT. Degreed in Physics (B.S.) and Solid State Physics (M.S.), Rodenbaugh has done original research in the area of partial discharge aging in polymers and laser physics. Employed by EPRI in 1974, Rodenbaugh had managed over 200 projects in the areas of superconductivity, cryogenics, gas-insulated equipment, thermal transfer problems, and ground probing radar and cable diagnostics and monitoring. He has also held assignments as a physics instructor and visiting researcher at SCE. He is currently the Manager of Cable Operations and Software Development for the Energy Delivery & Utilization Division of EPRI.

Juan Dominguez is a Senior Member of IEEE, received his B.S. degree in electrical engineering from the university of Miami in 1963. Following his graduation he worked for Burns Associates (Consulting Engineers) till 1967. In July 1967 he joined Con Edison. He is currently the Transmission Feeder Engineering Manager responsible for the overview of all overhead and underground transmission lines in Con Edison territory to insure their reliable operation.

Noah Tai (SM'85) received his M.S. and E.E. degrees from Columbia University in New York in 1969 and 1973 respectively. Upon joining Con Edison in 1969, he was assigned to the transformer and HVDC areas in the engineering department. He joined the research department in 1979 and is presently responsible for directing the transmission and distribution research program for Con Edison.