21, rue d'Artois, F-75008 PARIS
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Applications and Challenges for a New Lateral Line Sensor

R.S. RUMRILL
Sentient Energy
USA

SUMMARY

With wireless sensors for substations and feeders becoming more commonplace, this paper will explore the merits of adding sensors to the lateral lines. This added visibility will allow utilities to gain further insights into many of the issues that contribute to overall system reliability.

KEYWORDS

Distribution line, Lateral, Conductor-mounted sensor, Line Sensor, Fault location, Predictive Analytics

1. THE NEXT FRONTIER

Utilities that use modern line sensors and grid analytics have demonstrated that they can improve reliability indices such as SAIDI, SAIFI and CAIDI. Data from a multitude of sensors can be aggregated, processed and presented directly with a user interface or imported into various management systems. Software algorithms can identify a myriad of issues ranging from momentary outages, to fault localization and potential safety issues such as downed conductors.

As the rollout of sensors for substations, feeders, and smart meters progresses, the monitoring of lateral lines could be the next frontier for wireless sensors. Sensors designed for each of these different portions of the network must take into account several factors including, nominal currents, available fault currents, conductor size, etc. Consequently, a sensor designed for use on lateral lines must possess certain key characteristics. Yet, such a sensor will allow for some very specific monitoring opportunities.

2. DETECTION SENSITIVITY

Any single, feeder-based sensor will typically sense the combined current of numerous lateral circuits, so it becomes obvious that a low-current event on one lateral could be difficult to resolve. A dedicated lateral sensor will have increased sensitivity to such events by not

rrumrill@sentient-energy.com

simultaneously measuring non-relevant currents on neighboring circuits. This increased detection sensitivity is the basis of many of the new sensor's applications.

3. DISTRIBUTED GENERATION AND LATERALS

The American Public Power Association has estimated that distributed solar generation in the United States is expected to increase from 9 GW in 2016 to 20 GW in 2020 [1]. The increased penetration of distributed generation (DG) provides both benefits and risks.

Benefits include:

- Lower losses due to better utilization of distribution infrastructure
- Deferment of new generation capacity
- Increased reliability due to "grid support" provided by the DG

Risks include:

- Altering the coordination of protection devices - certain "fuse-saving" schemes can be rendered ineffective
- Local overvoltage's and improper functioning of voltage regulators
- Potential safety issues for line workers

The historical system model assumes that power flows from a relative few generation plants to a great many customers. The old adage was that if it worked at the peak load, then it would always work. However, with increasingly higher penetration of rooftop solar, networks are becoming bidirectional. Sensor data at the lateral level could give a better visibility of neighborhood rooftop PV than data gathered at the feeder level.

The capacity of a circuit to host DG is often limited by the voltage rise created by the new local source of power. As a rule, sites closer to substations can host more DG than sites located towards the far ends of feeders and laterals. With the continued increase of DG, utilities are also concerned about maintaining current levels within the ratings of their switchgear. The importance of this issue has caused California to pass new laws requiring utilities to specifically plan for DG [2]. The advent of modern smart inverters are enabling utilities to push the bounds of hosting capacity even further due to the inverter's ability to produce or absorb reactive power [3]. Because of the widely diverse nature of distribution systems, no two circuits are alike. A lateral sensor's bidirectional measurements and increased resolution will help utilities to plan and monitor their ever-changing system.

4. FAULT LOCALIZATION

Substation and feeder sensors can use several methods to determine fault locations. Most algorithms use fault magnitude and phase information together with circuit impedance to determine distance to the fault. Because of the radial nature of the distribution system, this will almost always result in multiple possible fault locations. Lateral sensors will greatly aid in the fault localization in two ways:

(1) The obvious method by identifying which lateral carried the fault current.

(2) The ability to set a lower detection threshold on the lateral sensors allows the lateral to detect faults that may be below the threshold of a feeder or substation sensor.

The importance of (2) above becomes apparent when we consider the effects of DG. As shown in Figure 1 below, depending on the relative locations of feeder sensors in relation to DG, during a fault both the substation and the DG will deliver fault current. In some cases, the substation's contribution of fault current can actually be reduced due to the presence of DG. If the reduction is great enough, this "protection blinding" can prevent substation or feeder sensors from detecting the fault. This lack of coordination could result in seemingly normal operation from a substation point of view, yet with an isolated "island" on the other side of a downstream switch [4]. Only by locating sensors closer to the actual fault locations can such a situation be detected.

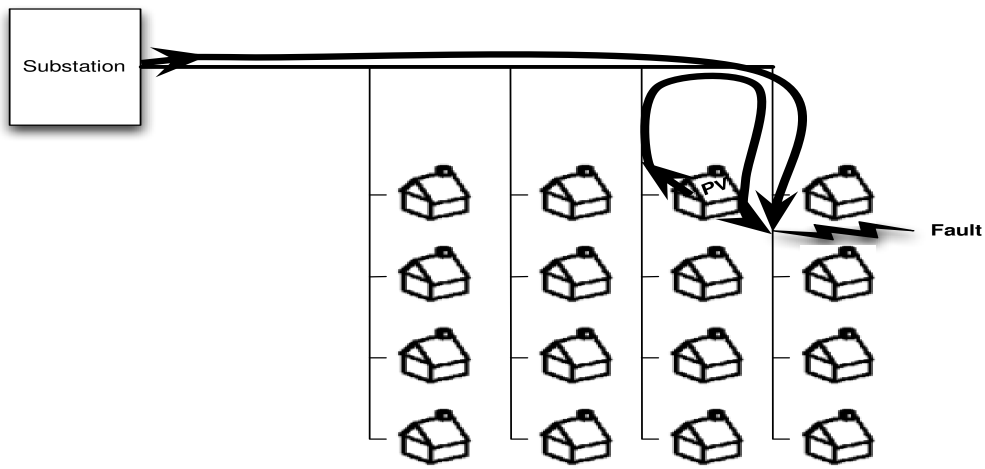

Figure 1 - Fault current contributed by DG

The importance of bidirectional current measurements can also be seen in Figure 1. It is possible that the pre-faulted flow of current is in the conventional direction, from substation to customers, but during a fault, the current in one lateral reverses direction as it contributes fault current.

In areas of predominantly overhead distribution, it is common that local sections of underground are fed via service drops. These drops provide excellent opportunities to monitor the underground portion of the system. A lateral sensor can be installed on the overhead conductors above the pothead. We therefore gain visibility into the underground section without losing the wireless communication ability of the overhead product. In cases where the underground portion is configured in a loop-type arrangement, the ability to quickly locate underground faults will allow crews to quickly isolate the faulted section and reconfigure power to the un-faulted sections.

5. INCIPIENT AND TEMPORARY FAULTS

The ability of a lateral sensor to measure current "undiluted" by neighboring laterals, makes it ideal to sense low-current or self-clearing events, such as:

- Animal Contact
- Vegetation Contact
- Lightning-caused Flashovers
- Insulator Flashover
- Lightning Arrestor Failure
- Underground Cable Failure
- Conductor Slap

In some cases, these events are one-time events that do not escalate. However, many of these cases are true incipient faults that are precursors for a future permanent fault. It has been noted that temporary faults and momentaries do not always result in a customer complaint. Such events during the overnight hours may, in fact not even be noticed by sleeping customers [5]. A lateral sensor can sense such events and in many cases, the enterprise software can categorize the event based on its characteristic signature. Together with a predictive analytic system, trends can be seen and crews dispatched before a permanent fault occurs .

Figure 2 below shows an event that could be missed with a feeder-based sensor. The ~40 Amp blip is easily discernable against the 80 amp baseline. The corresponding feeder may have a 400 Amp baseline, and its threshold settings may ignore this event altogether.

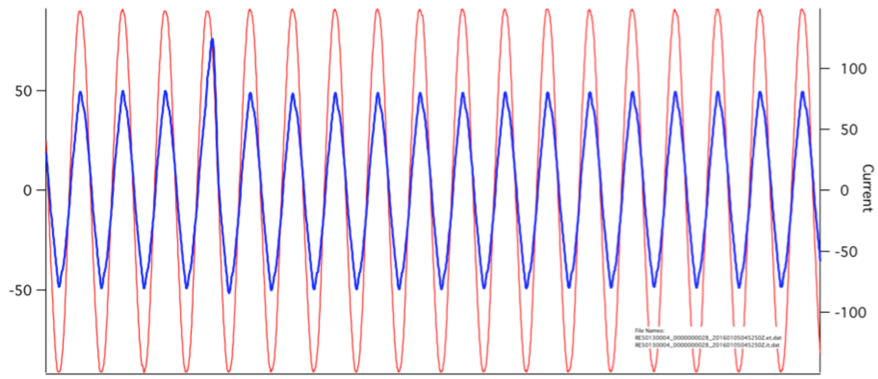

Figure 2 - Waveform as might be captured on a lateral sensor

Incipient faults cannot only escalate into repetitions of the same fault, but can actually cause other problems that may not be readily associated with each other. One utility reported that vegetation contact had caused a fault. Just upstream, a recloser actuated, as it should. Normally, this would have been the end of the event. However, simultaneously, a circuit breaker also opened far upstream. The utility assumed that this was a coordination problem. After several such events, they astutely discovered that the initial faults were causing conductors to sway far upstream. Those conductors slapped, causing a new, higher current fault. The widespread outages that followed were now correctly re-classified as excessive sag [6]. Having numerous sensors, distributed along both feeders and laterals, will help to localize such events to different sections of the system.

6. HIGH IMPEDANCE FAULTS

The higher sensitivity of a lateral sensor can aid in the detection of high impedance faults (HIF). These faults, by their nature, can range from very high impedance (virtually no current) to moderate impedance and thus easier to detect. The challenge in detecting HIF is how to differentiate them from normal load changes. Special algorithms have been developed that typically look for their random and erratic current signatures. One of the most dangerous scenarios that utilities need to detect is a fault-produced, downed conductor. Should a fault cause a burn down, the automated action provided by a recloser will restore power to a large majority of the customers and the system may appear ok. A lateral sensor may be able to detect the downed conductor as a HIF or sense the sudden shedding of a load. Admittedly, HIF and downed conductors are difficult to pinpoint due to the wide range of possible scenarios [7]. A sensitive lateral sensor can be helpful in this regard.

7. PHASE ID AND NEUTRAL CURRENTS

The 4-wire multi-grounded distribution system predominates in the U.S. This grounding method has several positive benefits such as the ability to use single bushing transformers. However, by virtue of its numerous grounding points, the neutral current is guarantied to divide between actual conductors and earth. EPRI estimates that only 40% of return current flows through the conductors, with the remaining 60% flowing through the earth [8]. This makes direct measurement of neutral current difficult. Neutral current however is a direct contributor to conduction losses and is directly proportional to the unbalance of the phase currents. A reduction of those losses would translate into cost savings, while the simultaneous lowering the earth currents could provide safety benefits. EPRI has documented several case studies showing current unbalance as the root cause of several ground-related safety issues [8]. Ideally, utilities could identify phase unbalance with feeder-based sensors and schedule re-phasing operations, but the fact is that many utilities do not have accurate (or up-to-date) phasing information for individual lateral circuits. Lateral sensors, by providing visibility of individual phase ID together with the individual lateral currents, can identify prime candidates for re-phasing.

Because the lateral sensor is specifically designed to operate on low line currents, another application may be to monitor capacitor bank health by measuring its neutral current. One utility is presently investigating the use of such sensors in this application. An unbalance of capacitor currents due to cap failure or fuse opening is readily detectable. This can alert the utility of the problem far in advance of a routine equipment inspection.

8. CHALLENGES

One primary challenge is how to provide power to such a sensor. Because the unit is line-mounted, the obvious answer is to harvest power via a current transformer (CT). Indeed, this is the accepted way of producing power for line-mounted sensors. However, CTs are heavy and might preclude their use on small diameter conductors. The more important consideration however is that many lateral lines operate at very low currents, below the practical limit of using a CT.

Figure 3 shows one utility's network of lateral lines is largely comprised of low current circuits.

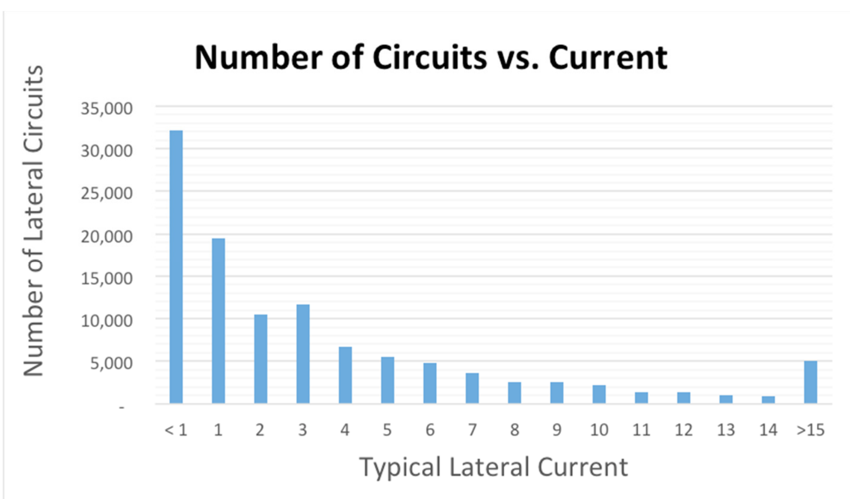

Figure 3 - Many laterals operate at low currents (<1 Amp)

Because many lateral circuits operate at near zero current, alternate power sources such as solar cells or batteries are likely to be needed.

9. CONCLUSION

Lateral sensors add increased visibility to the many miles of conductors extending from feeders to the distribution transformers. By measuring these naturally present "sub-circuits" of the feeders, a much greater sensitivity into low current events is obtainable. A lateral sensor can alert the utility without requiring a feeder-level event. Localizing the event to one specific lateral will help to pinpoint fault locations and in cases of incipient events, the lateral can be flagged for maintenance. Using enterprise software, a network of both lateral and feeder sensors can work together in harmony giving never-before-seen information to the utility.

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