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T&D Underground Innovations

Ben Lanz

Power Delivery Intelligence Initiative (PDI2.org)
Osmose Utility Services

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Author: Ben Lanz
Power Delivery Intelligence Initiative (PDI2.org)
Power Osmose Utility Services

Abstract

The transition toward a more electrified, data driven, and weather impacted world is forcing utilities, policymakers, and industry leaders to reevaluate long standing assumptions about the design and operation of the electric grid. For decades, the North American grid has been built predominantly as an overhead (OH) system, favored for its historically lower upfront cost, relative ease of access, and straightforward maintenance protocols. Yet as the demands on the grid escalate—driven by electrification, renewable energy integration, weather volatility, aging assets, economic pressures, and evolving public expectations underground (UG) transmission and distribution systems have emerged as a strategic alternative offering significant long-term advantages. While undergrounding has often been perceived as too expensive on a first cost basis, contemporary evidence shows that advancements in technology, improved lifecycle analysis, and shifting risk profiles are enabling underground solutions to outperform overhead systems across a growing number of applications. The trajectory of innovation is reshaping conventional wisdom around T&D planning and reinforcing a broader industry movement toward strategic undergrounding programs. This paper reviews key drivers, data insights, and technological advancements propelling this shift. More utilities are finding that undergrounding is not merely an alternative but increasingly a necessary part of their asset life-cycle strategy to achieve a resilient, sustainable, and economically efficient grid required for the 21st century.

1. Introduction

Electric utilities face an unprecedented convergence of external pressures. By many accounts electrification, is accelerating rapidly, and total energy delivery in the U.S. is projected to rise substantially due to widespread adoption of electric vehicles, distributed energy resources, heat pumps, data centers, and automated industrial systems. This growth is not only quantitative but structural; load shapes are shifting, and the spatial distribution of demand is altering planning and operational paradigms. Simultaneously, the reliability and resiliency expectations of customers, regulators, and policymakers have risen sharply. Nationally, reliability in the U.S. currently averages 99.97 percent, but this metric does not capture severe impacts of High Impact Low Probability (HILP) events—storms, wildfires, extreme heat, and other weather related phenomena—that impose prolonged outages and substantial economic damage. According to the Energy Information Administration (EIA), in 2024, the average American utility customer experienced approximately 11 hours of outage time, a figure heavily influenced by weather-related incidents. Historically, weather and its impact to aging infrastructure has been the

dominant threat to overhead infrastructure. Various utilities report between 70 and 90 percent of outage events stem directly from weather, including wind, ice and lightning, and indirectly from weather impacting surrounding vegetation and debris. Other notable risks to overhead systems are fire, vehicle impacts, climbing and flying animals, insects, and even conductive balloon proximity, underscoring the vulnerability of exposed, air insulated assets. Economically, the stakes are enormous. For example, Florida's daily GDP is approximately $3.7 billion and Virginia's is $1.8 billion, implying that even short outages can impose massive financial losses on regional economies dependent on uninterrupted power. Additionally, the United States now averages roughly 20, billion-dollar weather related events per year and while some states are more frequently impacted than others, all have experienced repeated weather-related disasters. These conditions create an environment in which the vulnerability and total cost of overhead systems are escalating while the economic, social, and environmental incentives for underground systems grow stronger.

2. Overhead vs. Underground: Rethinking Traditional Cost Assumptions

Historically, a central argument against undergrounding has been the perception that it is more expensive than overhead alternatives. In many cases, this has been true in terms of initial capital cost—but initial cost alone is no longer a meaningful metric when evaluating infrastructure with a 50 to 100 year lifespan. The presentation emphasizes that while overhead construction may "typically" have a lower initial cost, this assumption depends heavily on local conditions, including terrain, permitting constraints, weather exposure, and load density. In fact, for greenfield developments—particularly urbanized zones—underground residential distribution (URD) and secondary underground systems may already be more cost effective on a first cost basis. Moreover, when lifecycle cost considerations are applied, underground systems demonstrate lower total cost of ownership in many applications. Underground assets benefit from extended service life due to improved commissioning practices and superior environmental protection. They incur significantly lower maintenance costs, offer better utilization of real estate, and reduce or eliminate expenses related to vegetation management, storm hardening, and aerial inspections. Contemporary technology enables detailed underground inspections that were once impossible, while permitting for underground routes is faster and provokes far less public opposition than overhead siting processes, which often face protracted legal disputes and community resistance. The permitting challenge for overhead lines is particularly acute. One example describes an overhead line upgrade from 115 kV to 230 kV that incurred ten years of permitting delays, legal conflict, and substantial customer frustration—all before a single pole was installed. Underground infrastructure avoids many of these land use and aesthetic controversies, improving project certainty and stakeholder support. These compounding factors—maintenance, permitting, reliability, and community impact—have significantly contributed to the economic landscape. In many cases, undergrounding not only compares favorably but decisively outperforms overhead systems financially when assessed on a lifecycle basis.

3. Reliability, Resiliency, and Risk Elimination

Reliability and resiliency are often conflated but represent distinct priorities. Reliability refers to consistent day-to-day service with minimal interruptions, while resiliency describes the ability of the system to withstand and recover from high impact events. Underground systems excel at both. Empirical data clearly supports the reliability advantage. Edison Electric Institute (EEI) findings show that the System Average Interruption Frequency Index (SAIFI) for overhead systems is typically twelve times higher than underground. This dramatic difference reflects the core structural advantage of underground systems: they are shielded from nearly all causes of overhead outages, including weather, vegetation, wildlife, and accidental contact. Resiliency is equally compelling. By eliminating exposure to wind, fire, ice, and debris, underground systems dramatically reduce the probability and severity of catastrophic failures. This complements emergency response strategies by reducing the total line restoration burden during major events. For utilities and regulators concerned with risk elimination, undergrounding offers the most direct, controllable method for reducing outage frequency and negative societal impact.

4. Technological Advancements Driving Underground Adoption

The rapid evolution of underground technology has addressed many of the historic limitations associated with UG construction and maintenance. Today's underground cable systems can achieve a service life exceeding 100 years, when properly commissioned and managed under appropriate thermal and electrical duty cycles. This longevity is supported by major improvements in materials science, including new insulation formulations, oil free high voltage cable designs, and advanced accessory engineering. Industry standards, manufacturing protocols, installation training programs, and especially commissioning assessments like the offline 50 Hz partial discharge line scanning method, are enabling utilities to achieve high quality field installation and performance. Additional cost saving innovations include expanded trenchless construction technologies, joint utility trench installations, improved conduit and direct burial designs, concrete-protected surface installed cable trays, and 3D mapping capabilities that enhance installation speed and accuracy. Underground mapping, GIS integration, and digital twin, and augmented reality tools significantly reduce risk during excavation and streamline asset management. Monitoring systems such as distributed temperature sensing (DTS), distributed acoustic sensing (DAS), and periodic AI based line scanning introduce performance oversight once unimaginable in earlier underground systems. Perhaps most notable in the transmission space is the development of long distance direct current (DC) UG transmission capabilities that now allow multi hundred-mile installations up to 400kV and gigawatt power capacities—projects such as the Champlain Hudson Power Express (339 miles), SOO Green HVDC Link (350 miles), and Cascade Renewable (100 miles) illustrate the scale and feasibility of modern UG transmission projects connecting power generators across regions and many times directly buried in existing railroad rights-of-way, rivers, and other bodies of water. These

advancements collectively reduce costs, improve reliability, and expand the scenarios in which undergrounding is the superior choice with the lowest total cost of ownership.

6. Economic and Strategic Investment Models

Beyond engineering considerations, the economic case for undergrounding is increasingly supported by financial analysis. A simplified internal rate of return (IRR) demonstrates that a five year investment in undergrounding can yield positive IRR starting at ten years and continues to generate value through maintenance savings, asset longevity, and avoided outage costs. The IRR does not even account for many ancillary benefits such as safety improvements, real estate utilization, GDP protection, or reinvestment of O&M savings—factors that further strengthen the financial case for underground investment. In a simplified internal rate of return (IRR) analysis looking at the avoided future costs as returns, integrating avoided annual maintenance impact demonstrating accelerated recovery, repair, and replacement after routine storms, and avoidance of the frequency and severity of system impact due to severe or extreme weather or fire risks can yield a positive IRR over a 10-20 year timeline without the incorporation of multiple factors that will further augment and demonstrate that "Strategic" undergrounding is the source of the lowest life-cycle cost and if the path to achievement of resiliency and reliability targets. Qualitative benefits including improved sustainability performance, utility staff and public safety risk exposure reduction, streetscape beautification and real estate value improvement; improved quality of life for utility customers and improved customer service perspectives are not incorporated. Other financial factors not modeled include, return on invested capital, societal benefits including GDP impact, saving associated with lower maintenance activity, incorporation of inflation, reinvestment of maintenance savings as capital spend
and anticipation of cable life beyond 50 years.

7. Strategic Undergrounding Case Studies

Utility strategic undergrounding programs further highlight the systemic value. In fact, many utilities have implemented or are exploring undergrounding in some capacity, recognizing advantages such as substantial reliability and safety improvements, stable rate base growth, elimination of vegetation management burdens, and reduced O&M costs by a factor of ten in many instances. WEC Energy's program, a multi-year effort involving 2,200 miles of undergrounding reported a 97 percent reduction in customer minutes interrupted (CMI). Customer surveys revealed broad support, with most customers willing to pay modest monthly premiums to benefit from underground reliability. Dominion Energy's Virginia Strategic Undergrounding Program (SUP), supported by legislative cost recovery mechanisms, involves approximately $2 billion invested across 4,000 miles, with a goal of cutting total line restoration time by half. This program demonstrates how policy alignment can accelerate underground adoption and de risk utility investment. Florida Power & Light (FPL), serving one of the most

storm exposed territories in the U.S., is executing a ten year, $20 billion undergrounding and hardening program. The effort includes undergrounding 5,000 miles by 2032 and intends to eventually transition all 27,000 miles of overhead URD to underground systems. Pilot results show up to an 83 percent reduction in outages from storm events, validating undergrounding as the most effective resilience strategy in high risk zones. An interesting note about this data is that most examples of failure were reportedly involving transition structures from overhead to underground. These three utility examples reflect a broader trend: lifecycle thinking, combined with modern financial models and policy support, consistently identifying undergrounding as a high value, low risk, and socially beneficial investment.

7. Conclusion: A Necessary Evolution for the 21st Century Grid

The movement toward undergrounding is more than a technical shift—it represents a structural transformation in how utilities conceive, plan, and justify infrastructure investment. Overhead systems have served the industry well for over a century. The evolving landscape of electrification, resilience requirements, weather and aging risks, and economic expectations requires a more durable and future-proof approach. An accurate condition and risk assessment and thorough lifecycle analysis for all grid upgrades and replacements is key to an affordable and sustainable grid. In some cases the solution may be to simply upgrade poles and towers supported systems with reinforcements, covered conductor, or improved sensor and switching technology. However, what is now clear, underground T&D systems, once viewed as niche or prohibitively expensive, are now emerging as a foundational component of a resilient and adaptable grid. Utilities embracing a strategic undergrounding today are positioning themselves—and their customers—for a safer, more stable, and more prosperous energy future.