Utility Wires Investments

Resilience Investment Guide

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GRID DEPLOYMENT OFFICE

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Acknowledgments

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Resilience Investment Strategy Overview

This resilience investment guide is one of six guides that describes the costs and benefits of a range of projects that are eligible under the Grid Resilience State and Tribal Formula Grant program and the Grid Resilience Utility Industry Grant program as described in Section 40101 of the Bipartisan Infrastructure Law (BIL). These two U.S. Department of Energy (DOE) grant programs are designed to enhance electric grid resilience against extreme weather, wildfire, and other natural disasters and are intended for states; federally recognized Indian tribes, including Alaska Native Village and Regional Corporations; U.S. territories; electric grid operators; electricity storage operators; electricity generators; transmission owners or operators; distribution providers; and fuel suppliers.

This guide focuses on grid investments that enhance the performance and resilience attributes of electric utility wires and cables. These measures include technologies that help with managing line tension, preventing excess sag of lines that may lead to conductor contact with objects, managing the position and organization of lines and keeping them out of the way of anticipated hazards, protecting lines with strengthened materials and inspecting and managing lines across the system. There are several strategies available for reinforcing wires, including:

- **Line management and inspections:** The initial phase involves inspections of transmission and distribution electric lines, particularly in high-risk regions. Mandatory inspections typically encompass thorough assessments of electrical lines and equipment, alongside routine patrol inspections. However, utilities operating in regions with elevated risk levels may choose to employ more extensive and enhanced inspection methods that extend beyond the minimum requirements mandated by regulations. These techniques, such as infrared assessments, corona scanning, and high-definition imagery acquisition, can detect defects and abnormalities that may not be visible during mandatory inspections [1].
- **Covered conductors over bare cables:** Covered conductors are equipped with an external polymer sheath to prevent accidental contact with other conductors and grounded objects, like tree branches. The composition and layering vary with voltage ratings, and multi-layer options provide higher protection against conductor-to-conductor and conductor-to-ground contact and have higher impulse strength, often featuring a semiconducting conductor shield. Covered conductors over bare conductors can be applied either overhead or underground and are a mature technology that has been commonly used for distribution system hardening since the 1970s [2, 3].
- **Reconductoring with high-temperature low-sag conductors:** Reconductoring with high-temperature low-sag conductors involves replacing existing overhead high-voltage transmission lines with new advanced conductors like Aluminum Conductor Composite Reinforced (ACCR), Aluminum Conductor Composite Core (ACCC), and Aluminum Conductor Carbon Fiber Reinforced (ACFR). These conductors offer advantages such as reduced losses, increased current-carrying capacity, lower weight, and minimal sag at high temperatures. This not only addresses thermal limits but also enhances line efficiency,

extends length between structures, resists cyclic load fatigue, and maintains self-dampening characteristics [4, 5].

- **Spacer cables:** Despite the protections provided by covered conductors, the network remains susceptible to electromagnetic interference, atmospheric discharges, and induced voltages, which can cause high voltage surges and insulation failures [6]. To mitigate these risks, the spacer cable system is employed. This system uses diamond-shaped spacers to support covered conductors in a spaced bundle configuration on a high-strength messenger wire, installed at intervals of 30 feet (see Figure 1 below). In this design, the poles are the strongest components, followed by the messenger wire, with the specialized attachment brackets being the least strong. This ensures that if an impact load affects the phase conductors or poles, the system remains intact, but the attachment of the bracket to the pole "fails," allowing for quick repairs [7].
- **Breakaway service connector:** A breakaway service connector is designed to automatically disconnect overhead service cables, preventing damage to structures or equipment when the attached power line faces falling debris [8]. This proactive measure, tested by groups like ConEdison and EPRI, reduces the risk of chain events caused by falling trees or heavy branches, averting potential scenarios of nearby pole toppling and cascading power line failures [9,10].

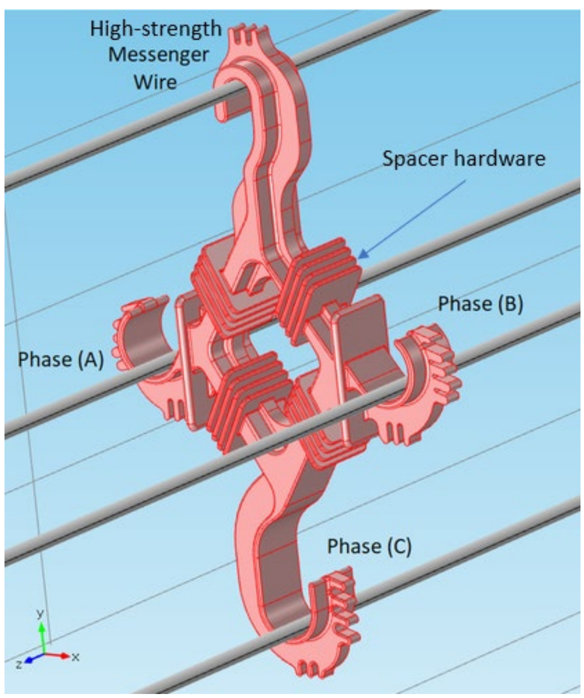

Figure 1. Covered conductors supported by a spacer cable (Source: adapted from [11]).

Strengthens grid reliability and resilience by:

- Preventing initial outages
- Preventing cascading outages

Improves performance against these hazards:

- Vegetation
- Tornado
- Thunderstorm
- Hurricane
- Derecho
- Wildfire
- Ice/Snowstorm
- Equipment Failure
- Extreme Heat

Advantages

Wire investments have been considered a cost-effective measure for mitigating power delivery disruptions compared to other options and have therefore been widely adopted by utilities. Overhead system hardening can be completed more quickly than undergrounding or relocating power lines, leveraging existing rights-of-way and easements [10].

Durable coatings on conductors reduce flashover risks from wildlife or trees and enhance system reliability and public safety. Furthermore, covered conductors and reconductoring often entail replacing bare or existing conductors with higher-gauge wires, thus increasing the capacity of lines [11]. Spacer cables with insulated conductors and a messenger mitigate power outages by minimizing fault currents and protecting against tree-related damage, ensuring uninterrupted service even in severe conditions [6, 13]. Breakaway service connectors not only safeguard distribution wires but also substantially reduce downtime during outages, enhancing the overall resilience of the electrical distribution system [9].

Refer to Table 1 below for a summary of reviews on the effectiveness of wire investment strategies.

Table 1. Summary of the effectiveness of wire investment strategies

Utility (organization)	Investment Type	Period	Impact
Pacific Gas & Electric (PG&E)	Covered conductors	2023	Mitigate risks of fire ignition by 60% to 90% [14]
Finnish Electricity Association Sener	Covered conductors	Historic up to 2003	Automatic reclosing events decreased by two-thirds as covered conductor lines increased from 10% to 50% [15]
Utilities in Taiwan	Covered conductors	Historic up to 2005	SAIFI decreased by 75% and SAIDI decreased by 86% as covered conductor percentages increased from 0% to 55% [16]
Eversource Energy	Covered conductors	2008 to 2015	Two-thirds reduction in storm outage event rate per mile compared to bare conductors [17]
Duke Energy	Covered conductors	2012 to 2014	70% of tree-caused outage events resulted in no damage to circuits with covered conductors [17]
Xcel Energy	Covered conductors	2007 to 2011	42% of tree-caused outage events resulted in no damage to circuits with covered conductors [17]
Southern California Edison (SCE)	Covered conductors	2019 to 2022	98% reduction in risk of wildfire ignition [18, 19]
PacificCorp	Spacer cables	2022	90% reduction in tree-caused customer interruptions [13]
Electric Power Research Institute (EPRI)	Spacer cables	2015	While substantial utility data on performance is lacking, covered conductors are anticipated to offer similar benefits to covered conductors. These benefits include a potential 50% reduction in tree-caused outages, a 32% decrease in overall outage events, and an 8% decline in damage rates [17].
EPRI	Breakaway service connector	2021	Reduce restoration times from 36 hours to 3 hours [20]

Disadvantages

There are two primary drawbacks to these approaches. First, while insulation for wires – particularly in the form of covered conductors – is a well-established approach with decades of industry use, it generally requires an upfront investment higher than vegetation management costs. As a result, it tends to be implemented in areas with exceptionally dense vegetation; and where traditional vegetation management was neither feasible nor cost-effective [5]. Recent technological advancements have significantly improved the performance of covered conductor products, reducing historical operational limitations associated with their design. However, challenges remain with logistics. For example, the added weight of the covered conductor, particularly during heavy snow or ice loading, may necessitate the installation of more and/or sturdier poles to support them [5]. Moreover, the product itself is costlier than bare conductors, and its implementation can introduce increased complexity due to new material properties and designs [5].

Second, although wire insulation is significantly cheaper, costing about half as much as undergrounding, it is also correspondingly less effective. For instance, PG&E’s undergrounding program claims a 99% reduction in wildfire risk by eliminating potential sources of contact with electric lines, including vegetation and animals. In contrast, covered conductors offer risk reduction against wildfires ranging from 60% to 90%, according to data from participating utilities in Wildfire Mitigation Plan (WMP) updates, including SCE, PG&E, SDG&E, PacificCorp, BVES, and Liberty [13]. Utilities operating in high wildfire-risk areas may argue that covered conductors do not provide sufficient risk reduction.

Costs

Limited adoption and insufficient data collection have led to a scarcity of publicly available research assessing the cost-effectiveness of these strategies, particularly for technologies beyond covered conductors. Some utilities have implemented these strategies on a small scale, with costs summarized in Table 2 below. The capital cost per circuit mile for covered conductors varies due to factors like the specific system used, terrain, access constraints, permitting, environmental requirements, construction methods, equipment replacement, vegetation management, and economies of scale [21]. A recent study reviewing wire investments has revealed that material costs account for 6% to 49% of the total costs [21]. Labor and contractor expenses, on the other hand, tend to be more significant, ranging from 43% to 70% [21] of total costs. This reflects the added complexity and vulnerability introduced by advanced overhead conductors, necessitating careful consideration in transmission and distribution system design, planning, and operations [5].

Table 2. Examples of wire investments and their costs

Utility	Investment Type	Period	Cost
SCE, CA	Replace 6,500 miles of distribution bare wire in high-fire-risk areas with covered conductors	2018-2024	$629K/mile (2021 USD, including the costs of pole replacements and additional poles to shorten spans) [14]
SCE, CA	Inspect 50% of distribution circuits and 1,000 transmission circuit miles in high-fire-risk areas	2020-2022	- Average cost of routine inspection of electric lines and equipment (2020-2022): $1.16/distribution line mile $0.12/transmission line mile - Patrol inspections of vegetation: $52.7/distribution line mile $22.7/transmission line mile - Vegetation inspection using Light Detection and Ranging technology: $1.21/transmission line mile [1]
PG&E, CA	Submitted proposal of undergrounding and insulating overhead distribution lines for their second-round of 2023 general rate case review (200 miles of undergrounding and 1,800 miles with covered conductors)	2023-2026	$1,350K per mile on average (2023 USD), including the costs of work beyond installing covered conductor, replacing poles, and other equipment [14]
PG&E, CA	Submitted alternate proposal of undergrounding and insulating overhead distribution lines for their second-round of 2023 general rate case review (973 miles of undergrounding and 1,027 miles with covered conductors)	2023-2026	$2,140K per mile on average (2023 USD), including the costs of work beyond installing covered conductor, replacing poles, and other equipment [14]
Liberty Utilities, CA	Installed covered conductors (11 miles) and spacer cables (9 miles) on overhead distribution system in areas especially prone to tree-caused outages that are too costly to rely on vegetation management	2020-2025	$1,220K per mile (2022 USD) [22]
PacifiCorp, CA	The Tulelake project (6 miles) which served as a pilot of spacer cable project of PacifiCorp	2007-2014,	$200K per mile plus the costs of pole replacement (2022 USD) [21]

Utility	Investment Type	Period	Cost
PacifiCorp, CA	Pilot projects encompassing the implementation of spacer cable systems on 76 miles of high-risk PacifiCorp wires, incorporating covered conductors, a structural messenger, and specialized attachment brackets	2007-current	$777K per mile in total (2022 USD) [22]
ConEdison, NY	Installed 300 breakaway service connector devices on overhead service cables within various municipalities in southern Westchester	2014-2015	$2,000 per device installation (2022 USD) [10]

References

1. Southern California Edison (SCE). (2020). Southern California Edison 2020-2022 Wildfire Mitigation Plan. Available at: https://www.sce.com/sites/default/files/AEM/Wildfire%20Mitigation%20Plan/SCE's%202020-2022%20Wildfire%20Mitigation%20Plan%20-%20Revision%2003.pdf

2. Exponent, Inc. (2021). Effectiveness of Covered Conductors: Failure Mode Identification and Literature Review. Available at: https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=52749&shareable=true

3. Electric Power Research Institute (EPRI). (2022). Reconductoring, Tensioning, and Advanced Conductor Technologies for Increasing the Capacity of Transmission Lines. Available at: https://www.epri.com/research/products/000000003002023335

4. Americans for a Clean Energy Grid. (2014). High Temperature, Low Sag Conductor. Available at: https://cleanenergygrid.org/wp-content/uploads/2014/08/High-Temperature-Low-Sag.pdf

5. U.S. Department of Energy (DOE). (2020). Advanced Transmission Technologies. Available at: https://www.energy.gov/oe/articles/advanced-transmission-technologies-report

6. Bouford, J. D. (2008, April). Spacer cable reduces tree caused customer interruptions. In 2008 IEEE/PES Transmission and Distribution Conference and Exposition (pp. 1-3). IEEE.

7. Southern California Edison (SCE). (2022). Direct Testimony in Support of GRC Track 4 Activity Forecasts Request. https://docs.cpuc.ca.gov/PublishedDocs/SupDoc/A1908013/5023/475764943.pdf

8. U.S. Department of Energy. (DOE). (2022). State Energy Security Plan Optional Drop-In: Energy Sector Risk Mitigation Measures. Available at: https://www.energy.gov/sites/default/files/2022-06/DOE%20CESER%20SESP%20Drop-in_Risk%20Mitigation%20Measures_FINAL_508.pdf

9. EPRI. (2021). EPRI Distribution Structural Resiliency Testing. Available at: https://distribution.epri.com/resources/applications/structure-testing/EPRI_Distribution_Structure_Testing.pdf

10. Consolidated Edison Company of New York, Inc. (ConEd). (2014). Amended Storm Hardening and Resiliency Collaborative Phase Two Report. Available at: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B2137E970-DC34-4630-839C-DD2F08357F2C%7D

11. Stefenon, S. F., Seman, L. O., Pavan, B. A., Ovejero, R. G., & Leithardt, V. R. Q. (2022). Optimal design of electrical power distribution grid spacers using finite element method. IET Generation, Transmission & Distribution, 16(9), 1865-1876.

12. Focus NM Daily. (2022). Xcel Energy to Improve Line Along Old Cavern Highway. Available at: https://focusnmdaily.com/2022/04/04/xcel-energy-to-improve-line-along-old-cavern-highway/

13. PacificCorp. (2022). 2022 WMP Update Progress Report Issue Identified in the Final-Action Statements of the IOUs' 2021 WMP Update Limited evidence to support the effectiveness of covered conductor. Available at: https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/wildfire-mitigation/2022_WMP_Update_Attachment_6_CC_Effectiveness_Workstream_R0.pdf
14. Pacific Gas & Electric (PG&E). (2023). Alternate Proposed Decision of Commissioner John Reynolds. Decision on Test Year 2023 General Rate Case for Pacific Gas and Electric Company. Available at: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M520/K114/520114360.PDF
15. Li, M. B., Su, C. T., & Shen, C. L. (2010). The impact of covered overhead conductors on distribution reliability and safety. International journal of electrical power & energy systems, 32(4), 281-289.
16. Leskinen, T., & Lovrencic, V. (2004). Finnish and Slovene experience of covered conductor overhead lines. In CIGRE proceedings (pp. 54-60).
17. EPRI. (2015). Distribution Grid Resiliency: Overhead Structures. Available at: https://www.epri.com/research/products/000000003002006780
18. SCE. (2019). Application 18-09-002, Application of Southern California Edison Company for Approval of Its Grid Safety and Resiliency Program.
19. Electrical Connection. (2021). Covering the Risk of Bushfires. Available at: https://electricalconnection.com.au/covering-the-risk-of-bushfires/
20. Washington Post. (2021). Burying power lines isn't the only way to weatherproof the grid. Available at: https://www.washingtonpost.com/technology/2021/09/04/weather-power-lines-climate-change/
21. California Public Utility Commission. (2019). R. 18-10-007/ Data Request to PacifiCorp. Available at: https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/wildfire-mitigation/responses-issued/Response_to_CPUC_WMP_Team_Data_Request_Set_1_March_4_2019.pdf
22. California Wildfire Safety Advisory Board. (2023). 2023 -2025 WMP Joint IOU Covered Conductor Working Group Report. Available at: https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=53548&shareable=true

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