Undergrounding Transmission and Distribution Lines

Resilience Investment Guide

SEPTEMBER 2024

GRID DEPLOYMENT OFFICE

BERKELEY LAB
Bringing Science Solutions to the World

Disclaimer

Acknowledgments

This report was prepared by Lawrence Berkeley National Laboratory for the U.S. Department of Energy, Grid Deployment Office.

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 in projects that relocate parts of electric power transmission and distribution systems from aboveground to belowground.

The share of the total length of electric distribution lines underground in the U.S. has increased from 18% in 2009 [31] to approximately 20% in 2023 [32]. While undergrounding of electric distribution is on the rise and already a significant fraction of line length, undergrounding of lines at transmission voltages is much less common in the U.S. As few as 0.5% of total line lengths at capacity 200 kV or higher were installed underground as of 2009 [31].

Major differences between aboveground systems and underground systems are the types of insulating materials used for lines, and the construction technique. Common construction techniques for undergrounding include trenching and tunneling.

- **Trenching:** Trenching techniques consist of digging an appropriate width and depth below ground, preparing the floor of the trench with select sand or cement materials using tools like power rollers, installing appropriate lines and infrastructure components within the trench, and backfilling or covering the line with a protective and thermally-stable cover. Trenching can be completed in longer sections with material backfill providing tight insulation around the cables or completed using shorter sections of exposed trenches and ducts or surface troughs [33].
- **Tunneling:** In places where trenching and burying techniques are difficult, construction crews can use boring and drilling machines to create tunnels that lines can be installed in. Directional drilling machinery and various tunneling techniques can be employed to scale tunnel depths and diameters appropriately for the type of infrastructure being moved underground.

Strengthens grid reliability and resilience by:

- Preventing initial outages

Improves performance against these hazards:

- Vegetation
- Animal
- Vehicle
- Tornado
- Thunderstorm
- Hurricane
- Derecho
- Wildfire
- Ice/Snowstorm

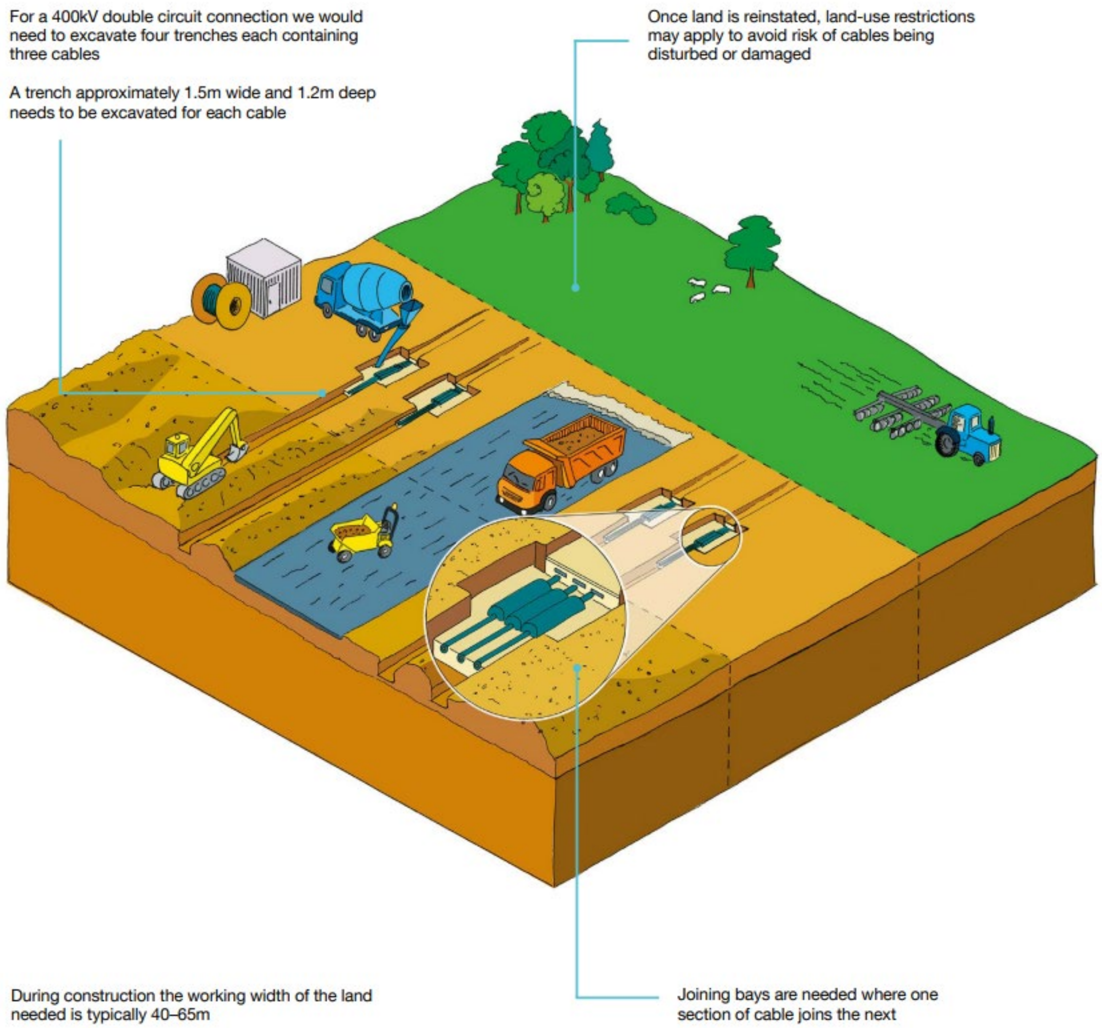

Figure 1. Direct Buried Cable Installation Diagram from National Grid (Source: [33].)

Advantages

The key advantage of underground transmission and distribution lines is substantially reduced vulnerability to disruption from extreme weather and wildfires (by preventing initial ignition as well as propagation), resulting in both reliability and resilience improvements [3,4,5,6]. Underground infrastructure prevents outages that would otherwise occur on overhead lines (e.g., lightning strikes, icing), and in doing so reduces overall system restoration times, or interruption durations. Researchers at Stanford [3] found that a 10% increase in a system's underground line miles was correlated with a 14% reduction in annual interruption durations across the U.S. More recent data corroborates undergrounding benefits; see Table 1. Other benefits of undergrounded transmission and distribution lines include improved aesthetics and reduced risks of damage and injury from fallen overhead lines [7].

Table 1. Examples of the benefits of undergrounded transmission and distribution lines

Utility (organization)	Investment Type	Period	Impact
Wisconsin Public Service Commission (WPSC)	Overhead-to-underground distribution line conversion	2012-2021	95% performance improvement in SAIDI.[1] (137-minute reduction compared to before the project) during storms [8 ,9,10]
Florida Power & Light (FP&L)	Underground new line installations and conversions from overhead-to underground for distribution systems	Historical to 2017	4% outage rate during Hurricane Irma in 2017, compared to 24% for unhardened overhead systems [11]
Virginia Electric and Power Company (VEPC)	Overhead-to-underground distribution line conversion	2016-2022	99% improvement in SAIFI.[2] after project completion; 27% reduction in system restoration times (from reduction in number of outages) during 5-day power interruption following January 2022 snowstorm [8,18]; estimated avoided GDP losses of $270K to $3.6M during June 2016 thunderstorm [12,13]

[1] System Average Interruption Duration Index; a reliability metric, the average duration of a power outage for each customer served by a utility or other provider.

[2] System Average Interruption Frequency Index; another reliability metric, the average number of interruptions a customer experiences during some time period, typically one year.

Utility (organization)	Investment Type	Period	Impact
Pacific Gas & Electric (PG&E)	Overhead-to-underground distribution line conversion	Current estimate	Projected 99% ignition risk reduction during wildfires in affected areas [14]
N/A; studies in the United Kingdom and Montreal, Canada	Overhead compared to underground high-voltage transmission lines	1990s and 2000s	Avoided adjacent real-estate property value losses of ~5% - ~20% (reported in [3])

Disadvantages

The higher direct cost (materials, labor, administrative) of underground lines relative to overhead is their primary disadvantage [15,16]. Moreover, although failure rates are lower for underground lines compared to overhead, underground repairs generally take longer because accessing lines and locating faults is more difficult, especially without system monitoring capabilities [17,18]; for example, across three hurricanes in 2016-2017, Duke Energy Florida's CAIDIs[3] associated with underground lines exceeded those for overhead by 5-46% [17]. Underground lines also have generally shorter lifetimes than overhead, with estimates ranging from being 20-60% shorter (20-40 years compared to 30-50 years) [19,20,21], for reasons including excessive heat buildup leading to degradation of cable insulating materials and susceptibility to moisture, which can result in corrosion. Depending on location, underground transmission and distribution lines may be at risk from flooding, including flooding due to sea level rise and storm surge [22]. There are also issues with environmental impacts and susceptibility to cable damage [3,6]; the latter may be particularly relevant in earthquake-prone locations [18].

Costs

A review by Bohman [18] of studies conducted before 2018 found a wide range of direct costs for both new underground lines and conversions from overhead in both transmission and distribution systems, depending upon the location, technical details, and utility. Costs will generally be higher for transmission compared to distribution systems (roughly 3 to 10 times higher for new construction, and 1.5 to 5 times higher for conversions [23]), and in areas where labor costs are higher. The type of cable, insulation, and other engineering details also affect costs, e.g., high-pressure fluid-filled transmission cables are more expensive than cross-linked

[3] Customer Average Interruption Duration Index; another reliability metric, the average customer interruption duration defined as SAIDI divided by SAIFI.

polyethylene [24], while single-phase lines are less expensive than three-phase [25]. Table 2 provides several examples.

Costs can be significantly higher or benefits can be reduced for undergrounding projects in locations where environmental factors increase the complexity of a project. New construction on wetland areas or former wetlands, for example, can complicate undergrounding projects and add system requirements to mitigate inundation risks. Geological factors can also restrict the application of undergrounding in some areas. Undergrounding projects can only be completed successfully where appropriate environmental and subsurface conditions exist.

Benefits of undergrounding may outweigh the direct costs. Some utilities take into account customer avoided costs or societal benefits such as avoided state or regional gross domestic product losses, or aesthetic impacts, in assessments of underground conversions. Others undertake "strategic" undergrounding, for example, to reduce the risk of wildfires and avoid the need for public safety power shutoffs[4] [26]. It has also been noted that in some cases the direct costs of underground conversion may not be substantially different from those of hardening overhead systems against, e.g., extreme weather [27].

Table 2. Examples of overhead-to-underground conversion costs

Utility (organization)	Investment Type	Period	Cost	Details
(Edison Electric Institute)	Urban, Rural, and Suburban Transmission	Approx. 2013	$0.54 - $12 million/mile urban (2013 USD); $1.1 - $11 million/mile rural (2013 USD); $1.1 - $6 million/mile suburban (2013 USD)	Materials and labor Urban: 150+ customers/sq. mile; suburban: 51 to 149 customers/sq. mile; rural: 50 or fewer customer/sq. mile. [23]
New Hampshire Electric Co-op	Urban and rural distribution	2009	$1.43 million/mile urban; $0.99 million/mile rural (2009 USD)	34.5 kV [28]

[4] Deliberate cessations of electricity service by utilities to prevent ignition of fires by electrical infrastructure.

Utility (organization)	Investment Type	Period	Cost	Details
New Hampshire Electric Co-op	Urban and rural distribution	2009	$2.88 million/mile urban; $1.78 million/mile rural (2009 USD)	15 kV [28]
New Hampshire Electric Co-op	Urban and rural distribution	2009	$1.15 million/mile urban; $0.9 million/mile rural (2009 USD)	1 & 2 Phase [28]
Pacific Gas & Electric	Urban and rural distribution	2023-2026	$2.97 million/mile (2019 USD)	Initial cost of $3.3 million/mile, decreasing to $2.8 million by 2016 [29]
Virginia Electric & Power Company	Rural distribution	2016-2022	$0.48 million/mile (nominal USD averaged over years)	Single-phase tap lines; planning and construction costs [30]
Wisconsin Public Service Corporation	Rural distribution	2012-2021	$0.16 million/mile (nominal USD averaged over years)	Single- and three-phase primary circuits; construction and other costs[5] [25]

[5] Construction costs were 78% of the total; “other” included overhead line removal costs, taxes, and employee benefits.

References

1. Reuters. (2017). “Irma knocks out power to about 5.8 million.” Available at: https://www.cnbc.com/2017/09/11/irma-knocks-out-power-to-nearly-four-million-in-florida-utilities.html (Ricky Carioti/The Washington Post via Getty Images)

2. Waymer, J. (2020). “FPL statewide pilot program strengthens grid with underground lines in Palm Bay.” Available at: https://www.floridatoday.com/story/news/2020/11/04/florida-power-and-light-buries-power-lines-stop-hurricane-outages/6120450002/

3. Larsen, P. (2016). “Severe Weather, Power Outages, and a Decision to Improve Electric Utility Reliability.” Ph.D. dissertation, Stanford University. Available at: https://searchworks.stanford.edu/view/11607362

4. Florida Public Service Commission (FPSC). (2018). “Review of Florida’s Electric Utility Hurricane Preparedness and Restoration Actions 2018.” Available at: https://www.psc.state.fl.us/reports

5. Power Delivery Intelligence Initiative (PDi2). (2021). “Utility Infrastructure Resiliency Playbook.” Available at: https://pdi2.org/wp-content/uploads/2021/12/index.html

6. Watts, C. (2023). “The Changing Economics of Utility Investment in Undergrounding.” Report 100-T144, S&C Electric Company. Available at: https://www.sandc.com/globalassets/sac-electric/documents/public---documents/sales-manual-library---external-view/technical-paper-100-t144.pdf?dt=638228028579375741

7. Beehler, M. (2023). “Underground Resiliency for FERC 2222.” Available at: https://pdi2.org/insight/https-pdi2-org-wp-content-uploads-2023-06-underground-resiliency-whitepaper-pdf/

8. Wisconsin Public Service Corporation (WPSC). (2022). “System Modernization and Reliability Project (SMRP) 2021 Post Construction Report.” Available at: https://apps.psc.wi.gov/pages/viewdoc.htm?docid=430842

9. Musser, P. (2018). “Strategic and Data-Driven Grid Resiliency Programs.” Available at: https://www.tdworld.com/intelligent-undergrounding/article/20971992/strategic-and-datadriven-grid-resiliency-programs

10. Wisconsin Public Service Corporation (WPSC). (2021). “WPS earns national awards for exceptional reliability, service to customers.” Available at: https://news.wisconsinpublicservice.com/wps-earns-national-awards-for-exceptional-reliability-service-to-customers/

11. Florida Power & Light Company (FPL). (2022). “Direct testimony of Michael Jarro, in Petition for Approval of the Florida Power & Light Company 2023-2032 Storm Protection Plan.” Submitted to Florida Public Service Commission in Docket 2022-0051-EI. Available at: https://www.floridapsc.com/pscfiles/library/filings/2022/02358-2022/02358-2022.pdf

12. Virginia State Corporation Commission (VSCC). (2017). “Staff’s GDP impact benefit calculation for the Father’s Day storm.” VSCC staff exhibit No. 25 in Case No. PUE-2016-00136. Available at: https://www.scc.virginia.gov/DocketSearch#caseDocs/136692

13. Brown, R. (2016). “Testimony of Richard E. Brown on behalf of Virginia Electric and Power Company before State Corporation Commission of Virgina, Case No. PUE-2016-00136.” Available in docket at: https://www.scc.virginia.gov/DocketSearch#caseDocs/136692

14. Pacific Gas & Electric Company (PG&E). (2023). “2023-2025 Wildfire Mitigation Plan R3.” Available at: https://energysafety.ca.gov/what-we-do/electrical-infrastructure-safety/wildfire-mitigation-and-safety/wildfire-mitigation-plans/2023-wildfire-mitigation-plans/

15. North American Wooden Pole Council. (2017). “Undergrounding: Hidden Lines, Hidden Costs.” Technical Bulletin 17-U-102. Available at: https://woodpoles.org/portals/2/documents/TB_Undergrounding.pdf

16. Maranan, P. (2021). “Do the Benefits of Underground Power Lines Outweigh the Costs?” *The Cooperative Accountant*, summer issue. Available at: https://nsacoop.org/members/database/view-article?id=2902

17. Duke Energy Florida (DEF). (2018). “Presentation to Florida Public Service Commission Hurricane Workshop.” Available at: https://www.floridapsc.com/pscfiles/library/filings/2018/02983-2018/02983-2018.pdf

18. Bohman, A. (2022). “Investing in Power System Resilience: A mixed-methods approach to assessing the tradeoffs of resilience strategies.” Ph.D. dissertation, Department of Engineering and Public Policy, Carnegie Mellon University. Available at: https://www.cmu.edu/ceic/research-publications/angelena-bohman-phd-thesis-2022.pdf

19. Leman, J., Olsen, R. (2022). “Overhead or Underground Transmission? That is (Still) the Question.” T&D World. Available at: https://www.tdworld.com/intelligent-undergrounding/article/21215620/overhead-or-underground-transmission-that-is-still-the-question February 24.

20. Csanyi, E. (2017). “Overhead vs. Underground Residential Distribution Circuits. Which One is ‘Better’?” Available at: https://electrical-engineering-portal.com/overhead-vs-underground

21. Sims, J. (2021). “Comparison of Overhead Power Lines vs. Underground Cables.” Available at: https://www.critterguard.org/blogs/articles/comparison-of-overhead-power-lines-vs-underground-cables

22. Ilen-Dumas, M. (other authors). (2019). “Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods.” Oak Ridge National Laboratory report ORNL/TM-2019/1252. Available at: https://www.osti.gov/biblio/1558514

23. Hall, K. (2013). “Out of Sight, Out of Mind 2012 – An Updated Study on the Undergrounding of Overhead Power Lines.” Edison Electric Institute, January. Available at: https://woodpoles.org/portals/2/documents/OutofSightOutofMind2012.pdf

24. KEMA, Inc. (2012). “Life-Cycle 2012: Connecticut Siting Council Investigation into the Life-Cycle Costs of Electric Transmission Lines.” Available at: https://portal.ct.gov/-/media/CSC/LifeCycle2011/LifeCycleFinalReportpdf.pdf

25. Wisconsin Public Service Corporation (WPSC). (2022). "System Modernization and Reliability Project 2021 Final Actual Cost Report." February 9. Available at: https://apps.psc.wi.gov/pages/viewdoc.htm?docid=434571

26. San Diego Gas & Electric Company. (2022). "Strategic Undergrounding." Available at: https://www.sdge.com/undergrounding-overhead-powerlines

27. Wisconsin Public Service Corporation. (2013). "Initial Brief: Application of Wisconsin Public Service Corporation for its System Modernization and Reliability Project." Submitted to the Public Service Commission of Wisconsin in Docket No. 6690-CE-198, May 30.

28. NEI Electric Power Engineering. (2009). "New Hampshire December 2008 Ice Storm Assessment Report." Available at https://www.puc.nh.gov/2008IceStorm/Final%20Reports/2009-10-30%20Final%20NEI%20Report%20With%20Utility%20Comments/Final%20Report%20with%20Utility%20Comments-complete%20103009.pdf

29. California Public Utilities Commission (CPUC). (2023). "Decision on Test year 2023 General Rate Case for Pacific Gas & Electric Company. Application 21-06-021 (Application of Pacific Gas & Electric Company for Authority, Among other Things, to Increase Rates and Charges for Electric and Gas Service Effective on January 1, 2023." Available at: https://www.rcrcnet.org/cpuc-issues-competing-draft-decisions-pge%E2%80%99s-general-rate-case

30. Virginia Electric and Power Company (VEPC). (2023). "Strategic Underground Program Annual Report." Submitted to the Virginia State Corporation Commission in Case No. PUE-2016-00136. Available at: https://www.scc.virginia.gov/DocketSearch#caseDocs/136692

31. U. S. Energy Information Administration. (2012). "Power outages often spur questions around burying power lines." *Today in Energy*, July 25. Available at: https://www.eia.gov/todayinenergy/detail.php?id=7250

32. Beehler, M. (2023). "Distribution Goal: 50% Underground by 2040." Available at: https://www.tdworld.com/smart-utility/article/21253499/distribution-goal-50-underground-by-2040

33. National Grid. (2015). "Undergrounding high voltage electricity transmission lines – the technical issues." Available at: https://www.nationalgrid.com/sites/default/files/documents/39111-Undergrounding_high_voltage_electricity_transmission_lines_The_technical_issues_INT.pdf

Undergrounding Transmission and Distribution Lines

Resilience Investment Guide

SEPTEMBER 2024

GRID DEPLOYMENT OFFICE

BERKELEY LAB
Bringing Science Solutions to the World