Improved Fault Location on Distribution Circuits Using Advanced Inputs

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Presentation Outline

- Texas Power Line-Caused Wildfire Mitigation Project
- Introduction to Distribution Fault Anticipation Technology
- The Importance and Challenge of Distribution Fault Location
- Distribution Fault Location – State of the Art and Current Limitations
- Advanced Inputs for Improved Distribution Fault Location
- Proof of Concept Status
- Next Steps

Texas Power Line-Caused Wildfire Mitigation Project

- Wildfires have devastating consequences:
  - Direct losses
  - Fire suppression costs
  - Disruption of commerce
  - Not to mention injuries and even fatalities
- Power line events can cause wildfires:
  - Downed conductors
  - Clashing conductors (direct arc + ejection of molten, possibly burning particles)
  - Exploding apparatus (transformers, switches, …)
  - Vegetation intrusion (electrical and mechanical effects)

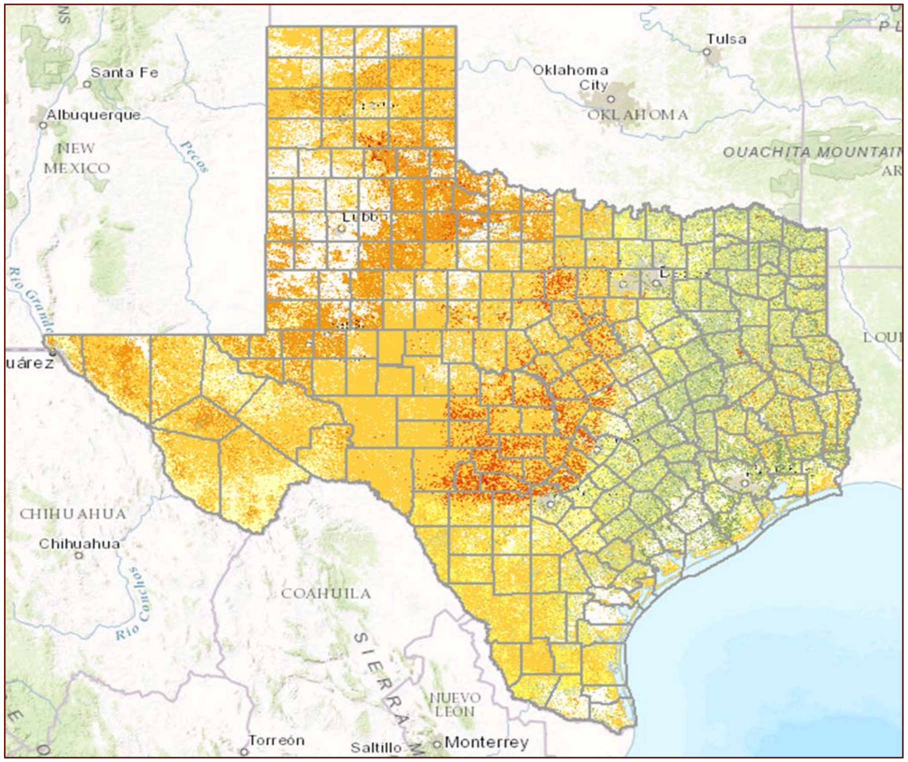
Texas Power Line-Caused Wildfire Mitigation Project
(cont'd)

- State of Texas experiences wildfires annually and had particularly bad year 2011.
- Legislature is supporting Texas Power Line-Caused Wildfire Mitigation project.
- Participating Texas-based utility companies:

  Austin Energy
  Bluebonnet Electric Cooperative
  BTU (Bryan Texas Utilities)
  Mid-South Synergy
  Pedernales Electric Cooperative
  Sam Houston Electric Cooperative
  United Cooperative Services

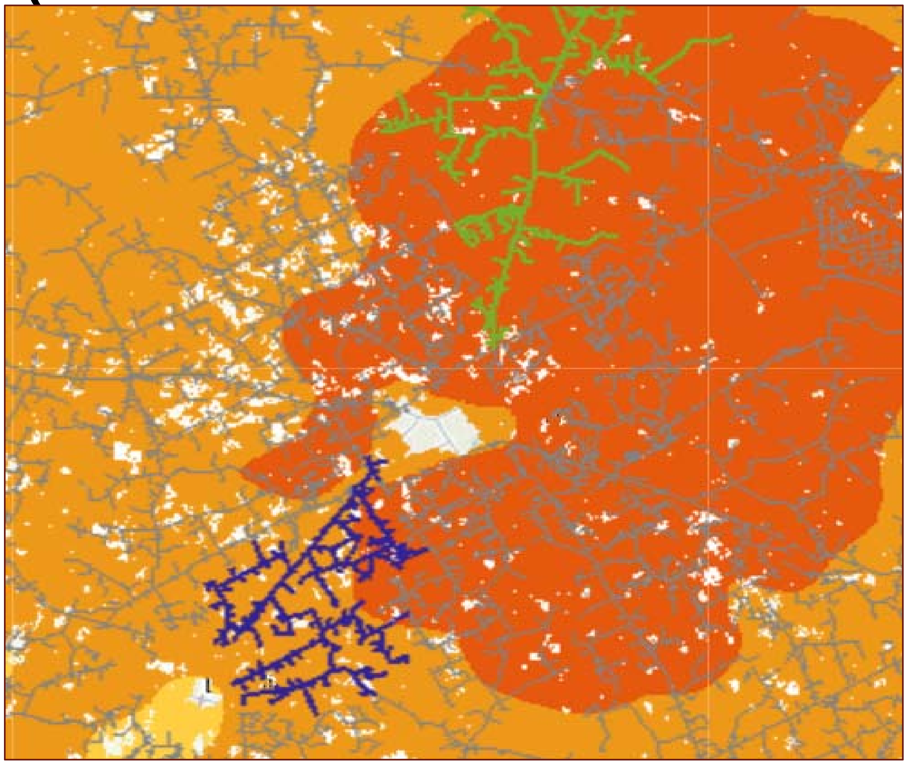
- Demonstrating Distribution Fault Anticipation (DFA) technology on 58 circuits
- Integration of wildfire risk profile from Texas A&M Forest Service
- Goal: To demonstrate reduction of wildfire risk through synergistic use of DFA, wildfire risk mapping, and other tools.

Texas A&M Forest Service Wildfire Risk Map



- Fire risk profile “heat map” provided as a public service of the Texas A&M Forest Service
- Long-term and short-term risk profiles
- Industry standard format and interface
- Accessible via web portal

Texas A&M Forest Service Wildfire Risk Map
(with Electrical Circuit Model overlay – zoomed)



- Image shows smaller region, with elevated wildfire risk.
- Utility circuit model information appears as overlay.
- DFA-monitored circuits are highlighted in color.
- Synergy of technologies combines electrical information with wildfire risk information.

Distribution Fault Anticipation (DFA) Technology

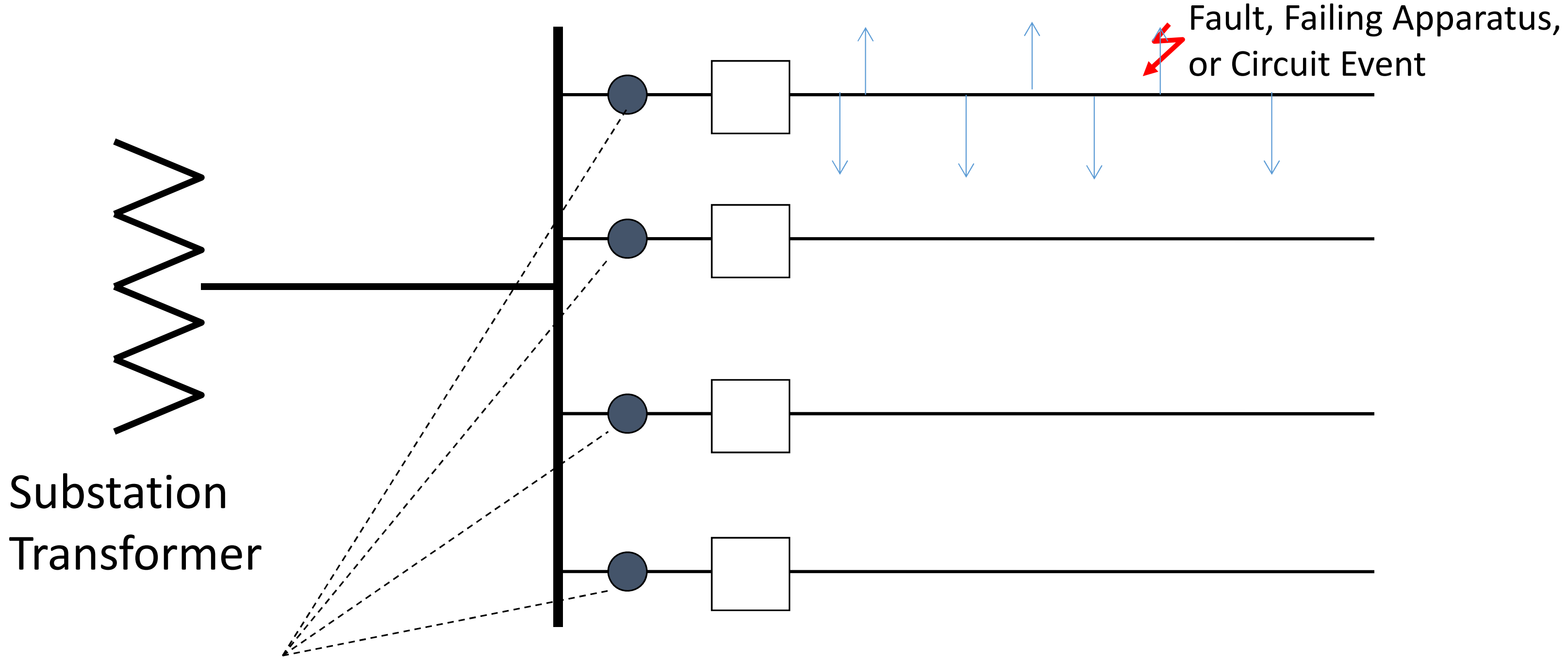
- Developed by Texas A&M Engineering in collaboration with EPRI
- Based on advanced analytics applied to sensitive monitoring of conventional CT and PT waveforms
- Uses real-time monitoring to provide awareness of circuit health and events
- Reports faults and protection operations with greater detail than conventional devices, potentially enabling improvement fault location

Distribution Fault Anticipation (DFA) Technology

DFA Application Fundamentals

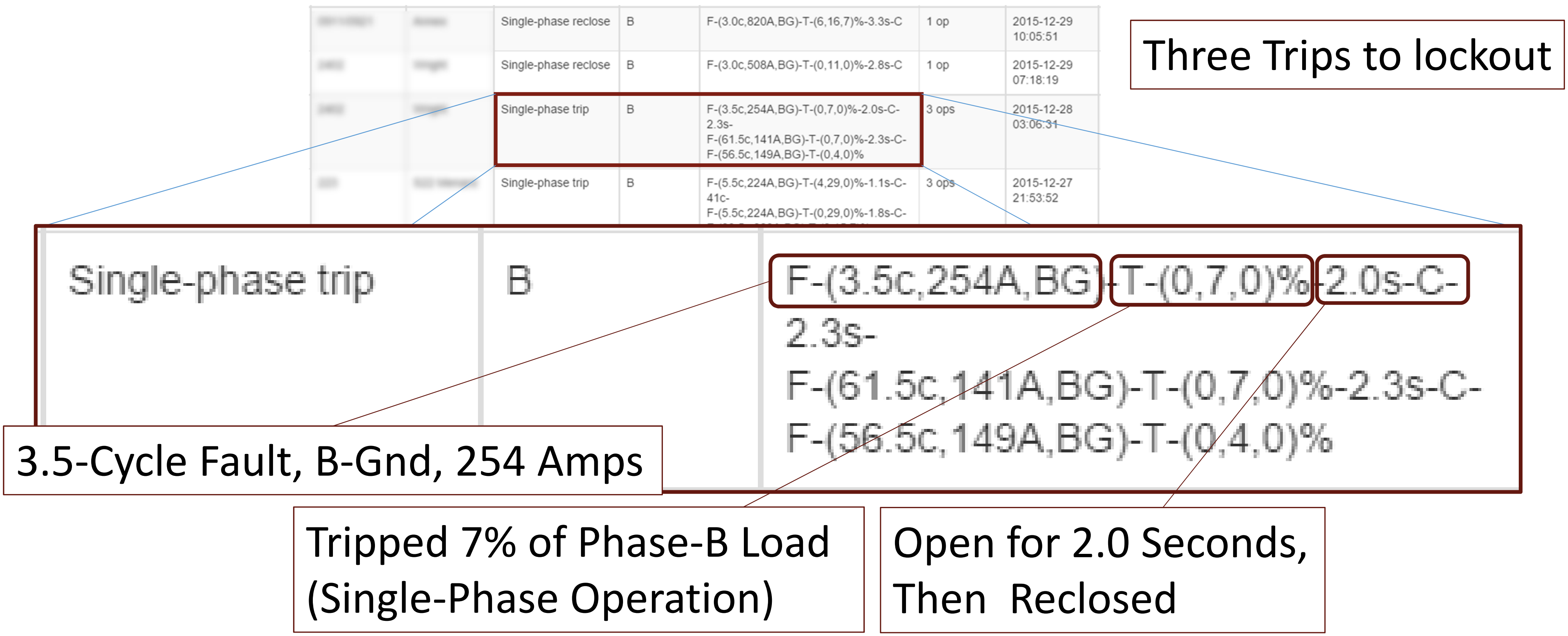
- DFA devices typically are applied at the substation, one per circuit.
- Inputs are conventional CTs (3) and PTs (3), unit power, and Internet.
- Devices detect faults and protection operations without communications to line devices.
- Each DFA device applies sophisticated algorithms to assess circuit conditions and events.
- Each DFA device reports to a central master station via secure protocol over Internet.
- Users access DFA reports via browser using secure login to master station.
- For faults, system reports detailed sequence of events, not just fault detection or fault current magnitude.

DFA Technology Monitoring Topology



High-fidelity DFA devices, connected to conventional CTs and PTs, one per distribution circuit.

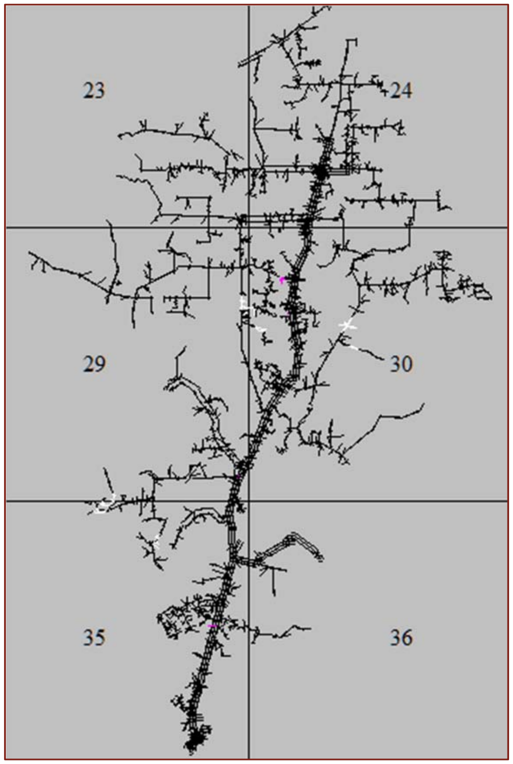
Sample DFA-Generated Output Screen



Distribution Fault Location – State of the Art

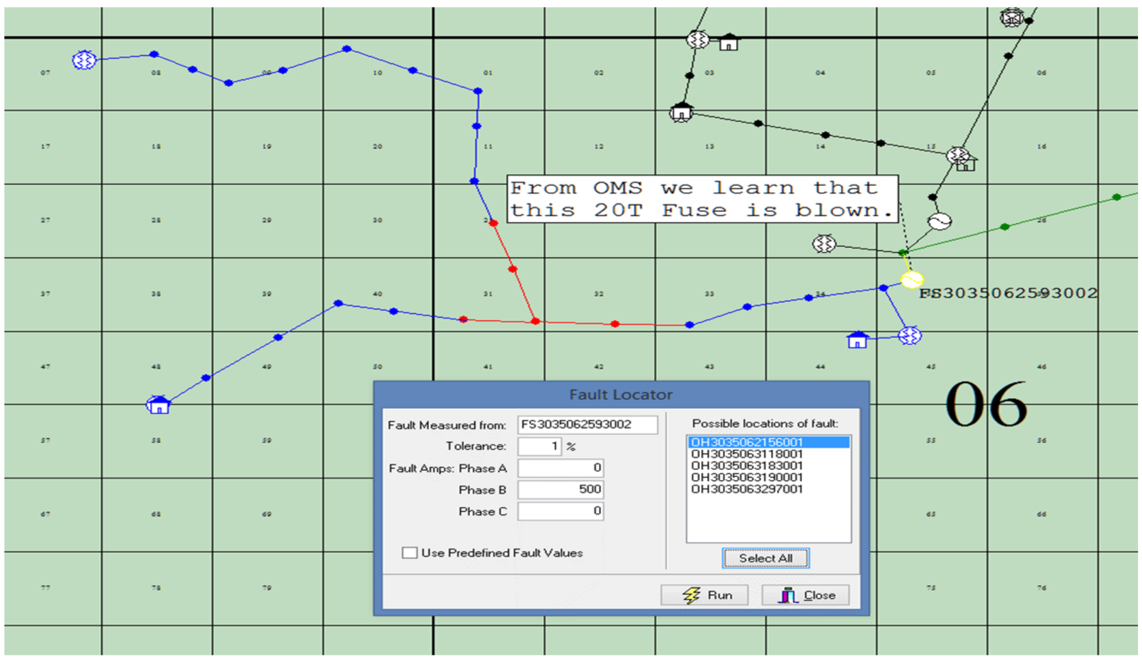
- Complex topology of distribution circuits
  - Main three-phase trunk, plus three-phase branches, plus single-phase laterals
  - Non-uniform conductor (large near substation, then progressively smaller)
  - Numerous geographically dispersed locations with the same calculated bolted fault current
- Hodgepodge of devices for detecting, reporting, and locating faults
  - Relays, electronic reclosers, hydraulic reclosers, sectionalizers, fuses, faulted circuit indicators
  - For many utility companies, only limited information (trip, min pickup event) is available automatically, if at all, without special effort (e.g., retrieving event data for individual faults via communications link or by driving to device with laptop).

Distribution Fault Location – State of the Art



- Distribution circuit topology limits the usefulness of transmission fault location techniques (e.g., impedance, fault current level).
- For example, on this example circuit, 96 locations, at geographically diverse points, all predict a fault current level of 500 amps +/- 2%.
- Distance algorithms in some relays assumes uniform per-unit-length conductor impedance, limiting their usefulness to the main trunk.

Distribution Fault Location – State of the Art



- In cases where we know the location of the tripped device, we can reduce the possible set, in this case to 10 locations.
- Changing tolerance to 1% reduces the possible set to 5.
- For a momentary fault, OMS would not identify the tripped/blown device to narrow the search in this way. Recurrent faults often create multiple momentary interruptions.

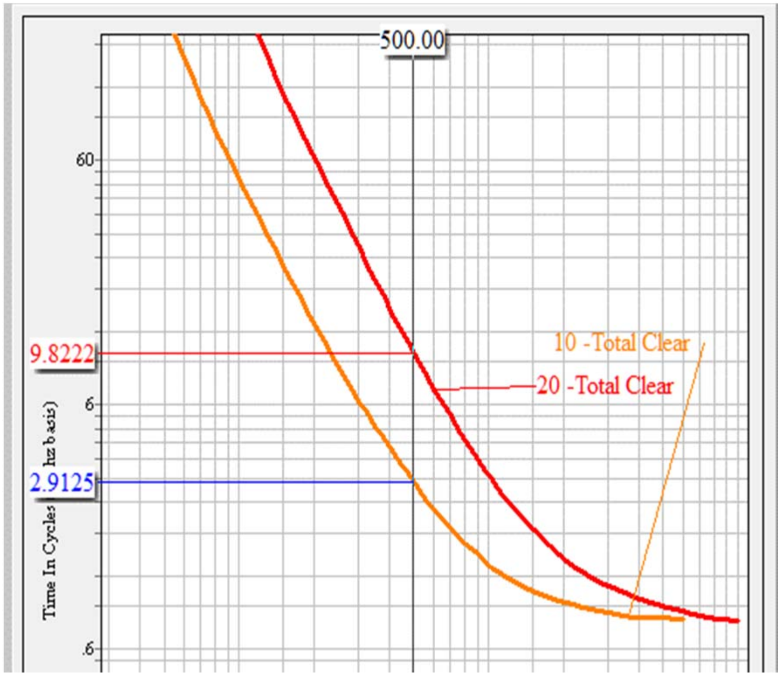
Better Information from New Systems

- A detailed sequence of events, from a technology such as DFA, can provide additional information to better predict location.
- This also helps with location of recurrent faults (trip/close each time but no permanent outage) that indicate latent problem, such as cracked bushings and intermittent tree encroachments.
- The remainder of this presentation discusses how better information can be used for better location, and provides results of initial proof-of-concept testing with field data from actual fault events.

Basic Approach – Find possible devices

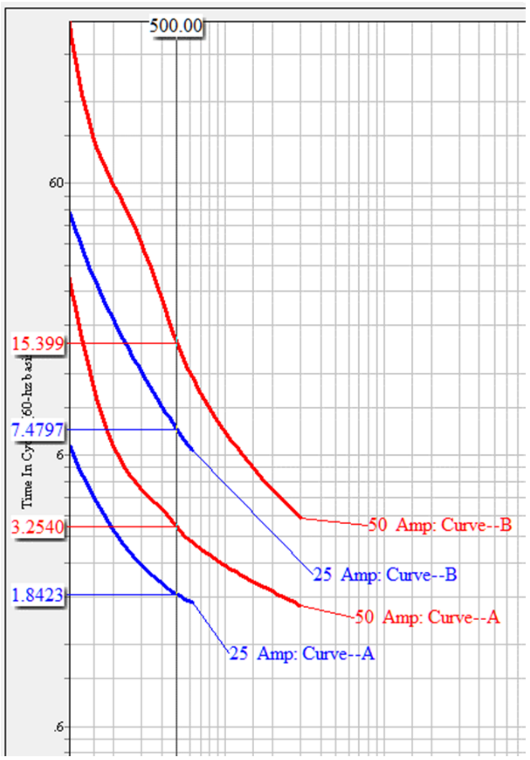
- The majority of overcurrent devices on a rural distribution circuit are fuses and single-phase reclosers (Types H, L and E).
- Given:
  - The fault magnitude at each trip or open
  - Duration of fault before trips or open
  - Time between reclosing
  - The TCC curves of all possible overcurrent devices on circuit
- Reduce list of possible devices to those matching measured fault characteristics.

Hypothetical Example – Fuse Open



- Information from DFA device
  - 500-amp fault
  - On phase B
  - Fault duration 10 cycles before open
  - No reclose
- Information from circuit model
  - 96 possible locations for 500 amp fault on phase B
  - Two possible fuse locations
    - 10T and 20T
- 20T (9.8 cycles) is best option

Hypothetical Example – Recloser Lockout



- Information from DFA device
  - 500-amp fault on phase B
  - First trip at 2 cycles
  - Second trip – after 1 sec at 2 cycles
  - Third trip – after 1 sec at 9 cycles
  - Lockout – after 1 sec at 9.5 cycles
- Recloser Characteristics
  - Type L has 2-second reclosing interval
  - Type H has 1-second reclosing interval
- DFA-reported open interval is consistent with type H devices but eliminates type L devices.
- 25H is best match for tripping and reclose intervals.

Test Results to Date

Four field cases used to test concept manually

- Case 1 – Squirrel on transformer
  - Correctly predicted fuse and predicted location within one span
- Case 2 – Self-clearing temporary fault of 6 ms (~1/2 cycle) duration
  - Experience has shown that fault current estimates for faults lasting less than one cycle often are inaccurate. For this 1/2-cycle fault, DFA estimated 1289 amps, versus 1951 amps predicted by model. It may be possible to modify the signal processing used for calculating the estimate.
  - Experience also has shown that non-DFA devices also give poor estimates for short faults.
- Case 3 – Squirrel on transformer
  - Correctly predicted fuse and actual location of fault
- Case 4 – Ice and wind broke line
  - Correctly predicted recloser and location within 827 feet

Analysis Cautions

- Any current-based or impedance-based location approach presumes reasonable model accuracy (e.g., wire sizes, lengths, …).
- Curve-matching process to select which device has tripped (recloser, fuse) presumes that the model indicates the right size/type of device.
- Highly erratic fault currents may cause unpredictable results for curve matching. (Fortunately the vast majority of fault currents are reasonably well behaved.)
  - Decaying Faults: Arc elongation increases impedance and fault current decays.
  - Progressing/Evolving Faults: Initial line-to-ground progresses to multi-phase.

Current Status and Next Steps

- Basic process has been developed and tested on a small number of real cases.
- Additional field data may refine approach.
- Future step is to automate process of receiving DFA-generated information and comparing it to model to predict locations automatically.

Conclusions

- Locating faults on distribution circuits is important but difficult.
- Current state of the art is an improvement over 20 years ago but still leaves much to be desired.
- New technologies, such as Distribution Fault Anticipation, offer previously unavailable information that enable improved location.
- Work to incorporate DFA information for improved location is in early stages but is encouraging.

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