Unintended Consequences of Extra Sensitive Protection

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Introduction

Exceptional weather events and conditions such as extreme wildfire ignition danger have caused some utilities to practice modification of protection settings to mitigate wildfire ignition and maximize safety. The most extreme example of this is a decision to fully de-energize circuits until dangerous conditions have passed. This practice in California for wildfire prevention is called Public Safety Power Shut-off (PSPS).

A more common practice that has been used for many years is placing breakers and reclosers on "one-shot" settings, blocking devices from reclosing after their first trip. In this case the protection curve for the first trip remains as normally programmed. Long outages can result, often due to patrol requirements before circuits can be reenergized. Protection engineers have long known that most faults are temporary and cleared by one or more trips and auto-reclose operations, providing service continuity after a brief "blink."

Recently, utilities faced with extreme wildfire liability have experimented with "extra sensitive protection." The first trip of a breaker or recloser is set much faster than normal, and all auto-reclosing is blocked. Protection engineers fully recognize that this is a trade-off, sacrificing considerable reliability of service and making circuits susceptible to long outages while patrols are performed. The justification for these extremely fast tripping operations is the idea that rapid de-energization will reduce the probability of wildfire ignition from a downed, arcing conductor. Quantification of the of benefit of this concept is still under scientific study for validation.

Until recently, the above description defined the state of knowledge of these various methodologies including their deficiencies and benefits. But recent research has described another fault characteristic of circuits that reveals a further problem for those who use extra sensitive protection.

Protection engineers clearly understand that there are a wide variety of fault conditions that can occur on a distribution circuit. These are primarily characterized by fault magnitude and duration. However, using high fidelity fault capture devices on multiple circuits has revealed that circuits may experience high magnitude, very short duration faults that are self-clearing in nature but are sufficient to trip reclosers with extra sensitive protection settings. Utilities using the Distribution Fault Anticipation (DFA) system have documented this unintended consequence. The behavior of circuits with extra sensitive protection is best understood with actual examples.

Recurring Fault (Intermittent, Incipient Failure) Example

From December 2021 through July 2022 a utility circuit experienced 79 self-clearing line-to-ground faults. Each of these faults was a sub-cycle pulse with a duration of less than 8 milliseconds. The magnitude of these pulses varied, but each was hundreds of amps of fault current. During this entire 200 day period of repetitive faults no conventional protection device operated. This was to be expected given the very short duration of the faults. The utility using its conventional systems had no independent notice of these recurring faults.

Post incident investigation revealed that the root cause of the faults was the failure of a single cable fitting which intermittently caused a ground fault. Because the circuit was instrumented with a Distribution Fault Anticipation (DFA) system, each individual fault was captured and recorded. It is this data that has allowed us to understand how this incipient failure event progressed over time and the previously unrecognized effect on circuits with extra sensitive settings enabled.

The following observations are important.

- Conventional protection did not trigger on the short pulses.
- Sensitive DFA recording captured these individual faults.
- 79 faults occurred over 200 days without load interruption from conventional protection devices.
- There were no customer calls reporting problems.
- The utility had no independent awareness of this 200 day fault progression without DFA. (Digital protection recorded individual pulses, but there was no mechanism to raise this to an actionable level of awareness.)

Figure 1 below shows the time sequence of the short duration faults.

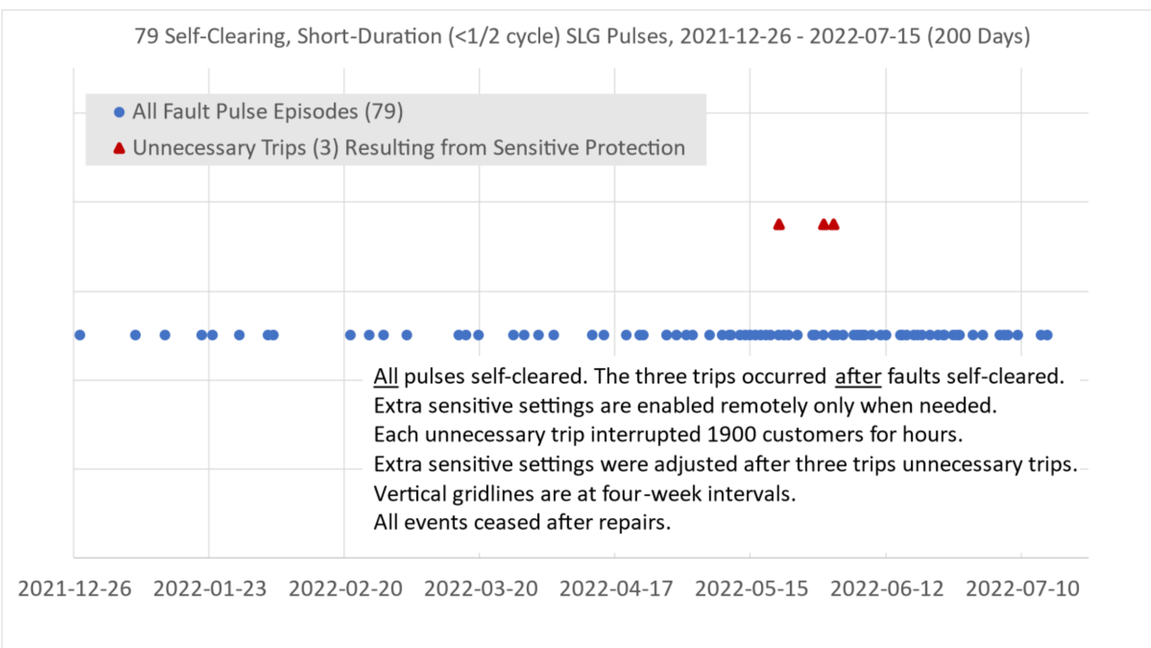

Figure 1. Time sequence of 79 short-duration pulses related to failure of a single cable fitting.

In May of 2022 the utility began intermittent utilization of extra sensitive protection settings as shown in Figure 2. When sensitive protection was enabled, the faults caused a recloser to trip. Reclosing was blocked so when the extra sensitive protection operated, 1900 customers experienced an outage. These outages only occurred when extra sensitive protection was enabled. It is critical to understand that the tripping recloser did NOT clear the faults; rather the fault set the recloser trip sequence in motion but then self-cleared before that trip occurred.

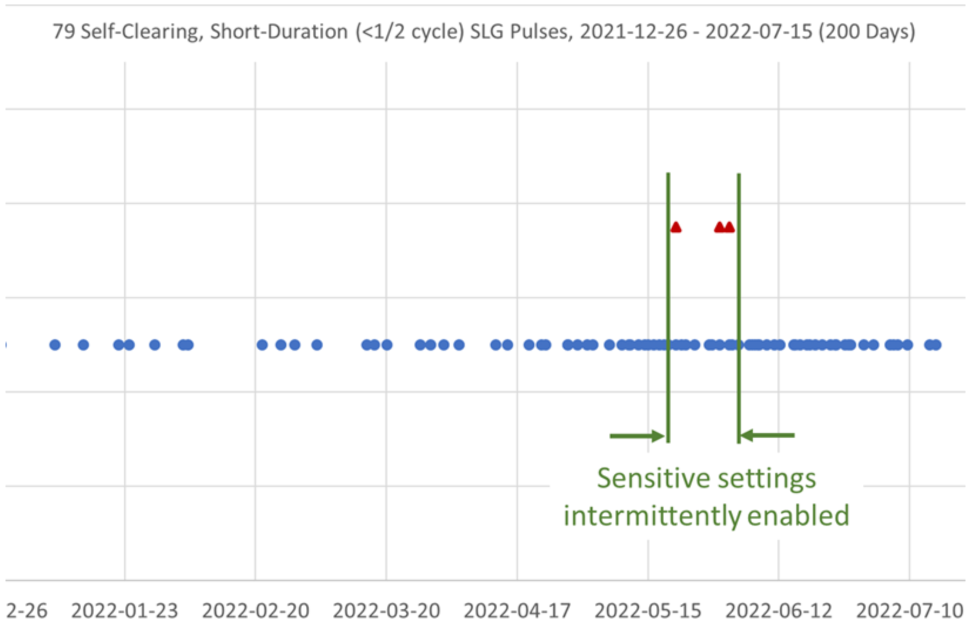

Figure 2. Three extra-sensitive protection recloser operations (red triangles).

Figure 3 shows DFA waveform recordings of one of the individual sub-cycle fault pulses. Each pulse was a single-line-to-ground fault of several hundred amps in magnitude but not more than 8 milliseconds in duration. It can be seen from the waveform that each pulse self-cleared in a fraction of a cycle, well before the recloser opened. The moment of opening of the recloser is inferred from the 30% reduction in load current, between two and three cycles after the fault pulse occurred and self-cleared. In other words the high current magnitude of the pulse picked up the recloser, because of the extra sensitive protection setting, and caused it to open. It is important to note that the decision time of the recloser and the time to open the breaker took multiple cycles, clearing the fault well after the fault self-cleared.

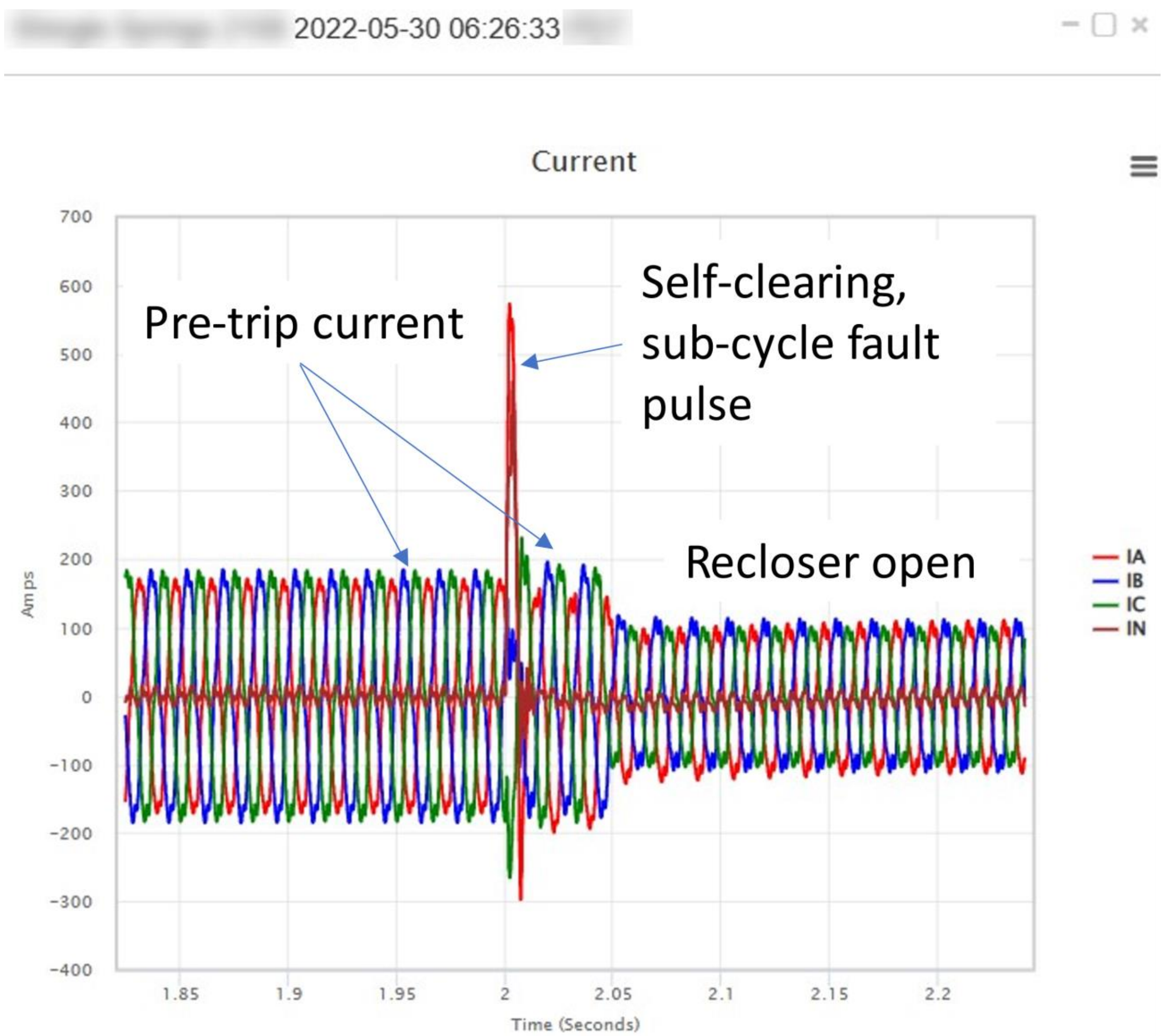

Figure 3. Cable-fitting current pulse that self-cleared but the recloser tripped.

These observations are shown more clearly in Figure 4 below. This graphic representation reveals that the sub-cycle pulse self-cleared. Note that the load current level on the circuit before the fault and immediately after the fault was the same. Two to three cycles after the fault had cleared, the recloser opened and interrupted 30% of the circuit's load.

Possibly the most important observation is that the opening of the recloser played no part in clearing the fault! The fault cleared itself, and the tripping of the recloser had no consequence other than deenergized a portion of the circuit and putting 1900 customers in the dark.

Conventional interruption of recorded data of these faults and recloser operations would have indicated to most protection engineers that sensitive protection cleared faults on the circuit. Such a conclusion would have been an error. These faults cleared themselves, without respect to the recloser operation, in fact before the recloser opened! Without extra sensitive protection enabled, the faults self-cleared without interruption or outage; with extra sensitive protection enabled, the faults still self-cleared, but the recloser then tripped and caused a sustained outage.

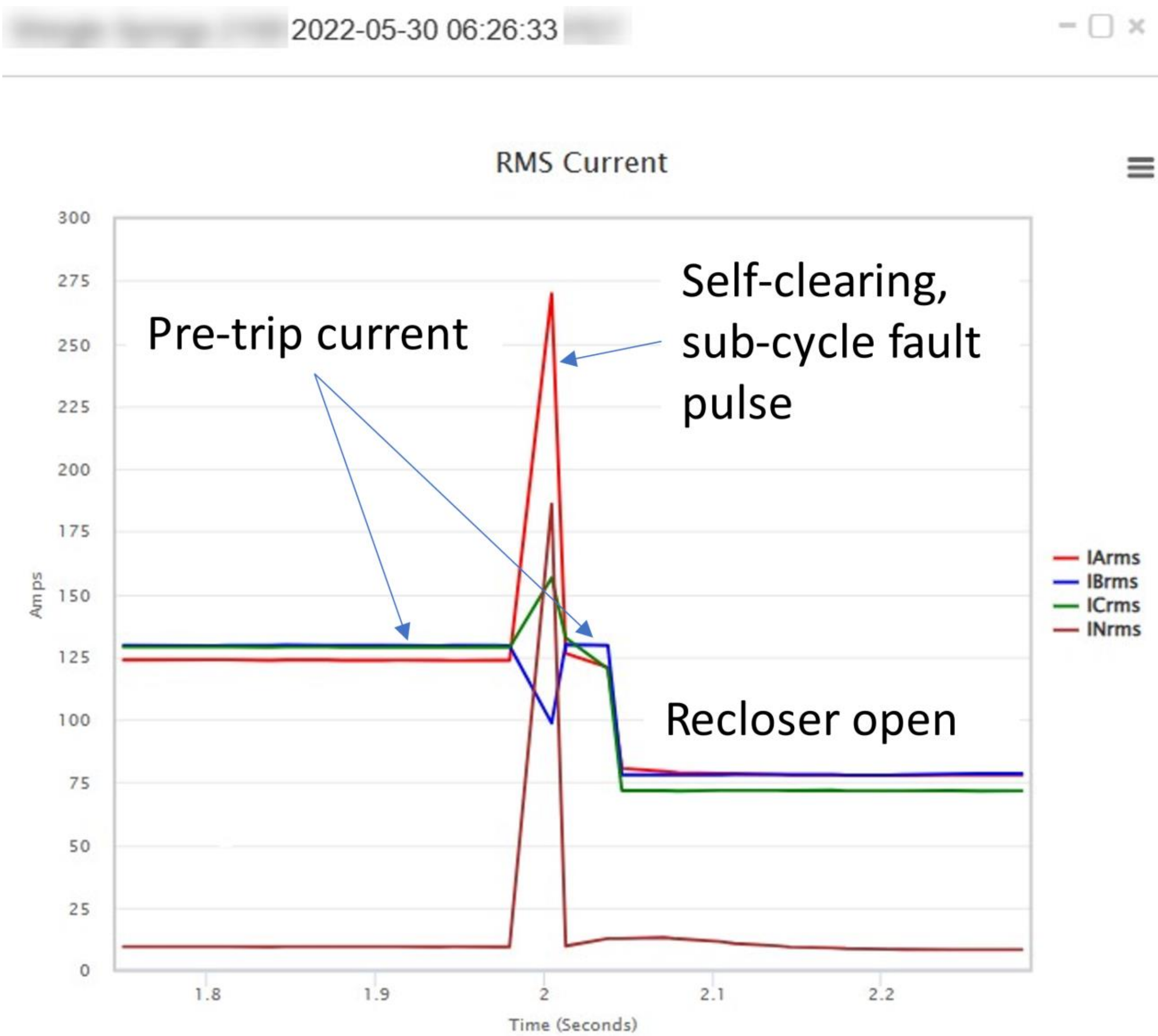

Figure 4. Cable-fitting current pulse that self-cleared but then unnecessarily tripped 1900 customers (RMS)

Findings and Conclusions

1) Short duration, high current faults can occur on circuits in a repetitive fashion without operator knowledge or notice from customers. These faults often do not cause a recloser operation.
2) DFA monitoring of circuits has shown that these short fault pulses can be detected and captured, giving operators important information concerning the health and condition of the circuit.
3) Extra sensitive protection settings can trigger on very short duration faults but may deenergize a circuit unnecessarily after the faults self-clear.

4) Protection engineers who are using extra sensitive protection to reduce wildfire ignition probability need to be aware of the liability for causing long unnecessary outages when a circuit experiences these sub-cycle faults.
5) DFA could be used to inform operators that the circuit outage that had just occurred was not due to an operation of a recloser set for extra sensitive protection. Using this information, operators could have manually reclosed the circuit with no increase in liability and no long duration outage.

Operational Considerations

Extra sensitive protection has a place in the toolbox of utilities particularly when extreme wildfire danger makes the only other alternative a preemptive shutoff of the circuit. The data analysis shown above reveals that circuits may be deenergized unnecessarily when very short duration self-clearing faults occur. Such faults are often associated with such things as cable terminations and incipient bushing failures that are not, in general, associated with wildfire ignition. When a recloser deenergizes the circuit, a full patrol of the circuit is often required. In the case of cable related faults, linemen would often report "no cause found."

Using DFA information operators would know the circuit could be manually reenergized without fear of wildfire ignition.

References

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