Distribution Fault Anticipation Technology

Intelligent Algorithms and Diagnostics for Operations and Maintenance

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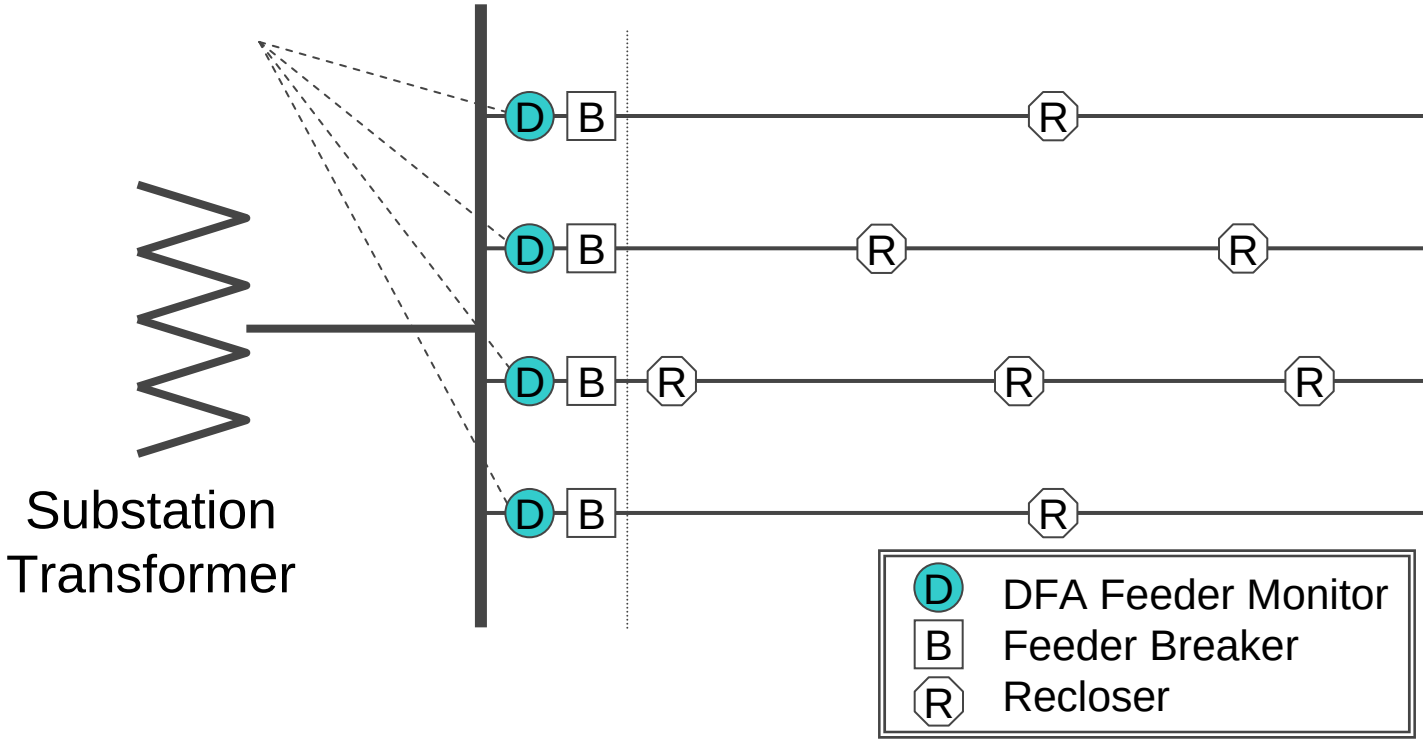
Brief History of Distribution Fault Anticipation (DFA)

- EPRI-funded research at Texas A&M
  - Collected high-fidelity waveforms from 60+ feeders for multiple years
  - Developed intelligent algorithms to analyze waveforms to determine underlying causes
- Premise: Analysis of electrical waveforms can predict, or "anticipate," line-apparatus failures.
- Discovery: Waveforms can predict failures, but also can provide better general awareness about other conditions.
  - Capacitor bank failures/problems
  - Permanent faults cleared by line reclosers, fuses
  - Recurrent faults (e.g., flashovers of cracked bushing)
- DFA moniker is now overly restrictive, but persists for historical reasons.

General Monitoring Topology

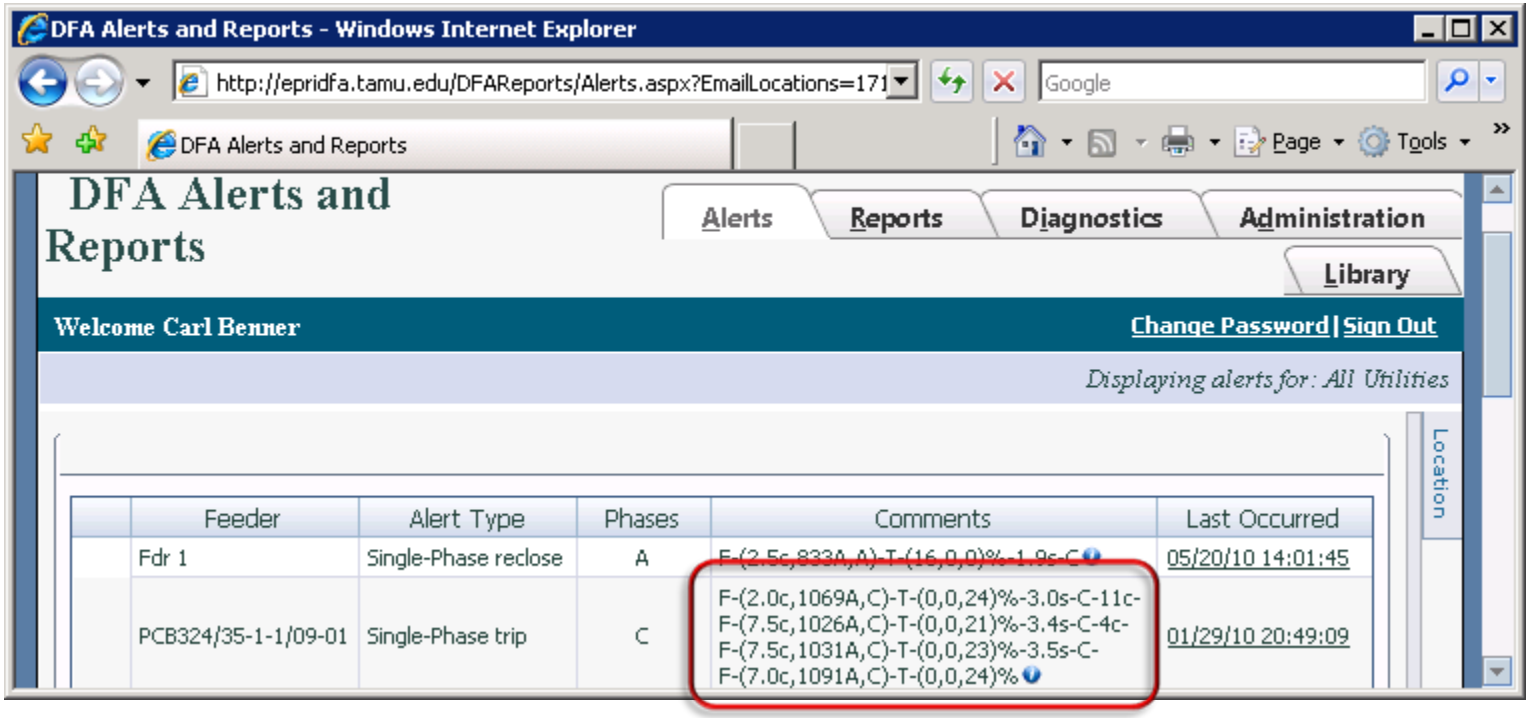
Feeder Monitors "see" bus voltages and feeder currents.



Self-Imposed Constraints (Initial)

- **All signals from conventional CTs and PTs**
- **No digital/status inputs (analog waveforms only)**
- **No communications with sectionalizing devices (e.g., pole-mount reclosers)**

Brief Primer on Web Presentation of DFA Information



2-cycle, 1069-amp, phase-C fault

Trip 24% of phase-C load

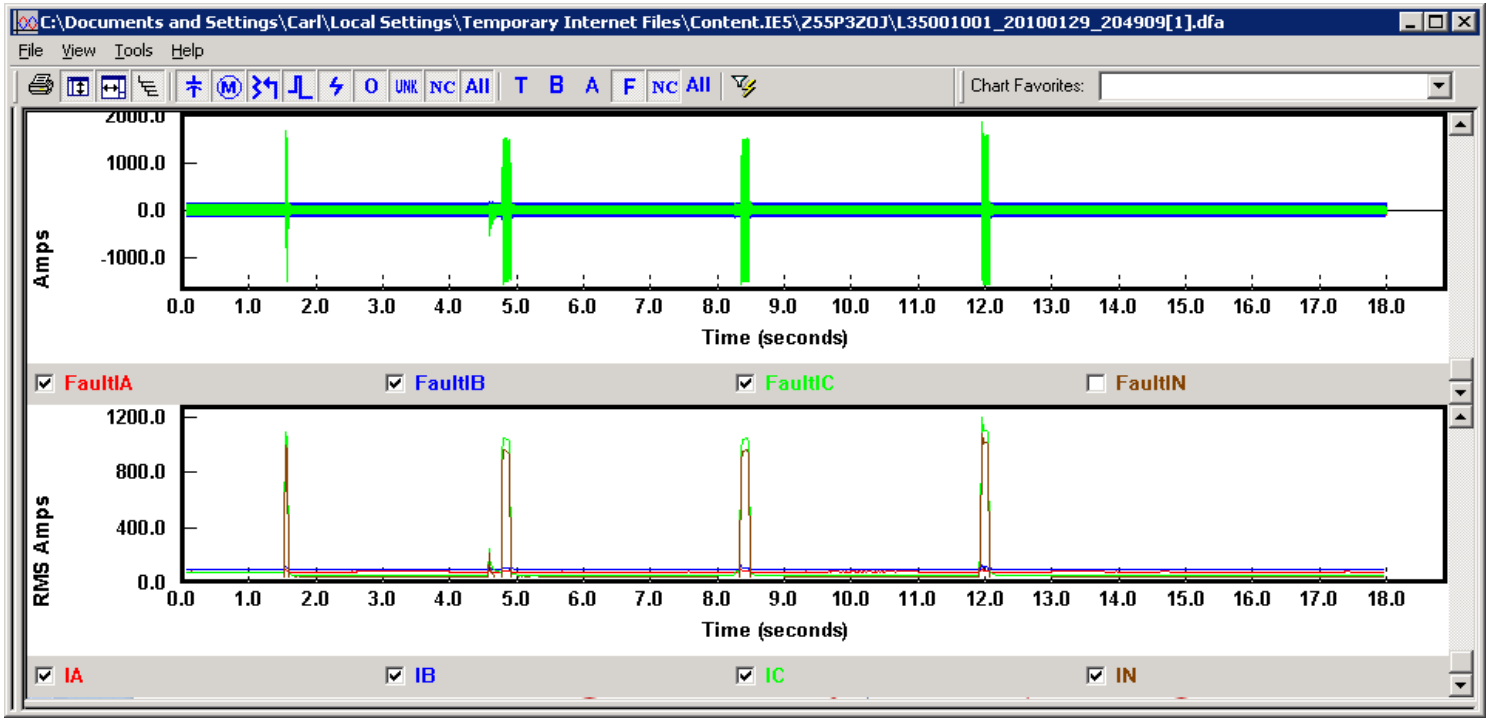
Close after 3.0 seconds

No fault for next 11 cycles

Single-Phase Trip: **F-(2.0c,1069A,C)-T-(0,0,24)%-3.0s-C-11c-**
F-(7.5c,1026A,C)-T-(0,0,21)%-3.4s-C-4c-
F-(7.5c,1031A,C)-T-(0,0,23)%-3.5s-C-
F-(7.0c,1091A,C)-T-(0,0,24)%

Second, third, and fourth faults. Lack of reclose after fourth suggests lockout.

Algorithms automatically generate diagnosis ('Single-Phase Trip') and operating sequence from CT/PT waveforms.
Fault durations (2.0, 7.5, 7.5, 7.0 cycles) describe one fast-curve trip followed by three slow-curve trips (1F+3S).
Device operation characteristics and per-phase load loss may tell utility exactly which device operated.
Consistency in fault-current estimates (1059 +/= 33 amps) suggests reliable estimate for location.



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Current Demonstrations

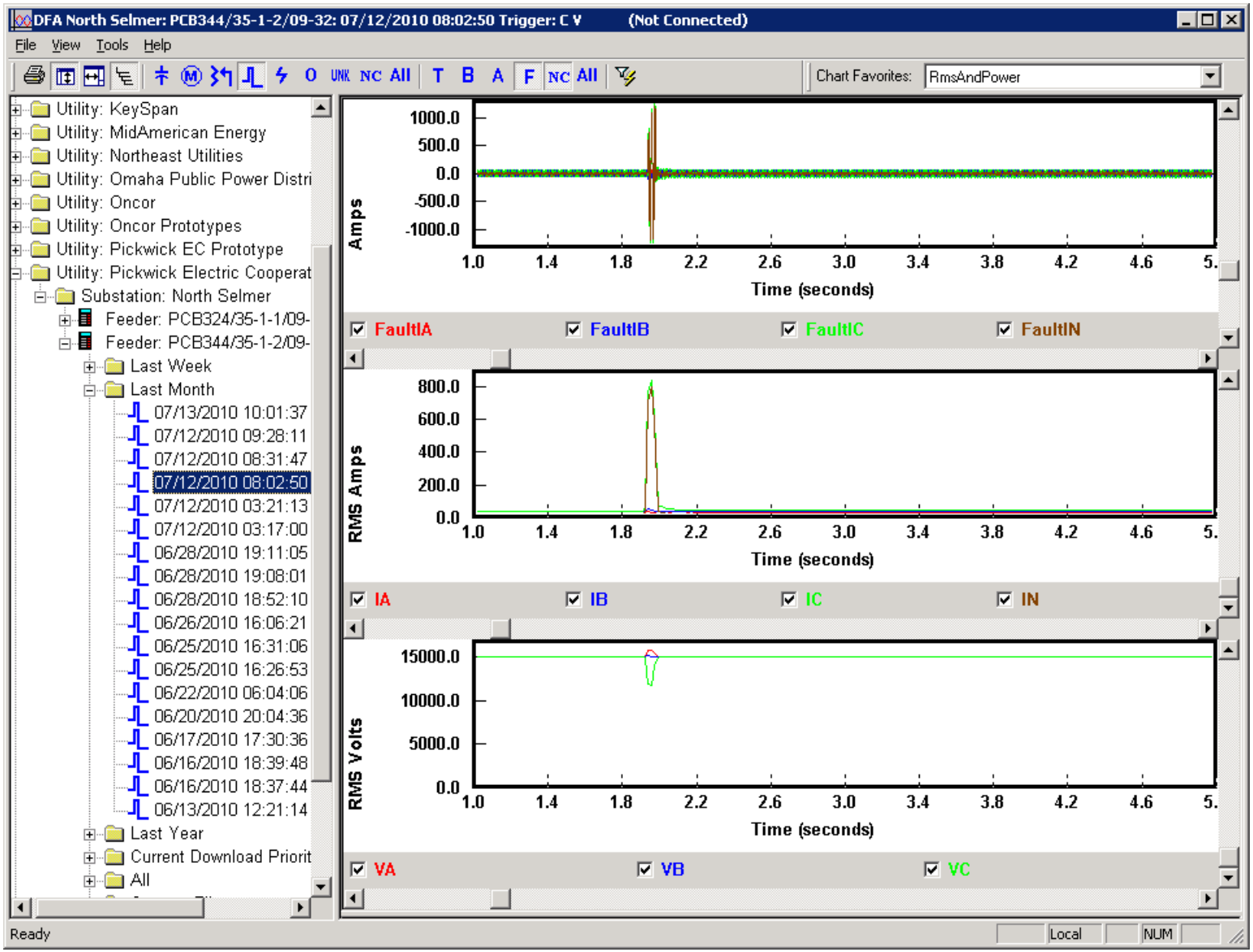
- Alabama Power/Southern Company (substation and distributed)
- Oncor Electric Delivery (substation)
- TVA/Pickwick Electric (substation)
- Arizona Public Service project starting (substation and distributed)
- CenterPoint Energy (Houston) project starting (substation and distributed)
- Bryan Texas Utilities (substation)
- Also beginning investigation of DFA-style techniques applied to transmission
- Additional demonstration partners welcome

Scenario at Subject Utility (and ~~probably~~ at your company, too!)

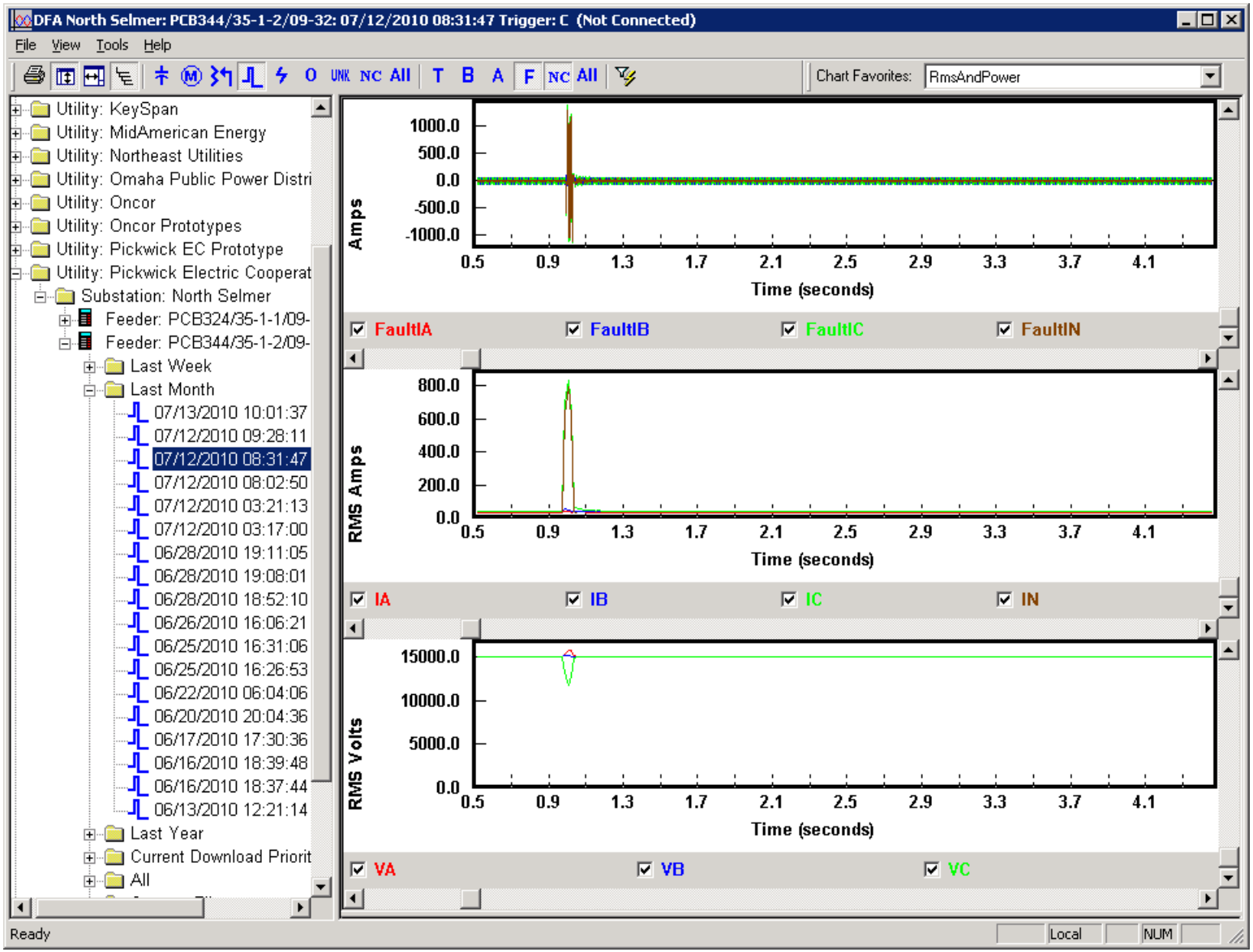
- Customer reports "blinking lights"
- Does this mean …
  - Secondary problem (loose neutral, premises wiring, …)?
  - Voltage sags from faults on other feeders?
  - Momentary interruptions from intermittent faults on that customer's feeder?
- How do we figure it out?
  - Check for loose secondaries
  - Patrol lines for limbs, cracked insulators, etc, but where?
  - Check multiple reclosers' counters multiple times

On DFA feeders, utility knows about momentary faults before the customer calls. They also know when report of "blinking lights" does not mean a primary fault.

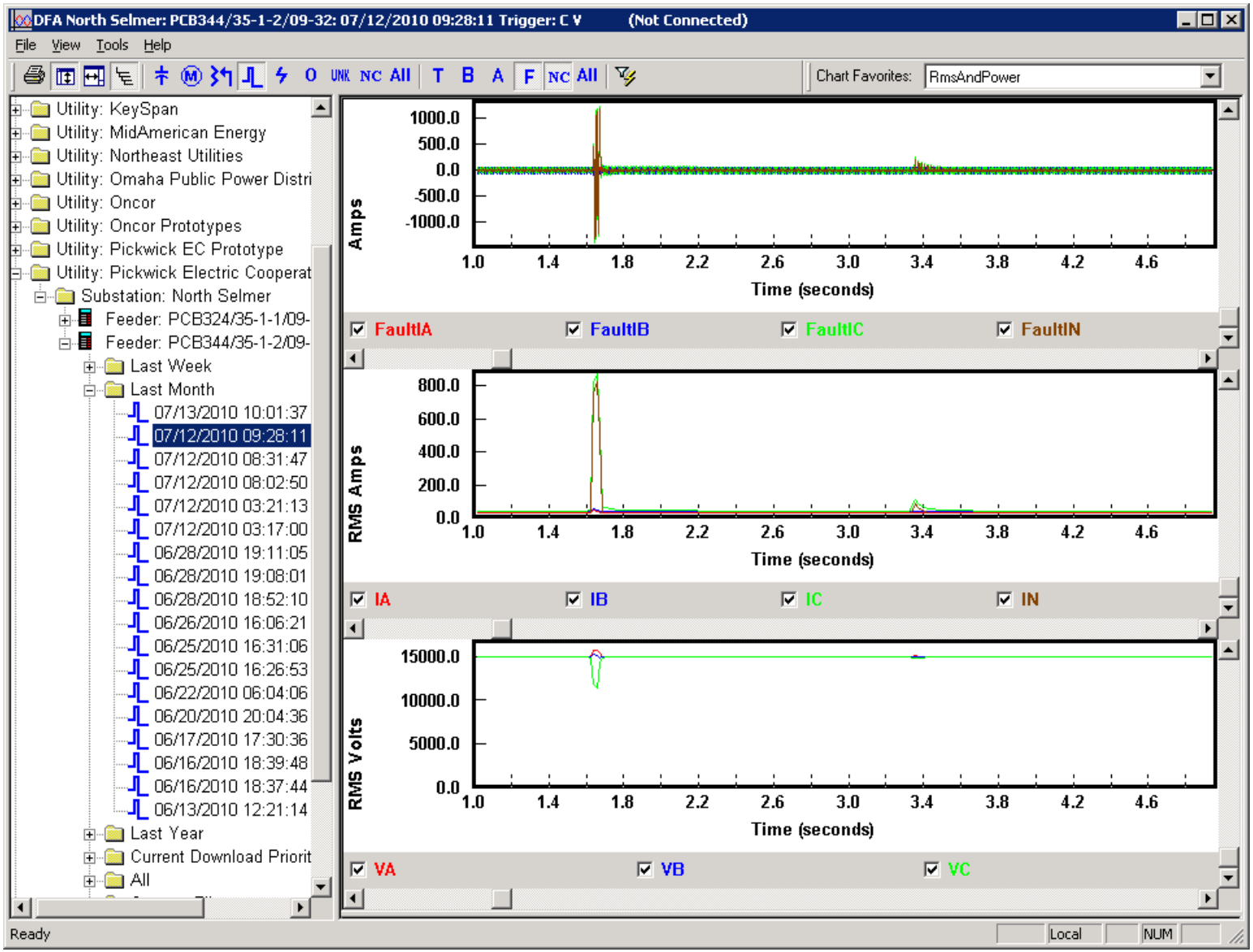
Recent Event: Monday, 7/12/2010 8:02 AM
Single-Phase Fault, Momentary, No Customer Calls



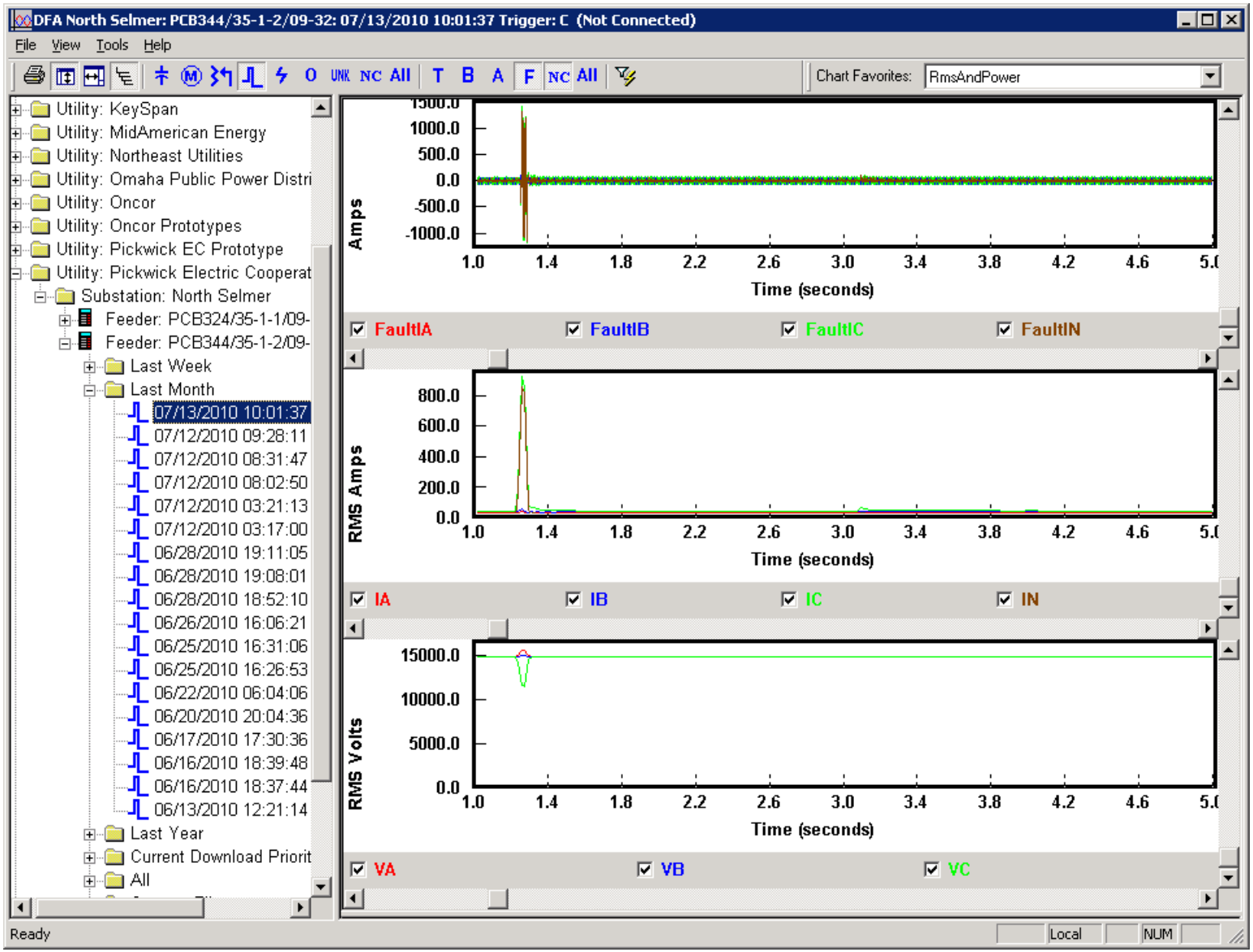
Recent Event: Monday, 7/12/2010 8:31 AM
Single-Phase Fault, Momentary, No Customer Calls



Recent Event: Monday, 7/12/2010 9:28 AM
Single-Phase Fault, Momentary, No Customer Calls



Recent Event: Tuesday, 7/13/2010 10:01 AM
Single-Phase Fault, Momentary, No Customer Calls



Recent Event – "Blinking Lights"

- Lights have blinked four times, but no one has reported it.
  - Conventional wisdom: Customers always call.
  - Reality: DFA project has shown this often is not the case.
- DFA information provides location information
  - Single-phase fault and single-phase interruption (phase C)
  - Fault magnitude (805-850A)
  - Fault duration (2-1/2 cycles)
  - Load momentarily interrupted (less than five percent)
  - Open interval (1.7-1.9 seconds)
- Feeder has numerous single- and three-phase reclosers, with ten single-phase reclosers on phase-C alone.
- DFA information indicated three possible reclosers, with one the most likely.

Recent Event: Found Tuesday, 7/13/2010 PM Using DFA Data (Still No Customer Calls)

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Summary of Recent Event – "Blinking Lights"

- Fault blinked lights four times, with no customer calls.
- DFA information identified three possible reclosers (out of ten on that phase), with one most likely.
- Crew found and trimmed trees downstream of recloser.
- Faults have not recurred in two weeks since.

- Contrasting case several years earlier
  - A cracked bushing caused five momentary interruptions over period of seven weeks, again with no customer calls.
  - Sixth flashover of same bushing caused sustained outage of 900 customers.
  - Today, DFA algorithms automatically "cluster" recurrent faults and generate alert.

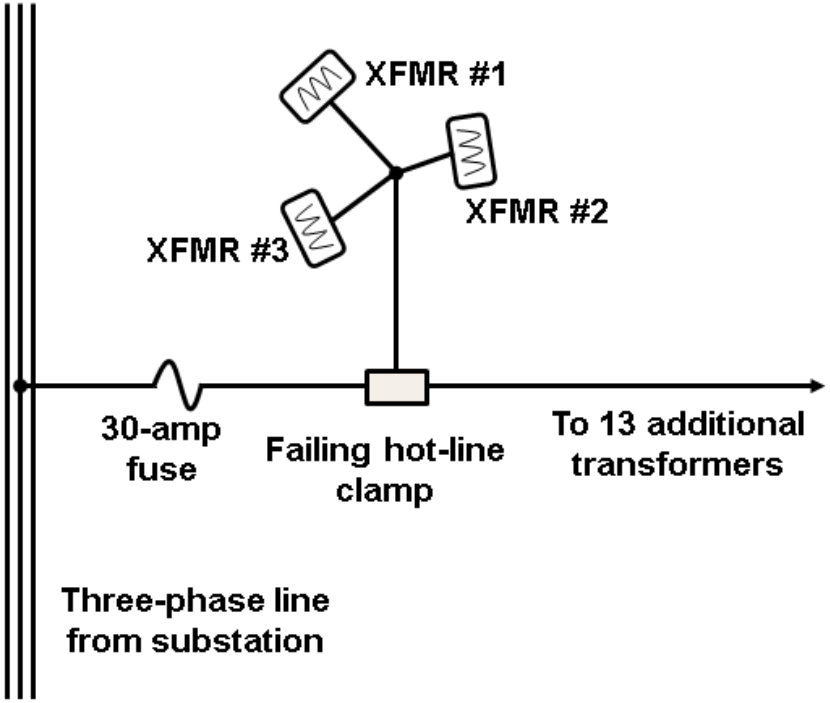
Use Scenario: Recurrent Faults

Engineer with direct access to DFA reports

- Check DFA reports daily.
- Investigate any reports of Possible Recurrent Faults using DFA information
  - Time/date of similar faults
  - Fault phase, magnitude, and duration.
  - Protection characteristics (recloser characteristics, percent load interrupted)
  - Optionally view and analyze waveforms
- When warranted, dispatch crew to find problem
  - Compare fault magnitude, phase, duration, etc. to fault-current study maps
  - Compare protection characteristics to installed devices
  - Advise of likely location(s)
  - Advise of likely causes (e.g., cracked bushing, tree limb)

Case Study
Hot-Line Clamp Failure

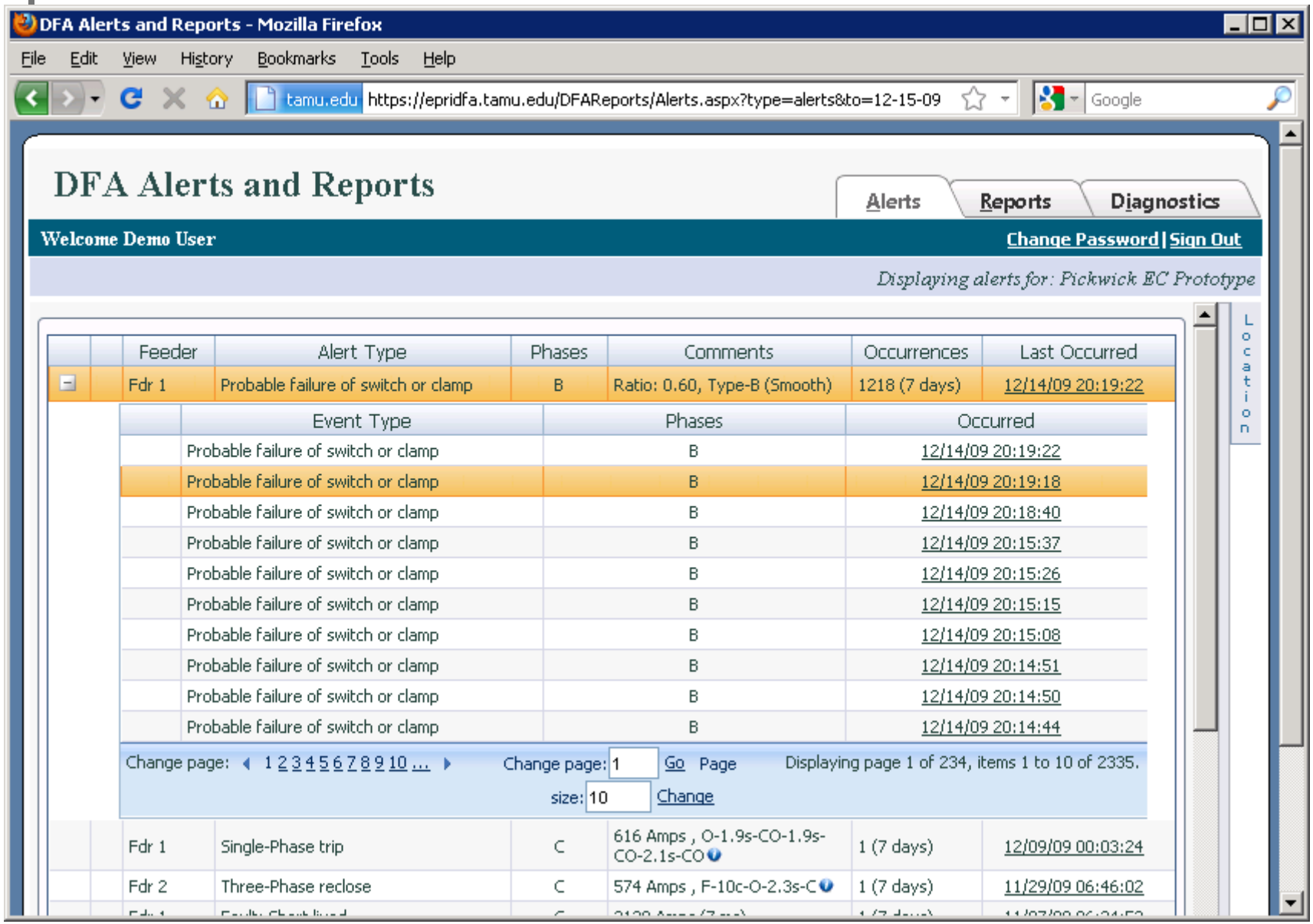
Conventional Response to Customer Calls

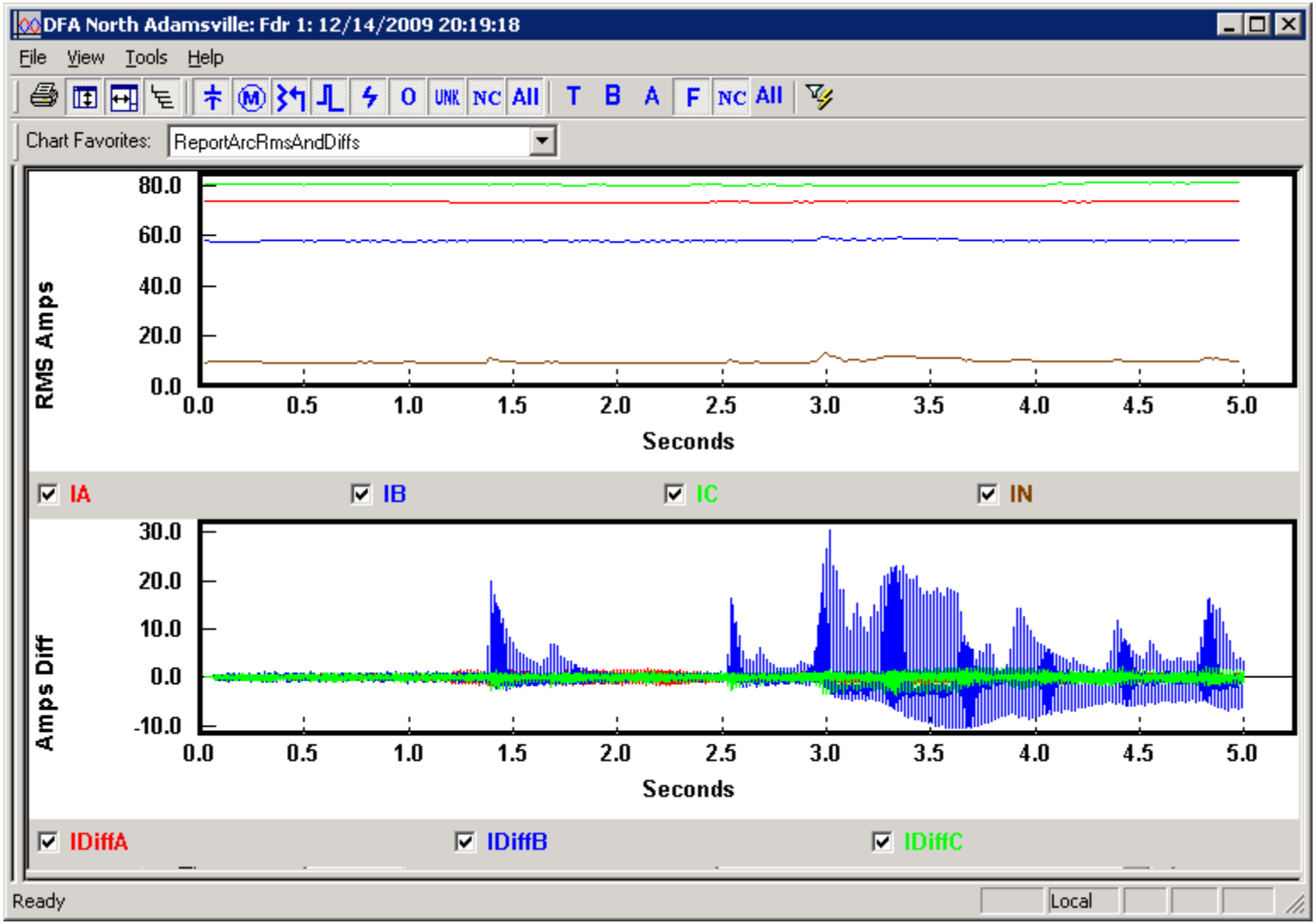


One-line diagram of hot-line clamp and other apparatus relevant to case study

- Customer call #1: 13 Dec 2009 04:30
  - Blown 30-amp fuse
  - Crew finds no cause
  - Replace fuse and leave
- Customer call #2: 14 Dec 2009 17:58
  - Flickering lights at XFMR #1
  - Crew hears abnormal buzzing
  - Replace XFMR #1 and leave
- Customer call # 3: 14 Dec 2009 19:44
  - Flickering lights again at XFMR #1
  - Crew finds arcing clamp
  - Replace clamp and leave
- Customer call # 4: 14 Dec 2009 21:13
  - No service at XFMR #2
  - Crew measures zero secondary voltage
  - Replace XFMR #2 and leave

DFA began reporting incipient hot-line clamp failure three weeks earlier, but dispatcher did not have access to research-project report.





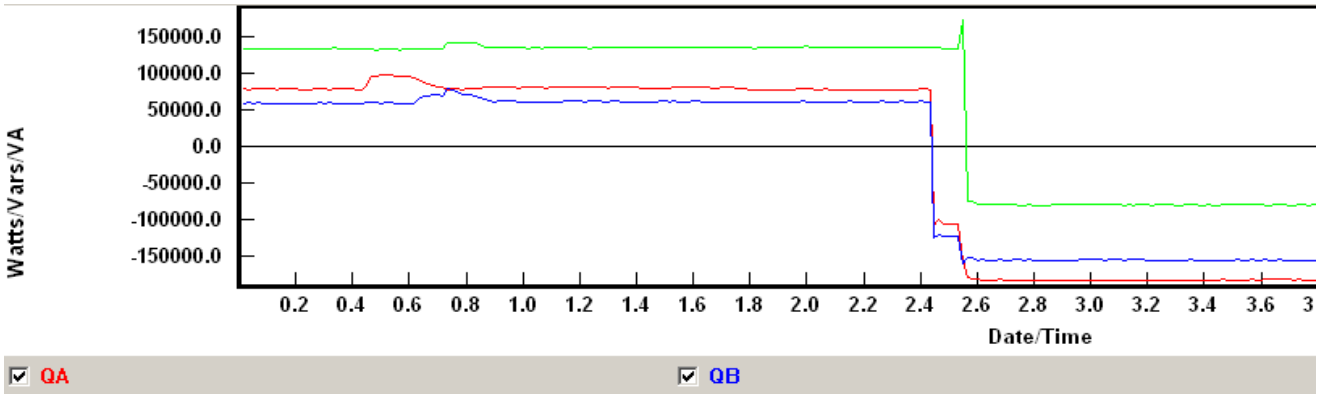
Use Scenario: Mysterious Trouble or Outage

Dispatcher with direct access to DFA reports

- Dispatcher receives trouble call and dispatches crew.
- Dispatcher checks DFA console/website for incipient failures or fault reports for affected feeder.
- Dispatcher advises crew of suspected problem(s).
- In the previous hot-line clamp example:
  - DFA had been reporting "possible failure of switch or clamp on phase B" repeatedly for three weeks.
  - Utility received four trouble calls in 1-1/2 days.
  - Crew found no obvious problem on first truck roll and misdiagnosed problem on second truck roll.
  - With access to DFA, dispatcher could advise crew to look for a failing clamp on first trip.
  - Utility could avoid three trouble calls, three extra truck rolls, and two transformer change-outs.

Capacitor Controller Incorrect Setting

- 8/9/2004
  - Capacitor bank change for normal maintenance
  - Capacitor control settings changed
  - Control settings change results in continuously switching capacitor bank
- 8/10/2004
  - DFA captured 22 capacitor switching events
  - Controller settings corrected
  - Continuous switching stops
- No outage, no complaints, no further consequences
- Today, DFA web site will report this as "CAP: Excessive Operations"



NC 08/11/2004 14:38:09
NC 08/11/2004 14:30:26
08/10/2004 22:13:25
08/10/2004 11:47:24
08/10/2004 11:38:24
08/10/2004 11:29:24
08/10/2004 11:13:24
08/10/2004 11:04:25
08/09/2004 21:48:25
08/09/2004 21:39:25
08/09/2004 21:29:24
08/09/2004 21:20:24
08/09/2004 21:11:23
08/09/2004 21:02:23
08/09/2004 20:53:22
08/09/2004 20:44:24
08/09/2004 20:35:22
08/09/2004 20:21:24
08/09/2004 20:12:22
08/09/2004 20:02:23
08/09/2004 19:51:23
08/09/2004 19:42:24
08/09/2004 19:32:23
08/09/2004 19:23:24
08/09/2004 19:13:23
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08/09/2004 17:41:22
08/09/2004 15:45:23
08/09/2004 15:36:21
08/09/2004 15:10:23
08/09/2004 15:01:22
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08/09/2004 13:39:23
08/09/2004 13:30:23
08/09/2004 13:21:23

Malfunctioning Capacitor Controller – What Happens When You Don't Know

- Early January 2004: bank cycled 28 times per day
- Late February 2004: >100 cycles per day
- February 16, 2004: capacitor can failure
- February 18, 2004: worst day, 186 cycles
- February 29, 2004: oil switch contact failure
- February 29 – March 3, 2004
  - Switch arced
  - Severe voltage transients at bus
  - Other capacitors failed sympathetically
- Final consequences of bad controller
  - >4,000 cycles since last maintenance cycle nine months earlier
  - Burned up switch (other two are questionable)
  - Severe, sustained voltage transients at bus
  - Multiple blown capacitors and fuses
    - Two cans at bank with bad controller
    - One can at another bank on same feeder
    - Yet another can at bank on other feeder on same bus

Use Scenario: Capacitor Maintenance

Engineer with direct access to DFA reports

- Check DFA reports daily or weekly.
- Note capacitor problems specified in DFA reports
  - Blown fuse/capacitor
  - Excessive operations
  - Switch bounce (if you care)
  - Switch restrike (if you care)
  - Unbalanced operations (e.g., only two phases operating)
- Note capacitor size from DFA report
- Dispatch crew, with knowledge of bank size and likely problem.

Conclusions

- Incipient failures, recurrent faults, and other phenomena are not new – knowing about them is.
- Electronic devices at substations (and on lines) provide substantial data collection capability – but data overwhelms personnel.
- DFA technology provides means to enhance reliability by detecting and correcting failures before they escalate to outages, using intelligent algorithms to create targeted information from mass of data.

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