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**Wildfire Ignition from Latent, Undiscovered Distribution Faults - Early
Detection Using Signature Recognition**

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SUMMARY

Utilities, out of necessity, operate distribution circuits in a reactive mode. Circuits are assumed to be healthy until a high current fault or failure causes a protection system operation. The subsequent outage triggers a reaction to find and fix the problem. These high current events are possible fire ignition mechanisms. A 15-year monitoring study involving over 250 distribution circuits has shown that there are fault and failure mechanisms that begin as low magnitude events and may persist for days, weeks or months before catastrophic failure. These failures in their incipient stage are also fire ignition mechanisms. This paper discusses the wildfire problem and powerline causes of wildfires. It presents examples of unhealthy distribution circuits with failing devices that remain undetected for long periods of time, unknown to utility operators. The possibility of detecting these low-grade fire ignition events at an early stage is discussed.

KEYWORDS

Wildfires, wildfire ignition, powerline faults, incipient fault detection, high impedance fault detection

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THE WILDFIRE PROBLEM

At the time of this writing, according to The National Interagency Fire Center, 104 significant wildfires are burning in the United States [1]. Each night horrific scenes of devastation are shown on news stations. The Dixie fire now burning may prove to be the largest fire in California history. The western states including California, Arizona, Idaho, Colorado, Washington, and Oregon have been particularly hard hit, but over the last several years other states including Texas and Oklahoma have had comparable losses. In summary, the United States is burning due to long term drought and climatic changes.

Statistical evidence for the recent increase in wildfire activity is abundant and easy to find. A quick internet search shows the dramatic increase in the number and scale of fires including dramatic increases in the loss of property and lives. There have been 1.5 million wildfires in the United States since 2000. In California in 2020 there were 8112 significant fires that burned 1,443,152 acres [2]. Projections are that in 2021 the losses in California may be even greater, with single fires burning larger areas. Because of the spread of residential construction into wildland areas, approximately 60% of all structures burned in wildfires are individual residences [3]. The loss of life is correspondingly high.

WILDFIRE CAUSES

While most wildfires burn only a few acres and consequently do little damage, there are no insignificant fire ignitions. Without respect to cause, with the right environmental conditions and fuel, any ignition can become a large fire. There are many causes of wildfires and a substantial number of fires are labeled “cause not found”. However, we do know the following. The majority of wildfires are attributed to human causes. A compilation of cause statistics from multiple sources, including those referenced above, yields the following rough approximations.

- Human activity (unintentional) including camp fires, burning of trash/debris, outdoor barbecues, fireworks, cigarette disposal, etc. (19%)
- Equipment use, vehicles, dragging chains (15%)
- Powerline related (8%)
- Dry lightning (6%)
- Incendiary/Arson (6%)
- All other known causes (18%)
- Cause undetermined/not known (28%)

While powerline ignition causes are a relatively small part of the total, some of the more significant fires in the last few years were attributed to powerline events. The level of significance of a fire is correlated with the scale of the fire, area burned, loss of structures, and loss of life. Inadvertent, accidental ignition by humans is often reported early so that the fire can be attacked before it is out of control. However, with powerline caused ignition, the area of origin may be remote and go unobserved until the fire is out of control. Therefore, losses can be very significant before a response can be mounted. While there will never be a total prevention solution to power line fire ignition as long as utilities must deliver electric power to customers, considerable attention should be given to reducing certain causes of ignition, including those described hereafter.

POWERLINE IGNITION MECHANISMS

When conditions are favorable, namely dry fuels, low humidity, and high winds, all that is needed for a fire is an ignition heat source. When electric energy “escapes” the normal bounds of conductors and power delivery apparatus, often by some arcing mechanism, fire ignition is possible. The various ignition mechanisms can be characterized as follows.

- Failure of a part or device such as a switch, clamp, or connector (e.g. arcing, heating, melting)
- A downed arcing conductor
- Explosion of apparatus such as transformers and capacitors
- Clashing of conductors in the air
- Arcing across conductors bridged by foreign objects (e.g. Mylar balloons)
- Vegetation interference

Often there are multiple mechanisms in play. When a tree or branch falls and tears down powerlines, arcing may occur between multiple contacting conductors or between conductors to ground. Electrical arcing is the heat source, but the vegetation interference with powerlines is the true cause. Capacitor failures which create significant electrical transients can cause the failure of arrestors or connection devices at other very remote locations resulting in a distant fire ignition. Clearly, ignition from powerline causes is often a complex series of events [4].

WILDFIRES-INEVITABLE OR PREVENTABLE IGNITION?

There are many powerline events that cause ignition of fires that cannot be avoided or controlled by utility action. A 60 foot healthy pine tree, 50 feet off the right of way, that falls and tears down powerlines to ignite a fire is not under the control of the utility company. From the utility perspective, the fire was not preventable. Certainly, there are methods to mitigate risk which are now being considered including covered conductor and underground conductors. But these introduce different risks, as well as considerable cost. A risk/benefit analysis indicates that the vast majority of electric energy in the United States will, for the foreseeable future, be delivered by overhead, bare conductor.

So which mechanisms of ignition can be avoided? A degrading clamp due to a loose connection, damage, or overload may develop an arcing and/or heating mechanism that may etch through a conductor and drop the conductor to the ground to start a fire. This mechanism may persist for many weeks with aperiodic arcing episodes before final line failure. A switch may develop a failure mechanism that is very innocuous at first, does not interrupt load, and causes no consequence that results in a customer call. Yet the switch is failing. Ultimately, the switch may catastrophically fail or explode under heavy load or under a fault condition, spreading materials that ignite a fire. In both cases, the circuit is unhealthy and becoming increasingly unreliable.

In these examples, fire is a consequence of the failure of a device. If the incipient stage of a failing device or line fault can be detected and located, the final catastrophic failure may be avoided and a fire will not be ignited. No existing protection device or powerline monitoring system commonly used today can detect the incipient stage of a clamp or switch failure. However, it has been shown that waveform analytics applied in real time to high fidelity captures of the electrical signatures of failing devices can identify certain failures at an early stage, long before catastrophic failure [5]. By using the results of these analytic algorithms,

coupled with other utility tools such as AMI, failures can often be found and fixed in a timely manner, thereby preventing a fire.

DETECTION OF FAILING DEVICES

In order to take action in response to a developing arcing ignition condition, it is necessary to reliably provide early detection of the failure event. This is not easily accomplished. Consider a circuit with approximately 150 amps of highly varying load with rich harmonic content. Typical voltage and current waveforms for such a circuit are shown in Figure 1. Study of thousands of circuit load measurements have demonstrated that currents are most often not sinusoidal in nature. Consider that a failing device such as a connector or clamp on a tap line or a service transformer may be modulating only a few amps of the circuit load. The non-sinusoidal characteristics of the load current mask the presence of low magnitude faults and failure signatures. No device generally used by utilities will “see” or detect this developing failure. Research has shown however that it is possible to recognize the signatures of failing devices using real time waveform analytics. [6]

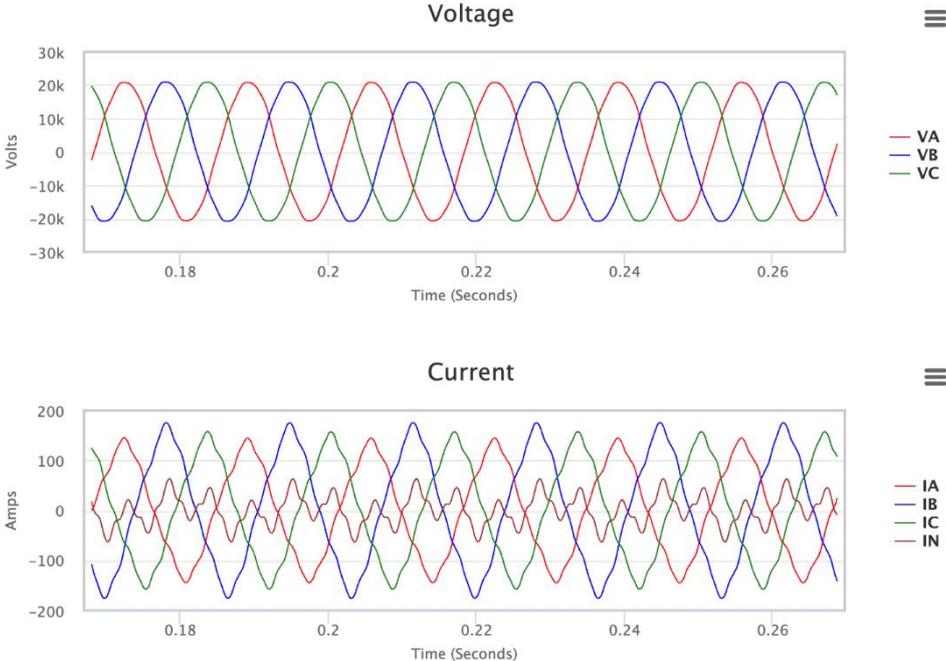


Figure 1: Voltage and current waveforms from a typical distribution circuit

EXAMPLES OF LOW MAGNITUDE FAILURE EVENTS

The following examples were captured and documented from utility circuits under normal operating conditions. Each of the following cases represents a potential fire ignition failure mode on a circuit with the following characteristics.

- Low current magnitude
- Persisted over considerable time
- Intermittent in behavior
- Undetected by conventional means
- Known to ignite fires

Example 1: Secondary fault ignition mechanism

During long term monitoring of a utility circuit, a secondary fault was detected as shown in Figure 2. The current waveform shows substantial arcing for a brief period. These arcing events were aperiodic, but repeatedly occurred over a three month period. These events occasionally caused an outage by tripping a CSP transformer. Service could be restored to customers after inspection revealed no root cause.

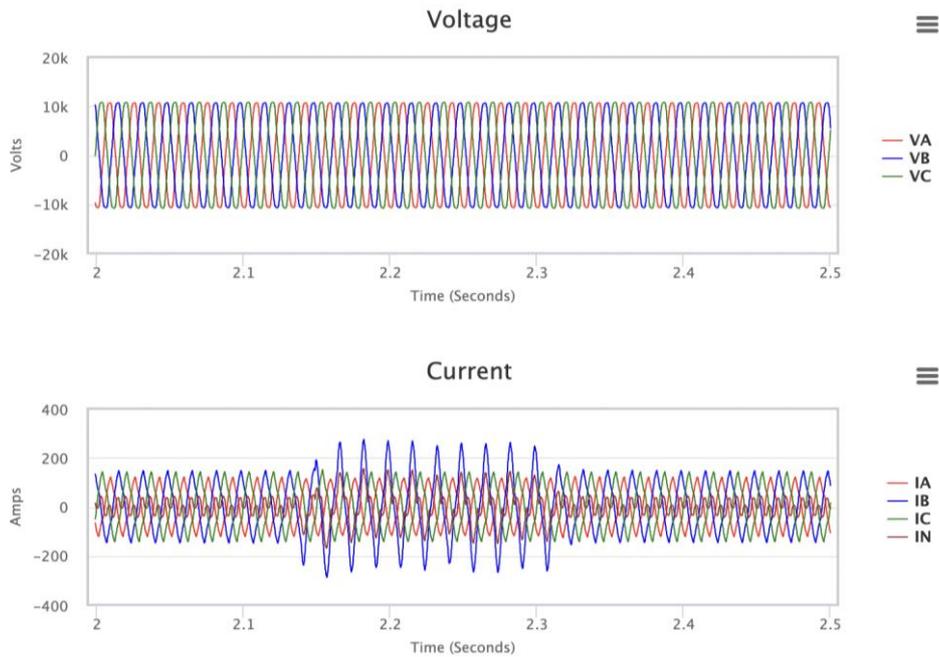


Figure 2: Aperiodic secondary fault

Using advanced monitoring techniques, each incident of arcing could be detected prior to the final event which caused a permanent fault. Figure 3 shows the failed cable that had continued to provide customer service during the three months of progressive failure.

This example demonstrates that relatively low magnitude failure events, including cable degradation, can be detected even when outages do not occur.



Figure 3: Damaged secondary cable

Example 2: Fault caused by backfeed

This event involved a single-phase transformer served by phases A and B on a three-wire circuit. An initial fault on phase B operated a phase B fuse resulting in a backfeed condition on phase A. This backfed fault persisted without other protection operations. Obviously, this fault affected customer voltage and represented a potentially dangerous condition. The current waveform for this fault is shown in Figure 4.

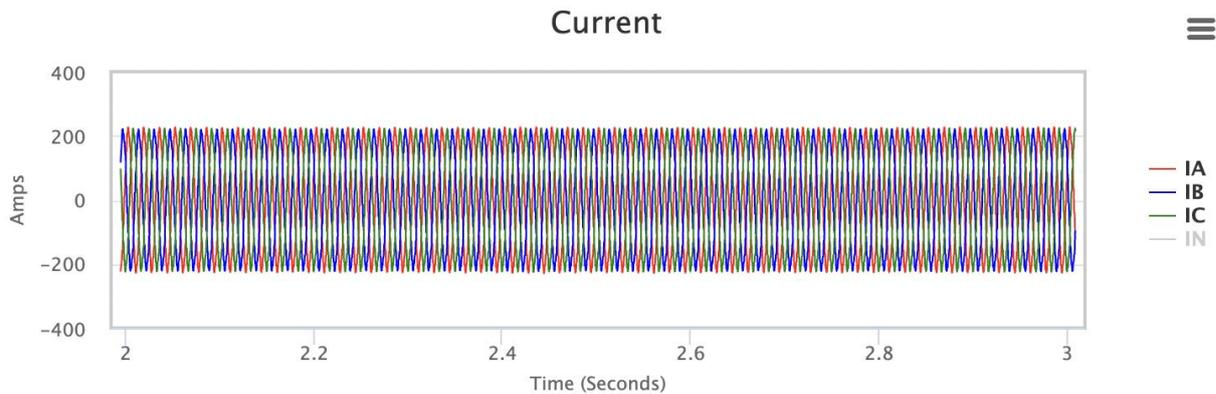


Figure 4: Circuit current including backfed fault.

Viewing the current waveform in Figure 4 does not reveal the backfed fault condition and, once again, the fault will likely persist without protection operations. However, waveform analytics using sensitive data analysis techniques can detect the backfed condition.

Example 3: Switch Failure

Early one morning, a substation blade switch at 25kV substation began to exhibit periods of arcing. Figure 5 shows some of the most persistent and severe arcing produced by the switch, which modulated virtually all of the substation load. While the transients stand out due to the relatively lightly loaded circuit, their magnitudes are still small compared to many transients on a typical circuit, e.g., under 40 amperes. Based on information reported by an advanced waveform analytics system, the utility dispatched a crew to the substation to investigate the problem, and they promptly found the failing switch; repair was completed later that evening. At no point during the switch failure did the utility receive notice of the failing switch from any other conventional system, even as the waveform analytics platform made them aware of the problem. The repair was “just in time”, as a storm blew through the area the next day causing faults, which would likely have resulted in a catastrophic switch failure and an outage to all 3,000 customers served by the bus. Additionally, the switch could have caused catastrophic damage in the substation, including starting a fire. The photography in Figure 6 shows the small arc condition in the switch that persisted for several hours.

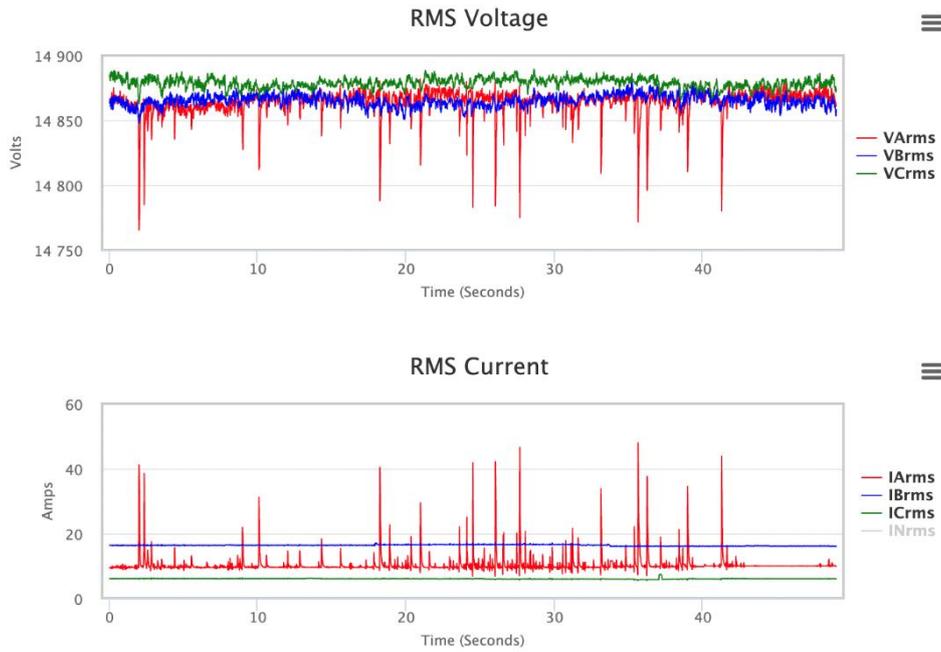


Figure 5: Arcing currents produced by failing substation switch



Figure 6: Arcing switch

Example 4: Failing current-carrying connection device

Sensitive monitoring of a circuit revealed an ongoing failure of a connection device. The series arcing was initiated by a downstream fault that likely weakened a connection device. The arcing condition exhibited in Figure 7 persisted over ten days before final catastrophic failure resulted in a broken connection.

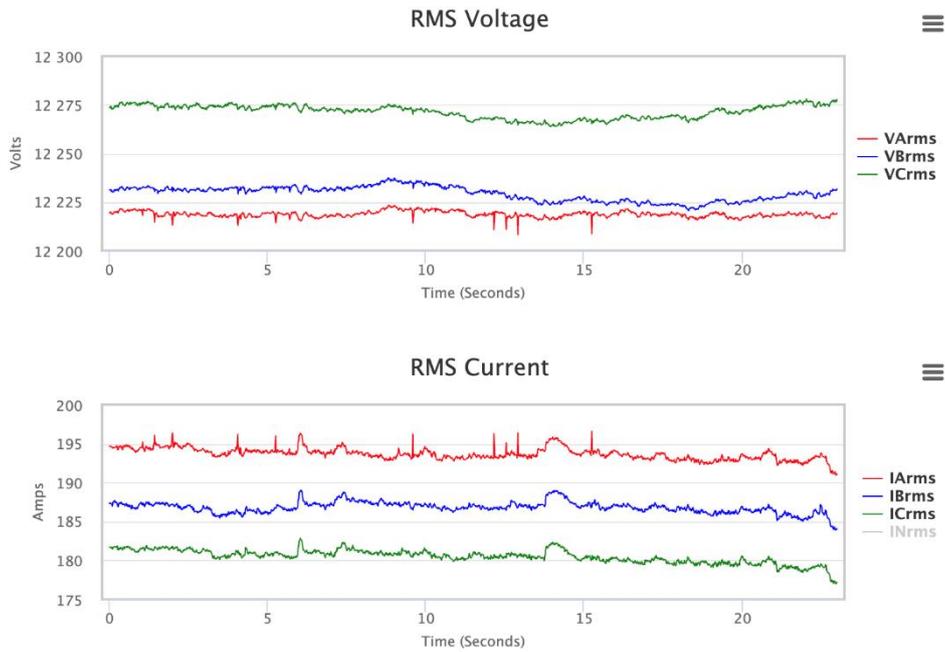


Figure 7: Failing connection device

This example of an in-line connection device is an example of a known ignition mechanism that can persist for many days before total failure occurs. Early detection of this unhealthy condition on the circuit can be very valuable to operators. In the subject case, using the knowledge that the failure condition existed and targeting AMI data can focus crew inspections to find the failing device.

A similar series connection failure is shown in Figures 8 and 9. The waveform in Figure 8 is typical of the aperiodic arcing bursts for a failing clamp. Left unresolved, a clamp can deteriorate as exhibited in Figure 9.

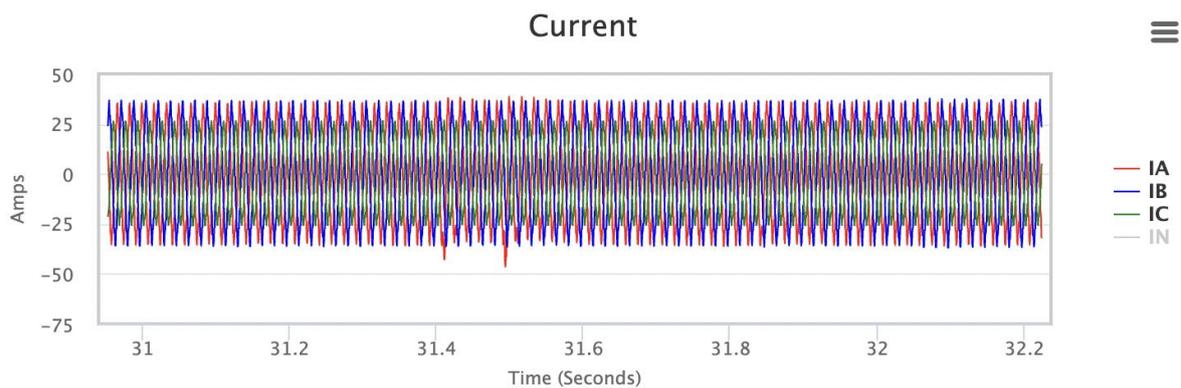


Figure 8: Arc Burst from Failing Clamp



Figure 9: Damaged hotline clamp

CONCLUSION:

Circuits that are presumed to be healthy and are continuing to deliver load, with no customer calls or outages, are often not healthy at all. Failing devices may persist for days or weeks before catastrophic failure expels ignition particles or drops a line to earth – known ignition mechanisms. Real-time waveform analytics with highly sensitive event triggering can detect and sometimes identify a failing device before the failure develops to an ignition competent condition. New tools now exist to identify circuits with low magnitude failure mechanisms providing operators and engineers advanced awareness of impending ignition events.

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