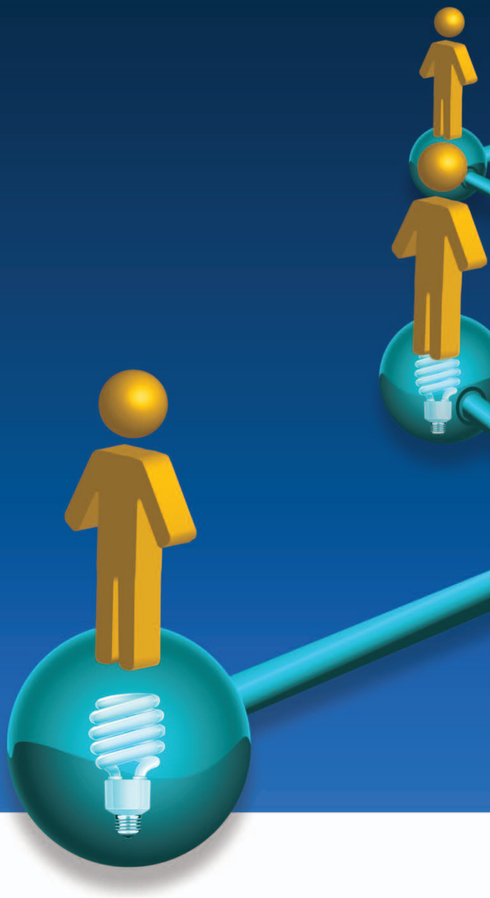
# The Local Team

## Leveraging Distributed Resources to Improve Resilience



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IN RECENT YEARS, EXTREME WEATHER EVENTS HAVE severely affected the performance of the electric grid. Very large-scale events (VLSE) with potentially catastrophic impacts on the grid pose more than an inconvenience in today's electricity-driven lifestyle, and the frequency and severity of such events may continue to increase as a consequence of global climate change. This article summarizes the state of the art in leveraging distributed resources to improve resilience of the electric grid. It also highlights the technical questions that need to be addressed through additional research and development if the value of distributed resources is to be maximized.

### VLSE Costs and Mitigation Strategies

The electric grid represents a critical vulnerability of modern society. VLSEs associated with catastrophic failures of the electric grid and other infrastructure have occurred with increasing frequency and severity in recent years, a trend that may continue in the face of climate change. A 2014 report by the U.N. Intergovernmental Panel on Climate Change (IPCC) addresses the vulnerability and exposure of human systems and infrastructures to climate-related extremes such as floods, cyclones, and wildfires and also points out a significant lack of preparedness for current climate variability in countries at all levels of development.

Along with intentional violations of the cyber and physical security of the electric grid, the issue of resilience with respect to VLSEs has attracted the attention of governments, the power industry, and electric customers. It is also important to recognize

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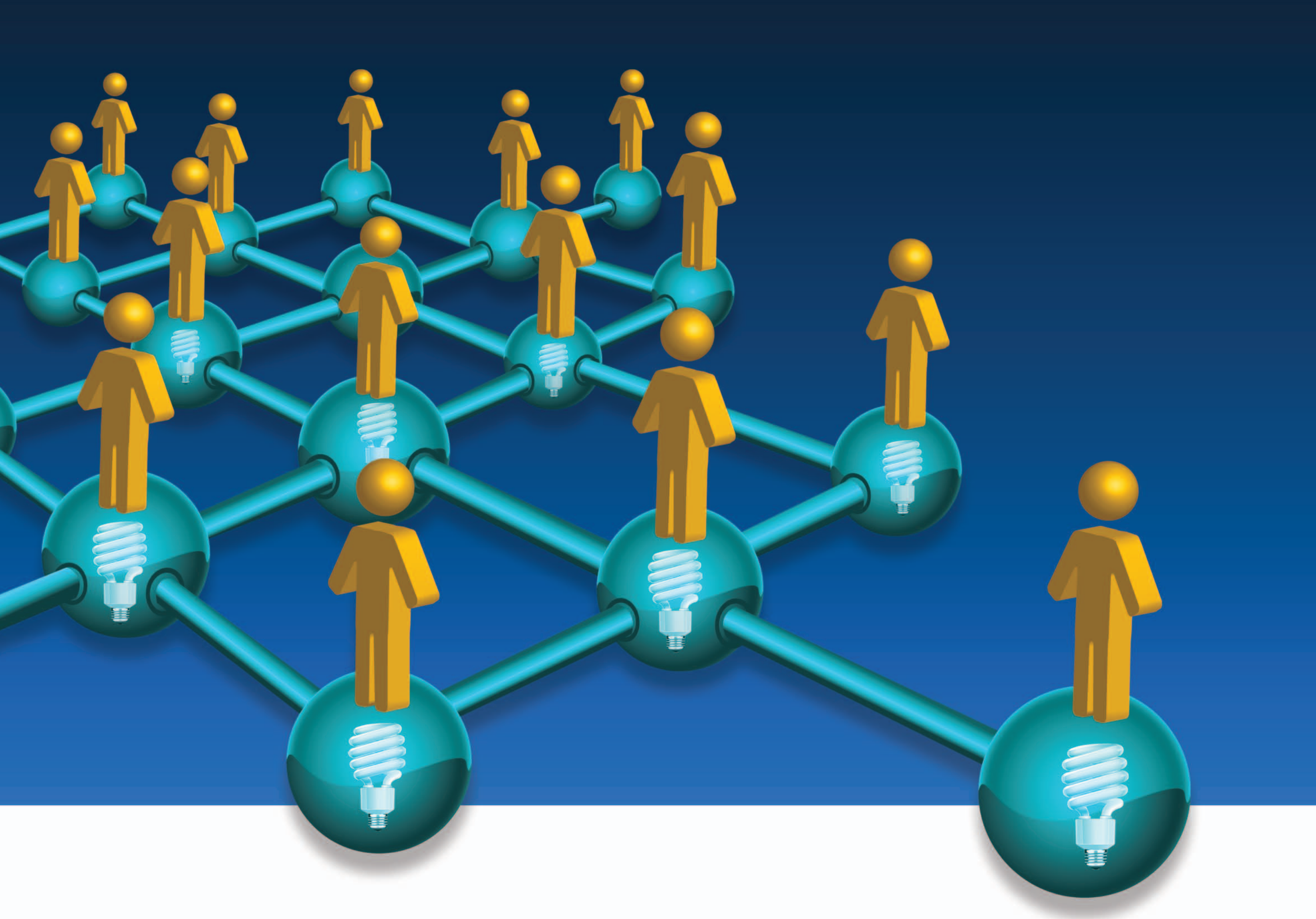
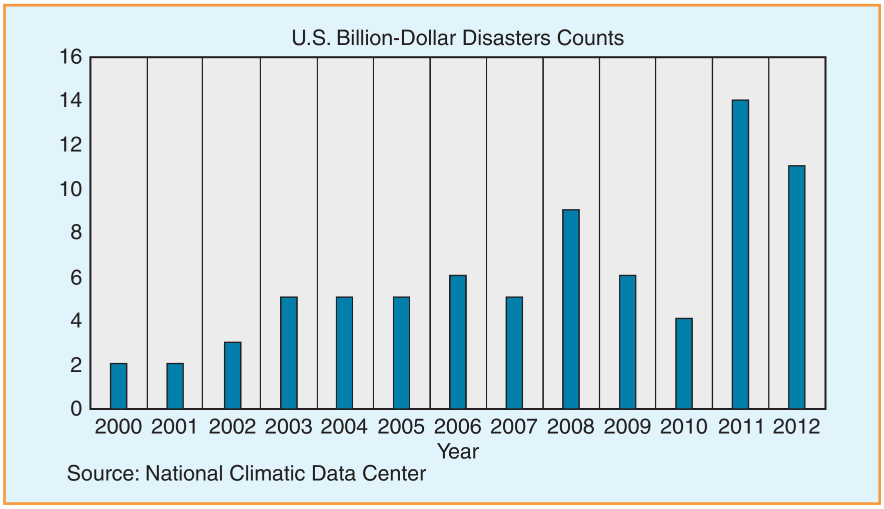


that the impacts of VLSEs extend far beyond the electric grid because of the high level of interdependency among infrastructure networks in sectors such as communication, transportation, and water supply. Figure 1 illustrates the growing number of natural disasters in the United States that have caused more than a billion U.S. dollars' worth of damages. Note that the total social, political, and economic impacts resulting from a lack of access to electricity could exceed these estimated damages.

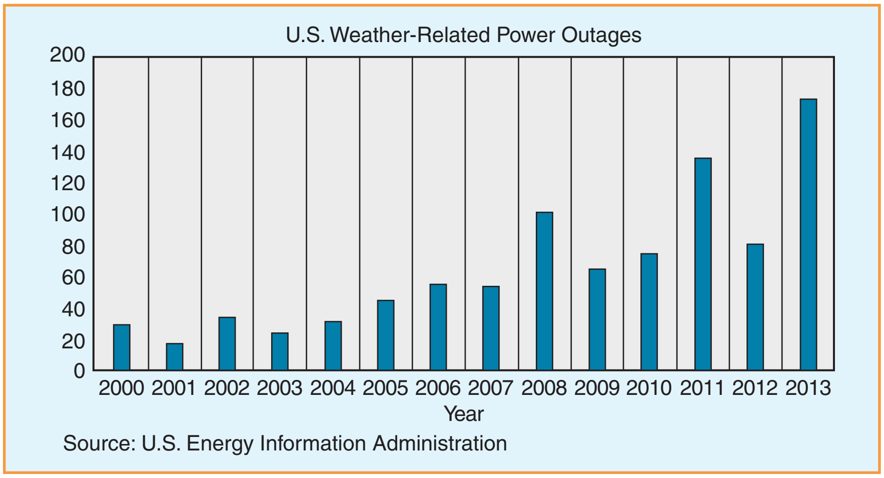
Severe weather is already the leading cause of power outages in the United States, accounting for 87% of outages according to the 2013 report of the Executive Office of the U.S. President. A recent congressional study estimates the average annual cost of outages related to severe weather at between US$25 billion and US$70 billion. Distribution networks are the most vulnerable parts of the electric grid. It has been estimated that 90% of electricity customer outages in the United States are related to distribution network problems. Figure 2 shows the number of power outages related to weather conditions; it is based on a database maintained by the Energy Information Administration of the U.S. Department of Energy (DOE).



Source: National Climatic Data Center

**figure 1.** The number of natural disasters in the United States with more than a billion U.S. dollars' worth of damages.

Interdependencies among infrastructure components create the risk of cascading effects during and after a VLSE. Moreover, utilities investing in the smart grid and modernization are implementing advanced information technologies and new media for communication, control, and



Source: U.S. Energy Information Administration

**figure 2.** The number of bulk power outages related to U.S. weather conditions.

computation. It is generally expected that cybercomponents and applications will increase the operability, reliability, and controllability of the grid. But they also introduce greater vulnerability to cascading effects via cyber-physical interdependencies.

The cyber and physical resilience of transmission and distribution (T&D) networks must be a temporal, agile, and holistic practice that makes the electric grid less vulnerable to outages and reduces the time of service recovery. Many U.S. utilities now have initiatives to improve grid resilience and the responsiveness of loads. Examples include programs for T&D grid reinforcements; smart grid technology implementations (e.g., automated demand response); reliable and interoperable communication infrastructure; better vegetation management; extended mutual aid agreements; incident management process improvements; and emergency preparedness. There are several related multiutility initiatives led by utility organizations, as well as initiatives led by federal and state government agencies to improve grid resilience. For example, the Federal Emergency Management Agency (FEMA) has implemented the Incident Command System, and the U.S. Department of Homeland Security has initiated various programs to protect critical infrastructure, such as the DOE-led Emergency Support Function 12, aimed at improving preventive measures, restoration, and recovery of energy supply systems. The Connecticut legislature is also providing microgrid grants and loans to enhance emergency preparedness and response.

Hardening the distribution network is the other approach for preventing or mitigating the catastrophic effects of weather-related disruptions. Structurally reinforcing towers and poles is one effective way to increase robustness. Vegetation management is crucial for preventing faults, especially in distribution networks. Utility customers with sensitive loads guard against VLSEs by hardening their networks and increasing their on-site backup and renewable generation capabilities, their storage capacity, and their participation in demand response programs. Federal and state governments are committing R&D funds to accelerate the development of the requisite technology and standards; a recent example is the DOE-led initiative to standardize the microgrid interface.

This article proposes that one of the crucial values of distributed resources to society stems from their contribution to grid resilience during emergency operating conditions associated with VLSEs. Distributed resources—including standby generation, distributed generation, distributed storage, microgrids, and demand response mechanisms—can play an important role in helping the grid survive and recover from extreme events. With rapidly maturing technologies and growing penetrations of distributed resources, their potential to provide local energy (or "negawatts") as well as more advanced ancillary services including operating reserve, spinning reserve, frequency regulation, and voltage regulation is being recognized. To date, these capabilities have been primarily considered in the context of T&D network operations, often in terms of the challenges involved in integrating various advanced distributed resources functionalities with the legacy distribution infrastructure.

The supporting role of distributed resources for resilience during and after a VLSE reflects a combination of the roles of central generating units at the transmission level, switching operations at the distribution level, and customer-side response strategies. They include provision of local energy and ancillary services, support for essential congestion management, and restoration processes, including islanding schemes that are adaptive to circumstances. Some of these roles are understood and proven while others remain to be investigated and demonstrated.

It is vital that we fully explore the role that distributed resources can play to enhance grid resilience. Indeed, the response to VLSEs could prove a crucial test for distributed resources capabilities—or, if we fail to prepare, an opportunity lost.

## Assessing Grid Resilience with Distributed Resources

Resilience with respect to VLSEs requires knowledge of a system's behavior and its ability to flexibly accommodate quick changes without a severe decline in performance. Resilience therefore begins with electric grid identification and the characterization of distributed resources. Distribution network topology, network physical characteristics, operational constraints, and distributed resource capacities are all clarified in the network identification step. The next step is network vulnerability analysis. The consequences of disturbances or disruptive events are time dependent, as are the system's adaptive responses and its recovery speed. Vulnerability analysis therefore requires taking into account system response before, during, and after disturbances.

Resilience operation is another part of the system resilience framework. The ultimate goal of a resilient system is to maintain system functionality after disturbing events. Resilience operation control defines new settings and equilibrium points for the distributed resources. It has two main components: "grid recovery potential" and "grid absorbing potential." This means that the system can absorb disturbances, adapt itself to the disturbing events, then recover fast enough to mitigate disturbing event consequences. Figure 3 illustrates this resilience assessment framework for the electric grid.

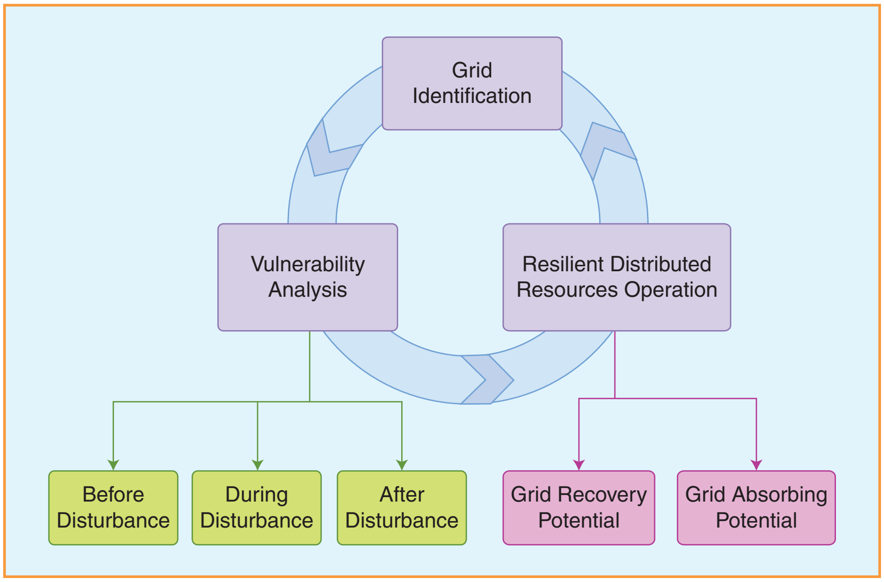


**figure 3.** A resilience assessment framework for power T&D networks.

Disturbance absorption in T&D networks depends on a range of factors that include component design characteristics, system topology, control philosophy, and protection coordination. The recovery potential is also characterized by the speed of the power system's return to its normal or restorative state.

As mentioned above, the majority of physical vulnerabilities are related to the disruption of overhead distribution and transmission lines following severe weather. Faults caused by contact between conductors and ground are a major source of service interruptions, safety hazards, and fires; transformers are second among the most vulnerable components in T&D networks. Hardening the T&D system is one approach to prevent or mitigate the catastrophic impact of weather-related disruptions. Structural reinforcements and vegetation management are thus among the most effective actions that can be taken to increase robustness.

Beyond robustness, however, system resilience involves active adaptation to conditions during and after disruptive events. By introducing a vast range of new possibilities for operating and control actions that can be taken at the distribution level, the presence of distributed resources brings a fundamentally new complexity to resilience analysis. These possibilities need to be studied carefully so that existing assets can be leveraged for maximal advantage—not *if* but *when* the next VLSE occurs.

## Overview of Distributed Energy Resource Technologies

In this article we use the term *distributed resources* to refer to distributed energy resources (DERs) as well as demand response (DR) resources. On the generation side, DERs include resources such as solar PV that are typically installed by electric customers on their side of the meter, either to increase reliability or to partially supply the customer's own load to reduce the electric bill. Their operation is subject to an interconnection agreement with the local electric utility. Most such agreements require compliance with applicable engineering standards (primarily IEEE 1547) and are intended to ensure that the DER interconnection is safe, does not adversely affect power quality for other customers, and is compliant with regulatory rules. The exact requirements vary by resource size and are more restrictive for larger resources. The IEEE 1547 standard and many of the regulations related to interconnection of DER are evolving in reaction to the increased penetration of DERs and the emergence of smart grid technology. Interconnections that fall under federal jurisdiction because they sell into wholesale markets, even if connected at the distribution level, are subject to standard procedures and agreements established in the United States by the Federal Energy Regulatory Commission (FERC)—for example, the Small Generator Interconnection Procedures. All of the above standards and procedures are vitally important because they define what DERs can and cannot do in response to grid disturbances.

DERs also include small-scale generation and storage technologies owned and operated by utilities or service providers at the distribution voltage level. Such resources may be either stationary or mobile. Moreover, DR can be considered as a DER source. So-called "emergency DR" is employed to avoid involuntary service interruptions during times of supply scarcity. This could be one strategy employed during VLSEs. For customers and distributed resources interested in participating in DR programs and receiving notifications of emergency and load change requests during VLSEs, the key will be providing reliable data and communication that are secure and can interoperate efficiently with electric grid systems.

Hardening the distribution network is the other approach for preventing or mitigating the catastrophic effects of weather-related disruptions.

## Distributed Resources Operation: Current Practices

This section describes the most common industry practices today related to the operation of the distributed resources described above. The focus of our discussion is on emergency operating conditions prior to, during, and following a VLSE. These are the conditions typically dealt with at the emergency operations centers (EOCs) set up by utilities to respond to VLSEs.

### *Standby Generators*

Perhaps the most common application of distributed resources during outage conditions is the use of standby generators. Within seconds of a utility outage, an automatic transfer switch senses the power loss, commands the standby generator to start, and then transfers the electrical load to the standby generator to supply power to the circuits. After utility power returns, the automatic transfer switch transfers the electrical load back to the utility and signals the standby generator to shut off. It then returns to standby mode, where it awaits the next outage.

Automatic standby generator systems may be required by building codes for critical safety systems such as elevators in high-rise buildings, fire protection systems, standby lighting, or medical and life support equipment. Residential standby generators are increasingly common, providing backup electrical power to HVAC systems, security systems, and household appliances. Current interconnection agreements do not allow customer-owned standby generators to operate during normal conditions when the customer's load is fed by the utility.

### *Distributed Generation (DG)*

Utilities routinely use utility-owned DG, especially mobile diesel generators, for support during restoration. Using customer or third-party-owned DG in the restoration process is much less common.

In many U.S. utility service territories, customers can install DG to offset their demand. With net metering (as is well known in California, for example), a customer's excess generation may feed back to the utility grid during normal operation when output is higher than the customer's own load.

Standard interconnection agreements generally require that customer-owned DG be disconnected during an outage. This is primarily for the protection of utility crews, who must be certain that everything downstream of any breaker they open is deenergized, allowing them to perform work without risk of electrocution. There are control and anti-islanding mechanisms to automatically trip the DG during outage conditions and avoid back-feeding the distribution grid. An exception is when a customer disconnects from the utility grid (islands) but has the capability to independently serve his own load with DG, storage, and appropriate control.

These standard practices do not allow for the islanding of a group of customers to enable them to share their DG during an outage, for both technical and legal reasons. A crucial concern is liability, since one customer's DG could damage other customers' assets by introducing power quality problems such as excessive harmonics or voltage surges or simply by failing to control voltage and frequency when attempting to balance local generation and load. Further, the direct trading of services among customers over utility distribution networks is normally prohibited, as current laws governing safety, quality of service, asset ownership, and economic transactions are based on the model of the utility as an exclusive franchise.

### *Energy Storage*

The current practices regarding customer energy storage resources are similar to those described above for standby generators and DG. Their operation during outage conditions is strictly limited to supply-only loads on the customer's side of the meter, not back-feed power into the grid.

A number of U.S. utilities are experimenting with energy storage systems to improve resilience. One example is the Portland General Electric Smart Feeder demonstration project in downtown Salem, Oregon, which aims to improve distribution reliability by leveraging distributed resources such as energy storage, commercial DG, and DR.

### *Microgrids*

A microgrid, defined as a subset of the grid that can be islanded (e.g., at the level of a university or corporate campus), can supply all or part of a customer's load during an outage or in case of grid contingencies. Again, the customer may not back-feed into the grid or supply third-party loads during outage conditions, due to safety and liability concerns. In particular, multicustomer microgrids, in which several electrically adjacent customers are islanded together, are not generally permitted because existing laws governing safety, quality of service, asset ownership, and economic transactions generally are deficient.

Distributed resources by and large can provide many of the same energy and ancillary services that central resources can provide.

### Demand Response

Today, most demand response programs are designed to reduce peak demand or avoid system emergencies. These programs are mostly designed for system-wide participation of load and are not specific to a certain distribution feeder. Some utilities (e.g., Progress Energy and Pacific Gas and Electric) are evaluating locational-based DR within their DR notification systems. Some wholesale power markets also allow demand aggregators and large customers to contribute certain ancillary services through DR. There are also reported applications of DR in managing transmission congestion by Transpower in New Zealand.

All of the above DR applications are targeted for normal operating conditions or to avoid emergencies. The best-known application of DR during emergency operating conditions is voluntary load reduction. As is the case with the DER resources, current regulations for franchises granted to public utilities do not allow a customer's DR resources to be leveraged to help another customer during outage conditions. For example, a customer's capability to adjust load to provide frequency regulation to the system cannot be leveraged if that customer is islanded during an outage.

## Leveraging Distributed Resources for Grid Resilience

The current state of the art is largely the result of engineering standards and interconnection agreements that were developed when the penetration of distributed resources was low. Given the significant amount of distributed resources that already exists at many utilities and the forecast growth in distributed resources, it is prudent to explore whether utilities could further leverage these resources in response to VLSEs. Below, we present some examples of distributed resources applications. In many cases, further research is needed to explore viability or to address current technical and nontechnical barriers. Existing engineering standards and interconnection agreements would need to evolve to make some of these applications possible. While it may seem bold to suggest such changes, it is worth noting how dramatically today's landscape of renewable resource integration already differs from the situation one or two decades ago. The proposed applications are analogous to the coordinated operation of interconnections, in which neighboring utilities cooperate and cooptimize their resources for the benefit of the interconnection.

### Maximizing Resource Availability During VLSEs

Utilities defer discretionary maintenance of central generation units to maximize resource availability if they predict a VLSE. They also coordinate with neighboring utilities to increase reserve margins.

Currently there is little or no communication between utilities and DER owners related to distribution network operation during and after VLSEs. Increased communications could help the utility and the DER owners better plan and coordinate their response. For example, emergency condition alerts in media outlets could include some recommendations for DER owners and their neighbors. Customers could ensure that their backup generators are ready to come on line and their batteries are fully charged, if the utility is anticipating a critical event. In conjunction with these actions, DER owners could communicate the status of their resources to the utility, and allow, for example, the coordinated disconnection and islanding of local microgrids from at-risk feeders.

### Riding Through Faults

IEEE Standard 1547, which is central to most interconnection agreements, requires DG to cease to energize the grid for all faults or major disturbances on the grid to which it is connected. This requirement may not be optimal when there is a large penetration of distributed resources that could all disconnect simultaneously, causing an unintended adverse impact on the grid. The standard should be modified to allow for different requirements under conditions mutually agreeable to the grid operator and the DG owner, especially during a VLSE. The grid operator may then, in some cases, want distributed resources to ride through a fault to avoid bigger issues. Smarter protection and automation schemes will need to be devised for such ride-through capability.

### Optimizing Restoration Prioritization

Most utilities prioritize the restoration of loads based on their importance to public health and safety, giving higher priority to loads designated as critical (e.g., hospitals, police facilities). This prioritization is normally a static process and does not take into account the real-time conditions in the field. The prioritization could be optimized, however, if the utilities were made aware of the status of the distributed resources. As an example, if a utility knew that a certain customer had islanded, was supplying his own critical load, and was able to continue to do so for 24 h, the utility could then focus its effort on other critical loads that were completely

Most utilities prioritize the restoration of loads based on their importance to public health and safety.

without power or were islanded but cannot sustain themselves for many more hours.

Such a coordination of restoration priority could be implemented today without any insurmountable technical barriers. The major technical requirement is communication between the utility and its customers regarding the VLSE and the status of the resources. This particular application is “low-hanging fruit” that utilities could implement rapidly.

### *Global Optimization of Distributed Resources*

Current industry practices during outage conditions impose constraints on the local use of customer-owned distributed resources. This raises the question of whether greater societal value could be gained if such constraints were relaxed and these resources were optimized more broadly (beyond an individual customer’s premises) to support resilience. Some examples include:

- ✔ scheduling distributed resources to manage congestion in the distribution grid and maximize its load-carrying capability, e.g., using distributed resources to eliminate an overload on a transformer that would otherwise require switching operations to reduce load
- ✔ scheduling distributed resources to optimize the voltage profile on the feeder and eliminate overloads.

While some distributed resources such as solar PV are not dispatchable, advanced technologies such as smart inverters can provide the capability for voltage regulation (and already do so in Europe). U.S. utilities do not presently rely on customer resources for any such global optimization for a variety of reasons, including concerns about reliability; the dependability of non-utility-owned resources; and the logistics involved in communication, control, and data integration.

### *Multicustomer Microgrids*

In theory, utility customers may be able to dynamically island several customers in a multicustomer microgrid, meaning a group of customers could isolate itself from the rest of the grid and sustain itself in that state for a period of time, as long as local resources and load management are adequate to meet the island’s needs and the physical or economic condition prompting the islanded operation persists.

Many questions need to be addressed before this practice could become feasible, including:

- ✔ technical issues, such as protection, control, and power quality
- ✔ legal issues, such as liabilities for damage to third-party assets
- ✔ regulatory issues, particularly customer competition with utilities
- ✔ economic issues, including the need to create markets for energy and ancillary services from distributed resources and how to measure and bill for services exchanged among customers.

### *Hardening of the Distribution Grid Using Distributed Resources*

Many utilities are making investments to harden their distribution grids to increase their resilience to VLSEs. Examples include taking overhead feeders underground, increasing network redundancy, and investing in smart grid technologies. As part of such hardening initiatives, utilities can also invest in distributed resources that are strategically placed near critical loads. Such placement could help:

- ✔ reduce distribution bottlenecks
- ✔ allow special islanding schemes designed to minimize the loss of critical loads
- ✔ mitigate negative consequences (e.g., stability or voltage issues) that may arise when the protection schemes automatically disconnect a large amount of customer-owned DG (for example, in response to a fault on a feeder with a large penetration of renewables).

## The Way Forward

The preceding discussion suggests that substantial further research is needed in the area of resilience analysis and especially the recruitment of distributed resources in support of resilience goals. The following is a partial list of topics:

- ✔ frameworks for global optimization of distributed resources, especially during emergency conditions
- ✔ data availability, monitoring systems, and communication requirements for leveraging distributed resources for resilience
- ✔ load balancing and frequency regulation in microgrids using distributed resources
- ✔ technical, legal, regulatory, and economic issues related to multicustomer microgrids
- ✔ issues related to protection schemes, such as:
  - How may distributed resources ride through faults at the discretion of the grid operator?
  - What protection capabilities would need to be added to distribution networks to allow the safe operation of multicustomer microgrids?

> A recent congressional study estimates the average annual cost of outages related to severe weather at between US$25 billion and US$70 billion.

  - Whose assets—utility assets, customer assets, or those of a third party—should protection relays protect first?
  - How can we effectively detect short circuits in the presence of many dc-based sources such as PV and storage?
- ✔ the business case for utilities to invest in utility-owned distributed resources to improve resilience, vis-à-vis hardening the distribution grid itself
- ✔ issues related to data and communication security and reliability
- ✔ issues related to the islanding of microgrids, such as:
  - standard designs for microgrid controllers
  - the detection of DER-based islands and the visibility of islands to the utility.

## Summary and Conclusions

Based on the previous discussion, distributed resources could play the following roles in resilient operation:

- ✔ Distributed resources by and large can provide many of the same energy and ancillary services that central resources can provide.
- ✔ Since most distributed resources are geographically and electrically closer to loads, they could be less vulnerable to grid component failures during a VLSE.
- ✔ Some leading utilities have already begun to leverage distributed resources during outage conditions. Such applications are mostly limited to utility-owned distributed resources, however, and do not extend to distributed resources owned by customers or third-party service providers.
- ✔ Customer-owned distributed resources are generally shut down during outage conditions and are not leveraged during VLSEs. The only exception is when the customer can be islanded, in which case it can use its distributed resources for its own individual benefit.

Given the significant amount of distributed resources already interconnected at many utilities and the forecast for substantial growth in distributed resources, it is prudent to explore whether utilities could further leverage these resources to increase resilience with respect to VLSEs. Opportunities to do so may grow as the redundancy in distribution grids increases as a result of network upgrades. It is conceivable that many of today's distribution grids will evolve away from their current radial configurations, supplying power from substations, into meshed networks that will primarily serve as "interconnection" services among customers, distributed resources, microgrids, and utilities. In this case, it will become even more important to understand the potential applications of distributed resources in response to VLSEs.

A key motivation for many customers when installing distributed resources is to protect themselves individually against grid outages. For a number of good reasons, these distributed resources are at present not fully leveraged in a way that would better serve the grid in response to VLSEs. In the future, however, a number of things may change: technology may ease the inherent difficulties in safely coordinating DERs; society may expect more tangible value for the grid from individual DERs; and VLSEs may increase in frequency and severity. Significant additional research is needed to explore suitable solutions if the value of distributed resources is to be maximized for resilience.

## For Further Reading

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