- Turning 10 -

A Decade of Synchrophasor Technology at Dominion Energy

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April 16, 2019

NASPI – San Diego, CA

10-Year Anniversary

Our Synchrophasor Footprint

Analytics Philosophy

Cost of Experimentation

High Performance Sandbox

New Collaboration

Networking Lessons Learned

Contingency Plan

Use Case Development

On Cloud Nine

Sustainability

The Dream Team

Super User Workshops

Graduate Interns

Power Delivery Transformation

Building All the Things

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Some Historical Context

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History of Synchrophasors at Dominion

2009 – Kicked off synchrophasor initiative; DOE SGIG kickoff;

2012 – Began standardized relay/PMU sensor deployment

2013 – DOE SGIG Demonstration

- *Linear State Estimator v1.0 released as OSS*

2014 – CERTS Synchrophasor Data Conditioning and Validation Project

2015 – DOE FOA970 Kickoff

2017 – DOE FOA970 Demonstration

- *Linear State Estimator v2.0*

2017 – DFR PMU Conversion begins

- *Total transmission system coverage*

2019 – Scaling towards Sustainability

- High Performance Analytics Sandbox for Use Case Development

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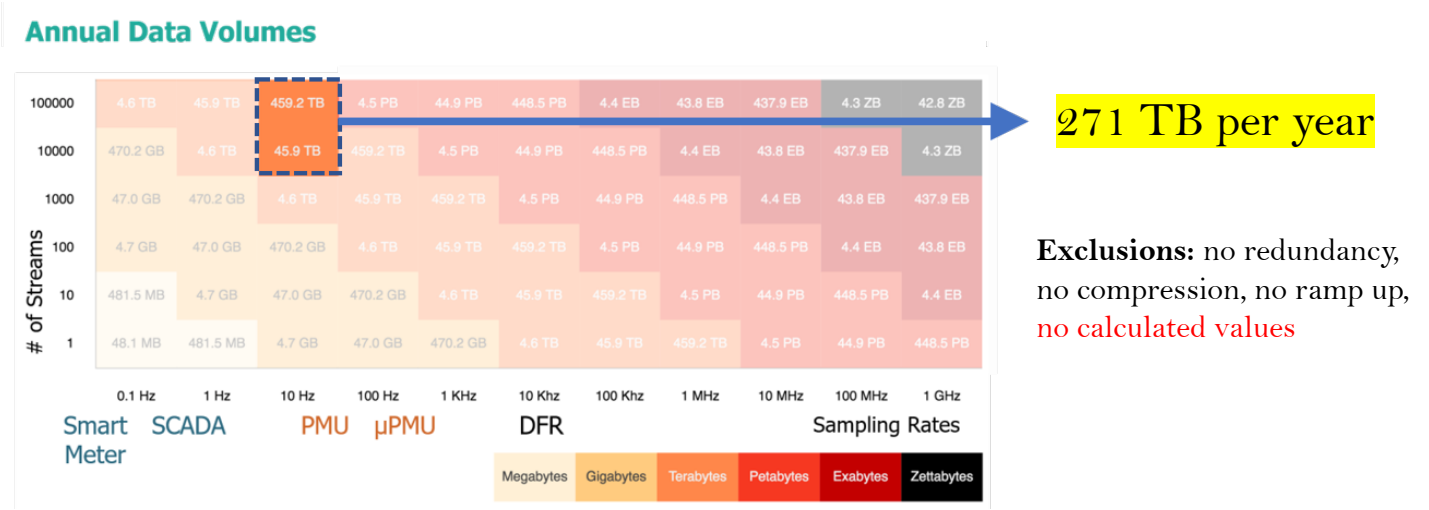
Grid Scale Synchrophasor Data

	Average Per DFR PMU	DFR-PMU EOY 2019 Total	Average Per Relay-PMU	Relay-PMU EOY 2019 Total	Total Measurements
Frequency	1	280	1	600	880
DFDT	1	280	1	600	880
Status	1	280	1	600	880
Voltage Magnitude	16	4,480	5	3,000	7,480
Voltage Angle	16	4,480	5	3,000	7,480
Current Magnitude	23	6,440	6	3,600	10,400
Current Angle	23	6,440	6	3,600	10,400
Digital	4	1,120	1	600	1,720
Analog	0	0	0	0	0
Totals	85	23,800	26	15,600	**39,400**



271 TB per year

Exclusions: no redundancy, no compression, no ramp up, no calculated values

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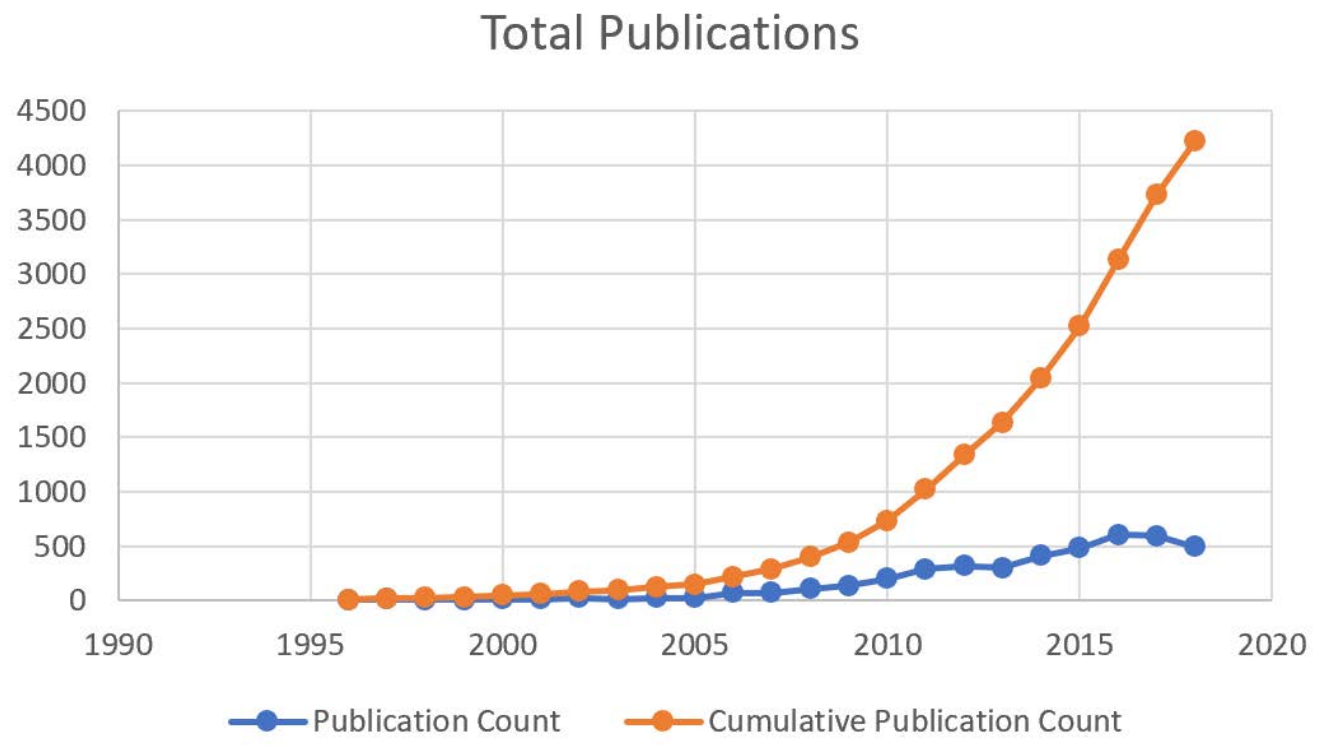
No Single Killer App for Everyone

The true realization of the synchrophasor value proposition will be as an ensemble of functionality, derived through experimentation, made progressively more ubiquitous.



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Searching for Use Cases

A priori

What *might* be useful to my business?

A posteriori

How do I address *this* issue/event?

Analytic Experimentation

What does the *data* tell me that I might not have think of or directly observe on my own?

Rapid prototyping and hypothesis testing!

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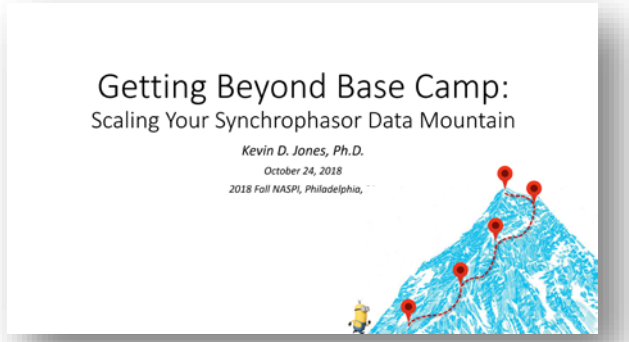
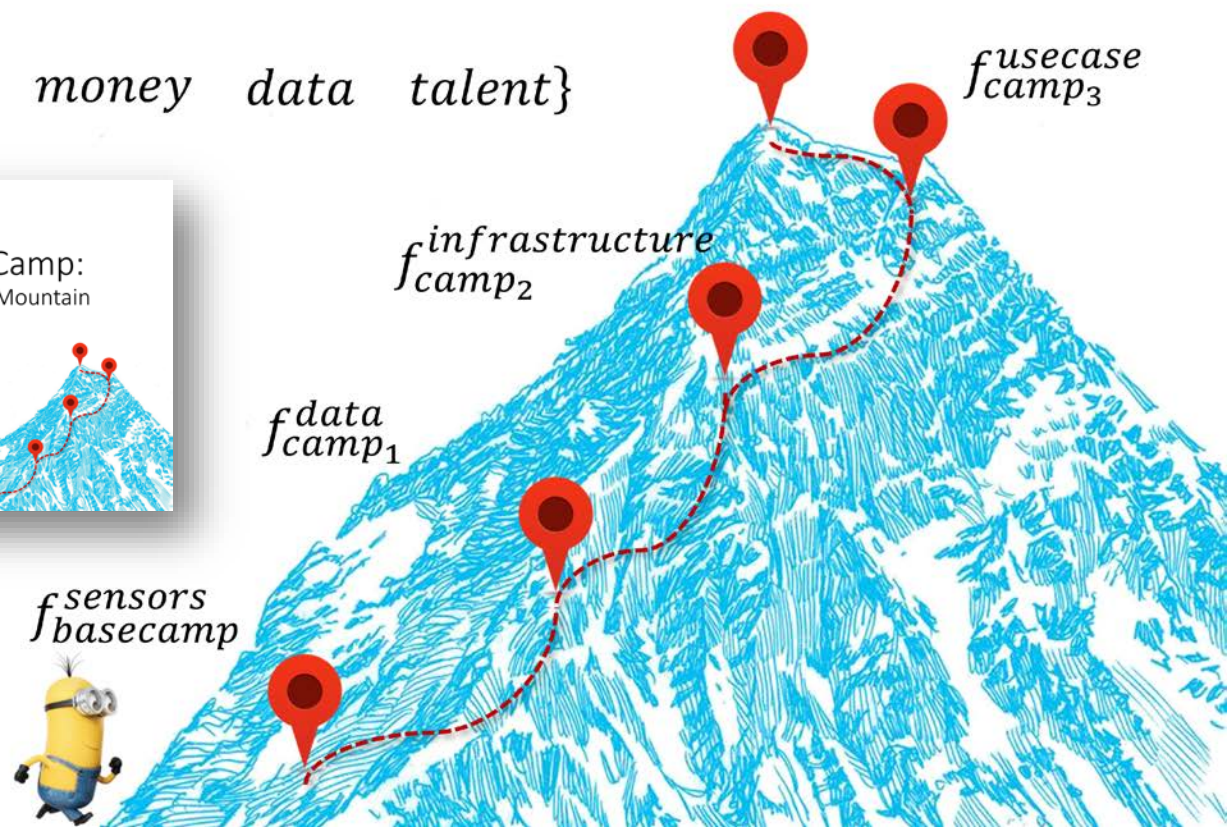
Scaling Mt. Synchrophasor

The common objective function for each dimension of scaling is to drive down the cost of analytic experimentation.

$$outcome = f_{system}^{metric}(resources)$$

$$resources = \{time \quad money \quad data \quad talent\}$$





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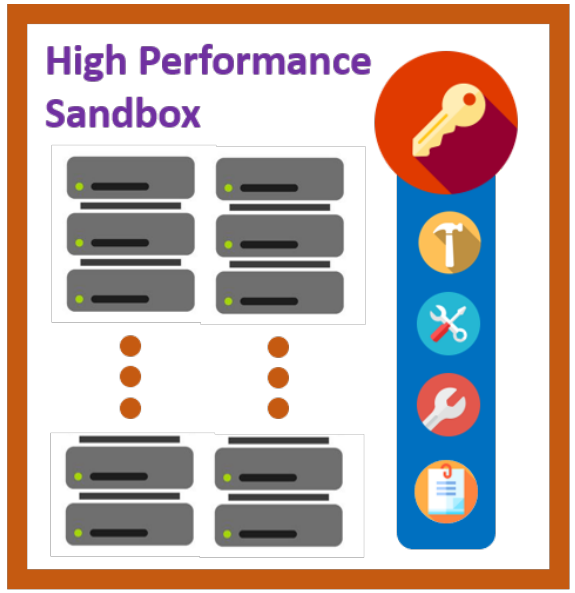
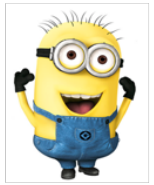
A Vision for a High Performance Sandbox

Business Owned/ Cloud Hosted

- Infrastructure exists in the cloud to provide best/fastest flexibility for growth
- On-demand resources for new-innovative efforts
- Open stack to provide best-in-class tooling for the analytic of interest





super-users

[analytic developers, data scientists]

- Growing numbers!
- Complex use cases
- LARGEST VALUE CREATION OPPORTUNITY

general purpose users

- Many in number
- Simple use cases
- Consume results of super-users
- Lower value creation opportunity

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Making the Sandbox a Reality

IT Capital Project kicked off January 2019

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Getting Connected

Many options were considered. The challenge was primarily adapting the dynamic, elastic environment of the cloud to Dominion's carefully managed on-prem network.

Long Term Solution:
Dedicated fiber to Cloud Exchange

Short Term Solution:
IPSec Tunnel from GovCloud to On-Prem

In the Works:
Lessons Learned Document

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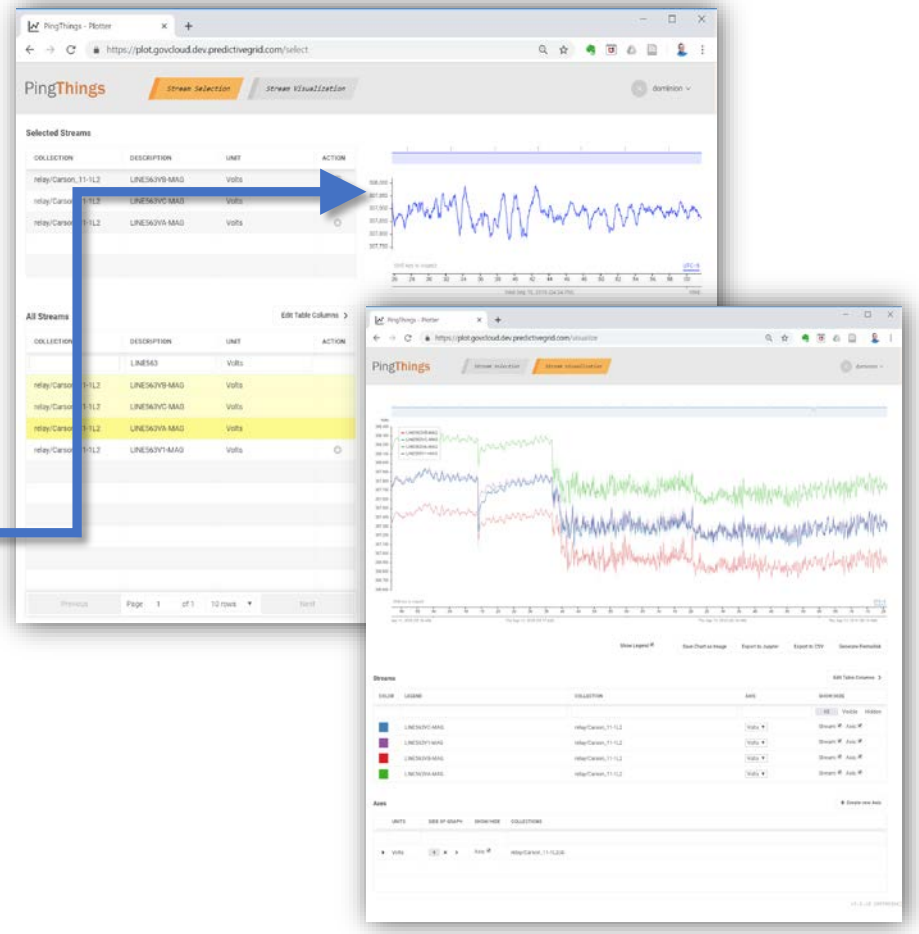
Expecting the Unexpected

Past experience suggested there would be delays.

How to get up and running as fast as possible?

In parallel, shipped historical data into dev-cluster to accelerate testing and early analytic development



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Early Use Case Exploration with PingThings

- SNR
- Angle Differencing/Baselining
- Phase Identification
- PCA FFT Anomaly Detection

Early focus on broadly applicable, low-level, descriptive analytics that can be built upon by others or used as high quality tutorial material.

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conduit: A Python Library for Common Power Engineering Stream Transformations

Metadata Annotations, Typed & Compound Streams, and Common, Low Level Transformations

- [C] Angle (Stream)
- [C] VoltageMagnitude (Stream)
- [C] VoltageAngle (Angle)
- [C] CurrentMagnitude (Stream)
- [C] CurrentAngle (Angle)
- [C] Phasor (StreamSet)
- [E] PhasorType
- [C] PhasorPair (StreamSet)
- [C] PhasorGroup (StreamSet)
- [C] PhasorGroupPair (StreamSet)
- [C] Digital (Stream)
- [C] BreakerStatus
- [E] BreakerStatusBit
- [C] StatusWord (Stream)
- [E] StatusWordBit
- [C] Frequency (Stream)
- [C] Dfdt (Stream)

Feature Coverage:

Per-Unitization; L-L, L-N; Calibration; Wrap/Unwrap; Bit-Extraction, Power Calculations, Symmetrical Components,

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Streaming Synchrophasor Data to the Cloud

We established our first stream of synchrophasor data to our instance of the PredictiveGrid hosted in AWSGovCloud on Wednesday, April 10, 2019.

For the history books:
The first PMU to be sent was from LynnHaven Substation.

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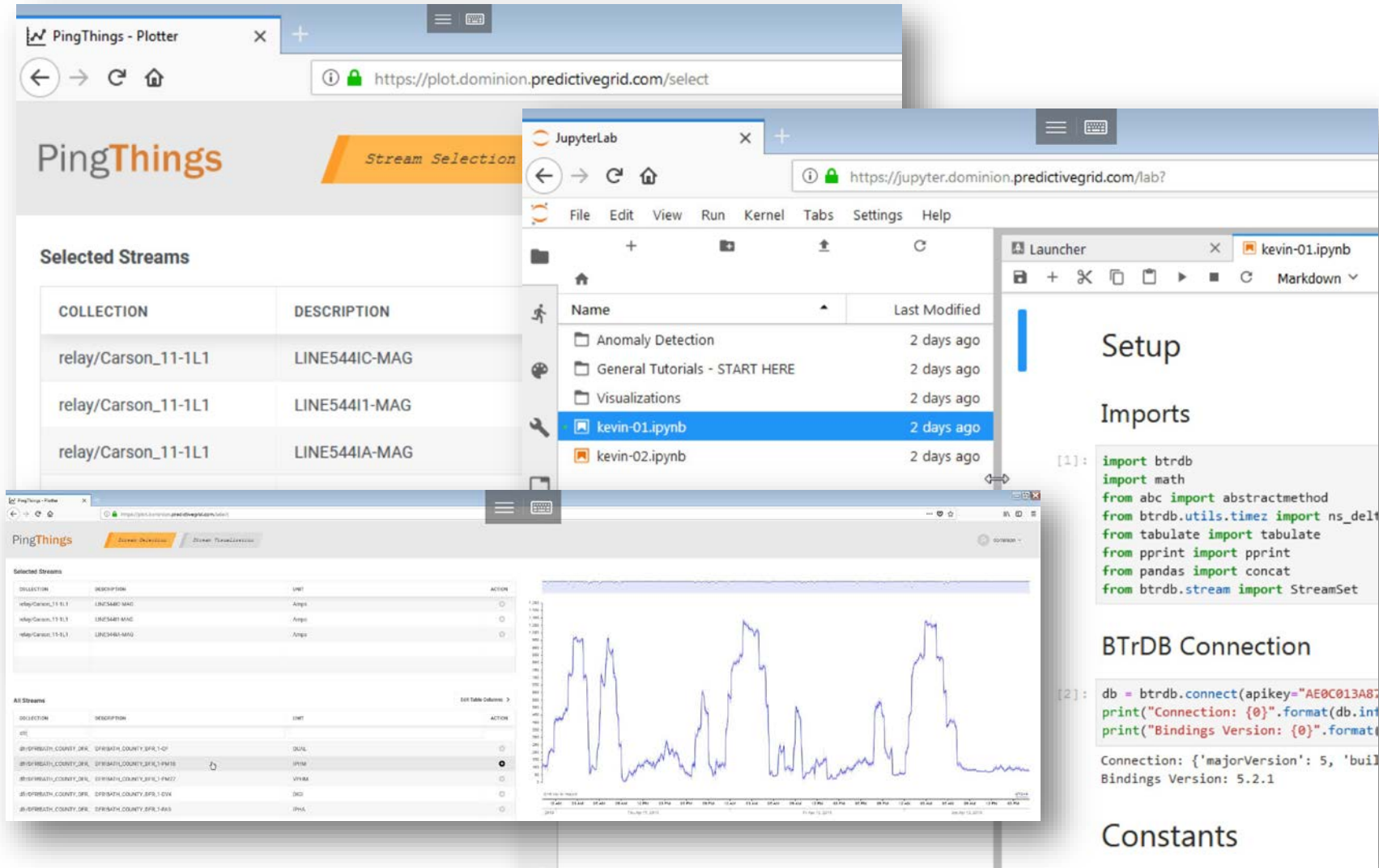

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Streaming Synchrophasor Data to the Cloud

How we are scaling:

40 signals →
400 signals →
4,000 signals →
Then linearly up to 40,000 signals
over a period of a few months

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The Need for Sustainability

We've been thinking about sustainability of our synchrophasor program since the beginning.

Grass roots initiatives must evolve beyond their originators.

Time is the greatest bottleneck.

(Non-uniform) Cultural barriers

With such a prolific footprint, sustainability again becomes a critical part of the conversation.

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Building a Team of Super Users

Eligibility: Deep SME from Graduate Power Systems Engineers, Developers

Broad Participation: Intradepartmental collaborators

- Transmission Special Studies
- Data Engineering
- Data Communication
- Fault Analysis
- T&D System Protection
- Operations Planning
- EMS Engineering
- Transmission Planning

Currently includes 18 individuals

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Building a Team of Super Users

Maximizing Creativity:
Completely voluntary participation. No mandate for what to produce. Incentivized to participate through community involvement.

High Level Guidance:
Small Steering committee to provide road-mapping/research support

Recruitment:
One-on-one and small group engagement;
No giant meetings.

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Workshops for Our Super Users

In concert with PingThings, we will be providing deep-dive workshops for our super users throughout the summer months on topics such as:

- Platform Features
- Data Exploration
- Working with the Python Language Bindings
- Data Science Libraries, Tools and Workflows
- Machine Learning and Deep Learning

All activities performed on our own data in our own system.

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Including Our Graduate Interns

Dominion has a strong graduate student intern program. Each summer we bring in as many as 10 students from across the country to work on real utility problems.

This summer, each student will have one of their projects as a synchrophasor analytics development project.

At the end of the summer, we always hold a report out where the students present to our Directors and Executives.

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Changes at Dominion

Ongoing *Power Delivery Transformation* Initiative

Building a culture of innovation

A new group will be formed this year to focus on data systems and analytic development.

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Descriptive → Predictive → Prescriptive

High Level Roadmap

Transmission Network KPIs

- Better informs planners, engineers, and leaders about overall system performance exposing success stories and opportunities for further investment in infrastructure.

Automated System Event Narrative Generation

- Improved organizational situational awareness
- Events and event statistics can become KPIs

Generator Model Validation, Parameter Identification

- Provides continuous refinements to simulation based future predictions impacting investment.

Equipment Health Monitoring, Awareness, & Management

- Improves safety
- Minimizes operational impact of failure

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Prioritized Analytic Domains*

- Basic Power Engineering Calculations
- **[Event Narrative]** Event/Anomaly Detection/Identification/Classification – This is foundational to many other analytic domains
- **[Event Narrative, KPIs]** Fault Detection/Classification/Location
- **[KPIs]** Voltage Stability
- **[KPIs]** Time Series Techniques
- **[KPIs]** Inertial Estimation
- **[KPIs, Modeling]** Topology Identification
- **[Modeling]** Generator & Load Model Validation, Parameter Identification
- **[KPIs, Event Narratives]** Cyber Security

* Based on the use case, deliverables include Jupyter Notebooks, Distillers, and/or Full-stack Applications

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QUESTIONS?

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