Cable Rejuvenation

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During the two decades since the first cable injection project was completed, cable rejuvenation technology has proven itself as an important tool to enhance the reliability of aging medium voltage power cable infrastructure at the lowest possible cost.

From 1984 through 2009, approximately 90 million feet of medium voltage underground power cables were treated with available injection technologies as shown in Figure 1. Cable 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.

Why consider cable rejuvenation?

The main reason circuit owners use cable rejuvenation today is for **cost savings**. Typically, the cost to rejuvenate cables is one-half the cost of cable replacement. Many times, the cost savings can be even greater, if the area is highly landscaped, difficult to access, or the soil is rocky. With cable rejuvenation, the circuit owner can **stretch their capital budget** two or more times and have a more significant impact on system reliability.

Cable rejuvenation is also **faster** than cable replacement. Typically, it takes **one-third the time** to rejuvenate a cable compared to replacement. This increased productivity allows the circuit owner to spend yearend money faster, when the situation demands.

When committing to cable replacement, the impact on electricity customers must be considered. Cable rejuvenation is more **customer friendly** than cable replacement by hand digging, trenching, or boring. There is no equipment noise, the injection equipment is small, the process is fast, and there is almost no disruption to established landscaping. Typically, 3-5 segments can be completed per day almost silently with no customer inconvenience.

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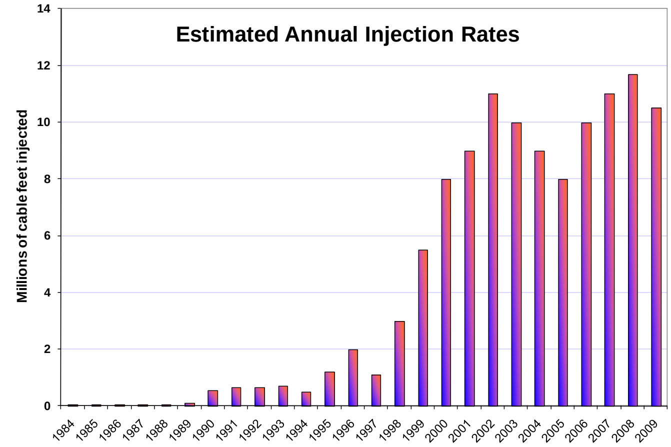


Figure 1. Annual Rejuvenation Rates. Cumulative injection footage compiled from dozens of industry sources [1], [2], [3], [4] demonstrates the growing importance of cable injection technology.

Cable rejuvenation has had a **long successful history**. Over the past several decades, over 90 million feet of cable have been rejuvenated and less than 1% of those injected cables have failed. It works!

Finally, cable rejuvenation can be **capitalized**. FERC and RUS have both approved cable rejuvenation for capitalization, because it extends the useful operation of the cables past their original planned life.

When does cable rejuvenation not work?

When circuit owners need to **increase the ampacity** of the cable run, or if to **increase the voltage** of the line, cable replacement is the only choice.

Solid core URD cables cannot be rejuvenated, because the fluid must be able to flow through the cable strands. However, even circuit owners with solid URD cables have stranded feeder cables, which are good cable rejuvenation candidates.

Beginning in the mid 1990s, some circuit owners began using **strand blocked cable** to prevent water from moving longitudinally in the strands. This also prevents rejuvenation. Luckily, most of the cable targeted for injection was installed before this time.

Why do cables fail?

XLPE and EPR cables more than 25 years old begin to fail because of a problem know as **water trees**. When cable was manufactured in the 1970s and 1980s, insufficient care was taken to keep the ingredients free from contaminants. This dirt created stress points in the insulation, and water trees began to grow. When the water trees grow to a sufficient size and can no longer hold the voltage stress, an electric tree will form. In a couple of weeks after the electric tree forms, the cable will typically fail.

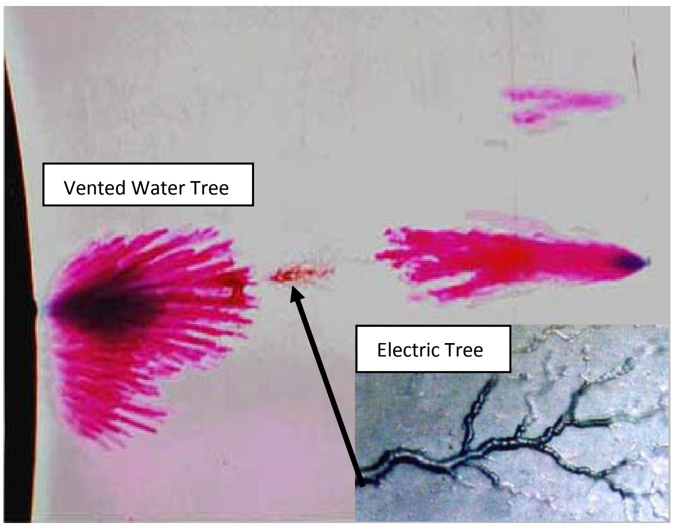


Figure 2. Water and Electric Trees. Water trees initiate from defects (often dirt) in the insulation. When water trees grow large enough, an electric tree is formed (see inset). After an electrical tree is formed, cable failure usually follows.

What is cable rejuvenation?

Cable rejuvenation **injects silicone fluid** into power cable and fills the strand area. The fluid contains a mixture of materials to repair water tree damage, prevents new water trees from growing, and in some cases, upgrades the cable with ingredients that are found in modern cables.

The fluid **migrates into the conductor shield and insulation**. This diffusion process allows the injected materials to move from the strand area into the insulation where the water trees are found. The amount of pressure used for injection greatly affects the speed of rejuvenation.

The injection fluids then **modify the chemistry of the insulation and the physics of the cable** to extend the reliable life of the circuit by filling the water trees, retarding the formation of new water trees, and in some cases, upgrading the insulation properties to that of new cables.

What vendors provide cable rejuvenation?

There are only two vendors and their licensees who currently provide cable rejuvenation services.

What injection fluids are available?

Table 1 shows the various injection fluids that are available for cable rejuvenation today.

Fluid:	**Generation 1 [5]**	**Generation 1+ [6]**	**Generation 2 [7]**
Introduced	1994	2006	2006
No. of Components	3	5	9
Main Components	TMDMS PMDMS	iLA PMDMS	iLA TEMDMS CBMDMS
Upgrades Cable? †	No	No	Yes
Flammable?	Yes	No	No
Temperature Adjusted?	No	No	Yes
Warranty in Years	20	25*	40*
Time to Restoration	2 years	7 days*	7 days*

Table 1: URD Cable Rejuvenation Fluids Available See vendor websites for more information.
†Provides functionality found in new cables: Antioxidant, UV stabilization, PD suppression, voltage stabilization.
*When injected with SPR process described on the next page.

Are there different fluids available for feeder cables?

Feeder cables run hotter and are larger. Therefore, they require different fluids to rejuvenate them. Table 2 outlines feeder fluids.

Fluid:	**Feeder 1 [8]**	**Feeder 1+ [9]**
Introduced	2008	2009
No. of Chemicals	2	8
Main Chemicals	$DMDMS_4$	$TEMDMS_8$ $CBMDMS_8$
Upgrades Cable? †	No	Yes
Flammable?	No	No
Time to Restoration	2 years	7 days
Warranty in Years	20	40

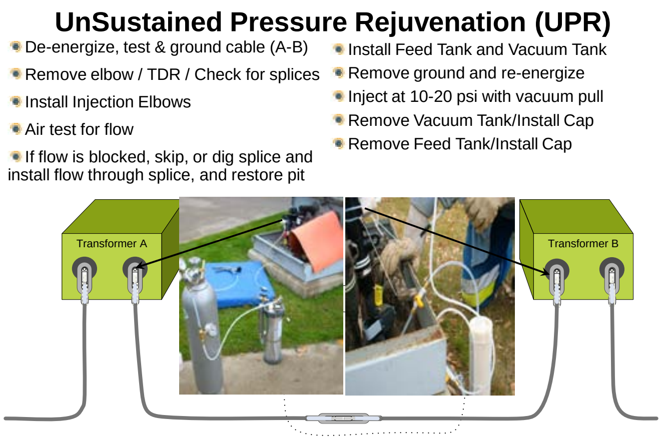
Table 2: Feeder Cable Rejuvenation Fluids. See vendor websites for more information.

What processes are available for cable rejuvenation?

There are two processes available for cable rejuvenation: Unsustained Pressure Rejuvenation and Sustained Pressure Rejuvenation.

Unsustained Pressure Rejuvenation (UPR)—this process injects fluid into the stands **through injection elbows or live front terminators** at low pressure (10-15 psi). Because of the lower pressure injection, it is **sometimes possible to flow fluid through splices**. About 50% of legacy molded splices support flow, but taped splices, pin-and-socket splices, and shrink-to-fit splices will not flow.

The steps in Unsustained Pressure Rejuvenation are:



1. Switch, de-energize, test, and ground the segment.
2. Remove the old elbows.
3. Run a TDR (time domain reflectometer or radar) to check for splices and neutral corrosion.
4. Install two injection elbows.
5. Perform an air test to insure a flow path.

Figure 3: Injection Elbow cutaway showing injection port for the Unstained Pressure Rejuvenation process

6. If no flow, skip segment, or dig splice and install a flow-through splice.
7. Install an injection bottle.
8. Install a vacuum tank.

Figure 4: Injection Elbow and vacuum tank installed on a pad mount transformer.

9. Remove ground, re-energize, and switch circuit back into service. Typical time for the UPS process first visit is 1-2 hours.
10. In 2-48 hours when the fluid comes through the other end of the cable, make a second visit to remove the vacuum tank at far end and install the permanent cap on the vacuum end.
11. For Generation 1+ and Generation 2 fluids, the injection bottle can also be removed from the transformer during the second visit. For the Generation 1 fluid, the feed bottle is left for 60-120 days to "soak" the cable. At the end of this soak period, make a third visit to remove the soak tank from the transformer.
12. Install the permanent cap at the injection end.

A 300 foot segment of 1/0 will take 2-48 hours for the fluid to flow from the injection elbow to the far end. Longer segments, or segments with strand corrosion, may take several days.

After injection, the dielectric strength of the cable will increase to that of new cable in about 24 months at a rate of about 0.5% per day.

Sustained Pressure Rejuvenation (SPR)—this process injects fluid into the stands through injection adaptors at moderate pressure (100-

300 psi). Legacy splices, often of questionable reliability, are replaced to support sustained pressure injection.

The Sustained Pressure Rejuvenation approach **rejuvenates the insulation quickly**, increasing the dielectric strength to that of new cable in as little as seven days. This rapid increase in dielectric strength helps prevent early cable failures. It also allows the **injection of more fluid** into the cable, extending the life of the cable up to **40 years**.

Injection adaptors are installed at each end of the cable and at each end of a splice connector. Fluid is then injected through these adaptors until it comes out the other end of that segment.

The steps in Sustained Pressure Rejuvenation are:

1. Switch, de-energize, and ground the cable.
2. Remove the old elbows and terminations.
3. Run TDR to check for splices and neutral corrosion.
4. If there are splices, excavate, replace the splice, and swage on two injection adaptors.
5. Swage one injection adaptor on each end of the cable. See Figure 5.
6. Inject fluid into the cable strands through the injection adaptor until it comes out the far end.
7. Seal the fluid into the cable strands, so that no fluid touches the accessories.
8. Install standard elbows and standard splice accessories.

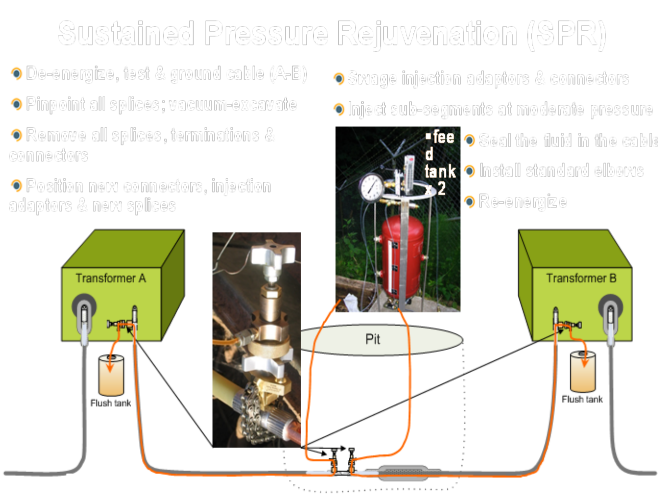


Figure 5: Swaging on injection adaptors during the Sustained Pressure Rejuvenation process.

9. Remove the ground, re-energize, and switch the circuit back into service. The typical time required for the single SPR visit is 1-2 hours.

A 300 foot segment of 1/0 cable with round strands will take about 20-30 minutes to inject. After injection, the dielectric strength of the cable will be like-new in 7 days, preventing early cable failures that could occur before the fluid diffuses into the water trees.

What is the basis for comparison?

To compare the cost of replacement with rejuvenation and to select the best rejuvenation process, a circuit owner must first gather information. The most important information to gather is the cost of cable replacement and the cost of digging a splice pit. This data will allow the circuit owner to calculate the savings enjoyed with rejuvenation. Be sure to include all costs, not just the trenching or boring cost alone.

Typical 1/0 **cable replacement costs** in developed areas of North America are $25/ft with a range of $12/ft in soft sand to $80+/ft in rocky soils. Typical **splice pit costs** are $800 with a range of $300 to $2500 depending on soil and required landscaping restoration. Generally, **rejuvenation costs are one-half to one-third the cost of cable replacement**.

What rejuvenation choices are available?

1. Choose the chemistry

- Good – Generation 1
- Better – Generation 1+
- Best – Generation 2

2. Choose a rejuvenation process

- Good – UPR
- Better – SPR
- Best – Integrated

3. Choose to minimize disruption, or maximize total rehabilitation

If your goal is for Total Rehabilitation of a subdivision, then rejuvenating the most cable segments provides the lowest total cost, even if this means digging a lot of splice pits, because digging splice pits is generally less expensive and less disruptive than replacing a complete cable segment.

Figure 6 shows graphically the relationship between total cost and the percentage of segments treated. The more cable you can inject the lower the total capital cost, because the cost of replacing the remaining segments is typically 2-3 times the cost of rejuvenation.

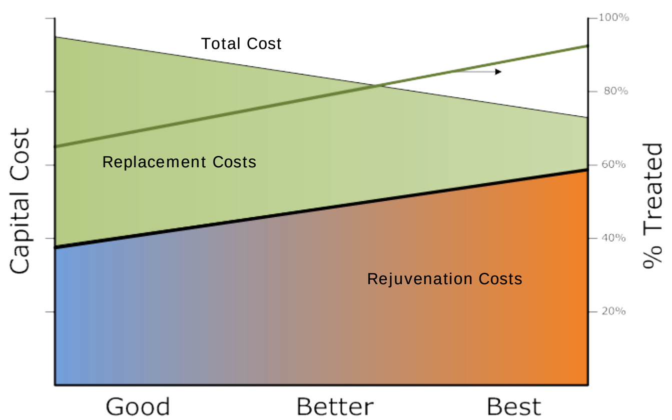


Figure 6: Seduction of the Good—Left scale and shaded areas provide the total capital cost. Right scale and the upper line show the percent of segments rejuvenated.

Initially, it may seem better to just rejuvenate the easy segments and achieve the lowest rejuvenation cost. However, when you add in the cost of replacing the remaining cable, the total capital cost for the subdivision rises significantly as shown on the left side of the graph in Figure 6.

Make your third decision: Do you want to inject with **minimal short-term disruption** (Good), or do you want **total rehabilitation** of the subdivision (Best) at the lowest possible cost?

4. Minimize injection cost, or minimize total rehabilitation costs?

You can minimize injection costs by only injecting sections that have no splices, or that have splices that can support fluid flow. In practice, this might achieve a segment completion rate of 50-70%.

The alternative integrated approach is to inject the clear segments with SPR, dig the splices that are economic to excavate and inject with SPR, and inject with UPR those segments that are not economical to dig, but have splices that support flow. This approach will achieve a segment success rate in the range of 90+%, leaving only a few segments to replace at a much higher cost.

Make your fourth decision: Do you want to **minimize injection cost** or **minimize total rehabilitation costs**?

5. Replace all accessories, replace only splices that do not flow, or flow through splices that can be injected?

Some utilities have never had a splice failure and feel that their splices are in good condition—they might choose to flow through all splices that support fluid flow. Other utilities have had many splice failures already and want all splices replaced. Finally, some utilities want to replace most splices, but are willing to attempt flow though splices that are economically challenging to dig, because of their location or accessibility.

Make your fifth decision: Do you want to **dig and replace only splices that do not flow** (Good), **flow through only high-cost-to-replace splices** (Better), or **replace all splices** (Best)?

6. Maximize injection productivity, or inject as many segments as possible?

There may be times when you have limited manpower, or when you have a fixed time to spend a budget (yearend). In this case, you might choose high injection productivity, skip segments that do not flow, and come back another time to clean up the skipped segments, either by digging/injecting, or by replacement.

Alternatively, you could be focused on economics and want to increase the percent of segments injected in order to minimize your capital cost to achieve total rehabilitation.

Make your sixth decision: Do you want **high injection productivity** (Good), or do you want to **inject the most segments possible** (Best) and achieve the lowest cost.

What other criteria should be considered when choosing a rejuvenation fluid and a rejuvenation process?

A partial list of items to consider includes:

1. Total Rehabilitation Costs
2. % of Segments Treated
3. Productivity
4. Number of Pits Required
5. Outage Time (radial feeds)
6. Splice Location Accuracy
7. Multiple Products Available
8. Multiple Processes Available
9. Transparent Procedures
10. Detailed Craft Accessory Templates
11. Training of Internal Craft Labor
12. Safety of the Process/Fluid
13. Length of the Warranty Period
14. Labor Source/Mix

The first four items have been discussed above. In item 5 when you have a radial feed and need to take outages for rejuvenation, sometimes it can be quicker to use the UPR injection method to install elbows quickly, get the customers back in service, and then complete the injection on segments that flow through splices with the system energized. For segments that do not flow, you might consider using a primary jumper when excavating these splices.

Items 6-14 are vendor related items and you will have to visit the vendor websites, or meet with the vendors, to learn more about these topics.

What Midwest utilities have successfully used cable rejuvenation?

Some Midwest utilities that have successfully used cable rejuvenation include:

- Kansas City P&L
- Win Energy
- Exelon
- AEP Ohio
- NPPD
- City of St. Charles, IL
- City of Naperville, IL
- Alliant, IA

Final Thought

Your URD cables are a Renewable Resource!

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Richard K. Brinton is the Vice President of Business Development of Novinium. He has been responsible for introducing cable rejuvenation to utilities around the world. Brinton has over 30 years experience in business development in the Americas, Europe, Asia, and Australia. He has focused his career on the worldwide introduction of new technologies and has gained worldwide experience in industrial processes, machine tools, robotics, and construction. Mr. Brinton holds a B.S. in Industrial Engineering and a B.A. Liberal Arts from the Pennsylvania State University, is a Senior Member of the IEEE, and is a licensed Professional Engineer.