

WHITE PAPER

Make It Strong: The First Step in Modernizing the U.S. Grid

By Doug Houseman

The grid is undergoing more change today than it has seen in the last 60 years. A typical household's load in the 1960s was less than half of what it is today — 60 amps compared to 200 amps. Safety measures built into the grid allowed it to absorb load changes without serious issues until recently, and now utilities must develop strategies that will keep the grid strong into the future.



With the advent of air conditioning, transmission systems became the focus of utility investment during the cooling revolution of the 1960s, especially when it became clear that added grid strength would be required to prevent large-scale blackouts such as those in 1965 and 1977.

Based on the generally accepted distribution asset depreciation life of 40 years, one would assume that these decades-old systems would by now have been replaced with larger conductors, stronger poles and other changes. Unfortunately, the reality is that utilities often assume the attitude of “if ain’t broke, don’t fix it.” Based on Federal Energy Regulation Commission (FERC) data, the distribution asset

replacement rate is closer to once every 100 years. That means that roughly 50% of the grid equipment that was in place in 1970 is still in use today.

With electric vehicles, distributed generation, lower customer tolerance for outages and the move toward all-electric households just beginning, the grid once again is being asked to do far more than it was designed to do. Historically, safety factors meant the grid had spare capacity. Today much of that spare capacity has been used, which means extensive grid upgrades are necessary. Doing so will provide added strength, starting utilities down a path of building strong, smart and sustainable power grids.

Why Strengthen the Grid Now?

There are three major reasons — and hundreds of smaller ones — for making the grid stronger.

1. **Weather-related events.** Populations have grown in areas where weather-related events — be they hurricanes, tornadoes, floods or fire — will impact them. People have moved into forested areas, where large trees overhang power lines and homes. Others have moved to the edge of rivers and oceans, causing a 40% increase in population in coastal areas from 1970 to 2010, according to National Oceanic and Atmospheric Administration data. In other areas, general population growth has put far more people and assets in the path of extreme weather.

In many cases the value of homes and real estate has skyrocketed. What may have been a summer cottage with cast-off furniture in the 1970s could be a year-round home today, with a price near the upper end of the local market. This puts a much higher percentage of a family's wealth at risk in an extreme weather event.

2. **Distributed generation.** By far the fastest-growing demands of the grid in the last decade have come from distributed generation, primarily in photovoltaic (solar) generation. Solar has quickly grown from an uncommon and insignificant form of generation in the 1990s to producing enough power to cause reverse flow to substations in some distribution circuits in Hawaii and California.

While the trend toward solar has moved more slowly in other areas, it is growing. At DistribuTECH 2020, a survey of utilities from every part of the U.S. and Canada showed that solar projects doubled in 2018 and doubled again in 2019. For some utilities, the trend is just beginning and an occasional request for interconnection is seen. For others, the trend is impacting overall distribution design and construction.

The average home solar installation is becoming larger, too. According to the Solar Energy Industries Association, the average home installation in 2011 was just 5 kilowatts (kW). By 2018, it was 10 kW, doubling in seven years. The costs of system components have fallen enough that today a 10-kW system costs less than the 5-kW system did in 2011, according to data from Wood Mackenzie. Even in Louisiana — where residential energy rates are under \$0.09 per kilowatt-hour (kWh) — solar is taking hold, and the number of applications is increasing at a similar rate to that seen by other utilities with higher rates.

In Michigan, for example, it takes 6.64 kW of solar generation to meet a 1 kW per-hour flat load. The customer will export just under 70% of total production over the course of a year, and then reimport it, sometimes months after the power was produced. Because of this bidirectional power flow, the typical net-zero customer in Michigan uses 20% more distribution over the course of a year than a non-solar customer. From a pure grid capacity point of view, these customers use over three times more capacity than a non-solar customer uses.

3. **Electrification.** Electrification is coming, but how fast is still uncertain. Electric vehicles are already being considered in many scenarios, and substitution of electricity for fossil fuels now used for heating, hot water, cooking and other purposes will happen eventually.

Transportation alone represents a third of energy usage in the U.S.; simply electrifying all means of transportation will double the total electricity required. Add to this the generation required for the electrification of the rest of the economy and electric energy use could easily increase by 2.5 times.

Thoughtful application of energy efficiency measures could lighten that load. By 2022, if the major U.S. automakers keep to their schedules, electric vehicles in every segment should be available from almost every automotive dealer in North America. Again, the speed of this transition is unknown and will vary both by state and on changing federal regulations and incentives.

Some will argue that the issues with such initiatives are easy to solve by simply adding energy storage with solar at every building, thus limiting the need for the electric grid. If the only juxtaposition between generation and demand were the day/night cycle, these critics would be correct. However, there is also a seasonal cycle that requires that the grid continue to exist and to be strengthened.

As an example, a typical residential consumer in Ottawa, Ontario, could install 4 kW of solar generation and supporting batteries and do day/night shifting without a problem in June. But in December that consumer would need 40 kW of solar generation capacity to cover its 24-hour power needs. If that consumer adds an electric vehicle and an average commute to the current home power consumption, the individual's need for solar generation in December jumps to almost 100 kW.

The farther south the location of the residence, the lower the seasonal mismatch between solar production and hourly demand becomes. However, some seasonal mismatch is inescapable in locations where seasonal changes are evident.

Tenets of Strong

Overhead transmission and distribution make up the vast majority of the grid in North America and represent a large portion of the distribution grid in the rest of the world. The distribution system was built overhead because overhead is faster, more cost-efficient to build and easier to maintain. It is, however, subject to weather, wind, fires, trees, squirrels and even automobiles.

To minimize these problems without requiring utilities and their customers to absorb the cost of transitioning existing overhead lines to underground lines, some changes are recommended to legacy practices:

1. Use poles that are rated to withstand the maximum expected wind loading for their expected life. New poles will be sized to survive various conditions, but is the pole with average wear going to survive a 10-, 20- or even 80-year replacement cycle, as the FERC data suggests? Concrete, steel and laminate poles show less wear and are less susceptible to insects and other biological attack than wooden poles.

2. In towns and along rural roads, trees have grown taller. In the 1940s and 1950s, when most suburbs were built, small saplings were planted under the overhead conductors as “street trees” meant to spruce up the neighborhood. Fast forward to 2020, and 70 to 80 years of growth have made many of these trees 40 to 80 feet high, providing shade but also creating squirrel habitat and putting them in the path of power lines.

Some utilities have turned to a Y-type vegetation management method, dividing the tree into two parts with an opening in the middle for the conductors. This can work well, but if the trees are attacked by insects — as ash trees were by the emerald ash borer in the upper Midwest — then there is potential for them to fall and take the lines down with them.

Increasing line height on taller poles puts the lines above the larger limbs of even mature trees. This method has the added benefit of allowing the lines to be spaced farther apart in vertical construction, increasing the basic insulation level (BIL) and providing the opportunity to increase the circuit voltage in the future when electric vehicles and heating increase demand.

3. Legacy circuits often take shortcuts through fields and forests. While tree wire can help reduce the risks of this practice, the reality is the parts of the circuit that are not near the road need to be moved there for ease of maintenance, reduced vegetation management, ease of inspection and reduced outage risk.

4. As the distribution system grew, one method of providing additional electricity was to double or triple circuits on a pole rather than running higher voltage conductors, finding a different right-of-way or building new substations. Not only does this method add to the wind loading of that pole and reduce resiliency, but it makes it slightly more hazardous to work on the system to repair one circuit.

Returning to the standard of a single circuit on a pole helps fix these issues and provides an opportunity to add to resiliency by using larger conductors to create capacity to backfeed another circuit in an outage. It does add cost to the system, which must be weighed against the benefits of resiliency, reliability and safety.

5. Wind loading increases when transformers and other equipment are installed on a pole. As the requirements increase to add more fiber bundles and telecommunications equipment to a pole to support 5G telecoms, the communications zone on utility poles will become very full. In some communities where 5G must use the highest approved frequencies, antennas the size of large trash cans are going to appear on pole tops, further adding to that wind loading.

Moving as much utility equipment as possible to a pad-mount design helps minimize wind loading — especially the asymmetric wind loading — on the poles. Telecommunications upgrades will drive pole loading studies and replacement; utilities should take full advantage of these pole replacements to use taller, bigger poles.

6. Electric vehicles are probably going to come into mainstream use within the lifetime of insulators and conductors being installed today (given the 40-year-plus replacement cycle). Instead of replacing these assets or building new circuits based on old standards, utilities can strengthen the grid by creating new standards for construction, rebuild and repair that provide capacity for future voltage upgrades when they become necessary. Typically, the equipment costs for a rebuild are outweighed by the labor and other costs.

Ideally a standard future voltage class would be used for procurement and construction standards. In most cases, 34.5 kV with 795 conductors would provide enough capacity for future needs. In longer circuits where there has been significant housing infill over time, the circuit might still need to be split and a second circuit installed in the area, particularly as electric vehicle load grows. Upgrading the insulators on the circuit to a higher voltage class also means the likelihood of voltage flashover decreases significantly.

7. Increasing conductor spacing to meet BIL and avian standards is useful to prevent several animal-related issues and to limit damage from lightning and fault currents. While the Institute of Electrical and Electronics Engineers' 1410 standard offers more "how to" than a strict table of recommended spacings, the math can be done and conductor spacing in all the construction standards can be determined.

If all future construction and rebuilding is done to a single future voltage class design, then the time and energy to determine BIL and the amount of double checking needed is limited. The result of this small effort will be fewer squirrel-caused outages and less damage in the long run to utility and customer equipment from lightning and other sources.

8. To maintain BIL as voltages get higher, the spacing between conductors must increase and so must the crossarm length in horizontal construction. Moving to vertical construction for future designs removes the long crossarm from the pole, reducing the wind loading and the tipping moment. Crew retraining will be required for building and maintaining vertical construction and new construction standards will need to be written. Balancing this effort and cost are lower wind loading, ease of tapping all three phases, reduced animal-induced outages and high resistance to storm-induced issues. Installing all the conductors on one side of the pole also provides a safer path from the 5G telecommunications antennas to the equipment boxes and fiber optics in the communications zone.
9. Placing bayonets and the neutral wire on the top of the pole is going to become harder to install and maintain. As telecommunications companies work to use the existing pole tops for 5G antennas and get support from regulators for that access, utilities will be asked to rework circuits to leave the top 6 inches to 36 inches of the pole for antenna mounts.

Updating standards for construction now, instead of later, will mean that as the requests start happening, the cost of rebuilding the circuit can be split with the telecommunications company. It also means that "field fixes" engineered by the line crew will not be the primary redesign of the circuit. Creating this standard early and teaching crews how to use it will preserve engineered characteristics of the circuit.

10. Preventing conductors from breaking due to a tree fall — while also making sure they do not take the pole down instead — is useful for impacts from smaller trees and limbs. Clamp-top insulators provide some of that assurance. When a smaller tree impacts the line, the clamp-top can spread the impact across the span

and allow more slack into the span where the tree strike happened.

There are issues with the sag of the affected conductor and the possibility that they may cause a short in the system if conductors are too close together. Also, once the tree is cleared, crews must add tension to the conductor to even out the catenary. A side benefit of this practice is that clamp-top insulators tend to be faster to install and to attach to conductors.

11. Fire-resistant designs need to rely on one of four methods of design. First, there is undergrounding the line. This is costly, time consuming and potentially not permitted by local authorities. Second is a covered conductor. The issue with this method is that not all accessories for the covered conductor may be as effective at preventing fires as the conductor itself. As splices are added, they must be done correctly to maintain fire resistance. The third approach is adding fast ground fault interrupters (GFI) to the circuit. The fast GFIs autonomously stop the flow of current in the circuit. Finally, there is the option of combining taller and stronger poles with excellent vegetation management on 100% of the circuit — no exceptions. This approach has drawbacks in operation and maintenance costs, as well as potential landowners who will fight to save a tree. There is no perfect answer for preventing a fire and neither design nor maintenance alone can provide for a fire-free system.

Many of these items, taken individually, are simple adjustments to existing construction and material standards and may not seem worth the effort. However, when taken together as a package to build a grid that can support future electrification efforts in increasingly hostile environments, these items make a significant difference in preparing the system for such needs. Additionally, they provide higher reliability even in bad weather conditions and reduce operations and maintenance cost in the long run.

Underground

Today, more of the grid is being placed underground, minimizing issues with certain types of weather and accidents. Undergrounding is up to five times as expensive per mile as overhead transmission; even so, some communities are mandating any new or rebuilt circuits be placed underground.

Direct burial cable installed between 1965 and 1980 was mostly composed of an insulated cable that had a flaw in the insulation material and now requires either total replacement or the injection of gel to prevent further electrical treeing. Both methods are being done with success, but this work adds to the cost of maintaining existing underground systems.

Buried cable location was approximated on many drawings, being routed around trees and other objects, or laid in the approximate location of the drawings for expediency. This means that finding issues with underground cables in order to repair or replace them takes extra time. Groundpenetrating radar can be helpful in updating actual locations of underground cable.

Many of the conduits that were installed before 1990 were concrete or clay pipes, installed under streets that now see much heavier vehicles and heavier traffic. As such, these conduits have, in many places, collapsed. The use of ground-penetrating radar can find the locations of such collapsed conduit.

With the electrification of transportation and other areas where fossil fuel is used, larger or higher numbers of conductors are going to be needed. In an underground system, large cables are hard to pull, especially around bends. Changing standards to provide larger conduits and larger radius corners will make both of those upgrade options easier. Oversizing conduit for today's needs, will mean that if strong enough conduit is used that larger or more conductor can be pulled at a future date. Another alternative is to install an extra circuit's worth of conduit when trenches are opened to install new duct banks.

An advantage of installing larger underground conduit is that longer lengths of conductor can be installed in a single pull. Georgia Power, for example, has pulled underground cables over 1,500 feet, with better conduit design and specialized equipment. Since splices are the cause of 70% of outages in the underground system, the longer distances between splices can mean fewer outages and less operations and maintenance cost.

Underground conductors should have high-quality jackets to avoid future electrical treeing incidents. Ideally, underground conductors will last for 50 or more years when properly installed and spliced. The extra capital cost for quality cables typically can be justified with reduced costs for operations and maintenance.

Like overhead systems, underground cable systems should work to pad-mount as much of the accessory equipment as possible. This allows for quicker, safer inspections and battery changes and makes wireless communications more reliable. While excellent, highly durable antennas exist to be installed in the center of manhole covers, pad mounting is in the long run easier to deal with from an operations and maintenance standpoint. The other advantage of pad mounting is that less training and fewer stock keeping units are required when the underground system equipment matches overhead equipment.

Paper-wrapped lead splices are commonly disliked among utility workers. They require work to be performed in extremely tight quarters with little room to move and at chest height to the worker. When stacked brick was used to provide support for manholes, this kind of tight quarters was required. Today, structural design has advanced so significantly that manholes and vaults can be made large enough to support all maintenance activities.

With arc flash, air quality and other safety concerns, these larger underground structures are justified. Installing permanent cable racks and monitoring equipment in these spaces becomes both possible and desirable. High-pressure air lines can be permanently installed in manholes, ready for a hookup to a compressor or tank on the truck. This means faster degassing and a quicker turnaround for inspections and maintenance, just as airline hose masks or air packs provide for utility workers. Permanent insertion points for safety rails and hoist rigs also lessen setup time and make the equipment safer and sturdier. These measures add up to make workers safer, reducing the chance of injury while entering and leaving an underground structure.

In spot networks, the standard is to avoid having multiple feeders that follow the same route. Larger vaults provide the means to put distance between feeders when required. They give space to create fire-resistant structures in the manhole to shield one or more feeders from the rest of the conductors in the vault. New materials that provide better fire resistance are on the market, and standards engineers should consider adopting them.

Strength for the Future

Larger or higher numbers of conductors are going to be needed if we are indeed to electrify society as a whole, covering urban, suburban and rural areas. Batteries and local generation may eventually reduce the need for the grid to provide peak power as frequently. Instead, the consumer will dip into local storage to fill their needs. One issue with this scenario is that if consumers in the northern half of the United States or almost anywhere in Canada rely purely on solar but have only a day or two of battery capacity, they will need up to 20 times more generation to be fully independent of the grid.

Expecting that most single-family homes can be independent is difficult to imagine based on size and cost of doing so with solar alone. In cities it is even harder to imagine, as space does not exist in urban areas to produce all the power needed locally from solar. The taller the average building in a city, the more power will have to be made elsewhere and brought into the city by a grid of some sort. Planning on more or larger conductors being required to support society is a prudent idea.

Too often, providing a temporary generation feed into a circuit requires on-the-spot engineering work. This work, in many cases, delays the temporary hookups that would return some customers to service. Planning for and creating jumper points both in the overhead and underground systems is recommended. This will allow a crew to quickly choose a site for temporary generation and install it. It also provides operators and dispatchers with known points of interconnection.

It takes a lot more than what is covered here to build strength into a modernized grid. But using these tools and others more specialized to serve particular regions and situations can allow utilities to begin the journey down the path to a strong, smart and sustainable grid of the future.

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