Detecting and Diagnosing Protection Anomalies on Distribution Systems

Contact Information

Jeffrey Wischkaemper
Associate Research Professor, Electrical and Computer Engineering, Texas A&M Engineering, jeffw@tamu.edu
Phone: +1-979-575-7213

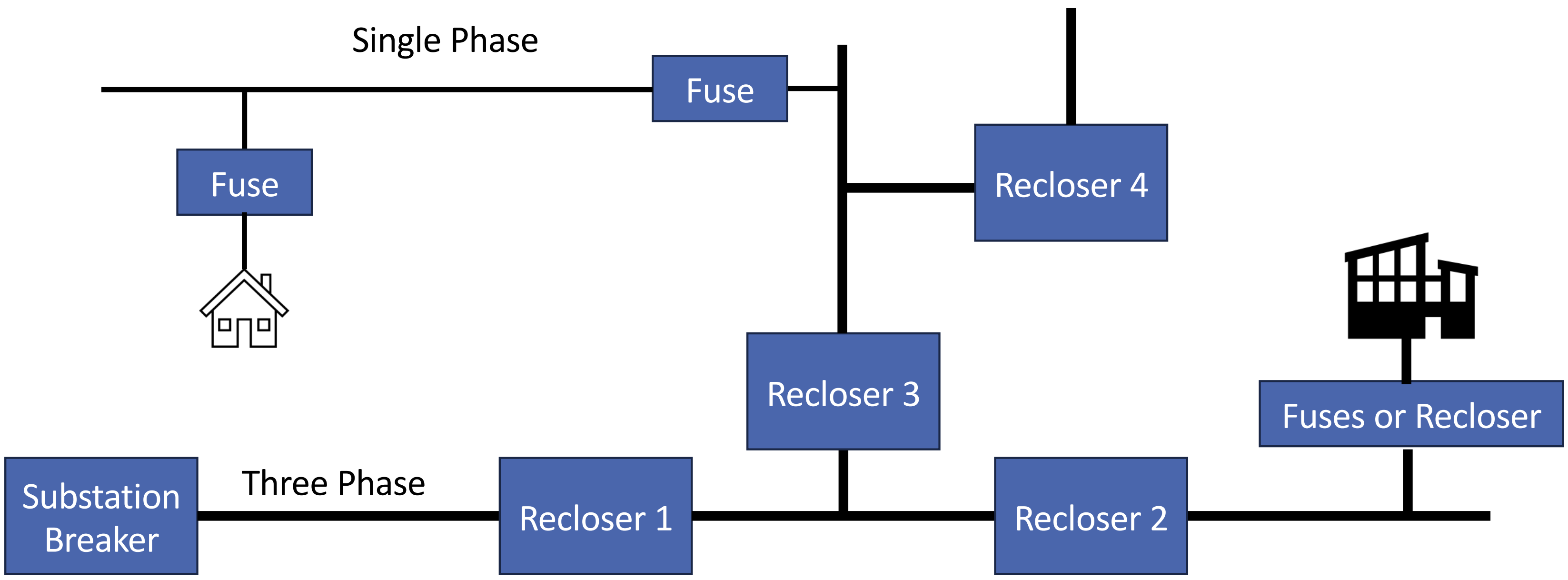
What happens when protection fails?

- System protection is designed to prevent Bad Things™ from happening.
- Generally speaking this means means clearing faults before they cause damage to the system, though recently it has also become a focus for wildfire risk mitigation.
- Protection systems are generally reliable, but how do you know when they aren't working properly, diagnose, fix, etc.?
- Data to solve these problems is often unavailable or difficult to interpret.

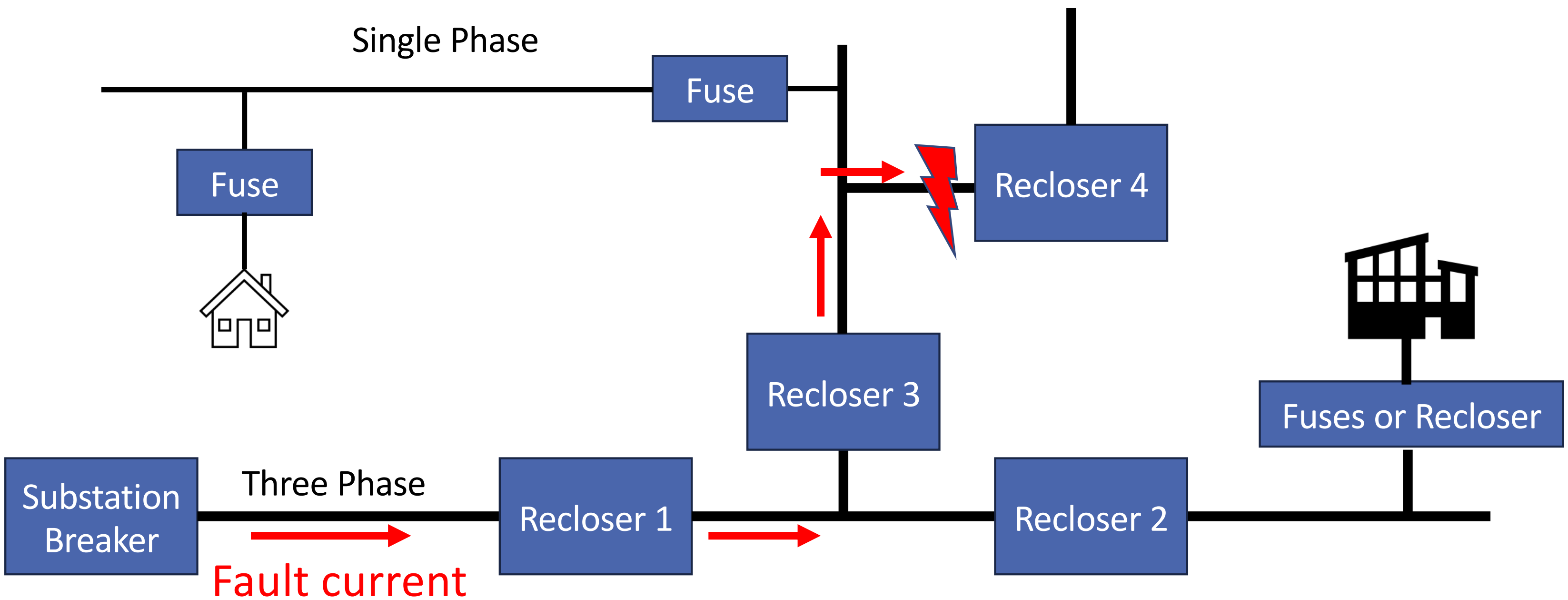
Distribution protection overview

- Some exceptions exist (and will be discussed), but distribution protection is generally provided by 50/51-like elements (instantaneous overcurrent and time-overcurrent), with 51-like elements (i.e. fuses) being the most common.
- A typical arrangement on a North American distribution circuit would be a reclosing circuit breaker at the substation, one or more overhead reclosers distributed along the circuit, and hundreds of fuses protecting individual loads.
- For example, a utility might have a 960/480A phase/ground pickup breaker at the substation with 200A/100A phase/ground reclosers at 3-ph tap points, with single phase laterals protected using 80A fuses and individual transformers protected using fuses ranging from 2-40A, depending on kva rating and voltage level.
- Ideally these all coordinate such that the device closest to the fault operates first, but on long or complex circuits perfect coordination is not always possible.

Distribution protection overview



Distribution protection overview



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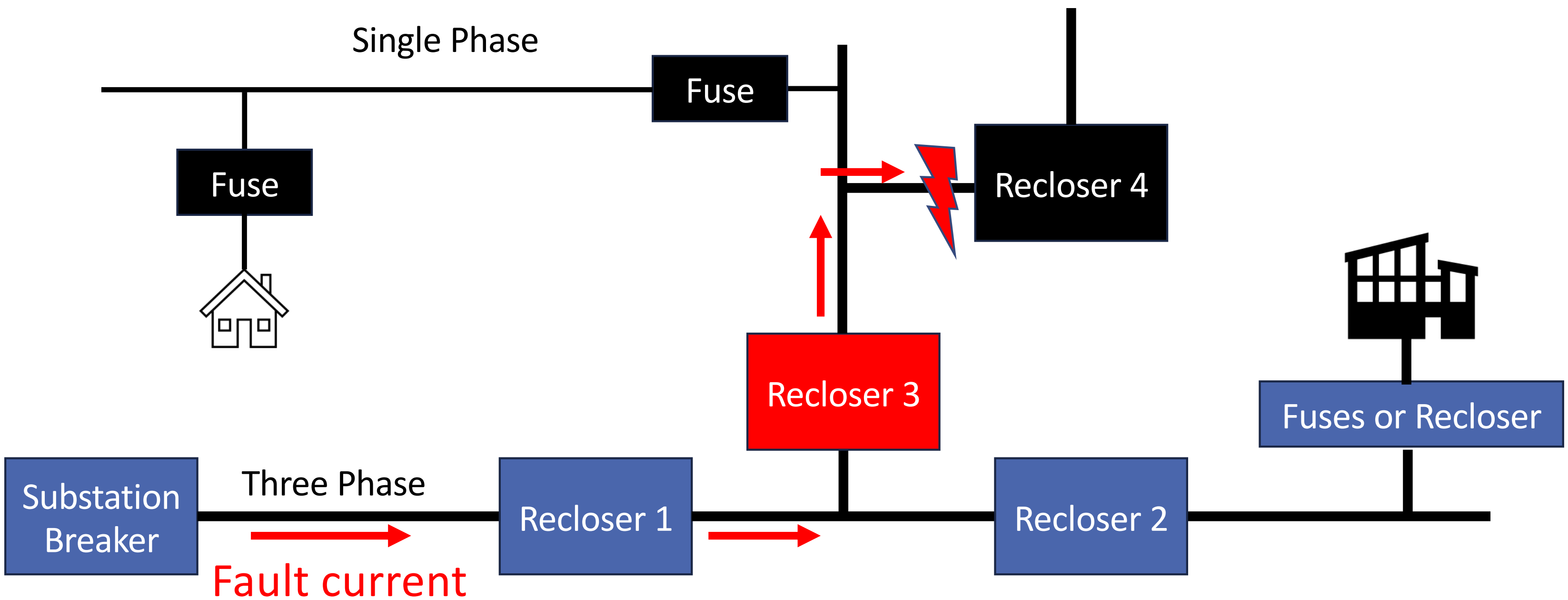

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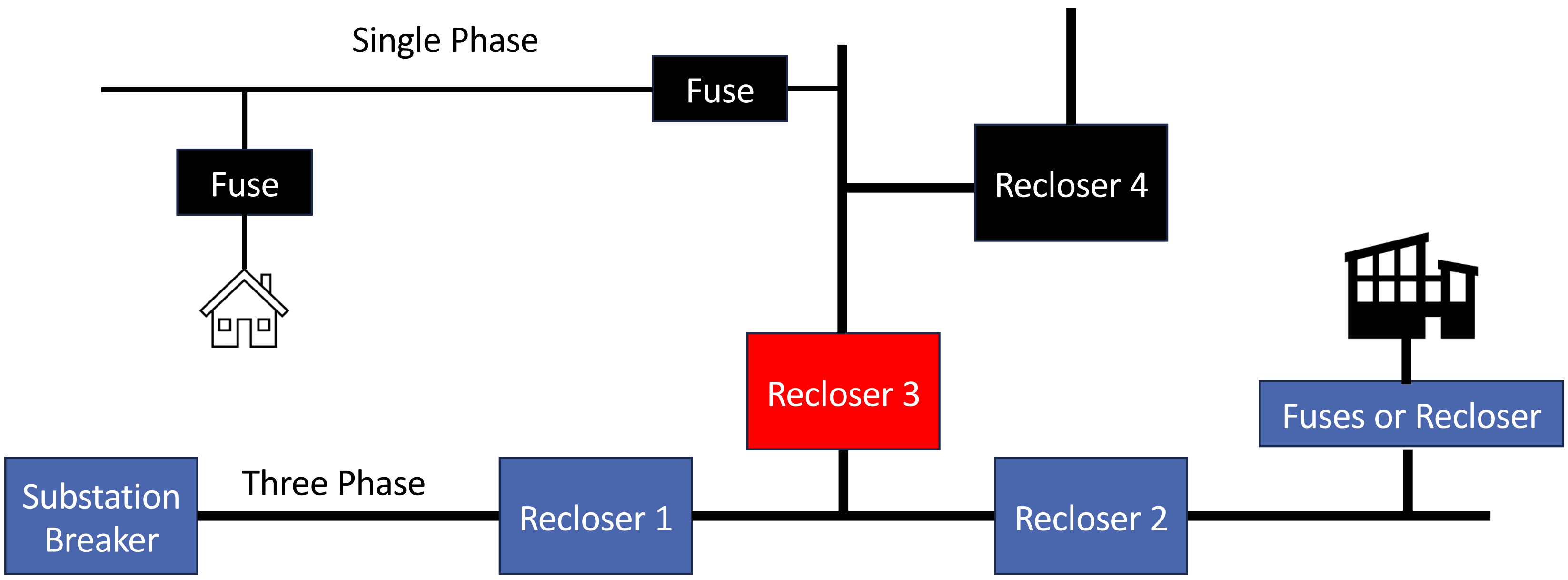

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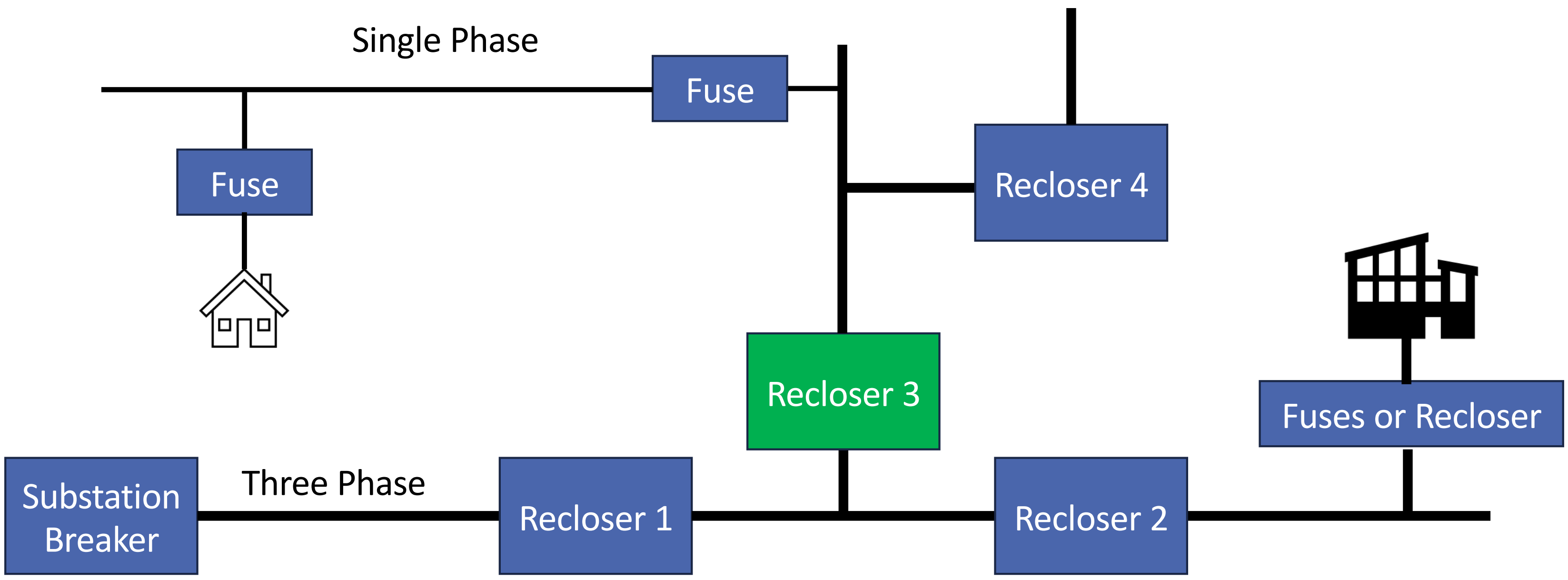


Protection oversight

- So again, the question is: how do you know this is working properly?
- Field anomalies
  - Coordination issues
  - Failures to operate
  - False trips
  - Bad Things™ happening
- For older equipment (e.g., hydraulic reclosers) you generally have only a trip counter.
- New equipment may have diagnostic capability, but the data you actually want may not be available.

Distribution Fault Anticipation Project

- Researchers at Texas A&M have worked for over 20 years characterizing normal and abnormal electrical events on distribution systems.
- Sensitive monitoring equipment measures substation CTs and bus PTs to detect incipient failure conditions and alert utility companies.
- As a by-product, DFA often detects failures or misoperations of system protection.

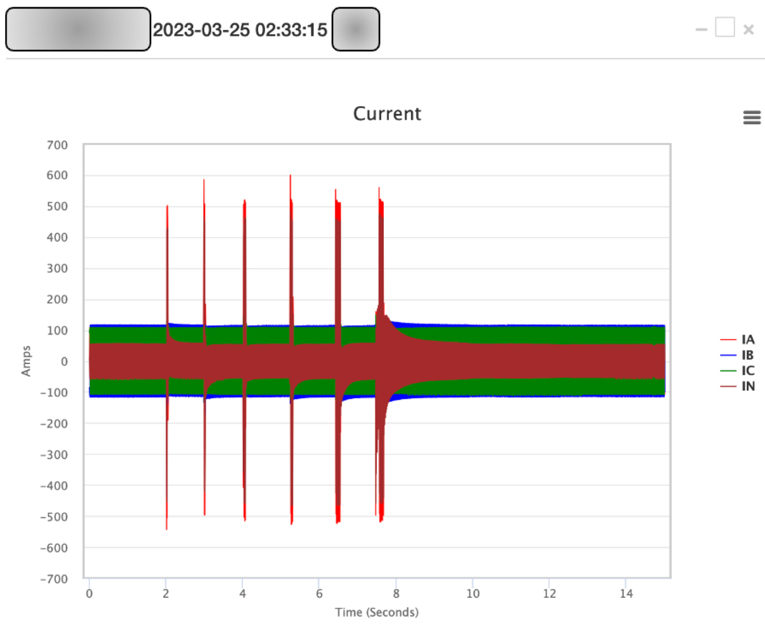
Example 1: Excessive recloser operations

- Because most faults are believed to be temporary*, reclosers generally attempt multiple reclose operations to ensure reliable service.
- A typical scheme would be two fast trips and two slow trips, shown at right.

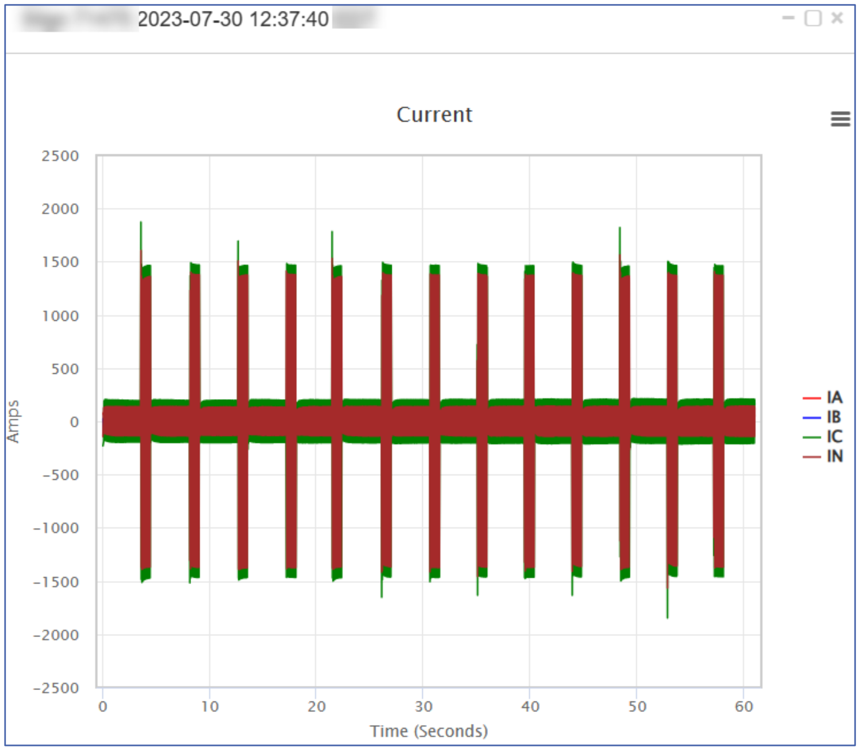
* Typical cited numbers are that 95% of faults can be cleared with 3 reclosing attempts, but empirical data is old/limited to substation breakers.

Example 1: Excessive recloser operations

- DFA has detected multiple instances of reclosers set to operate 4 times but operating more (e.g., 6 trips) before locking out.
- This behavior is difficult to diagnose because the sequence ultimately “works” but results in additional, unnecessary faults.



Example 1: Excessive recloser operations



- What if your recloser operated 1,000 times instead of 4?
- DFA has observed multiple reclosers on ten circuits at six utility companies where reclosers operated dozen or hundreds of times over minutes or tens of minutes.
- An example from one event is shown at left.

Example 1: Excessive recloser operations

Case #	# Auto-reclose operations without lockout	Period spanned by those pumping operations
1	800 operations	24 minutes
2	680 operations	26 minutes
3	107 operations	3 minutes
4	88 operations	2 minutes
5	140 operations	12 minutes
6	120 operations	2 minutes
7	120 operations	6 minutes
8	300 operations	14 minutes
9	740 operations	26 minutes
10	320 operations	22 minutes
11	1100 operations	33 minutes
12	73 operations	3 minutes
Cases 9 and 10, which occurred six months apart, probably involved a single recloser.		
Similarly, cases lines 11 and 12, which occurred three months apart, probably involved a single recloser.		
The twelve cases of pumping involved ten distinct reclosers at six distinct distribution companies.		

- The table at right details a dozen cases of “pumping” reclosers.
- The exact mechanism is not known but is believed to be a failure of the lock-out mechanism in a hydraulic recloser.

Example 1: Excessive recloser operations

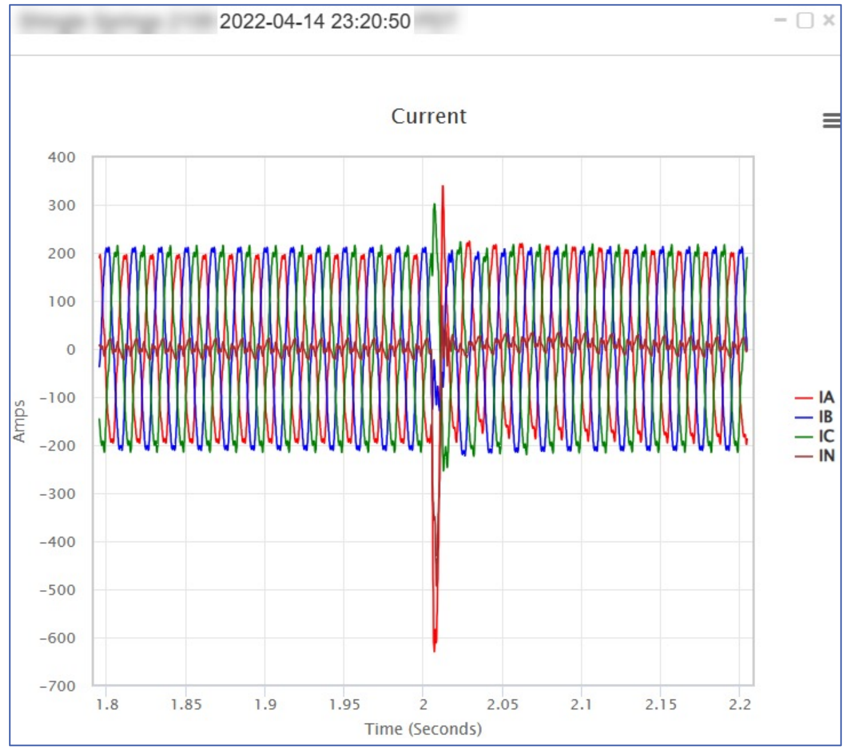
- Excessive recloser operations are bad. Thousands of excessive recloser operations are very bad.
  - Prolongs safety hazards / increases ignition risk
  - Each trip/reclose causes a momentary interruption for all downstream customers
  - All upstream devices between fault and substation are subjected to electrical and thermal stresses.
  - Excessive fault current at the point of the fault increases likelihood for damage/burndown.

Example 2: Fast tripping self-clearing faults

- Many utilities in high fire risk areas are experimenting with temporary fast-trip settings during red-flag days.
- Fast tripping combined with blocked reclosing reduces the amount of fault energy available to ignite a fire, and theoretically reduces ignition risk.
- Separately, events like incipient cable fitting failures can produce time limited (i.e., subcycle) pulses which may draw significant amounts of current, but self-clear without the operation of protective devices.
- DFA has documented multiple cases of incipient fitting failures over years with this signature.

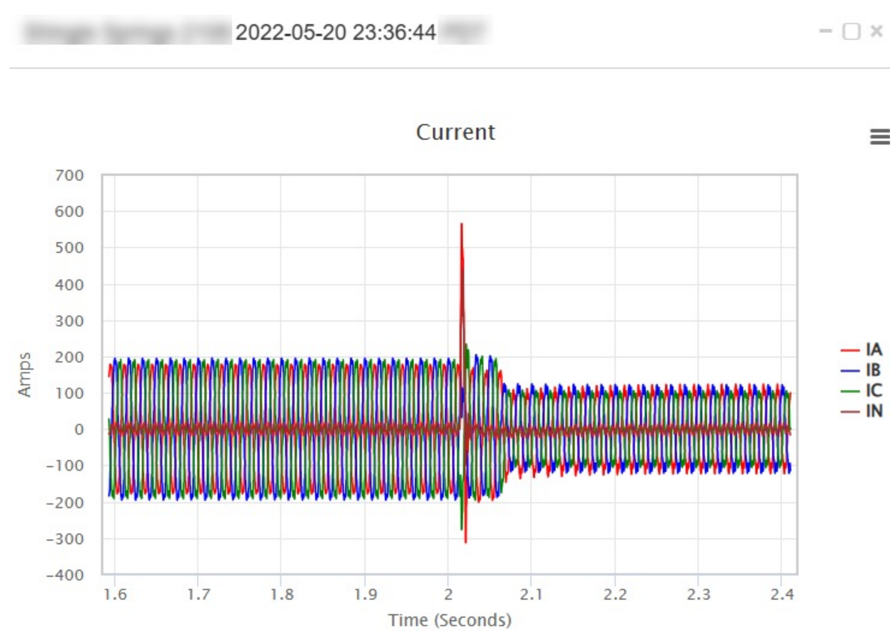
Example 2: Fast tripping self-clearing faults

- The combination of short, self-clearing faults with fast trip settings can create unintended outcomes.
- The graph on the right shows a self-clearing pulse from an incipient cable fitting failure.
- This event did not operate a protective device, and did not cause an outage.



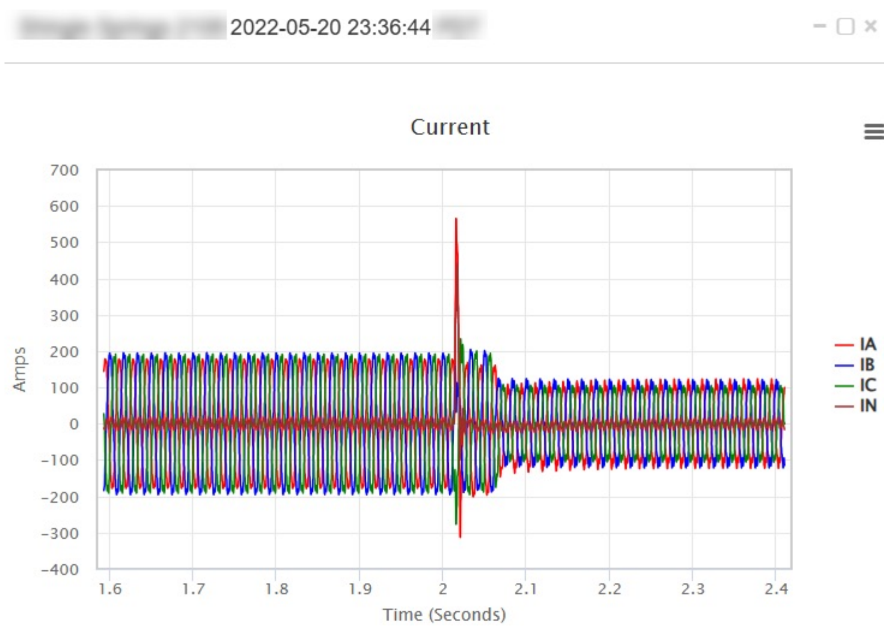
Example 2: Fast tripping self-clearing faults

- This graph, however, shows a similar pulse from the same failure event on the same circuit when fast trip settings were enabled.
- Three cycles after the fault self clears, an upstream recloser operates, interrupting approximately 1,900 customers.



Example 2: Fast tripping self-clearing faults

- Because of the fast trip settings, the recloser initiated its trip cycle, and did not reclose, even though the fault was no longer present.
- Because the fault happened at 2330, the utility was unable to patrol the area (and hence unable to restore power) until the following morning.



Example 3: Downed conductor false trips

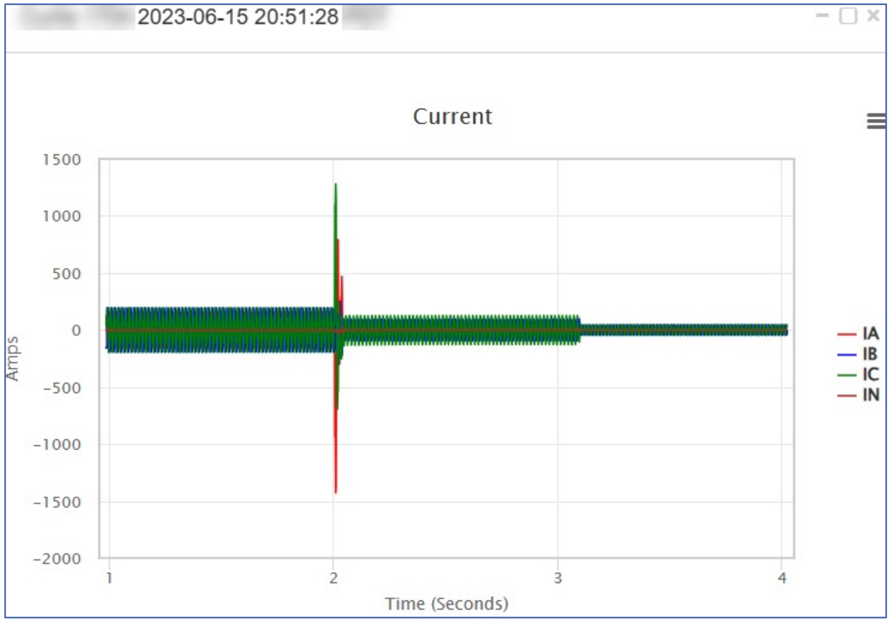
- Detecting an energized conductor on the ground remains a challenging problem with difficult tradeoffs.
- Most broken conductors produce fault currents which trip protective devices, but some draw currents on the order of or less than normal system loads.
- There are inherent tradeoffs between a method’s true positive rate (i.e., correctly detecting a downed conductor when there is one), its false positive rate (i.e., tripping a circuit when there was no downed conductor), and the amount of time a method waits to make a decision (more time generally produces more accurate decisions).

Example 3: Downed conductor false trips

- Of these, the most operationally challenging has always been the false positive rate – that is to say, tripping a circuit when no fault exists.
- When developing in the 1990s: “If it false trips twice a year across our entire system, we’ll turn the whole thing off.”
- The potential for downed conductors to start fires has changed this calculus for some utilities, resulting in a higher tolerance for false trips.
- That said, a higher tolerance for false trips is not an infinite tolerance for false trips.

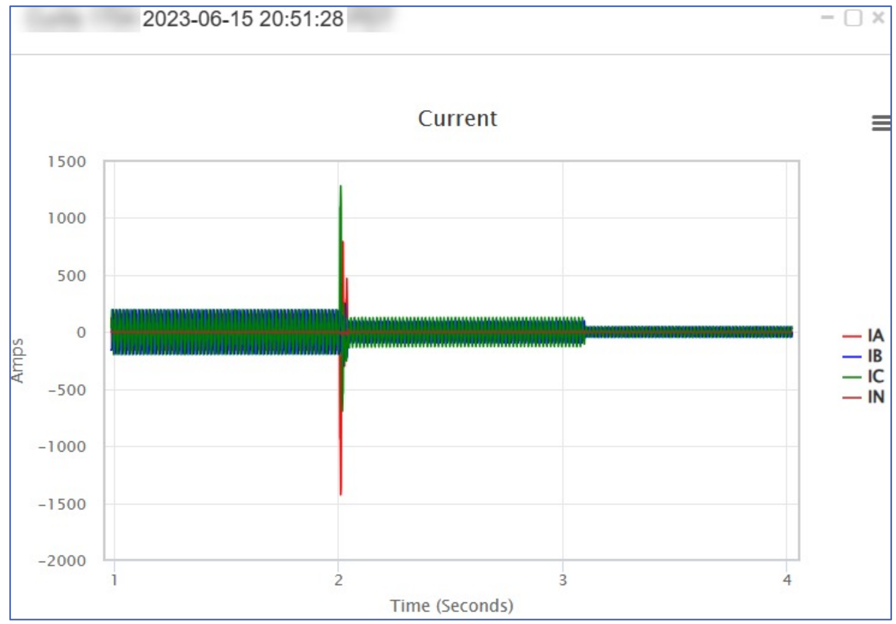
Example 3: Downed conductor false trips

- A utility deploying downed conductor detection technology has experienced a high rate of false trips (e.g., 3-4 per week when normalized to a full deployment).
- The graph at right shows a sub-cycle fault with two recloser operations, the second 1.2 seconds after the first.



Example 3: Downed conductor false trips

- The first trip was a line recloser properly clearing the fault in its zone.
- The second trip was the downed conductor detection algorithm reacting to changes in load levels after the first trip.
- The utility has used DFA data to debug multiple false trip operations and provide feedback to the vendor.



Conclusion

- The protection system is supposed to keep Bad Things™ from happening, but utilities seldom have systems that let them know when system protection is misoperating.
- Advanced data collection and analytics can allow utilities to correct or respond to protection anomalies in a more efficient manner.
- Data can also provide critical insights into the actual circuit conditions which caused a device to misoperate, avoiding assumptions and speculation.
- Multiple benefits including improved reliability, power quality, public safety, reduced ignition risk, etc.