

# ***Distribution Fault Anticipation Technology***

***Intelligent Algorithms and Diagnostics for Operations and Maintenance***

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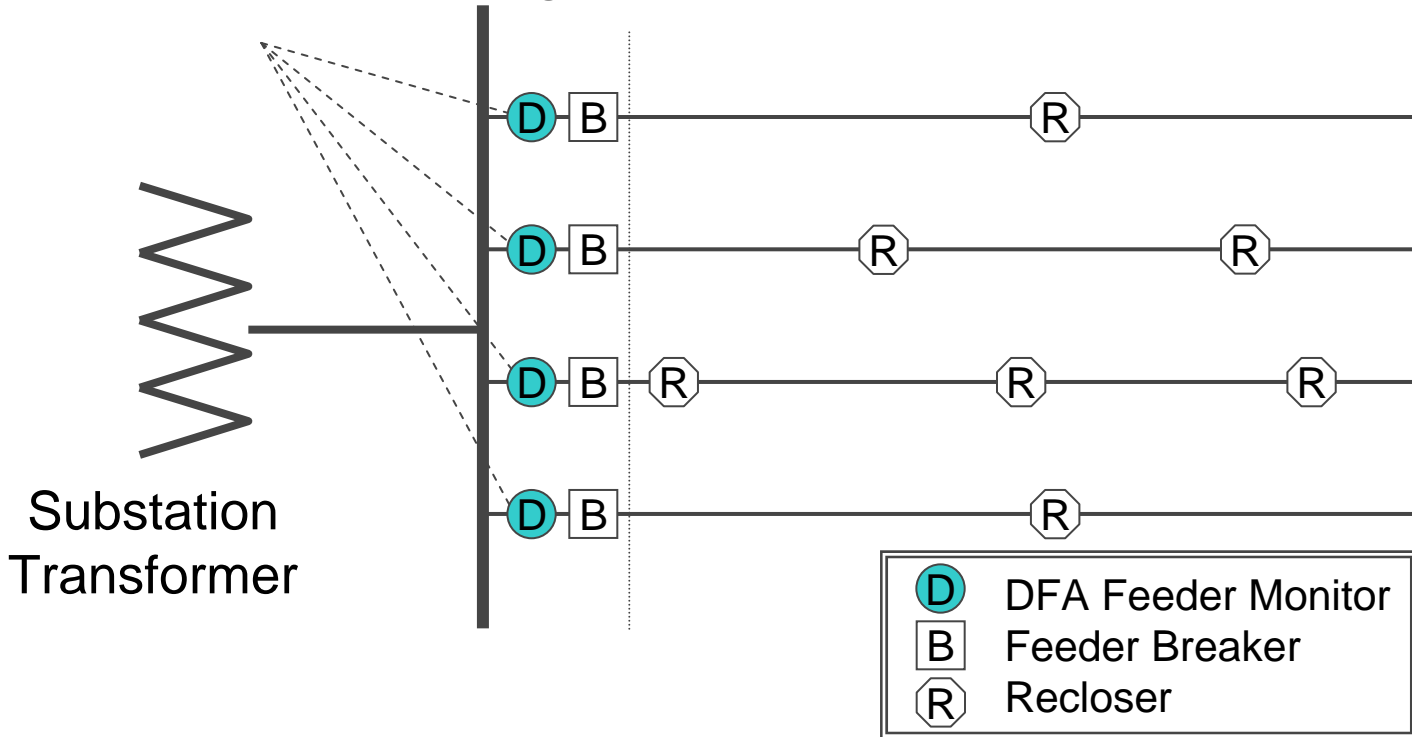
***Working Group on Smart Distribution Combo Session  
2010 IEEE PES GENERAL MEETING  
Minneapolis, MN, USA  
Monday, July 26, 2010 15:00-18:00***

# 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

DFA Alerts and Reports - Windows Internet Explorer

http://epridfa.tamu.edu/DFAReports/Alerts.aspx?EmailLocations=171

DFA Alerts and Reports

Alerts Reports Diagnostics Administration

Welcome Carl Benner [Change Password](#) | [Sign Out](#)

Displaying alerts for: All Utilities

Feeder	Alert Type	Phases	Comments	Last Occurred
Fdr 1	Single-Phase reclose	A	F-(2.5c,833A,A)-T-(16,0,0)%-1.0s-C	05/20/10 14:01:45
PCB324/35-1-1/09-01	Single-Phase trip	C	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)%	01/29/10 20:49:09

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

Trip 24% of  
phase-C load

Close after  
3.0 seconds

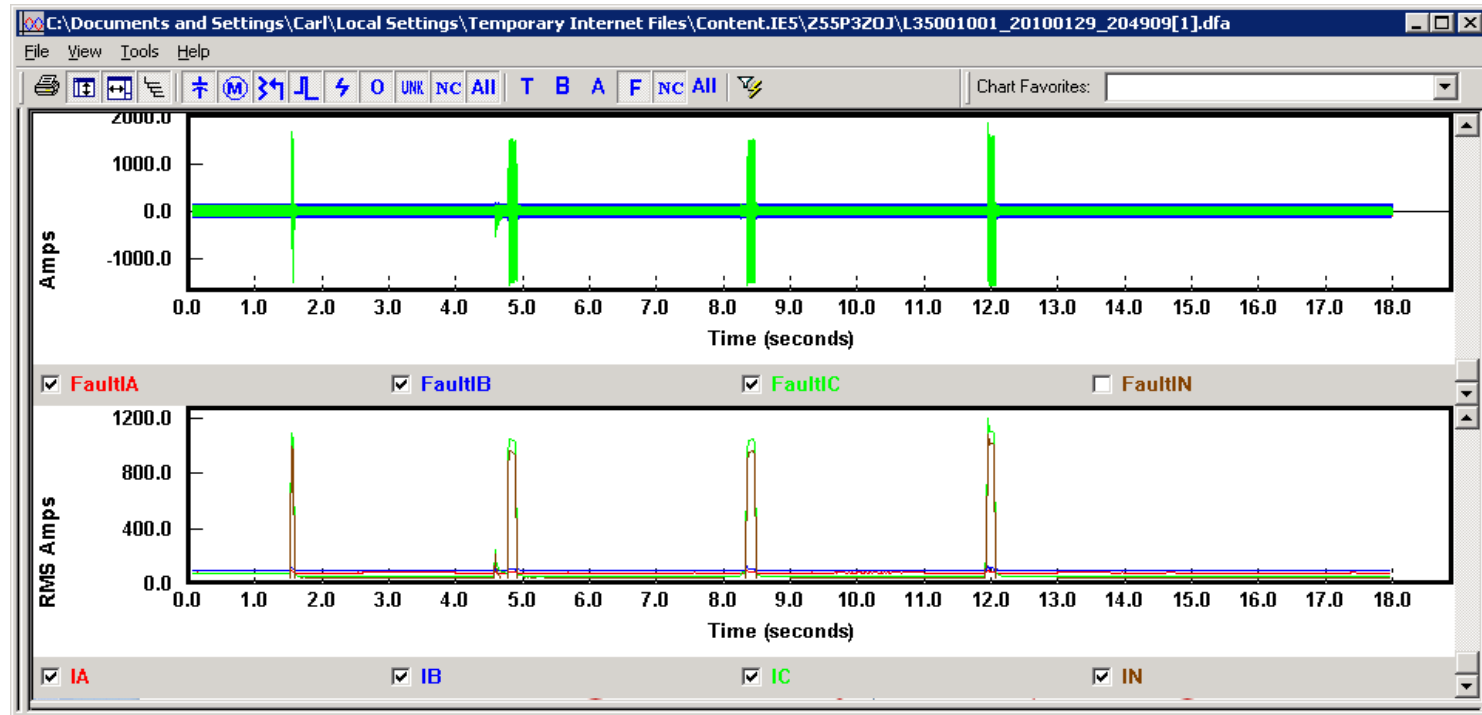
No fault for  
next 11 cycles

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.



2-cycle, 1069-amp,  
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Single-Phase Trip:

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 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-4c-  
 F-(7.0c,1091A,C)-T-(0,0,24)%

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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

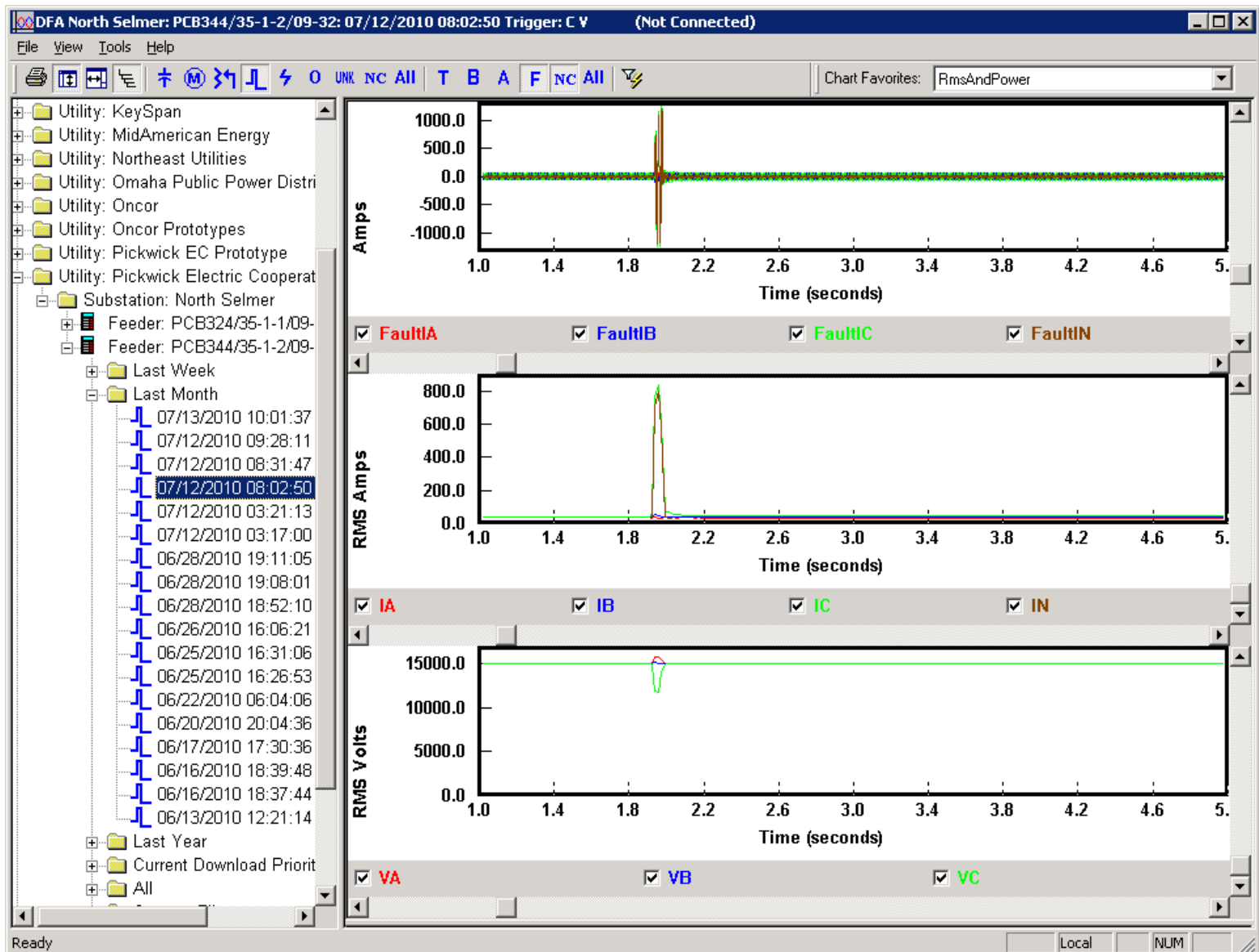
## Scenario at Subject Utility (and ~~probably~~ at your company, too!)

- 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

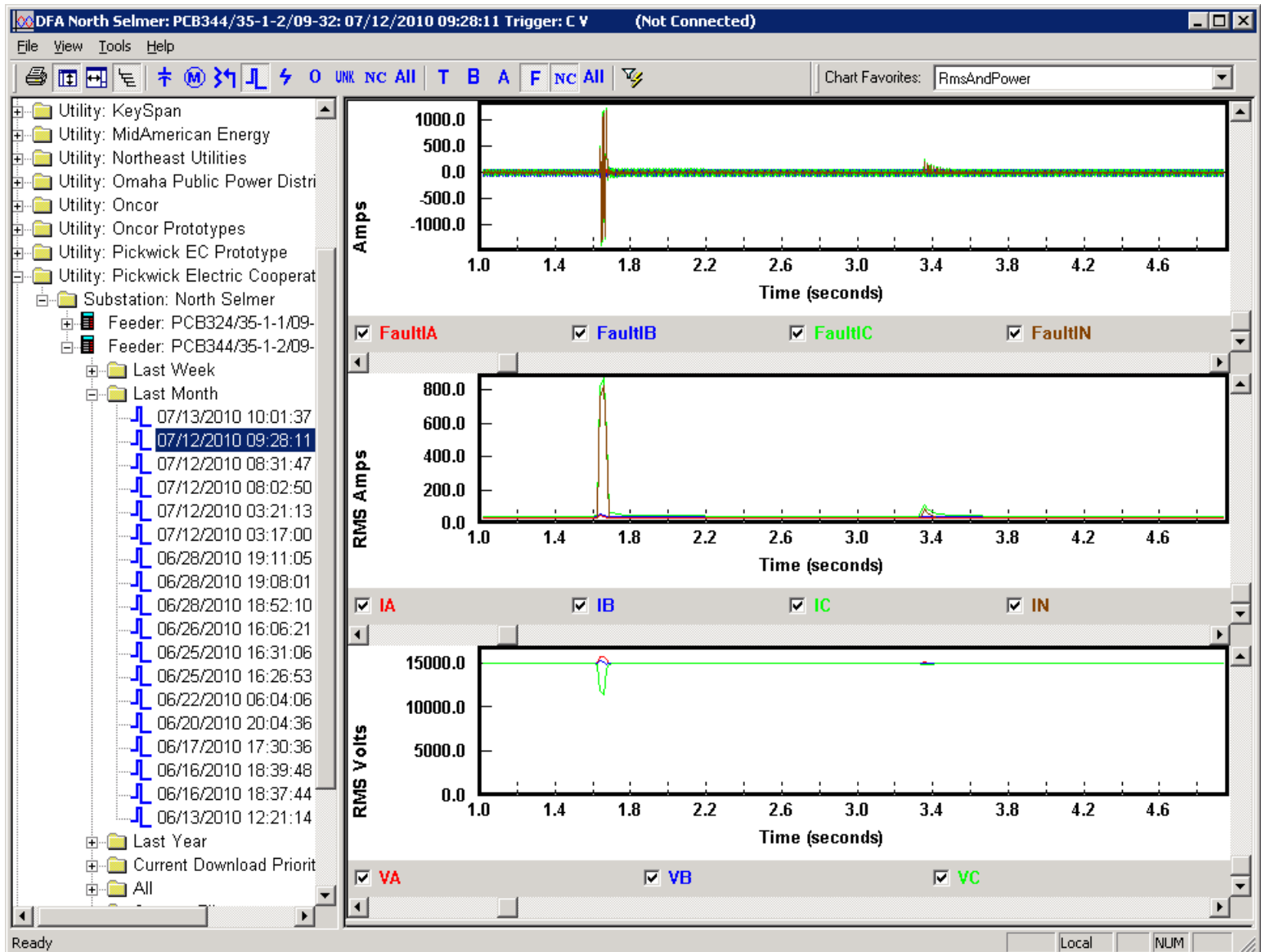
## Single-Phase Fault, Momentary, No Customer Calls





# Recent Event: Monday, 7/12/2010 9:28 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)



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



## 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

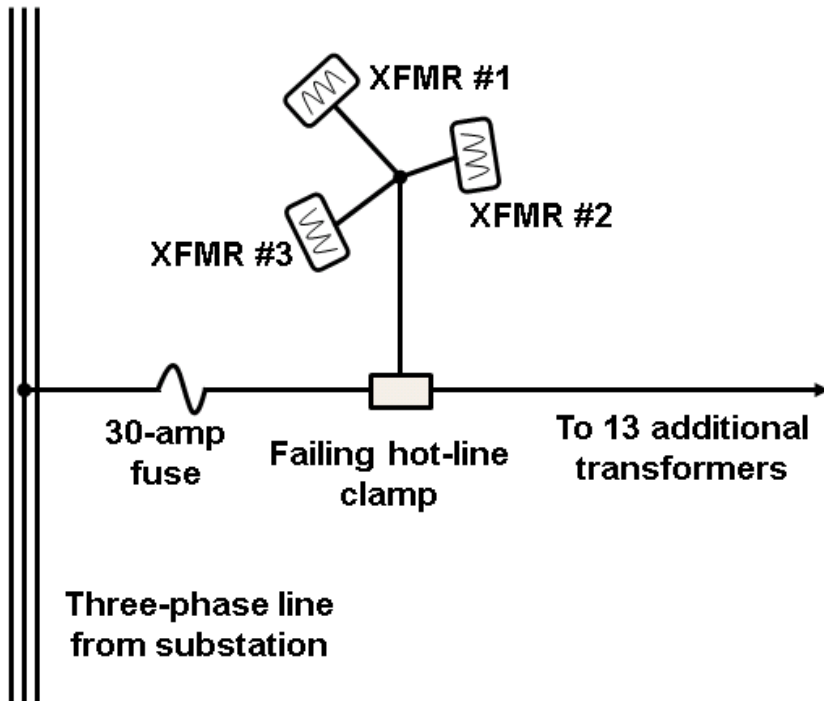
## Engineer with direct access to DFA reports

- 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.*

# DFA Alerts and Reports

Alerts

Reports

Diagnostics

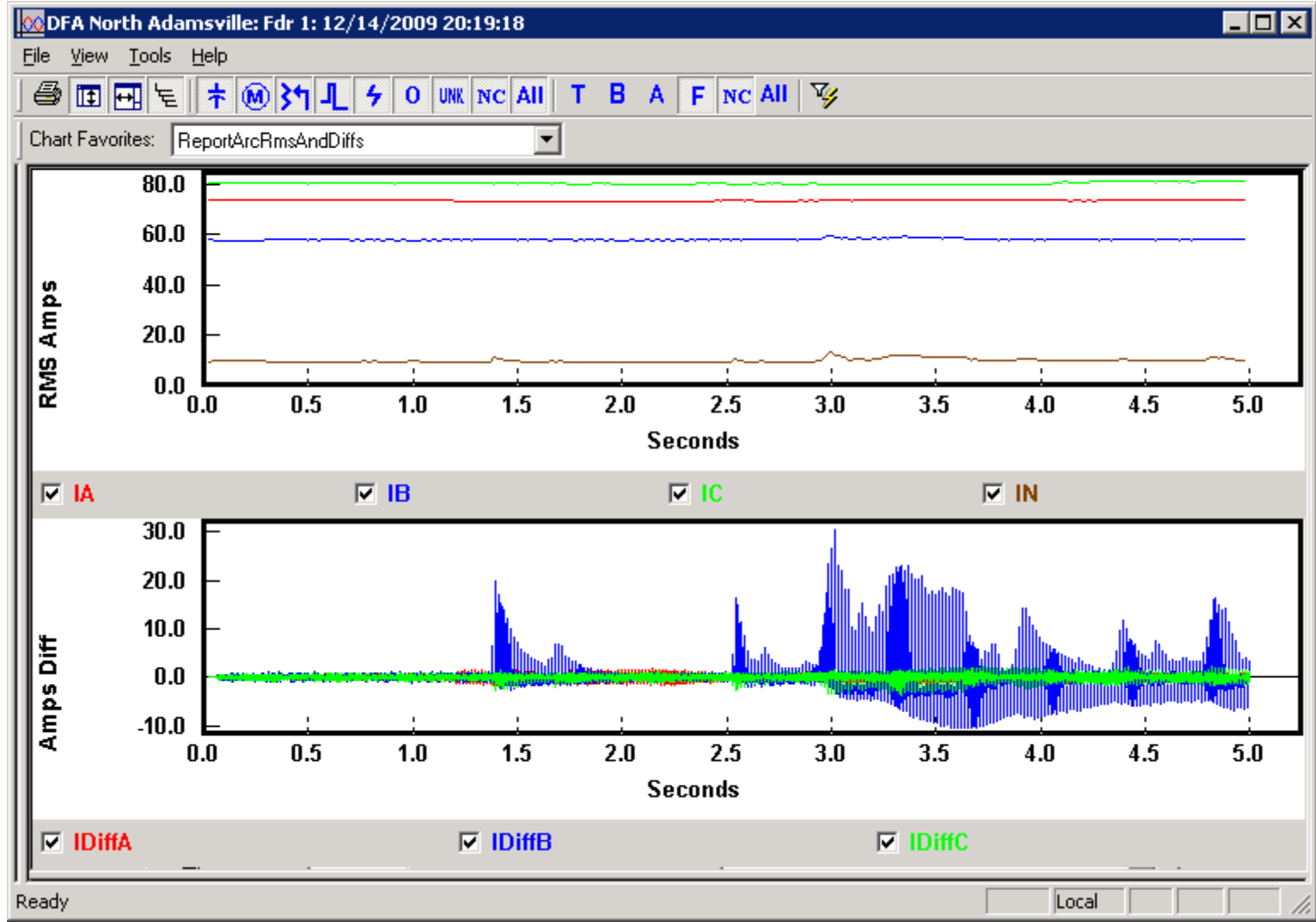
Welcome Demo User

[Change Password](#) | [Sign Out](#)

Displaying alerts for: Pickwick EC Prototype

Feeder	Alert Type	Phases	Comments	Occurrences	Last Occurred
Fdr 1	Probable failure of switch or clamp	B	Ratio: 0.60, Type-B (Smooth)	1218 (7 days)	12/14/09 20:19:22
Event Type		Phases		Occurred	
	Probable failure of switch or clamp	B			12/14/09 20:19:22
	Probable failure of switch or clamp	B			12/14/09 20:19:18
	Probable failure of switch or clamp	B			12/14/09 20:18:40
	Probable failure of switch or clamp	B			12/14/09 20:15:37
	Probable failure of switch or clamp	B			12/14/09 20:15:26
	Probable failure of switch or clamp	B			12/14/09 20:15:15
	Probable failure of switch or clamp	B			12/14/09 20:15:08
	Probable failure of switch or clamp	B			12/14/09 20:14:51
	Probable failure of switch or clamp	B			12/14/09 20:14:50
	Probable failure of switch or clamp	B			12/14/09 20:14:44
Change page: < 1 2 3 4 5 6 7 8 9 10 ... >    Change page: <input type="text" value="1"/> Go Page    Displaying page 1 of 234, items 1 to 10 of 2335.					
size: <input type="text" value="10"/> <a href="#">Change</a>					
Fdr 1	Single-Phase trip	C	616 Amps , O-1.9s-CO-1.9s-CO-2.1s-CO	1 (7 days)	12/09/09 00:03:24
Fdr 2	Three-Phase reclose	C	574 Amps , F-10c-O-2.3s-C	1 (7 days)	11/29/09 06:46:02
Fdr 1	Single-Phase trip	C	616 Amps (7 days)	1 (7 days)	11/07/09 06:04:50

Location



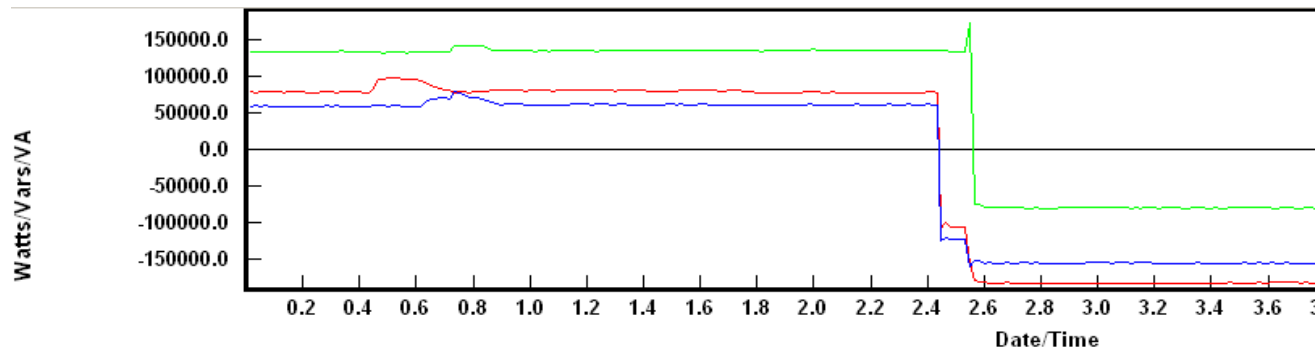
# Use Scenario: Mysterious Trouble or Outage

## 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
*	08/09/2004	19:04:24
*	08/09/2004	18:55:23
*	08/09/2004	18:46:24
*	08/09/2004	18:37:22
*	08/09/2004	18:28:23
*	08/09/2004	18:19:23
*	08/09/2004	18:10:23
*	08/09/2004	18:01:22
*	08/09/2004	17:50:23
*	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
*	08/09/2004	14:51:23
*	08/09/2004	14:42:22
*	08/09/2004	14:33:23
*	08/09/2004	14:24:22
*	08/09/2004	14:15:24
*	08/09/2004	14:06:22
*	08/09/2004	13:57:23
*	08/09/2004	13:48:23
*	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

02/18/2004 13:44:59	02/18/2004 15:02:17	02/18/2004 15:52:23	02/18/2004 17:07:06	02/18/2004 18:27:01	02/18/2004 22:10:52	02/18/2004 23:28:56
02/18/2004 13:44:15	02/18/2004 15:01:33	02/18/2004 15:51:22	02/18/2004 17:06:27	02/18/2004 18:26:22	02/18/2004 22:09:32	02/18/2004 23:28:16
02/18/2004 13:43:35	02/18/2004 15:00:53	02/18/2004 15:50:42	02/18/2004 17:05:43	02/18/2004 18:21:16	02/18/2004 22:08:52	02/18/2004 23:27:31
02/18/2004 13:42:51	02/18/2004 15:00:09	02/18/2004 15:49:57	02/18/2004 17:05:03	02/18/2004 18:20:37	02/18/2004 22:08:06	02/18/2004 23:26:52
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02/18/2004 12:57:31	02/18/2004 13:56:24	02/18/2004 15:16:00	02/18/2004 16:23:53	02/18/2004 17:21:51	02/18/2004 21:23:58	02/18/2004 22:41:44
02/18/2004 12:56:43	02/18/2004 13:55:44	02/18/2004 15:15:00	02/18/2004 16:22:53	02/18/2004 17:20:51	02/18/2004 21:22:58	02/18/2004 22:41:05
02/18/2004 12:56:04	02/18/2004 13:55:04	02/18/2004 15:14:00	02/18/2004 16:21:53	02/18/2004 17:19:51	02/18/2004 21:21:58	02/18/2004 22:40:26
02/18/2004 12:55:17	02/18/2004 13:54:24	02/18/2004 15:13:00	02/18/2004 16:20:53	02/18/2004 17:18:51	02/18/2004 21:20:58	02/18/2004 22:39:47
02/18/2004 12:49:37	02/18/2004 13:53:44	02/18/2004 15:12:00	02/18/2004 16:19:53	02/18/2004 17:17:51	02/18/2004 21:19:58	02/18/2004 22:38:68
02/18/2004 01:41:43	02/18/2004 13:47:03	02/18/2004 15:05:18	02/18/2004 15:54:57	02/18/2004 17:09:14	02/18/2004 18:38:44	02/18/2004 22:18:25
02/18/2004 00:56:54	02/18/2004 13:46:23	02/18/2004 15:04:32	02/18/2004 15:54:17	02/18/2004 17:08:30	02/18/2004 18:29:42	02/18/2004 22:15:46
02/18/2004 00:56:15	02/18/2004 13:45:39	02/18/2004 15:03:52	02/18/2004 15:53:02	02/18/2004 17:07:51	02/18/2004 18:29:03	02/18/2004 22:11:31
02/18/2004 00:55:29	02/18/2004 13:44:59	02/18/2004 15:02:57	02/18/2004 15:52:23	02/18/2004 17:07:06	02/18/2004 18:27:01	02/18/2004 22:10:52

Capacitor switching events for one feeder for one day!

- 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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