Gridmetrics™ Data Provide Insights and Improve Situational Awareness of the Electric Power Grid

Powering 10G: What It Takes & How to Do It

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

The newly available Gridmetrics data platform dramatically improves the situational awareness of the electric power grid worldwide by providing an entirely new and independent view of real-time, localized power conditions. Gridmetrics data deliver insights enabled by the existing cable broadband infrastructure that measures, monitors, and tracks the availability and stability of voltage and other power measures in the last mile of the grid known as the secondary distribution network. Voltage measurements can reflect stresses on the grid and provide an early warning of unstable, unsafe, or inefficient operating conditions. Insights include specific locations on the grid where voltage observations are abnormally high, low or fluctuating, and provide much-needed visibility to the vast majority of the grid, which heretofore has been sensor starved. Analysis reveals voltage anomalies and outages that likely impact customer experience, safety, and equipment longevity.

Situational awareness of the electric power grid is gaining in importance with the increasing number of power generators, powered 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, the lower voltage, less-instrumented local distribution lines that connect the remaining 96.5% of the grid to end users, account for 5.5 million miles, with limited network visibility in the last mile.[1]

The rapidly growing penetration of electric vehicles (EVs), distributed energy resources (DERs), such as solar generation and battery storage, and connected buildings are creating new end-use dynamics and 2-way power flows that the existing grid was not designed to accommodate. These changes at the “grid edge” in the distribution network necessitate improving situational awareness to manage operations and detect grid stresses. State and local mandates to increase penetration of EVs and DERs, while critical to address the global climate crisis, further accelerate the changing grid edge dynamics.

Despite a mean life expectancy of 65 years, the average grid infrastructure element is 68 years old, with some elements well past the century mark. Unfortunately, we have already witnessed the effects of this aging infrastructure, through decreased reliability and deadly wildfires due to mechanical failures of the hooks that hold charged wires.[2,3] It is estimated that the U.S. power grid requires $51 billion of annual maintenance and capital upgrades (up 57% from 2016 to 2018) to improve reliability and catch-up on deferred maintenance.[4] Using information on the locations of voltage anomalies, provided through the Gridmetrics platform, can help electric utility managers to more quickly and efficiently target maintenance and upgrades on problem areas, increasing grid reliability and, ultimately, saving lives.

Gridmetrics is an early-stage project being incubated at CableLabs that connects and overlays a vast high-speed private communications network to supply as-delivered performance, insights, and knowledge about the power distribution grid. A new, widely available, and rapidly growing

[1] https://www.scientificamerican.com/article/what-is-the-smart-grid/

[2] https://www.wsj.com/articles/pg-e-knew-for-years-its-lines-could-spark-wildfires-and-didnt-fix-them-11562768885

[3] https://www.wsj.com/articles/this-old-metal-hook-could-determine-whether-pg-e-committed-a-crime-11583623059

[4] https://www.utilitydive.com/news/aging-grids-drive-51b-in-annual-utility-distribution-spending/528531/

dataset of voltage observations from hundreds of thousands of in-service cable broadband power sensors provides 5-minute updates, insights, and situational awareness of the distribution grid. Work from early Gridmetrics participants has shown a path to significantly more frequent updates, providing an increasingly real-time big data stream that represents multiple orders of magnitude improvement on existing distribution grid monitoring solutions. Power industry experts have estimated that utilities would have to invest billions of dollars over multiple decades to replicate the existing Gridmetrics sensor platform, which at the same time would have already evolved to superior higher fidelity spatiotemporal sensing and analytics.

The Gridmetrics platform makes sensor data available via secure, authenticated, machine-to-machine application programming interfaces (APIs) that allow utilities and other authorized third parties to access and utilize streams of readings and anomaly events to augment their existing supervisory control and data acquisition systems and processes. Using Cable's 10G broadband network, sensor data is transported at gigabit speeds and millisecond latencies to meet the immediate need to provide real-time APIs that improve grid visibility at a time when utilities need better insights now

2. Fundamental Cable Architecture

Understanding the cable television network and how it works can help decision makers outside the cable industry in considering the use and application of Gridmetrics data. By way of background, cable services are enjoyed by tens of millions of U.S. households in urban, suburban, and rural areas. Cable high-speed internet is available to 90% of U.S. households and 80% of homes have access to gigabit speeds.[5]

Similar to the evolution of the electric power grid, cable networks started as one-way transmission paths from a central location, called a headend, to each customer's home. The current cable architecture involves extensive use of fiber optics that carry two-way interactive data with millisecond latencies. Much like the grid, the cable network topology has evolved over the years into a tree-and-branch architecture as shown in Figure 1.

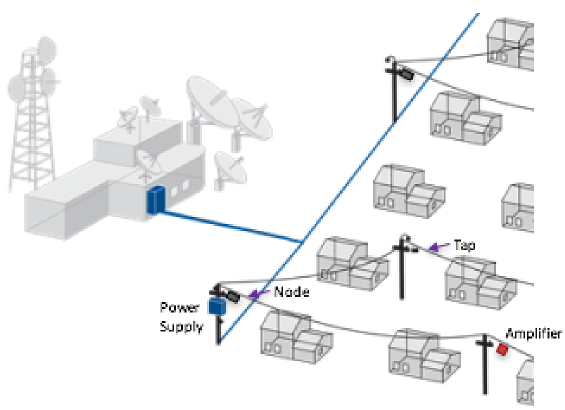

Figure 1 – Cable tree-and-branch architecture

[5] https://www.ncta.com/industry-data

3. Normal Grid Operating Voltages

The American National Standards Institute (ANSI) documents nominal voltage ratings and operating tolerances for electric power systems in ANSI C84.1-2016, which is available from the National Electrical Manufacturers Association (NEMA).[6] As shown in Table 1, the lower and upper acceptable voltage limits are 95% and 105% respectively, and there are additional considerations for the frequency, intensity, and duration of voltage excursions.[7]

Table 1 - Normal operating voltage limits [Volts AC]

Nominal Voltage	95% Lower Limit	105% Upper Limit
120	114	126
240	228	252

Within the normal operating voltages in Table 1, the customer experience is expected to be acceptable. Above or below voltage limits, issues may 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 water pumps. Low voltages lead to overheating and a shortened lifespan of motors. The observed voltages in the Gridmetrics national data set regularly deviate from the NEMA boundaries and are shown in Figure 2.

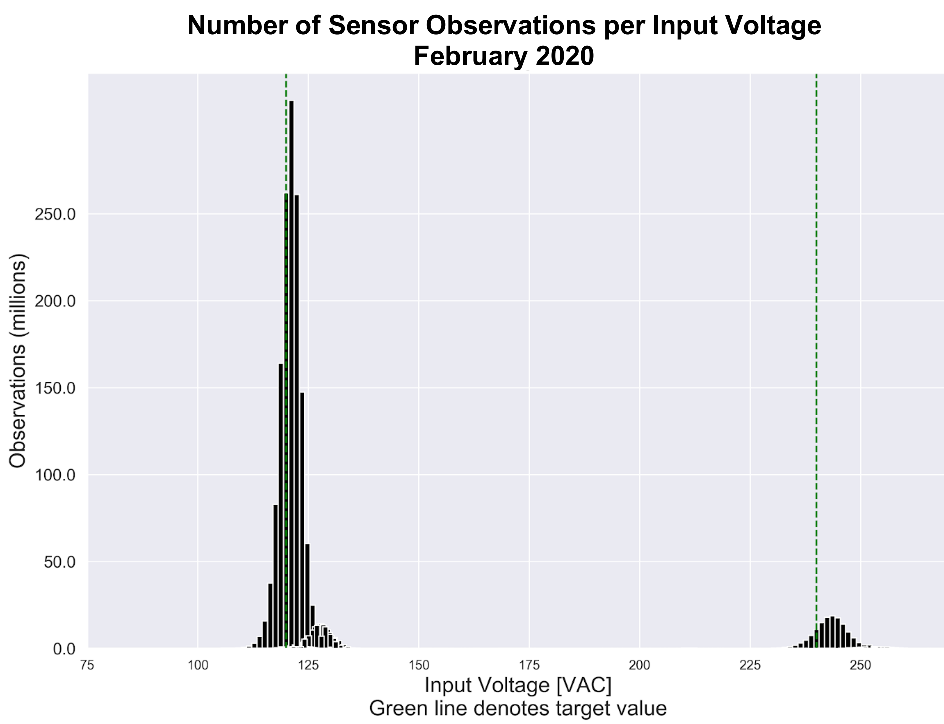

Figure 2 - Observed voltages in Gridmetrics national data set

6 https://webstore.ansi.org/standards/nema/ansic842016
7 https://www.spgsamerica.com/information/acceptable-voltage-ranges

Figure 2 depicts the distribution of voltage observations. The horizontal axis represents the range of sensor voltages and the vertical axis is the number of observations of each voltage. The green vertical lines represent the target voltages of 120 VAC and 240 VAC[8]. In the Gridmetrics national data set, approximately 92% of sensors are connected to 120 VAC, 8% of sensors are connected to 240 VAC, and less than 1% of sensors are connected to 208 VAC.

The average voltage per sensor in the Gridmetrics national data set is shown in Figure 3.

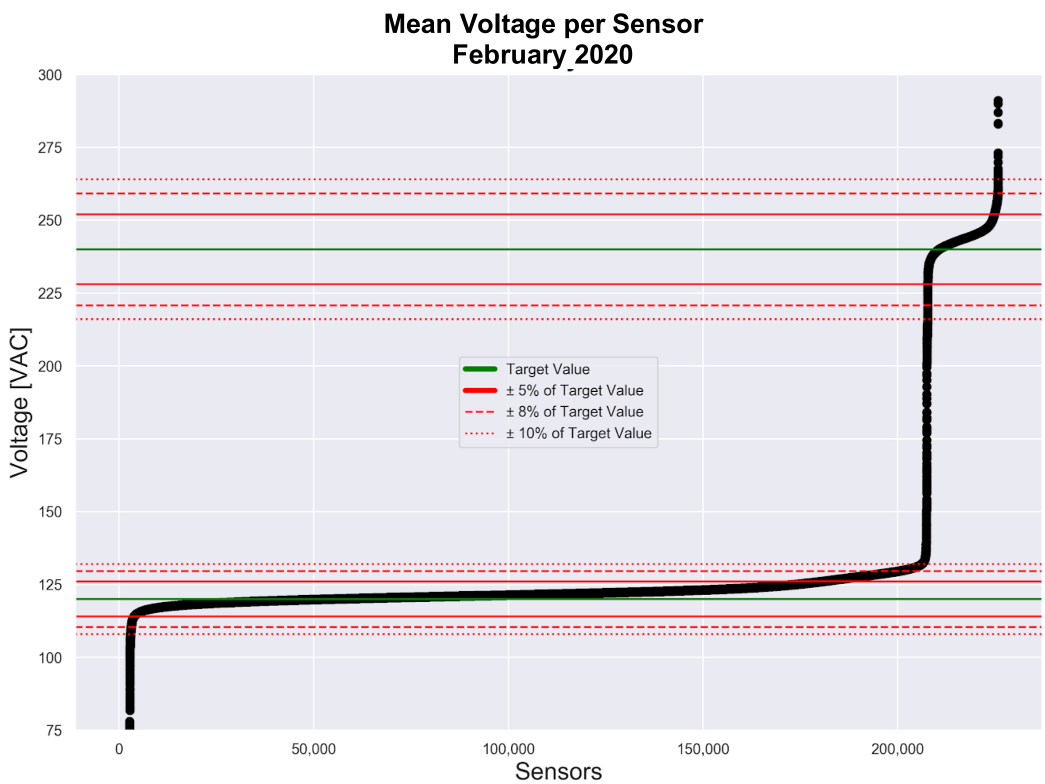

Figure 3 - Observed voltages in Gridmetrics national data set

Figure 3 depicts the mean (average) voltage per sensor in the Gridmetrics national data set. All sensors are sorted by mean voltage along the horizontal axis, with the lowest voltages at the left and highest voltages at right. The vertical axis is the mean of all voltages observed by each sensor. The target values of 120 VAC and 240 VAC appear in green, and NEMA limits of ± 5%, 8%, and 10% appear in red. In a perfect world, instead of voltage observations above and below the red lines, all voltages would be depicted along the flat green lines at 120 VAC or 240 VAC.

[8] Data used in all figures are available for select U.S. areas to allow for troubleshooting voltage quality issues and for comparison of the performance of individual utility serving areas to each other and to the national data set.

4. High Voltages

An example of high voltages observed by one sensor in the Gridmetrics national data set is shown in Figure 4.

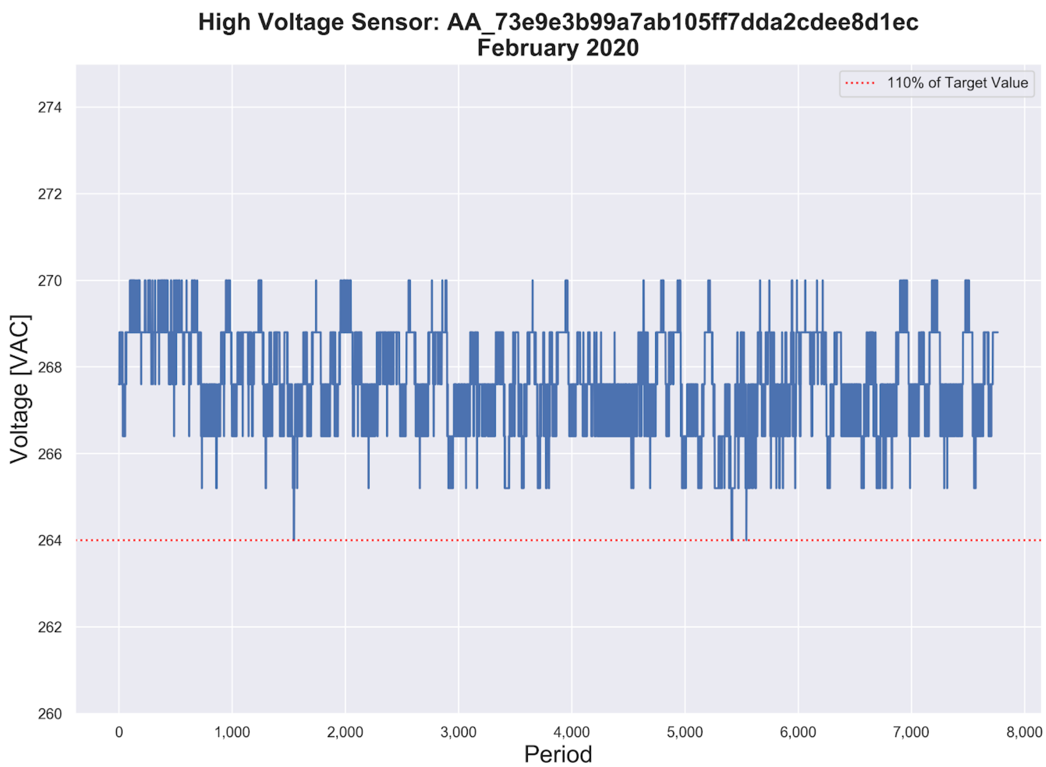

Figure 4 - Example of high voltage in the Gridmetrics national data set.

Figure 4 depicts voltages above 240 VAC that are so high that the target voltage and some NEMA limits are not visible. The horizontal axis is one month of time expressed in 5-minute periods and the vertical axis is the observed voltage.

Utility operations procedures can include checking sensor locations for anomalies. Additional examples of locations reporting high 120 and 240 voltage ranges are collected and available.

5. Low Voltages

An example of low voltage observed by one sensor in the Gridmetrics national data set is shown in Figure 5.

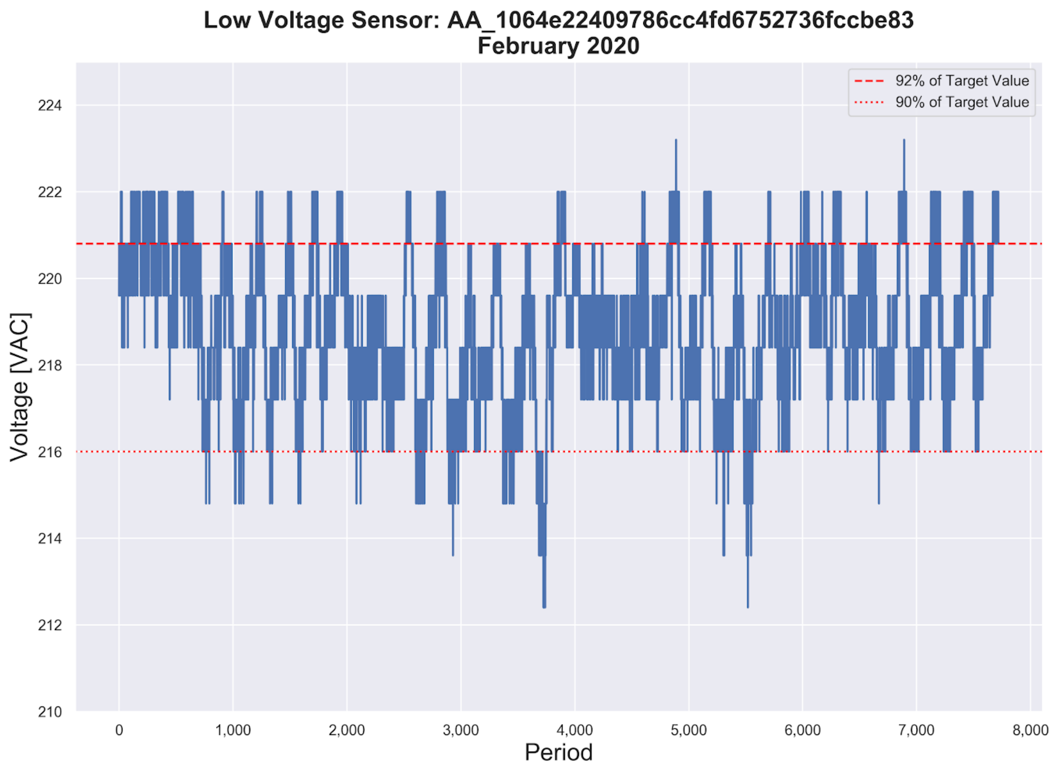

Figure 5 - Example of low voltage in the Gridmetrics national data set.

Figure 5 depicts voltages below 240 VAC, so low that the target voltage and some NEMA limits are not visible. The horizontal axis is the 5-minute time period and the vertical axis is the observed voltage. Additional examples of locations reporting low 120 and 240 voltage ranges are available.

6. Fluctuating Voltages

Some voltages fluctuate randomly, others fluctuate periodically. An example of a periodic fluctuation observed by one sensor in the Gridmetrics national data set is shown in Figure 6.

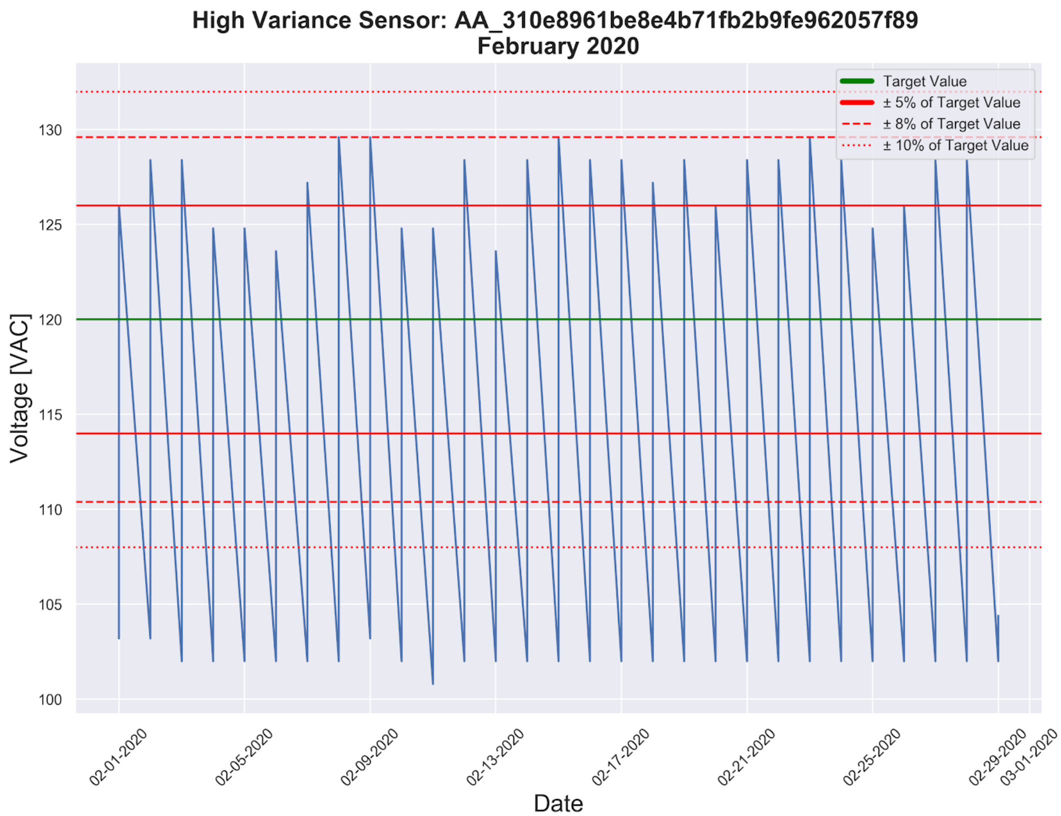

Figure 6 - Example of fluctuating voltage in the Gridmetrics national data set.

In Figure 6, the 120 VAC target is denoted in green and the ANSI limits are denoted in red. The horizontal axis is time in 5-minute increments and the vertical axis is the observed voltage.

Fluctuations can be caused by loose connections, faulty appliances, and malfunctioning motors. Large fluctuations from commercial and industrial loads can affect many consumers on the same circuit. Perhaps most problematic is electric arcing from loose connections that can result in overheating, sparks, and downed wires that cause wildfires. Additional examples of locations reporting fluctuating 120 and 240 voltage ranges are available.

7. Outages

Interruptions in electricity service vary by frequency and duration across geographic areas and are affected by weather and other variables. For any area, outage data can be very valuable to utilities in prioritizing and justifying investments that help mitigate outage impacts as measured in their System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). In recent years, the number of outages and the number of customers affected have consistently risen, in some areas by as much as 200%.[9] For example, in 2017, the average U.S. utility customer experienced 1.4 interruptions and lost their power for a total of 7.8

[9] https://www.bloomenergy.com/bloom-energy-outage-map

hours over the year, nearly double the average total duration of interruptions experienced in 2016.[10]

Power outages are both irritating to utility customers and regulators and are also incredibly expensive. According to a 2017 analysis by Sentient Energy, each minute of mitigated SAIDI can save a utility $500K to $1.5 million in O&M (operation & maintenance) costs.[11,12] Gridmetrics data can aid in reducing SAIDI and SAIFI by assisting utility outage prediction and detection algorithms.

A smarter grid can reduce the economic costs associated with power disturbances. Studies by the Electric Power Research Institute have estimated the yearly cost of power disturbances across all business sectors in the United States at between $104 billion and $164 billion as a result of outages, and another $15 billion to $24 billion due to power quality phenomena.

Gridmetrics data are helpful in finding and quantifying unforeseen and previously invisible outages and power quality issues in the secondary distribution grid. Gridmetrics data can be leveraged to complement existing utility outage frequency and duration processes as well as the metrics that utilities are required to report to the U.S. Energy Information Administration.

For example, Gridmetrics automated 5-minute near real-time observations during a severe storm in Sioux Falls, SD, have proven insightful. Sioux Falls was struck by three tornadoes around 11:30 PM on September 10, 2019, as depicted in Figures 7, 8, and 9.

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10 https://www.eia.gov/todayinenergy/detail.php?id=37652
11 https://www.sentient-energy.com/blog/15-minutes-could-save-you-15000000-or-more
12 https://www.epri.com/research/products/1022519

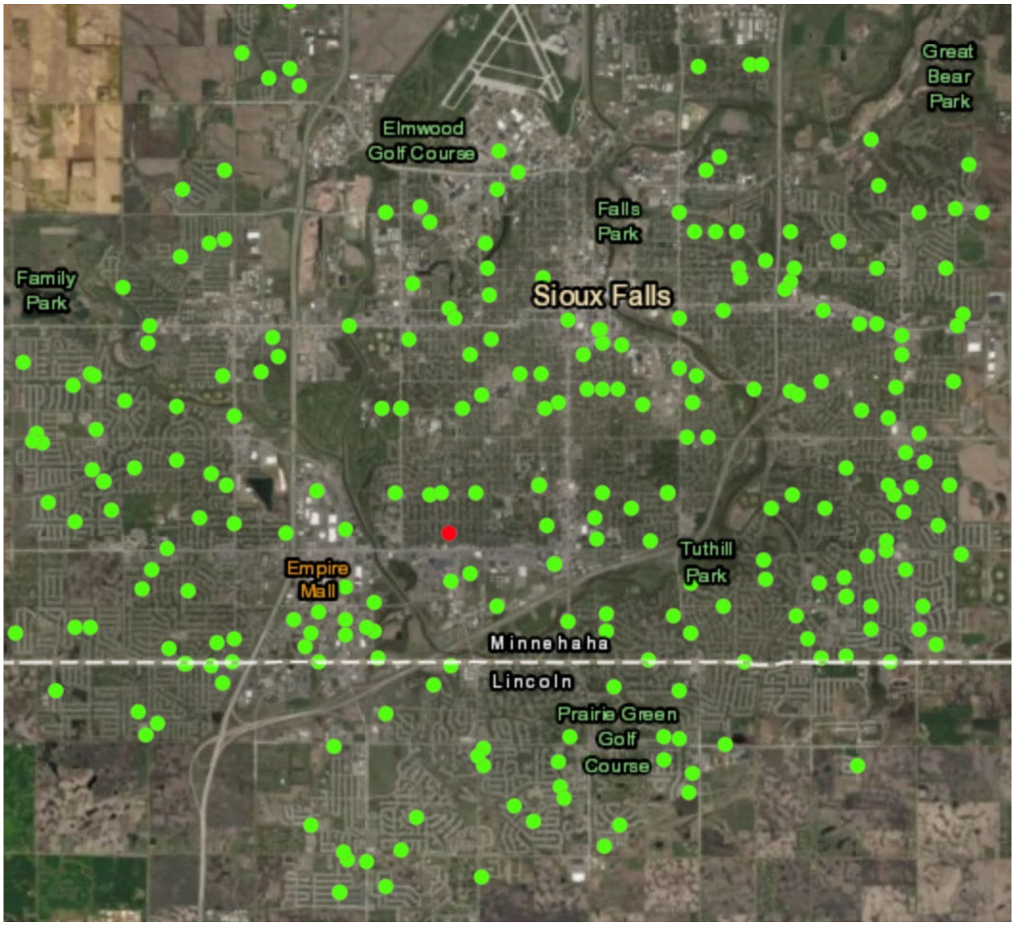

Figure 7 - Status of the secondary distribution grid prior to the outage.

Figure 7 shows the "green" status of sensors before the tornadoes hit. All but one sensor is green, indicating the grid power is "on" and widely available. This is a normal grid status.

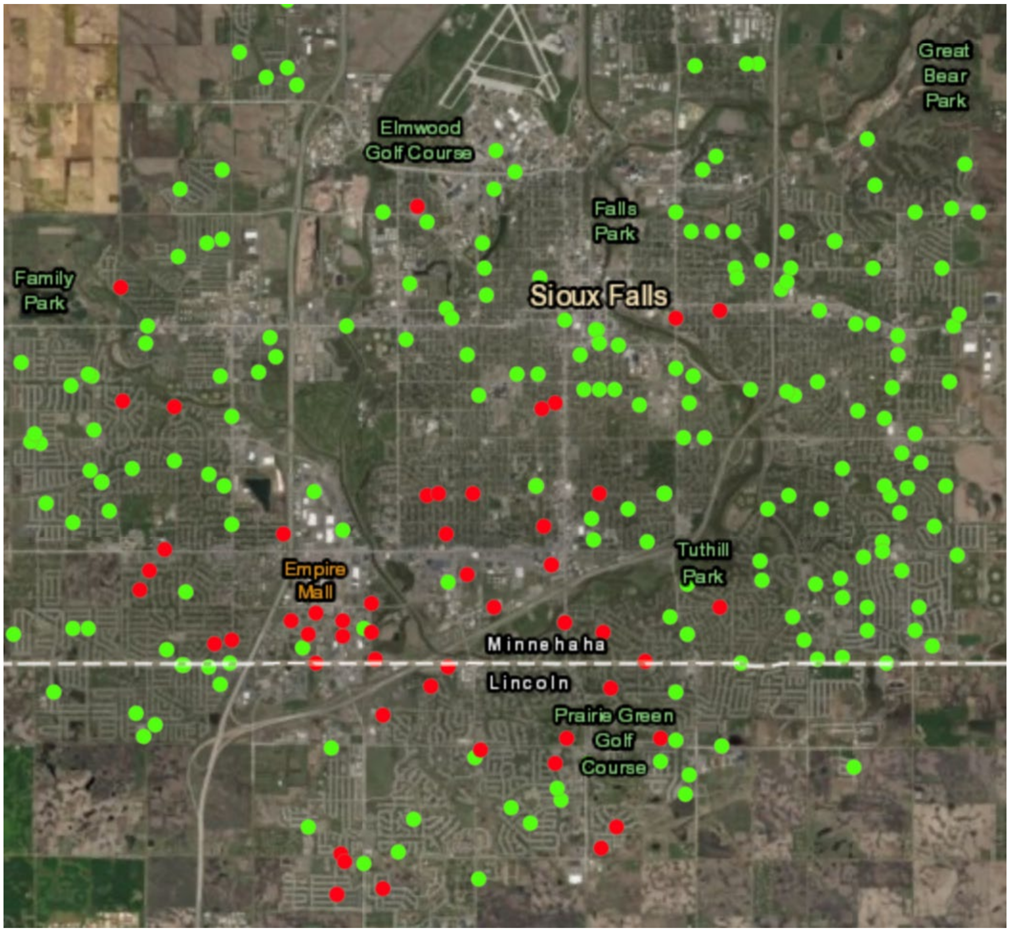

Figure 8 - Status of the secondary distribution grid during the outage.

In Figure 8, broadband sensors show the path of the Tornadoes starting at the lower left. The location of each red dot depicts a power failure. A changing map over time reveals where power outages come and go, while clusters of red provide a sense of the size of areas affected.

A unique capability of Gridmetrics sensors is their ability to continue to report status during grid power failures. Continuous reporting by all Gridmetrics sensors during weather catastrophes and other outages is made possible by battery-backed uninterruptible power supplies in each sensor. Batteries in each sensor provide 3 to 5 hours of backup power for sensing functions as well as high-speed real-time communications for backhaul of voltage observations.

Two benefits have become apparent to users of Gridmetrics data. First, due to Gridmetrics' enhanced visibility of the secondary distribution grid, new outages are being exposed over and above those detected by and reported through existing utility energy management and SCADA (supervisory control and data acquisition) systems. As such, the additional visibility in the last mile of the grid provided by Gridmetrics is benefiting utilities and their customers.

Second, utilities generally have limited tools to verify service restoration and as such can use Gridmetrics data to automate and augment their existing processes that involve utility staff driving around to see where power appears to have been restored. As one might expect, few utility customers call to report their service has been restored, making Gridmetrics real-time data APIs a natural fit to fill this need.

Figure 9 depicts a reduction in outages after the storm passed.

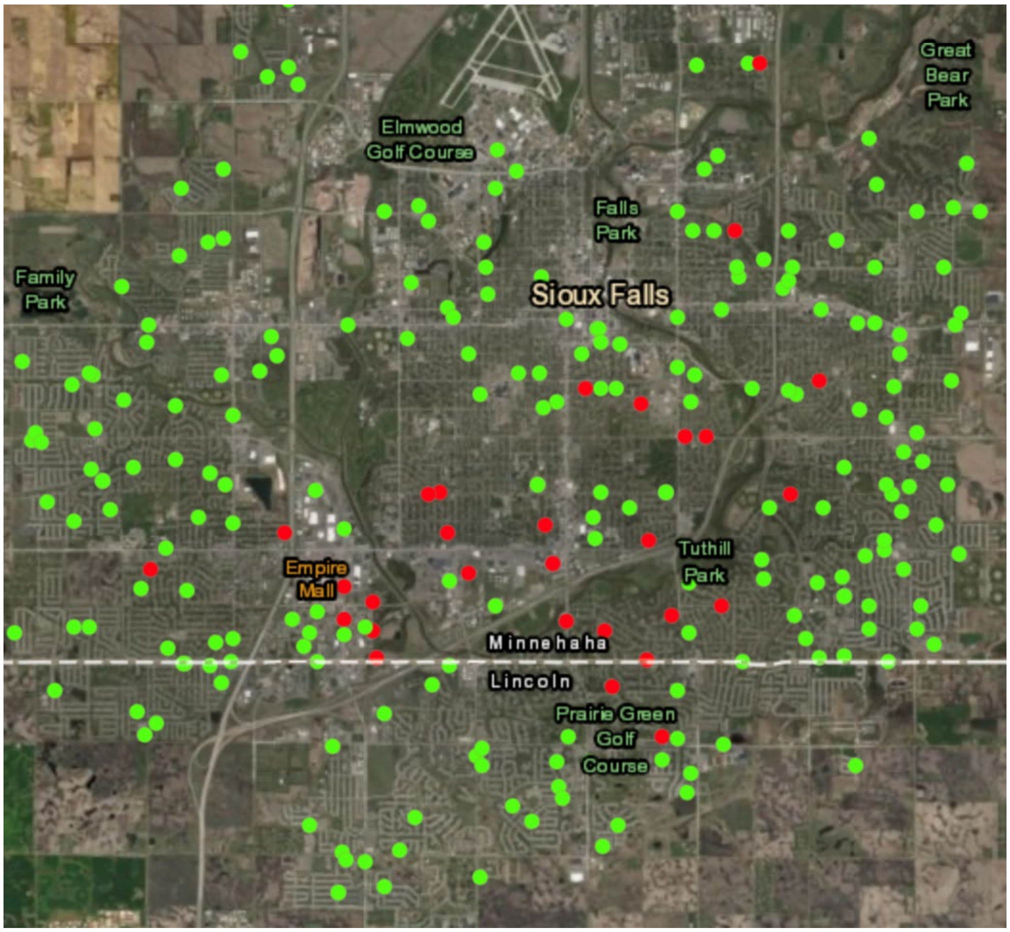

Figure 9 - Example of service <u>near the end</u> of the outage

The reduction in outages in Figure 9 is likely the result of utility service crews working to restore power around the city, especially at lower left. The remaining red dots depict serving areas that still require attention by utility crews.

8. Cable TV Broadband Sensor and Network Advantages

While most utilities have some level of experience with automatic meter reading (AMR) and advanced metering infrastructure (AMI), it is important to note inherent limitations of these technologies.

A) By design, all meters used for AMR 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. For reference, all Gridmetrics sensors are grounded, battery-backed, and provide continuous reporting during grid outages. Over 90% of Gridmetrics sensors are connected via leg-to-neutral to 120 VAC, which enables visibility of potential loss-of-life safety issues and reduced equipment longevity issues due to insufficient or intermittent grounding and unbonded neutral circuits.

B) While more than half of U.S. households have AMR deployed, the capability is often unused in daily operations due to bandwidth limitations in the backhaul communications infrastructure that results in bottlenecks in utilities receiving and processing AMR data.[13,14] In contrast, all Gridmetrics sensor data are backhauled over gigabit networks with millisecond latencies, allowing for near real-time 5-minute updates for all sensors in the national data set. The latency, loss, throughput, and jitter of the Gridmetrics sensor backhaul network far outperform commonly deployed AMI networks.

9. Conclusion

As the number of DERs and the two-way electricity flows they create rapidly increase, aging grid infrastructure elements that are supposed to keep the grid safe are failing and causing unprecedented loss of life and property.[15] 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 5-minute 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 by using an existing fleet of power sensors deployed across broadband networks.

The growing and evolving Gridmetrics data set is available to aid U.S. utilities 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 utility operations. Through utility 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 real-time Gridmetrics APIs and near real-time data feeds. Through collaboration with utilities and sharing best practices for anomaly detection and classification, it is expected that anomalies that foretell of impending infrastructure failures, resiliency and safety issues, and high-risk for loss-of-life can be identified. In addition, working with utilities, the criteria used to identify anomalies can be expanded, refined, and validated to achieve maximum benefit from Gridmetrics data.

Data from broadband power quality sensors can help utilities pinpoint existing portions of the grid that can be inspected for high, low, and fluctuating voltages 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 utility data sets to create a more comprehensive understanding of distribution network frailties. Combining insights

[13] https://www.smart-energy.com/top-stories/ami-system-operations-pose-unexpected-challenges/
[14] https://pubs.naruc.org/pub/FA865F09-934E-F89E-5141-7E766D260068
[15] https://www.tdworld.com/distributed-energy-resources/article/21120102/democratizing-energy-the-rise-of-ders

from utility SCADA systems and Gridmetrics data can help improve network reliability, resilience, and safety.

Abbreviations

AMI	advanced metering infrastructure
AMR	automatic meter reading
ANSI	American National Standards Institute
API	application programming interface
DER	distributed energy resource
EV	electric vehicle
O&M	operations and maintenance
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index.
SCADA	Supervisory Control and Data Acquisition
SCTE	Society of Cable Telecommunications Engineers
U.S.	United States
VAC	volts alternating current

Bibliography & References

U.S. Electrical Grid Undergoes Massive Transition to Connect to Renewables, Jennifer Weeks, Scientific American, The Daily Climate, April 28, 2010. https://www.scientificamerican.com/article/what-is-the-smart-grid/

PG&E Knew for Years Its Lines Could Spark Wildfires, and Didn't Fix Them, Katherine Blunt and Russell Gold, The Wall Street Journal, July 10, 2019. https://www.wsj.com/articles/pg-e-knew-for-years-its-lines-could-spark-wildfires-and-didnt-fix-them-11562768885

This Old Metal Hook Could Determine Whether PG&E Committed a Crime, Russell Gold and Katherine Blunt, The Wall Street Journal, March 8, 2020. https://www.wsj.com/articles/this-old-metal-hook-could-determine-whether-pg-e-committed-a-crime-11583623059

ANSI C84.1-2016: *Electric Power Systems And Equipment - Voltage Ratings (60 Hz);* NEMA: National Electrical Manufacturers Association. Accessed July 16, 2020. https://webstore.ansi.org/standards/nema/ansic842016

Acceptable Voltage Ranges, Safety Protection Grid Solutions. Accessed July 16, 2020. https://www.spgsamerica.com/information/acceptable-voltage-ranges

California Power Outage Map, Bloom Energy. Accessed July 16, 2020. https://www.bloomenergy.com/bloom-energy-outage-map

Average U.S. electricity customer interruptions totaled nearly 8 hours in 2017, Today in Energy, U.S. Energy Information Administration, November 30, 2018. https://www.eia.gov/todayinenergy/detail.php?id=37652

15 Minutes Could Save You $15,000,000 or More…., Sentient Energy Blog, August 22, 2017. https://www.sentient-energy.com/blog/15-minutes-could-save-you-15000000-or-more

Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid, Electric Power Research Institute, 2011. https://www.epri.com/research/products/1022519

AMI system operations pose unexpected challenges, David Gordon Kreiss and Masoud Abaei, Smart Energy International, September 23, 2013. https://www.smart-energy.com/top-stories/ami-system-operations-pose-unexpected-challenges/

Toward an End-to-End Smart Grid: Overcoming Bottlenecks to Facilitate Competition and Innovation in Smart Grids, Johann J. Kranz and Arnold Picot, National Regulatory Research Institute, June 2011. https://pubs.naruc.org/pub/FA865F09-934E-F89E-5141-7E766D260068

Democratizing Energy: The Rise of DERs, Stephan Marty, T&D World, January 9, 2020. https://www.tdworld.com/distributed-energy-resources/article/21120102/democratizing-energy-the-rise-of-ders

