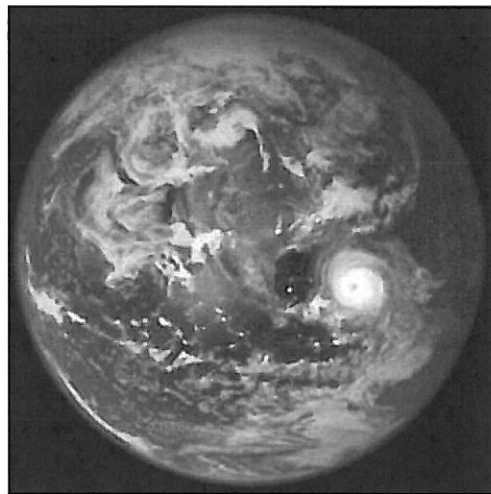




**Cost-Benefit Analysis of the
Deployment of Utility Infrastructure Upgrades
and Storm Hardening Programs**

FINAL REPORT



Prepared for: **Public Utility Commission of Texas
Project No. 36375**

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5.5 Underground Distribution

The conversion of overhead electric power facilities to underground has been a topic of discussion for more than twenty years. The topic has been studied, discussed, and debated many times at the state, municipal, and local levels. A detailed assessment of publically available documentation can be found in the report *Undergrounding Assessment Phase 1 Final Report: Literature Review and Analysis of Electric Distribution Overhead to Underground Conversion*, submitted to the Florida Public Service Commission per order PSC-06-0351-PAA-EI.

Analyses and investigations consistently find that the conversion of overhead electric distribution systems to underground is costly, and these costs are far in excess of the quantifiable storm benefits, except in rare cases where the facilities provide particularly high reliability gains or otherwise have a higher than average impact on community goals. This conclusion is reached consistently in many reports, which almost universally compare the initial cost of undergrounding to the expected quantifiable benefits. No prior cost-benefit study recommends broad-based undergrounding, but several recommend targeted undergrounding to achieve specific community goals.

As a rough estimate, the cost of converting existing overhead electric distribution lines and equipments to underground is expected to average about \$1 million per mile. In addition, there are costs required to convert individual home and business owner electric service and meter facilities so they will be compatible with the new underground system now providing them with electricity. Further, there are separate, additional costs associated with site restoration and placing third-party attachments underground.

When only considering the direct utility cost of a conversion from overhead to underground, studies find that undergrounding distribution facilities in residential neighborhoods served by investor-owned utilities would cost an average of about \$2,500 per residential customer affected. Undergrounding residential main-trunk feeders (those lines leading to residential neighborhoods) would cost an average of about \$11,000 per residential customer affected. Undergrounding all main trunk commercial feeders (those feeding business and office areas, etc.) would cost an average of about \$37,000 per commercial customer affected.



Costs in any particular situation could vary widely from these estimates depending upon electric system design, construction standards, customer density, local terrain, construction access issues, building type, and service type. Existing studies estimate the wholesale conversion of overhead electric distribution system to underground would require that electricity rates increase to approximately double their current level, or possibly more in areas with a particularly low customer density.

In return for the considerable expense, electric customers can receive a number of potential benefits from the undergrounding of their overhead systems. The following is a list of benefits most often mentioned in undergrounding reports and studies:

Potential Benefits of Underground Electric Facilities

- Improved aesthetics;
- Lower tree trimming cost;
- Lower storm damage and restoration cost;
- Fewer motor vehicle accidents;
- Reduced live-wire contact;
- Fewer outages during normal weather;
- Far fewer momentary interruptions;
- Improved utility relations regarding tree trimming; and
- Fewer structures impacting sidewalks.

There are a number of potential disadvantages which need to be considered whenever the conversion of overhead facilities to underground is evaluated. The following is a list of potential disadvantages most often mentioned in undergrounding reports and studies:

Potential Disadvantages of Underground Electric Facilities

- Stranded asset cost for existing overhead facilities;
- Environmental damage including soil erosion, and disruption of ecologically-sensitive habitat;
- Utility employee work hazards during vault and manhole inspections;
- Increased exposure to dig-ins;
- Longer duration interruptions and more customers impacted per outage;
- Susceptibility to flooding, storm surges, and damage during post-storm cleanup;
- Reduced flexibility for both operations and system expansion;
- Reduced life expectancy
- Higher maintenance and operating costs; and
- Higher cost for new data bandwidth.

The amount of overhead distribution within 50 miles of the Texas coastline is 28,263 miles. Assuming an average underground conversion cost of \$1 million per mile, the total conversion cost for this area amounts to an initial cost of \$28 billion. Assuming a 40 year life for underground facilities and a 10% discount rate, this amounts to an annual cost of \$2.9 billion per year.

The average total electric facilities restoration cost of hurricanes over the last ten years for Texas is \$180 million per year. The total societal cost of hurricanes is estimated at \$122 million per year (see Appendix B). Even if undergrounding eliminated all electric system damage and eliminates all societal cost (neither



close to true), underground conversion is not even close to being cost-effective. These results are similar to other analyses that have been done in other states.

Underground conversion can actually be detrimental in areas subject to storm surge damage. Overhead distribution facilities are generally much faster to repair compared to underground equipment that has been flooded, eroded away, or otherwise damaged by storm surges.

Undergrounding of new facilities is potentially cost-effective, provided the location is not subject to storm surge, depending upon the cost differential of overhead construction versus underground. A typical distribution structure costs about \$4000 to replace during hurricane restoration. The failure rate of poles can be approximated by the following equation:

$$\text{Wood Pole Failure Rate} = 0.0001 \times \exp(0.0421 \times W)$$

W is sustained wind speed in miles per hour.

This equation is explained in the report *Undergrounding Assessment Phase 3 Final Report: Ex Ante Cost and Benefit Modeling*, submitted to the Florida Public Service Commission per order PSC-06-0351-PAA-EI.

Using these assumptions, the cost per year in restoration costs can be computed for each of the hurricane prone areas. This analysis is shown in Table 5-6. The highest annual expected restoration cost is \$1.69 for the Corpus Christi area. Assuming a wood pole life of 60 years and a discount rate of 10%, this amounts to a present value of about \$16.85. With 40 distribution poles per mile, this amounts to \$674 per mile. Therefore, installing new facilities underground is worthwhile if the incremental cost per mile is less than \$674 per mile. This amount will vary based on region and distribution span length, but in any case will be small as a percentage of total construction cost since typical new overhead distribution facilities cost between \$100,000 and \$200,000 to construct.

Greater societal benefits will not result from hardening of new facilities since the percentage of hardened facilities is small and total storm restoration time is not likely to be affected.

Although the undergrounding of new distribution may not be justified purely on reduced hurricane damage, underground may be desirable for other reasons. If the primary issue is hurricane damage, hardening the overhead design may be more cost-effective. For example, a Class 1 pole is 50% stronger than a Class 5 pole, but typically only costs about \$200 more. At 40 poles per mile, this amounts to \$8000 per mile for a much stronger system. Because of these economics, some utilities in hurricane-prone areas design their distribution systems to Grade B construction rather than Grade C.



Table 5-6. Annual restoration cost of wood distribution poles.

	Hurricane Category					
	1	2	3	4	5	
	Annual Probability of Occurrence					
Beaumont-Port Arthur	4.45%	1.18%	0.38%	0.11%	0.01%	
Brownsville-Harlingen	1.61%	0.30%	0.08%	0.01%	0.01%	
Corpus Christi	4.34%	1.09%	0.42%	0.09%	0.07%	
Houston-Sugar Land-Baytown	3.54%	0.83%	0.17%	0.03%	0.00%	
Victoria	3.87%	0.75%	0.37%	0.03%	0.00%	
Sustained wind speed (mph)	84.5	103	120.5	143	168	
Failure rate	0.35%	0.76%	1.60%	4.12%	11.79%	
	Annual Restoration Cost (\$/yr)*					Total (\$/yr)
Beaumont-Port Arthur	0.62	0.36	0.24	0.18	0.05	1.46
Brownsville-Harlingen	0.23	0.09	0.05	0.02	0.05	0.43
Corpus Christi	0.61	0.33	0.27	0.15	0.33	1.69
Houston-Sugar Land-Baytown	0.50	0.25	0.11	0.05	0.00	0.91
Victoria	0.54	0.23	0.24	0.05	0.00	1.06

* -Annual restoration cost is equal to the restoration cost per structure (\$4,000) multiplied by the failure rate multiplied by the probability of occurrence. For example, the annual restoration cost in Beaumont-Port Arthur due to Category 1 hurricanes is $\$4,000 \times 0.35\% \times 4.45\% = \0.62 per year.

In terms of total conversion, there are 28,263 miles of overhead distribution within 50-miles of the Texas coast. At \$1 million per mile, total overhead to underground conversion is estimated to cost \$28 billion. Assuming that 70% of hurricane damage is eliminated (80% is due to distribution), annual reductions in utility restoration costs are \$126 million and annual societal benefits are \$85.4 million.

5.6 Underground Transmission

Underground transmission is extremely expensive. New underground transmission is roughly ten times the cost of overhead, and presents other technical challenges due to the high phase-to-ground capacitance. Hardening existing transmission structures has already been examined in Section 5.3, and has been shown to not be cost-effective. New transmission is already required to be built to NESC extreme wind criteria. Therefore, any incremental benefit in moving from an extreme-wind-rated overhead transmission design to underground will be minimal, although the additional cost will be substantial.

Using the hardened transmission failure rate assumptions represented in Figure 5-5, the cost per year in restoration costs can be computed for each of the hurricane-prone areas. This analysis is shown in Table 5-7. The highest annual expected restoration cost is \$25.18 for the Corpus Christi area. Assuming a transmission structure life of 60 years and a discount rate of 10%, this amounts to a present value of about \$251. With 10 transmission structures per mile, this amounts to \$2510 per mile. Therefore, installing new transmission facilities underground is worthwhile if the incremental cost per mile is less than \$2510 per mile. This amount will vary based on region and transmission span length, but in any case will be small as a percentage of total construction cost since typical new overhead transmission facilities cost \$1 million per mile or more.



Table 5-7. Annual restoration cost of wood transmission poles.

	Hurricane Category					
	1	2	3	4	5	
	Annual Probability of Occurrence					
Beaumont-Port Arthur	4.45%	1.18%	0.38%	0.11%	0.01%	
Brownsville-Harlingen	1.61%	0.30%	0.08%	0.01%	0.01%	
Corpus Christi	4.34%	1.09%	0.42%	0.09%	0.07%	
Houston-Sugar Land-Baytown	3.54%	0.83%	0.17%	0.03%	0.00%	
Victoria	3.87%	0.75%	0.37%	0.03%	0.00%	
Sustained wind speed (mph)	84.5	103	120.5	143	168	
Failure rate	0.12%	0.13%	0.77%	8.74%	34.64%	
	Annual Restoration Cost (\$/yr)					Total (\$/yr)
Beaumont-Port Arthur	3.20	0.92	1.76	5.77	2.08	13.73
Brownsville-Harlingen	1.16	0.23	0.37	0.52	2.08	4.37
Corpus Christi	3.12	0.85	1.94	4.72	14.55	25.18
Houston-Sugar Land-Baytown	2.55	0.65	0.79	1.57	0.00	5.55
Victoria	2.79	0.59	1.71	1.57	0.00	6.65

* -Annual restoration cost is equal to the restoration cost per structure (\$60,000) multiplied by the failure rate multiplied by the probability of occurrence. For example, the annual restoration cost in Beaumont-Port Arthur due to Category 1 hurricanes is \$60,000 x 0.12% x 4.45% = \$3.20 per year.

Like the case for distribution, greater societal benefits will not result from hardening of new facilities since the percentage of hardened facilities is small and total storm restoration time is not likely to be affected.

In terms of total conversion, there are 6,577 miles of overhead transmission within 50-miles of the Texas coast. At \$5 million per mile, total overhead to underground conversion is estimated to cost \$33 billion. Assuming that 15% of hurricane damage is eliminated (20% is due to transmission), annual reductions in utility restoration costs are \$27 million and annual societal benefits are \$18.3 million.



5.7 Targeted Storm Hardening

Hardening infrastructure for severe storms is an emerging but important topic. Ideally, a utility can compute the expected damage that will occur in future storms, compute the cost of various hardening options, and determine the expected damage reduction and societal benefits that will result from each of these options. This process allows for decisions to be made based on quantifiable costs and benefits, and goes far beyond the design of structures to a specific extreme wind speed.

There are four primary motivations for targeted storm hardening:

Primary motivations for targeted storm hardening

1. Keep high priority customers on,
2. Keep important structures standing,
3. Keep economic centers on, and
4. Strengthen structures that are likely to fail.

Keep high priority customers on. After a hurricane strikes, certain customers will be assigned a high priority for restoration. Examples include hospitals, dispatch centers, fire stations, and police stations. Regardless of where these high priority customers are on the system, crews must be assigned to quickly assess damage and make repairs. This can result in an inefficient use of crews when compared to an optimized restoration plan. Therefore, strengthening the system so that high priority customers remain on allows for faster and more cost-effective overall restoration.

Keep important structures standing. When a hurricane strikes, there are certain structures that utilities wish to keep standing. These include structures that are expensive to repair, take a long time to repair, are difficult to access, or are critical in the restoration process. Examples are structures with automation equipment, structure critical for Smart Grid functionality, structures used for freeway crossings, junction poles, and so forth. Therefore, strengthening the system so that certain structures remain intact allows for faster and more cost-effective overall restoration.

Keep economic centers on. From a customer perspective, life after a hurricane is much nicer if certain facilities are available such as gas stations, restaurants, and home improvement stores. There a utility may wish to harden certain areas so that economic centers with large concentrations of these types of customers can stay on or be more quickly restored.

Strengthen structures that are likely to fail. It may be desirable in certain cases to strengthen structures that are particularly vulnerable to failure, just so that less damage occurs. For example, extreme wind ratings could be calculated for all structures on a distribution circuit. All structures with an extreme wind rating lower than a specified value could be strengthened if practical.

There are a variety of ways to reduce the probability of a structure failing in a hurricane. Not all tactics are possible in all situations, but the following describes the major available approaches:

Stronger Structures. Structure strength is one of the most important factors for extreme wind rating. This is true for new construction, where stronger structures allow for longer spacing between structures, and upgrading of existing construction, where extreme wind ratings can be increased by upgrading exist-



ing structures with stronger structures. When selecting a structure, there are several important factors that must be considered. These factors include weight, visual impact, wind performance, insulating qualities, corrosion, and climbability.

Upgraded Poles. There are several ways to increase the strength of an existing pole. This includes using an extended-length steel brace that is driven below the groundline and extends above any third-party attachments. This can typically increase the strength of the pole by two to three pole classes. Another approach is to increase the strength of the pole with a fiberglass wrap, although this is much more expensive.

Shorter Spans. Shorter spans directly result in a higher extreme wind rating. Using shorter spans also allows hardened systems to use standard construction practices and materials. For this reason, shorter spans should always be considered as an approach to hardening. However, sometimes it is not practical to shorten spans in certain areas, and in many places, the span length required to meet extreme wind criteria would result in many close-spaced poles and a corresponding high visual impact.

Storm Guying and Push Braces. Adding transverse guys to existing poles (one on each side) serves to transfer some or all of the stress from wind forces from the pole to the guy wires, thus enhancing the overall ability of the installation to survive the storm event. Adding push braces to existing poles can provide similar benefits to adding storm guys.

Pole-Mounted Equipment. Wind forces on pole-mounted equipment transmit force to the pole in addition to forces generated by conductor, attachments, and the pole itself. Therefore, wind forces on pole-mounted equipment must be considered in the hardening analysis, especially for higher gust speeds. Equipment mounted on poles can significantly impact the maximum allowed span, especially for the higher extreme wind ratings. Therefore, it is important to understand this effect and potentially leverage it when considering hardening alternatives (e.g., converting a three-phase pole-mounted transformer bank to a pad-mounted unit).

Third-Party Attachments. For hardening purposes, the benefits of fewer attachments are reflected in the extreme wind rating of the overall design including pole height, pole strength, span length, conductors, attachments, and other pole loading considerations. All else equal, fewer and/or smaller attachments will result in a reduced probability of failure during a hurricane. Removing third-party attachments can be an effective way to increase extreme wind ratings from an engineering perspective. The practicality of removing third-party attachments will vary for each specific situation.

Pole Hardware. Wind forces can have adverse effects on framing materials such as insulators, crossarms, conductor ties/clamps, brackets, and other associated hardware. Use of stronger design standards can reduce damage in these areas.

Undergrounding. The conversion of overhead distribution to underground removes extreme wind as a design factor. This is almost always more expensive than bringing the overhead system up to extreme wind ratings.

Increased performance expectations for major storms will result in certain utilities choosing to exceed safety standards in an effort to reduce storm damage. This decision to harden the system is potentially expensive. It is therefore desirable to define a clear strategy for hardening and to translate this strategy into a hardening roadmap that identifies anticipated actions, costs, and benefits.



Cost-to-Benefit of Targeted Hardening of Transmission

For cost-to-benefit calculations, it is assumed that utilities harden 5% of transmission structures at a cost of \$60,000 per structure. This amounts to 40,000 hardened structures at a cost of \$2.4 billion. Historically, transmission has amounted to about 20% of restoration costs, or about \$36 million per year. It is assumed that each of the hardened transmission structures previously contributed to proportionally five times more to restoration times than typical structures. Therefore, the estimated savings in utility restoration costs is $\$36 \text{ million} \times 25\% = \$9 \text{ million per year}$.

The societal cost of hurricanes is estimated to be \$122 million per year, with about 20% due to transmission damage. Therefore, the estimated societal benefits of targeted transmission hardening is $\$122 \text{ million} \times 20\% \times 25\% = \$6.1 \text{ million per year}$.

Since Entergy Texas has experienced high transmission structures in several Hurricanes, a separate cost-to-benefit analysis is warranted. Entergy Texas has 27,000 transmission structures. Hardening 5% of these structures at \$60,000 per structure will cost \$81 million. With an expected life of 60 years and a discount rate of 10%, \$81 million is equal to \$8.13 million per year for sixty years.

It is assumed that targeted hardening can reduce transmission damage at Entergy Texas by 50%. The average transmission damage to Entergy Texas since 1998 is \$13.5 million per year, resulting in estimated restoration savings of \$6.8 million per year. Societal cost of hurricanes in the Beaumont-Port Arthur MSA is \$6.15 million per year. Transmission accounted for 14% of Entergy Texas restoration costs. Assuming that targeted hardening can reduce total restoration time by 7% results in a societal benefit of \$430,500 per year.

Based on this analysis, targeted hardening of the Entergy Texas system is potentially cost-effective and should be investigated in more detail.

Cost-to-Benefit of Targeted Hardening of Distribution

For cost-to-benefit calculations, it is assumed that utilities harden 10% of distribution circuits and 10% of poles within these targeted circuits. This amounts to 160,000 hardened distribution poles. At an assumed \$2,000 per hardened pole, this amounts to \$320 million. With an expected life of 40 years and a discount rate of 10%, \$320 million is equal to \$33 million per year for forty years.

Historically, distribution has amounted to about 80% of restoration costs, or about \$144 million per year. It is assumed that each of the hardened distribution poles previously contributed to proportionally ten times more to restoration times than typical poles (including higher failure rates and higher impact to repair times). Therefore, the estimated savings in utility restoration costs is $\$144 \text{ million} \times 10\% = \$14.4 \text{ million per year}$.

The societal cost of hurricanes is estimated to be \$122 million per year, with about 80% due to distribution damage. Therefore, the estimated societal benefits of targeted distribution hardening is $\$122 \text{ million} \times 80\% \times 10\% = \$9.8 \text{ million per year}$.



Cost-to-Benefit of Targeted Hardening of Transmission

For cost-to-benefit calculations, it is assumed that utilities harden 5% of transmission structures at a cost of \$60,000 per structure. This amounts to 40,000 hardened structures at a cost of \$2.4 billion. Historically, transmission has amounted to about 20% of restoration costs, or about \$36 million per year. It is assumed that each of the hardened transmission structures previously contributed to proportionally five times more to restoration times than typical structures. Therefore, the estimated savings in utility restoration costs is $\$36 \text{ million} \times 25\% = \$9 \text{ million per year}$.

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For cost-to-benefit calculations, it is assumed that utilities harden 10% of distribution circuits and 10% of poles within these targeted circuits. This amounts to 160,000 hardened distribution poles. At an assumed \$2,000 per hardened pole, this amounts to \$320 million. With an expected life of 40 years and a discount rate of 10%, \$320 million is equal to \$33 million per year for forty years.

Historically, distribution has amounted to about 80% of restoration costs, or about \$144 million per year. It is assumed that each of the hardened distribution poles previously contributed to proportionally ten times more to restoration times than typical poles (including higher failure rates and higher impact to repair times). Therefore, the estimated savings in utility restoration costs is $\$144 \text{ million} \times 10\% = \$14.4 \text{ million per year}$.

The societal cost of hurricanes is estimated to be \$122 million per year, with about 80% due to distribution damage. Therefore, the estimated societal benefits of targeted distribution hardening is $\$122 \text{ million} \times 80\% \times 10\% = \$9.8 \text{ million per year}$.