Power Quality Monitoring and Analytics for Transmission and Distribution Systems

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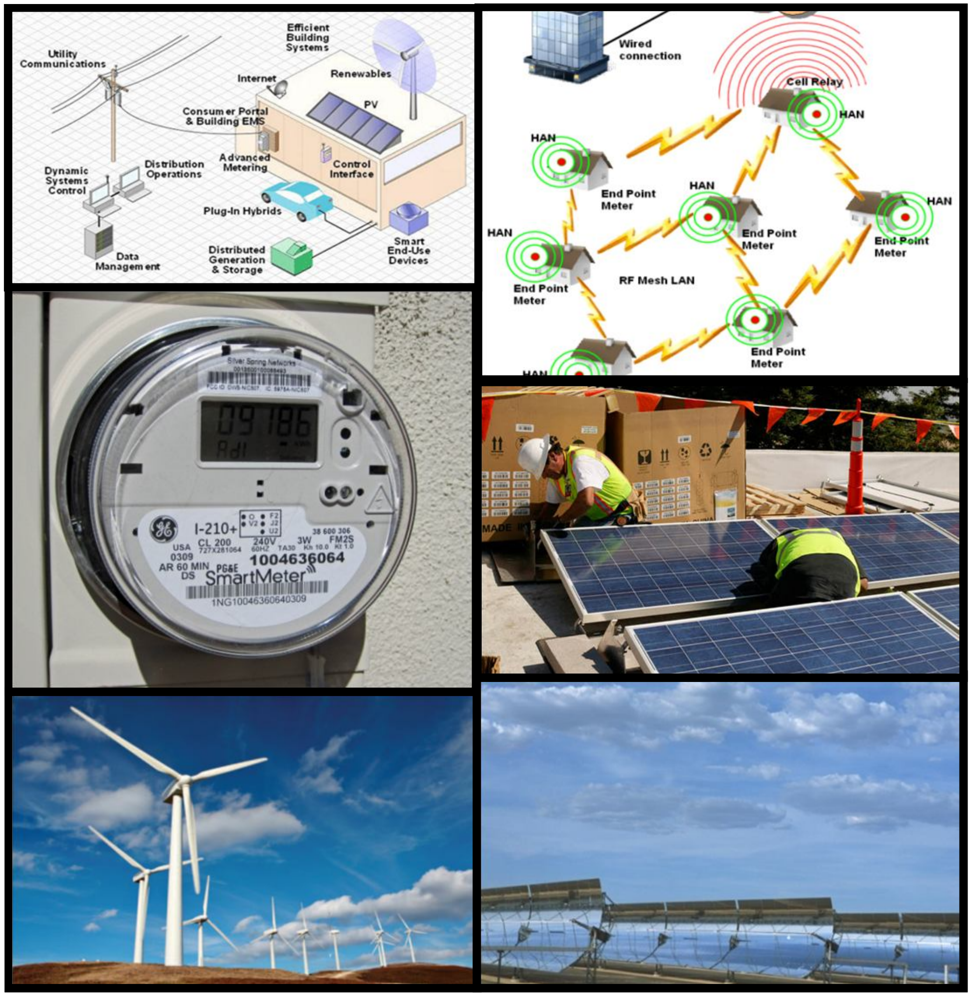
PQSynergy 2012

Evolving Smarter Grid



Widespread Incorporation of New Technologies

New Electromagnetic Environment

New Opportunities to Leverage Technology

Discussion Topics:

More visually useful PQ data

Advanced modeling tools

Strategically placed voltage and current sensors

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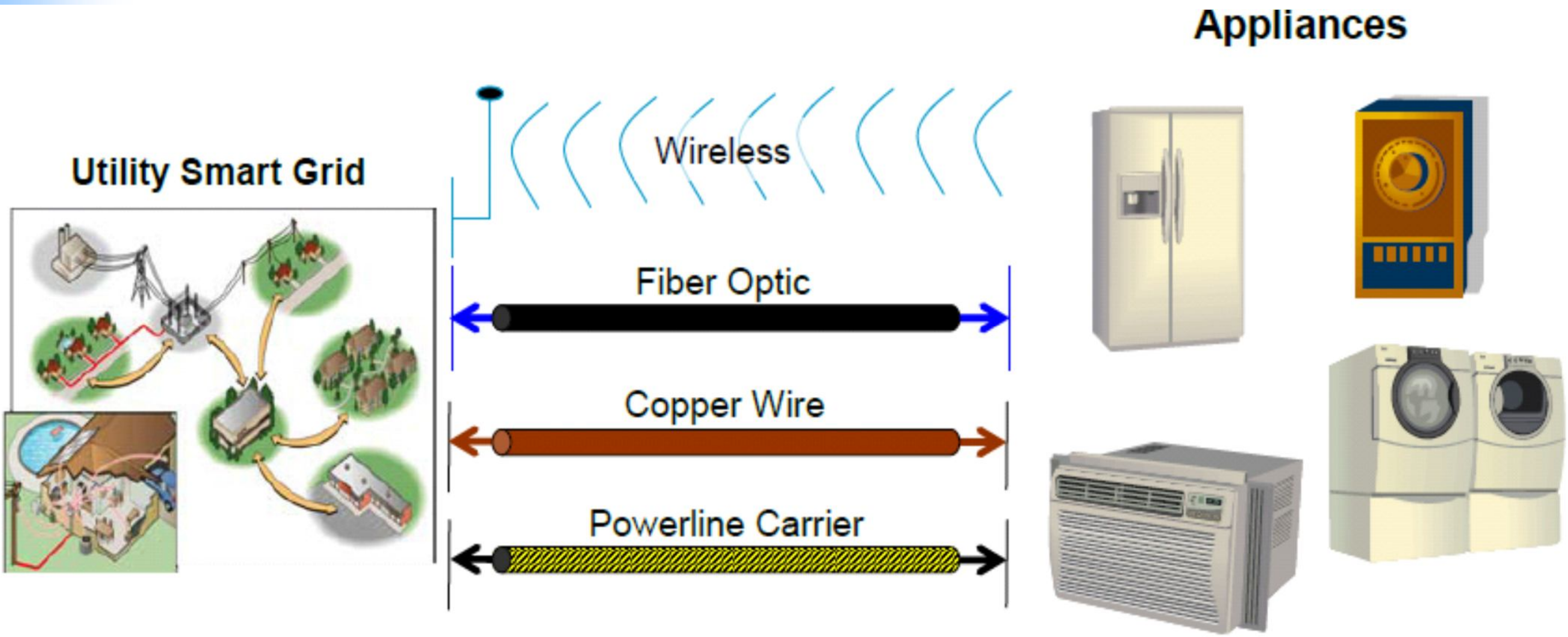
The Emerging Opportunity…



Power Quality Benefits from a Communications and Sensor Enabled Smart Electric Power Grid

- Better metrics and understanding regarding electric power system performance
- Automated methods for diagnosing power quality concerns and incipient failures
- Data that enables system planners to understand the implications of new power electronic load proliferation over time

- Requirements for accomplishing such objectives:
  - More visually useful power quality data
  - Strategically placed voltage and current sensors
  - Advanced modeling tools

Three Agenda Topics

1. A new modeling and simulation tool with capabilities to predict – future – harmonic load induced – system compatibility concerns
2. The use of high fidelity power quality measurements to provide more accurate and useful information to trouble crews responding to power quality complaints and to system outages
3. Better visualization methodology for benchmarking power quality parameters over time

Measure It – Model It – Explain It – Plan for or Remediate It

EPRI Transmission and Distribution Power Quality Research Area – Project Set (PS1-A)

1. Development of PQ Simulation and Application Tools Designed to Support the Power Quality Investigator
2. Benchmarking and Metrics Designed to Better Explain and Visualize PQ Trends and Levels of Concern
3. Key Insights Regarding Power Quality Related Data Analytics and Diagnostics

PQ Benchmarking

Diagnostic Tools

Investigation Guides and Analytics

Agenda Topics

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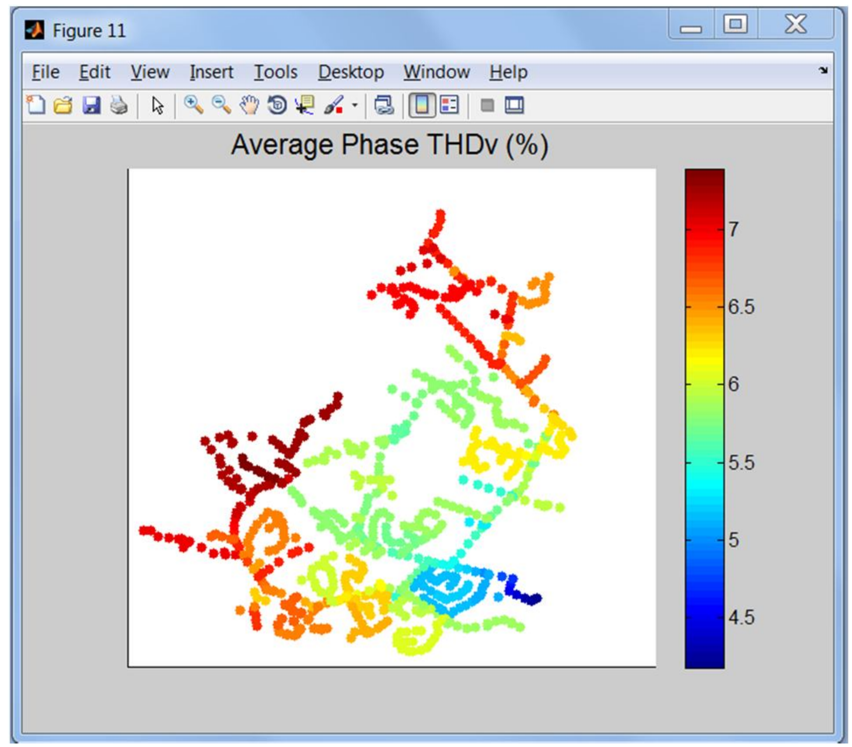
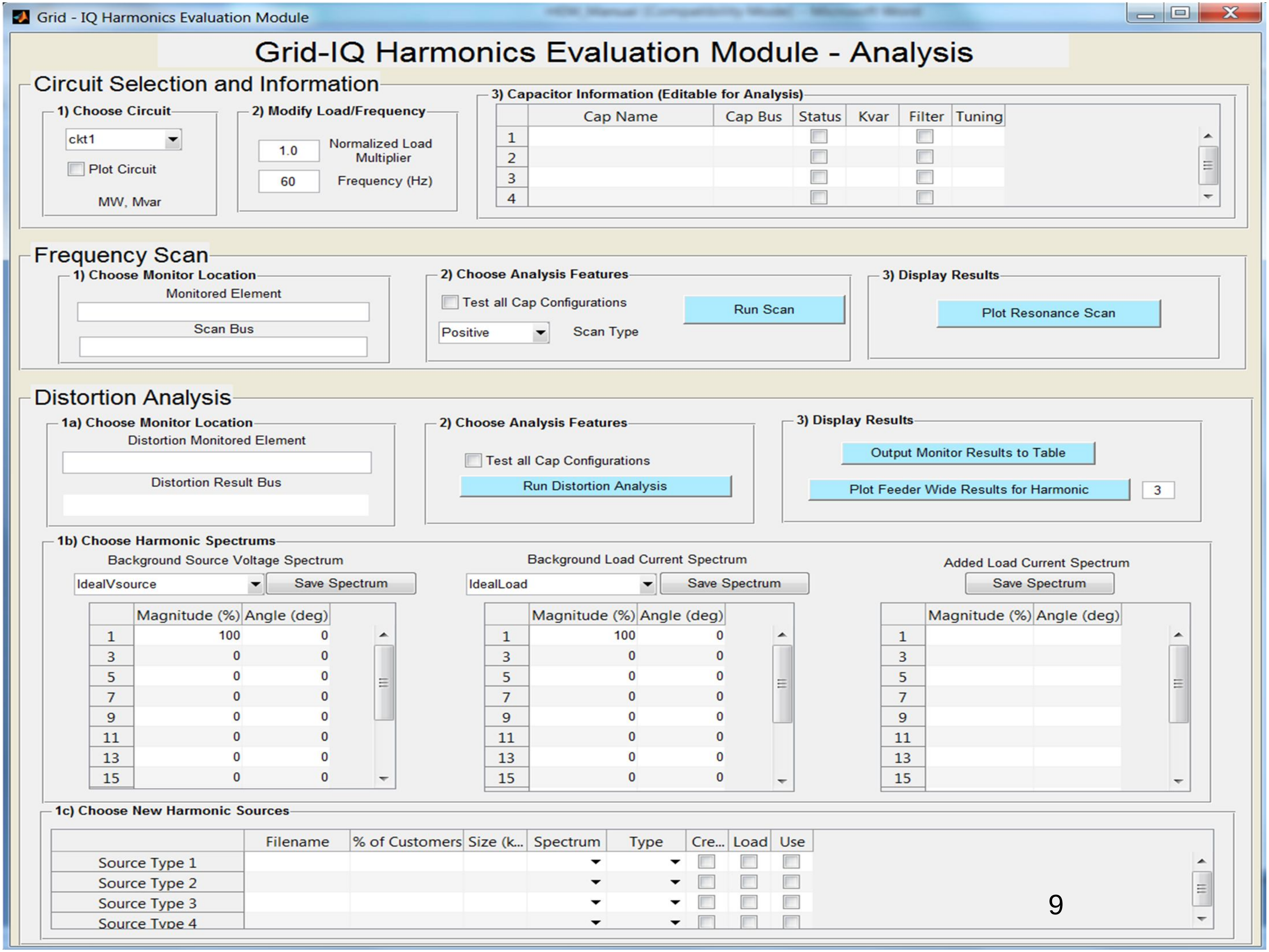
Power Quality Evaluation Modules

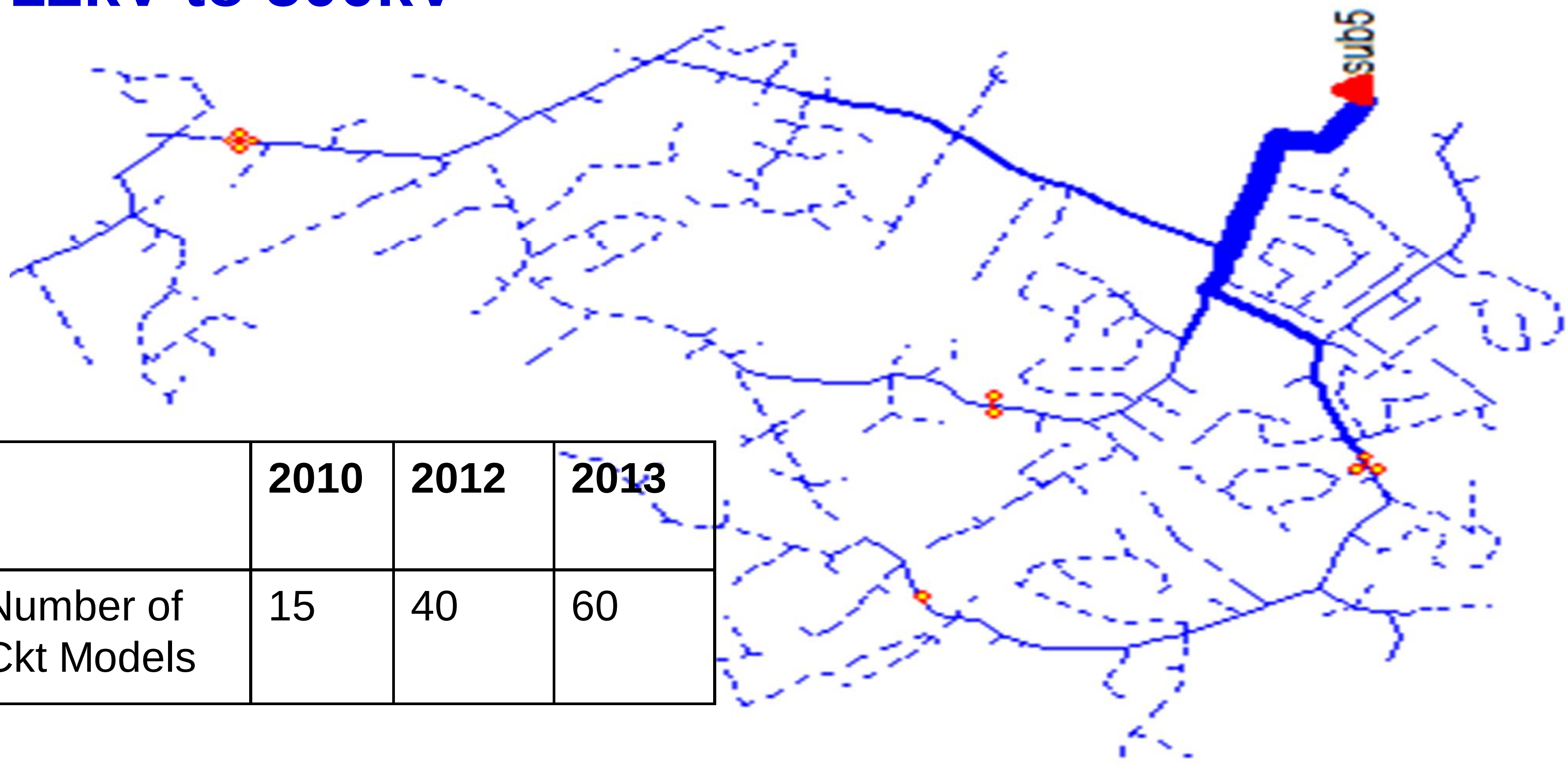
- Suite of PQ analytic modules
  - Capacitor Switching Module (CSM)
  - Motor Starting Module (MSM)
  - Lightning Surge Impact Module (LSIM)
  - Flicker Analysis Module (FAM)
  - Ferroresonance Analysis Module (FRM)
  - ***Harmonics Evaluation Module (HEM)***

Diagnostic Tools

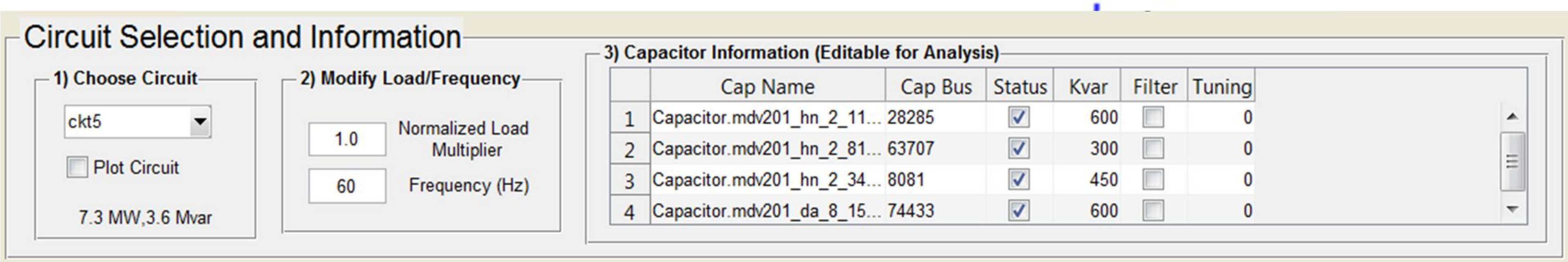



Grid - IQ Harmonics Evaluation Module
Grid-IQ Harmonics Evaluation Module - Analysis
Circuit Selection and Information
1) Choose Circuit
ckt1
Plot Circuit
MW, Mvar
2) Modify Load/Frequency
1.0
Normalized Load Multiplier
60
Frequency (Hz)
3) Capacitor Information (Editable for Analysis)
Cap Name
Cap Bus
Status
Kvar
Filter
Tuning
1
2
3
4
Frequency Scan
1) Choose Monitor Location
Monitored Element
Scan Bus
2) Choose Analysis Features
Test all Cap Configurations
Positive
Scan Type
Run Scan
3) Display Results
Plot Resonance Scan
Distortion Analysis
1a) Choose Monitor Location
Distortion Monitored Element
Distortion Result Bus
2) Choose Analysis Features
Test all Cap Configurations
Run Distortion Analysis
3) Display Results
Output Monitor Results to Table
Plot Feeder Wide Results for Harmonic
3
1b) Choose Harmonic Spectrums
Background Source Voltage Spectrum
IdealVsource
Save Spectrum
Magnitude (%)
Angle (deg)
1 100 0
3 0 0
5 0 0
7 0 0
9 0 0
11 0 0
13 0 0
15 0 0
Background Load Current Spectrum
IdealLoad
Save Spectrum
Magnitude (%)
Angle (deg)
1 100 0
3 0 0
5 0 0
7 0 0
9 0 0
11 0 0
13 0 0
15 0 0
Added Load Current Spectrum
Save Spectrum
Magnitude (%)
Angle (deg)
1
3
5
7
9
11
13
15
1c) Choose New Harmonic Sources
Filename
% of Customers
Size (k...
Spectrum
Type
Cre...
Load
Use
Source Type 1
Source Type 2
Source Type 3
Source Type 4

40 Unique Circuit Models from T&D Systems 12kV to 500kV



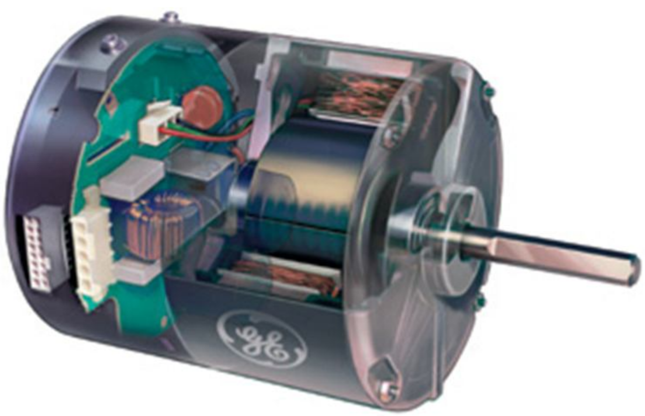
	2010	2012	2013
Number of Ckt Models	15	40	60

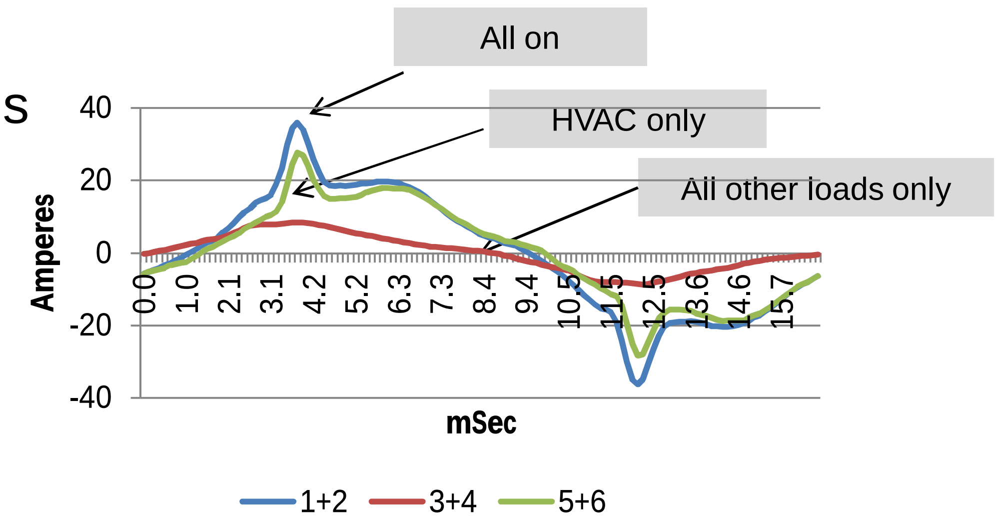


Load Spectrums

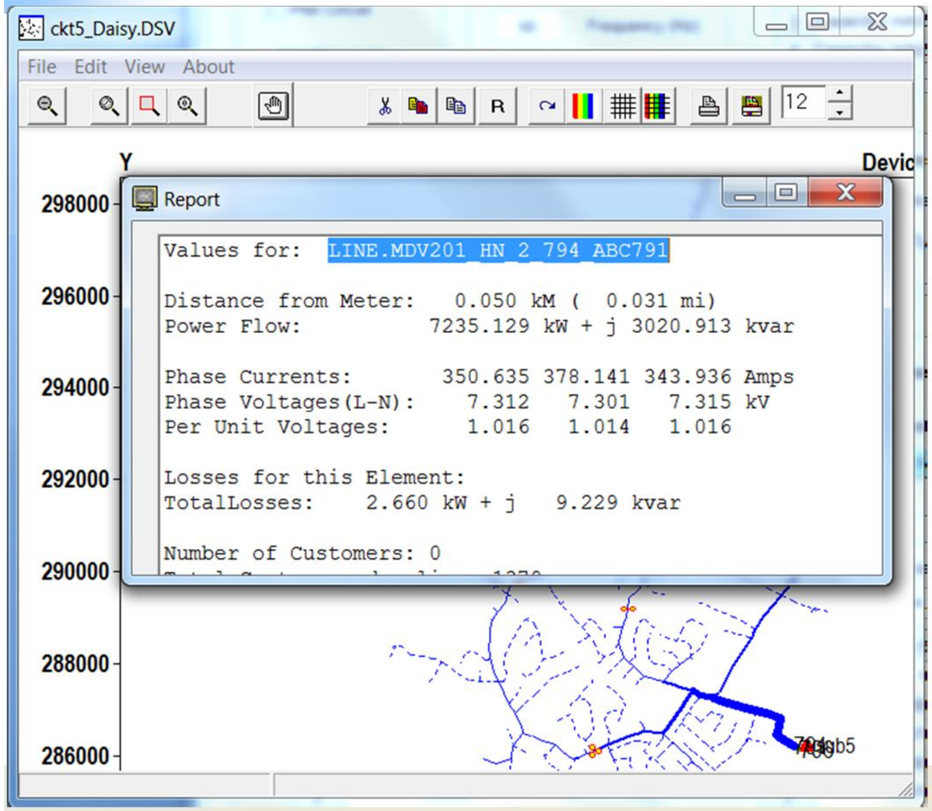
- 50/60Hz and Harmonic Spectrums for Hundreds of Products
  - Compact Fluorescent Lamps (CFLs)
  - Light Emitting Diode (LED) lamps
  - Electric Vehicle Chargers
  - Photo-Voltaic (PV) Units
  - Electronically Commuted Motor (ECM) based HVAC units
  - Home Entertainment Systems

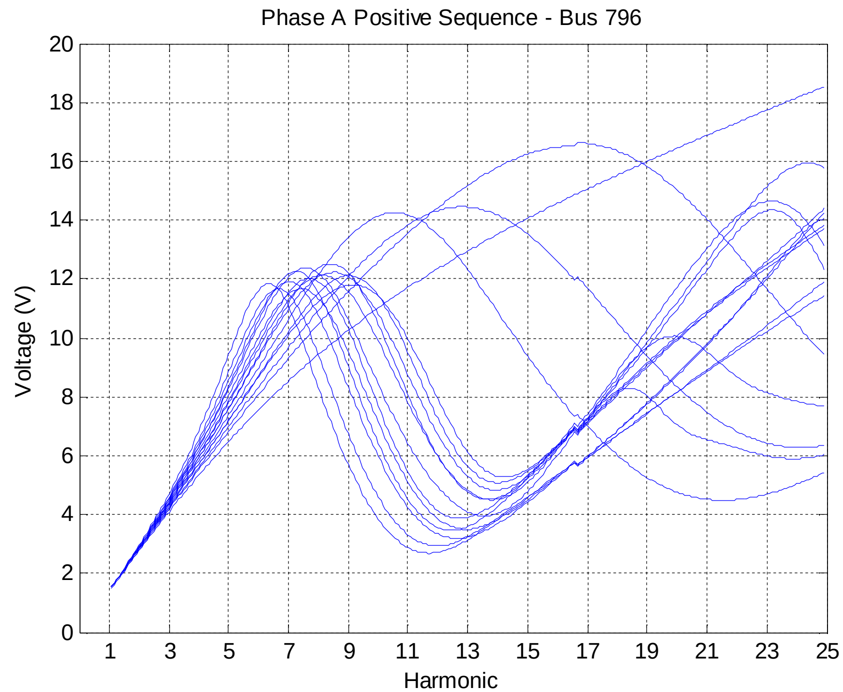
Harmonic	Mag (% fund)
1	100.00
3	0.09
5	0.08
7	0.05
9	0.02
11	0.01
13	0.01

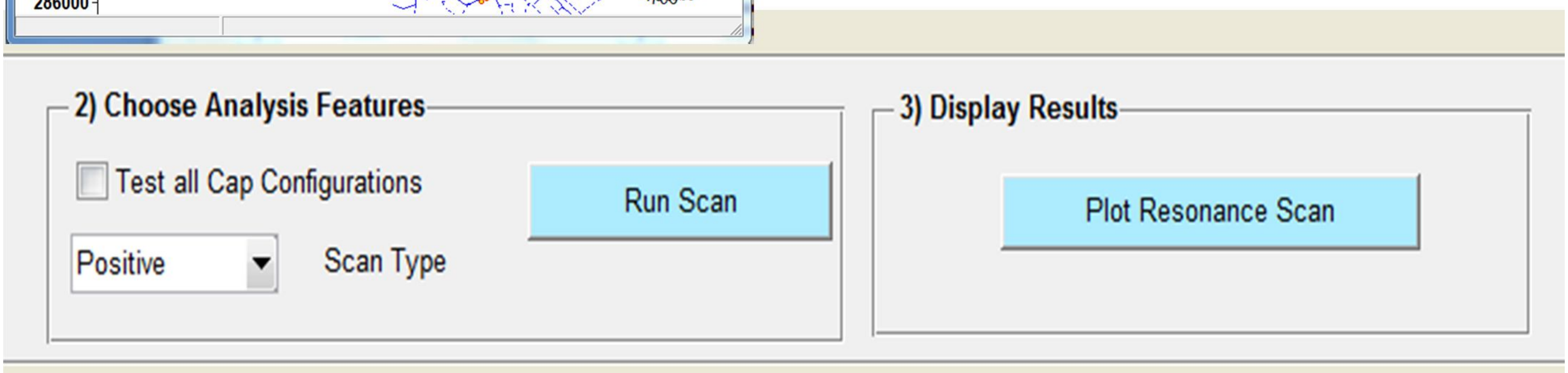


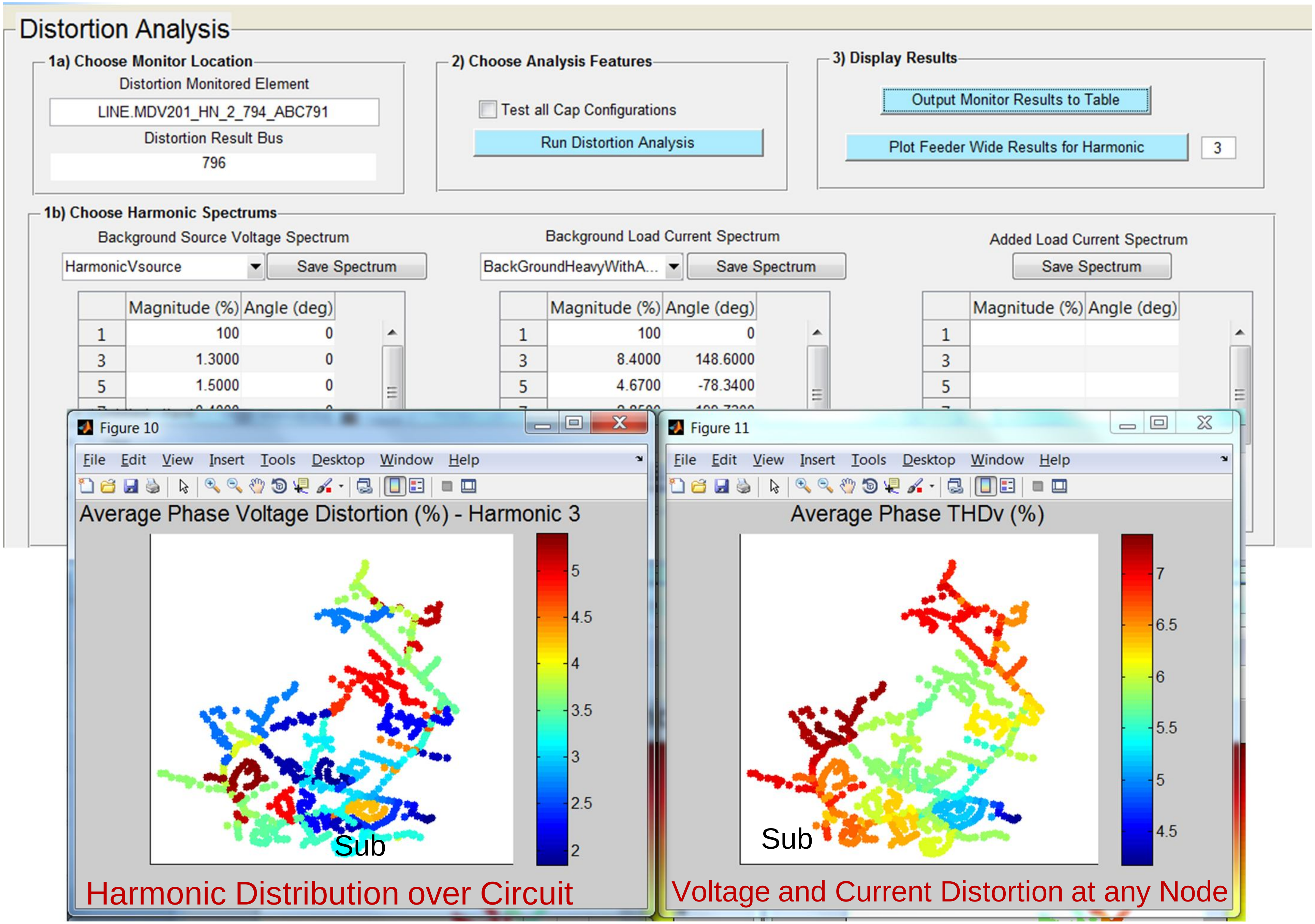


Frequency Scan Example

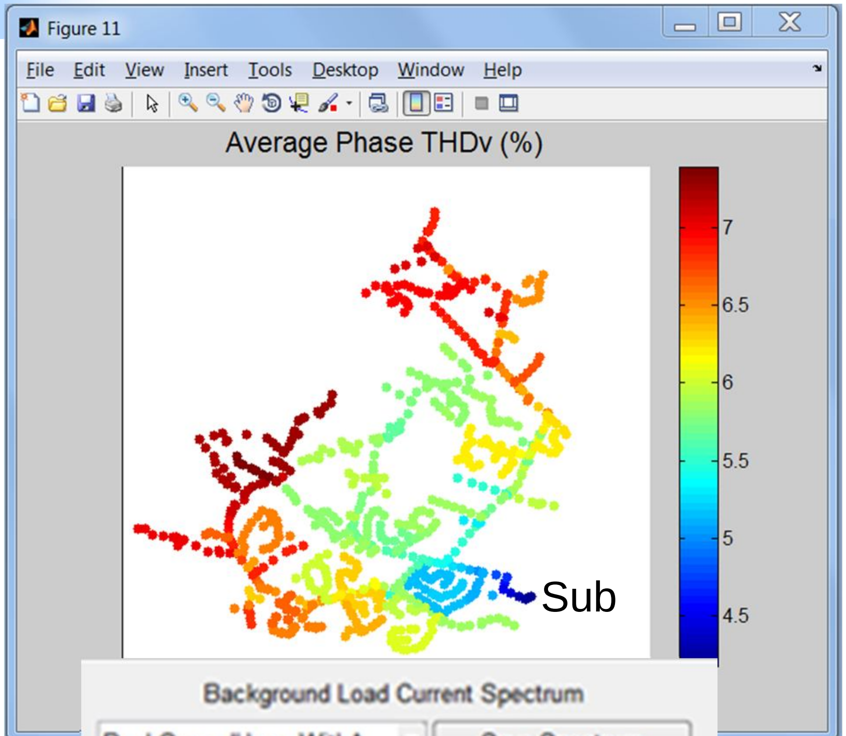


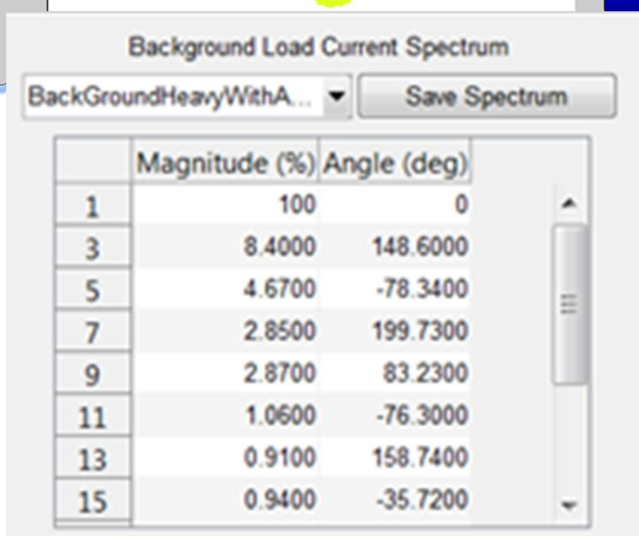





Distortion Analysis
1a) Choose Monitor Location
Distortion Monitored Element
LINE.MDV201_HN_2_794_ABC791
Distortion Result Bus
796
2) Choose Analysis Features
Test all Cap Configurations
Run Distortion Analysis
3) Display Results
Output Monitor Results to Table
Plot Feeder Wide Results for Harmonic
3
1b) Choose Harmonic Spectrums
Background Source Voltage Spectrum
HarmonicVsource
Save Spectrum
Background Load Current Spectrum
BackGroundHeavyWithA...
Save Spectrum
Added Load Current Spectrum
Save Spectrum
Magnitude (%) Angle (deg)
1 100 0
3 1.3000 0
5 1.5000 0
Magnitude (%) Angle (deg)
1 100 0
3 8.4000 148.6000
5 4.6700 -78.3400
Magnitude (%) Angle (deg)
1
3
5
Figure 10
File Edit View Insert Tools Desktop Window Help
Average Phase Voltage Distortion (%) - Harmonic 3
5
4.5
4
3.5
3
2.5
2
Sub
Harmonic Distribution over Circuit
Figure 11
File Edit View Insert Tools Desktop Window Help
Average Phase THDv (%)
7
6.5
6
5.5
5
4.5
Sub
Voltage and Current Distortion at any Node

2030 Load Mix Harmonic Analysis for 12kV Ckts





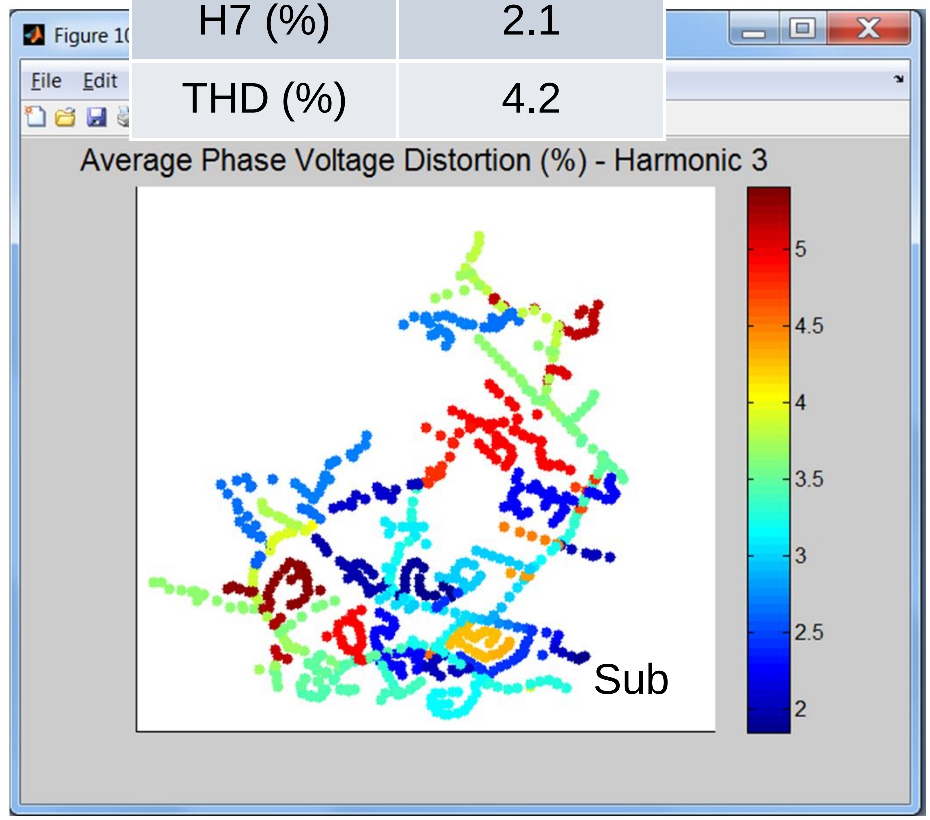
Background Load Current Spectrum

BackGroundHeavyWithA... Save Spectrum

	Magnitude (%)	Angle (deg)
1	100	0
3	8.4000	148.6000
5	4.6700	-78.3400
7	2.8500	199.7300
9	2.8700	83.2300
11	1.0600	-76.3000
13	0.9100	158.7400
15	0.9400	-35.7200

Voltage harmonics at Sub

Harmonic	Magnitude
H3 (%)	1.9
H5 (%)	2.7
H7 (%)	2.1
THD (%)	4.2



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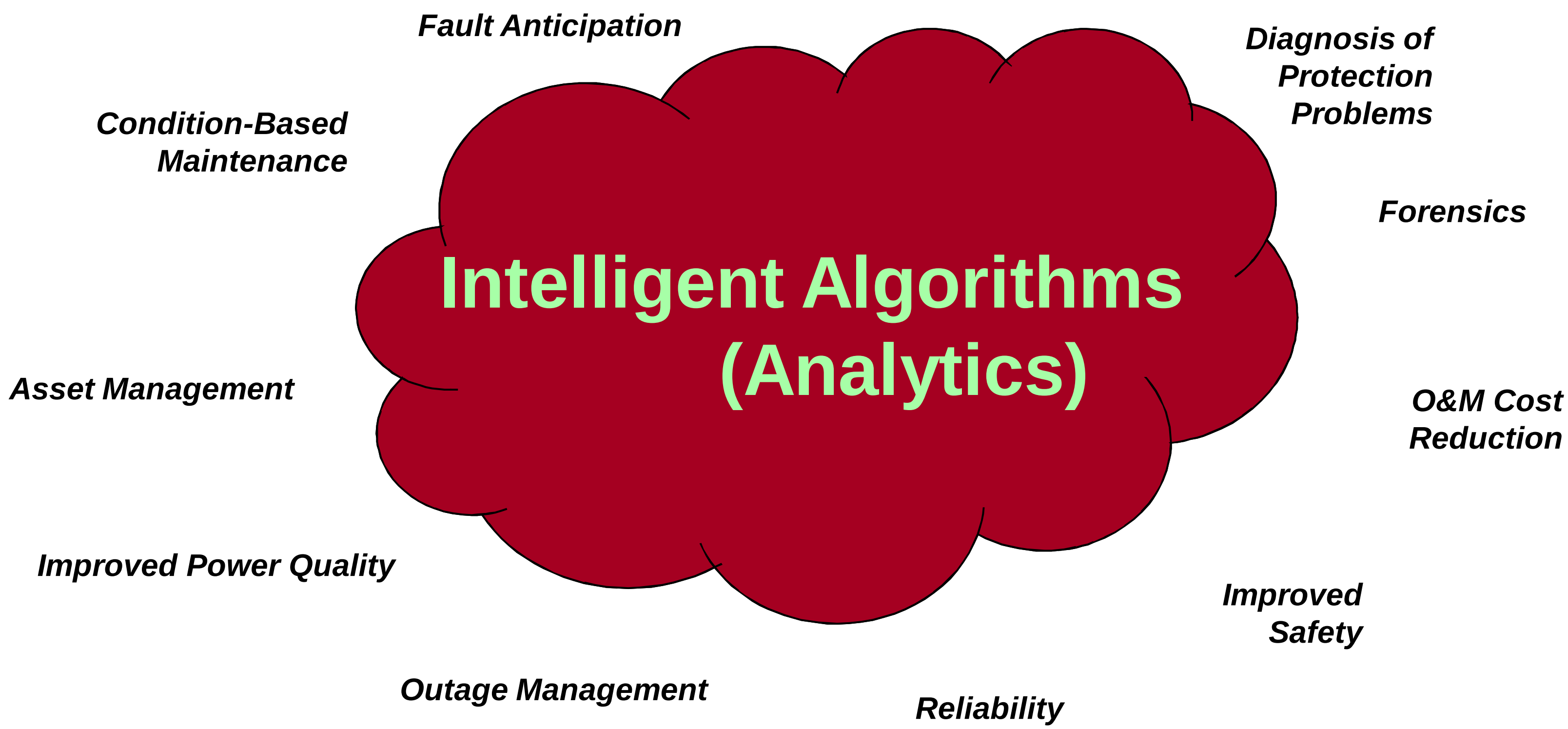
Measure It – Model It – Explain It – Plan for or Remediate It

Overview of Dynamic Event Diagnostics Technology

- Background: Technology's foundation lies in EPRI's DFA (Distribution Fault Anticipation) project, performed by Texas A&M, in close cooperation with multiple utilities. DFA label persists for historical reasons.
- Substation-based DFA devices sense high-fidelity current and voltage waveforms, using conventional CTs and PTs.
- DFA devices execute on-line algorithms that analyze waveforms to diagnose failures, maloperations, etc.
- DFA system provides actionable reports about "important" line-apparatus conditions.
- The result: Awareness of system conditions, including incipient faults and outages.

Conceptual Application of Intelligent Algorithms to Electrical Waveforms



Substation waveforms “know” about feeder activity. They can provide system awareness, if we measure them with sufficient fidelity and know how to interpret them.

Documented Failures

- Voltage regulator failure
- LTC controller maloperation
- Repetitive overcurrent faults
- Lightning arrestor failures
- Switch and clamp failures
- Cable failures
- Tree/vegetation contacts
- Pole-top xfmr bushing failure
- Pole-top xfmr winding failure
- URD padmount xfmr failure
- Bus capacitor bushing failure
- Capacitor problems
  - Switch restrike
  - Switch bounce
  - Pack failure

Many types of failures occur infrequently and only one or a few incidents have been documented. Ongoing field experience provides for continuous improvement and new algorithms to diagnose those types of failures better.

Complexity of DFA Setup Process

- Substation-based hardware
  - Install DFA devices in 19” racks.
  - Connect conventional CTs and PTs.
- Configuration
  - User sets CT ratio, PT ratio, and timezone.
  - Detailed feeder information is <u>not</u> required.
  - Algorithms discover switched line capacitors.
  - Algorithms discover line reclosers, including hydraulics.
- Communications
  - users access reports via secure web login.

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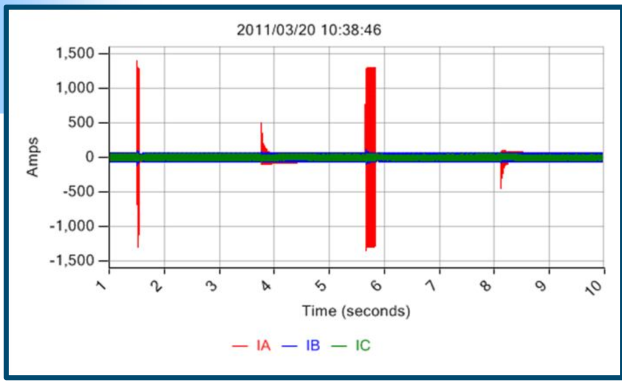
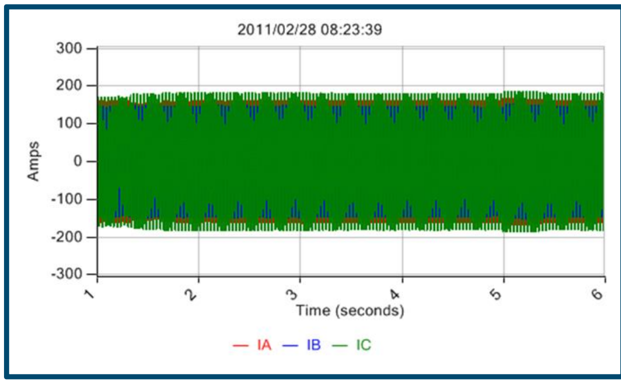
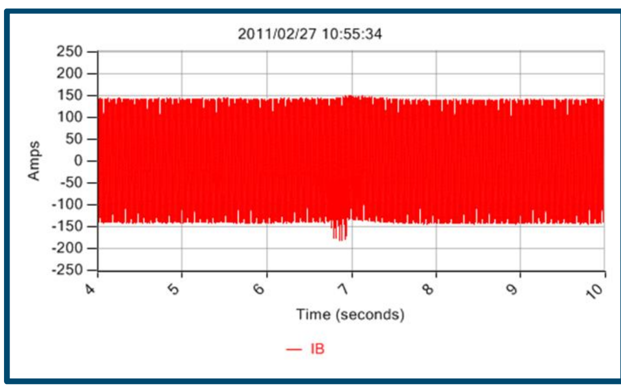
Inputs: Substation CT and PT Waveforms







DFA Algorithms

On-Line

Signal Processing and Pattern

Recognition

Algorithms

Performed by

DFA device in

substation

DFA Reports

→ Line recloser* trips 8% of phase-A load twice, but did not cause outage

→ Failed 1200 kVAR capacitor (phase B inoperable)

→ Failing hot-line clamp on phase B*

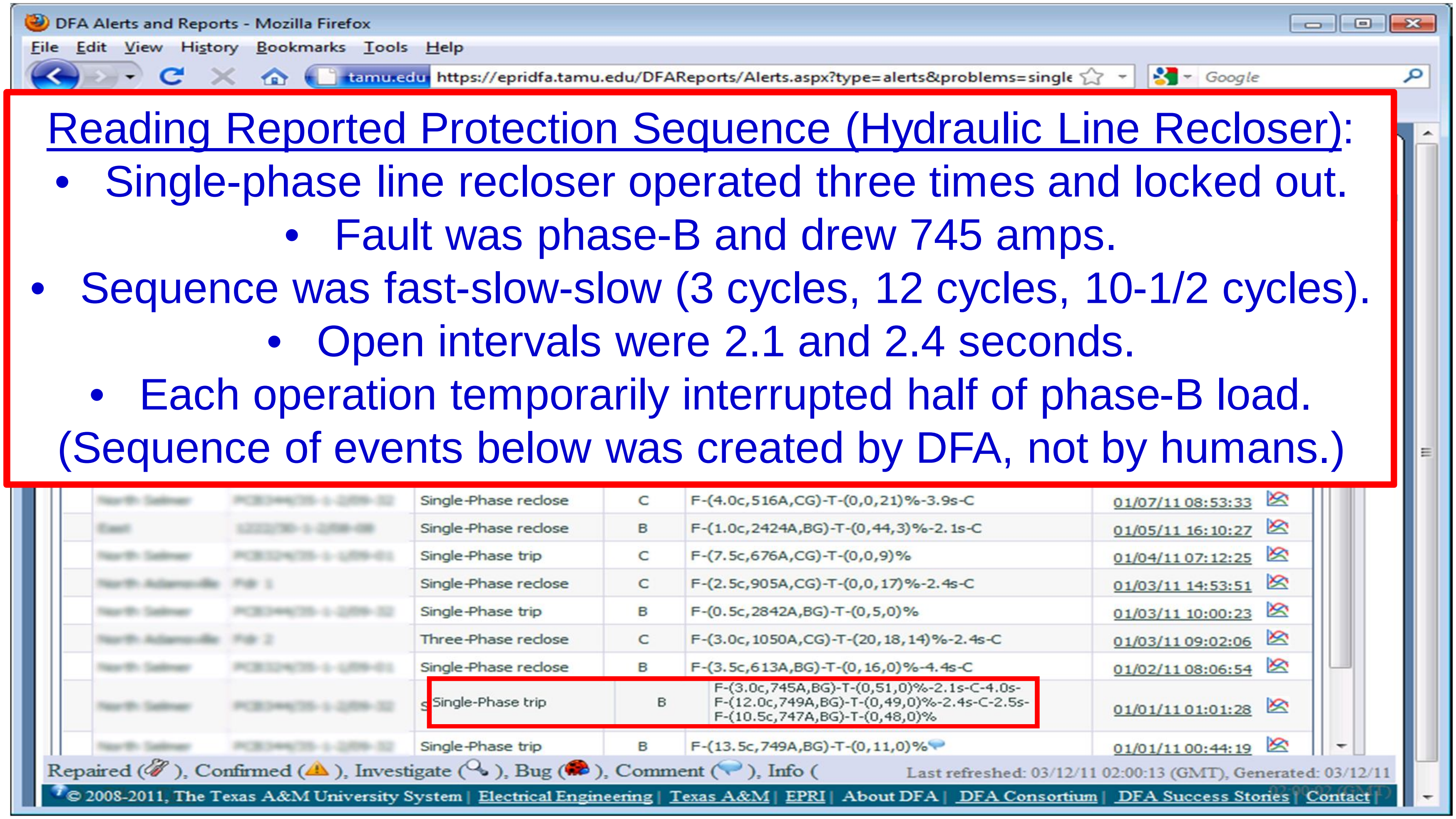
*DFA system reports hydraulic reclosers, switched line capacitors, line apparatus failures, etc, based on substation waveforms

DFA Web-Based Reporting Format

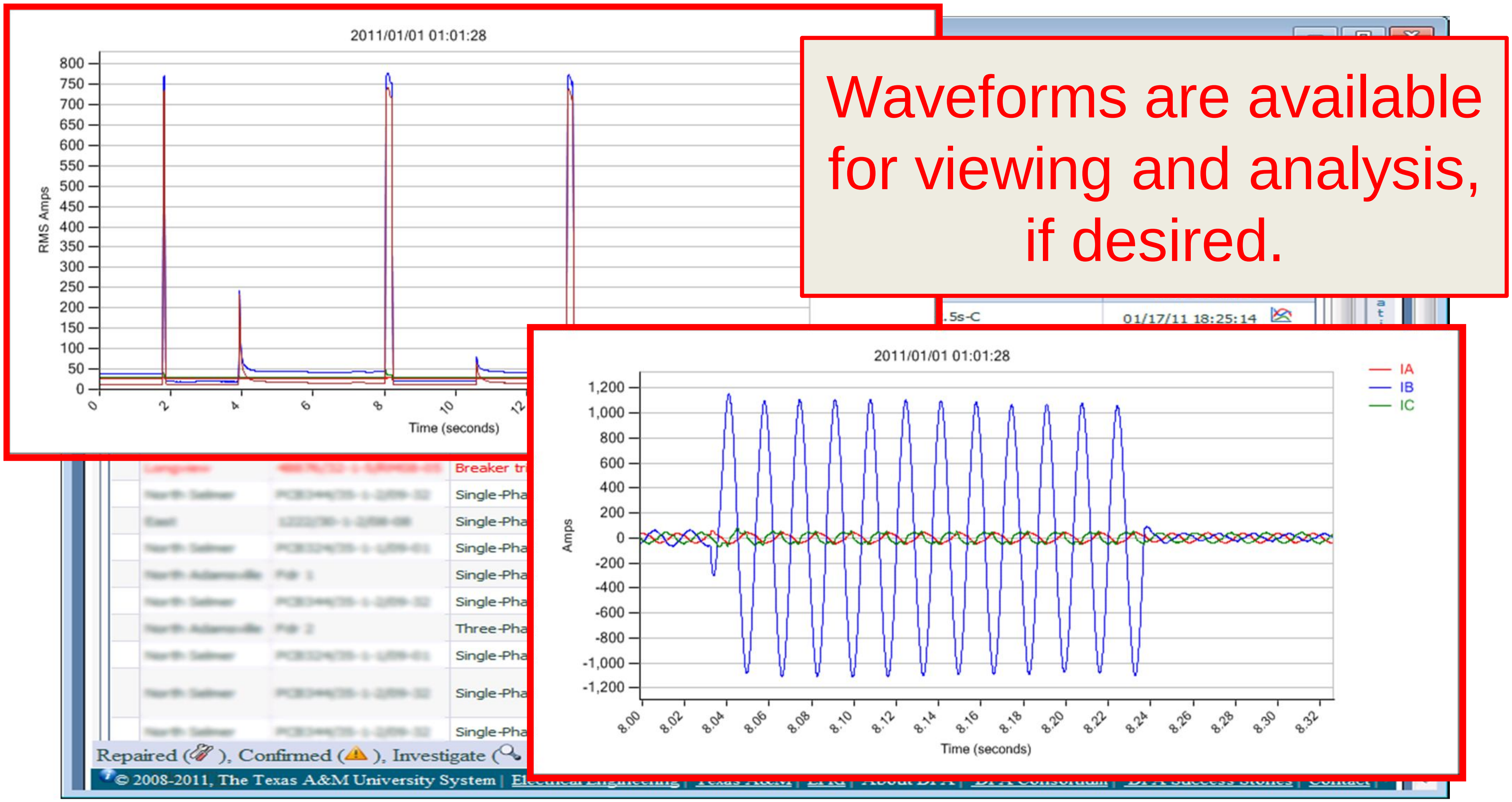
<u>Reading Reported Protection Sequence (Hydraulic Line Recloser)</u>:

- Single-phase line recloser operated three times and locked out.
- Fault was phase-B and drew 745 amps.
- Sequence was fast-slow-slow (3 cycles, 12 cycles, 10-1/2 cycles).
- Open intervals were 2.1 and 2.4 seconds.
- Each operation temporarily interrupted half of phase-B load.

(Sequence of events below was created by DFA, not by humans.)



DFA Web-Based Reporting Format



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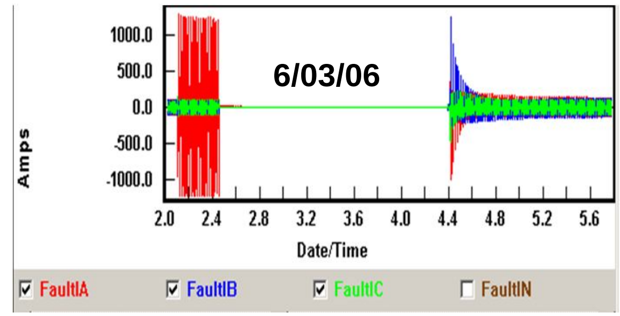
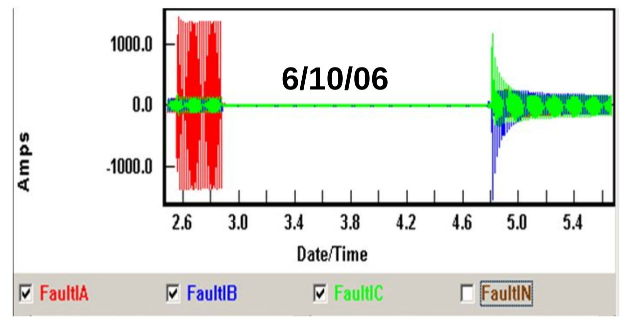
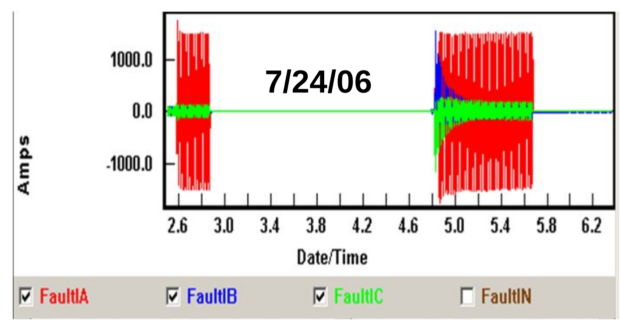
Example
Avoidable Outage – Without DFA

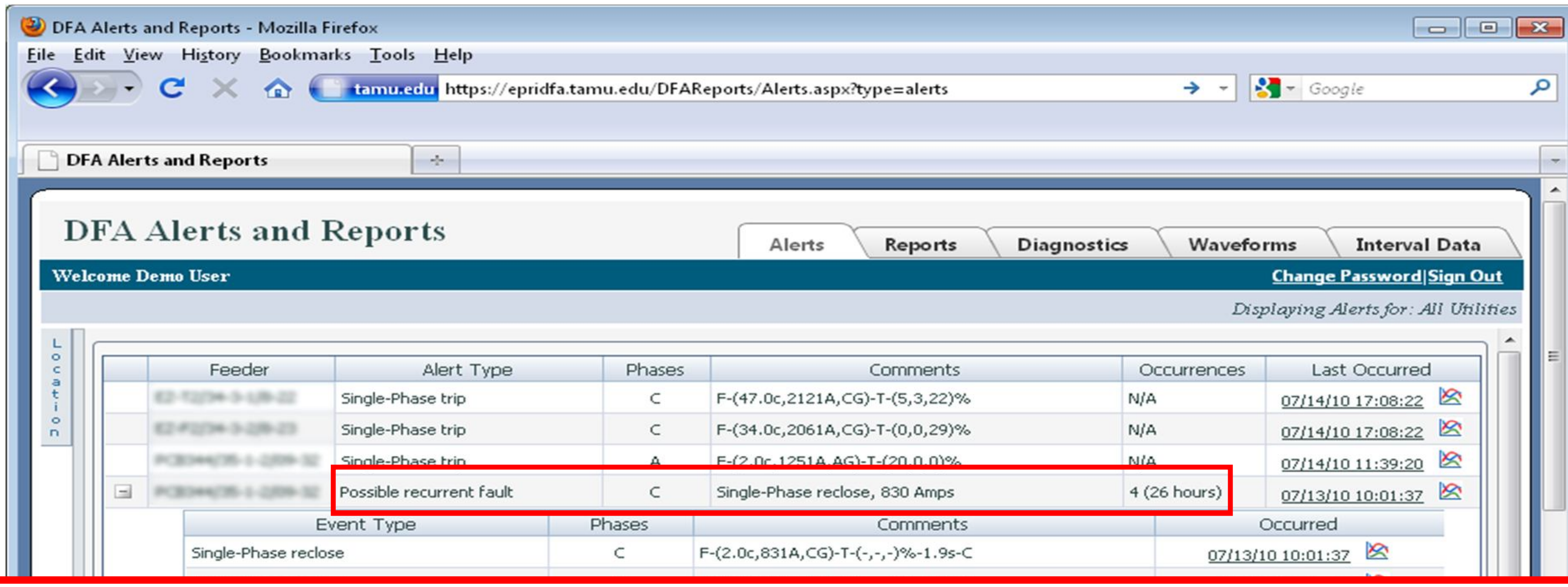
- 6/03/06 First fault; no outage
- 6/10/06 Second fault; no outage
- 6/17/06 Third fault; no outage
- 6/24/06 Fourth fault; no outage
- *6/28/06 Similar but unrelated fault*
- 7/04/06 Fifth fault; no outage
- 7/24/06 Sixth fault; outage
  - 35 minutes, 903 customers
  - 31,605 CMI







Example
Avoidable Outage – With DFA



Recurrent Fault:

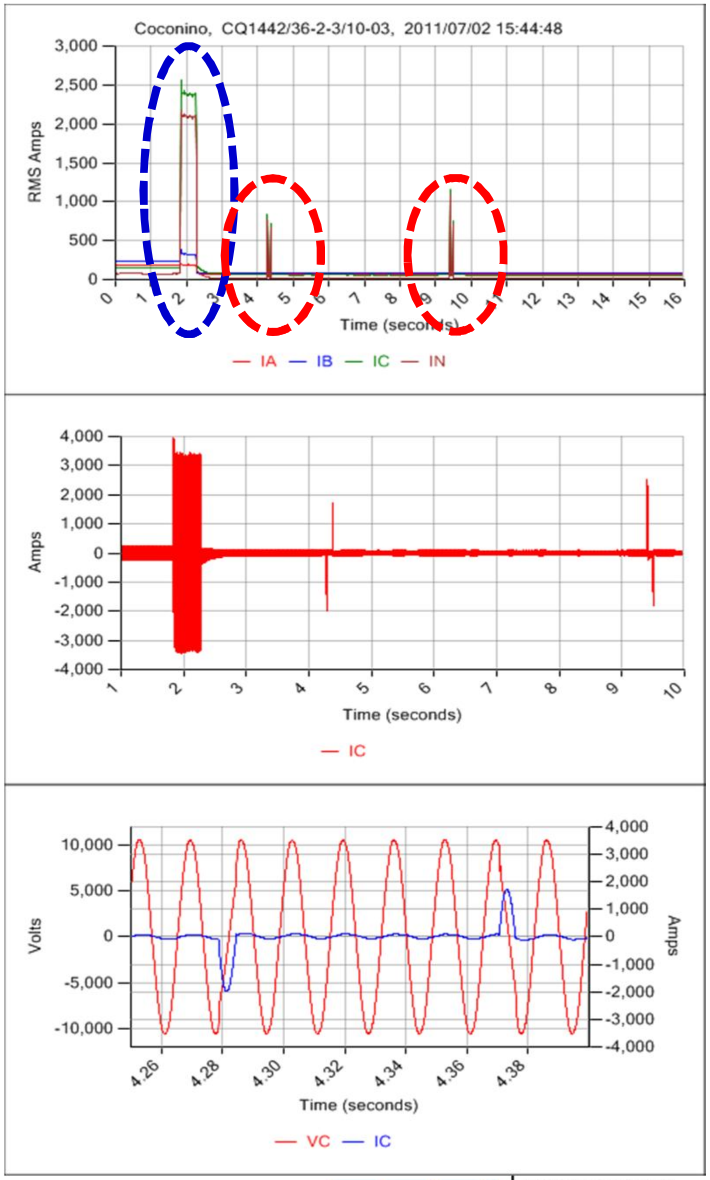
- DFA reported four individual faults, with recloser operations.
- DFA then identified that these four faults were the same fault.
- DFA also provided location information.

Example
Avoidable Outage – With DFA

DFA reported that problem existed and helped locate incipient fault. Outage was avoided.

Recent DFA Experiences

- Cable fault caused Intelligent pulse closer to trip 65% of feeder load.
- Device performed “pulse closes” after 2 seconds and again 5 seconds later, instead of full conventional recloses.
- Pulse closing indicated permanent fault, so device locked open.
- Pulse closing caused far less I^2t than full reclosing.
- DFA recordings enable validation of pulse closing and other advanced technologies.
- This information provides a basis for testing and improving location and diagnostic algorithms.



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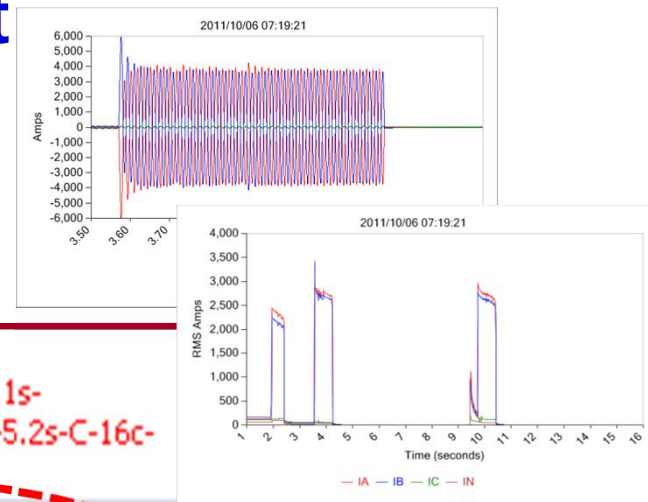
Pole Fire and Locked Out Circuit

- Customer reported a pole fire.
- Crew responded to the location pictured here, looking for a pole fire, but found none.
- At roughly the same time, a fault on the same circuit, but not near the reported pole fire, tripped a mid-point line recloser.
- The mid-point recloser should have isolated this fault, but the substation breaker tripped, too, and locked out the entire circuit.

Are these events related, or just coincidence? Does the “phantom pole fire” relate to the fault elsewhere on the circuit? Why did the substation breaker lock out the circuit?

Pole Fire and Locked Out Circuit



[illegible]	Possible conductor-slap	AB	Breaker trip F-(28.0c,2344A,AB)-1.1s- F-(40.5c,2861A,AB)-T-5.2s-C-16c- F-(41.0c,2780A,AB)-T	
[illegible]	Breaker trip	AB	F-(28.0c,2344A,AB)-1.1s- F-(40.5c,2861A,AB)-T-5.2s-C-16c- F-(41.0c,2780A,AB)-T	10/06/11 07:19:21

- DFA reported the fault, breaker lock out, and the operating sequence of the fault and protection system.
- DFA also recognized conductor slap and sent email alert.
- Putting DFA fault-estimates in system model indicated that the slap occurred within a few pole spans of the mystery pole fire.
- DFA also provided waveforms for further analysis.

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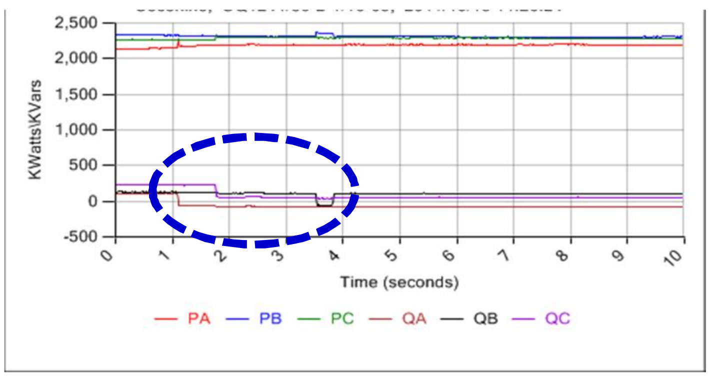
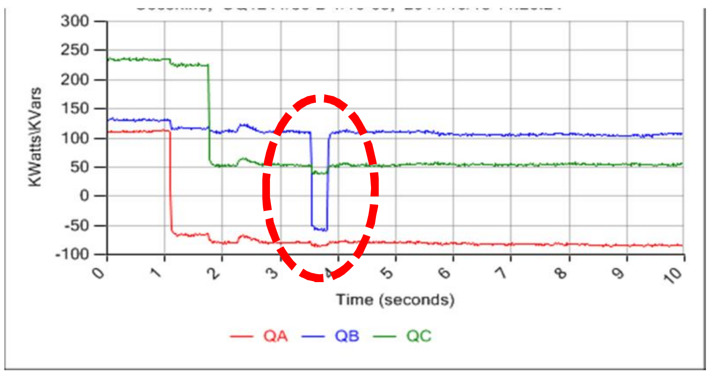
Pole Fire and Locked Out Circuit

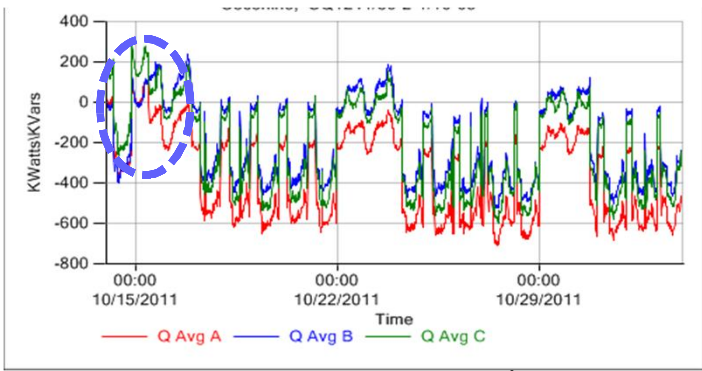
- DFA information directed the conductor-slap search near the reported pole fire, so utility inspected those spans again.
- Inspection identified arced wires, consistent with conductor slap.
- Conductor slap also would seem to explain layman's report of "pole fire."
- DFA has reported slap on multiple utility systems. Using DFA and system model alone has enabled utilities to locate those slapping conductors.
- Ancillary information, such as calls, also can assist search.
- Utility continues investigating the self-healing system's improper response. DFA provides holistic view for this study.

Real-Time Detection of Capacitor Failure

- DFA detected three-phase step-change in reactive power, with little change in real power, indicating capacitor switching.
- Time from phase-A closing to phase-C closing was 0.7 seconds, and from phase-C to phase-B was 1.7 seconds. This level of timing discrepancy is common and generally does not indicate a problem exists.
- 0.4 seconds after phase-B closed, it opened again and stayed off, indicating improper operation.
- Three weeks later, this 600 kVAR capacitor bank remains ON, but phase-B remains OFF.
- Field investigation and documentation have been requested.



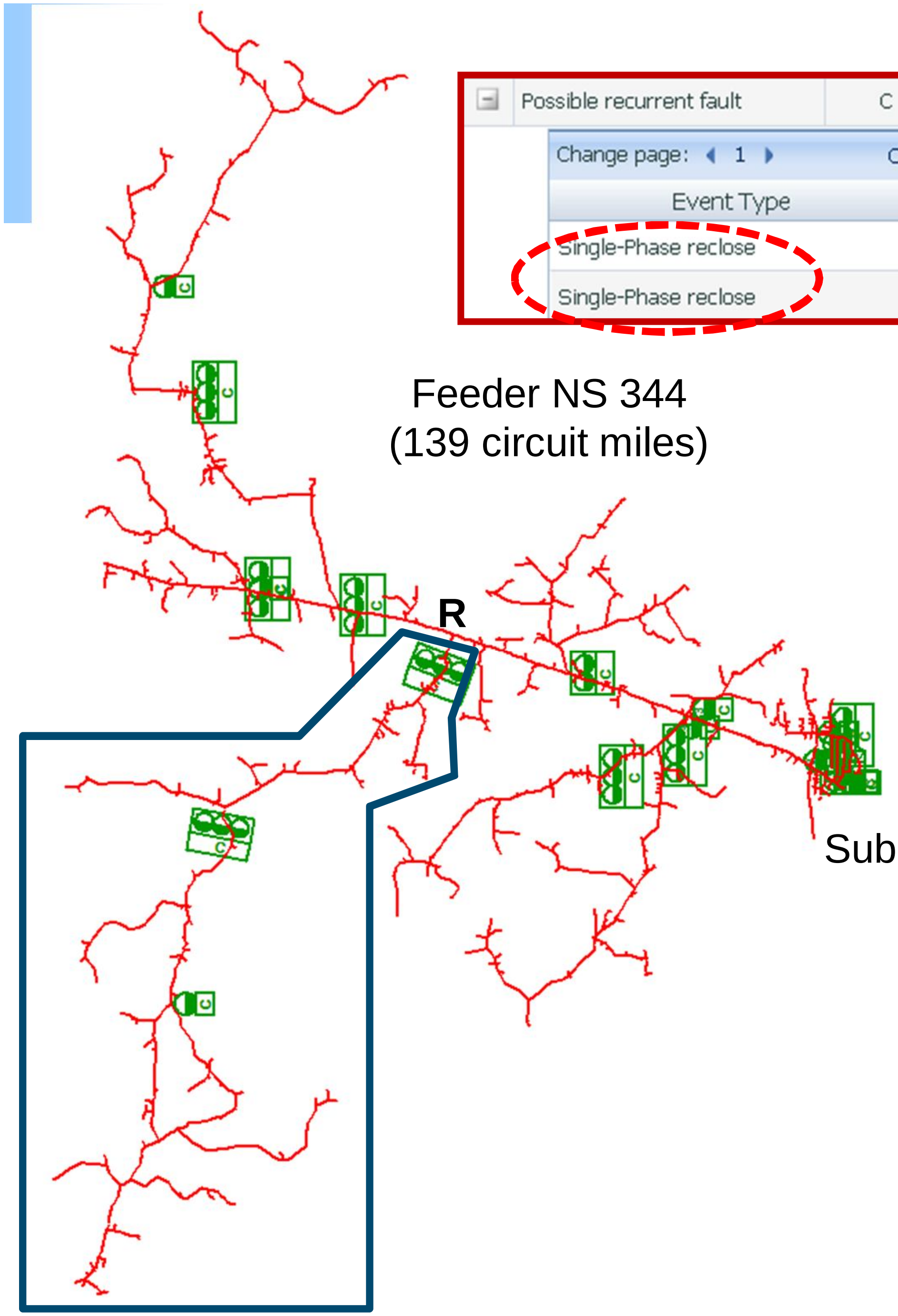




	Possible recurrent fault	C	Single-Phase reclose, 510 Amps	2 (18 days)	09/28/11 13:45:22

Change page: 1 | Change page: 1 Go | Page size: 2 Change | Displaying page 1 of 1, items 1 to 2 of 2.

Event Type	Phases	Comments	Occurred
Single-Phase reclose	C	F-(3.0c,510A,CG)-T-(0,0,19)%-2.1s-C	09/28/11 13:45:22
Single-Phase reclose	C	F-(3.0c,510A,CG)-T-(0,0,21)%-2.0s-C	09/10/11 14:19:25



Step 1: Learn of recurrent fault from DFA
Step 2: Compare DFA info to system model at various reclosers (e.g., recloser **R**)

- ✓ Protection
  - DFA: 1ø recloser
  - R_{Model}: Bank of 1ø hydraulic reclosers
- ✓ Momentary Load Interruption
  - DFA: 19-21% estimate
  - R_{Model}: 23% of load beyond **R**
- ✓ Reclosing Interval
  - DFA: 2-second interval
  - R_{Model}: Matches DFA information
- ✓ Conclusion: Failure is downstream of recloser R (26% of total feeder length).

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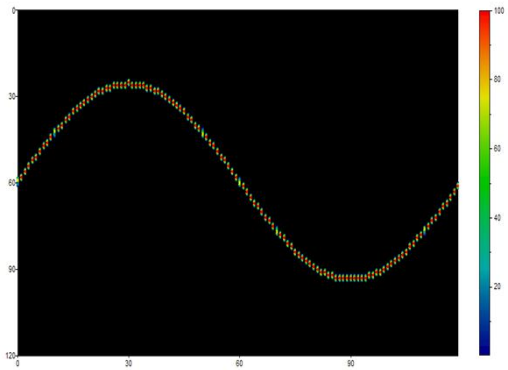
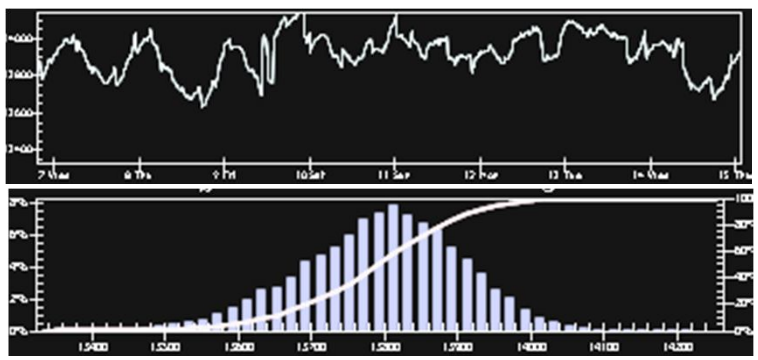
3. **Better visualization methodology for benchmarking power quality parameters over time**

Measure It – Model It – Explain It – Plan for or Remediate It

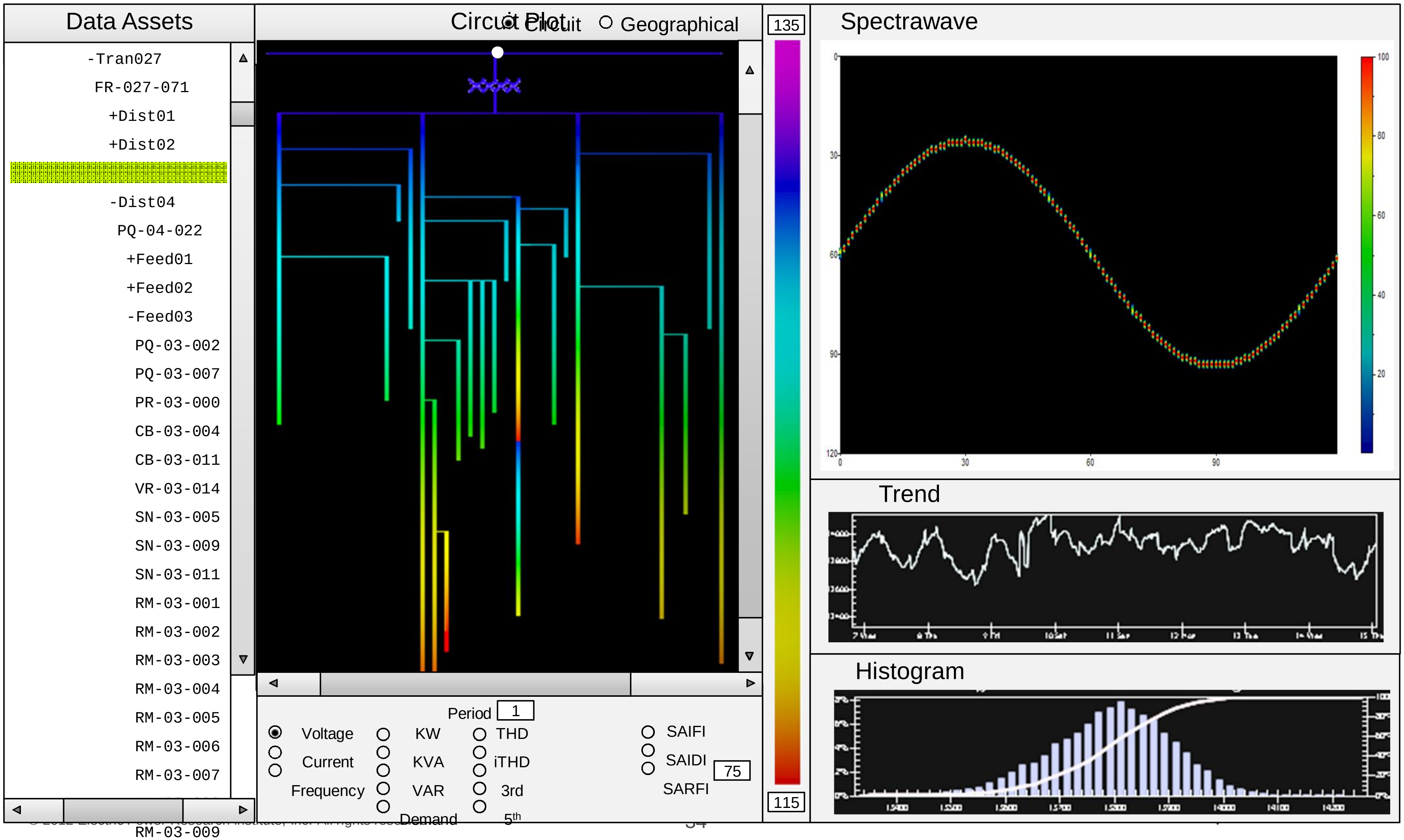
Better visualization methodology for benchmarking power quality parameters over time

- Another Component of the EPRI Power Quality Project Set
- Overall Research Objective
  – Develop state-of-the-art metrics and analytics for power quality
- Why is it valuable?
  – Provides state of the art analytics and visualization of PQ data and more structured and automated approaches to problem resolution
  – Develops a framework for customized (utility by utility) insights and visualization tool development

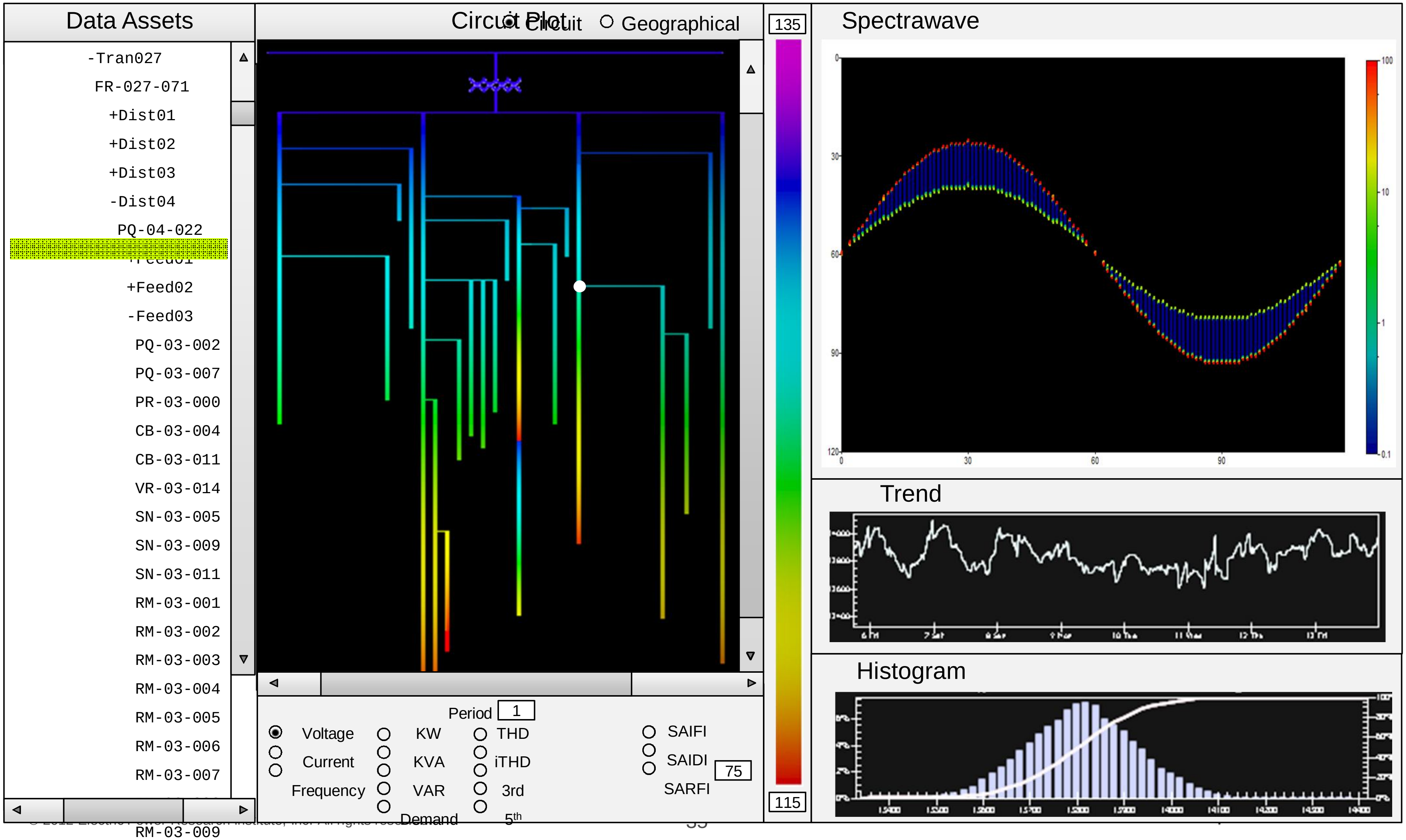




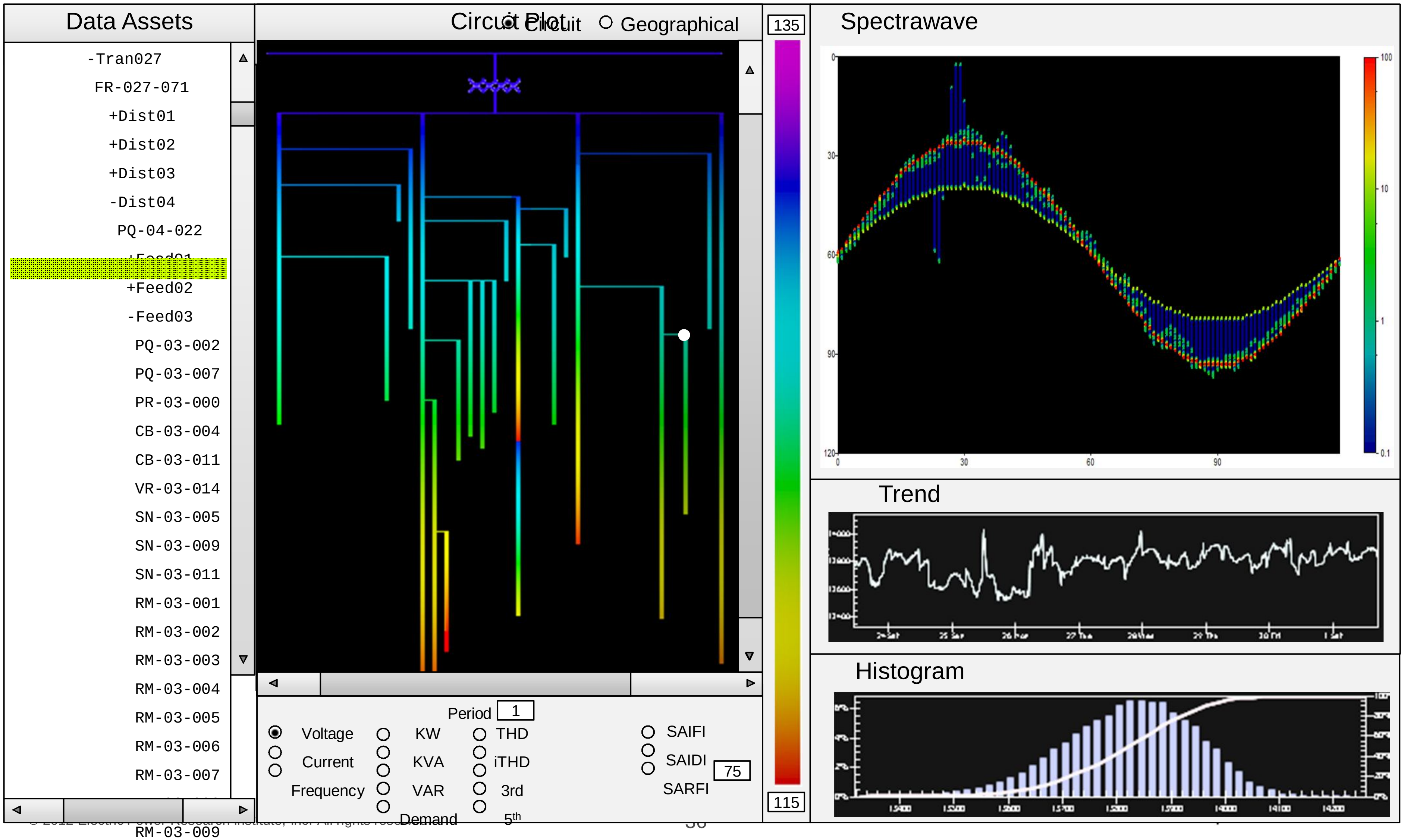
Better Feeder Level Visualization



Better Feeder Level Visualization



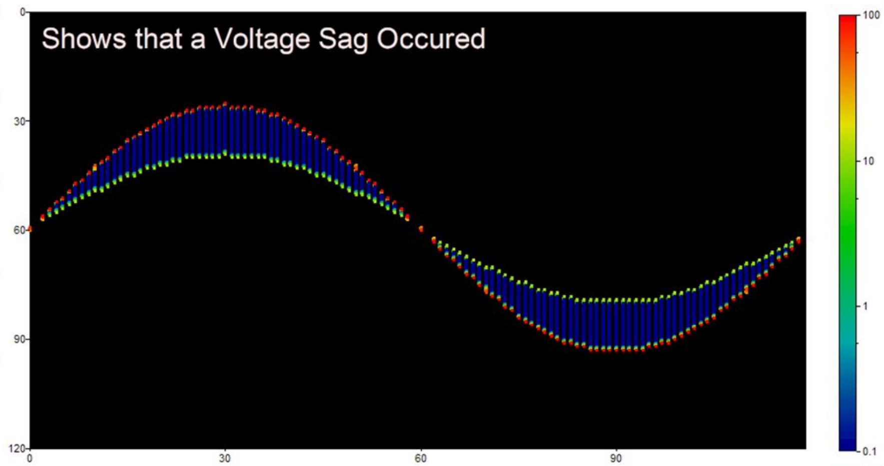
Better Feeder Level Visualization

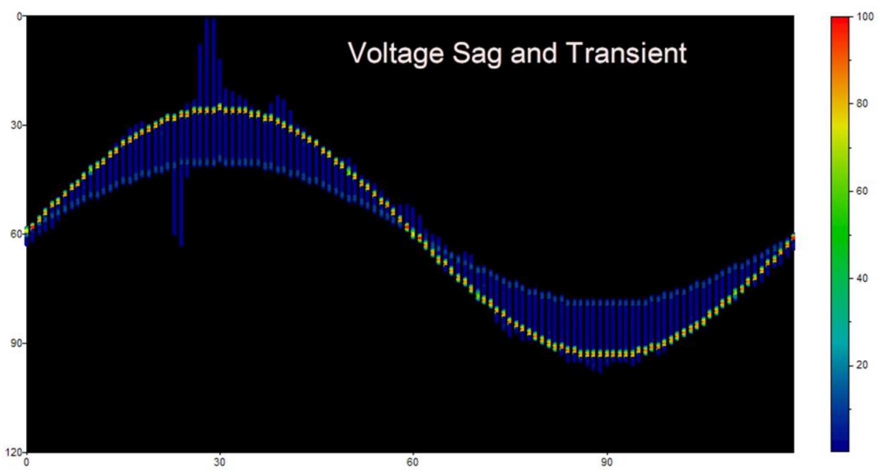


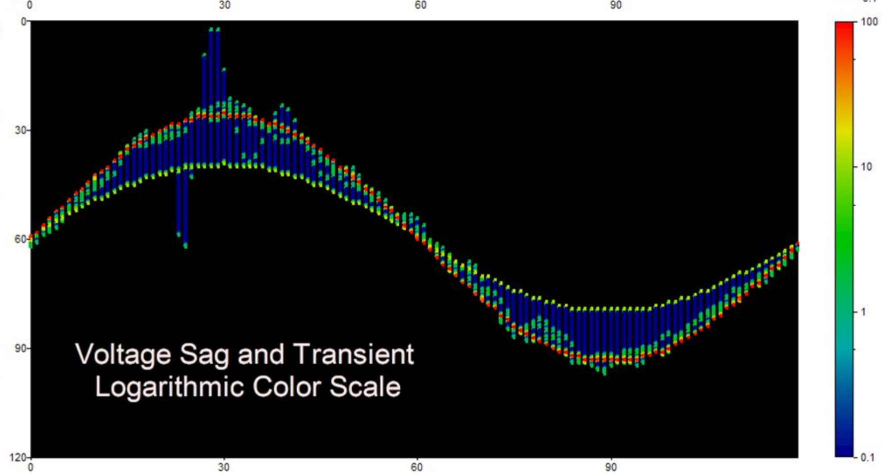
Advanced Compression and Optimization Techniques for PQ Resolution Data

Visualization Example

- Quick and efficient translations of current operations







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Conclusions:

- PQ Benefits from a Communications and “Sensorized” and “Smart” Electric Power Grid Enable:
  - Better metrics and understanding regarding electric power system performance
  - Automated methods for diagnosing power quality concerns and incipient failures
  - Data for system planners to understand the implications of new power electronic load proliferation over time
- Requirements for accomplishing such objectives:
  - More visually useful power quality data
  - Strategically placed voltage and current sensors
  - Advanced modeling tools

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