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EXTENDING THE LIFE OF UNDERGROUND TRANSMISSION LINES THROUGH CABLE REJUVENATION

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ABSTRACT

Underground transmission lines operating above 46 kV serve as critical infrastructure, delivering power to thousands of homes or businesses. As the first solid-dielectric transmission cables approach the end of their life estimation, circuit owners are faced with a decision on how best to ensure grid reliability, often weighing the cost, timeline, and impact of replacement against cable rejuvenation. This paper will highlight the recent application of injection technology toward a critical transmission circuit feeding a major regional employer, provide an overview of the rejuvenation process and detail cable accessories developed by G&W Electric to inject underground transmission class circuits.

Index Terms — Cable accessories, life estimation, power cables, power system restoration, reliability, silicone injection, transmission lines, underground power cables, water tree.

I. INTRODUCTION

The power grid is tasked with providing reliable power between the points of generation and the end users. Within the grid, transmission cables serve as the trunklines, transmitting power over great distances. With a single outage able to plunge thousands of homes and businesses into darkness, reliability of transmission circuits is paramount. In the United States, much of the transmission infrastructure is built overhead, with underground circuits often reserved for specialty applications. As the earliest solid-dielectric underground transmission cable systems reach the end of their life estimation, circuit owners are faced with a decision on whether to replace these critical pieces of infrastructure or rejuvenate the cable through silicone injection.

This paper will highlight the recent application of injection technology toward a critical transmission circuit feeding a major regional employer. An overview of the recent advancements in rejuvenation technology, including the development of cable accessories for the rejuvenation of transmission cable systems will be discussed. Further, the advantages of rejuvenation on transmission-class cable systems and its comparison to cable replacement will also be reviewed.

II. BACKGROUND

The power industry's move to underground power cable systems began to accelerate in the 1960s after the introduction of solid-dielectric materials like polyethylene and EPR [1]. As these early-generation solid-dielectric cables began to experience failures in as little as 10 years, water trees were soon discovered [2]. Consequently, a push toward higher quality cable construction techniques and solutions for the cables already installed, like silicone fluid cable injection, were born.

A. Underground Transmission Lines

The history of solid dielectric transmission lines is well summarized in [3]. Installation of solid dielectric transmission lines began in the 1950s using rubber insulation and expanded greatly in the 1970s with the advent of cross-linked polyethylene. Since their introduction, the industry has created guides and standards to aid their adoption [4].

As a complement, the means to terminate solid-dielectric transmission cables and make connections to ancillary equipment also evolved. Early termination designs mimicked those of paper insulated lead covered (PILC) power cables using porcelain insulators and hand-taped stress-relief cones. Over time, improvements were made to simplify installation. Modern designs feature push-on or cold-shrink style rubber stress-relief cones. The rigid and self-supporting porcelain bodies are being phased out in favor of lighter weight composites that are easier to lift and install. Alternatively, heat-shrink and cold-shrink terminations were introduced that are both lighter weight than some composites and offer more flexibility.

B. Cable Rejuvenation

Cable rejuvenation through silicone fluid injection has been a popular alternative to the replacement of aged and failing medium and high-voltage power cables for the past 30 years. Cable injection improves the dielectric strength of aged and water-treed cable insulation and, when coupled with new craftwork and accessories, elevates the rejuvenated cable system toward parity with the reliability achieved by replacement [5]. The chemistry, process, and efficacy of cable rejuvenation have been well documented and summarized in literature [6]. To date, over 46 million meters (150 million feet) of solid dielectric cable have been rejuvenated through silicone fluid injection by more than 300 utilities worldwide [7]. Of which, over 15 thousand meters (50 thousand feet) of sub-transmission and transmission cable have been rejuvenated to date. Projects have been completed using porcelain, heat-shrink and cold-shrink accessories from manufacturers including G&W Electric, Joslyn, TYCO and 3M. One exemplary project was performed in 1995 and documented in [8].

C. Atlantic Municipal Utilities

With the age of its critical transmission line surpassing 50 years, Atlantic Municipal Utilities (AMU) knew action was required to maintain the reliability of their grid. The circuit is a radial system that runs from the mainline switch station to a stepdown transformer. The line feeds several industrial customers making up a large share of the region's top employers including an ethanol plant that recently went online in 2019 [9]. While the majority of the transmission circuit is built of overhead construction, the crossing of the Atlantic Municipal Airport runway's glidepath required a 400-meter (1/4 mile) span be built underground (Figure 1).

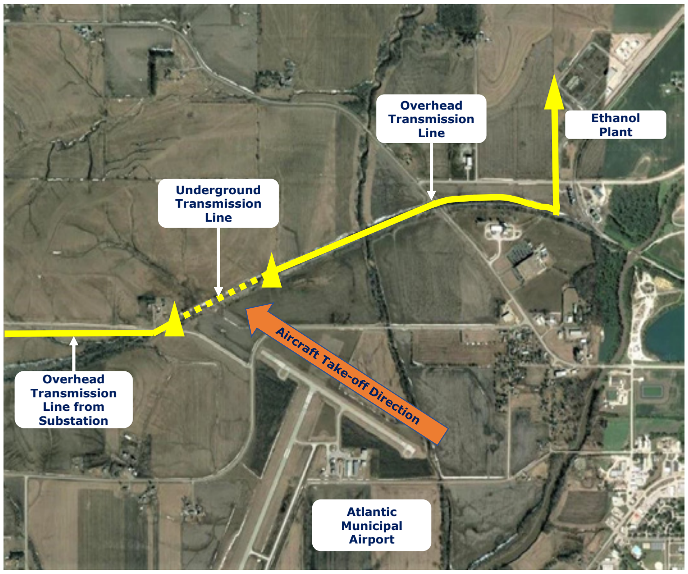

Figure 1: Circuit map

Construction of the underground circuit was performed in 1969. The cable is a 254 mm2 (500 kcmil) aluminum conductor cable with 69 kV rated cross-linked polyethylene insulation. Two risers supported the drop of the 400 meters (1,300 feet) of the circuit. The cable was terminated with oil-filled porcelain stress-control terminations.

Cable replacement was the traditional choice but after hearing of cable rejuvenation, Atlantic Municipal Utilities decided to take a closer look at the alternative.

III. PROJECT

Atlantic Municipal Utilities acted and chose to address their reliability concerns on their 50-year-old transmission line through cable rejuvenation. Even as a global pandemic set in, the project proceeded from an introductory meeting to completion in just over 11 months.

A. Initiation

After learning of silicone cable injection from a colleague, an introductory meeting with Southwire Novinium Services was held virtually in April of 2020. Atlantic Municipal Utilities shared their concern for their aged transmission line's reliability and critical details of their system's construction. Past successes on similar transmission circuits were shared with AMU and formal proposal was requested for consideration and inclusion in their following year's budget

B. Planning

Atlantic Municipal Utilities communicated their desire to replace the existing terminations with ones of the same configuration and avoid the added time and expense of rebuilding the risers' brackets and buss. With as-built information sparse on this 50-year-old circuit, an aerial drone outfitted with high-resolution camera was used to document part numbers. The use of the drone bypassed the minimal approach distance and allowed necessary information to be gathered and shared without the need of an inconvenient outage to their industrial customers (Figure 2). This information allowed G&W Electric to begin the necessary design work and ensure the compatibility of the new stress control terminations.

Figure 2: Photograph collected from aerial drone detailing the pole-top termination manufacturer's part numbers and specifications.

With cable specifications also sparse on this 50-year-old circuit, a 60 centimeter (24 inch) long cable sample that had been kept on display in the engineering office of the utility was loaned out to Southwire Novinium Services engineering to perform a detailed analysis of the cable's geometry. The information allowed the replacement terminations and mounting hardware to be fully specified.

The cable geometry was also used along with cable loading, to formulate the optimal injection fluid to restore the dielectric strength of the transmission line. Loading was found to be non-cyclic and near constant at roughly 50% capacity for the circuit. Peak load was documented at 15 MW (214 amps). Review of aerial maps and photos were used to understand access points to the work site and estimate the number of bucket trucks and personnel necessary to complete the project. A formal proposal was supplied in November of 2020 and included in AMU's budget for 2021.

C. Implementation

The budget was awarded in January of 2021, and the project was scheduled for that April to coincide with other maintenance scheduled inside the mainline switch station to upgrade meter banks and install a bypass to this radial feed. As travel restrictions eased, a pre-fielding visit was performed in February 2021. The project team walked the circuit to prepare a formal work plan, while confirming the scope and assignments. Access to the riser poles was verified and notice was provided to the Union Pacific railway and the adjacent corn farm of the work schedule.

The project plan created saw the outage start on April 13th and the power restored 8 days later on April 21st (Figure 3). Turnkey line crew consisting of 4 journeyman linemen were supported by engineers from G&W Electric and Southwire Novinium Services.

The project began on schedule and was completed 2 days ahead of plan on April 19th with the crew opting to work 12-hour shifts and make the most of the fair spring weather before winds were expected to resume later in the week. Craftwork to remove all six 50-year-old terminations was completed on the first day compared to the two-plus days forecast.

Craftwork to prepare the cables for injection was performed on Day 2 with the installation of the 6 injection adapters.

Injection of the 3 phases was completed on Day 3 with injection times under 7 hours. Treatment levels were near their estimates with each cable receiving approximately 25 liters of fluid.

Craftwork to complete the terminations began on Day 4 with two bucket trucks working in tandem (Figure 4). Craftwork and final proof testing of the circuit were completed two days early on Day 6, prior to the system being returned to Atlantic Municipal Utilities to be re-energized.

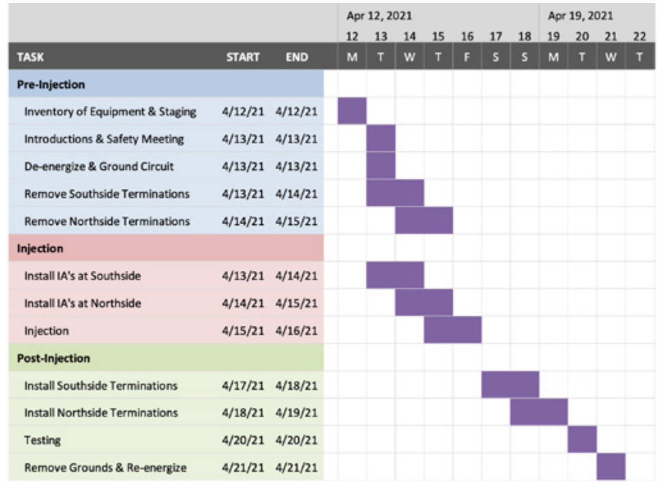

Figure 3: Gantt chart showing the initial project plan.

Figure 4: Lifting the porcelain body into position using jib crane.

IV. TECHNOLOGY

The Atlantic Municipal Utilities project marked the first factory and in-field collaboration between engineers from G&W Electric and Southwire Novinium Services. Additionally, given the requirements imposed by the oil-filled terminations, this project was the first to use an injection adapter (IA) installed within the porcelain housing (Figure 5).

The injection adapter (IA) was designed to fit the geometry of the cable and the electrical connector for termination kit. Once the constraints were fully identified during the planning stage of the project discussed in Section III, the manufacturing and testing of the new IA was completed as scheduled within a 4-month window.

The pre-assembled termination (PAT) from G&W Electric provides an efficient and reliable method for terminating underground cables across the transmission-voltage range from 69 kV to 345 kV. The electrical connector was designed to interface with the injection adapter through a tailored outer diameter and insertion depth of the ferrule. The changes implemented by G&W Electric simplified installation by minimizing the number of tools and die changes required to install the injection adapter and termination kit.

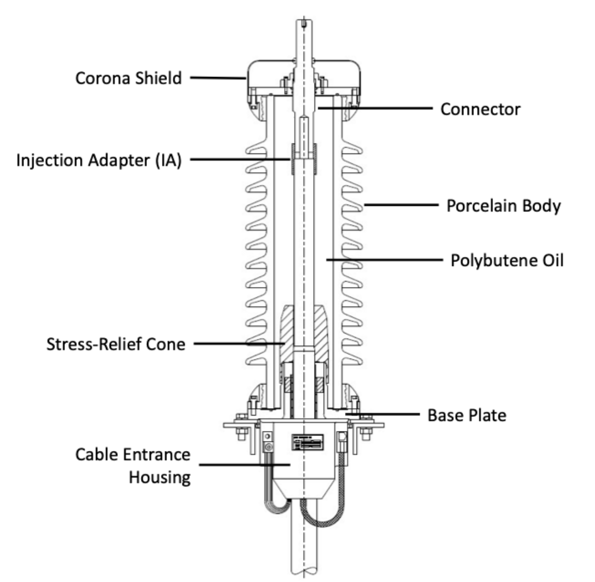

Figure 5: PAT series oil-filled porcelain termination with injection adapter.

With electrical craftwork paramount to the reliability of transmission cable, training was provided to the jointing crew by G&W Electric at their Bolingbrook, IL headquarters and assembly lab. The crew received certification that qualifies their craftwork on approved terminations for an extended warranty.

V. DISCUSSION

When faced with an aging underground cable population, cable rejuvenation is often selected over the alternatives based on economic considerations and its minimal disruption to homeowners and businesses they serve. Industry guides and other resources have been created to help circuit owners weigh their options. While these resources have generally been created with distribution and feeder systems in mind, they lay out several economic factors including material costs, soil considerations, current cable installation, new cable installation, landscaping and disposal [6]. This case study demonstrates that the same methodologies may be applied to transmission lines, and the economic advantages of cable rejuvenation over replacement may even widen.

A. Economic Considerations

Compared to distribution and service voltages, the cost for underground transmission cable systems increases sharply with voltage class. By one study, construction costs for underground transmission lines are estimated to be $1.5 million per mile for 69 kV and $2 million per mile for a 138 kV [10]. While another study finds underground transmission lines installed in urban areas may exceed $4 million per mile [11, 12]. For comparison, the installation of a typical underground residential distribution (URD) circuit will range from between $150 to $400 thousand per mile. These costs also fail to account for terminations and associated work including construction of substations and risers.

The economics of rejuvenation are often more in line with the economics of overhead construction. Rejuvenating existing circuits may result in further savings by eliminating the costs of environment impact studies and permitting. These advantages make cable rejuvenation an especially attractive option in environmentally sensitive areas near wetlands, estuaries and wildlife sanctuaries.

B. Stakeholder Considerations

The decision by Atlantic Municipal Utilities to move forward with cable rejuvenation required acceptance from the various stakeholders in the project. The stakeholders included Northwest Iowa Power Cooperative (NIPCO) who manages the maintenance and operation of the overhead transmission lines for Western Iowa, the industrial customers that rely on their power service to operate, the Federal Aviation Administration (FAA) who oversees Atlantic Municipal Airport and the Union Pacific Railway and farms that own the property and control access to the power poles.

While gaining acceptance for a new process is never easy with a project of this importance, the advantages of cable rejuvenation compared to the alternatives were able to win over the stakeholders. For NIPCO and the industrial customers served by the line, the 8-day project duration was the key factor and allowed injection to take place within the window already scheduled by NIPCO to perform the installation of a new switch and meter banks at the station, while avoiding additional power outages.

For the Union Pacific Railroad and the farms, the smaller overall footprint for injection was a win, with both stakeholders swayed by the minimal amount of equipment required to complete the project. By comparison, replacement would require trenching to carefully control the backfill around the cable bank per industry practice [3]. The added heavy equipment would have extended the project duration and impacted the crop for the season.

VI. CONCLUSION

Cable rejuvenation was selected by Atlantic Municipal Utilities to ensure the reliability of their 50-year-old solid dielectric transmission line that forms a critical underground link servicing some of the region's top employers. Cable rejuvenation was selected over the alternatives based on its favorable economics and reduced disruption to stakeholders. The project proceeded from initiation to completion in under 11 months, which included the development of stress-control terminations specific to cable rejuvenation by G&W Electric. The cable rejuvenation project was completed in 6 days, which was 2 days ahead of other maintenance performed in the switch station during the scheduled outage.

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