White Paper

Predictive Grid® Analytics

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Executive Summary

The distribution network is the unsung hero of the electric grid. It is the largest part of a complex network stretching well over 12 million miles in the U.S and Europe combined; that's like going to the moon 26 times and back. Due to its size, this portion of the grid has remained largely unmonitored and that has led to reliability issues with EEI attributing 90 percent of outages occurring on the distribution network in the U.S. As aging assets start to break down, it becomes impossible to troubleshoot grid health without real-time data. And, without situational awareness, grid operators will also struggle to bring renewables and low carbon technologies onto the grid. Without real-time intelligence, it becomes nearly impossible to bring the electric grid into the 21st century.

Real-time grid visibility is now an affordable reality with Aclara's Grid Monitoring platform – a next generation grid modernization technology consisting of Smart Grid Sensors and Predictive Grid® Analytics software. The platform enables distribution operators to proactively monitor the distribution network, improve reliability and safely bring distributed energy resources onto the grid. This is not a "rip and replace" strategy. Instead, by retrofitting the distribution grid with Aclara's Smart Grid Sensors, outages could be minimized or avoided entirely – and operators would have the intelligence needed to more confidently incorporate more renewables.

Aclara's Predictive Grid Analytics software is the first asset management and fault detection platform to provide real-time grid intelligence for utility distribution networks. The Aclara platform monitors the distribution network to give utilities real-time information to predict faults and failures of their assets before they occur, respond to outages faster and eliminate thousands of hours of drive-time (and greenhouse gases).

Aclara's Grid Monitoring Platform

Figure 1:
Hot-stick installation of Aclara's Sensors

The platform consists of Medium Voltage (MV) Smart Grid Sensors that provide the ideal combination of outage and fault detection with Predictive Grid Analytics software that can be used for a wide variety of distribution automation applications. Sensors quickly clamp directly onto overhead conductors and provide real-time fault data and alarms about other grid conditions (e.g. high current alarms) to enable utilities to proactively monitor the grid and avoid outages.

These purpose-built sensors offer utilities the easiest installation process available. Aclara holds the design patent for the way line sensors clamp onto the line so that crews only need to use the hot-stick once. Only one lineman is needed with a hot stick or insulated gloves and sensors are deployed on the

line in a matter of minutes. Deployment is quick and easy because our sensors do not require calibration, are lightweight and do not require pole mounted cabinets. In addition, there are no solar panels to manage and no batteries to maintain. Once installed, the line sensors are 100% maintenance-free.

Smart Grid Sensors communicate directly to Aclara's Sensor Management System (SMS) software with Predictive Grid Analytics. This is a server based application that forms the central repository for all data and events provided by our sensors. This software is provided by Aclara or can be hosted in the cloud on behalf of the utility. The software is a turnkey package that enables:

- Fault detection and location with predictive grid analytics
- Sensor firmware upgrades, remote diagnostics and parameter settings
- User Interface (UI) and visualization tools (for example, Google® Maps)
- DNP3 integration to SCADA, Historians, DMS, etc.
- Reporting dashboards and alarms
- Analytics functions to filter out or suppress data before it is passed to higher level systems
- An archive database of waveforms and fault events, available anytime to your engineers for post-event analysis

How the Platform Works

Planners, engineers, operations and field crews can interface directly with our Sensor data in two ways to monitor their distribution grid:

1. Accessing directly through SMS or
2. Passing SMS data through DNP3 to higher level systems (e.g. Historian, GIS, SCADA or DMS).

First, with browser-based access to SMS, users have full access to fault monitoring, fault location maps, load monitoring and waveforms for investigative purposes or analysis. SMS provides RMS fault current, power quality events, and waveforms to analyze disturbances from virtually any type of device (e.g. PC, laptop, tablet, cell phone).

Second, you can integrate information from SMS into your Historian, SCADA, and DMS systems through our DNP3 interface. Here, SMS offers a competitive advantage because it time-synchronizes and aggregates information coming in from all sensors. SMS then analyzes the data to capture, classify and analyze what types of events are occurring; most importantly it filters out the false positives that basic FCIs produce. The Aclara software also shows where faults are located (e.g. using GPS or RMS Fault Current) on your network so you have actionable intelligence.

Finally, fault current events that do not cause immediate outages, like momentaries or line disturbances, are logged in SMS so engineers can continue to mine this data to learn more about your network and prevent future outages. Here, they have full access to waveforms and event data for post-event forensic analysis. Using this data, you can send crews to investigate potential problems before they cause an outage. Many of our customers have been able to prevent outages using SMS data in this manner.

Predictive Grid Analytics

The platform provides sophisticated analysis of disturbances and grid events to provide analytics around faults, load and waveform analysis. This allows you to continuously review disturbances on the grid and keep a watchful eye to spot patterns or abnormalities.

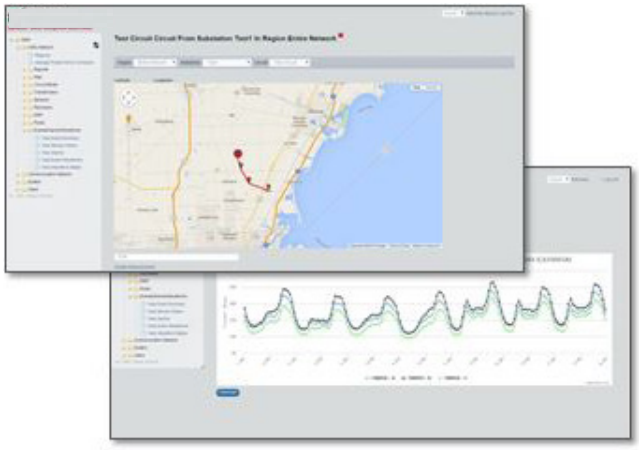


Figure 2: Screenshots of Aclara SMS

The Aclara system was designed to help utilities quickly transition from monitoring and reporting of grid events to having the actionable intelligence necessary to respond to real-time conditions and prevent outages. The software classifies events into the following categories:

1. Permanent Faults
2. Momentaries
3. Power Disturbances
4. Line Disturbances

The Aclara platform is the only solution to classify the “line disturbances” (e.g. a tree hitting the power line) and momentaries that precede an outage. Line Disturbances are fault events on the line which do not trip any protective devices. An example would be a 4,000 ampere fault that was only on the line for 3 cycles before it burnt clear of the line. The substation circuit breaker relay or recloser detected the fault, but the time-over-current curves in the relay did not time-out to initiate a trip. Typically, the utility would be completely blind to such events – even if they had SCADA.

Momentaries are short outages that cause clocks to blink, computers to lose their data or automobile manufacturing lines to stop unexpectedly, damaging equipment. EPRI estimates that momentaries and power quality events cost businesses as much as $15-$20 billion annually. In the Northeast blackout of 2003 that was caused by a tree hitting a power line and creating a cascading series of outages, Daimler Chrysler lost production at 14 of its 31 plants and had to scrap 10,000 vehicles. By monitoring and detecting these events, utilities can take preventative outages to stop outages – and significantly impact the cost outages have on business and households.

Once these events are classified, the “rules based engine” in SMS can categorize even more specific events as “rules” such as a blown fuse on a lateral circuit, an adjacent phase fault, a downstream trunk fault or if fault current is just a result of a Capacitor Bank switching, or load switching operation. This gives you visibility into events beyond just faults that cause an outage. Second, all data is available to analyze trends and evaluate “cause and effect” around faults to build actionable intelligence and accurate alerts to proactively troubleshoot new grid conditions (before they cause an outage).

New analytics rules can be defined as fault signatures are detected and classified. Rules can also be created to suppress events that are not of interest like standard network operations (e.g. load switching events). By filtering events, you can ignore the "non-events" that trick other systems like FCIs to report outages. By providing only the meaningful data that really matters, you can build trust with crews who value from having more situational awareness.

All events are recorded and statistical counts of these events over time are provided in a reporting dashboard that allows you to filter by event and compare across all monitored circuits. This allows you to determine your worst performing circuits by not only looking at the events we've captured but also analyzing voltage sag/swells, load, etc. Aclara's platform provides reports to rank circuit performance for each type of fault and disturbance event, and to track performance trends over time.

With all of this data at the utility's disposal, some interesting trends emerge. For example, utilities have noticed a seasonal component to line disturbances (for example, more trees cause line disturbances in the spring as leaves begin to appear). Whatever the event, the platform allows you to take sensor data, investigate it, take preventative measures, and create benchmarks to compare data the following year to see if things are outside your normal expectations. Because all waveforms are captured, these are retained for future for forensic analysis as well.

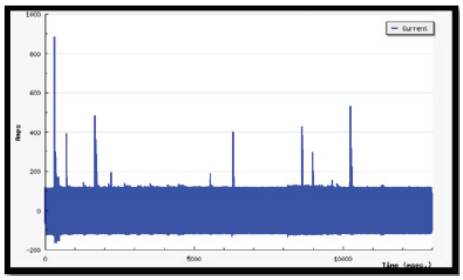
Real World Examples

This section articulates several examples of using line disturbances to correctly predict a future outage, including:

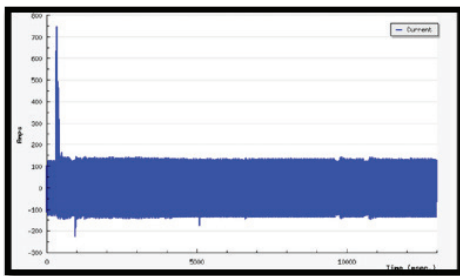
- Tree on a single phase tap
- Failing pole top transformer
- Broken pole
- Animal contact at transformer
- Failing underground cable
- Failing URD cable

Tree on a Single Phase Tap

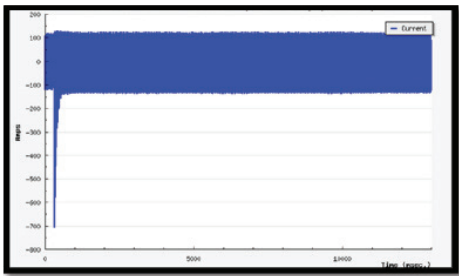
This event, captured by Smart Grid Sensors, was caused when a single phase fuse operated, interrupting 34 customers. Before the outage, the sensors and SMS identified three line disturbance events leading up to the outage over a three hour period. All of these events did not last long enough to trip a recloser or circuit breaker which means the utility did not have an indication that this was happening. With Aclara's Grid Monitoring platform, engineers are now alerted to the impending issue and patrol a focused portion of the line to identify the vegetation condition before it causes a future outage.



Event 1 – Fault Current approx. 650 amps



Event 2 – Approx. 2.5 hours later
Fault Current approx. 700 amps

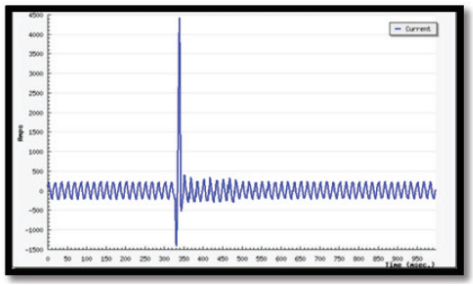


Event 3 – Aprrox. 1 hour after 2nd event
Fault Current approx. 700amps

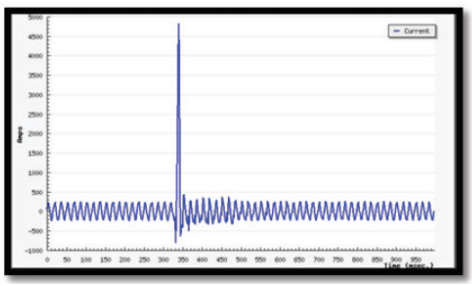
Figure 3:
Tree on a single phase tap

Failing Pole Top Transformer

This event captured by the Smart Grid Sensors was caused by a faulty pole top transformer (see waveforms below). On the initial trouble call, 14 customers were interrupted. The troubleman re-fused the transformer and closed the job. The same failure occurred 11 days later and interrupted customers a second time. The transformer was replaced. Moving forward, the utility knows what to expect when they see this type of event and will be ahead of this problem before it causes multiple dispatches which significantly increases overtime charges and reduces customer satisfaction.



Event 1

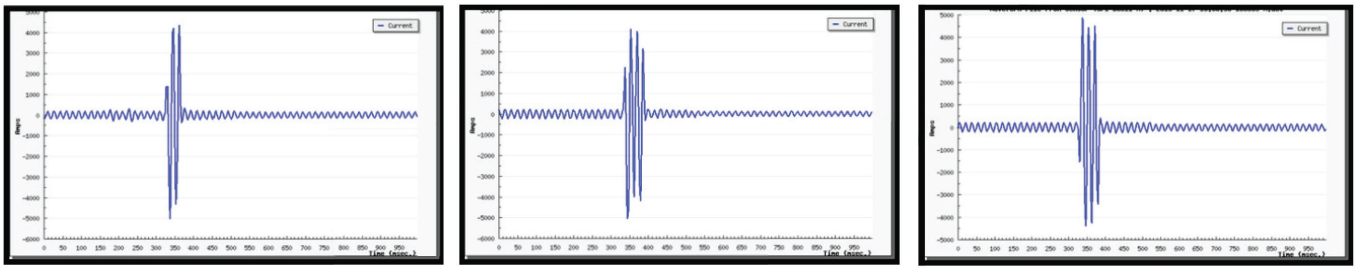


Event 2 – 14 days later

Figure 4:
Failing transformer

Broken Pole

During a wind storm, a three phase pole became damaged. Resulting line disturbances of the phase wires slapping together were recorded by the platform. The waveforms the line sensors picked up for all three phases are shown below. They all had approximately the same fault current of 5,000 amps. From the waveforms captured, it is clear that no protective device tripped because there was load on the line after the 3-phase event occurred. Because no relays operated and no information was reported through SCADA, the utility remained unaware of this condition. After approximately two hours, the broken pole subsequently caused a three phase recloser to go to lockout, interrupting 331 customers until repairs were made. By using analytics and fault current data, the utility can now proactively identify the location of these types of disturbances and better patrolled the areas to address the damaged pole prior to the outage.

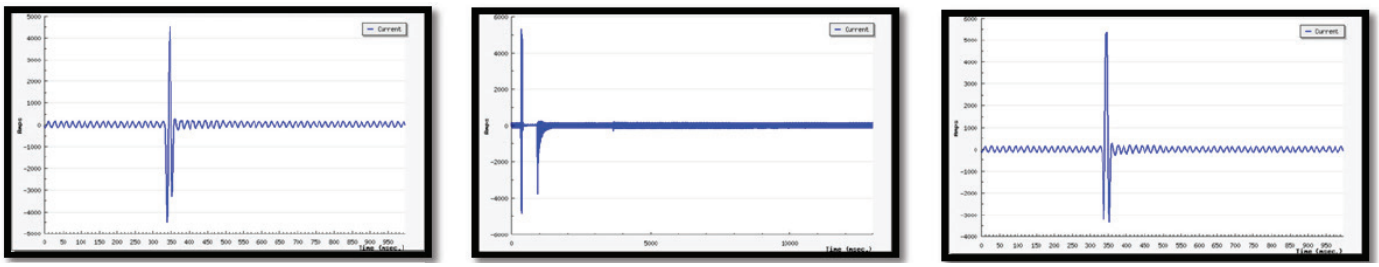


Phase A | Phase B | Phase C

Figure 5: Broken pole

Animal Contact at Transformer

In the waveforms shown below, the platform picked up an event where animals contacted the transformer, but did not completely clear from the area around the energized bushing, causing fault current disturbances without initially causing an outage. The fault happened several times without tripping a protective device. Over a 14 day period, the 4,000 amp fault was measured three times by the MV sensors. Ultimately, the transformer fuse cleared the fault but interrupted 38 customers until repairs were made. With future similar conditions, the utility can be alerted to the impending issue, schedule a patrol for the specifically identified location, and install or repair the appropriate animal guards before the animals cause an outage.



Event 1 | Event 2 – 6 days after the f rst event | Event 3 – 14 days after the first event

Figure 6: Animal contact at the transformer

Failing Underground Cable

Over a two month period, a utility received 10 flickering light and momentary complaints which resulted in at least three visits by troublemen. Each time, the troublemen reported that nothing was found and closed the tickets. Ultimately an underground cable failed and needed to be repaired which resulted in an outage to 17 customers two months after the initial event. The Smart Grid Sensors on the circuit measured six occasions that provided the fault current of 1,600 amps to locate the fault. In the future, the utility will use sensor data to help engineers identify that the complaints were due to a bad underground cable. The cable could have been taken out of service under planned conditions and repaired before causing an outage.

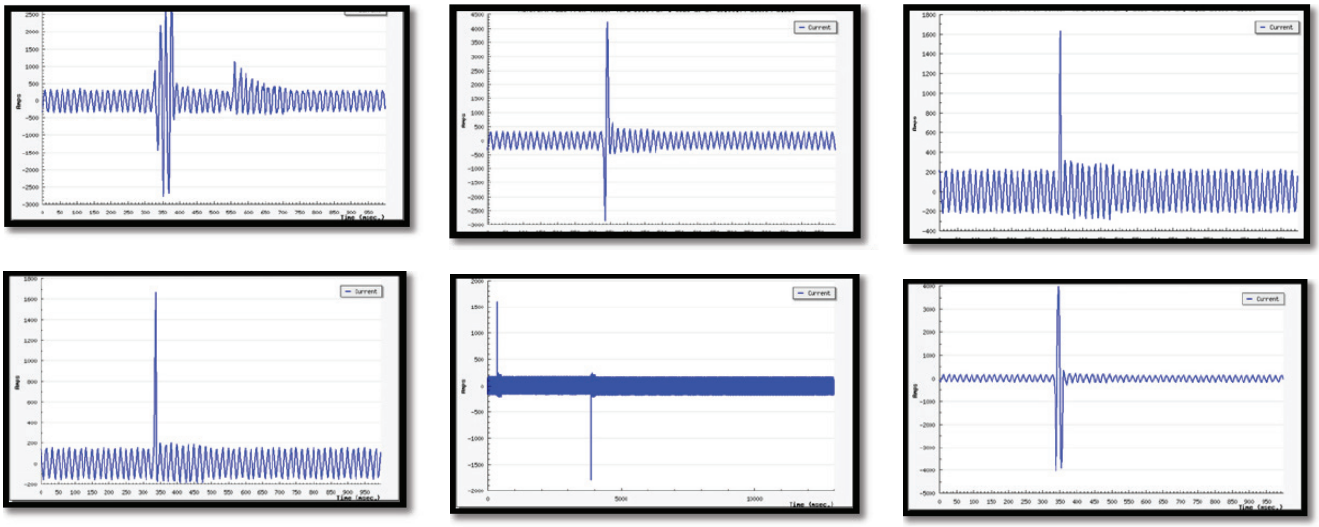


Figure 7: Failing underground cable

Failing URD Cable

In the example below, line sensors on a circuit recorded a series of five transient line disturbance events over a span of six days. For each event, the fault current was consistently around 5,400 amps and always on C phase. After the initial series of line disturbances, a URD cable on the circuit faulted, causing an outage for 20 customers. Prior to the outage, no protective devices tripped so the utility was not aware that this cable was failing. In the future, the utility could have used the sensor data to help the engineers identify that the complaints were due to a bad underground cable. The cable could have been taken out of service under planned conditions and repaired before causing an outage.

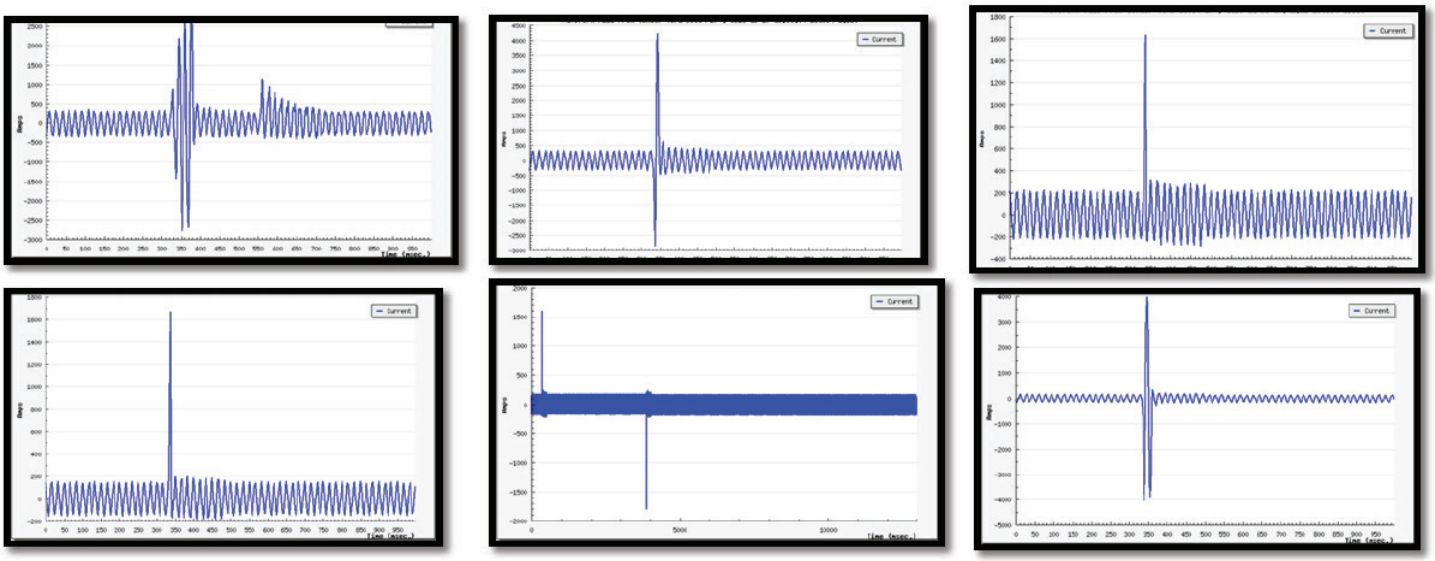


Figure 8: Failing URD Cable

How Aclara's Grid Monitoring platform is Used for Fault Detection and Location

In each of the aforementioned examples, the platform was used to analyze ways to prevent future outages. In addition, sensors were used to detect and locate faults in two ways:

1. Circuit Segmentation
2. Distance to Fault Estimation.

These approaches allow utilities to restore power faster when there is an outage. Both methods are described in more detail below.

1. **Circuit Segmentation:** When a fault occurs on a circuit, it will be captured by all sensors on that circuit. Sensors downstream from the fault will report only a Power Off event. SMS software receives all fault and outage notifications from Sensors on the circuit, analyzes them, and provides notification of the fault location via email or text messages, or via DNP3 messages to other back-office systems (SCADA, EMS, Historian, etc.) in near real-time. The platform also provides a Google Map view of the fault to aid in fault location.

When multiple line sensors are deployed on a circuit, the sensors closest to the fault is reported. Utilities are able to sectionalize their feeders with sensors to get immediate notification if the fault is upstream or downstream of the sensors deployed on the circuit.

2. **Distance to Fault Estimation:** Some utilities prefer to use the platform's RMS fault current measurements with their circuit impedance models. The fault information may also be combined with outage notifications from either customer calls or AMI smart meters to help narrow down the specific location (but not required). When a fault occurs on a circuit, sensors will report the phase(s) affected and the RMS fault current. If control center operators have access to impedance models for the circuit (individual spreadsheets, integrated with DMS, or other tools) and circuit maps, dispatchers can identify one or more candidate locations for crews to investigate. If multiple locations may be possible, dispatchers may be able to identify specific candidate locations based on customer outage calls, smart meter notifications, and/or downstream sensors notifications.

In all cases, Aclara's platform will provide notification via email or text messages, or via DNP3 messages to back-office systems (SCADA, EMS, Historian, etc.). The Grid Monitoring platform can report the following information:

- Event type: Permanent Fault, Momentary Fault, Power Off
- Timestamp
- Substation/Circuit/Phase (Multiple phase events can be reported together or independently)
- Fault current magnitude (Configurable to report RMS or Peak current)
- Sensors' logical and GPS location

Key Technical Differentiators

Because of its fault analysis capabilities, Aclara's platform is most often compared to FCIs. However, this is not an accurate comparison because the system can do much more than fault detection. Aclara's sensors also provide load monitoring to safely bring renewables online, substation monitoring for asset protection and predictive grid capabilities to allow grid operators to avoid outages. In addition, our fault location capabilities is provided on a map that crews can use to drive to the specific outage, not drive the circuit looking for blinking lights. Finally, Aclara offers a much lower Total Cost of Ownership (TCO) against a battery-powered FCI or solar-powered sensor because Aclara's sensors are inductively powered (battery-free) and maintenance-free.

Our Grid Monitoring platform also offers some unique capabilities as the only distribution monitoring solution to detect momentaries, classify line disturbances and offer "Auto-phase ID" which is a novel approach allowing utilities to accurately identify phases across your feeders and laterals. Additionally, Aclara's Grid Monitoring platform is the only solution of our kind that includes GPS coupled with auto-phase functionality, our sensors will always report back on their location when moved.

Aclara's platform is the only distribution monitoring solution that can aggregate data from all sensors and provide a single connection to the DMS or Historian rather than putting that burden on the utility's IT staff. Line sensors capture, time stamp and communicate critical measurements and event waveforms and sends only the most important, accurate information to your Historian, DMS or SCADA systems. In head-to-head field trials, basic Faulted Circuit Indicators (FCIs) generated as many as four false alarms to every true outage event confirmed by the platform. By reducing false alarms, Aclara's Grid Monitoring platform can be trusted to send only accurate data to back-end systems seamlessly through DNP3.

Figure 9: Example of Aclara's Sensor installation at a substation

Finally, Aclara sensors provide flexible communication options. Our cellular sensors include 3G communications for high speed, real-time reporting of events and data. Where other communications networks are preferred, our Wi-Fi Sensors support easy integration with public and private IP-based networks via Aclara's Aggregators or third-party communications nodes. All sensors are quickly installed, automatically power up, and connect to your preferred network to seamlessly send data to back office applications or our hosted data center. Because it is so ubiquitous and easy to deploy, the platform has been used in multiple applications from Fault Detection to Substation Monitoring and last year won Fierce Energy's coveted Distribution and Substation Automation Award.

Conclusion

Aclara's platform is designed to allow utilities to proactively manage their outages and with our superior fault detection capabilities, restore power faster. With Aclara's Grid monitoring Platform you are in the driver's seat. Rather than waiting for a momentary or fault to occur, the data provided by the sensors can allow the operations group to perform focused patrols within a few poles of the problem location to avoid outages.

With all of this data at the utility's disposal, you'll have the ability to find and resolve problems before they cause an outage and affect SAIDI, SAIFI and CAIDI. Whatever the event, Aclara's platform allows you to take sensor data, investigate it, take preventative measures, and create benchmarks to compare data the following year to see if things are outside your normal expectations. With the power of this type of technology priced with a lower TCO than FCIs, utilities will have tremendous business impact on improving reliability and other performance-based metrics.

About Aclara

Aclara is a world-class supplier of smart infrastructure solutions (SIS) to more than 800 water, gas, and electric utilities globally. Aclara SIS offerings include smart meters and other field devices, advanced metering infrastructure and software and services that enable utilities to predict and respond to conditions, leverage their distribution networks effectively and engage with their customers. In 2016 Aclara won a Frost & Sullivan Global Smart Energy Networks Enabling Technology Leadership Award and was named a finalist in three categories of the Platts Global Energy Awards. Aclara is owned by an affiliate of Sun Capital Partners.

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