# What's Smart About Smart Power?

## Modernizing the Power Grid and HFC Networks: Power Outage Notifications and Advanced Sensing

A Technical Paper prepared for SCTE by

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# 1. Introduction

This paper calls the cable broadband industry to action to investigate and capitalize on the increasingly important intersections between grid/utility power and cable network power. Managing the intersections of power and communications across the landscape and throughout our respective infrastructures—from communities to forests—is fundamental to improving network reliability and cost-effective operations. Additionally, working with organizations responsible for emergency response, corporate security, situational awareness, public safety, and business resilience is fundamental to preserving our way of life and preventing catastrophic loss of life and property.

The paper begins with motivational examples related to grid outages caused by severe weather and cyber-attacks, their exponential rise, and troubling forecasts for increasing numbers of issues. A deep dive into the failures of supply and demand during the February 2021 Texas Power Crisis includes a spatiotemporal summary of issues in Houston and sheds light on the global nature of the many grid operational challenges ahead.

The background on powering the grid and how it connects to the Hybrid Fiber-Coaxial (HFC) network includes a discussion of the connection points of HFC power supplies and the possibility for fatal back-feeding from misbehaving power electronics in the growing base of solar photovoltaic inverters, battery walls, and electric vehicles. The sea change of implications of the grid incorporating renewable energy sources and transitioning from 1-way central-station delivery of power to two-way flows among distributed energy resources are discussed.

The Gridmetrics™ Power Event Notification System (PENS™) is introduced as the most capable, fastest, and lowest latency system for monitoring the massive sensor-starved grid edge. Also discussed is Gridmetrics' role in U.S. Department of Energy (DOE), Office of Cybersecurity, Energy Security, and Emergency Response (CESER), Cybersecurity for Energy Delivery Systems (CEDS) R&D program. The new American National Standards Institute (ANSI), Society of Cable Telecommunications Engineers (SCTE) Standard 271 2021 is discussed along with a few of the plethora of anticipated operational applications in the field.

Readers focused on how to better access utility power data, improve relationships with utility ecosystems, and create new business opportunities will benefit greatly from this paper and the accompanying presentation and panel session.

## 2. Motivation: Operational Costs and Network Reliability

Issues resulting from outages and poor power quality affect everyone and directly impact cost and service reliability. Outages and poor power quality issues are on the rise and are expected to increase.

### 2.1. Outages

At best, outages are expensive and disrupt cable broadband operations and the customer experience. At worst, outages lead to property damage, human suffering, and lives lost. Outages from 2002 to 2020 are shown in Figure 1 [1].

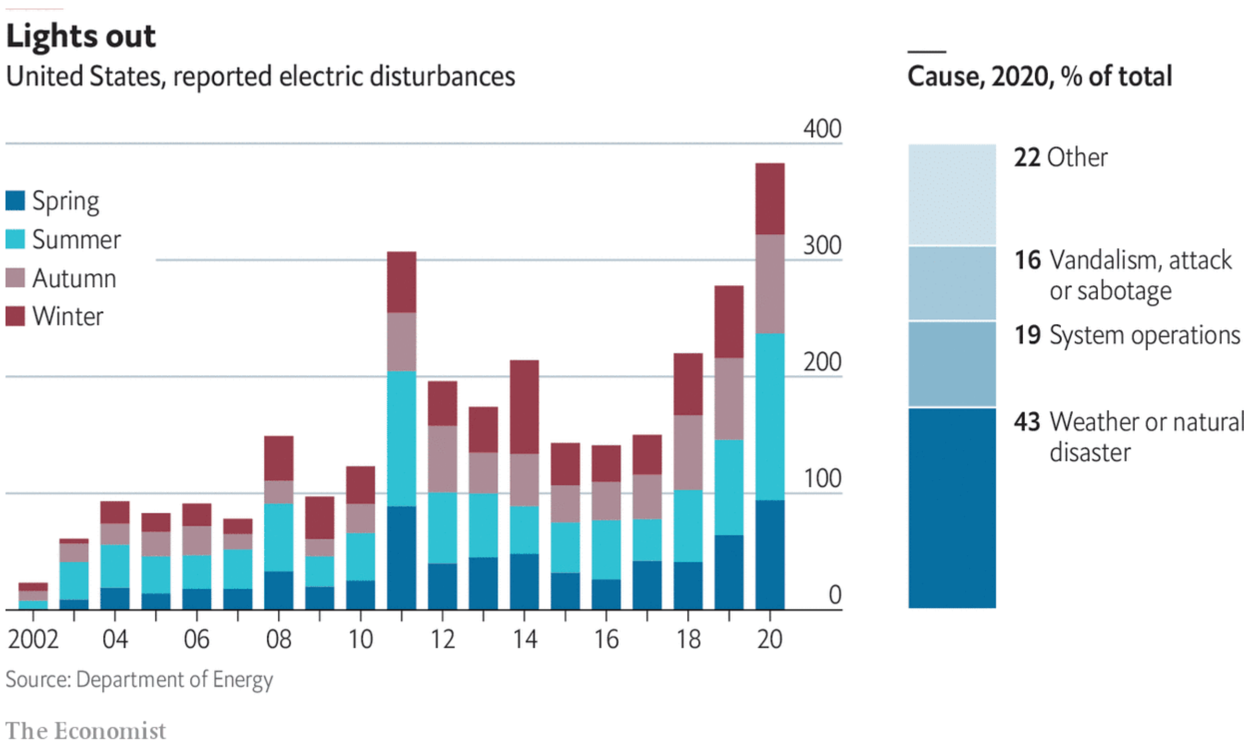


**Figure 1 – U.S. Power Outages 2002 – 2020**

Outages most often occur at the grid edge [2], and utilities are way behind the cable broadband industry in terms of being mostly unaware of an outage until customers call to report a loss of service. While both industries have made advancements in automatic outage detection and declaration, cable's battery-backed broadband networks are far superior to utility wireless mesh networks in terms of latency, loss, throughput, and jitter—and hence are the best alternative for monitoring grid voltage, phase, current, and on/off status.

### 2.2. Power Quality

Poor power quality is a silent and stealthy foe that is largely unmonitored. The American National Standards Institute establishes nominal voltage ratings and operating tolerances for electric power systems in ANSI C84.1-2016 provided by the National Electrical Manufacturers

 

Association [3]. The upper and lower acceptable voltage limits are 105% and 95% respectively, and there are additional considerations for the frequency, intensity, and duration of voltage excursions [4].

Within normal operating voltages, the customer experience is acceptable. Above or below voltage limits, issues arise with billing, resilience, safety, and equipment longevity. For example, high voltages lead to higher energy usage and higher electric bills and may damage capacitors on electric motors widely used in refrigeration, heating, air conditioning, and pumping water--and low voltages lead to overheating and a shortened lifespan of motors.
Unfortunately, utility "smart meters" are not up to the challenge of reporting costly power quality issues such as voltage spikes and sags. By design, all smart meters in the U.S. are limited to 240 VAC split-phase leg-to-leg measurements, providing no measurement of the performance of ground or neutral circuits. In every cable shop throughout the world, there is likely a prominently displayed section of melted in-home coaxial cable that serves as a warning to technicians of the fatal perils of unbonded neutrals and intermittent grounds.
While more than half of U.S. households have smart meters deployed, the capability is often unused in daily operations due to bandwidth limitations in the backhaul mesh communications infrastructure that results in bottlenecks in utilities receiving and processing smart meter data.

## 3. February 2021 Texas Power Crisis

The February 13–17, 2021 North American Winter Storm Uri, was a major winter and ice storm that had widespread impacts across the United States, Northern Mexico, and parts of Canada. The storm resulted in over 170 million Americans under various winter weather alerts and caused blackouts for over 9.9 million people in the U.S. and Mexico, most notably in the 2021 Texas power crisis [5]. The blackouts were the largest in the U.S. since the Northeast blackout of 2003 and resulted in economic costs, human suffering, lives lost. Losses were greater than Hurricane's Harvey and Ike.

### 3.1. Severe Storms

The Texas Power Crisis came about as a result of three severe winter storms sweeping across the United States from February 10–20, resulting in massive electricity generation failures, and resultant shortages of water, food, and heat [6]. Nearly than 4.5 million homes and businesses were left without power for four days of freezing darkness [7]. At least 210 people were killed directly or indirectly, with some estimates as high as 702 killed as a result of the crisis [8].

### 3.2. Failure of Generation and Fuel Supply

As shown in Figure 2, the arctic temperatures resulted in the failure of 48% of electricity supply as generators and fuel supplies for generators froze and were unable to operate to meet the unprecedented rising demand of heating loads. The February 15–18 gap between (colored) supply and demand depicts massive declines in hundreds of natural gas and coal-powered generators along with lesser declines in wind and increases in solar generation.

 

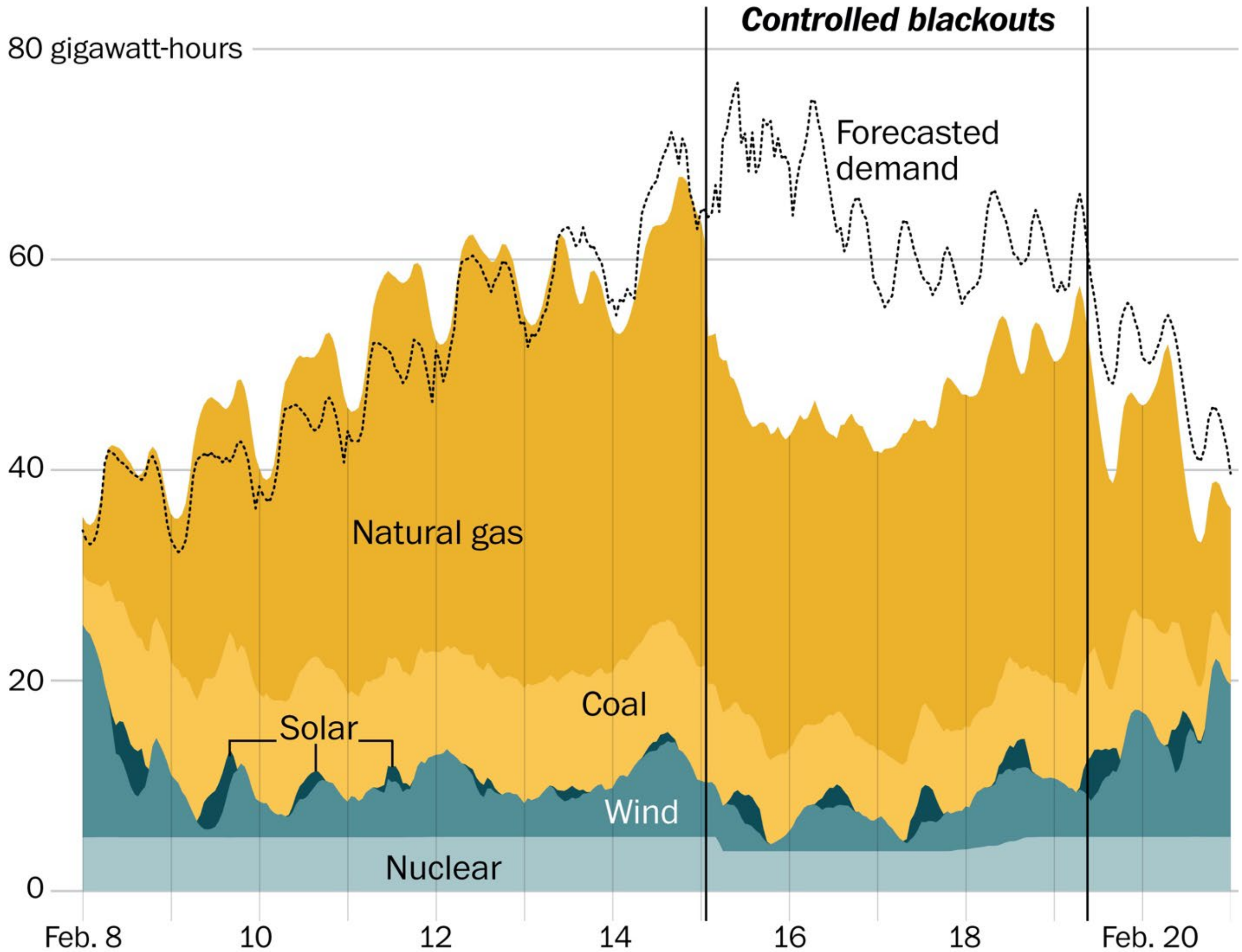


**Figure 2 – Texas Electricity Supply and Demand February 8-20, 2021**

The observations presented in Figure 3 are based on measurements from over 10,000 HFC power supply sensors distributed across the low-voltage distribution grid in the Houston, TX area. The sensors provide a voltage reading (± ~1.2 volts) at a particular latitude and longitude at 5-minute intervals. For the purposes of this analysis, power sensors have been aggregated and mapped to the U.S. National Grid, (USNG) a standard 1 km x 1 km square. The color scale at right is an index that denotes outage duration, where red denotes sensors out all three days.

### 3.3. Spatial and Temporal Analysis

In the data, both macro and subtle patterns can be seen as the widespread power outage and subsequent recovery unfold. The exact cause of an outage at any particular sensor cannot be inferred directly from the data—i.e., whether the outage was due to downed lines or due to operator-controlled power shutoffs (aka load shed)—but analyzing temporal and spatial behavior of voltages and power conditions reveals a new, independent lens to view and understand the severity and duration of outage events across the city and within particular neighborhoods. In addition, analyzing voltage trends prior to outage events, as well as residual voltage readings on de-energized lines during outage events, highlights an urgent need for better real-time situational awareness of the distribution grid to anticipate localized grid stresses and to manage utility worker and public safety. A special thanks goes to Dr. Scott Clearwater and the team at CableLabs for the analysis.

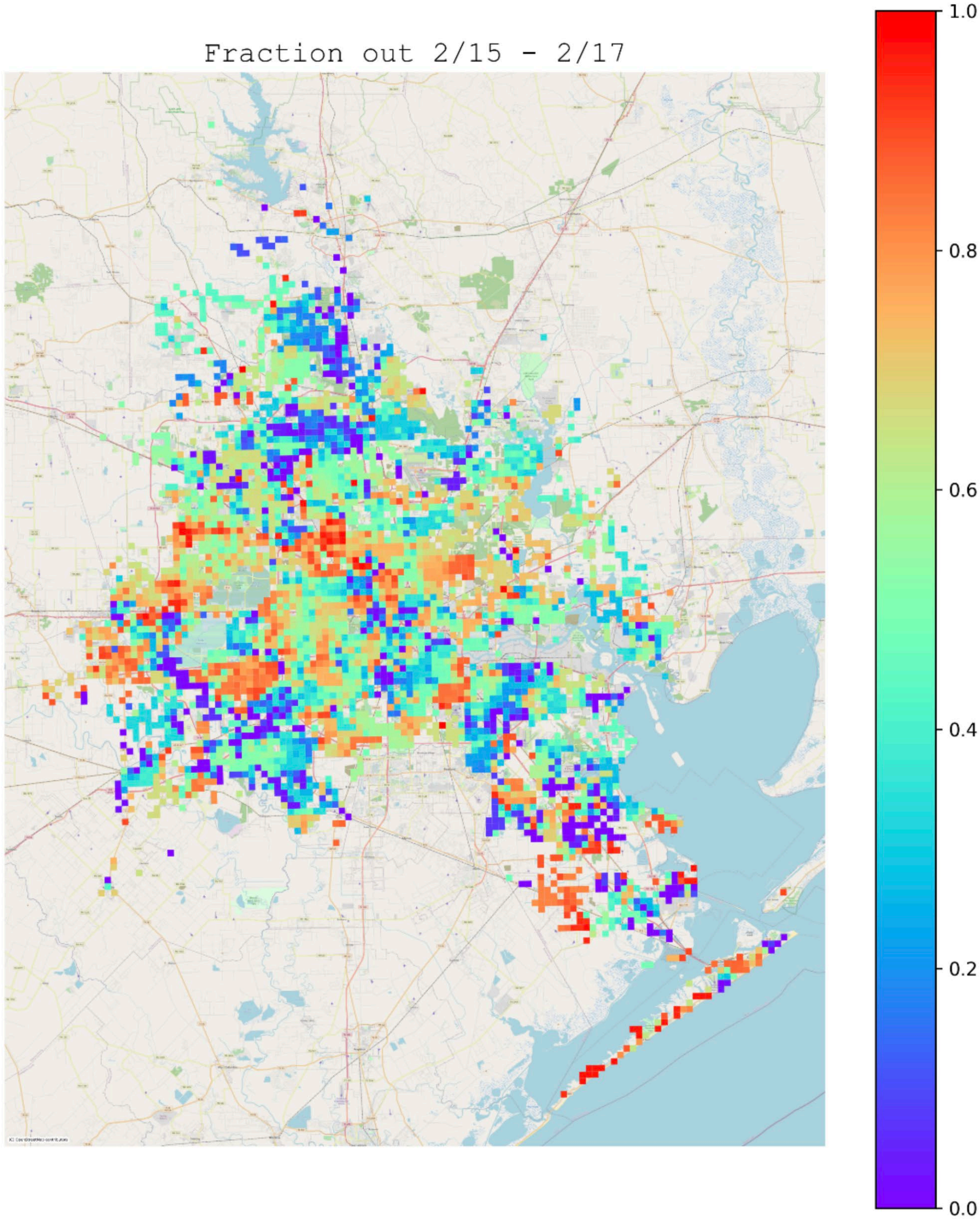


**Figure 3 – Spatiotempotral view of Texas Power Crisis, February 15-20, 2021**

 

### 3.4. Missing Focus on the Demand Side

The February Texas Power Crisis along with two more Texas blackout close calls in April and June resulted in a focus on improving the nexus of natural gas and power generation, better public communication, more power plant weatherization/protection, and new power transmission projects. Demand-side work has been ignored and missing to date is a focus on shoring up the grid by aggressively managing load [9].

## 4. Background on the Grid and HFC Powering

Situational awareness of the electric power grid is gaining in importance with the increasing number of power generators, power consuming devices, and power infrastructure failures. In the United States, 200,000 miles of well-instrumented high-voltage transmission lines make up the grid core, or backbone. However, lower voltage, local distribution lines connect the remaining 96.5% of the grid, accounting for 5.5 million miles of poorly instrumented grid infrastructure as shown in Figure 4. [2].

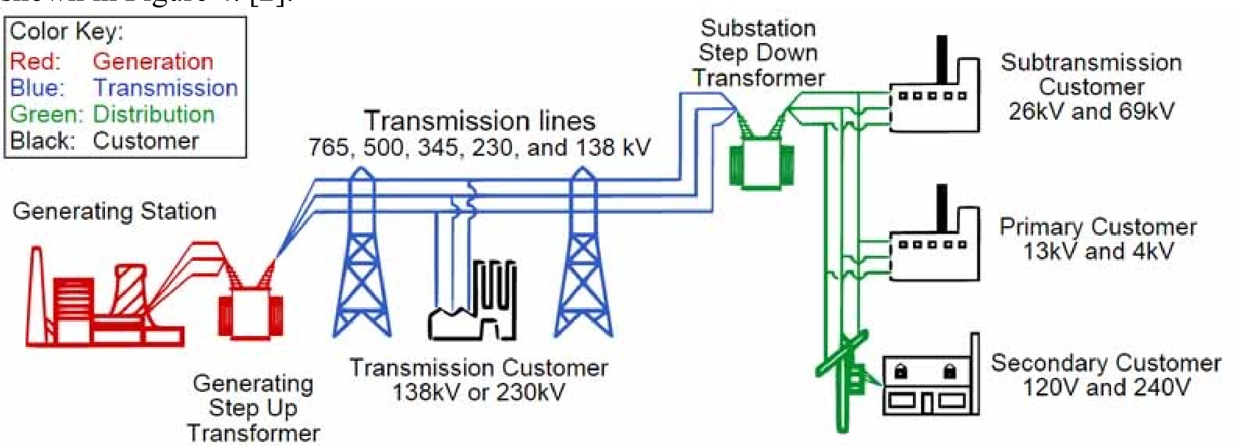


**Figure 4 – Power Grid Schematic**

The connection points for HFC power supplies, electric vehicle (EV) chargers, and photovoltaic systems are located in the distribution grid shown in green in Figure 4.

## 5. Solutions for Monitoring the Grid and HFC

There are inevitable requirements to get new, real-time instrumentation deployed into the last miles of the distribution grid, and the broadband industry already has a great head start.

### 5.1. Gridmetrics™ and PENS™

Gridmetrics is the premium supplier of power event notifications. Gridmetrics was born at CableLabs and inspired by 2017-2021 conversations with the National Renewable Energy Laboratory. Gridmetrics makes grid insights available via the Power Event Notification System (PENS™). PENS Aggregates unique data from ~300,000 sensors in HFC power supplies and provides an unmatched observational view of the state of power in the last mile of the distribution grid. PENS alerts are available via email, Esri, and an API for use by emergency response, public safety, FEMA, DHS, business resilience, and other users. The nationwide footprint of Gridmetrics sensors is shown in Figure 5, where red the notes outages.

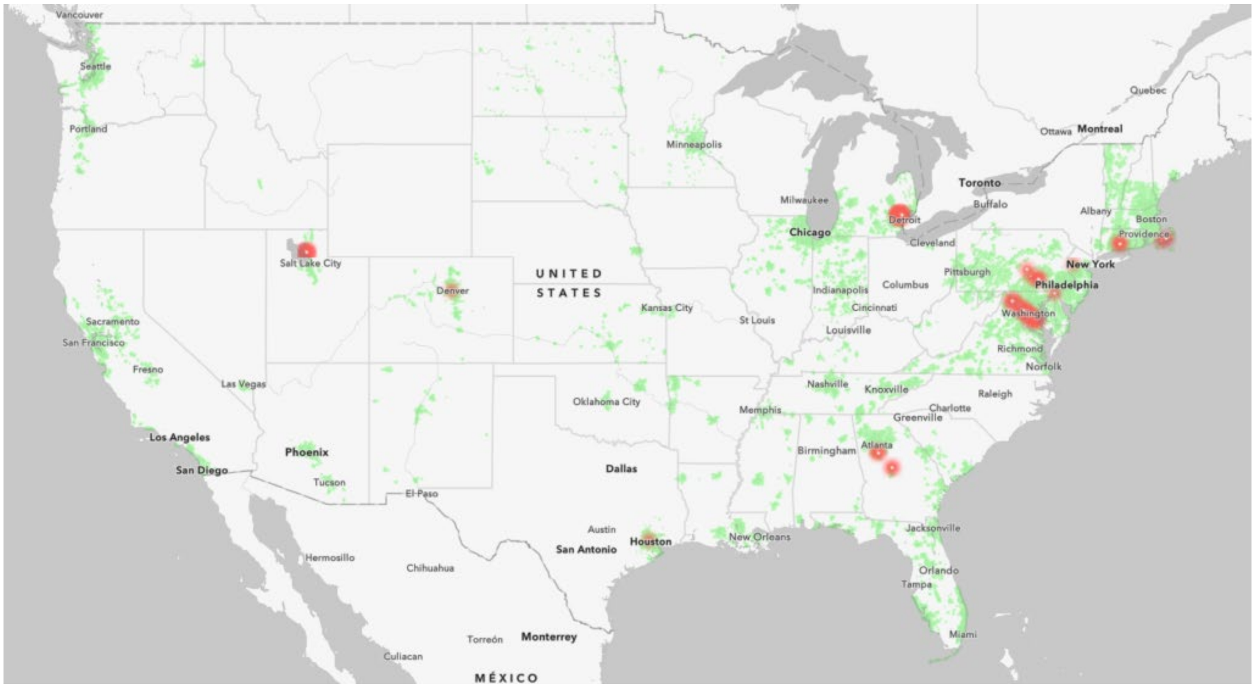


**Figure 5 – Gridmetrics™ U.S. Map**

Figure 6 shows an example of a PENS Alert for an area to the West of Tallahassee, Florida. Note how the event, the population, and Gridmetrics sensors are alongside the edge of a wildlife area.

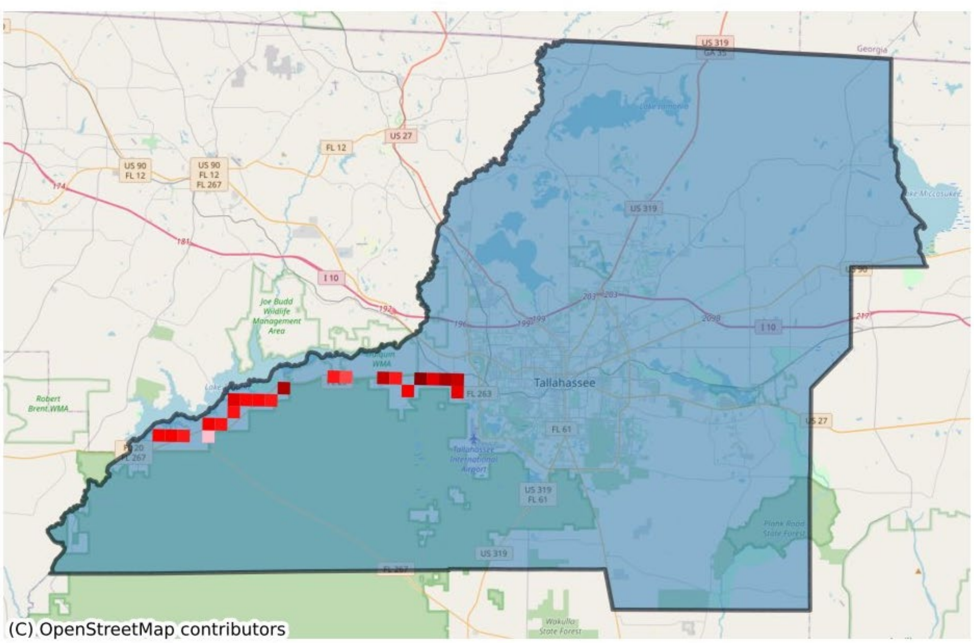


**Figure 6 – Example PENS™ Alert**

 

Figure 7 provides an additional example of Gridmetrics sensors tightly aligned with population. Darker green denotes denser populations and darker red denotes outages affecting more people.

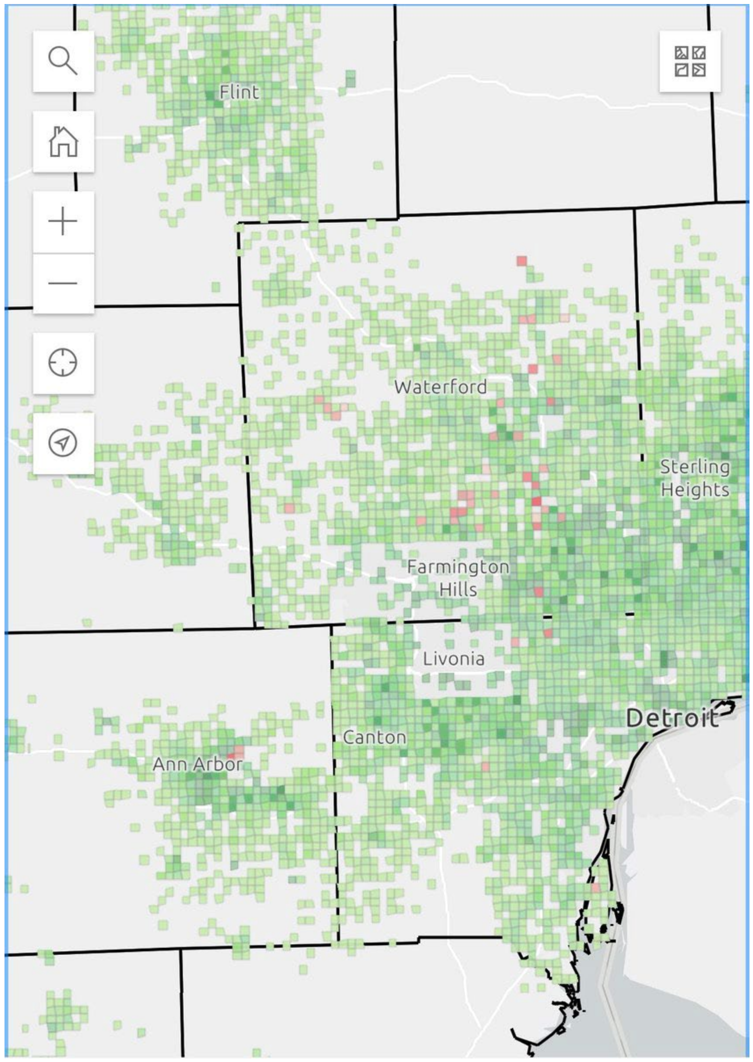


**Figure 7 – July 21, 20201 PENS™ Detroit Outage**

Today, there is no comprehensive, independent source for power event insights. Most solutions offer insights only at the county level. As mentioned previously, PENS provides insights using the USNG 1km x 1km grid overlay projection. In addition, most solutions offered by utilities and other entities provide updates only every 15 minutes. PENS scans the broadband sensor network every 5 minutes looking for events.

PENS Email Alerts are unique in that they provide: 1) Initial Alert, 2) Update Alerts over time, and 3) Closing Alerts to indicate service is restored. The combination of the three types of Alerts allows for automatic opening and closing of network incident tickets in different operations centers within a utility, broadband provider, emergency responders, etc. Interested users may sign up for alerts and more information at www.gridmetrics.io.

 

Gridmetrics is part of the Esri partner network and provides a Feature Service Layer view in Esri Marketplace [10]. For existing Esri users, the set-up is simple, and a no-fee trial version is available.

### 5.2. SAGA - Situation Awareness of Grid Anomalies

Another powerful solution for monitoring the power grid and HFC networks as SAGA, Situational Awareness of Grid Anomalies. SAGA is a $3M, 3-year project to develop near real-time cyber-physical resiliency through machine learning—using existing infrastructure. The U.S. Government funding for SAGA came in 2019, after several joint proposals were developed by the National Renewable Energy Laboratory (NREL) and CableLabs, submitted, and evaluated by the U.S. Department of Energy and the Advanced Research Project Agency.

SAGA identifies anomalous behavior using cable broadband's secure out-of-band in-service network and rapidly detects cyberattacks dynamically and in near real-time through machine-learning. The SAGA learning-aided low-voltage estimation framework is shown in Figure 8.

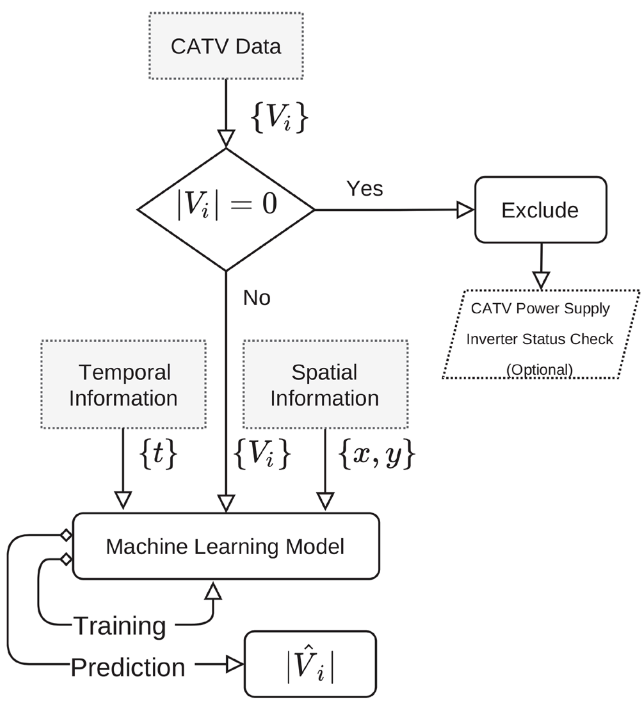


**Figure 8 – SAGA learning-aided low-voltage estimation framework**

The goals of SAGA include demonstrating a disruptive technology for power system data analytics using existing infrastructure while providing commercialization and product feature roadmaps. SAGA builds upon NREL's extensive collection of power system state estimation and mapping tools and integrates the growing set of Gridmetrics 'situational' data. SAGA assimilates other time-series geospatial data such as weather and cyber-physical phenomena, distribution infrastructure maps, and tax lots. To ensure the ongoing evolution of SAGA and global impact on operational efficiencies and network reliability, lessons learned inspired the development of a new next-generation ANSI/SCTE grid and HFC sensing standard.

## 6. New U.S. National Standard: ANSI SCTE 271 2021

Motivated by the successes of PENS and SAGA and recognizing that existing sensing capabilities are out of date, the new ANSI SCTE 271 2021 standard specifies requirements for Power Sensing in Cable and Utility Networks. SCTE 271 specifies additions, without replacing prior sensor specifications developed in the late 1990s during the development of DOCSIS 1.x.

SCTE 271 specifies how to monitor HFC and Grid for voltage and current anomalies and send *raw* waveforms to the cloud for further processing. The importance of the ability to observe, communicate, and then cloud-compare multiple high-resolution traces of voltage and current in real-time cannot be overstated. Secure backhaul of streaming continuous point-on-wave (CPOW) power observations is a quantum leap beyond phasor measurement units that assume a sine wave and then compress and distort all data before backhauling, as shown in Figure 9 (note the phaser approximation completely misses and misrepresents the voltage spike anomaly).

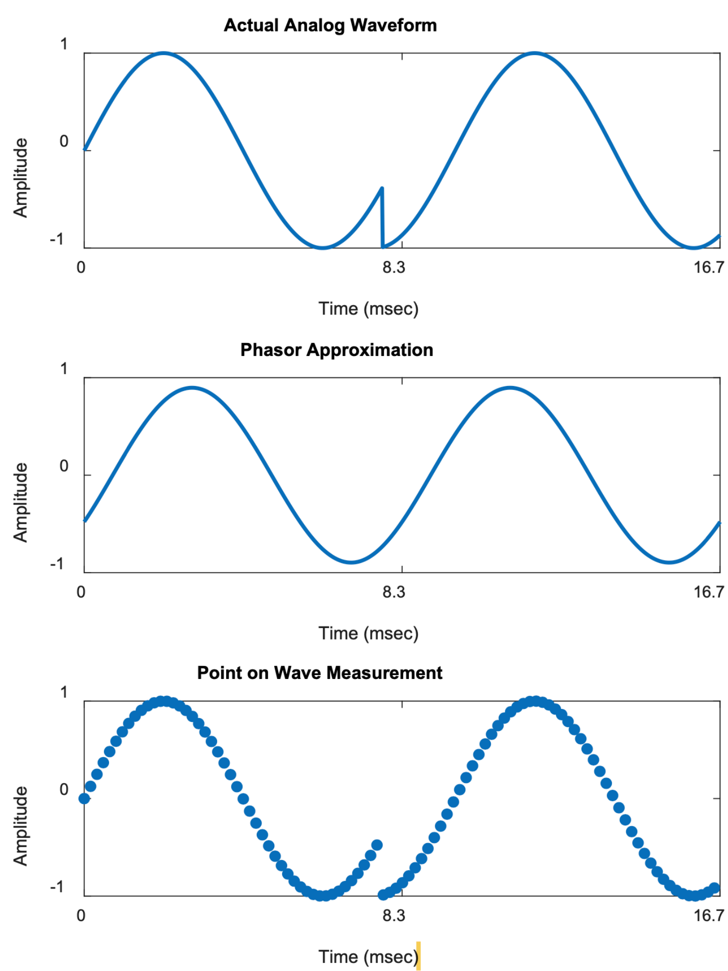


**Figure 9 – SAGA learning-aided low-voltage estimation framework**

 

SCTE 271 measures the 60/75/90 VAC quasi-square wave HFC network and the 120/240 VAC power grid. Goals include: 1) reducing network element reboots, outages, and issues that cause wildfires, and 2) improving the customer experience and the lifespan of the HFC, Customer Premise Equipment, and the grid. SCTE 271 can be used to identify voltage and current highs, lows, fluctuations, as well as outage and voltage sages that indicate grid congestion—that can be used to actively manage load and increase use of renewables.

The following requirements are included in SCTE 271:

1. If voltage or current is sensed, it ***shall*** be measured with a precision of 0.002 per-unit (0.2% of nominal value), e.g., +-0.24 volts at 120 VAC
2. If CPOW capture is provided, the sampling rate ***shall*** be a minimum of 10k samples/second = 166 samples/period at 60 Hz (more better)
3. If observation timestamp provided, the resolution ***shall*** be <= 1 microsecond. Clock accuracy ***shall*** be <= ½ microsecond, which is ~ 1/100$^{th}$ of a degree at 60 Hz
   (1 sec / 60 cycles) * (1 cycle / 360 degrees) * (1 degree / 100) = .46 microsecs
4. If configurable remote reporting is provided, control plane ***shall*** enable
   a) a 1-time poll reply, b) continuous replies and/or c) fixed interval replies
5. If a communication plane is provided, it ***shall*** use IETF/APSIS YANG model and SSL or TLS for authentication & encryption. No SNMP is required.

The new capabilities specified SCTE 271 are expected to unleash a plethora of opportunities for proving value in advanced grid sensing that helps modernize and manage the grid by predicting catastrophes and advancing grid state estimation with visibility to two-way electricity flows.

## 6.1. The Aging and Failing Grid: Predicting the Next Catastrophe

Figure 10 shows additional examples that reinforce the need for and benefits of advanced grid sensing. Both images were taken from *in-service* conductors and were made possible by developing and applying grid sensing capabilities in Australia in the wake of catastrophic wildfires. The image at left is a wire-rope conductor that is unravelling mid-span. Imagine looking up from a chairlift or gondola, that you are riding on, and seeing the wire-rope unravel! The image at right is a flat "Licorice" drop cable that is often used in direct burial applications.

**Figure 10 – Examples of failing in-service conductors**

 

### 6.2. The Changing Grid: Advancing State Estimation by Monitoring Two-Way flows at the Grid Edge

The grid edge is constantly changing. From with a historical perspective, in 1882, Thomas Edison installed generation in New York City and London using coal fired power plants, which use the thermoelectric Rankine cycle—and haven't changed all that much. All electricity delivered from power plants travelled outward through the grid to customers; this is referred to as a one-way delivery of central station power. And that's how the grid operated for the next hundred years; there was organic load growth in the sense that, new appliances, housing subdivisions, power substations were developed, but behavior was mostly predictable, and the grid had one normal state. It was either on or it was off.

Then came the Public Utility Regulatory Policies Act in 1978, which for the first time allowed non-utility generators to market their power to utilities. Suddenly, anybody could build and operate a generator, not just utilities. Fast forward to today where every state and nation has renewable portfolio standards, trying to achieve, say, 30% renewables within five years, 50% renewables within 10 years, etc. But that means generators are everywhere. And now we have not just one-way flow, we've got two-way flows at the grid edge! If the solar panels on your house make more energy than you're using, then grid electricity is not flowing into your house—it's flowing out of your house. And that's great, but the problem is, the sun and the wind are intermittent and variable. They're uncertain and forecast error is on the rise in the face of climate change and severe weather.

So, we're not certain what the production and demand at the edge is going to be; we do our best to forecast it, but we don't know for sure and that makes these two-way flows, even more unpredictable. The net effect is, it's much harder to "see" and estimate what's going on in the grid today—than in the old grid with one normal state—where you could easily tell if it was on or off based on customer call volume. Today, there's an unlimited number of dynamic normal states and that thwarts detection of non-normal conditions—caused by something really being wrong. For example, is a voltage sag or spike in a neighborhood just because a cloud went over the sun or because the sun came out again—or is it the result of a coordinated outside-in cyber-attack against thermostats, HVAC controllers, "smart" inverters at the edge with the intent of taking down the core?

Today, we struggle to identify failures and cyberattacks. It's difficult to detect cyberattacks and here's why: If you found the keys to a car and you were mischievous, you might wait until midnight, and then, lurk around and figure out which car those keys fit—very quietly and unobtrusively. Once you had access and you were in, then you'd wait until the owners left and then you'd steal the car. And that's the fear with cyberattacks; attackers constantly try to get in and might make only small disturbances—until they know that they're in. But the disturbance they create can be so small that we won't be able to detect their presence until they come back and do something terrible and bring down the grid. And we all know in the pandemic and severe weather, that the reliability of the network is extremely important, and we simply cannot have energy and communications networks go down—ever!

 

## 7. Conclusion

As the number of distributed energy resources and two-way electricity flows rapidly increase, the aging grid infrastructure elements that are supposed to keep the grid safe are failing and causing unprecedented loss of life and property. While the enormity of the electric power grid is such that in the U.S. alone, the 5.5-million-mile distribution network is long enough to reach the moon nearly 21 times—the performance of the last mile of the grid is sparsely monitored and hence unable to be optimally managed. Gridmetrics sensor readings fill the immediate need to augment utility supervisory control and data acquisition systems by rapidly improving the monitoring of the secondary distribution portion of the grid.

The growing and evolving Gridmetrics data set is available to aid in monitoring and managing the secondary distribution networks that make up the last mile of the grid. The locations of specific anomalies worthy of investigation are available for use in the utility ecosystem including emergency response, public safety, the Federal Emergency Management Agency, the Department of Homeland Security, business resilience, and other entities.

Through maintenance and repair efforts, infrastructure aging, wear, and tear—and local weather—the location and severity of anomalies will change over time, supporting the case for the real-time Gridmetrics API and real-time data feeds. Through collaboration with the utility ecosystem and sharing best practices for anomaly detection and classification, it is expected that anomalies that foretell of impending infrastructure failures and safety issues, and high-risk for loss-of-life can be identified. In addition, the criteria used to identify anomalies can be expanded, refined, and validated to achieve maximum benefit from Gridmetrics data.

Data from next generation broadband power quality sensors can help pinpoint existing portions of the grid that can be inspected for high, low, and fluctuating voltages—and high-impedance faults—which can cause unsafe conditions, poor customer experiences, and premature failures of customer equipment. In addition, outage data from broadband sensors can be correlated with existing data sets to create a more comprehensive understanding of distribution network performance and frailties. Combining insights from utility supervisory control and data acquisition systems and Gridmetrics data will help improve network reliability, resilience, and safety.

# Abbreviations

| | |
|---|---|
| ANSI | American National Standards Institute |
| API | application programming interface |
| CEDS | Cybersecurity for Energy Delivery Systems |
| CESER | Office of Cybersecurity, Energy Security, and Emergency Response |
| CPOW | continuous point-on-wave |
| DOE | U.S. Department of Energy |
| EV | Electric vehicle |
| HFC | Hybrid fiber-coaxial |
| NREL | National Renewable Energy Laboratory |
| PENS | Power Event Notification System |
| USNG | United States National Grid |

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