The Role of Intelligent Monitoring in Dealing with Evolving Grid Challenges

As Renewable Portfolio Standards and Distributed Energy Resources have captured an increasing mindshare over the last five years, we have forgotten that the number one mission of electric utilities is, in fact, the safe and reliable delivery of power to their customers. Safety and reliability discussions always seem to center around aging grid infrastructure. While, it's true that equipment reaching the end of its useful lifecycle diminishes grid resiliency, the resulting replacement with new infrastructure, such as wires, transformers and switches, is not the simple answer. Even as advances in grid hardware and software take us closer to a "self-healing grid," vegetation encroachment, animal intrusion, extreme weather or even load imbalances will eventually cause equipment to fail – old or new. The introduction of DER and two-way power flow adds a new set of challenges with additional infrastructure and less centralized control.

Digital Transformation Is Paving the Way Toward a More Reliable Grid

To their credit, the electric utility industry continues to adopt technologies in response to these challenges. Newer digital equipment is gradually replacing the aging electomechanical equipment in substations. At many utilities, feeder level distribution automation has advanced to a point where feeder level Customer Minutes Interrupted (CMI) has been reduced 20% to 30% of total CMI. Advanced Metering Infrastructures and Smart

Meters now provide complete monitoring and control of load connection points. Advanced Distribution Management Systems are slowly replacing disparate home-grown and vendor provided Outage Management and Distribution Management Systems with an integrated distribution model and a comprehensive set of outage and grid management applications, including DERMS.

There is little doubt that these technology investments have and will continue to drive significant benefits associated with reducing outage duration. This is already reflected in improved reliability indices such as CAIDI and SAIDI. While these technologies continue to reduce outage durations, they have had only marginal effect on achieving the real Holy Grail of safety and reliability – identifying the location and cause of potential failures before they occur.

Preparing for New Challenges

Despite the past success of distribution feeder automation, the grid of the future will have multiple sources of generation that challenge the protection schemes and work practices associated with a single-source grid. Operational systems such as ADMS are starting to provide applications to help manage these resources, but they have limited access to real-time monitoring data across the entire distribution circuit. For example, while feeder level automation has provided on average an additional 2-3 monitoring and control points on overhead feeders, these monitoring points are still only 5-10% of the total number of protection and sectionalizing devices on an entire circuit.

Underground portions of distribution feeders can represent 20-70% of a typical circuit. However, they totally lack any real-time monitoring despite the resulting increased customer outage duration and cost and safety issues associated with events that occur on these circuits. Also, for many utilities underground circuits can include a combination of residential, commercial and industrial loads that are prime targets for DER.

Overhead laterals lack real-time monitoring as well, even though the majority of outage and power quality events originate from these circuits. For utilities that have made significant investments in feeder-level automation, overhead lateral outages are becoming the primary contributor to the average customer outage time (CAIDI). Overhead laterals also provide a large portion of the direct grid connections to residential and commercial loads where solar panels are prominent and as well as an increasing number of charging stations for electric

vehicles. Overall, the distribution grid lacks any significant monitoring capabilities beyond a few automation devices between the substation and customer load point, as depicted in Figure 1 where Automated Reclosers (AR's) exist only at the substation, feeder midpoints and feeder normal open points:

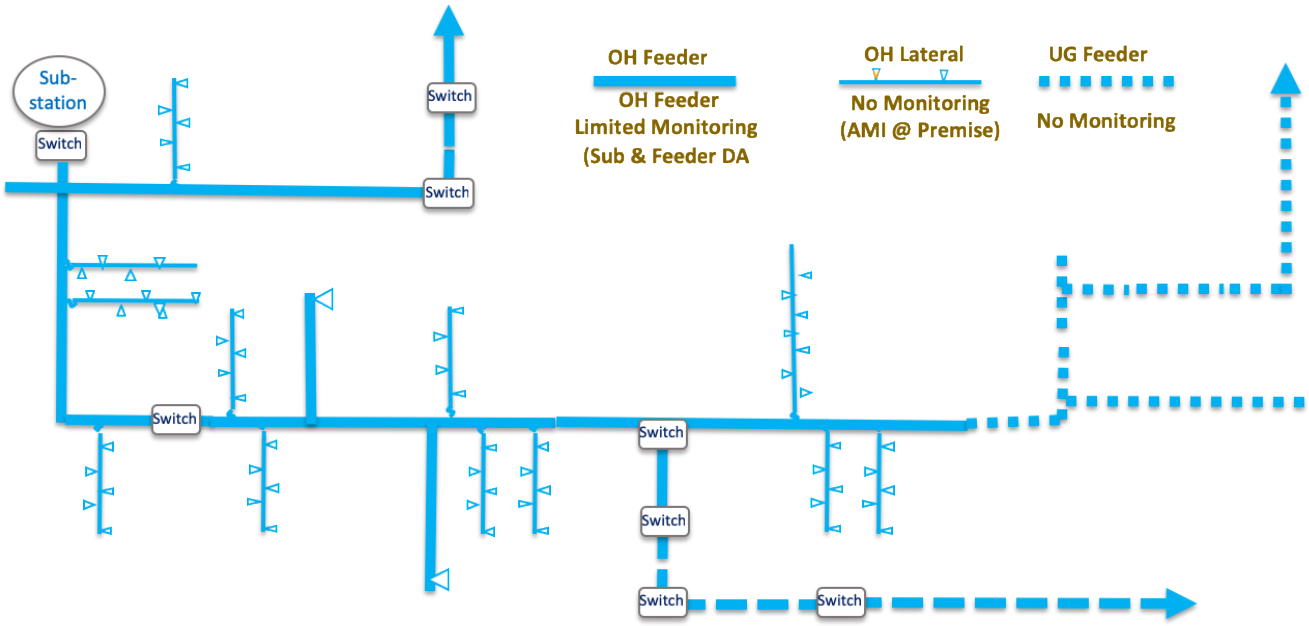


Figure 1 - Circuit Monitoring Today

Electric Utilities Lag Behind the Innovation Curve

Other industries have revolutionized their business processes with the deployment of monitoring and control devices to ensure timely and quality delivery of their products. It's time for electric utilities to step up to the plate. Given the advancement of monitoring and control in other industries, it is difficult to accept that electric distribution providers are still dependent on their customers as the primary notification mechanism for most outages and all power-quality issues.

There is a general lack of real time status monitoring across the entire grid that can help to reduce the impact of equipment failures associated with devices 30 or more years of age. About the best the industry has done is to make rough guesses when equipment should be replaced based on historical longevity models or manufacturer warranties, or simply replace large portions of the grid no matter what their functional status. This is an extremely inefficient approach to reliability. Instead, distribution grid providers need comprehensive grid monitoring tools to effectively manage and optimize power flow, and to detect and analyze all levels of grid events for fast mitigation. This can only happen by leveraging new data capture capabilities to analyze, predict and ultimately avoid future outages and power-quality events.

Distribution line monitoring capabilities have advanced in recent years with the addition of new capabilities and telecommunications technologies required to detect and report results to centralized applications such as SCADA and other operational systems. To date, the use cases have been limited to fault detection on the feeder backbone level where feeder automation may not be deployed, or to complement the limited number automation devices typically installed on a circuit. A gap remains in providing monitoring across the entire grid with advanced monitoring and analytics to support the challenges over the next 10 years.

Ubiquitous Grid Monitoring & Analytics Are Finally Here

Since its founding, Sentient Energy's vision has been to develop a comprehensive sensing platform to provide cost effective monitoring tools, software and analytics across all levels of the grid. That vision has now been realized, with a grid analytics system that offers:

- Sensing devices that capture high-resolution oscillography to support analytics for the entire grid
- Multi-purpose sensors that can be upgraded "Over-The-Air" with new features and applications beyond basic fault detections
- Easy to install devices that last a minimum of 10 years with zero maintenance required
- Zero maintenance costs associated with truck rolls or software upgrades
- Analytics are performed at the end point based on precision GPS time capture in support of future use cases
- Additional on-board capabilities such as load monitoring and direction to support circuit optimization resulting from the increased penetration of DER, an on-board accelerometer for currently targeting detection of safety issues related to pre-fault conductor movement and downed conductors
- Supporting software and analytics to capture historical data, provide additional analytics and visualization tools that identify pre-fault anomalies across sensor locations
- Provide intelligent sensing across the grid and not just limited to the main overhead feeder levels of a distribution circuit

Sentient Everywhere

Sentient Energy now offers the first comprehensive monitoring platform consisting of Intelligent sensors, software and analytics that monitor the entire distribution grid, including overhead feeder locations with its flagship MM3 line monitor, underground padmounted cabinets and cables with the new UM3+ underground line monitor, and overhead laterals with its new ZM1 line monitor.

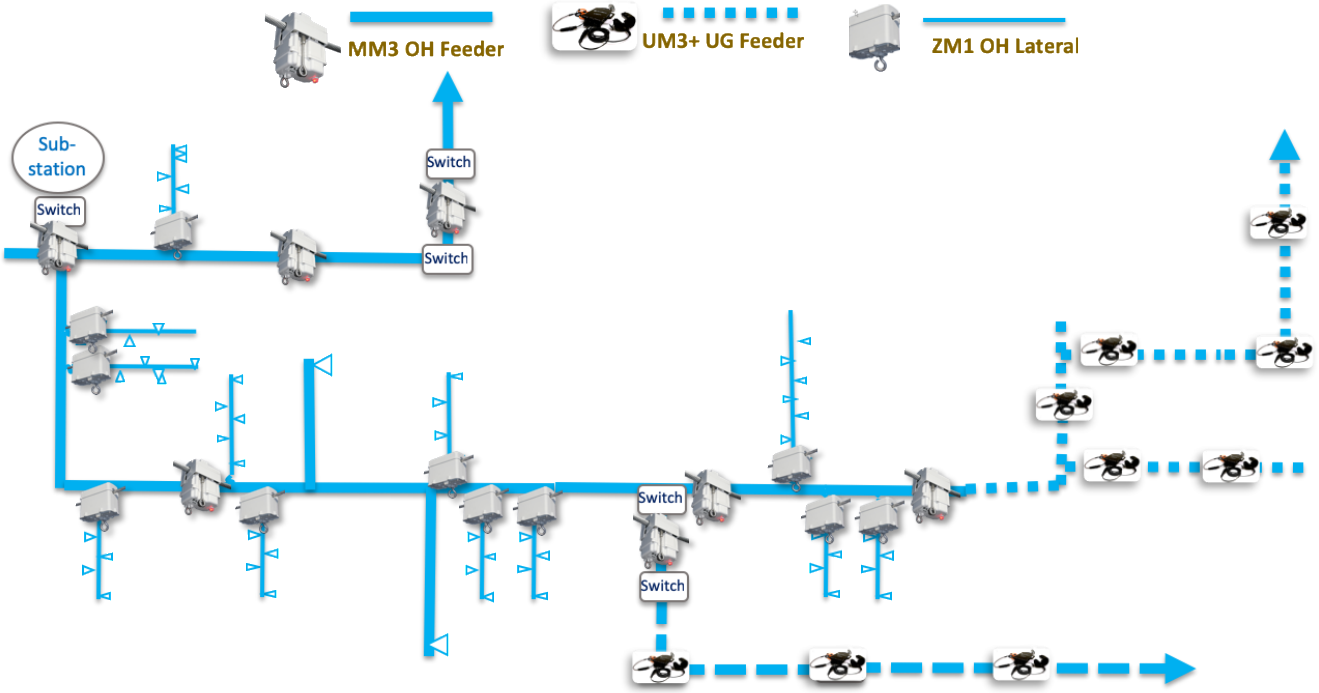


Figure 2 - Ubiquitous Grid Monitoring

Comprehensive monitoring across the entire distribution circuit addresses the limitations associated with existing sparse grid monitoring locations and single purpose use cases. With the addition of Sentient Energy's UM3+ for underground monitoring, utilities now can pinpoint fault locations on the underground feeder cable portion of a given circuit where isolation and restoration durations are exponentially longer than on the overhead portion of these circuits.

As feeder level outage durations improvements are realized, utilities can achieve additional duration reductions on high-CAIDI overhead laterals by deploying Sentient Energy's new ZM1 line monitor, where monitoring is a challenge due to lower loads and smaller conductor sizes. With the introduction of these underground and overhead lateral intelligent monitoring devices, utilities can now achieve outage duration benefits across the total distribution grid as represented in Figure 1.

Leveraging Analytics to Monitor and Detect Pre-Fault Failure Anomalies

An intelligent monitoring system must go beyond basic fault detection if utilities are going to meet the challenges of the next decade. Reducing outage duration must be complemented with reductions in outage frequency if utilities are to continue to drive duration indices lower. Sentient Energy's Grid Analytics Platform leverages the high-resolution oscillography provided in each intelligent monitor (overhead at 130 samples/cycle, underground at 256 samples/cycle). As result, fault waveforms and non-fault disturbance waveforms are captured that would otherwise be unnoticed by substation & distribution automation control equipment.

Disturbances are very small deviations in current that in many cases are precursors to faults that result from such causes as vegetation encroachment, animal intrusions or failed equipment. These disturbances are detected by patented algorithms that capture waveforms aligned with very accurate GPS time-stamps. They are visualized within the Sentient Energy's Ample Software Module called SAIFI Detect. As depicted in figure 3, they are counted with summary level visualization to provide indication of non-fault anomalies to operations and power quality engineers. Initial customer case studies have been documented where outage avoidance has been realized using rising counters for worst performing circuits to initiate crew and/or drone patrols that found vegetation and equipment issues that would have resulted in sustained outages.

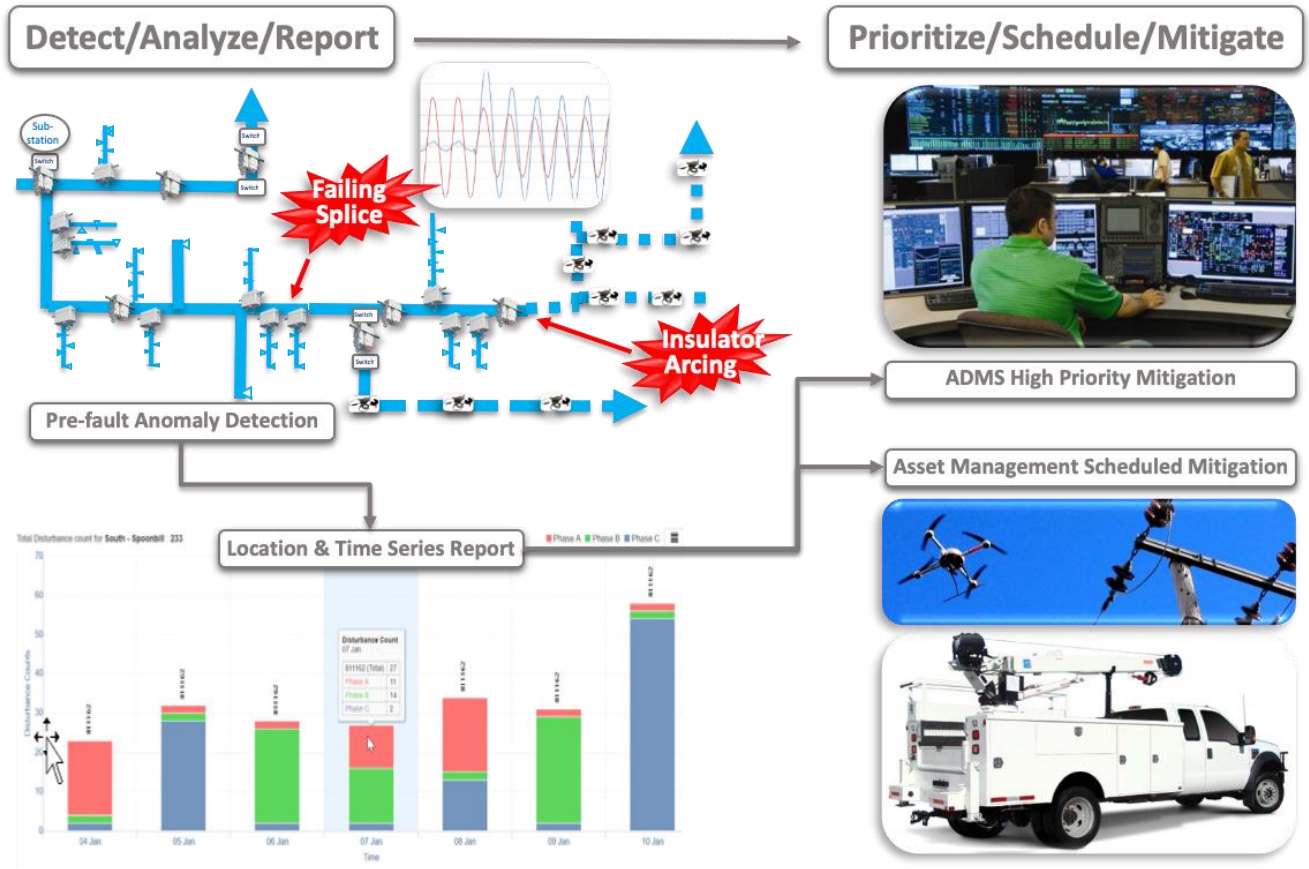


Figure 3 - Pre-Fault "Disturbance" Detection

Working with several customers, Sentient Energy's analytics team expects to have the first release of Ample Predict this year. Ample Predict will classify pre-fault anomalies for specific causes according to historical Utility reliability data. As circuit monitoring is expanded to overhead laterals, additional precision for crew patrols will be possible, along with expanded analytics algorithms to detect conductor sway, wire downs and high impedance wire downs. The additional level of high resolution in the UM3+ underground monitor will enable future algorithms for partial discharge detection in underground conductors.

Utilizing Analytics and Advanced Monitoring to Manage an Active Grid

Operational control systems simply do not have adequate real-time grid data to effectively monitor, optimize and react to events on a grid that continues to see significant increases in Distributed Energy Resources. DER drive dramatic daily and hourly shifts in load and load

direction. In the future, even basic fault detection will challenge grid protection schemes. Operational systems such as SCADA and ADMS will be hard pressed to provide advanced applications that can support circuit optimization, fault isolation and service restoration.

	No Interruption (NI)	Momentary Interruption (MI)	Sustained Interruption (SI)
Fault (F)	*Fault with no Interruption (FNI)*	*Fault with momentary Interruption (FMI)*	*Fault with sustained Interruption (FSI)*
No Fault (NF)	No Fault, no Interruption (NFNI)	No Fault but momentary Interruption (NFMI)	No Fault but sustained Interruption (NFSI)

Figure 4 - Interruption Classifications

Sentient Energy's Grid Analytics Platform can now provide information on the state of the grid at each monitoring location across all levels of the grid. At any point in time significant load changes and direction can be detected so that applications such as State Estimation can leverage real-time data for distribution power flow applications. During fault conditions, monitoring locations not only report the intelligent sensors that detected the fault, they also provide the state of the conductors that have detected these faults and indicate the current load and voltage reference at each of the monitoring locations.

With the increased deployment of advanced reclosers in today's grid, it is difficult to accurately assess the state of circuit line sections to determine whether they are part of a sustained outage, momentarily affected by loss of load and voltage reference, or they experienced a fault without any loss of load or voltage reference. Sentient Energy's intelligent devices provide six categories of states for circuit sections affected by a sustained fault. These are called **Interruption Classifications**. Each intelligent sensor provides this category during a fault for every intelligent sensor involved on the affected circuit, regardless of whether it detected the fault or not. These categories indicate not only which sensor detected the fault, but also the state of the conductor – complete loss of load, momentary loss of load or no loss of load (Figure 4).

Figure 5 (below) represents a simplified version of a feeder that is involved in a sustained outage caused by a fault on A-Phase towards the end of the feeder. The fault is cleared by the Automated Recloser at the midpoint of the feeder and the Recloser at the substation restores

service to the front half of the feeder within 30 seconds, avoiding a sustained outage in that portion of the feeder. The current state of the all conductors being monitored is provided by the intelligent sensors that can be used by operational systems to validate the status of various sections of the feeder as well as note where the fault was detected with a sustained loss of load, momentary loss of load or no loss of load at all.

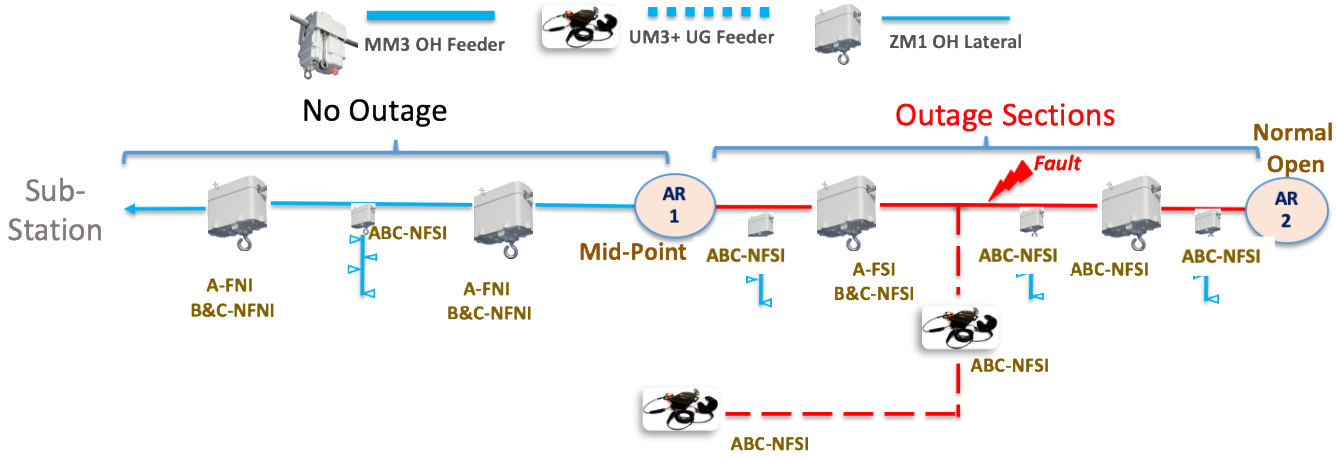


Figure 5 - Circuit Section Interruption Categories

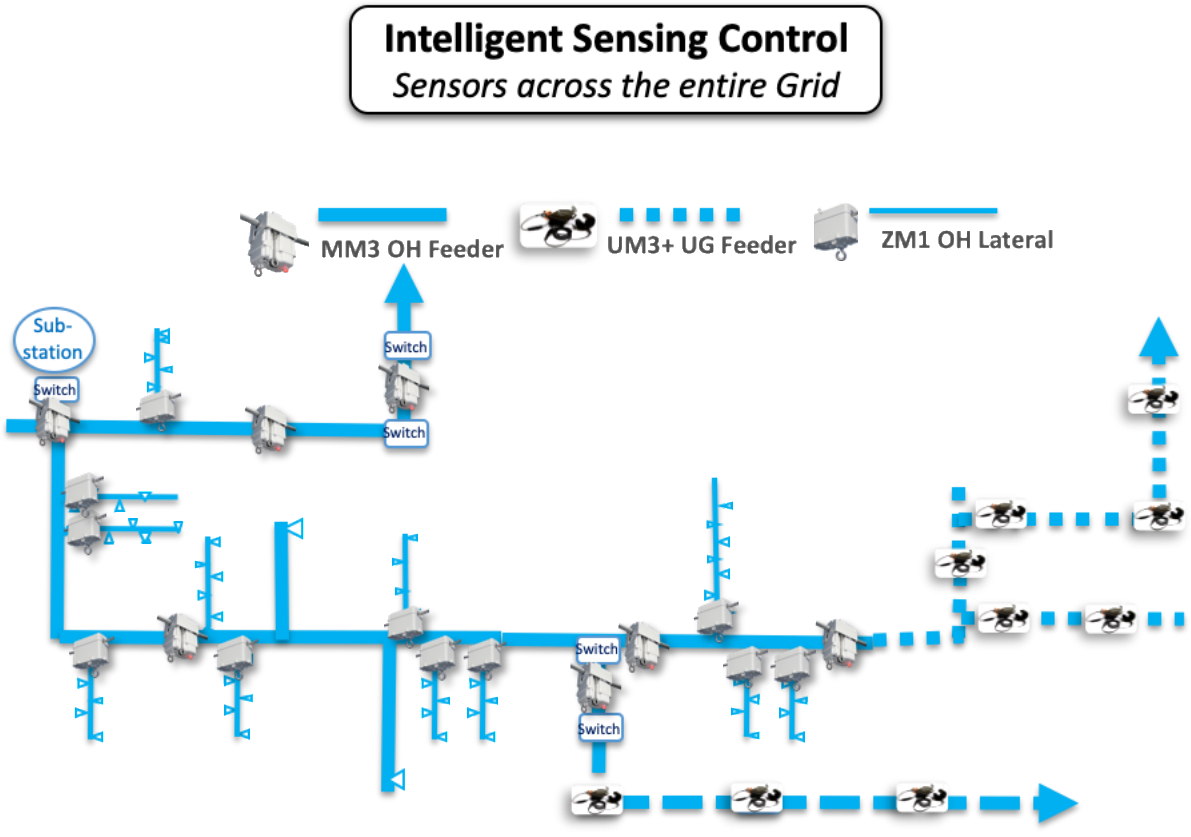
In Figure 5, we see a simplified version of a feeder that is involved in a sustained outage caused by a fault on A-Phase towards the end of the feeder with interruption categories assigned to each feeder section being monitored.

Significant Benefits to Multiple Operational Systems

Continuous detection, analysis and visualization at various circuit levels is extremely valuable data that can be provided to operational systems and back office applications. Circuit data such as such as outage triggers, faults, fault magnitudes and interruption categories can be leveraged by operational systems not only to pinpoint fault locations, but also to confirm the effect of the faults on the entire circuit. Combined with load, load direction, phasing validation and pre-fault disturbance anomalies, Utilities can gain additional value beyond basic fault detection that can be leveraged by operational systems such as ADMS for monitoring and control, Asset Systems for network model validation and Asset Performance Systems for pre-fault mitigation of disturbances to avoid the occurrence of sustained and momentary interruptions. Figure 6 represents examples of where added value and new capabilities can be enabled by intelligent monitoring across key points of the distribution grid.

Intelligent Grid Monitoring is finally here, and Sentient Energy's customers are leveraging the capabilities in new ways by:

- Achieving additional duration reductions at other levels of the grid associated with underground feeders and overhead laterals that typically have higher restoration times and operating costs
- Addressing the frequency aspects of reliability indices by identifying pre-fault anomalies for field mitigation to avoid future outages, momentary interruptions and power quality events
- Leveraging a comprehensive intelligent monitoring and analytics platform that can interoperate with ADMS and other operations systems in order to achieve the next level of benefits in the proactive monitoring, and optimization of an active, evolving grid



Sensor & Analytics enabled ADMS
Enhanced and new capabilities

Value Proposition	ADMS Function / Sensing & Analytics Network Data/App	Phase ID	Load	Load Direction	Fault Detection	Fault Direction	Hi Z Faults	Fault/ Disturbance Counters	Pre- Fault Disturbance Signatures
SAIDI/CAIDI	Operational Network Model	E	E	N	E	E	E		
	Power Flow/State Estimation	E	E	E	E	E	N		
	Real-time Network Visibility	E	E	E	E	E	E		
	Network Applications Fault Location, FLISR, Auto Switch Plan Generation	E	E	E	E	E	E		
	OM Outage Analysis	E			E		E	N	N
	Optimization & Planning tools	E	E	E	E				

E –Enhanced Capability Today
E –Enhanced Capability 2019
N –New Capability Today
N –New Capability 2019

Figure 6 - Grid Monitoring & System Integration

A More Intelligent Approach to Safety and Reliability

Intelligent, ubiquitous distribution line monitors and analytics transition the grid reliability paradigm from reactive to proactive. Service disruptions caused by natural disasters or severe whether are often unavoidable, but so many service disruptions can be avoided if we detect potential problems, as well as their cause, before they result in outages. Sentient Energy's intelligent Grid Analytics System provides the only integrated monitoring, communications and analytics platform with intelligent, high-resolution oscillography that can pinpoint, interpret, and identify anomalies before they result in equipment failures and service disruptions. The result is a significant improvement in SAIFI, SAIDI, asset life extension, maintenance and operations efficiency, vegetation and wildlife management, DER siting and integration, and overall grid resiliency.

About Sentient Energy

Sentient Energy is the premier Intelligent Sensing Platform Provider for power utilities. Sentient provides the industry's only Grid Analytics System that covers the entire distribution network with quickly deployed intelligent sensors and analytics that identify and analyze potential faults and other grid events. Sentient Energy leads the market with the largest mesh network line sensor deployments in North America helping utilities deliver power reliably and safely. Sentient partners with leading utility network providers including Landis + Gyr, Itron, Verizon, AT&T and Telus. For more information visit www.sentient-energy.com.

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