An Ironclad Solution:

Building a Resilient Transmission Line to Last a Lifetime

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***Abstract*— Electric utilities are in the business of providing cost effective, reliable electric power to customers and with that, comes the responsibility of keeping the lights on. Reliable power is a requirement in today's world. According to the U.S Energy Information Administration (EIA), on average, U.S. electricity customers experienced just over eight hours of electric power interruptions in 2020, the most since EIA began collecting electricity reliability data in 2013. The average U.S. electricity customer experienced nearly twenty more minutes of power interruptions in 2020 than in 2017, the year with second-longest duration of interruptions in EIA records [1]. The true cost of power outages is difficult to determine. A major weather event can easily cost utilities millions of dollars to restore power. According to a report from the PEW Charitable Trusts, the U.S. Department of Energy estimates power outages are costing American businesses around $150 billion per year, and while the rise in the number and intensity of weather events is a major contributing factor to power outages, there is no doubt that aging, antiquated power infrastructure also contributes to the increased number of outages [2]. The weather cannot be controlled, but aging, antiquated power infrastructure can be addressed. The paper presents in detail three Central Virginia Electric Power Cooperative (CVEC) transmission line projects (46 kV, 115 kV, and 138 kV) designed to last a lifetime and provide the resiliency needed using ductile iron poles, while overcoming some unique and difficult obstacles of construction.**

***Keywords*—Reliable electric power, resiliency, transmission line, U.S. Energy Information Administration (EIA)**

I. Introduction

Central Virginia Electric Cooperative is a member-owned, not-for-profit electric utility headquartered in Colleen, Virginia nestled next to the Blue Ridge mountains. Created by the members to provide electric service where it was previously unavailable, CVEC has been improving the quality of life since 1937.

CVEC serves approximately 38,800 active residential, agricultural, commercial and industrial member accounts in the rural portions of 14 Virginia counties with energy requirements of approximately 782,000 MWH for all rate classes. Commercial and industrial customers account for approximately 33 percent of the system's energy requirements. The projected normal 2024 system peak demand is 252.7 MW while the extreme weather peak demand is 324.7 MW.

CVEC has 36 distribution substation/metering points, just over 4,730 miles of distribution overhead and underground lines and 68 miles total of transmission lines consisting of 40.4 miles of 115 KV and 27.6 miles of 46 KV transmission lines, which supply nine distribution substations.

The Midway delivery point supplies 115 KV to the Martin's Store Substation through an 11-mile radial tap, where it is stepped down to 46 KV to serve Peggy's Pinch, Wintergreen, and Laurel Springs Substations through an 8.2-mile 46 kV transmission line. These three substations collectively serve the Wintergreen Resort, a 30 MW seasonal load.

The Gladstone delivery point supplies 46 kV to the Tower Hill Substation through a 6.5-mile radial tap.

Columbia Breaker Station is a 115 KV delivery point that serves the Shannon Hill, Ferncliff, Henson's Store, and Zion substations through a 26-mile radial tap. Collectively, these substations serve over 6,000 customers along the developing Interstate 64 corridor between Richmond and Charlottesville. In just ten years, the load on this delivery point grew from 24 MW to 40 MW. CVEC has completed an 11.3-mile extension of this line to Cash's Corner Substation to complete a dual-source transmission network that can serve the load from Cash's Corner and/or Columbia.

The Centenary Substation is served by a 5-mile radial 46 kV transmission tap.

CVEC is one of only a few other electric co-ops across the nation that has earned the prestigious Four-Star Cooperative recognition in the Touchstone Energy Service Excellence Program.

For 80 years, CVEC has been transforming lives and providing reliable delivery of affordable energy to its member owners.

II. Electric Utility Infrastructure in Need

It is easy to underestimate the seriousness of the aging electric transmission infrastructure in the Unite States. Over a quarter of the grid is fifty years old or older and the average age is forty years old. It is estimated that over the next three decades, nearly a hundred and forty thousand miles of transmission line will need to be replaced. To simply upgrade this infrastructure and maintain the status quo would require an investment of more than seven hundred billion dollars as calculated by Oliver Wyman Energy [3].

As reported in the Department of Energy (DOE) Quadrennial Technology Review 2015, 70% of power transformers are 25 years or older, 60% of circuit breakers are 30 years or older, and 70% of transmission lines are 25 years or older. The age of these components degrades their ability to withstand physical stresses and can result in higher failure rates. Failure of key grid components can lead to widespread outages and long recovery times. This situation represents a high loss of revenue for utility companies and for customers who require power to do business and provide services.

Consequently, appropriate maintenance of power system equipment is of significant importance. For instance, a single power transformer that is damaged can temporarily disrupt power to thousands of homes and businesses, and it can take up to two years to manufacture a replacement. Moreover, power outages from weather-related events and other causes are estimated to cost the United States $28–$169 billion annually.

In 2011, the American Society of Civil Engineers (ASCE) estimated an average expenditure of $27.5 billion annually for electric transmission and distribution investments in the United States, and they predict a cumulative investment shortfall of $331 billion by 2040. The average annual expenditures estimated by ASCE are consistent with data reported by the Edison Electric Institute in 2012.

Based on these estimates, approximately $1.1 trillion will be needed to replace, expand, and upgrade the U.S. electric grid through 2040. The total amount needed includes the net investment (investments in addition to those made for reliability or replacement purposes) of $338–$476 billion over a 20-year period, estimated by the Electric Power Research Institute to realize the full value of the "smart grid."

The investment cycle needed to replace, upgrade, and expand the U.S. transmission and distribution systems has already begun, with annual spending increasing from $28 billion in 2010 to $44 billion in 2013. The procurement of transmission and distribution goods and services today centers on refurbishment and upgrades of existing facilities and field assets, increasing the intelligence of older passive analog equipment to gain visibility to grid conditions [4].

CVEC's infrastructure is similar to many other cooperatives and other electric utilities, with some facilities approaching 50+ years of age.

III. Recognizing the Need for Change

The need to invest in transmission facilities and infrastructure will increase over time and can be a significant cost. Transmission projects require planning, right-of-way procurement and clearing, permitting, local, county, state, and sometimes federal approvals. In addition, there are public meetings and construction challenges. The process is very time-consuming.

There is a definite need to invest in the transmission system, but it is not an emergency. It is an opportunity to make a change and modernize the system to provide better reliability, more resiliency, improved efficiency, and provide for the future. Electric cooperatives need to reimagine the transmission system and not just replace existing facilities.

IV. Design Considerations and Characteristics

In an Energy Department Notice published in the Federal Register, modernizing, hardening, and expanding the grid will enhance the resilience of our entire electric system, and ensure that electricity is available to customers when it is needed most. Aging infrastructure leaves the grid increasingly vulnerable to attacks. The increasing frequency of extreme weather events is leading to energy supply disruptions that threaten the economy, put public health and safety at risk, and can devastate affected communities all over the country.

Investment in transmission infrastructure can help protect the grid against supply disruptions due to physical and cyber-attacks or climate-induced extreme weather, minimize the impact of supply disruptions when they happen, and restore electricity more quickly when outages do occur [5].

Three comprehensive design characteristics CVEC is implementing into the overall design of their transmission facilities and other infrastructure projects are reliability, resilience, and efficiency.

The reliability of the CVEC electric power system is critical to the economic strength and the well-being of our members. Reliability is simply ensuring the availability of electric service delivery when needed.

Resiliency is the ability to withstand and recover rapidly or the speed and ability to bounce back after disruptions. This is achieved through preparation. As Clint Eastwood, one of my favorite actors, stated in the movie Heartbreak Ridge, you must "Improvise, Adapt and Overcome!" That is resiliency, plain and simple.

Efficiency of the transmission system is to enhance or optimize the transmission system by utilizing new technologies. Technologies and tools such as improved advanced system monitoring to gather additional data, Supervisory Control and Data Acquisition (SCADA) utilization and controls, and tools for enhanced operations will assist to modernize the electric transmission system infrastructure and provide a greater degree of reliability and security.

Substation transformers typically are designed for thirty years life and transmission lines are typically designed for fifty years, although both transformers and transmission lines can be frequently found exceeding these numbers significantly.

Substation transformers can be found still in operation after fifty years or more and transmission lines still in operation between fifty and seventy-five years. Credit for the long life of the transmission infrastructure can be given to precise engineering, standards, and good maintenance. Nevertheless, the aging transmission infrastructure is long overdue for an upgrade and major renovation.

Transmission conductors typically can last a lifetime or more. The transmission structures and the insulators are more likely to fail before the conductors do.

Insulators are composed of either porcelain, glass, or polymer. While porcelain and glass may still be used in certain applications, the use of porcelain and glass material continued to have challenges. Polymer insulators were first introduced in the 1960s, but they now lead as the largest segment of the industry compared to glass or porcelain and are the preferred choice of most utilities for many applications.

CVEC prefers to and will use polymer insulators in most applications.

Transmission structures mainly consists of wood, steel (tubular and multi-sided), concrete (pre-stressed spun and static cast), ductile iron, composite, or laminated wood. This paper is not meant to cover all the pros and cons of each material in detail, but rather the process, choices, and reasons made by CVEC with the three transmission line projects in this paper. There are many sources on the internet for those of you that want more information.

This paper will make some very basic comparisons between wood, steel, concrete and ductile iron only. Statistics vary depending on the source, sometimes significant.

The life span of wood poles is 25 - 40 years and may begin to decay within that span, although there are some poles that last longer depending on the environmental conditions. They are also subject to woodpecker and insect damage at most any time. They have low reliability during extreme weather events. Wood poles require regular inspections to determine structural integrity and periodic preventive maintenance to prevent decay.

Steel poles are estimated to have a service life of 50-80 years and are completely resistant to rot, insects, and woodpeckers. They are often galvanized but may still exhibit corrosion. They are most susceptible to degradation at the ground line and below grade, especially without a preventive coating. They are reliable during extreme weather events. For equivalent pole size and class, steel poles are lighter than wood, concrete and ductile iron poles.

Static cast concrete poles have a service life of 40 – 60 years depending on conditions, while pre-stressed spun concrete poles claim a service life of 75+ years. They are resistant to rot, insects, and woodpeckers. The static cast concrete poles are susceptible to freeze-thaw effects, rust, and spalling where the pre-stressed spun concrete poles are not. The pre-stressed spun concrete pole is reliable and assists with storm hardening initiatives where the static cast concrete pole is not so much. Both types of the concrete poles are heavier than an equivalent size and class wood, steel, and ductile iron pole.

Ductile iron poles have a service life of 75+ years and similar to steel and concrete, are completely resistant to rot, insects, and woodpeckers. Bare ductile iron will not slowly rust away and will last longer than weathering steel. Ductile iron, or any other metal product, is most exposed for material degradation at the ground line or below grade. For maximum embed protection, the ductile iron poles are coated with a ceramic epoxy coating called Permasafe, patented in 1979 for corrosive environments with an excellent record of performance.

Ductile iron poles are exceptional for storm hardening and extreme weather events as they are designed to withstand 142% of class load before ultimate failure. The conductors will come down before the pole fails. A 50’ class 1 pole was tested to 173% of class 1 load (5.1 kips) with 103-inch deflection prior to failure. Below is a picture of the deflection test and test results performed.

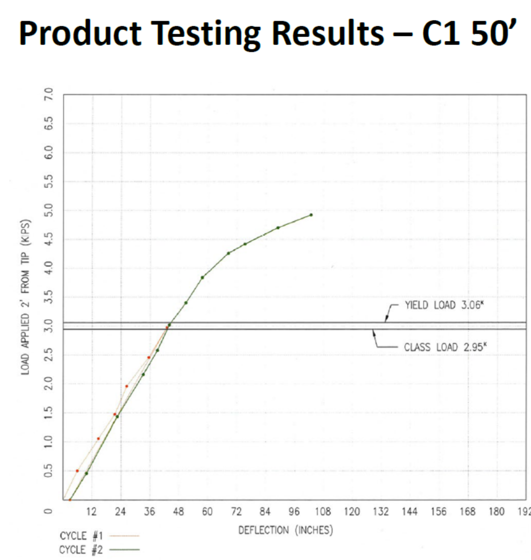


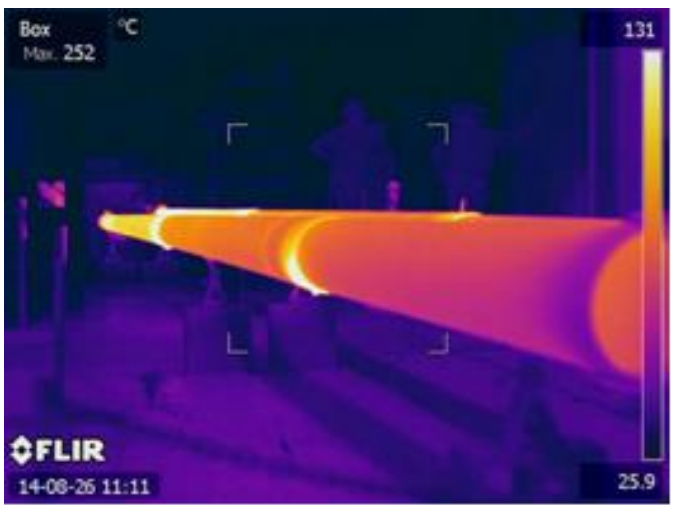
FIGURE 2
TEST RESULTS FOR 50/1

Ductile iron poles are approximately 45% lighter than wood, much lighter than concrete, and approximately 25% heavier than steel for an equivalent size and class of pole. The heaviest ductile iron pole is a 110’ H-3, weighing 9,806 pounds. Installation can be performed using standard distribution or Transmission equipment, depending on the size of the pole.

Ductile iron poles are considered “Green” as they are made of 96% recycled cars, appliances, and other metals. They are 100% recyclable and made in the USA. Poles up to 70’ are shipped as a single poles and poles over 70’ are shipped in sections depending on the length. Field installation is easy and jacking kits are provided.

Ductile iron poles can be pre-drilled up to 20 through-hole penetrations included in the price of the pole and if more holes are required, they can be pre-drilled to specifications for a nominal charge. If field drilling is required, they are much easier to drill than steel and concrete using a carbide-tipped hole saw bit or a step type bit.

The properties of ductile iron poles are a yield strength of 42,000 psi, ultimate strength of 62,000 psi, modulus of elasticity of 24,000 ksi, and a minimum elongation of 10%. Conductivity testing was performed by American Electric Power Company Inc. (AEP)on a 45’ ductile iron pole and resulted in approximately 2,000 micro-ohms impedance – equivalent to the resistance of a 4/0 copper ground. The pole is self-grounded; therefore, no copper ground wire is required.



Induron Coatings, Inc. performed an ASTM B-117/G-1 weight loss comparison of COR-TEN steel versus ductile iron in 2016. Samples of uncoated COR-TEN steel (sometimes known as “weathering” steel) and ductile iron were tested side by side to determine corrosion loss in accordance with the ASTM B-117 Standard Practice of Operating Salt Spray (Fog). Each bare sample was initially and subsequently weighed on certified scales. As the test progressed in hours, the samples were periodically removed from the salt fog chamber and gently brushed to remove loose rust particles (non-metallic bristle cleaning in accordance with ASTM G-1). Weight losses were recorded. The test was terminated after 5 weeks of study.

The end of the test showed a significant difference in weight loss from rust corrosion:

COR-TEN STEEL: 1.7% of total sample weight loss

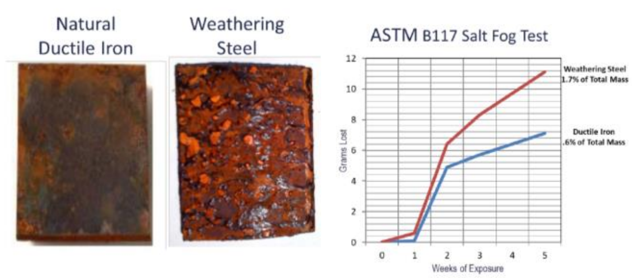
DUCTILE IRON: 0.60% of total sample weight loss

The totals indicate that COR-TEN steel corroded at over twice the rate of ductile iron in the ASTM B-117/G-1 testing [6].

Salt Spray Test — **Corrosion**
Material loss due to corrosion

	notes:	Date	Days	Cor-Ten	Loss	Ductile Iron	Loss
	Start	14-Sep	0 day	650.8 g		1179.7 g	
	w/ rust	21-Sep	1 wk	656.1 g		1186.8 g	
	cleaned			650.2 g	**0.6 g**	1179.6 g	**0.1 g**
	w/ rust	29-Sep	2 wks	655.3 g		1186.4 g	
	cleaned			644.4 g	**6.4 g (0.98 %)**	1175 g	**4.9 g (0.4 %)**
	w/ rust	5-Oct	3 wks	651.9 g		1184.3 g	
	cleaned			642.5 g	**8.3 g (1.27%)**	1174 g	**5.7 g (0.48 %)**
	w/ rust	19-Oct	5 wks	649 g		1182.7 g	
Total:	cleaned			639.7g	**11.1 g (1.71 %)**	1182.7 g	**7.1 g (0.60 %)**

Corrosion Resistance



Ductile iron poles offer the physical strength of steel with the corrosion resistance of cast iron, creating a versatile pole that has benefits of both.

The CVEC owned transmission system consists of 46 kV, 115 kV, and 138 kV. By 2025, CVEC will own a very small portion of 230 kV.

Most CVEC owned transmission structures are single wood pole or wood H-frame construction. CVEC has some steel and composite transmission structures with more steel than composite structures.

CVEC went through a bid process in early 2021 to evaluate the cost and lead time associated with a 1.2-mile 46 kV transmission line project. The RFP was sent to seven manufacturers of tubular steel or ductile iron structures. Research and evaluation of concrete poles was performed, but due to extremely rough terrain and accessibility issues, concrete poles were not considered in the bid process. Wood poles were also not considered due the terrain and the desire to have a resilient transmission line that would last more than a lifetime. All seven manufacturers provided a bid for the project.

At the time of bid opening, the ductile iron pole bid was 37% less cost than the second lowest bid and almost 67% less than the highest bid. In addition, the ductile iron poles had a lead time of 6 -8 weeks after drawing approval which was almost one-half the next best lead time at 14 weeks.

Based on the bid results, CVEC chose to use ductile iron poles for the construction of the three projects presented in this paper.

In addition to utilizing ductile iron poles and polymer insulators for the transmission line projects, CVEC is implementing other technologies to enhance and improve reliability, resiliency, and efficiency of the transmission line system.

ANSI C29.12 covers composite-suspension insulators made of a fiberglass-reinforced resin rod core, polymer material weathersheds and metal end fittings intended for use on overhead transmission lines for electric power systems, 70 kV and above and ANSI C29.17 covers line post insulators. High voltages can result in unwanted noise (radio-interference voltage or RIV) and corona. To minimize the effects of corona, corona rings are installed to one or both ends of the insulator (attached to the end fittings). Typically, corona rings are necessary for 230 kV and above. However, the Electric Power Research Institute (EPRI) and Swedish Transmission Research Institute (STRI) have published findings that show that electric stress control is also important in preventing water droplet corona at lower voltages. They recommend 3-D modeling to demonstrate that the electric field gradient is below 0.42 kV/mm for more than 10mm on the rubber surfaces. The recommendation is more stringent than ANSI's requirement. Inspections of in-service polymer insulators from all manufacturers, including those that have failed due to corona damage, have validated the EPRI and STRI recommendations. EPRI recently began recommending the installation of corona rings at voltages as low as 115 kV for some applications [7].

CVEC has implemented installing corona rings on new transmission line projects 115 kV and above.

CVEC has completed the installation of fiber for the entire CVEC system, including the availability of fiber to the home for every member. This is enabling the use of technologies with more reliable and faster communications that were not able to be utilized before. CVEC is implementing SCADA controlled fault indicators on existing and new transmission and distribution lines. This will enable CVEC to be more resilient, respond quicker, and improve overall reliability.

In addition, CVEC is implementing SCADA controlled motor-operated air-break (MOAB) switches on transmission lines. This will enable system operators to sectionalize a line fault and restore power to others more quickly. CVEC is working toward implementation of fault location, isolation, and service restoration (FLISR) on the Cash's Corner – Columbia Breaker 115 kV transmission line. This line has a dual feed from the power provider at Cash's Corner and Columbia Breaker with four substations between them and numerous transmission line switches that are being converted to SCADA controlled MOABs.

CVEC has 100+' transmission line rights-of-way for all transmission lines owned by CVEC. Right-of-way maintenance is a challenge. CVEC utilizes drones to inspect the rights-of-way, transmission line, and structures. CVEC is beginning to implement the use of satellite imagery to assist in right-of-way management.

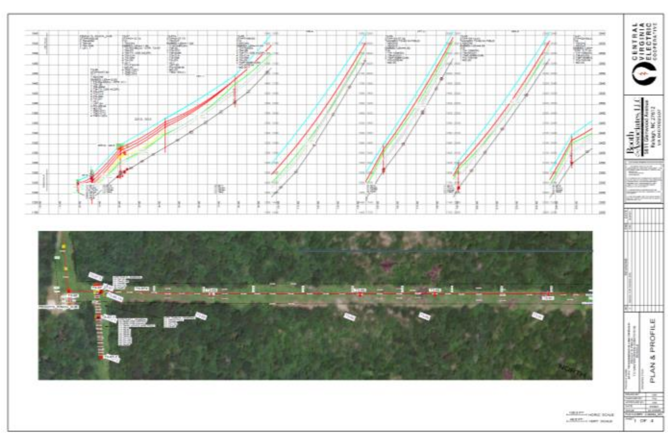
V. Peggy's Pinch – Winteregreen 46 kV Transmission Line

Peggy's Pinch – Wintergreen 46 kV transmission line before replacement:

- Originally constructed in 1974 – 48 years old
- 1.2 miles ascending Wintergreen Mountain.
- 20 structures total.
- Approximately 40 degrees grade ascending the mountain 3054', almost half of the total distance.
- 8 structures ascending the steep grade all in solid rock.
- Wood H-frame construction with wood cross-arms scaling the mountain.
- Single wood pole construction on top of mountain.
- Porcelain insulators.
- One gang-operated air-break (GOAB) switch.
- Poles and cross-arms were deteriorating and had woodpecker damage.
- Existing conductor was 336 ACSR.

Peggy's Pinch – Wintergreen 46 kV transmission line after replacement:

- Replaced existing transmission line in 2022.
- Existing transmission line was de-energized and removed. Wintergreen Resort was backfed from Laurel Springs substation.
- Due to the steep grade and inaccessibility to the area with trucks, helicopters were utilized to install the poles and line ascending the mountain.
- Ductile iron poles utilized.
- 100% Rock (every pole).
- Primarily single pole vertical construction.
- 5 ductile iron H-frame structures with steel cross-arms
- Polymer insulators utilized.
- One SCADA controlled, fiber connected, MOAB installed on the transmission line to Wintergreen, and one installed on the Laurel Springs tap.
- SCADA controlled, fiber connected, fault indicators installed on the transmission line to Wintergreen and one on the Laurel Springs tap.
- Longest span is 748'.
- Utilized pole setting compound to stabilize the pole in rock ascending the mountain.
- Utilized the ductile iron pole in conjunction with a grounding compound as the ground in rock ascending the mountain.
- Installed fiber on poles to Wintergreen substation.
- Installed new 336 ACSR "Linnet" conductor.



VI. Midway – Martin’s Store 115 kV Transmission Line Phase I

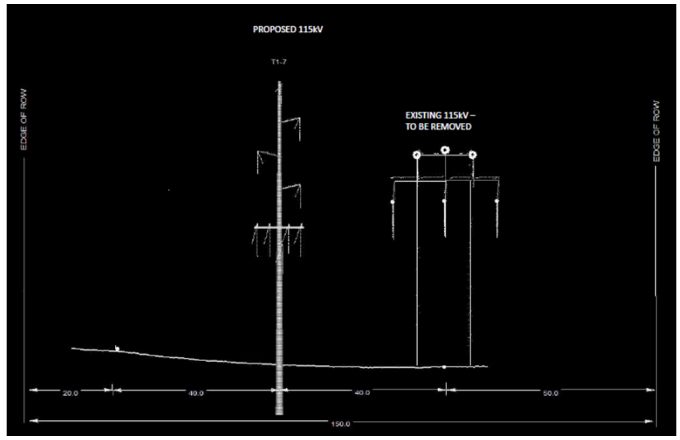
Midway – Martin’s Store 115 kV transmission line before replacement:

- Serves 6.750 members through four substations.
- Radial feed.
- Originally constructed in 1984 – 39 years old.
- 3.4 miles in Phase I of 11 miles total
- 48 structures total.
- Rough, hilly, cross-country terrain.
- Wood H-frame construction with wood cross-arms.
- Porcelain insulators.
- Poles and cross-arms were deteriorating and had significant woodpecker damage.
- Cross-arms were rotting from inside out.
- Existing conductor was 336 ACSR.
- Several spans nearing 1000’.
- 150’ right-of-way.

Midway – Martin’s Store 115 kV transmission line after replacement:

- Replaced existing transmission line in 2022.
- Existing 115 kV transmission line had to remain energized. No back feed capability for Martin’s Store substation.
- 150’ right-of-way allowed the new transmission line to be constructed alongside of existing transmission line.
- Rock on approximately 15% of the poles.
- Utilized ductile iron poles.
- Single pole vertical construction
- Polymer insulators utilized.
- SCADA controlled, fiber connected, fault indicators utilized.
- Installed new 336 ACSR “Linnet” conductors.
- Installed three-phase 25 kV distribution under build using 336 ACSR “Merlin” conductor.
- SCADA controlled, fiber connected, reclosers on distribution line.
- Fiberglass cross-arms used for distribution.

Typical Cross Section



VII. Gladstone – Tower Hill 138 kV Transmission Line

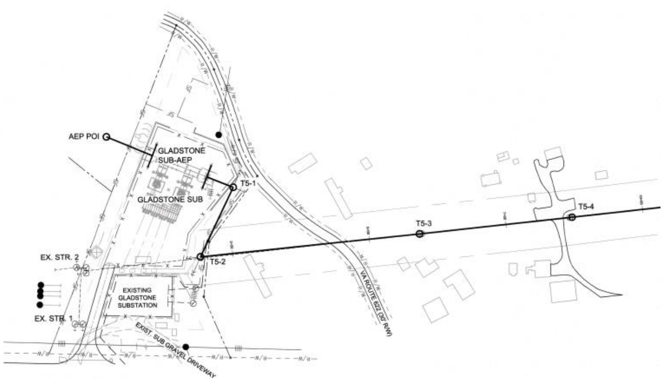
Gladstone – Tower Hill 46 kV transmission line before replacement:

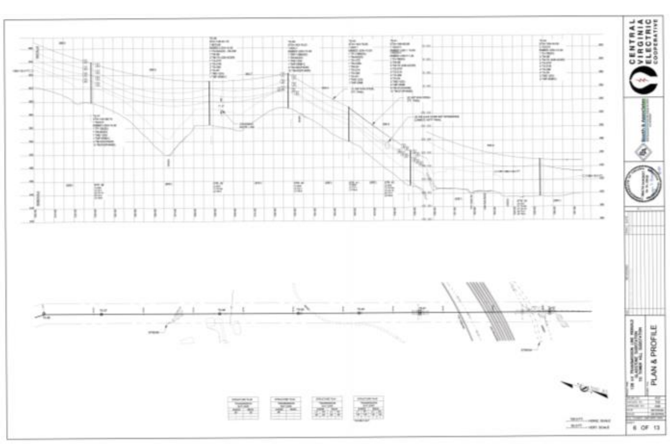
- 46 kV transmission line that serves two substations.
- Radial feed.
- Power supplier supplies 46 kV to Gladstone substation.
- Originally constructed in 1964 – 59 years old.
- 6.5 miles.
- 88 structures total.
- Rough, hilly, cross-country terrain and crosses the James River.
- Primarily single pole construction.
- Porcelain insulators.
- Poles, most are original structures, deteriorating, and had significant woodpecker damage.
- Existing conductor was 3/0 ACSR.
- 100’ right-of-way

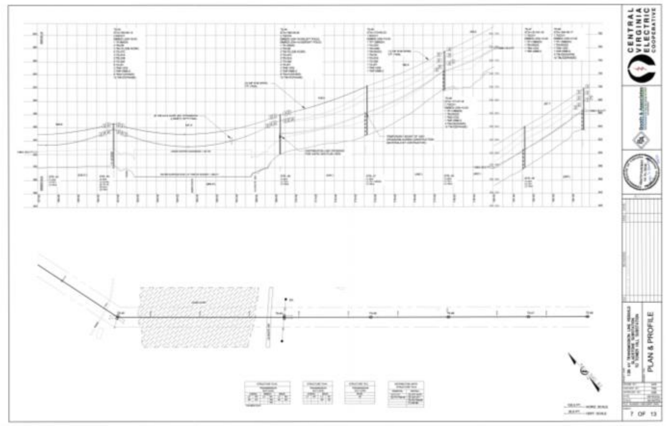
Gladstone – Tower Hill 46 kV transmission line after replacement:

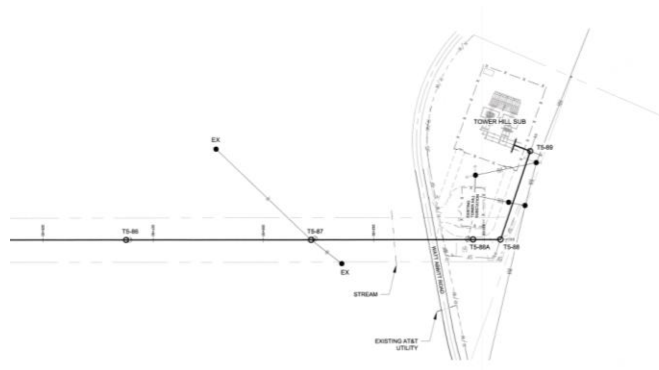
- Replacing existing transmission line in 2023.
- A three-phase 336 ACSR distribution tap was constructed from an existing Gladstone 12 kV 336 ACSR distribution circuit to tie into the existing 46 kV transmission line at midpoint (James River crossing), approximately 3.2 miles from Gladstone substation.
- The 46 kV transmission line was de-energized between Gladstone substation and the tie point at the James River.
- The 46 kV transmission line from the tie point at the James River to the Tower Hill substation was converted (three-phase with static wire as neutral) to operate at 12 kV, providing a new feed to the Tower Hill substation.

- Tower Hill feeders were balanced to minimize the neutral current flowing in the static wire (less than 5 amps).
- The transformers at Tower Hill substation were taken out of service.
- A set of regulators were installed on the Gladstone circuit to provide voltage support to the Tower Hill feeders.
- The existing 46 kV transmission line, now operated at 12 kV, will remain energized during construction. No back feed capability for Tower Hill substation.
- Power supplier is converting the existing 46 kV delivery voltage to 138 kV, requiring CVEC to convert to 138 kV for the new transmission line.
- Rock is estimated for 25% of the poles.
- Utilizing ductile iron poles.
- Single pole vertical construction
- Polymer insulators utilized.
- Corona rings implemented.
- SCADA controlled, fiber connected, fault indicators utilized.
- Installed new 336 ACSR "Linnet" conductors.
- Span crossing the James River is 841.9'.
- The existing Gladstone and Tower Hill substations are being completely rebuilt to 138 kV on new adjacent substation plots with dual 138 kV transformers and breakers in each substation.









VIII. SUMMARY

To summarize, the system infrastructure is aging for all utilities and CVEC recognizes the need for change. CVEC is implementing changes and technologies into the design of transmission and other projects to improve reliability, operations efficiency, and resilience to last a lifetime and beyond. Some of the changes and technologies are as follows:

- Utilizing polymer insulators where possible.
- Implementing Corona rings on transmission lines 115 kV and above.
- Utilizing ductile iron poles for transmission lines.
- Implementing and utilizing fiber connectivity.
- Implementing fiber connected SCADA controlled devices, such as, fault indicators, MOABS, reclosers, and other devices.
- Procuring more than sufficient rights-of-way.
- Utilizing drone technology for inspections and rights-of-way management.
- Implementing use of satellite imagery to assist in right-of-way management.
- Moving forward to implement FLISR on the transmission system and subsequently on distribution.

Within the next five years, CVEC is currently planning to complete three addition transmission line projects totaling approximately 20 miles and will implement the changes and technologies listed above, along with any new technologies that will improve reliability, operations efficiency, and resilience.

Through access to power and connectivity, communities can have a higher quality of life. CVEC believe this fundamental connection in our ever-changing world, transforms lives.

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