

Choosing the Best Underground Cable Rehabilitation Option

Glen J. Bertini and Gary A. Vincent
Novinium, Inc.

Abstract: Over twenty years have elapsed since the field introduction of the first solid dielectric enhancement technology. During those years, this technology has proven itself as an important tool to enhance the reliability of aging infrastructure. Incremental improvements during those twenty years have aided in the widespread commercial acceptance of the technology on at least four continents. For the majority of these two decades there was a single supplier of injection technology.

Beginning in 2006 novel injection approaches, which include new installation methods and new materials to extend the life of power cables, have become available. This paper provides a comparison of the merits of the available technologies. Comparisons are made in the broad categories of safety, short-term and long-term post-injection reliability, and end-user value.

INTRODUCTION

From 1984 through 2005 approximately 70 million feet of medium voltage underground power cable were treated with first generation injection technologies as shown in Figure 1. As demonstrated by [5], injection is typically a fraction of the cost of replacement and the economics are almost always in favor of rejuvenation. Undoubtedly the favorable economics of rejuvenation fueled the rapid growth depicted in Figure 1.

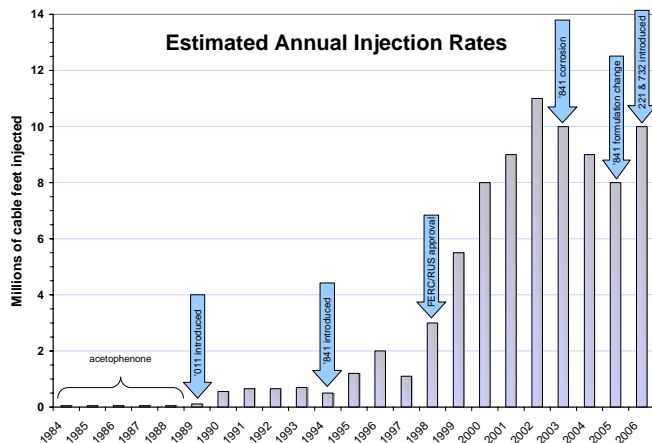


Figure 1. Cumulative injection compiled from dozens of industry sources including [1], [2], [3] and [4] demonstrate the growing importance of injection technology.

The first five years of commercial injections utilized acetophenone. While no cables treated with acetophenone ever failed in service, this technical success was not matched by commercial acceptance largely because of the fugitive nature of acetophenone and the safety and economic penalties imposed by the need for an ongoing maintenance requirement to re-supply fluid to the cable. In 1989 a silicone fluid (phenylmethyldimethoxysilane) invented by Vincent and

referred to as '011 [6] in Figure 1 was introduced. Because of its water reactivity, this new '011 fluid largely eliminated the need for a continual supply of fluid, at least for about 10 years at lower temperatures. About 5 years later in 1994, the authors of this paper Bertini and Vincent, et al [7] improved on the '011 technology when they introduced an additive called trimethylmethoxysilane. The '841 technology advancement solved a radial fluid distribution issue suffered by '011 [7]. This reformulation together with the approval by the FERC and RUS of the capital treatment of fluid injection were the foundation for the rapid growth of injection at the turn of the century. This growth faltered after 2002 when it came to light in [3] and [24] that the '011 and '841 technologies could cause corrosion to aluminum stranded cables. It was demonstrated in [7] that 30%_w of the trimethylmethoxysilane was preferred in the formulation together with 70%_w of the '011 fluid to achieve optimum fluid distribution and dielectric performance. In 2005 the '841 formulation was changed when the concentration of the trimethylmethoxysilane was reduced by a factor of 3 to 6, ostensibly to reduce the likelihood of corrosion of aluminum strands [23] experienced by the '841 chemistry discussed in [3] and [24].

The balance of this paper examines four dimensions to consider when choosing a rejuvenation technology. Those four dimensions are safety, short-term post-injection reliability, long-term post-injection reliability, and end-user value. Three technologies will be compared. All three of these technologies were conceived, reduced to practice and commercialized by the authors and their colleagues. The first technology referred to as '841 (and including its three incarnations) has been in widespread use for about a decade with the most recent formulation in use for about a year and is defined by [6], [7], and [8]. The second technology referred to as 221 utilizes specific fluid and fluid genres that have been in use for over two decades, but delivered with new injection technology. This second technology is available as a package for the first time in 2006. The third technology referred to as 732 includes the field proven technologies of 221, along with five completely new materials designed for very long life extension. The 732 technology is available for the first time in 2006.

SAFETY

Within the realm of safety there are two primary considerations in choosing a rejuvenation technology. The first is the exposure of injection contractors and circuit owner employees to high voltage. The second is the risk of fire and explosion.

When ‘841 technology is applied to URD cables at least three visits (i.e. 1. injection; 2. vacuum tank removal, typically 24 hours after injection; 3. soak tank removal, 60 to 120 days after soak tank removal.) are required to manipulate energized or potentially energized high-voltage components. Potentially energized bottles are left connected to terminations for a 60 to 120 day soak period. During that soak period utility troubleworkers and line-workers may encounter unusual and potentially dangerous situations. Unfortunately each encounter with high voltage runs the risk of accidental electrical contact. Both the 221 and 732 technologies require a single visit and a single switching operation. There are no unusual pieces of potentially energized equipment left near terminations.

Consider	‘841	221	732
Injection contractor HV electrical exposure	3+	1	1
Utility personnel exposure to unusual and potentially energized equipment	Yes	No	No
Potential flashover from open injection ports	Yes	No	No
Flammable	Yes	No	No
Known carcinogens	Yes	No	No

Table 1. Safety Considerations

The ‘841 technology utilizes injection elbows with ports described in [9], [10], and [11]. These ports are momentarily open to an energized conductor as permanent shielded caps are substituted for injection caps. These open ports have been known to flash over and create a hazard to employees including fire and explosion hazards as described by [12] and [13]. There are mitigating technologies described by [12] and [13] which remain unimplemented to date. With 221 and 732 technologies, injection is completed in minutes on de-energized cable and components. There is no open port injection into energized components.

Fire and explosion requires three components: fuel, oxygen, and a source of ignition. Unfortunately in a medium voltage distribution environment both oxygen and an ignition source are ever-present. Not all fuels are equal when it comes to the ease of ignition. The ease of ignition is measured as a flash point and the higher the flash point the less likely the fluid will ignite. According to the current material safety data sheet (MSDS) of the ‘841 fluid [14] its flash point is 0°C (32°F). Materials with these low flashpoints are rated by the U.S. Department of Transportation (DOT) as flammable. The fluids used by the 221 and 732 technologies have flash points in excess of 74°C (165°F) and are not rated as flammable by the DOT.

The ‘841 fluid includes the carcinogen benzene [14]. The 221 and 732 technology include no known carcinogens.

SHORT-TERM RELIABILITY

Most post-treatment failures experienced with the ‘841 technology occur shortly after treatment. For example in [15], Florida Power and Light (FPL) reports a post-treatment failure rate of close to 5%. FPL primarily uses injection on segments which have recently failed. Another example, provided by [16], is Salt River Project (SRP), which reports a failure rate of about 1% during the first two years. The high short-term post-injection failure of the ‘841 technology is exasperated by at least two characteristics of the ‘841 approach. First, there are no provisions in the ‘841 technology to address partial discharges (PD). Secondly, as demonstrated in [17], it takes about two years after treatment for the ‘841 technology to reach its maximum performance. Capital constrained cable owners generally delay their treatment programs until the cables have demonstrated that they are nearing the end of their reliable life. In these circumstances rapid rejuvenation is desirable to avoid early post-treatment failures.

Consider	‘841	221	732
Functionality included in technology to address partial discharges.	No	Yes*	Yes
Dielectric performance of cable greater than 16 kV/mm (400 v/mil) within week of treatment	No	Yes	Yes

Table 2. Short-term performance considerations. The asterisk indicates a short-term effect only from the acetophenone.

In [18] it was demonstrated that the 221 and 732 technologies enjoyed an 87-fold faster performance increase compared to ‘841. Put another way, cables treated with 221 and 732 technologies perform dielectrically as well as new cables within a week of treatment. See Table 2.

LONG-TERM RELIABILITY

In two-part paper [19] and [20] methods for the estimation of life for various conditions for each of the three technologies were provided and those estimations were validated against available accelerated-life data. The ‘841 and 221 technologies utilize a single formulation for all conditions. As indicated by [19] and [20], while this one-size-fits-all strategy might simplify the operations of those performing the injection, inherent performance compromises are required as even modest temperature differences have a profound influence on long-term performance.

Figure 2 provides a validated simulation (see [19] and [20]) of post-injection performance for a 1/0 URD cable buried in mesic soils (e.g. above the Mason-Dixon Line) in 1980 with a moderate load. The reliability threshold of 16 kV/mm (400 v/mil) was established by Steennis [21] as a level where no failures are likely to occur in service.

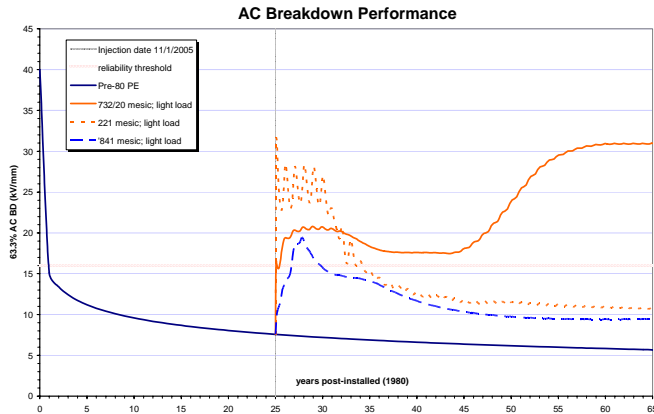


Figure 2. Post-treatment AC breakdown for lightly loaded cables in mesic (15°C) soils.

While the 221 technology provides much quicker and greater short-term performance than ‘841 as described by the previous section, both 221 and ‘841 suffer from a failure to stay in the insulation at a sufficiently high concentration for the long-term. ‘841 drops below the reliability threshold after about 5 years and 221 after about 10. In contrast, the 732 technology tailors the formulation for the anticipated thermal conditions the cable will face over its desired lifetime. With a temperature-adjusted formulation 732 can stretch life by 40 or more years for any cable, in any soil, with any anticipated load.

Consider	‘841	221	732
AC BD performance > 16 kV/mm	<u>YIS</u>	<u>YIS</u>	<u>YIS</u>
• mesic soils; light load	5	10	>40
• thermic soils; moderate load	4	4	>40
• hyperthermic soils; heavy load	1	1	>40
Volume tailored to cable geometry	No	Yes	Yes
Chemistry tailored to cable conditions	No	No	Yes
Includes stress grading	No	Yes*	Yes
Includes voltage stabilization	No	No	Yes
Includes UV stabilization	No	Yes*	Yes
Includes PD suppression	No	No	Yes

Table 3. Long-term performance considerations. Note: Asterisk indicates short-term only.

These authors will present a paper on March 14, 2006 in Subcommittee A of the ICC which will provide a theoretical framework and data to explain the substantial post-injection performance enjoyed by the 732 technology. Table 3 provides a high level preview of some of the key differences which will be disclosed in more detail next month.

VALUE

In the end, users must weigh performance and economics in their decision-making process. There are a wide variety of conditions which affect cost and individual utility costs may be considerably different than the typical case provided in Table 4.

Along with cost comes the confidence that the technology will perform as anticipated. The authors invented all three technologies compared in this paper and our collective representations have stood the test of time and peer review. All three technologies come with warranties that are far superior to the warranties offered by cable replacement contactors or cable manufacturers. Contrary to some public representations [22] however, there are no fully insured warranties.

When it comes time to collect on a warranty decades after treatment, the circuit owner must judge the ability of the warrantor to pay in an uncertain future. In most cases, faith is better placed upon individuals than faceless institutions. For long-term warranties, however, some institutional trust is required. There are at least five elements which should be considered to differentiate the commercially available warranties.

1. What conditions are established by the warranty provider to restrict a remedy?
2. What is the warranty length?
3. Is there a substantial portion of the warranty obligation that is insured?
4. Is there an actual fund of cash held by a third-party and accumulating interest to pay long-term obligations?
5. What is the history and future of the ownership and management teams for the suppliers?

The summary answers for each of these questions are found in Table 4.

Consider	‘841	221	732
Typical fully absorbed cost as a percentage of replacement (1Φ, direct buried, 1/0 15kV cable)	40%	35%	41%
Unconditional warranty	No	Yes	Yes
Warranty length in years	20	20*	40
Warranty fully insured	No	No	No
Warranty funding held in appreciating 3 rd -party trust	No	Yes	Yes
Management team with 2 decades of experience	No	Yes	Yes
Service supplier is for sale and future is uncertain	Yes	No	No
Developed by technical team with 2 decades of experience	Yes	Yes	Yes
State-of-the art in ...	1994	2005	2006

Table 4. Value Considerations. Note * indicates warranty is available only for lightly loaded cables in cool soils.

The state-of-the-art in 1994 was the ‘841 technology [7]. Some have argued [23] that it is best to stick with the “tried and true” ‘841 approach. The authors would suggest

that a more prudent approach is to embrace changes for the better that are learned from the lessons of the past. If everybody stuck with the old approach, the Earth would still be flat. Unlike the leap of faith of Columbus who could not see beyond the horizon, circuit owners today have access to a wealth of accelerated experimental work and sophisticated models which together provide a glimpse of anticipated performance.

SUMMARY

Rejuvenation technology is almost always the most cost effective rehabilitation strategy. The circuit owner has three rejuvenation technology choices. The most recently developed state-of-the-art technologies, 221 and 732, enjoy superior safety, short-term performance and value compared to the older '841 technology. The 732 technology outperforms the '841 and 221 technologies by over a factor of 3 in long-term performance. For the cost conscious buyers, the advantages of 221 can be enjoyed at a lower cost than the '841 technology with a comparable medium-term performance. In light of recent discoveries, neither the '841 or 221 technologies should be employed in the warmer soils common below the Mason-Dixon line or where cable loading exceeds 25% of rated ampacity if 20-year post-injection reliable life is desired.

REFERENCES

1. Tarpey, "Cost Effective Solution to URD Reliability: Cable Rehabilitation", Pennsylvania Electric Association T&D Committee Meeting, May 8, 1990.
2. Bertini & Chatterton, "Dielectric Enhancement Technology", IEEE Electrical Insulation Magazine, March/April 1994-Vol.10, No.2, pp 17-22.
3. Bertini, "Failures in Silicone-Treated German Cables Due to an unusual Methanol-Aluminum Reaction", ICC meeting Minutes, October, 29 2002, p. 1104.
4. Bertini, "Injection Supersaturation in Underground Electrical Cables", U.S. Patent 6,162,491.
5. Bertini, "Advancements in Cable Rejuvenation Technology", IEEE/PES 1999 Summer Meeting, Reliability Centered Maintenance, July 21, 1999.
6. Vincent & Meyer, "Restoring Stranded Conductor Electrical Cable", U.S. Patent 4,766,011.
7. Bertini, Vincent et al, "Method for enhancing the dielectrical strength of a cable using a fluid mixture", U.S. Patent 5,372,841.
8. Bertini, "Injection Supersaturation in Underground Electrical Cables", U.S. Patent 6,162,491.
9. Borgstrom & Stevens, "Separable Connector Access Port and Fittings", U.S. Patent 4,946,393.
10. Borgstrom, Bertini & Meyer, "Removable Media Injection Fitting", U.S. Patent 5,082,449.
11. Muench, et al, "High Voltage Electrical Connector with Access Cavity and Inserts for Use Therewith", U.S. Patent 6,332,785.
12. Bertini & Stagi, "Method and Apparatus of Blocking Pathways Between a Power Cable and the Environment", U.S. Patent 6,517,366.
13. Bertini & Stagi, "Method and Apparatus of Blocking Pathways Between a Power Cable and the Environment", U.S. Patent 6,929,492.
14. MSDS dated 05/14/2005, downloaded by author 01/12/2006 & available online at http://www.utilx.com/pdfs/MSDS_XL_Fluid.pdf.
15. Dudas & Fletcher, "Underground Cable Specification Advances and Installation Practices of the Largest Investor-Owned Utilities", IEEE Electrical Insulation Magazine, V.21. No.4, July/August 2005.
16. Hudson & Crucitt, Salt River Project, "SRP Enhances Reliability of Underground Distribution Cable", Transmission & Distribution World, Aug 1, 2000.
17. Mokry et al, "Cable fault prevention using dielectric enhancement technology", Jicable 1995.
18. Bertini, "New Developments in Solid Dielectric Life Extension Technology", IEEE ISEI, Sept. 2004.
19. Bertini, "Accelerated Aging of Rejuvenated Cables – Part I", ICC, Sub. A, April 19, 2005.
20. Bertini, "Accelerated Aging of Rejuvenated Cables – Part II", ICC, Sub. A, November 1, 2005.
21. Steennis, "Water Treeing: The behavior of water trees in extruded cable insulation", Ph.D. Thesis, 1989, published by KEMA.
22. See unsubstantiated claim: "This outstanding warranty ... is fully insured." at <http://www.wiredynamix.com/power/warranty.aspx>.
23. Stagi, "The Evolution of Cable Injection Technology", 2004 Fall ICC, Subcommittee A.
24. Brüggemann et al, "Influence of Electrochemical Effects on Vented Tree Initiation in Accelerated Tests", JICABLE '03 - International Conference on Insulated Power Cables, 2003.