Sharpen Your Senses

Enabling the No-Touch HFC Power Network Through Next-Gen Instrumentation

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1. Introduction

The Near-Future hybrid-fiber coax (HFC) network will evolve beyond being a highly efficient 10G data transport system, to a self-configuring, self-diagnosing and self-healing, neural network. With a brain powered by artificial intelligence (AI) sitting at the network core, the HFC network will have the ability to analyze unfathomable amounts of data and use yet-unknown insights to make split second decision to optimize performance and eliminate unnecessary human intervention. Yet, just as the human brain relies on the senses to provide information streamed from its environment for reflexive decisions, the near-future network will only be as good as its ability to stream the high-fidelity data effectively.

Broadband operators have developed the technology, tools, and systems to ensure that the radio frequency (RF) elements of the HFC network are well-instrumented leading to benefits in reliability and availability. However, much less instrumentation has been developed for the power elements of the HFC network. With network power being so critical for reliability and achieving energy savings, how can we enhance our understanding of power in the network and how can MSOs get maximum value out of this new sensory data?

1.1. Beginning with the End in Mind

The goal of this paper is to explore concepts that can drastically reduce operational cost and carbon impact from unnecessary truck rolls in the outside plant (OSP.) Operators have continued to hone operations processes and have made huge strides toward reducing wasted effort due to unnecessary truck rolls. However, there may still be millions of dollars annually wasted rolling trucks due to power issues that cannot be easily seen or that are transient in nature and never identified. This paper will provide more detailed examples, but having this end goal in mind will provide context for the concepts discussed.

1.2. “The Brain”

Describing AI as the brain of the near-future network is much more than an analogy to make the ideas in this paper more concrete. As AI evolves it has grown to mimic how the human brain functions in both its strengths and its quirks.

> “Think of AI algorithms as intricate models, mimicking the way neurons connect and fire in the brain. By studying these models, scientists are gaining unprecedented insights into how our own brains process information, learn, and make decisions. It’s like holding a mirror up to the mind, reflecting its hidden patterns and processes. Using AI’s learning algorithms, scientists can simulate how this virtual brain reacts to stimuli, mimicking the intricate processes of the biological brain.” (Seekmeai, 2024)

One of the key ways in which AI mimics the function of the human brain is in how it responds to sensory data or stimuli, or the lack thereof. AI machine learning (ML) models, like those being used to improve RF plant functionality today and plant powering in the near future, are designed to ingest large amounts of data and recognize patterns in order to recommend corrective action or, in some cases, even initiate corrective action. This happens in a similar way to the function of the human brain. Additionally, there are similar consequences when models are deprived of good or complete sensory data. In the human brain this sensory deprivation can lead to what is called the Ganzfeld Effect

> “By altering your sense of sight and sound, you deprive your brain of the sensory input it needs to understand the outside world. As your brain searches for information, it begins to fill in the missing pieces, which can produce visual and auditory hallucinations.” (Pietrangelo, 2020)

As the brain searches for information that it cannot find to make sense out of its surroundings it makes inferences with the limited sensory data available and essentially sees things that are not there. In much the same way, an AI/ML model will begin to see correlations that are not there and recommend actions that are counterproductive. Simply put, without enough high-fidelity input from the senses AI will not have value.

2. Current state of power data in the HFC network

The SCTE defines information to be commonly available for outside plant (OSP) power supplies in ANSI/SCTE 38-4, originally released in 2002 and most recently revised in 2022. The standard provides for several key datapoints that have some value in understanding network powering functionality. These include input and output current, voltage, power and frequency. With these data points much can be understood about the power in the HFC network. However, there are significant caveats and limitations to the available data.

First, measurement accuracy for these datapoints was never clearly defined so most older power supplies deployed before 2014, an estimated 40% of the deployed population, can have an error of 5% or greater in many of these datapoints due to less precise accuracy from measurement sensor tolerance. Due to this inaccuracy, some values that were previously derived via calculation in older power supplies, such as input and output power, will have even less precision due to stacked component tolerances. Additionally, older devices may not have the ability to provide input power, input current, or frequency values.

2.1. RMS vs Waveform Data

Beyond the potential inaccuracy and lack of some data availability, the very nature of the available data masks the ability to truly understand power in the OSP. The datapoints available for input and output current and voltage in ANSI/SCTE 38-4 calls for root mean square (RMS) value which essentially eliminates any visibility to the waveform nature of those values and represents them as their DC equivalent value.

To help visualize this point, Figure 1 below shows the output waveform of an OSP power supply over a short 4 cycle (65 ms) period of time. To understand the limits of reporting RMS values, Figure 2 shows the same power supply over the exact same period of time, but shows only the RMS reported values. By contrasting these two charts, one can easily see the drastic reduction in fidelity of the data that comes by only viewing the RMS values.

The final significant limitation of the data currently available is the time intervals at which the data can be collected and ingested. Currently even the fastest OSP power monitoring platforms will generally collect power data at one-minute intervals. To give perspective, in the time period that one RMS value for current or voltage is reported, the actual waveform cycles 3600 times and within those 3600 cycles any number of anomalies can occur and then clear before ever being seen. This limitation means that many anomalies that happen within the power path are not seen until they create an issue somewhere else in the plant, and without visibility to their origins, often create unnecessary truck rolls without ever having their root cause diagnosed.

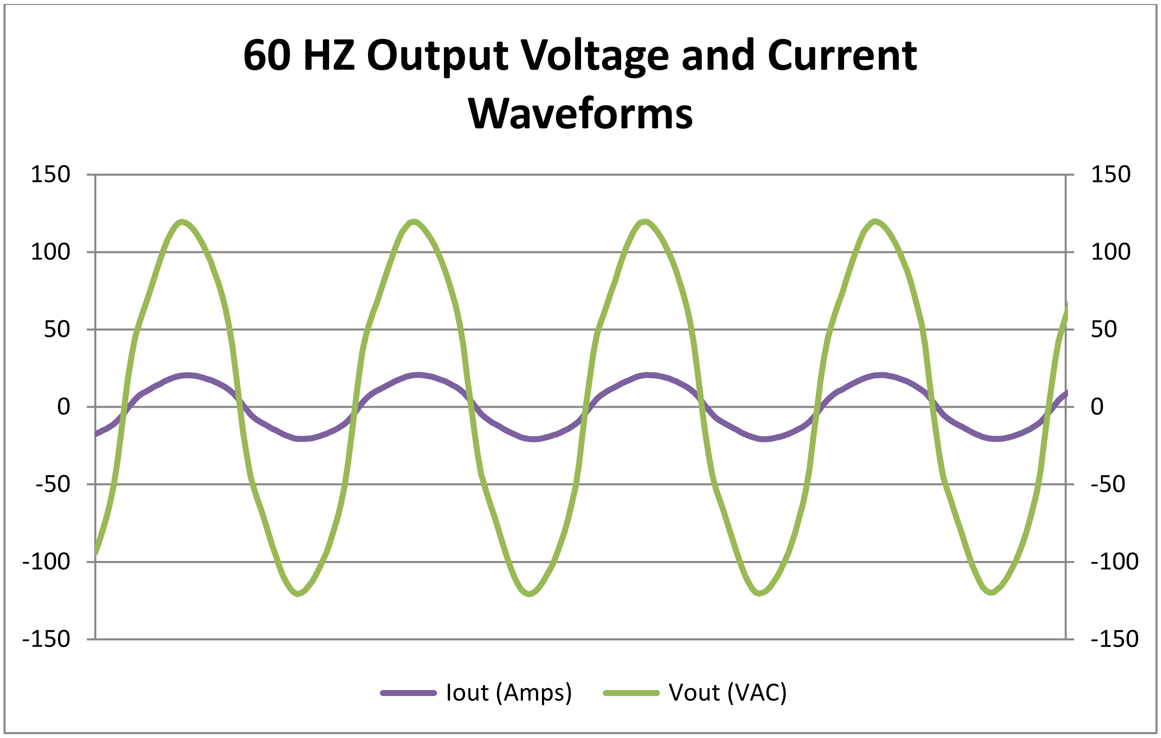


Figure 1- Example 60 Hz Waveform Capture of Current and Voltage on the Coaxial plant

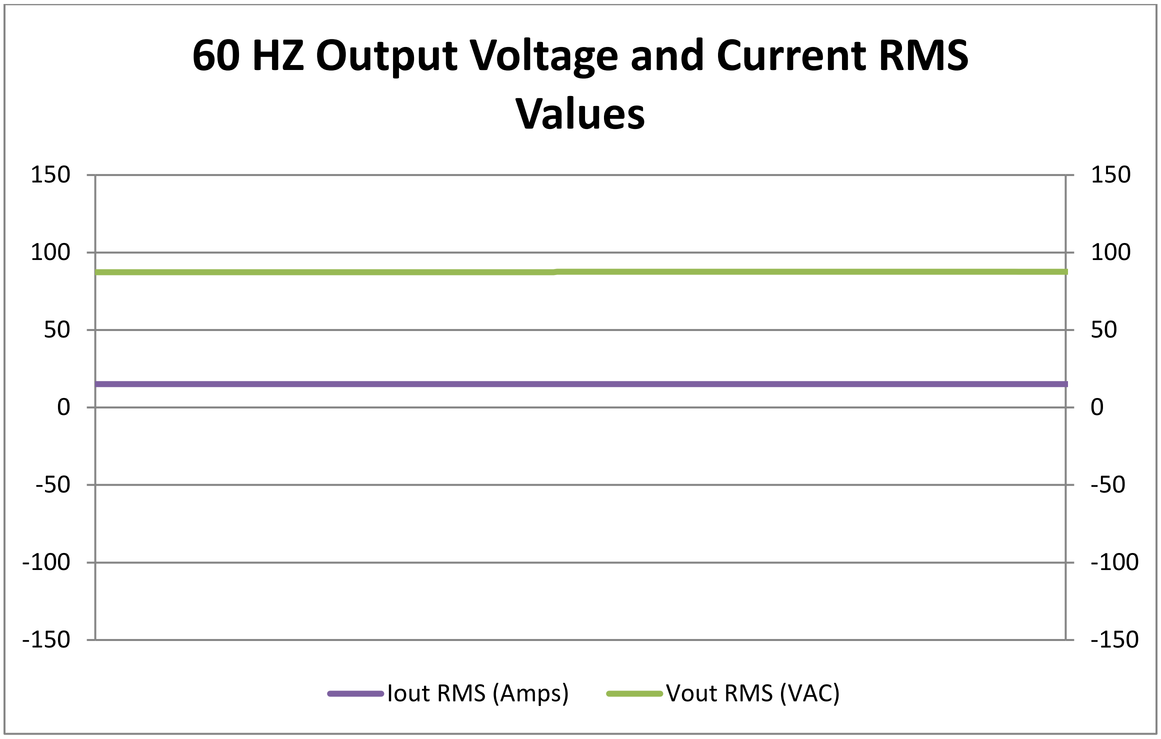


Figure 2 - Example 60 Hz RMS values reported from waveforms in Fig 1

To be pragmatic, the data that we have historically had access to has provided significant value. RMS current and voltage values allow us to understand steady-state power and identify many basic issues.

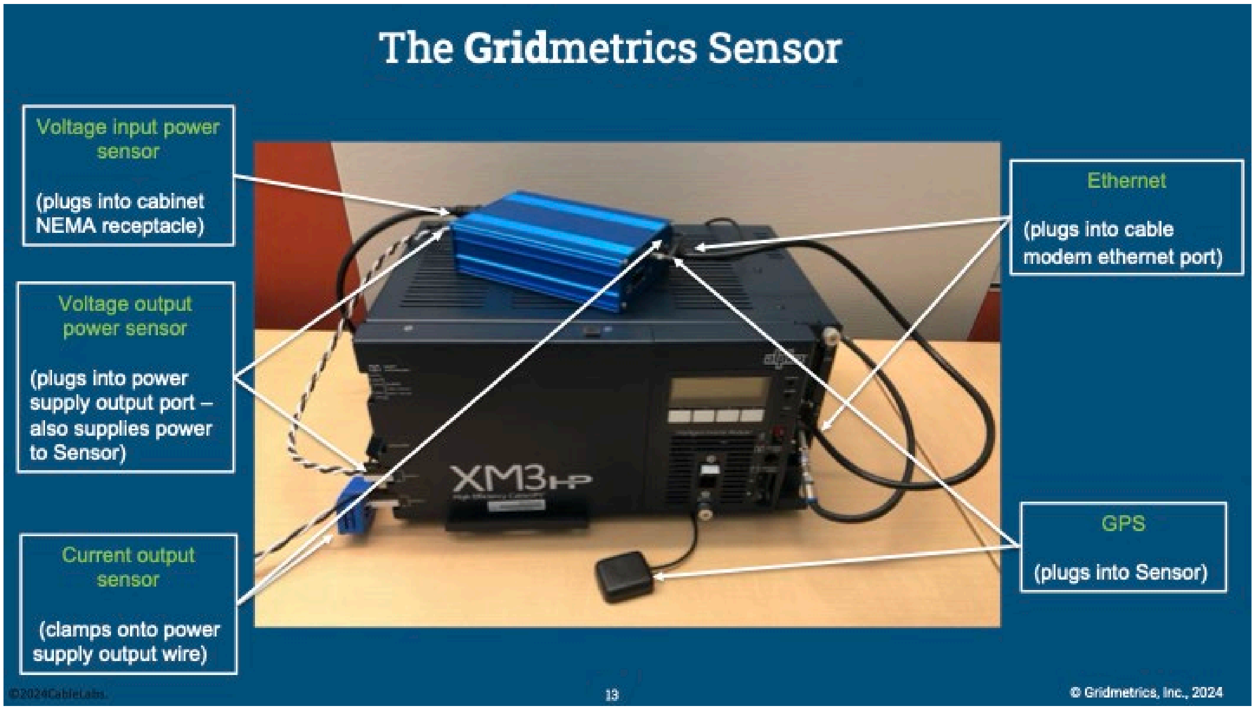
Additionally, in the past having waveform data for thousands of devices would have only buried operators under a pile of data without the manpower to analyze it. Now AI will open the door for this information to become not just useful, but invaluable. So how do we get access to it?

3. A Solution To Collect the Right Data

3.1. Gridmetrics

Gridmetrics, an innovation project started at CableLabs several years ago, has evolved into a platform for providing high fidelity HFC power data. As mentioned previously, today most of the power data is characterized as point-in-time and limits visibility, particularly into the transient behaviors which are so prevalent yet difficult to identify such as a tap face plate short, water ingress or a tree slap. Therefore, power characteristics are best represented when captured as continuous-point-on-wave (CPOW), much like an oscilloscope. The Gridmetrics platform essentially enables the collection of continuous-point-on-wave data, including voltage and current, and leverages the available cable modem (transponder) in the power supply to stream it to an aggregation server for analytics and event identification.

To summarize, the Gridmetrics platform supports three basic waveform sensors. One sensor captures the voltage waveform supplied from the power utility to the power supply. One sensor captures the voltage waveform leaving the power supply and one sensor captures the current waveform leaving the power supply. In aggregate, this is high fidelity power waveform instrumentation. It turns out, the HFC power supply is a rather unique, if not precious piece of equipment capable of bridging the two “networks”, one which delivers power, the other that uses power to deliver data. See Figure 3 for a visual representation of the sensors and their connections to the power supply.



The Gridmetrics Sensor

Voltage input power sensor

(plugs into cabinet NEMA receptacle)

Voltage output power sensor

(plugs into power supply output port – also supplies power to Sensor)

Current output sensor

(clamps onto power supply output wire)

Ethernet

(plugs into cable modem ethernet port)

GPS

(plugs into Sensor)

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Figure 3 - Gridmetrics sensor implementation

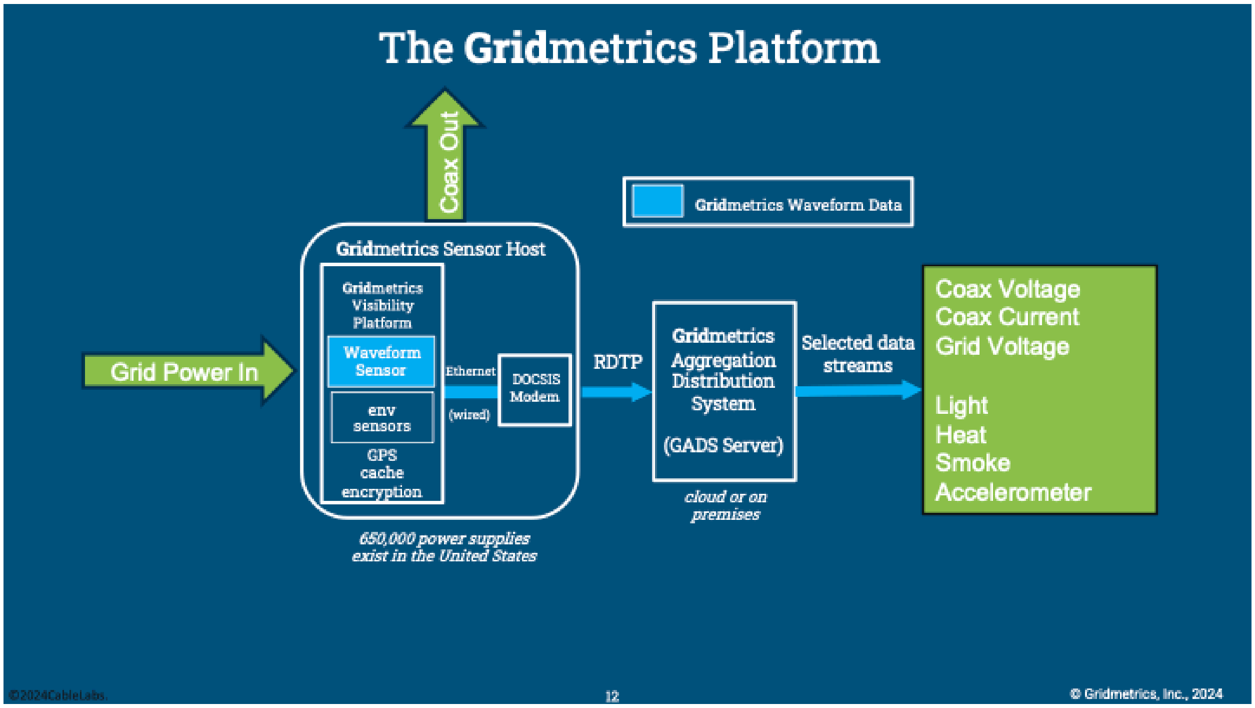
Ironically, this same type of visibility is becoming increasingly critical to the power industry. The distribution power grids operate *blind* between the substation and the meter simply due to the lack of instrumentation, or more precisely, the lack of ubiquitous, secure, cost-efficient communications systems. As the old adage goes – you cannot manage what you cannot measure. The Gridmetrics platform is being utilized by the power industry by leveraging the existing OSP power supplies coupled with a Gridmetrics sensor to provide the necessary high-fidelity visibility of the power waveform to “modernize the grid”. Gridmetrics provides the instrumentation that enables the power industry to transform their view of their grid. The ultimate win is helping the power companies create more reliable, resilient power which in turn ensures more reliable broadband service.

For the power industry, the notion of time synchronized CPOW available from hundreds of thousands of locations across their distribution power grid is mind blowing. The power industry understands the need for high fidelity waveform data. In fact, the high voltage transmission lines operate bi-directional power flows with high reliability and resilience primarily because they have this type of visibility through devices called synchrophasors, which generate time synchronized waveforms by phase. The challenge is that the high voltage transmission lines represent about 600,000 miles of power lines, while the distribution grid that OSP power supplies generally draw power from, is comprised of 6,000,000 miles of power lines. This is a genuine 10x problem and one which the HFC network, coupled with a Gridmetrics Sensor, is positioned to solve. The instrumentation infrastructure and expertise of the HFC operations creates a win-win outcome for the power industry, yielding better customer experiences for both industries. Gridmetrics was created to help capture this valuable utility data and help solve a big problem for utility operators. At the same time, sensing infrastructure can help MSOs solve powering problems on the HFC grid.

3.2. SCTE 271-2021 and Gridmetrics Sensor

SCTE 271-2021 is a published standard which defines the measurements of the power waveform. In essence, it stipulates that measurements should be captured at 10,000 samples/second, with 12 bits of resolution and time stamped with .5 microseconds of accuracy. What the specification does *not* stipulate is how that data is transmitted, shared, or processed. Gridmetrics created a data transport solution called RDTP (Raw Data Transport Protocol) which captures the raw waveform sampling data and streams it continuously at 20 packets/second to the Gridmetrics Aggregation and Distribution System (GADS) server. The Gridmetrics data architecture then enables the generation of “summary” data at ingestion for each packet, which roughly encompasses 3 cycles or 50ms of waveform data. Therefore, 20 times a second, there’s a derived value for RMS, max, min, frequency, etc. This in turn enables rapid identification of events based on thresholds, including rates of change over selected periods of time. These events create a trigger to view the raw waveform data for full analysis, and specifically, to feed the AI.

The Gridmetrics platform utilizes this same raw data streaming architecture to support additional sensors as well. Built into the Gridmetrics Platform are sensors for heat, light, smoke and an accelerometer. The Gridmetrics data architecture enables a plethora of possibilities for additional sensors, and since the platform provides resilient power, GPS, caching and comms, the cost to add a sensor is literally, the sensor itself. The architecture is zero-compute at measurement data collection, which is only possible due to the HFC’s supply of ample bandwidth. This is a tremendous advantage when instrumenting the HFC network or the power grid. See Figure 4, a diagram illustrating the Gridmetrics Platform.



The Gridmetrics Platform

Coax Out

Gridmetrics Waveform Data

Gridmetrics Sensor Host

Gridmetrics Visibility Platform

Waveform Sensor

env sensors

GPS cache encryption

Grid Power In

Ethernet (wired)

DOCSIS Modem

RDTP

Gridmetrics Aggregation Distribution System

(GADS Server)

cloud or on premises

Selected data streams

Coax Voltage
Coax Current
Grid Voltage

Light
Heat
Smoke
Accelerometer

650,000 power supplies exist in the United States

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Figure 4 - The Gridmetrics Platform

4. Use Cases and Value of Enhanced High-Fidelity sensing

Now that we have explored Gridmetrics sensing capabilities and we understand what is possible for monitoring network power in the very near future, let us clearly articulate the value that operators can gain from this newly available high-fidelity data.

To set the tone for this, it is important to understand that the coax voltage and current waveforms are generally extremely stable, producing a consistent pattern with only the occasional gradual increase or decrease due to normal daily temperature cycles. They oscillate rhythmically 60 times a second, 3600 times a minute, 216,000 an hour and so on, rarely with any significant change. The beauty of this consistency is that it sets a perfect backdrop for detection of anomalies. To understand what is possible with regard to identifying powering anomalies, we can look to power utility companies who have been observing waveform signatures of home loads for years in order to understand how to improve powering. By observing and categorizing the pattern breaks caused by specific appliances turning on, utilities can often know what is drawing power in the home. See Figure 5 for some common examples.

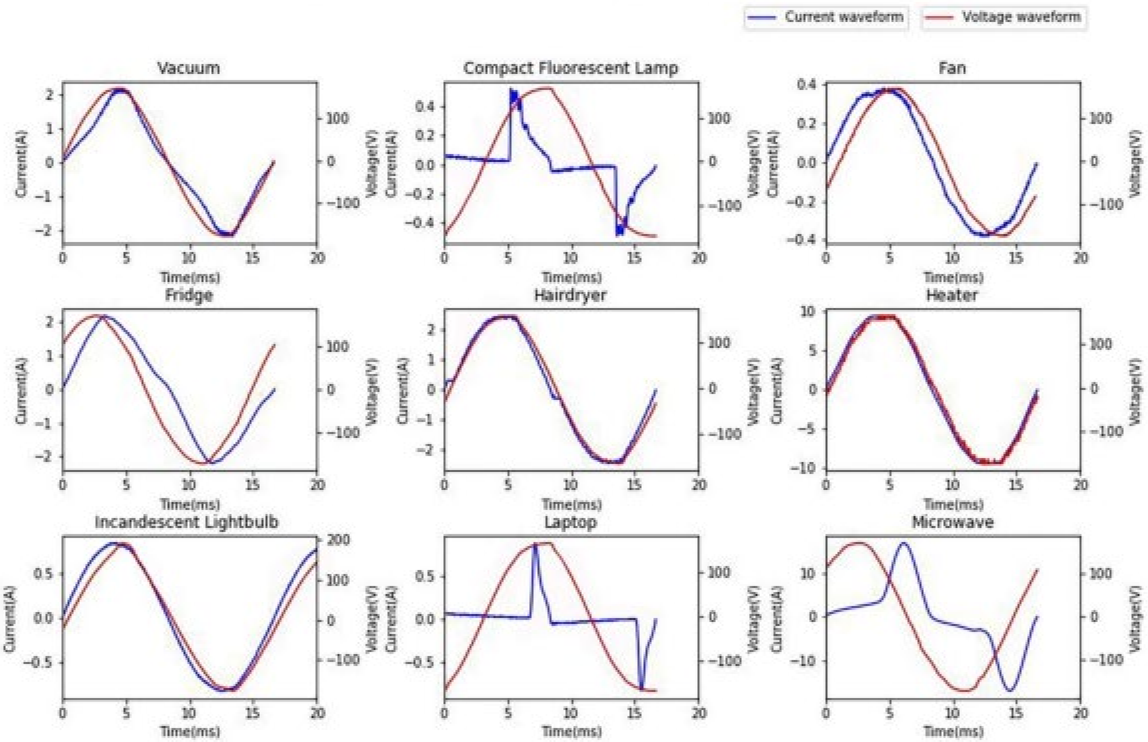


Figure 12. Typical current and voltage waveforms of nine types of appliance.

Figure 5 - Typical waveforms of several common home appliances (Zhuang Zheng, 2018)

4.1. Newly Available Insights Into Common Anomalies

Just like these unique waveforms of appliances, plant anomalies have unique patterns that can be identified to diagnose issues with plant powering. Now that we have high-fidelity sensing data and a method by which to capture and analyze anomalies, we can begin to answer the question that will unlock value for operators: What can we see that will help save truck rolls and energy? And, while the possibilities are endless, there are some typical anomalies that we should be able to detect and identify.

4.1.1. GDT Example – Saves Outages and Truck Rolls

One example that should be relatively easy to identify and could have significant value is the identification of a Gas Discharge Tube (GDT) firing on a plant active. A GDT is a transient voltage suppression (TVS) device often used in active plant equipment due to their high current handling, their ability to handle multiple transients, and the fact that they are relatively cost effective. While they are an effective method for protecting OSP actives from damaging transients, they can also have some drawbacks. Specifically, they generally fail as an internal short within the GDT which can lead to an open circuit, potentially causing a truck roll and an outage due to failure at the active, or worse, lead to short causing an outage in an entire leg of the plant. Conversely, they can often handle hundreds or even thousands of transients before they fail, although their activation voltage can drop the more often that they fire. (Tim Ardley, 2008)

GDT’s have a very recognizable effect on the output waveform as they fire and absorb energy from transients. Figure 6 shows an example of this. Failures from GDTs often come not from large transients, but from improper sizing of the GDT for the normal peak voltage tolerance in a particular section of plant. Hence, their failure is preventable, as is the eventual plant outage, if we can see that the GDT is firing before it fails. From there, it may even be possible to adjust the peak or shape of the output wave to prevent them from failing and eventually plan to have a properly sized GDT installed.

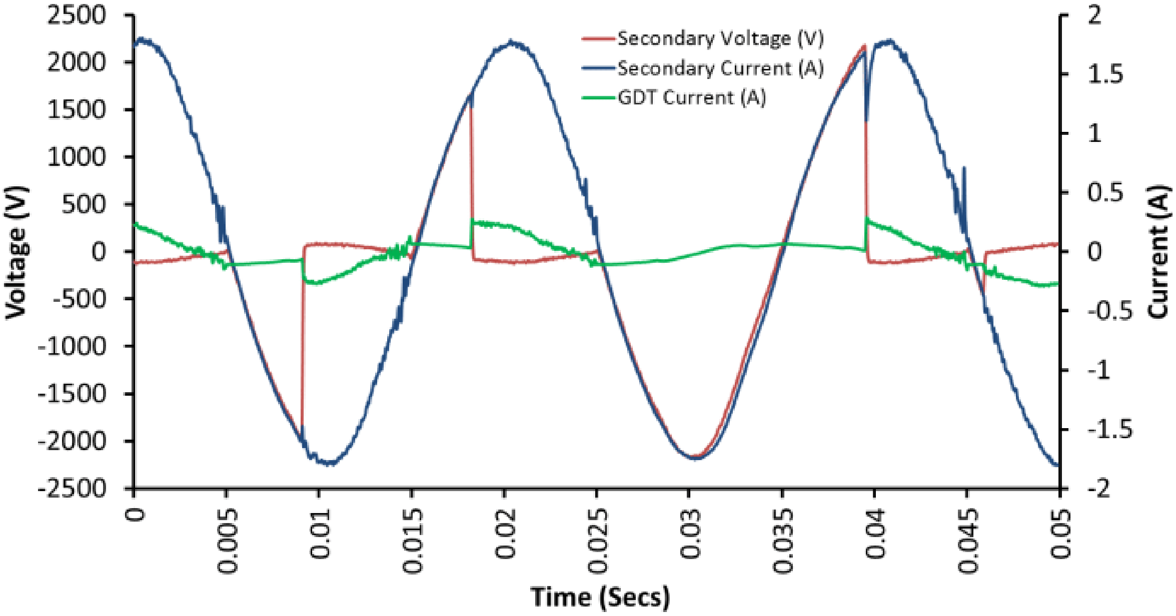


Figure 6 - Example Current and Voltage Waveforms of Gas Discharge Tube Activation (Robertson, 2018)

4.1.2. Other Diagnosable Plant Issues

There a several other common plant issues which can lead to unnecessary truck rolls that should be diagnosable using waveform analysis including.

- Dead shorts
- Momentary shorts from tap face plate removal
- Intermittent power drop-outs from an active (flapping)
- Active drops due to power issues
- Tree impacts
- Animal or water ingress
- Provide correlation to ambient temperature or time of day for root cause insight

Work is currently being undertaken to analyze waveform anomalies caused by these plant impacting issues. As the patterns of these anomalies are studied and categorized, these issues will become remotely identifiable and save explorative truck rolls. Additionally, as more of this high-fidelity waveform data is available from the field, issues that are currently unknown will undoubtedly come to light.

4.1.3. Possible Correlations of RF and HFC Power Data

In addition to simply identifying power anomalies in the access network, there may be correlations that can be seen between RF and powering functions of an active. As networks become smarter and gain the ability to self-diagnose and self-correct, there will be additional value that can be gained by using the power signature to glean additional data to help the network self-correct. In the near future, as next gen actives with embedded monitoring capability come online, added power monitoring data from actives combined with the high-fidelity power data will provide higher resolution into fault/problem cause and location. There is an opportunity to explore correlations between transient power behaviors and impacts on the RF data layer such as dropped packets or retransmits.

4.2. Using Utility Power Data to Improve Plant Operations

Not only can potential plant powering issues be identified with high-fidelity sensing data, but in addition deploying enhanced sensing capability will enable operators to leverage similar data from the utility grid to potentially improve plant functionality.

4.2.1. Event Correlations Between Utility Events and Plant Issues

Although the US grid is fairly stable, there are more potential anomalies on the grid than can be easily enumerated here due to the complexity of sources and loads. In addition to the steady increase in outage minutes and frequency being seen through Utility Reliability Metrics released by the Department of Energy, there are countless momentary outages and utility anomalies that impact the function of the cable plant.

Below is an example of a utility anomaly that was seen via the Gridmetrics Sensor where a generation source in the distribution grid had a malfunctioning component causing a brief instability in the input frequency from the grid. This issue would never have been seen in the past because of its short duration. However, it would have caused the plant power supply to transfer to inverter momentarily and over a period of time could lead to degradation of backup capability.

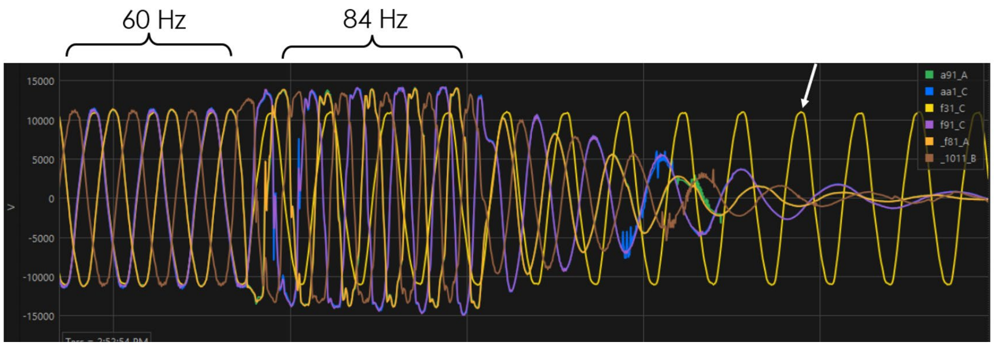


Figure 7 - Example of a previously unseen utility anomaly

By having the ability to first see, and then correlate these momentary outages and anomalies, decisions can be made to help improve plant functionality. There may be a series of recognizable anomalies that generally lead to an outage which allow us to have advanced warning of a utility outage. There may be a pattern of repeated occurrence that can be used to identify potential plant impacting issues, such as a sudden, brief reduction of input voltage at a certain time every day from a large load coming on the grid. In either of these scenarios, understanding what is happening on the grid will allow operators to drive changes that improve plant reliability and reduce truck rolls.

Additionally, there may be correlation between utility anomalies that can only be recognized with high-fidelity grid sensing appliances and reliability of plant equipment. One specific example is the inverter in the plant power supplies. While contactors in these inverters are designed to handle tens of thousands of transfers from utility to back-up power over their lifetime, a series of small, previously undetectable, frequency events could very quickly force that number of transfers in a very short period and render the plant without critical backup capability. Recognizing a scenario like this before it causes failure is just one way to use utility data to improve plant equipment performance, but there may be many more that come to light.

4.2.2. AC Generator Recognition

Another potential benefit of seeing higher fidelity input power data to network power supplies from the grid, or in this case AC source, is the ability to recognize a system with a portable AC generator deployed by field technicians during a utility outage. During an outage, operators often deploy these generators to key locations in order to keep the plant running for longer durations. While most operators have processes to track where these generators are deployed, they are generally reliant on technicians which can allow for human error, when post-outage efforts to remove generators take place. By using CPOW comparisons between pre-outage, stable utility power and current input power to the power supply, minor variations in frequency or waveform can be identified, that are generally indicative of a small gas-powered mechanical AC generator. This would give more definitive guidance on where technicians need to remove generators and can even avoid small secondary outages caused by AC generators running out of fuel by allowing for runtime predictions to more accurately manage refueling during outage.

4.3. Beyond Power Sensing

As previously identified, there are a set of environmental sensors built into the Gridmetrics Platform that creates an opportunity for further operational insights. For instance, the light sensor indicates a cabinet opening, either confirming planned maintenance or identifying unauthorized access. The heat sensor provides an ambient temperature within the power supply. The smoke sensor provides an alert for a possible battery fire. The accelerometer gives visibility into pole sway induced by wind. And in combination, the light, heat and smoke sensor function as a neighborhood fire detector. Aggregating these time synchronized data also allows for applications such a lightening detection, tracking wildfires and identifying high wind impacted areas. The Gridmetrics Platform is designed to be flexible and can accommodate additional sensors through a built-in expansion port. Optional sensors to consider are air quality, humidity, electromagnetic pulse (EMP,) etc.

5. Feeding the Brain

While all this new high-fidelity data is enticing for analysis and problem solving, it is understandably not ideal for operators who have neither the time nor the manpower to make sense of massive amounts of raw information. Which brings us back to our AI brain, thirsty for information and ready to provide answers for our outside plant power problems. With the power of AI and Machine Learning, we can now build tools that can bring value to this waveform data by learning how to recognize anomalies, interpret them and provide valuable direction to help solve problems in the plant or avoid them altogether.

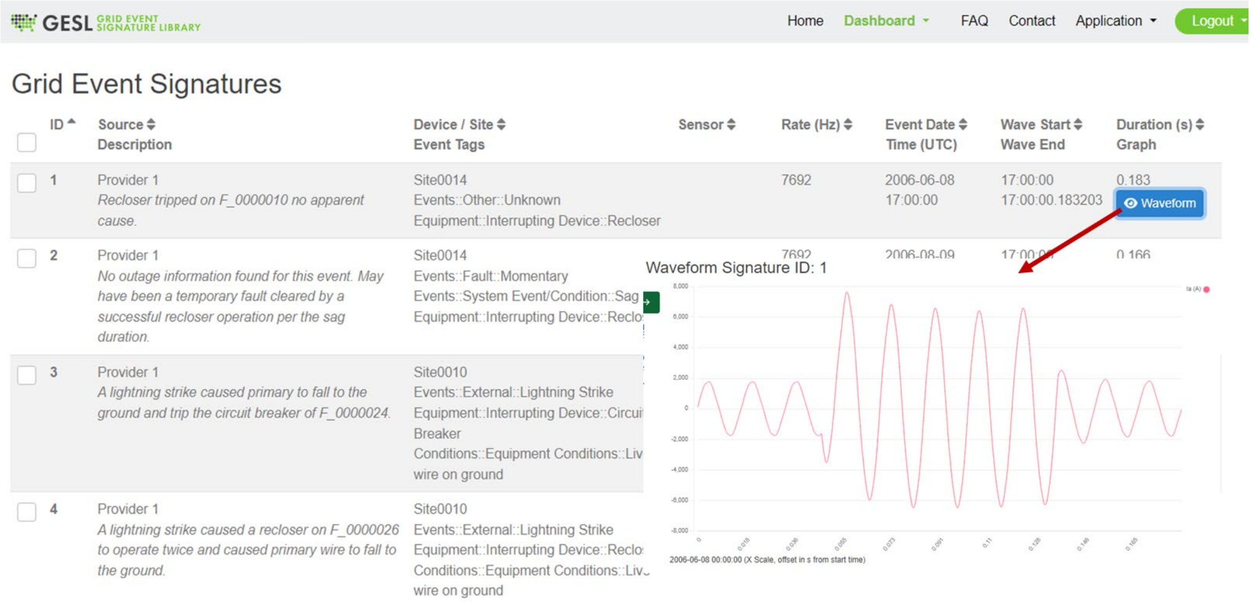
So how will AI help us with this data? Work is underway to build the process for this and there is still much to be done to reach the end goal of using AI to identify issues and reduce time and energy used in the OSP, but here is an outline for how our industry can make this a reality.

5.1. A Library of Answers

Initially, we must do everything we can to capture data in the real world that can be used to catalogue anomalies. Some of this is already being undertaken in controlled settings in “Living Lab” environments where common anomalies can be replicated and data captured to build a library of waveforms for an AI/ML model to draw from. Significant effort has already gone into cataloguing waveform data on grid anomalies to enable AI to learn how to interpret grid events and provide rapid solutions. Oak Ridge National Laboratory and Lawrence Livermore National Laboratory have created the Grid Event Signature

Library for just this purpose and has already catalogued more than 5000 anomaly signatures. (Oak Ridge National Laboratory/Lawrence Livermore National Laboratory, 2023)

While this may seem like a daunting task, it is important to note that understanding power on the HFC plant is much less complicated than it is on the power grid. The HFC plant is always powered from a single source and has a relatively small number of loads to understand compared to exponentially more loads with greater complexity on the grid. While it will be important to ensure there is a large enough dataset assembled for an AI/ML engine to make decisions with a high degree of certainty, merely being able to categorize the top ten most frequent anomalies confidently will address the vast majority of previously unseen issues. Collaboration amongst the MSO and equipment manufacturer community, akin to the accumulated grid anomaly library is a prime opportunity to elevate HFC network operating efficiency.



Grid Event Signatures

☐	ID	Source Description	Device / Site Event Tags	Sensor	Rate (Hz)	Event Date Time (UTC)	Wave Start Wave End	Duration (s) Graph
☐	1	Provider 1 *Recloser tripped on F_0000010 no apparent cause.*	Site0014 Events::Other::Unknown Equipment::Interrupting Device::Recloser		7692	2006-06-08 17:00:00	17:00:00 17:00:00.183203	0.183 Waveform
☐	2	Provider 1 *No outage information found for this event. May have been a temporary fault cleared by a successful recloser operation per the sag duration.*	Site0014 Events::Fault::Momentary Events::System Event/Condition::Sag Equipment::Interrupting Device::Reclo		7692	2006-08-09	17:00:0	0.166
☐	3	Provider 1 *A lightning strike caused primary to fall to the ground and trip the circuit breaker of F_0000024.*	Site0010 Events::External::Lightning Strike Equipment::Interrupting Device::Circui Breaker Conditions::Equipment Conditions::Liv wire on ground					
☐	4	Provider 1 *A lightning strike caused a recloser on F_0000026 to operate twice and caused primary wire to fall to the ground.*	Site0010 Events::External::Lightning Strike Equipment::Interrupting Device::Reclo Conditions::Equipment Conditions::Liv wire on ground					

Figure 8 - Grid Event Signature Library dashboard- (Oak Ridge National Laboratory/Lawrence Livermore National Laboratory, 2023)

5.2. Train The Brain

Once a significant library of waveform data exists, an AI/ML engine can be trained to compare the current anomaly to the library of existing data. There are multiple methods by which AI can be trained to compare current anomalies to a known library including, but not limited to, pattern recognition, mathematical curve fitting, clustering, and outlier detection. As the homepage for the Grid Event Signature Library states – "This repository is more than just a collection; it stands as an essential tool, propelling the evolution of AI/ML applications within the realm of grid systems." Currently several methods are being explored with regard to AI/ML recognition of waveform data for grid systems, but the fundamental tenants will be identical to what will be needed for the HFC grid. This work, along with other efforts to develop the necessary AI/ML capability within the MSO and vendor communities will ensure that automated waveform anomaly recognition will be available in the very near future.

While the initial library of data will be built on common and known anomalies it will be necessary to develop a simple feedback loop to ensure data is continually improved and yet unknown anomalies are identified, then root-cause analysis performed, and finally, catalogued into the library. While this need is out in the future it is important to plan for this type of user input into the library and ensure that the method for updating the library is simple and maintains library data integrity.

6. Conclusion

We are at an exciting inflection point in our quest to continually improve the reliability of the HFC network and reduce the time and energy required to support its operation. For the first time we have AI to observe the powering of the network with a level of detail and at a speed the human mind is incapable of. This capability will allow us to understand unseen issues within the OSP that have wasted energy and generated unnecessary truck rolls for years, because they can now be observed and processed at the millisecond scale in which they happen.

Yet, without the senses the brain lacks the capability to accurately interpret its environment and can even conjure correlations that result in costly mistakes. The capability we have with AI to function as the brain of a smarter network behooves us to ensure the right sensory data is available to guide decisions. Leveraging the sensing capability of Gridmetrics, which also has valuable capability to help improve grid performance, we now have the necessary high-fidelity power data. And, by deploying this capability and using it to build a knowledge base for AI to draw from, we will be able to resolve significant plant issues and save significant time and money.

Abbreviations

AC	alternating current
AI	artificial intelligence
CPOW	continuous-point-on-wave
GADS	direct current
GDT	gas discharge tube
HFC	hybrid fiber coax
ML	machine learning
OSP	outside plant
RDTP	Raw Data Transport Protocol
RMS	root mean squared
TVS	transient voltage suppressor

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