

## Using the cable TV network to detect local power outages and voltage events

*Sunhee Baik, Lawrence Berkeley National Laboratory*

*Robert F. Cruickshank, Cable Television Laboratories and Robert Cruickshank Associates*

*Alan Meier, Lawrence Berkeley National Laboratory*

### ABSTRACT

The rapid adoption of photovoltaics, batteries, electric vehicles, and other distributed energy resources can create highly localized voltage fluctuations (including outages), leading to equipment failures for both suppliers and consumers. Rapid, unmanaged electrification may compound these problems. Local voltage fluctuations are generally not visible in real-time with present sensing methods employed by utilities. We worked with cable TV broadband providers to apply their communications network to detect voltage fluctuations and outages at the neighborhood level. This network consists of over 300,000 sensors across the United States. Each sensor tracks grid conditions every five minutes for an area with roughly 250 homes. The sensors were placed in the vendors' distribution boxes located on utility poles and pedestals, so there are no privacy implications. Unlike smart meters, this system provides active notification because the sensors and network have battery backup for about 6 hours of operation. We investigated system performance in a service territory of a partner utility. We show that the sensors can rapidly identify highly localized outages, in addition to voltage fluctuations and brief periods of over-voltage and under-voltage. This information can help utilities proactively address incipient failures at the sub-distribution level and prepare for a more dynamic, decentralized grid. The sensor network can also be used to prioritize locations for network upgrades that can minimize power interruption costs. Finally, we discuss how the dataset and our study could address the issues of energy equity and justice.

## Introduction: The Smart Grid and Building Electrification Programs Intersect at the Distribution Network

Most causes of power interruptions, such as lightning strikes, falling trees, small animal (e.g., squirrel) electrocutions, or vehicles crashing into poles occur at the distribution level, or the last leg of the delivery of electrical power from generation to the consumer. The rapid increase in behind-the-meter photovoltaics, batteries, and electric vehicle charging is creating new, unpredictable stresses on the utility system's "last mile." These stresses will be further exacerbated by decarbonization policies, which shift natural gas end uses to electricity (Shaffer, Quintero, and Rhodes, 2021). Climate change may bring even more intense storms and disruptions. The combined result of these trends will be more frequent, highly localized voltage events, premature transformer failures, and power outages on already aging infrastructure. No single technology or policy will fix these problems; however, improved visibility of the distribution level will help utilities identify incipient failures, prioritize repairs, and minimize their impacts. To be effective, this enhanced visibility must capture high-frequency events in real-time and at a neighborhood scale. We describe below the present level of utility visibility where the smart building meets the smart grid. Then we introduce a new and potentially attractive method of monitoring grid conditions at the distribution level.

The utility's visibility into grid conditions typically ends at the electrical substation. Each substation serves the equivalent of 1,500 residential customers. There, supervisory control and data acquisition (SCADA) systems provide real-time, high-frequency data on power and voltages. Relays, switches, and other controls ensure automatic responses to normal deviations in the load. Some utilities have sensors and alarms downstream of the substation but not in any consistent way. These data feed Outage Management Systems (OMS), which most utilities use to track outages and other service anomalies.

Customers remain the primary source of power outage reports. A national survey in 2015 found that customers were the primary source of outage notification in over half of the utilities, while SCADA systems accounted for less than a third of the notifications (SkyVision, 2015). Pacific Gas & Electric (PG&E) (2016) found that not all transformers had reliable communications through the normal SCADA network and that a parallel communications network deserved consideration, especially for smaller, less critical units.

The modern smart meter and its associated advanced meter infrastructure (AMI) was designed to provide instantaneous alerts to the utility when an outage occurs. When the meter detects an outage, it broadcasts a "last gasp" into the mesh network.<sup>1</sup> In practice, the message often fails to be broadcast or transmitted through the mesh network to a receiving station. The "receipt rate" for last gasps falls with the size of an outage. When only one meter is affected, PG&E found that the last gasp reaches the OMS 82% of the time, but the rate falls to below 20% during a widespread outage. The two chief causes for transmission failure were last-gasp messages sent to other meters experiencing the same outage and congestion in the mesh network. False alarms are also common. For instance, a British utility noted that the last gasps caused by local contractors and over-the-air firmware upgrades were major nuisances (Western Power

---

<sup>1</sup> A capacitor in the meter stores enough electricity to broadcast a "last gasp" on the mesh network. When a power loss occurs, the smart meter should have enough reserve power for 300ms during which time it can properly log the outage event and send out a last gasp to its nearest neighbor device on the mesh network. However, PG&E discovered that successful transmission depends on many factors, including what the meter was doing at the time of the outage and its sensitivity to power sags.

Distribution, 2021). Finally, the widespread adoption of distributed energy resources (DERs) in homes will reverse power flows in ways that may confuse smart meters and render their sensing architecture inadequate (Liao et al., 2021).

Smart meters can, in principle, also collect and transmit real-time measurements of voltage, power factor, and other key operating parameters (Alahakoon, Damminda, and Xinghuo, 2016). The measurement interval is typically 15 minutes, although this can be adjusted (Duan et al., 2022). These data can provide highly granular information about grid status at the distribution level.

In practice, few utilities exploit this feature because the mesh network lacks the bandwidth to transmit such large amounts of data. Data congestion often occurs when many meters are sending a single, last-gasp message. To minimize data transfers and errors, most utilities poll their meters about twice a day and collect little more information than time-of-use electricity consumption (Duan et al., 2022). These limited operations typically consume about one-quarter of the available bandwidth on the mesh network. Given this erratic performance, it makes sense that utilities do not rely heavily on smart meters for outage information. Indeed, the earlier survey found that only 16% of the utilities relied on the last-gasp messages as their primary source of outage information (Bridge, 2015).<sup>2</sup>

In summary, smart meters cannot provide the level of visibility at the distribution level to help utilities reliably identify incipient failures and other events. The mesh network lacks both the capacity and reliability to operate in real-time. This situation will gradually improve but only after expensive upgrades to meters, the mesh network, and other parts of the AMI. A higher-resolution sensing network at the distribution level is still required to track both outages, voltages, and other parameters that can be impacted by the increasing numbers of PVs, EVs, and batteries appearing in customer premises.

## **The Cable TV Network**

Cable TV and broadband providers deliver content to homes through an independent data network. The cable TV network uses about 500,000 nodes located in neighborhoods across the U.S., and about two million nodes around the world. The node's power supply unit (PSU), which draws power from the electric utility, is a frequent point of failure, so the cable TV providers carefully monitor the PSU's input voltage (Network Operations Subcommittee, 2021). Thus, for internal maintenance purposes, the cable TV vendors already measure and collect local grid voltages every one to five minutes at the neighborhood level for nearly 90% of U.S. households. Broadband providers already continuously monitor the voltage sensors and immediately send repair crews when an outage is detected. The protocols for sensing and collection of the PSU voltage measurement were recently standardized. Arguably, some cable TV vendors have better visibility into power outages and voltages at the secondary distribution level than the electric utilities.

In the cable TV network, information flows from the head end (the central facility serving a local area for cable television systems) to thousands of individual nodes and ultimately to the individual customers (and in reverse). A schematic diagram of the cable network is shown in Figure 1. One node typically serves about 250 homes. The node consists of the server, a PSU, inverter, sensors, and battery. These nodes draw power from the utility's secondary distribution system at 120, 208, or 240 Volts depending on local installation conditions and have batteries

---

<sup>2</sup> Note that the quality of this survey is suspect but appears to be the sole public discussion of this issue.

that enable about six hours of independent operation in case of a power outage. Figure 2 shows the location of the voltage sensor in the electric power distribution system.

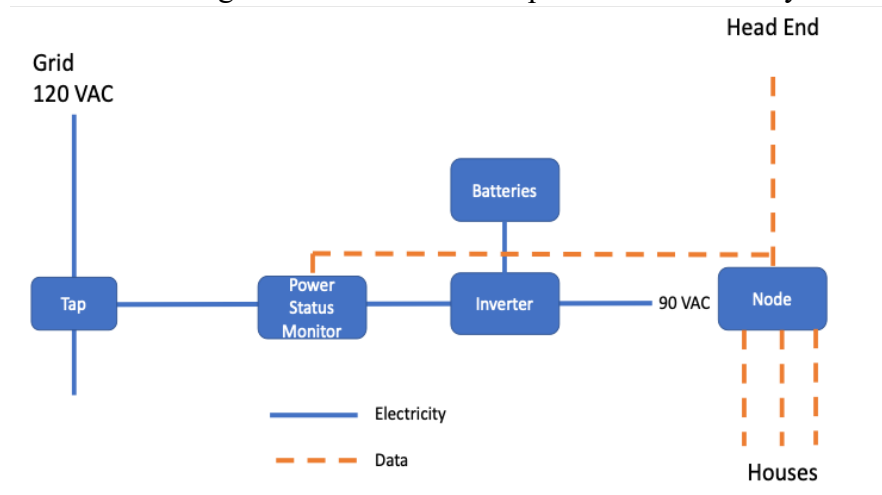


Figure 1. Schematic representation of the cable TV infrastructure.

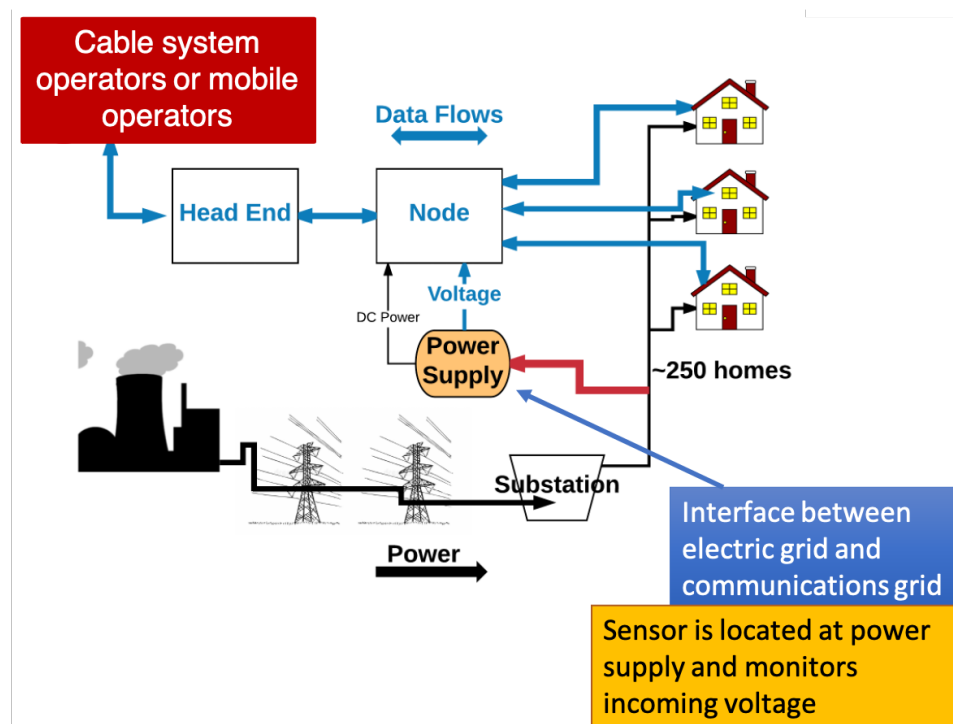


Figure 2. The interface between the electrical grid and the cable TV network

The cable TV network offers a promising method of inexpensively monitoring conditions at the distribution level. We investigate the feasibility of leveraging a network of over 500,000 existing voltage sensors in the cable TV system to provide granular, real-time situational awareness throughout the nation's secondary electrical distribution system.

## Earlier Investigations

The possibility of explicitly using the cable TV network to detect power outages was first proposed in 2016 and soon expanded to include detecting voltages with the same sensors.<sup>3</sup> Further work was needed to standardize sensor specifications and consolidate data, which culminated in an international standard (Network Operations Subcommittee, 2021). The research lab for the cable industry, CableLabs Inc., created an independent entity, Gridmetrics®, in 2021 to provide sensor data to utilities, governments, researchers, and other interested parties. Gridmetrics created the Power Event Notification System (PENS) to distribute the information and published a detailed study on Texas 2021 power outage (Gridmetrics, 2021).

The voltage data have only recently been examined, though informally. For example, Cruickshank et al. (2020) found that the overwhelming majority of voltages collected by these sensors are within recommended limits. However, instances of significant fluctuating voltage, over-voltage and under-voltage were identified. These events could have been caused by any of the problems described earlier. Unfortunately, no further information was available to help identify the source of the voltage event.

## Case Study: Using Cable TV Network Data to Identify Voltage Anomalies and Power Outages

We analyzed the voltage information of a small municipal electric utility in the western United States for the period of June 1 to December 17, 2020. The study area covers 18 square miles with ~48,000 residential customers, 6,500 business customers, and 1,800 large commercial and industrial customers. During the study period, 141 cable TV voltage sensors operated (although some sensors stopped transmitting data and/or were replaced with new sensors). See Figure 3 below for the satellite map of the service area and the locations of the cable TV network sensors.

---

<sup>3</sup> Other networks relying on the Internet had already been proposed and investigated. For example, Meier et al. (2019) demonstrated that a network of connected thermostats could reveal the paths of hurricane and storm-induced power outages. These networks suffered from several limitations, including insufficient coverage, frequent Internet outages, and privacy considerations.

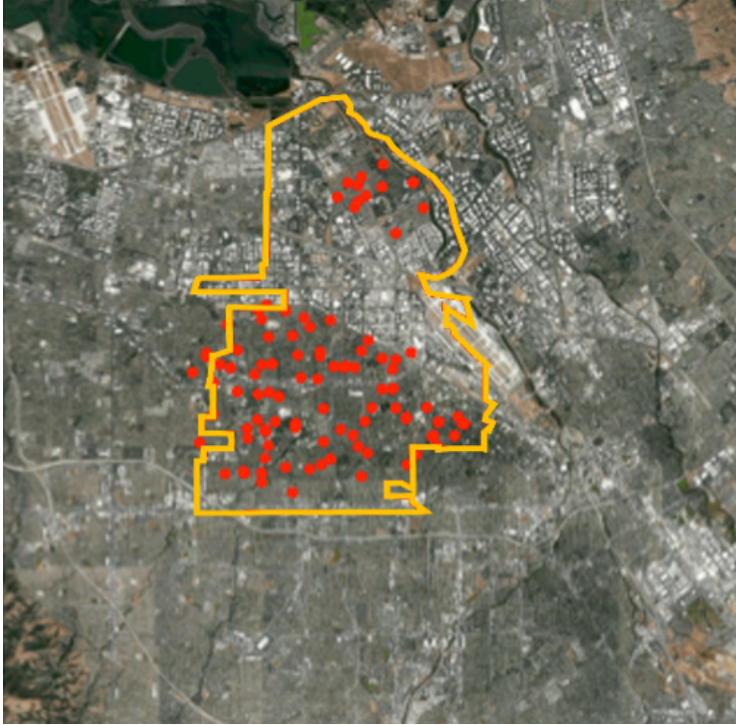


Figure 3. Satellite map of the service area and the location of the sensors. Source: Google Maps.

Each sensor provides data once every 5 minutes, reporting the timestamp, the average input voltage, and the inverter status. Table 1 below is an extract of the data stream. Three scenarios can be detected:

- a short-duration power outage on a single sensor or multiple sensors that are restored within battery backup hours:
- a long-duration power outage on a single sensor or multiple sensors that were restored after batteries expire, and
- a brown-out, when sensors receive power from the grid at a voltage level lower than the lower limit of the operating voltage.

While the cable TV network dataset provides rich information at high geospatial resolution, the dataset also suffers from reliability issues. Figure 4-A below suggests that some sensors did not provide inverter status information during the study period. In addition, the heatmap of the number of data sent to the server by date of measurements (rows) and the sensors served at 120V (columns) suggests that two server outages occurred (rows with only red cells; mid-August and late November). In addition, less data was collected in September and more data was collected during October.

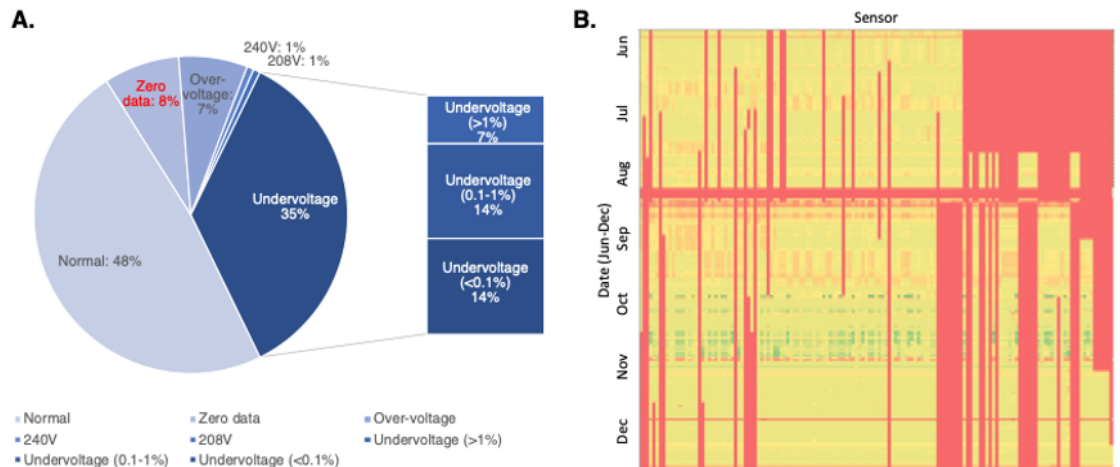


Figure 4. (A) Pie chart demonstrating the percentages of sensors that had over- or under-voltage data, only with normal grid operating voltages, and only with zero-data during the study time period. (B) Heatmap of data availability by date (rows) and sensor ID (columns). Red cells suggest that the number of data received during the day is either small or zero, and the green cells suggest that the number of data received during the day is large.

We describe below, through three examples, how the cable TV sensor dataset can be used to inform utilities' planning and operating decisions. We also present a methodology for evaluating the effectiveness of the sensor data.

### Local Voltage Anomalies

We used the dataset to identify the location of the sensors with abnormally high, low, or fluctuating voltage during the study period. Figure 5 below shows examples of the high- or low-voltage observations. The sensor in Figure 5-A had 99.5% voltage measurements exceeding the 105% limit of 120V (blue dotted line in the figure). An overvoltage of this magnitude may cause higher energy usage, higher electricity bills, overheating, and premature failure of electrical and electronic components. The sensor reported in Figure 5-C had 41% of data below the 95% limit of 120V (red dotted line in the figure). Under-voltages of this magnitude may increase delivered current to customer equipment, leading to overheating and a shortened lifespan of motors. Several sensors did not display consistent trends in voltages (e.g., Figure 5-A), but others showed trends in the voltages such as periodic fluctuations (Figure 5-B) or a trend to increase (Figure 5-C). Identifying these trends is important to utilities and service providers for addressing the power quality degradation problem. However, this information can also identify locations of equipment with loose connections, faulty appliances, or malfunctioning motors. They can also help utilities address the problems before they escalate to overheating, sparks, downed wires, or even wildfires and maintain voltages within the normal operating voltage range.

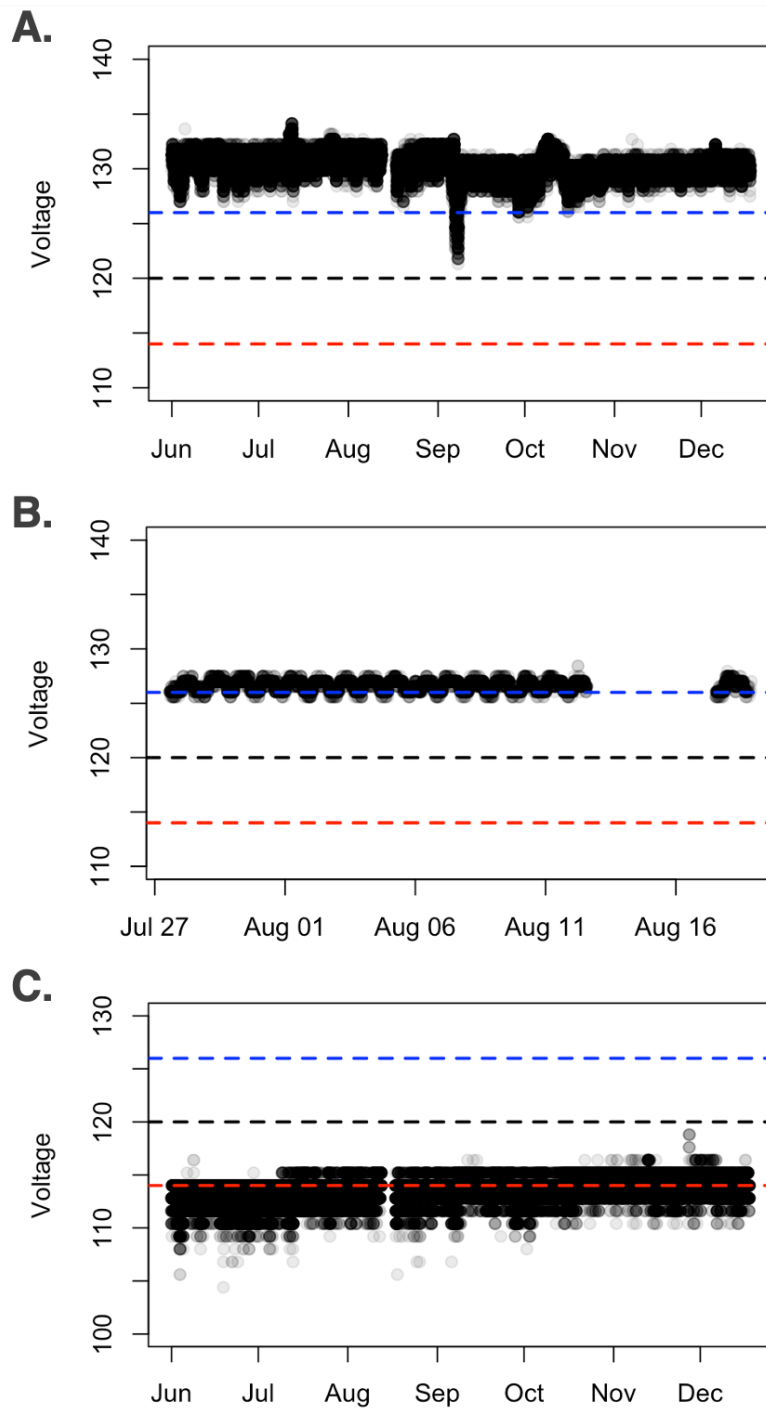


Figure 5. Example of the voltage anomalies detected by the cable TV network dataset. (A) shows the consistent high voltage data with a sudden drop, whereas (B) and (C) show some trends such as voltage fluctuations and linear increase.

## The Value of Local Voltage Measurements

The previous analysis identified some sensors with potentially dangerous trends in voltage whose causes need to be explained. One of the potential causes is temperature changes. A changing climate is likely to affect both the frequency and intensity of extreme events, such as heat waves (National Academies of Science, 2018, Karl, Melillo, and Peterson, 2009). Heatwaves also reduce the transmission and distribution capacity (Fant et al., 2020). We examined the relationship between daily high (solid red lines in Figure 6) and low (solid blue lines in Figure 6) temperatures and voltage events. If a node suffers persistent voltage problems (see Figure 6-A for an example), it is hard to determine a clear relationship between ambient temperature and voltages. On the other hand, some sensors indeed showed moderate correlations with the portion of data with voltage anomalies ( $\sigma_{6B, High Temp} = 0.4$ ,  $\sigma_{6B, Low Temp} = 0.4$ ) and temperature and decreasing trends over the study time period (see Figure 6-B for the downward trend). On-site field inspections will be needed to identify the causes.

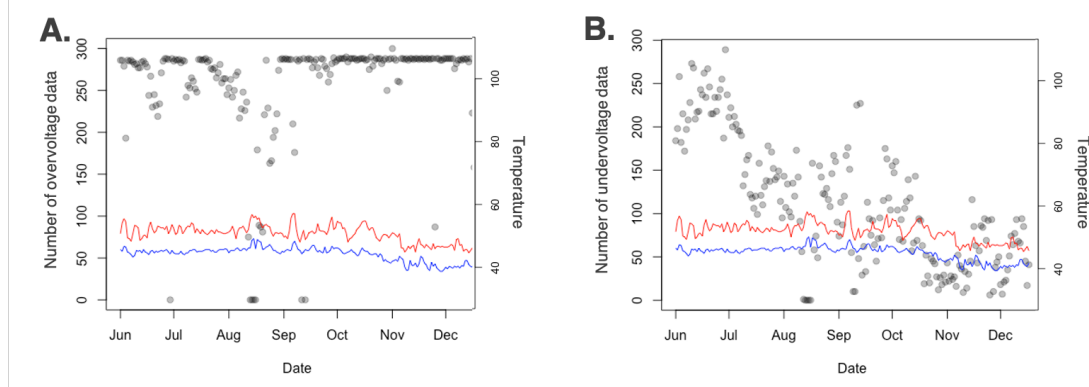


Figure 6. Example of the voltage anomalies detected by the cable TV network dataset. (A) shows the consistent high voltage data with a sudden drop (mainly due to the server shutdown and power outage), whereas (B) shows a trend of voltage fluctuations and linear decrease.

## Geospatial Distribution of Power Outages in Real-Time

The cable TV network dataset can be used to precisely identify power outages on an almost real-time basis. We worked with the utility and compared the cable TV network's outage data to the utility's outage logs. The utility provides the start and end time, area, number of customers impacted, and the outage cause (see Figure 7-A below). The cable TV network dataset provided higher geospatial and time resolution than the utility. For the same power interruption, the cable TV network dataset provided more precise locations and outage duration information. Each cable sensor operated with an error range of  $\pm 5$  minutes and reported the outage duration for each of the sensor (see the table in Figure 7-B), whereas the utility reported only the manually detected end time when the power was completely restored. Thus, the cable TV network sensors could help find and quantify previously invisible outages at the sub-distribution level, support rapid service restoration, and reduce power interruption costs.

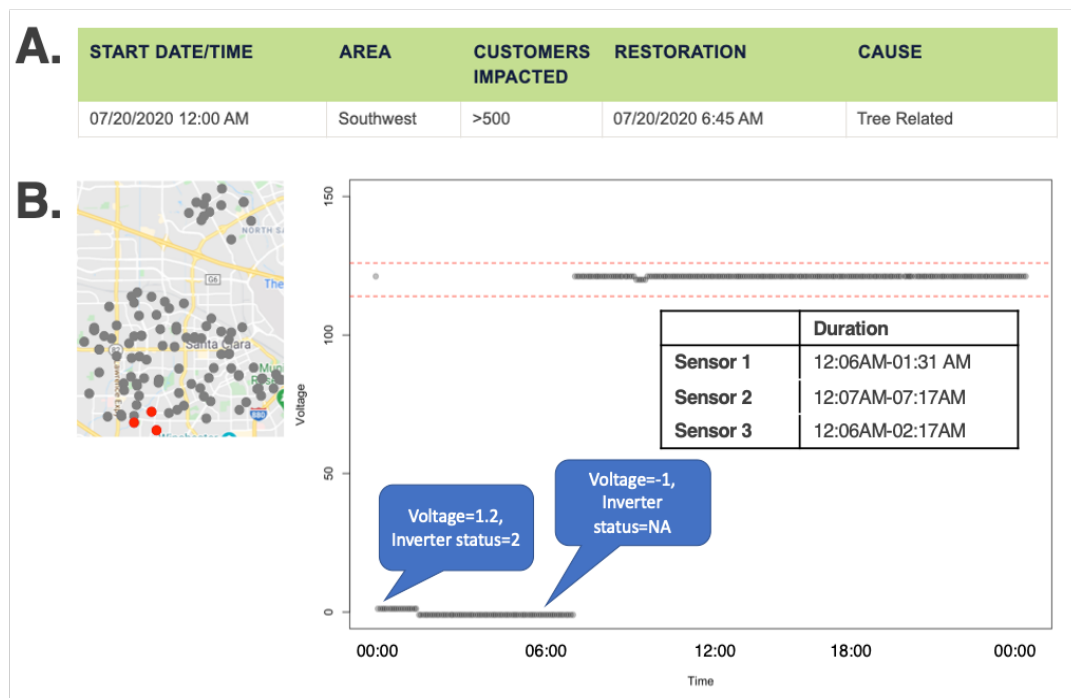


Figure 7. An example of outage logs generated by utilities (top) and the information that could be drawn from the cable TV network dataset, including the locations of the affected sensors, voltages against time, and duration of the power outages with an error range of 5 minutes (bottom).

## Future Work

Future work will proceed in four directions. First, we will explore in detail the anomalies detected by the cable sensors and compare them to the utility repair/outage records. We will then compare events logged by the utility to measurements by the cable sensors nearest to those events. This "triangulation" will help determine the value of the cable sensor data for maintenance and planning.

Second, we will examine the impact on voltages in neighborhoods with high penetrations of DERs to compare utilities' ability to detect voltage anomalies and outages against detection capabilities using the cable sensor network. The analysis will give us an insight into whether the utility's current sensing and control adequately handle negative power flow during limited periods.

Third, we will examine the impact of extreme utility-side events, such as upstream failures at substations and high-voltage lines on measurements by the cable sensors.

Finally, we will expand our analysis to determine the effectiveness and efficiency of advanced grid control technologies that enhance grid resilience but require incremental investment.

## Discussions and Conclusions

This paper investigated the feasibility of leveraging a presently under-utilized network of existing voltage sensors in the cable TV network. The cable TV network sensors and dataset can enhance the visibility of power outages and quality disturbances by transmitting data at

approximately ten times the frequency and ten times the granularity. The case studies provide examples of how to utilize the cable TV network dataset can provide actionable, real-time status and voltage at the sub-distribution level to proactively address incipient failures and prepare for a more dynamic and decentralized system.

Aside from increased visibility in terms of frequency and granularity, the cable sensor network offers four important advantages. First, it tracks the status of the power grid through a cyber-secure, independent data network (i.e., cable TV and broadband networks).<sup>4</sup> Second, utilities can have secure and independent visibility into grid conditions that could resolve the “last gasp” signal issue of OMS. Third, utilities do not need to invest to achieve additional situational awareness because the cable TV network and sensors are already installed and operational. Finally, the cable TV network dataset provides better visibility into grid conditions at the edge of the grid and explains with greater specificity what results in power interruptions and how to improve the reliability and resilience of the grid network.

With the cable TV network dataset, decision-makers would be able to perform additional analyses for the edges, such as exploring the role of the low-voltage ride-through capability of DERs for the mitigation of voltage sags, distributed generation impact on voltage sags in distribution networks, impacts of incipient transformer failures, or long-term impacts into energy infrastructure. Finally, the dataset can help facilitate informed reliability investment decisions. Utilities and public utility commissions (PUCs) justify their future investments in reliability using reliability indexes and customer interruption cost estimates. These indexes can be improved by applying more precise and granular inputs. One outcome might be prioritizing investment projects that upgrade energy infrastructure in neighborhoods that face voltage fluctuations and outage issues that were previously not detected or quantified.

The exceptional granularity of the cable node power data makes possible an investigation of a policy issue related to energy justice. Anecdotal reports suggest that historically disadvantaged neighborhoods experience wider voltage fluctuations and more outages than other regions. For instance, Carvallo et al. (2021) investigated the impacts of February blackouts in the Texas power grid in 2021 and suggested that low-income and minority groups were over four times as likely to suffer a blackout than predominantly white areas. Environmental justice issues like this can be further investigated by combining the cable TV network dataset with demographic information (Carvallo et al., 2021)

## Acknowledgments

The authors deeply appreciate the cooperation of Gridmetrics and the anonymous utility personnel, who reviewed the analysis results and gave us constructive feedback. This research used data from Google Maps for visualization. This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

---

<sup>4</sup> On February 23<sup>rd</sup>, 2022, a large outage was reported on PG&E's website and outage map. In fact, power was never lost but an error had occurred in the OMS. It took several hours for PG&E to confirm that power had not been interrupted. The cable TV sensor network could have verified this in minutes.

## References

- Cruickshank, R., N. Metts, P. Schauer, and C. Snyder. "Gridmetrics Data Provide Insights and Improve Situational Awareness of the Power Grid." 2020 SCTE®-ISBE Cable-Tec Expo. <https://www.nctatechnicalpapers.com/Paper/2020/2020-gridmetrics-data-provide-insights>.
- Duan, N., C. Huang, C. Sun, and L. Min. "Smart Meters Enabling Voltage Monitoring and Control: The Last-Mile Voltage Stability Issue." *IEEE Transactions on Industrial Informatics* 18, no. 1 (January 2022): 677–87. <https://doi.org/10.1109/TII.2021.3062628>.
- Fant, C., B. Boehlert, K. Strzepek, P. Larsen, Alisa White, Sahil Gulati, Yue Li, and Jeremy Martinich. "Climate change impacts and costs to US electricity transmission and distribution infrastructure." *Energy* 195 (2020): 116899.
- Gridmetrics. "Houston, We Have A Problem." March 11, 2021. <https://gridmetrics.io/resources/>.
- Karl, T. R., J. M. Melillo, T. C. Peterson, and Susan J. Hassol, eds. *Global climate change impacts in the United States*. Cambridge University Press, 2009.
- Liao, Y., Y. Weng, C. Tan, and R. Rajagopal. "Quick Line Outage Identification in Urban Distribution Grids via Smart Meters." *ArXiv:2104.02056 [Cs, Eess, Stat]*, April 1, 2021. <http://arxiv.org/abs/2104.02056>.
- Martin, T. "EPIC 1.14 – Next Generation SmartMeter Telecom Network Functionalities." San Francisco: Pacific Gas and Electric Company, November 30, 2016. [https://www.pge.com/pge\\_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/EPIC-1.14.pdf](https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/EPIC-1.14.pdf).
- Meier, A., T. Ueno, and M. Pritoni. "Using data from connected thermostats to track large power outages in the United States." *Applied Energy* 256 (2019): 113940.
- Higgins, R. 1989. *Analysis for Financial Management*. Homewood, IL: Irwin.
- National Academies of Sciences, Engineering, and Medicine. (2017). *Enhancing the resilience of the nation's electricity system*. National Academies Press.
- Network Operations Subcommittee WG4. "Requirements for Power Sensing in Cable and Utility Networks - NOS 207." Society of Cable Telecommunications Engineers (SCTE) / International Society of Broadband Experts (ISBE), 2021.
- Shaffer, B., Quintero, D., and J. Rhodes. "Changing Susceptibility to Cold Weather in Texas Power Demand." USAEE Working Paper No. 21-533. Available at SSRN: <https://dx.doi.org/10.2139/ssrn.3980881>.
- SkyVision Solutions. "Customer Calls, Not Smart Meters, Still Primary Source of Power Outage Notification for Utilities." *Smart Grid Awareness* (blog), April 30, 2015. <https://smartgridawareness.org/2015/04/30/customer-calls-not-smart-meters-still-primary-source-of-power-outage-notification-for-utilities/>.

Western Power Distribution. “Smart Meter Strategy,” July 2021.  
<https://www.westernpower.co.uk/downloads-view-reciteme/357223>.