Experience with Synchrophasor-Only State Estimation at Dominion

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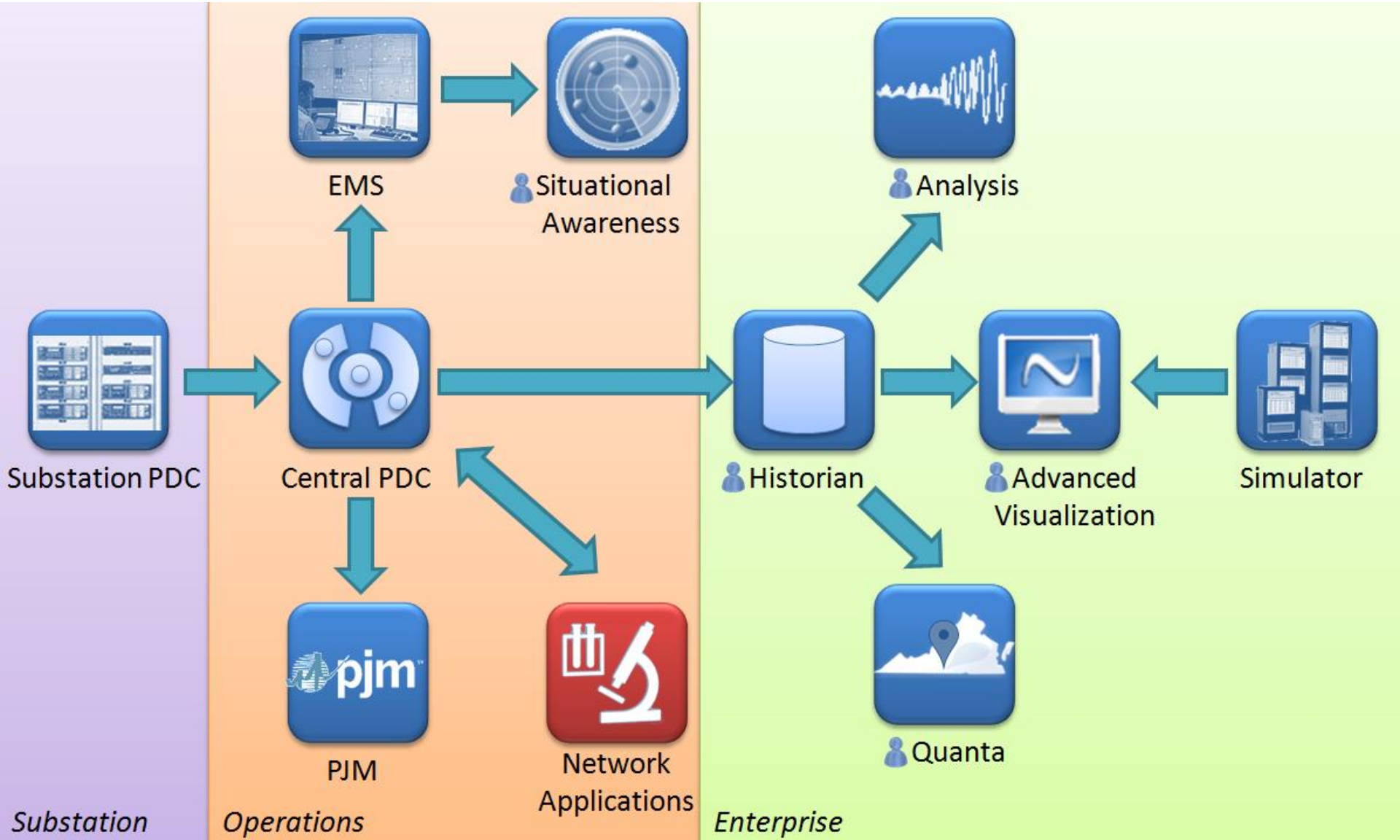
Highlights

- What have we done?
- How have we done it?
- How do we feel about it?
- What have we learned?
- What’s next?

Architecture



3φ Linear State Estimation

- Why state estimation? – polish & extend
- PMU-only SE appeared early in literature (1980)
  - Directly measuring system state
  - No scan times! No divergence!
    - SE availability is critical during stressed conditions
- Three phase is only way to get true (+, -, 0)

Our Implementation

- Dominion's 3ΦLSE operational since July 2012 with full build out in Summer 2013
- Synchrophasors in the context of a network model
  - Breaker/Switch model fully emulates information in the production state estimator
  - Network Model contains:
    - 107 Circuit Breakers
    - 216 Switches
    - 329 Nodes
    - 28 Substations
    - 30 Transmission Lines
- LSE and calibration leverage the network model

Source Code

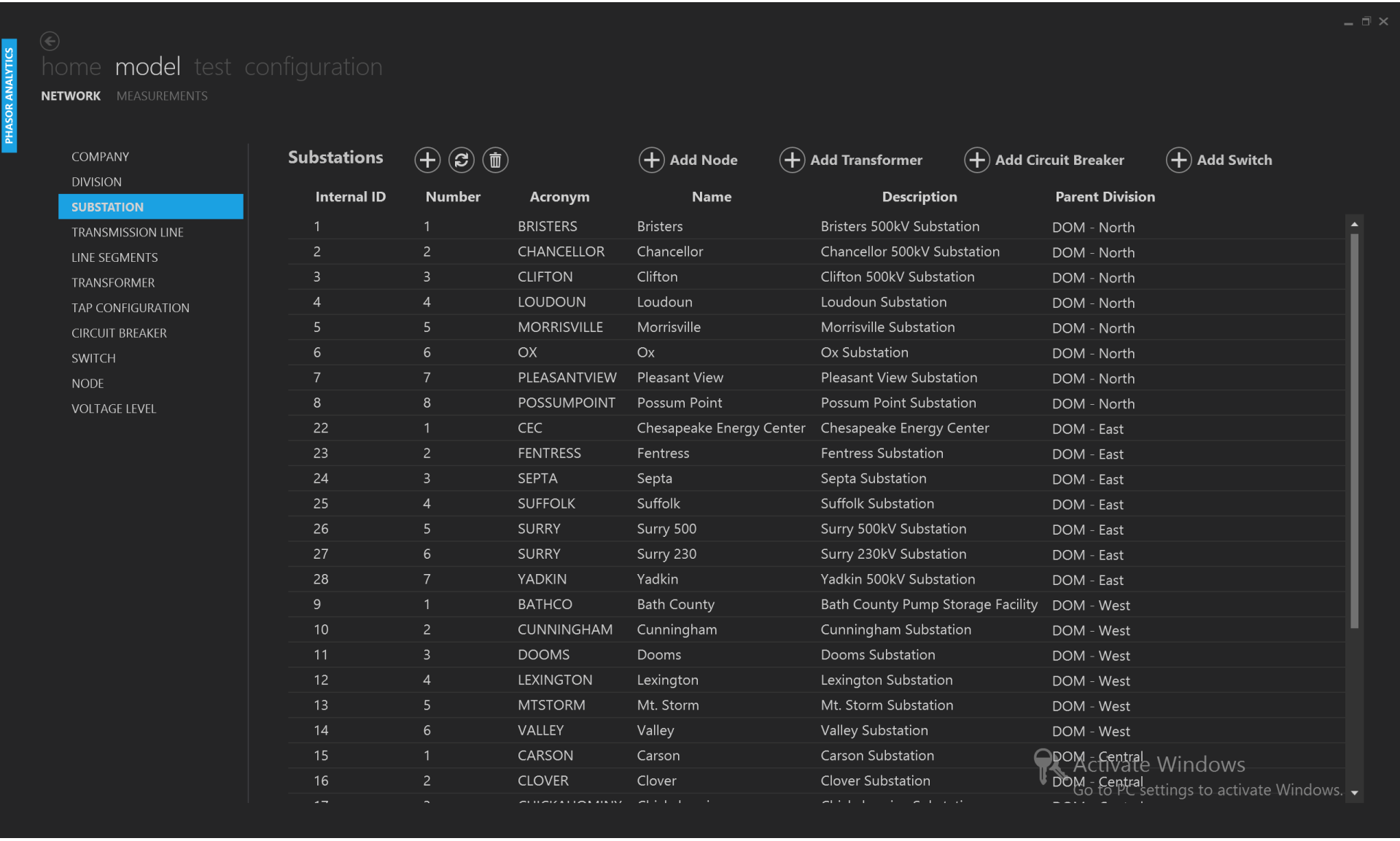
- First iteration – “Hey, it works! But man would this be hard to use or maintain…”
- Second Iteration – “You know what, I think we could really extract value from this and even other entities could use it!”
- Third Iteration – “This is what will carry us forward and there is value in sharing with others”

What's Inside?

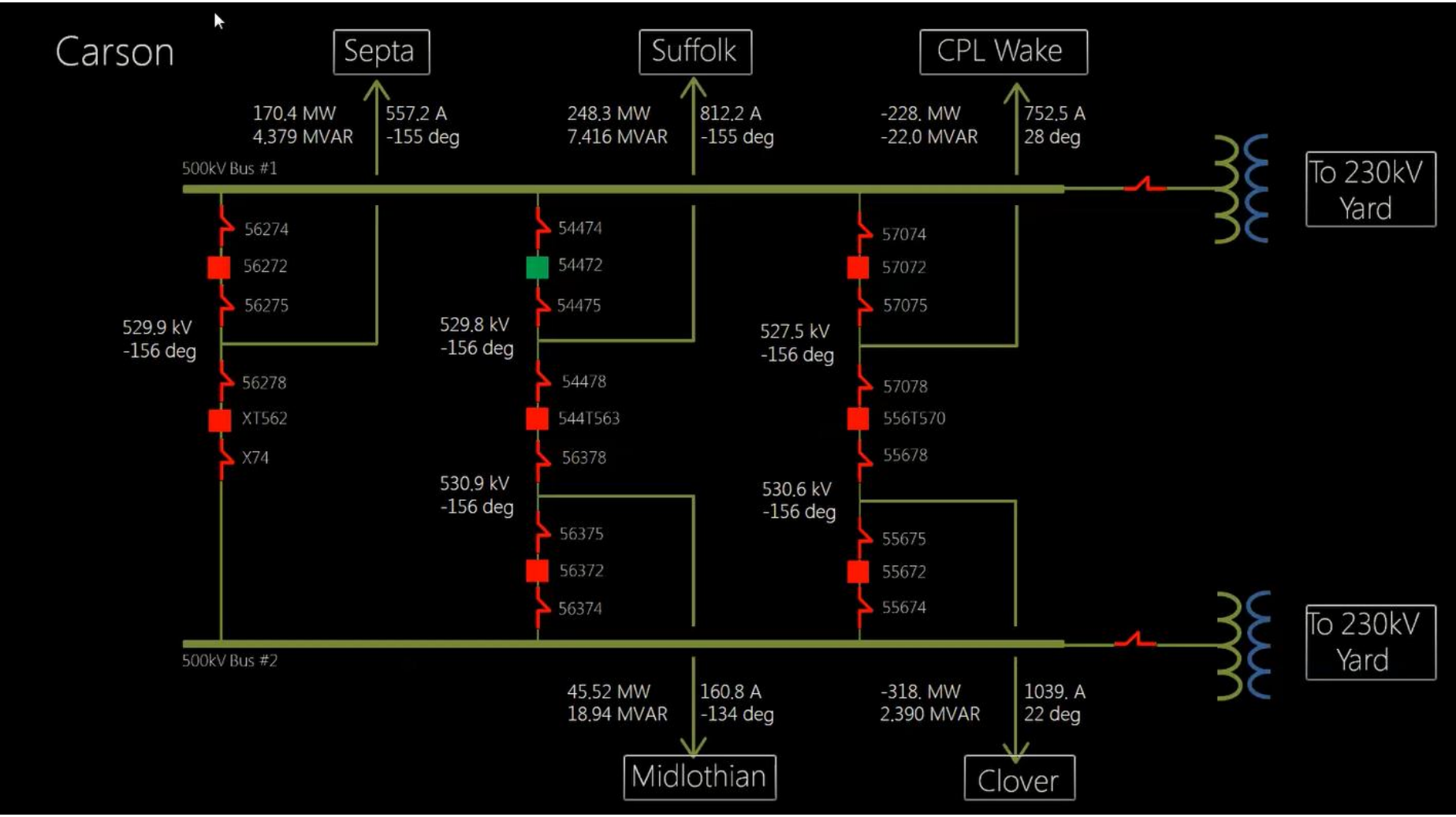
- Basic Bad Data Management & Plausibility Checks
- RCF/PACF correction with CT/PT calibration
- Handles computational and physical islands
  (think state estimation during black start)
- Built in P-Q Flow and (+, -, 0) component calculation

What's Inside?

- Fully extensible as synchrophasor footprint grows to encompass entire transmission network
- Applications and data model support system snapshots and measurement samples on schedules & on-demand
- GUI to support building network model and running calibration; Basic in-house visualizations



Framework is open source, Google “Modern UI for WPF”



In house visualization uses Subscription API extensively

Click to Return to Branch Summary Last Received Data at: 5:49:14 PM

Surry - Suffolk 254.1 MW → 14.25 MVAR ← 531	Dooms - Cunningham 377.2 MW → 14.56 MVAR → 534	Ox - Bristers 93634 MW → 0 MVAR → 539	FirstEnergy - PleasantView → → 543	Carson - Suffolk 254.9 MW ← 12.43 MVAR ← 544	Bristers - Morrisville → → 545	Bath Co. - Lexington 347.6 MW → 8.239 MVAR ← 547
Bath County - Valley 419.7 MW → 32.90 MVAR ← 548	Valley - Dooms 309.1 MW → 7.794 MVAR → 549	Chancellor - Bristers 149.2 MW → 20.05 MVAR ← 552A	Cunningham - Elmont 376.1 MW → 7.142 MVAR → 553	Dooms - Lexington 285.5 MW ← 8.104 MVAR ← 555	Clover - Carson 262.6 MW → 33.24 MVAR ← 556	Chickahominy - Elmont 175.5 MW ← 10.55 MVAR → 557
Loudoun - Pleasant View → → 558	Septa - Carson 151.8 MW ← 3.361 MVAR ← 562	Carson - Midlothian 51.00 MW ← 6.690 MVAR → 563	Suffolk - Yadkin 269.3 MW → 1.170 MVAR ← 565	Surry - Chickahominy 60.09 MW → 19.42 MVAR ← 567	Possum Pt - Ladysmith 293.9 MW ← 4.653 MVAR → 568	Loudoun - Morrisville 278.0 MW ← 11.86 MVAR → 569
Carson - Wake 146.9 MW ← 17.15 MVAR → 570	Possum Point - Ox 17.08 MW ← 81.40 MVAR ← 571	Morrisville - N. Anna 243.1 MW ← 27.50 MVAR → 573	Elmont - Ladysmith 45.06 MW → 10.96 MVAR → 574	N. Anna - Midlothian 96.84 MW → 56.58 MVAR ← 576	Surry - Septa 106.4 MW ← 17.30 MVAR → 578	Septa - Fentress 265.5 MW → 4.304 MVAR ← 579

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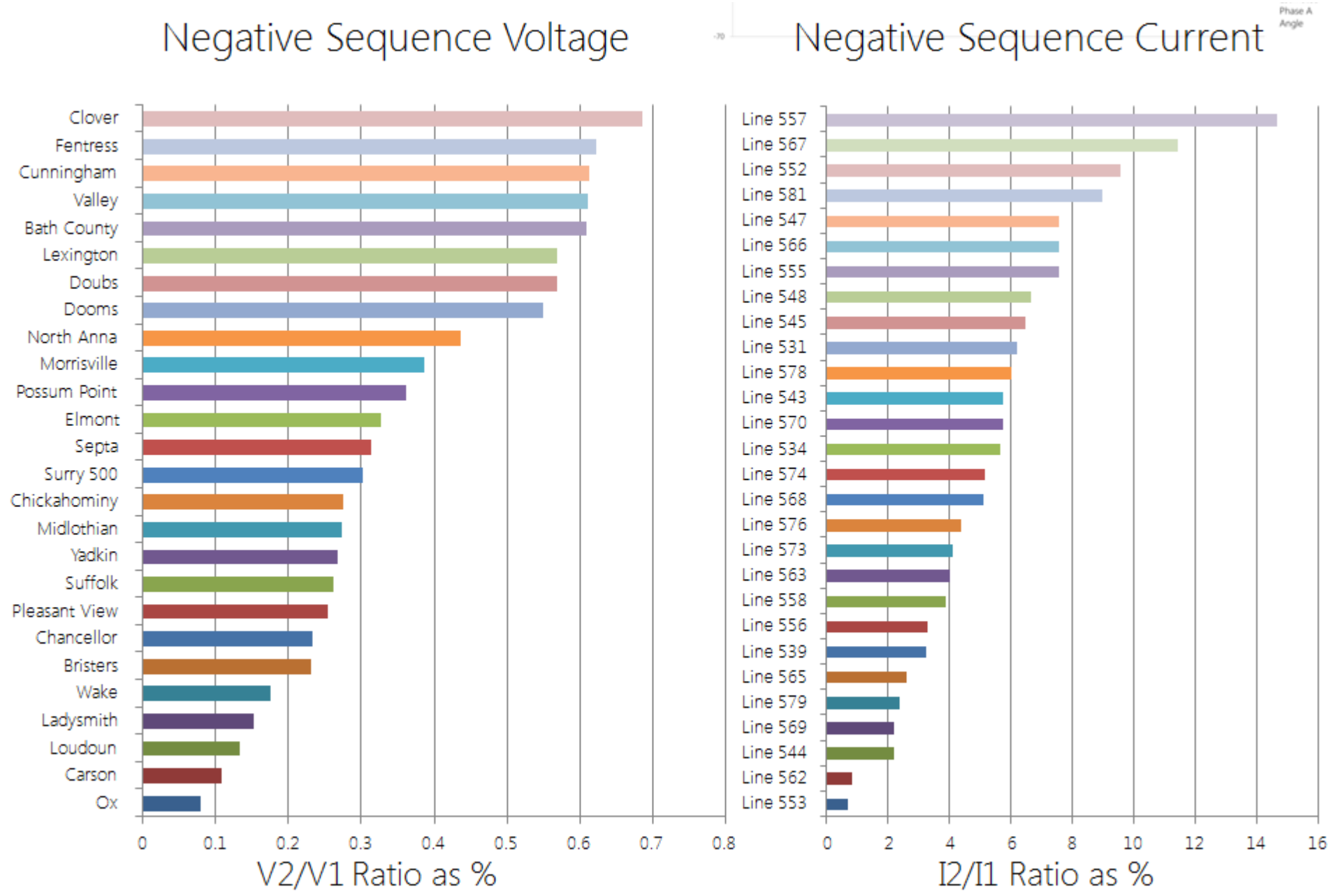
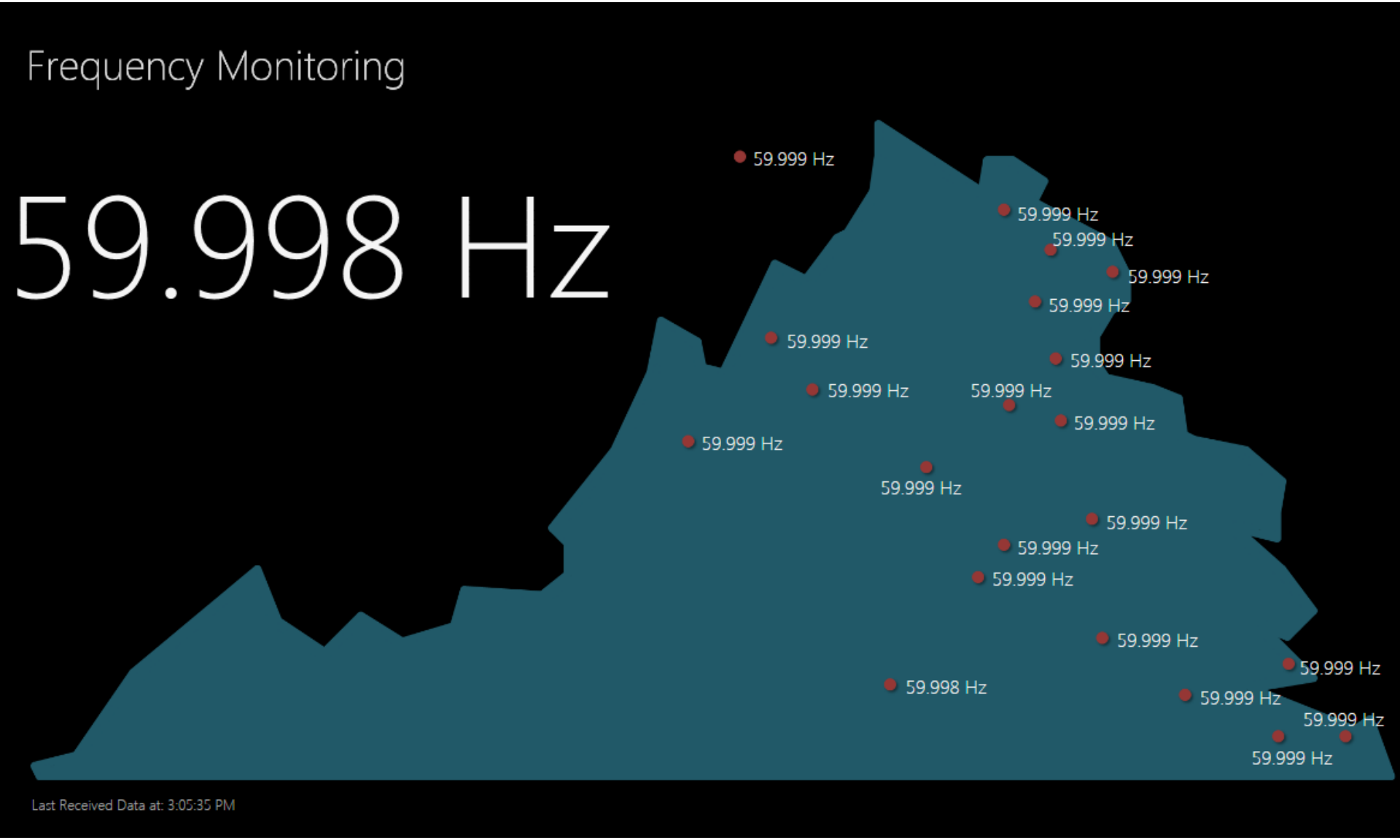
Sending End		Line		Receving End	
Surry		531		Suffolk	
A Phase Voltage:	529.0 kV 127 deg			A Phase Voltage:	528.5 kV 124 deg
A Phase Current:	776.5 A 125 deg			A Phase Current:	773.5 A -60 deg
A Phase Real Power:	237.0 MW			A Phase Real Power:	-235. MW
A Phase Reactive Power:	8.667 MVAR			A Phase Reactive Power:	-19.5 MVAR
B Phase Voltage:	531.1 kV 7 deg	I2/I1		B Phase Voltage:	528.8 kV 4 deg
B Phase Current:	747.2 A 11 deg	5.75%		B Phase Current:	750.9 A -174 deg
B Phase Real Power:	228.5 MW			B Phase Real Power:	-229. MW
B Phase Reactive Power:	-17.1 MVAR			B Phase Reactive Power:	5.242 MVAR
C Phase Voltage:	532.2 kV -112 deg			C Phase Voltage:	532.0 kV -115 deg
C Phase Current:	811.2 A -109 deg			C Phase Current:	809.0 A 64 deg
C Phase Real Power:	247.4 MW			C Phase Real Power:	-246. MW
C Phase Reactive Power:	-13.4 MVAR			C Phase Reactive Power:	0.636 MVAR


Negative Sequence Voltage
Clover
Fentress
Cunningham
Valley
Bath County
Lexington
Doubs
Dooms
North Anna
Morrisville
Possum Point
Elmont
Septa
Surry 500
Chickahominy
Midlothian
Yadkin
Suffolk
Pleasant View
Chancellor
Bristers
Wake
Ladysmith
Loudoun
Carson
Ox
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
V2/V1 Ratio as %
Negative Sequence Current
Phase A Angle
Line 557
Line 567
Line 552
Line 581
Line 547
Line 566
Line 555
Line 548
Line 545
Line 531
Line 578
Line 543
Line 570
Line 534
Line 574
Line 568
Line 576
Line 573
Line 563
Line 558
Line 556
Line 539
Line 565
Line 579
Line 569
Line 544
Line 562
Line 553
0
2
4
6
8
10
12
14
16
I2/I1 Ratio as %



SCADA brings us 3 good frequency measurements…

Going Forward

- LSE as EHV Observability Backup
  - Paralleled infrastructure
  - High availability
- Augmenting Production EMS
  - LSE output (Voltage magnitude, P-Q flows) as high accuracy pseudo measurements

Protecting Our Investment

- Homegrown solutions have intrinsic downfall
- DOE funded work is already public domain
- As a hedge against the future…
  - Use the open source model!
  - All source code and documentation available at: http://phasoranalytics.codeplex.com
  - Anyone with phasor data can use it with host openPDC
- Why Open Source?
  - Public Domain ≠ Open Source
  - Generating user base provides mechanisms for growth and support
  - University use dramatically increases use base and trains engineers of tomorrow

Thinking to the Future

- Computation
  - Pushing the current limitations of our architecture
  - Computational Burdens
    - (+, -, 0)
    - P-Q
    - Circuit Switches
- Host openPDC required
  - Large modeling burden for estimated values
  - Potentially sub-optimal system
- Lack of integrated database makes modeling tedious
- Stand-alone software desirable/necessary

Summary

- Production realization of PMU-only LSE
  - Industry first LSE; Industry first 3ΦLSE
- LSE as front end for PMU data consumers
- LSE can serve as EHV backup observability
- LSE & applications augment production EMS
- Real-time sequence component monitoring
- Not just a research project – want to move forward