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Resilience of Underground Power Transmission: Viability Assessment and Future Strategies

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SUMMARY

This paper explores the role of underground power transmission in bolstering the resilience of the electric grid, with a particular focus on its distinct advantages over traditional overhead transmission. By delving into the extended lifespan and remarkable durability of underground power cables, this study highlights their significant contribution to the overall resiliency of the power grid. This paper serves as a conceptual analysis of the benefits afforded to underground transmission systems through analysing historical data on outages and growing demand trends. In doing so, it showcases how underground power systems have consistently demonstrated greater resistance to environmental factors, extreme weather events, and external disturbances.

One of the key aspects addressed in this paper is the reduced need for maintenance and repairs associated with underground power transmission. This characteristic significantly diminishes downtime during disasters and unforeseen circumstances, contributing to a more resilient grid with minimal disruptions in power delivery. Moreover, the significantly reduced vulnerability to weather-related damage and exposure to physical hazards make underground cables an effective option for ensuring grid stability and continuous power flow.

The goal of this paper is not to discourage the use of overhead power transmission lines, but rather to advocate for the incorporation of underground power cables where appropriate, recognizing the strengths these options offer in bolstering the overall resiliency of the power grid. While it would be impractical to convert all existing overhead structure to underground transmission, the effects of severe weather on overhead installations may suggest that having a portion of transmission lines undergrounded for increased reliability may be greatly beneficial for both utilities and consumers.

New investments in sustainable power generation have spurred the need to provide new power transmission infrastructure to connect these new renewable sources of electricity such as wind, hydroelectric, solar, and more. Each new installation must be tied into the power grid so that consumers can benefit, which provides a great opportunity for underground transmission lines to be used in the new construction. The introductions of renewable energy sources to the existing grid have created the need for new transmission line interconnections, and so it follows that there should be a strategized approach to the design of such new installations. Now is the time to prepare for the future, rather than continue to react to the problems of the past.

Reviewing a collection of data from line failures, this paper aims to identify the vulnerabilities and limitations of overhead transmission line installations. Suggestions are made for future strategies in advancing power grid resiliency through the supplementation of underground power infrastructure. By incorporating these insights, utilities can proactively plan for, and address, potential weaknesses in their power grids, effectively bolstering their capacity to withstand unexpected challenges.

The information presented in this paper seeks to provide valuable insights for the power industry and future efforts to make informed decisions regarding power infrastructure investments. In doing so, utilities can plan for a more resilient and reliable electric grid. By embracing the advantages of underground power transmission, utilities can experience strengthened grid resiliency, reduced electricity supply disruptions, and a commitment to sustainable and secure energy delivery. Data supporting the longevity, durability, and cost effectiveness of underground transmission systems suggests that it may be more effective in many circumstances than traditional overhead installations.

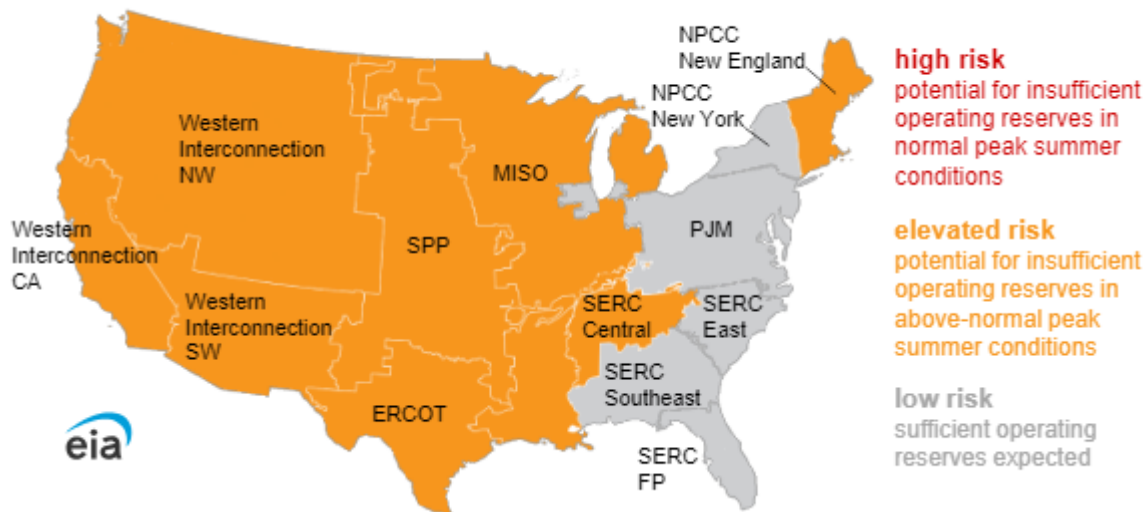
KEYWORDS

Underground cable, Power grid resiliency, Power transmission, Cost-benefit analysis, Infrastructure, Severe weather, Stakeholder collaboration

Introduction

In a dynamic world that experiences continued growth and expansion, outdated and static power infrastructure leaves societies acting in response to outages, repairs, and disasters, rather than being able to plan, mitigate, and grow sustainably. The problems posed by an outdated system are exacerbated by an increase in global temperatures and increasing frequency of severe weather events. Several large-scale power outages such as the Northeast Blackout of 2003, outages from Hurricane Sandy in 2012, and the Texas Power Crisis of 2021 have proven that a damages to power infrastructure can result in loss of essential heating and cooling, widespread food spoilage, risk of fire or human contact with downed electrical lines, and more. These events have the potential to cause catastrophic loss of resources, revenue, and life. Though the severe events listed above are extreme cases, preventable power interruptions are experienced around the world every day. As existing infrastructure continues to age and the demand for power increases, many utilities are faced with the choices to repair, replace, or create new power infrastructure. The U.S Energy Information Administration has estimated that two-thirds of North America is at risk of energy shortfalls in the summer of 2023 [1].

Risk of electricity supply shortfalls in summer 2023



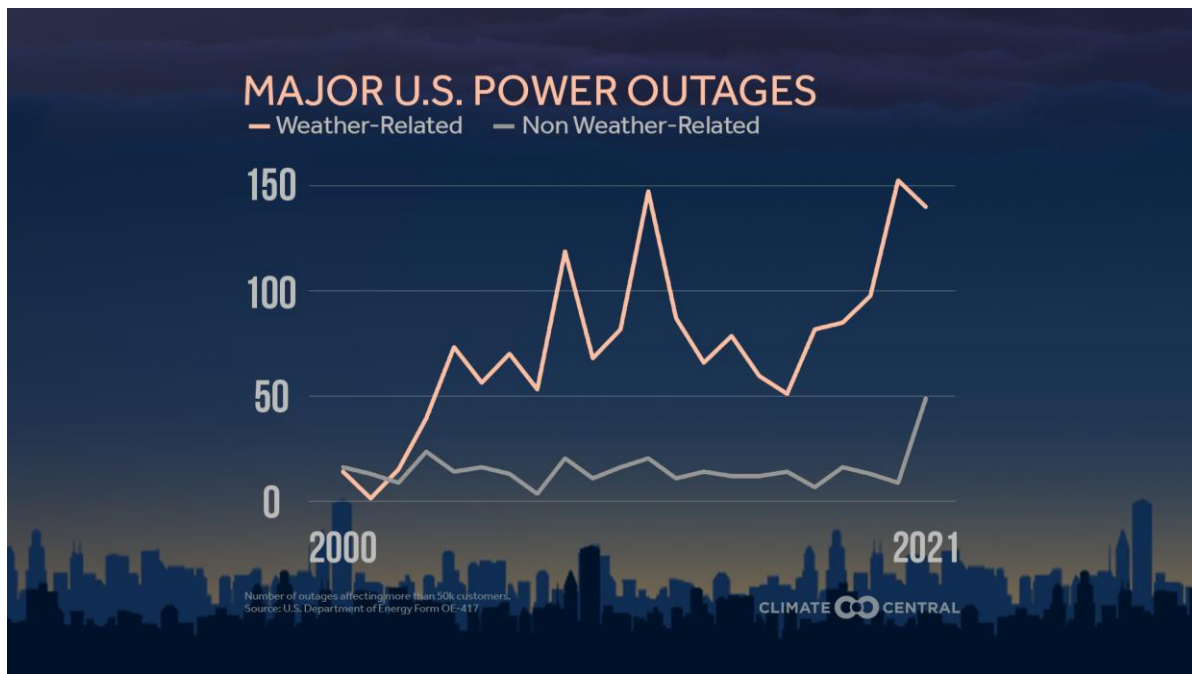
It is critical that new and existing power infrastructure is dependable and able to meet the essential energy needs for industries, businesses, and households. In 2021, global electricity demand grew by 6% from the previous year, with coal meeting more than half of that increase [2]. As demand grows for reliable energy, an already strained grid is at risk for increased frequency of failures and lack of supply. The resulting condition would lead to higher prices for consumers, potentially rendering electricity unaffordable for a significant portion of the population. Faced with growing demand for reliable electricity and investment in new sustainable energy systems, underground transmission provides solutions to many of the problems faced by modern power grids.

Longevity and Durability

The longevity and durability of underground power systems are vital to their ability to enhance electric grid resilience. The installation conditions of underground transmission systems are responsible for their ruggedness. Typical underground transmission installations consist of the cables being pulled through a series of PVC conduits that are encased within

high strength concrete providing mechanical strength to the underground transmission cables. This can mitigate damage caused by accidental dig-ins from future underground construction or other external damage. To assist with construction permitting, these installations are usually built under public roadways, so they are designed to be able to handle constant traffic loading and are highly durable. This level of protection results in another key benefit of reduced maintenance needs. With the cables protected below ground, the underground system experiences less service interruptions and maintenance events which increases the system lifespan, leads to shorter system downtime, and contributes to grid reliability.

One of the greatest advantages of underground powers lines is their ability to withstand severe weather events and to mitigate damages caused. Some of the most common sources of outages for overhead power lines are from heavy rain, wind, and trees falling or contacting the line, and vehicle collisions. While there is potential for these sources to affect underground transmission lines, they are mostly unique to overhead lines. Between 2000 and 2021, approximately 83% of reported major outages in the U.S were attributed to weather-related events, and these events have been increasing in frequency [3].



Underground cables are generally understood to have a designed life expectancy of 40 years, but many are operated for longer. To ensure the maximum lifetime on underground cables, they must be designed to withstand some amount of emergency loading in the event of an outage elsewhere in the system. Above a certain threshold of time or heating cycles, the insulation may begin to deteriorate, so extra care must be taken during the design and operation of these systems to maximize their benefits.

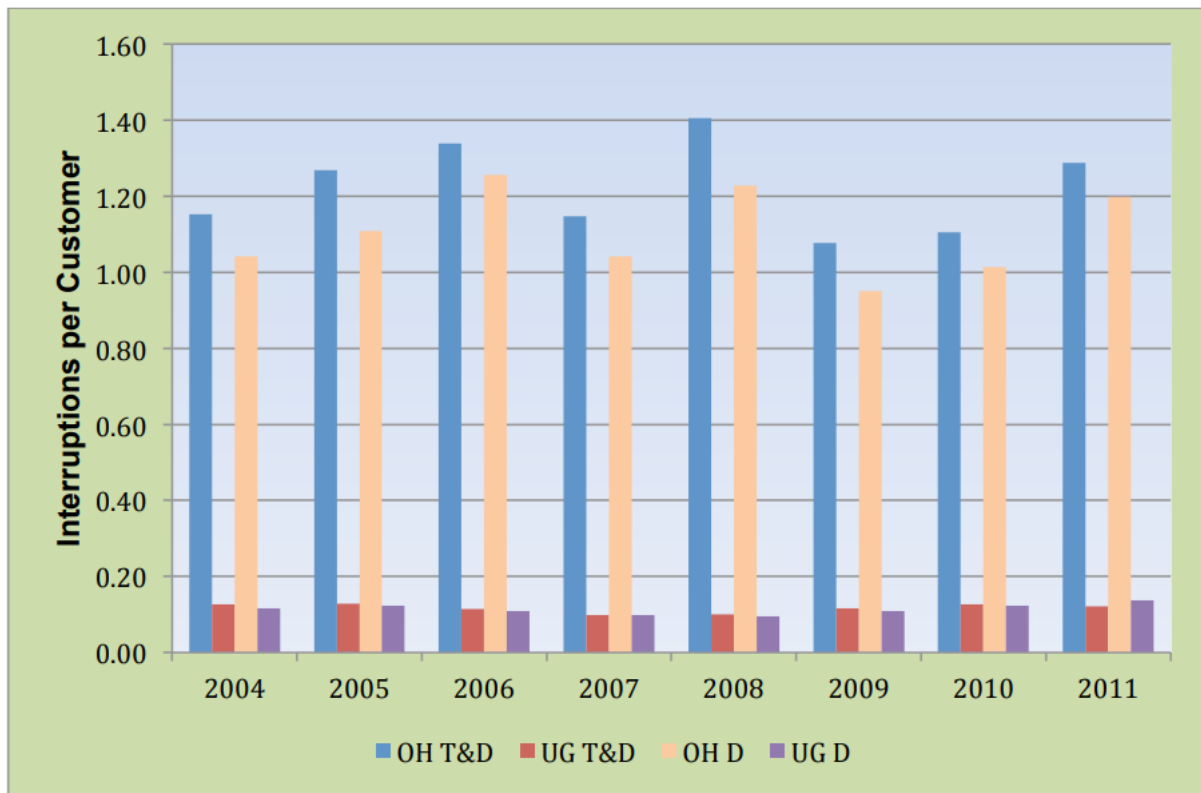
On the other hand, new overhead transmission lines can have a designed life of up to 80 years, but many of them do not reach this limit due to being directly affected by their geographic conditionals and potential for extreme weather events. Many of the existing lines were built in the 1950s and 1960s with only a 50-year life expectancy, so the need to upgrade is already overdue in many installations [4]. These existing power systems were not designed to handle the present-day demand they are experiencing, so in many instances a line cannot be taken down for maintenance without overloading the interconnected lines in the system.

Growing demand for electricity coupled with the increasing frequency of severe weather-related outages highlights the need to invest in critical power infrastructure. Areas that can experience wildfires due to dry conditions would also benefit in utilizing more underground power transmission as falling power lines can contribute to starting widespread fires. Undergrounding can nearly reduce all ignition risk as there is no potential for the cables to contact dry brush. This has led utilities to begin initiatives increasing the percentage of underground transmission lines they have in service.

Cost Benefit Analysis

While the aforementioned points support a greater adoption of underground cables, cost has historically been the limiting factor when it comes to transmission projects. The initial capital cost required for installing underground power systems is substantially higher than that of overhead lines. This higher cost comes from the excavation, cable laying, and other protective measures associated with the installation of each system. By conducting an economic analysis on a case-by-case basis, utilities and grid operators can determine their break-even points to find the point at which the long-term savings outweigh the initial cost.

Over the operational lifetime, underground power systems demonstrate considerable savings in maintenance costs. While maintenance for an underground system is more costly than for an overhead system, maintenance is very uncommon. According to a case study from the Public Service Commission of Wisconsin, it is estimated that at most, a 1:1,000 chance for the most common type of repair to be needed in any one mile of XLPE underground line over any one year [5]. Unlike overhead lines that require regular inspections, tree trimming, repairs, and replacements due to frequent weather-induced wear and tear, underground cables are largely protected from external factors. Reduced maintenance frequency can make up for the higher costs associated if underground cables need to be repaired or can allow utilities to reallocate resources that would have otherwise been used inspecting and repairing overhead lines. Furthermore, a study prepared for the Edison Electric Institute suggests that customers served by overhead infrastructure experience an average of at least one outage event per year, while those served by underground infrastructure experience an average of 0.10 outages per year [6].



While the upfront investment in underground power transmission may appear substantial, the cost-benefit analysis provides evidence for its economic justification. The reduced downtime during disasters and extreme weather events, combined with minimized maintenance needs ultimately lead to uninterrupted electricity supply and increased customer satisfaction. The economic resilience of underground transmission offers utilities a more stable revenue stream as grid reliability builds consumer trust. This can attract new customers and can encourage further economic development in the benefiting service areas.

Stakeholder Perspectives and Policy Implications

To successfully implement an underground power system to bolster grid resiliency requires the collaboration of various stakeholders. While investor-owned utilities only make up 6% of utility providers, they serve 68% of electric customers [4]. Utility companies and grid operators play a critical role in the planning, development, and maintenance of power infrastructure. By embracing the reduced maintenance needs and extended lifespan of underground cables, utility companies can optimize their operational budgets and invest in more long-term infrastructure planning such as upgrading equipment and undergrounding more lines. An increased focus in asset management and smart grid technologies may be necessary for utility companies to be successful in these endeavours.

Policymakers and regulatory authorities serve a vital role to shape the energy landscape and to drive infrastructure investments. From their perspective, supporting the development of underground power delivery aligns with the broader objectives of ensuring energy security, sustainability, and grid resilience. Policymakers can develop clear guidelines and standards for the incorporation of underground transmission technologies into grid expansion and hardening plans. This process can be aided using subsidies, incentives, or special funding and permitting mechanisms to encourage utility companies to prioritize the long-term economic benefits and societal impact of a resilient grid supported by underground power systems.

Underground power systems align with environmental and community interests by reducing visual disruptions to aid in the preservation of natural landscapes and to nearly eliminate interaction with local flora and fauna. The reduced environmental impact provides an attractive option for eco-conscious stakeholders, promoting support for infrastructure investments that enhance grid reliability while safeguarding local ecosystems.

Consumers are an integral stakeholder group as well, with interests in energy affordability and a reliable electricity supply. From the perspective of a consumer, policies that promote underground power delivery investments should balance the benefits of enhanced resilience with the potential impact on electricity prices. This, in turn, calls on policymakers to consider the measures to mitigate the cost that is translated to consumers to ensure that access to reliable electricity remains equitable and affordable.

Conclusion

The pursuit of a resilient and reliable electric grid has become imperative due to growing energy demands and evolving uncertainties in the face of environmental factors and natural disasters. Throughout this paper, we have explored the pivotal role of underground power transmission in enhancing grid resilience and the ability to address the challenges that traditional overhead lines experience.

Underground power delivery offers distinct advantages that support the longevity and durability of the electric grid. A focus on the utilization of underground transmission lines would ensure a stable and continuous power supply through extended system lifespan, reduced vulnerability to environmental factors, and ability to withstand extreme weather events. These features fortify the overall resilience of the electric grid, minimizing disruptions and bolstering the energy security of critical infrastructure.

The reduced maintenance needs of underground systems lead to shorter downtime and lower operational expenses over time. Though the capital investment may be much higher than overhead systems, the long-term cost savings achieved through minimized maintenance costs and reduced outages and failures can justify the economic feasibility of underground power transmission.

However, the successful implementation of underground power systems relies on the collaboration of stakeholders and effective policy making. By considering the perspective of utility companies and operators, policymakers, and consumers, we can begin to create comprehensive policy frameworks that promote the adoption of resilient power infrastructure. Clear guidelines, incentive, and subsidies can empower utility providers to invest in long-term grid resilience to ensure the stable and affordable supply of electricity for all.

Underground power transmission systems offer a promising solution to address the challenges of an evolving energy landscape. Enhanced grid reliability, minimized disruptions, and reduced environmental impact, are all benefits that position underground systems as an effective strategy in future grid planning. By embracing the strengths of underground power transmission and through fostering stakeholder collaboration, we can pave the way towards a more resilient, sustainable, and secure electric grid, empowering homes, businesses, and industries with uninterrupted access to reliable electricity.

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