CABLE REJUVENATION CHANGES THE COURSE OF HISTORY AT NV ENERGY

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ABSTRACT

For the past 22 years, cable rejuvenation has played a key role in NV Energy's (NVE) delivery of reliable electric power to its customer base of over 1.3 million homes and businesses in the United States' desert southwest. Since the beginning of the program in 1998, more than 12 million conductor feet of their underground residential distribution (URD) system have been successfully rejuvenated by silicone injection. This paper will explore the evolution of NVE's reliability program from trial phase to present and the metrics used to gauge the success of silicone injection. Further, the application of predictive modeling as a tool for forecasting future outages and estimating outages saved will be defined.

I. INTRODUCTION

For the past 22 years, cable rejuvenation has played a key role in NV Energy's (NVE) delivery of reliable electric power to its customer base of over 1.3 million homes and businesses in the desert southwest. When a population boom began to unfold during the second half of the twentieth century that aligned with the industry's adoption of underground power distribution systems, NVE selected to build much of their new infrastructure underground. Today, their infrastructure includes over 15 million conductor feet of underground distribution-class cable. As a rise in cable failures began to unfold in the 1990s on those early vintage URD cables, NVE took decisive action and implemented a reliability program centered around cable rejuvenation. Since the beginning of that program in 1998, more than 12 million conductor feet of their URD system have been successfully rejuvenated by silicone injection.

This paper will explore the evolution of NVE's rejuvenation program starting from a pilot to present day and the metrics used to gauge the success of silicone injection. Further, the application of predictive modeling as a tool for forecasting future outages and estimating outages saved compared to the conventional approach using the '3-strike rule' will be defined.

II. BACKGROUND

Throughout the second half of the twentieth century, the state of Nevada experienced an unprecedented population boom that coincided with the power industry's adoption of underground distribution systems. When failure rates on early-vintage URD cable increased in the 1990s, NV Energy took decisive action and implemented a reliability program centered around cable rejuvenation

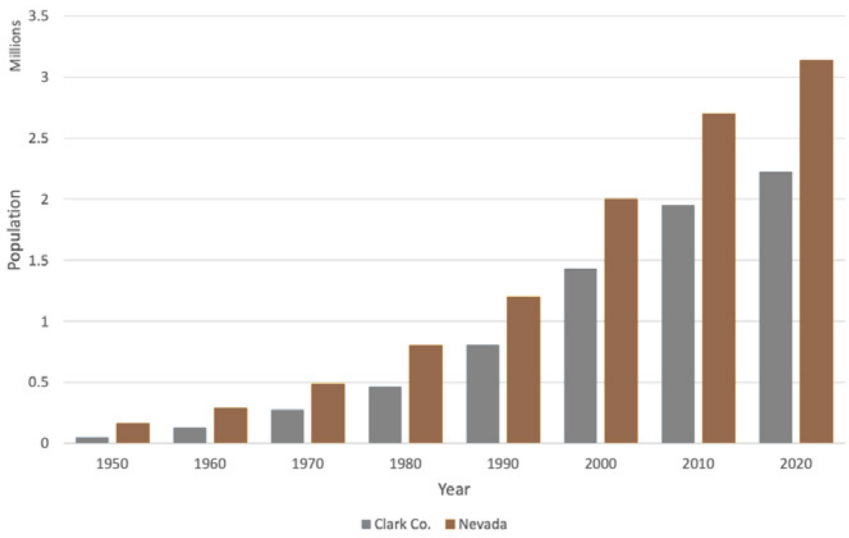

Figure 1: Population growth of Clark County and the State of Nevada 1950-2020 (US Census).

A. Supporting the Growth of Clark County and the State of Nevada 1950-2020 (US Census).

Throughout its 150 year history, NV Energy has helped power the California gold rush and illuminate the transition for the city of Las Vegas from a watering stop along the transcontinental railroad into the international tourist destination it is today [1] and [2]. During that time, NV Energy has enabled the growth of the fastest growing state in the country and a cosmopolitan region that has seen its population double in 20 years [3] (Figure 1). This period of growth coincided with the power industry's adoption of underground power distribution systems made possible by the confluence of 3 inventions post World War II; pad-mount transformers, polyethylene insulated URD cables and load-break elbows [4].

NV Energy's service territory is broken into two main geographic regions spanning from the Great Basin Desert in the North and East to the Mojave Desert in the South and West. The northern region services 355 thousand customers and includes cities such as Carson City, Reno, Lake Tahoe and Elko where peak load reaches 1,800MW [5]. In the more densely populated southern region that services Las Vegas and the surrounding regions of Clark County, power is delivered to 960 thousand customers with a peak load of 5,600MW [5]. In this region, the underground distribution system was primarily built around a network of 3-phase switches feeding single-phase loop systems using 1/0 AWG, 15 kV cable. By comparison, the underground residential distribution system in the northern region was built primarily as a 25 kV system using 1/0 AWG cable.

B. Rising Failure Rate

While the power cables that made up the early underground distribution system were expected to last for 100 years, the industry's experience has fallen well short [4]. Testing found a rapid drop in AC breakdown strength of early-vintage cables and field experience revealed the onset of failures in as little as 10 to 20 years. Research identified water trees as the fundamental aging mechanism in the polyethylene insulation which are formed when ions concentrate around imperfections in the insulating polymer and in the presence of a strong AC electric field and produce micro voids [6]. Each clustering of micro voids is referred to as a water tree because of its appearance when cross sectioned and stained for viewing [7].

To support the population growth of the second half of the twentieth century, NVE built much of its electric power distribution infrastructure underground. On those systems, NV Energy experienced a rise in failures that lagged installation by 20 to 30 years. Using various reliability indices like those prescribed by the IEEE [8] along with other predictive modeling techniques, NV Energy forecast a failure rate in the late-1990's that would quickly exceed their capacity to repair and replace these cables through the application of the traditional '3-strike rule' (Figure 2). Deferring action would lead to a runaway system average interruption frequency index (SAIFI). Coupling this crisis with industry's shortage of lineman [9], the frequency of outages would lead to a corresponding increase in the system average interruption duration index (SAIDI).

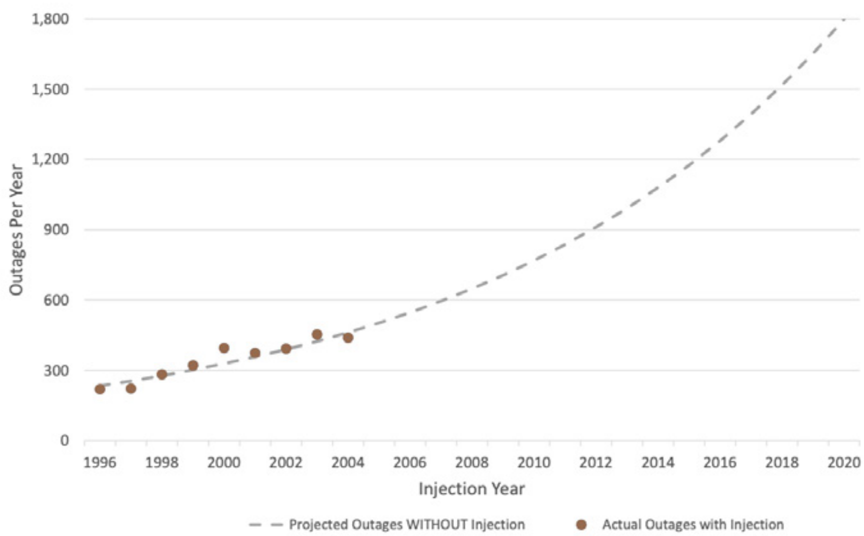

Figure 2: NV Energy's forecast of outages per year on 1/0 URD cable.

C. 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 coupled with new craftwork and accessories, brings the rejuvenated cable system to the same reliability standard to that achieved by new cable installation. The chemistry, process, and efficacy of cable rejuvenation have been well documented and summarized in literature [10]. To date, over 140 million feet of solid dielectric cable have been rejuvenated through silicone fluid injection by more than 350 utilities worldwide [11]. With a relative cost difference to replacement often around 50% and the ability to capitalize the program expense, utilities often find they are able to address more cable in less time with less impact to ratepayers through rejuvenation.

III. REJUVENATION PROGRAM

NV Energy considers itself a pioneer in the field of renewing underground cable without interruption in service to their customers [12]. As part of a broad cable reliability program initiated in the late 1990s, NV Energy began to pilot cable rejuvenation in 1998. After proving the merits of cable rejuvenation over the first several years, NV Energy scaled their program to address all eligible cables during the next 15 years. As the program nears completion, over 12 million feet of URD cable has been rejuvenated through silicone injection (Figure 3). This section will explore the evolution of the rejuvenation program through its three distinct phases; initiation, scaling, and completion.

A. Program Initiation (1998-2004

NV Energy's pilot rejuvenation program began in 1998 and during this initiation period, over 4 thousand segments, a total of over 1.5 million conductor feet, were rejuvenated (Figure 3). Annual injection footage targets started modestly but by the year 2000 grew into a year-round program that annually addressed an average of 250 thousand conductor feet. In those early days, priority was given to those segments with a documented history of failure and repeated service interruptions. The cables consequently tended to have multiple splices, higher instances of neutral corrosion and were from the earliest vintage URD cable installed on the system. Despite the history of poor performance on these cables prior to injection, NVE noticed a drastic reduction in failure rate with over 98% remaining in service after 20 years. This result gave NVE's management confidence to continue the program and by 2004 NVE began to scale the rejuvenation program's annual target so that the entire system could be addressed within the next 15 years.

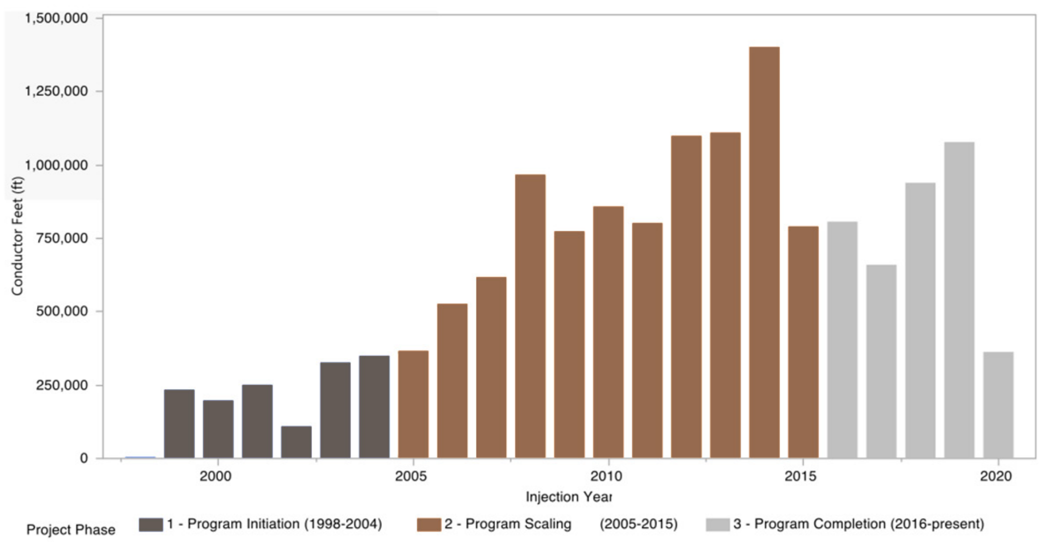

Figure 3: Annual Injection Footage by Year

B. Program Scaling (2005-2015)

Starting in 2005, NV Energy began to scale the rejuvenation program so that the entire underground residential distribution system could be addressed within 15 years. During this phase, loops and neighborhoods were selected primarily by cable vintage when manufacturing information was documented. In some cases, the age of the neighborhood was used to approximate cable vintage and cumulative years in service for the cable system. To achieve the increased footage targets that averaged over 750 thousand conductor feet per year, the number of injection crews were increased to between 3 and 4 crews working year round. Between 2005 and 2015, the program rejuvenated over 23 thousand segments with a cumulative footage of 9.4 million conductor feet. During 2014 alone, 1.3 million conductor feet of cable were rejuvenated.

C. Program Completion (2016-2020)

In 2016 NV Energy began the final stage of the rejuvenation program known as the completion phase that continues through the authoring of this paper in summer 2020. During this phase, the neighborhoods and segments not previously injected are addressed. These cables tended to require additional coordination and support. This includes lane blocks, drop and picks, residential and commercial outages, and structure replacements. For much of this work, 3 crews were employed through year-round work. To date, over 10 thousand segments and nearly 4 million conductor feet have been addressed during this final phase of the rejuvenation program.

D. By the Numbers

Over the rejuvenation program's 22 year duration, NV Energy has addressed more than 37 thousand segments with an injection rate above 80%. In total, over 30 thousand segments were injected and the breakdown of segment outcomes across the program's history can be seen in (Figure 4). This section will explore some of the reasons for this variation between the 3 phases of the rejuvenation program and demonstrate the benefits of scaling the rejuvenation program to get ahead in the failure curve.

Prior to starting the rejuvenation program, NV Energy outlined the threshold criteria that each cable must meet to qualify for injection. These pre-injection checks are built into the rejuvenation protocol to screen out segments with excess neutral corrosion, excess splices and blocked conductor among other criteria. Neutral corrosion and splice count are evaluated through a time domain reflectometer (TDR) test [10]. Neutral corrosion assessment is conducted per IEEE guide [13] which categorizes the level of neutral corrosion into the 4 categories shown in Figure 5. NV Energy established their threshold to inject only those segments with over 50% of the concentric neutral's original ampacity unless the segment is granted special consideration. Despite finding fewer than 3% of the segments to fall outside this threshold, variation is noted between the 3 phases of NVE's rejuvenation program (Figure 5). During program initiation when segments were prioritized based on past failure history, a higher instance of neutral corrosion was recorded. Further, during the completion phase a mere 1% of segments were found to have more than 25% loss of ampacity. This finding could be contributed to the age of the segments that tended to be manufactured in the 1990s and after the adoption of jacketed cable.

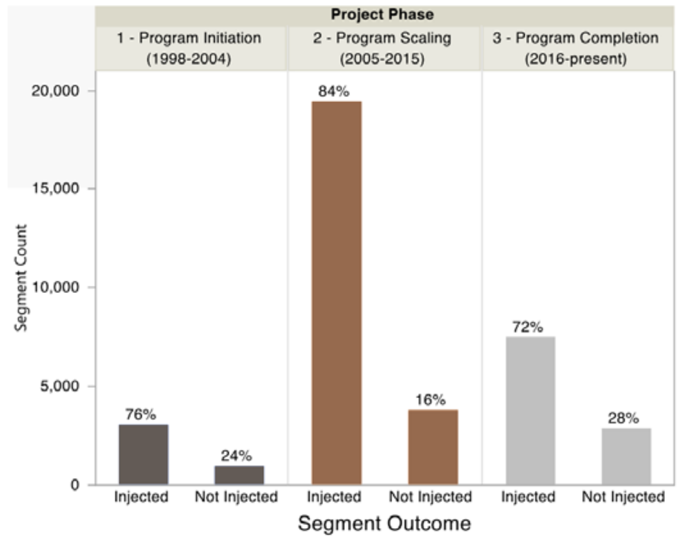

Figure 4: Segment outcome by segment count by project phase.

Splice count and location is also identified by TDR and has been discussed previously in literature [10]. During the initiation phase of the program, 40% of the segments were found to have 1 or more splices that doubled the rate observed during the remaining phases (Figure 6). This is primarily due to the selection method used by NVE, where segments with past failure history were prioritized. In the later stages, priority was given based primarily around cable vintage as NVE was able to get ahead of the failure curve and proceed to cables installed later in the 1980s and 1990s. Interestingly, segment length remains consistent across all 3 phases of the program and averaged 391ft.

The ability of the cable's conductor to pass fluid was also evaluated prior to starting injection as part of the rejuvenation program's protocol. The frequency in which segments failed this test remained fairly low through the first two phases of the rejuvenation program however, became the dominant factor during the completion phase. This was primarily due to strand-filled conductor adopted by NVE in the 1990s.

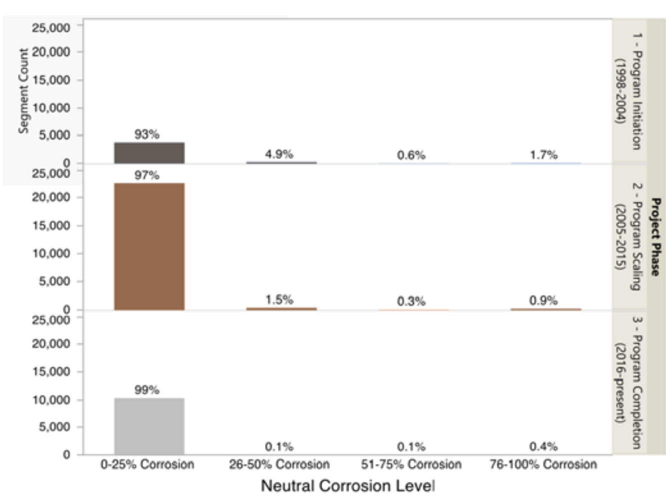

Figure 5: Neutral corrosion level by segment count by project phase.

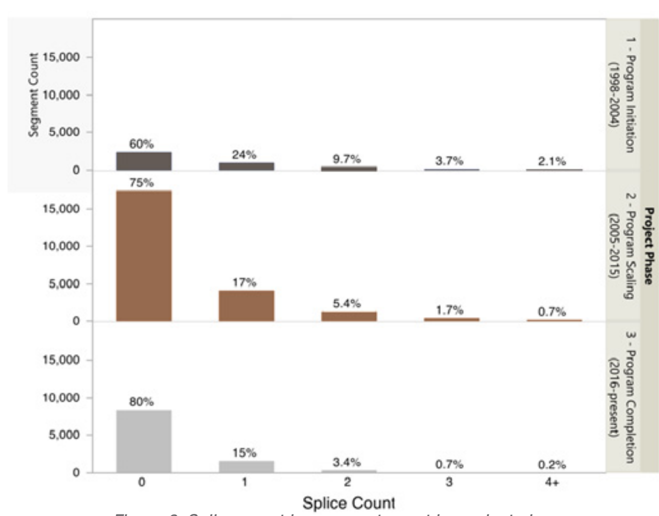

Figure 6: Splice count by segment count by project phase.

IV. MEASURING SUCCESS & PREDICTING THE FUTURE

Critical to the success of NV Energy's rejuvenation program is their ability to demonstrate its value to their investors. Tracking the annual number of outages recorded on their 1/0 AWG underground residential distribution system allows NVE to see the direct impact of their investment and serves as a comparison for their predictive model created using the conventional '3-strike rule' approach (Figure 7). After the annual number of outages follow the model closely throughout the first phase of the project, the data begins to reveal a drastic departure from the model beginning in 2008 after 19% of the segments had been rejuvenated. This trend continues through to the present and can be used to estimate outages mitigated. In 2019, the last full year that data is available, 1,300 outages were mitigated.

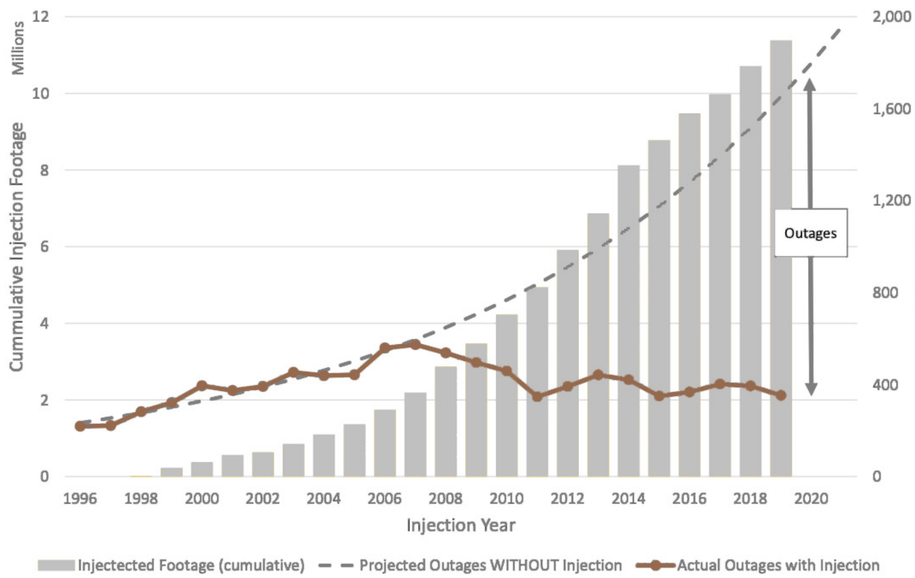

Figure 7: Actual outages per year compared to the 1990s predictive model using the conventional approach.

As is a commonly recommended practice for reporting failure data, the rejuvenated cable data reveals a failure rate of 1.21 outages per 100 miles per year [10]. Alternatively, when viewed as a percentage the data reveals a failure rate of 0.09% of injected cables per year. These data points have given NVE confidence in their ability to defer replacement for 25-30 years [14]. NVE estimates a deferred cost of over $800 million over the life of the program [14].

V. CONCLUSIONS

For the past 22 years, cable rejuvenation has played an integral role in NV Energy's (NVE) delivery of reliable electric power to its customer base of over 1.3 million homes and businesses in the United States' desert southwest. Since the start of the program in 1998, more than 12 million conductor feet of their underground residential distribution (URD) system have been successfully rejuvenated through silicone injection. When NVE compares their annual outages against the predictive models they created in the late 1990s to justify the initiation of the program, an annual reduction of 1,300 outages per year is realized. Through the rejuvenation of their underground distribution system, NVE has deferred the need for replacement by more than 25 years and saved their rate payers over $800 million.

VI. REFERENCES

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