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Categorizing Applications Driven by Time-Synchronized Data

Spring NASPI

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Agenda

1. A First Attempt
2. Problem Statement
3. Motivation
4. The Johari Window
5. Proposed Ontology
6. Examples

ABSTRACT
The space of applications enabled by time-synchronized grid measurements is usefully described by the concept of the Johari Window, borrowed from psychology, which sorts characteristics known or unknown to oneself, and known or unknown to others, into four categories (open, blind, hidden, and unknown). In our context, we may consider well-known applications (such as oscillation detection and monitoring); applications whose mechanics are understood by the data science community but that have seen limited implementation in the industry (such as event detection and analysis); recognized needs by the industry that are not supported by available tools; and finally, those categories of data-driven applications of which we have not yet conceived and that may challenge and even invalidate fundamental industry assumptions.

This talk provides an overview of a multi-organization effort to build a hierarchy or ontology of use cases for applications driven by time synchronized grid sensors including transmission synchrophasors, distribution synchrophasors, and continuous point-on-wave (CPOW) devices. We present a grammar of data-driven use cases -- a way of deconstructing use cases into relevant defining characteristics to better understand and categorize each. Finally, we explore and discuss the industry and market dynamics that drive value creation from grid sensors for electric utilities. These drivers explain why vendors and other participants in the industry have favored certain types of applications while other categories have been largely ignored.

SYNCHROPHASOR TECHNOLOGY
FURTHER READING


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Article

A Novel Framework for Synchrophasor Based Online Recognition and Efficient Post-Mortem Analysis of Disturbances in Power Systems

Andre Kummerow [1,2,*], Cristian Monsalve [1], Christoph Brosinsky [2], Steffen Nicolai [1] and Dirk Westermann [2]

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[2] Institute for Electrical Energy and Control Technology, Technische Universität Ilmenau, Gustav-Kirchhoff-Strasse 1, 98693 Ilmenau, Germany; christoph.brosinsky@tu-ilmenau.de (C.B.); dirk.westermann@tu-ilmenau.de (D.W.)
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Featured Application: Synchrophasor based data compression and post-mortem analysis as well as online detection and classification of grid disturbances.

Abstract: Synchrophasor based applications become more and more popular in today's control centers to monitor and control transient system events. This can ensure secure system operation when dealing with bidirectional power flows, diminishing reserves and an increased number of active grid components. Today's synchrophasor applications provide a lot of additional information

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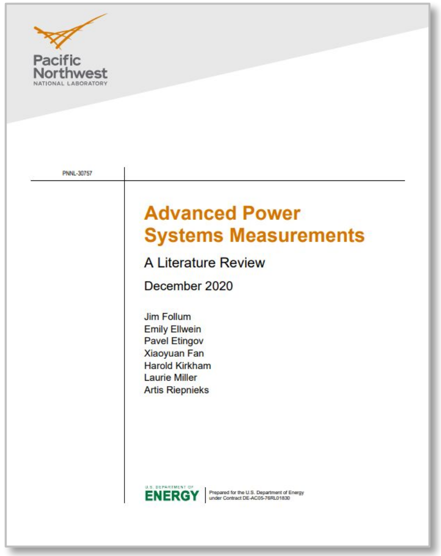
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Advanced Power Systems Measurements

A Literature Review

December 2020

Jim Follum
Emily Ellwein
Pavel Etingov
Xiaoyuan Fan
Harold Kirkham
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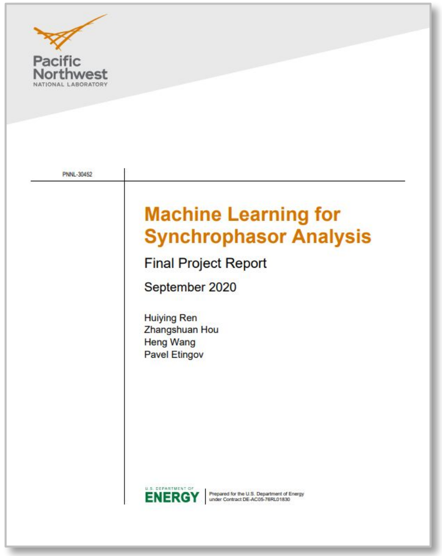
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Machine Learning for Synchrophasor Analysis

Final Project Report

September 2020

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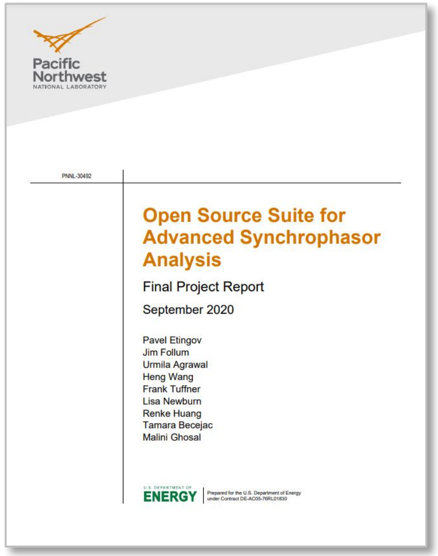
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Final Project Report

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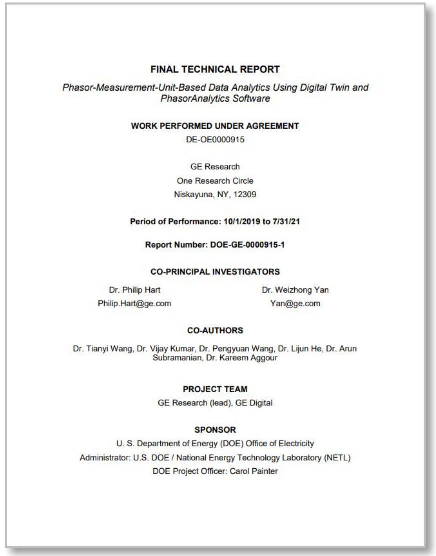
FINAL TECHNICAL REPORT
Phasor-Measurement-Unit-Based Data Analytics Using Digital Twin and PhasorAnalytics Software

WORK PERFORMED UNDER AGREEMENT
DE-OE0000915

GE Research
One Research Circle
Niskayuna, NY, 12309

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Administrator: U.S. DOE / National Energy Technology Laboratory (NETL)
DOE Project Officer: Carol Painter


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STANDARDS ASSOCIATION

IEEE Guide for Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control

STANDARDS

IEEE Power and Energy Society

Developed by the
Power System Relaying and Control Committee

IEEE Std C37.242™-2021
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ELSEVIER

State-of-the-art of data collection, analytics, and future needs of transmission utilities worldwide to account for the continuous growth of sensing data

Felix Rafael Segundo Sevilla [a,*], Yanli Liu [b], Emilio Barocio [c], Petr Korba [a], Manuel Andrade [d], Federica Bellizio [e], Jorrit Bos [f], Balarko Chaudhuri [e], Hector Chavez [g], Jochen Cremer [h], Robert Eriksson [i], Camille Hamon [j], Miguel Herrera [k], Marnick Huijsman [f], Michael Ingram [l], Danny Klaar [f], Venkat Krishnan [l], Jorge Mola [m], Marcos Netto [l], Mario Paolone [n], Panagiotis Papadopoulos [o], Miguel Ramirez [a], Jose Rueda [h], Walter Sattinger [p], Vladimir Terzija [q], Simon Tindemans [h], Alberto Trigueros [k], Yajun Wang [r], Junbo Zhao [s]

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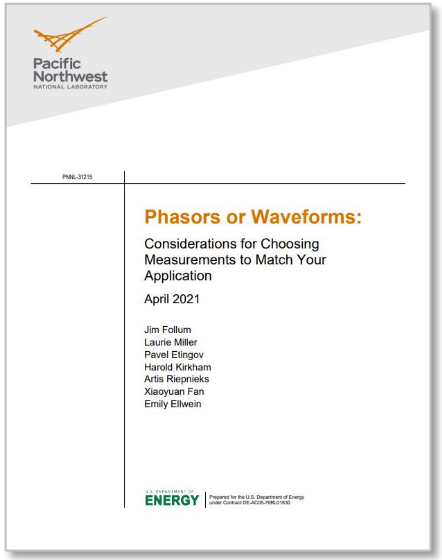
ABSTRACT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PNNL-31215

Phasors or Waveforms:

Considerations for Choosing Measurements to Match Your Application

April 2021

Jim Follum
Laurie Miller
Pavel Etingov
Harold Kirkham
Artis Riepnieks
Xiaoyuan Fan
Emily Ellwein

U.S. DEPARTMENT OF ENERGY
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Review

Research Trends and Applications of PMUs

Gian Paramo [1,*], Arturo Bretas [2] and Sean Meyn [1]

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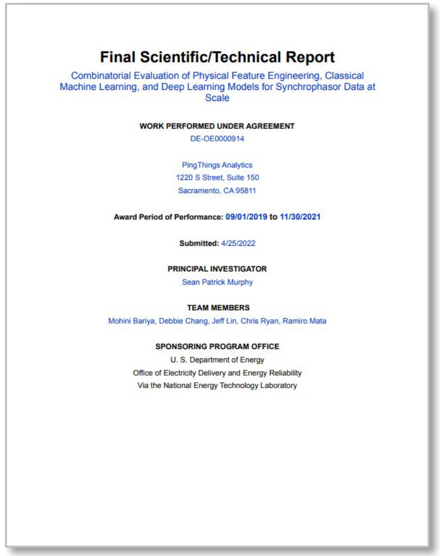
Abstract: This work is a survey of current trends in applications of PMUs. PMUs have the potential to solve major problems in the areas of power system estimation, protection, and stability. A variety of methods are being used for these purposes, including statistical techniques, mathematical transformations, probability, and AI. The results produced by the techniques reviewed in this work are promising, but there is work to be performed in the context of implementation and standardization. As the smart grid initiative continues to advance, the number of intelligent devices monitoring the power grid continues to increase. PMUs are at the center of this initiative, and as a result, each year more PMUs are deployed across the grid. Since their introduction, myriad solutions based on PMU-

1. Introduction


Final Scientific/Technical Report

Combinatorial Evaluation of Physical Feature Engineering, Classical Machine Learning, and Deep Learning Models for Synchrophasor Data at Scale

WORK PERFORMED UNDER AGREEMENT
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PingThings Analytics
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SYNCHROPHASOR TECHNOLOGY
USE CASE TAXONOMY

*Each **category** is mapped to one or more **use cases**, and each **use case** is mapped to one or more **objective.** Further, each **use case** is assigned applicability to the transmission system (T), distribution system (D) or both (T&D). Use cases that only pertain to D are omitted from these slides.*

Category	Use Case	Monitoring	Control	Planning	Analysis	T or D
Wide area visualization	Improved wide area situational awareness (T&D)	X				T&D
	Integration of customer site FNET information	X		X	X	T&D
	Visualization of dynamic system response	X	X	X	X	T&D
Technical and commercial loss reduction	Energy accounting			X		T&D
Real-time distribution system operation	Distribution state estimation				X	T&D
Power quality assessment and analysis	Flicker measurement	X				T
	Harmonic state estimation/diagnosis	X	X			T
	Harmonics measurement	X				T
	Short-duration interruption measurement	X				T
	Voltage and current imbalance measurement	X				T
	Voltage sag and swell measurement	X				T
Integrated Gen, Tx, and Dx system planning & analysis	Integrated Gen, Tx, and Dx system planning & analysis		X	X	X	T&D
Improved stability management	Control instability, hunting, or oscillation detection - voltage, var, switching	X	X			T&D
	Fault Induced Delayed Voltage Recovery (FIDVR) detection	X			X	T
	Voltage stability monitoring and control				X	T&D
Improved load shedding schemes	Improved load shedding schemes - frequency		X			T
	Improved load shedding schemes - load flow based		X			T
	Improved load shedding schemes - voltage		X			T
	Load shedding real time compensative arming to balance 1547 compliant PV		X			T
High-accuracy fault detection and location	Falling conductor protection			X		T
	High accuracy fault location	X			X	T
	High impedance fault location	X			X	T
	Incipient fault & failure detection	X			X	T
	Open conductor fault detection	X			X	T
Distribution load, DER, and EV forecasting	DER forecasting			X	X	T&D
	EV forecasting			X	X	T&D

SYNCHROPHASOR TECHNOLOGY
USE CASE TAXONOMY

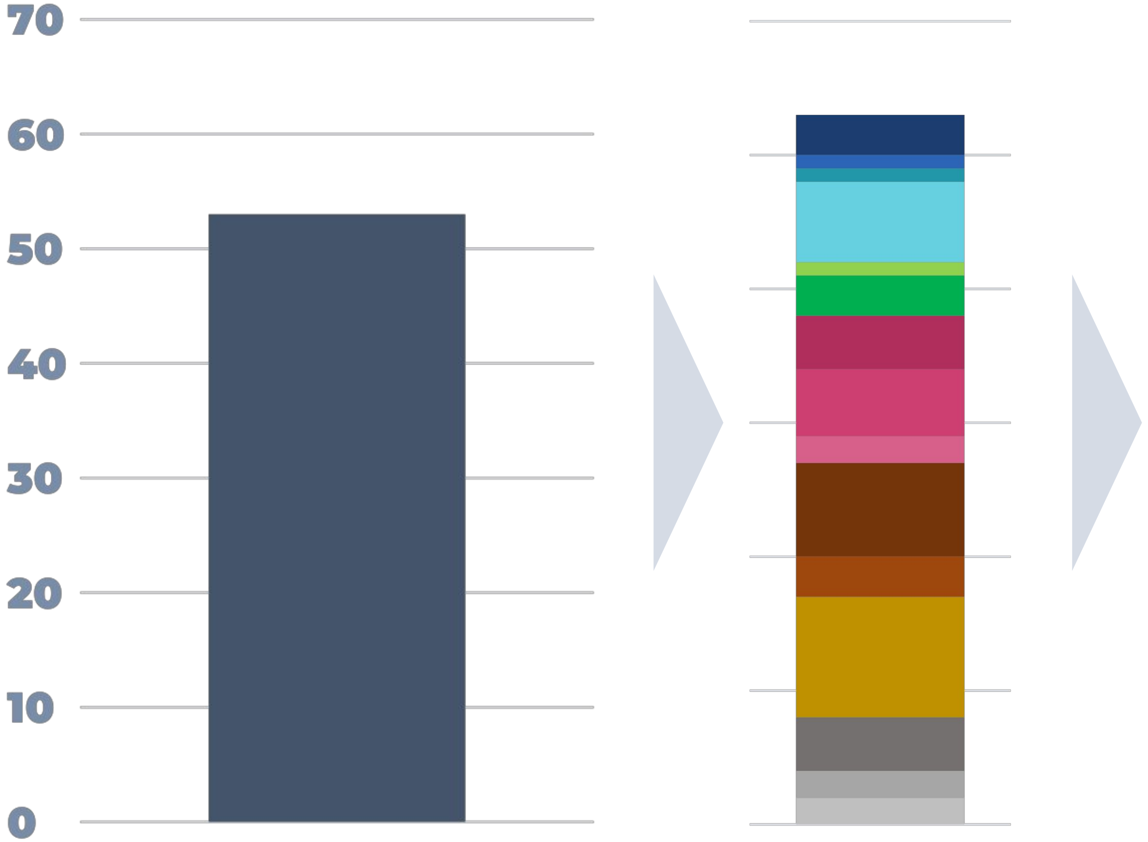
*Each **category** is mapped to one or more **use cases**, and each **use case** is mapped to one or more **objective.** Further, each **use case** is assigned applicability to the transmission system (T), distribution system (D) or both (T&D). Use cases that only pertain to D are omitted from these slides.*

Category	Use Case	Monitoring	Control	Planning	Analysis	T or D
DER integration	Active and reactive reverse power flow management	X	X	X		T&D
	DER management and energy balancing with energy storage		X			T
	Inertia estimation for turbine monitoring	X	X			T
	Load unmasking (behind-the-meter DER)	X				T
	Monitoring of intermittent DER	X				T
	Site optimization			X		T
	Voltage impact assessment and mitigation due to high penetration of intermittent energy resources			X	X	T&D
Asset management of critical infrastructure	Equipment commissioning	X				T&D
	Power apparatus asset management	X				T&D
	Underground secondary/spot network monitoring and analysis	X				T
Advanced monitoring of distribution grid (linear state estimation)	Active and reactive power flow monitoring	X			X	T
	FACTS performance validation		X			T
	Frequency monitoring	X				T
	Monitoring of communications system/equipment performance with management metrics	X				T
	Near real-time event monitoring (cyber)	X	X			T
	Near real-time event monitoring (physical)	X	X			T
	Phase angle monitoring for voltages and currents	X				T
	STATCOM controller design		X			T
	Voltage profile monitoring	X		X		T
Advanced microgrid applications and operation	Advanced distribution system topology, automation and control (holonic grids)	X	X			T
	Advanced protection of microgrids		X			T
	Islanding detection for distributed generation (anti-islanding scheme)	X				T
	Planned islanding and restoration of microgrids		X			T
Advanced distribution system planning	EMS back-up		X			T&D
	Phase identification	X				T&D
Advanced distribution protection and control	Current differential protection of feeder sections		X			T
	Reclosing assistance for fast circuit recovery after fault	X	X			T

SYNCHROPHASOR TECHNOLOGY
USE CASE TAXONOMY

A Darcy-led survey resulted in the identification and classification of ***81 use cases*** *across* ***19 categories****, each with varying* ***objectives*** *(monitoring, control, planning, analysis),* ***deployment maturity*** *and* ***application*** *(transmission system, distribution system or both). The full list of use cases and categories is available via separate file; the following slides focus only on the* ***53 use cases*** *and* ***15 categories*** *with applicability to the transmission system.*

53 Transmission Use Cases



15 Categories

- Wide area visualization
- Technical and commercial loss reduction
- Real-time Dx system operation
- Power quality assessment and analysis
- Integrated resource, Tx, and Dx system planning and analysis
- Improved stability management
- Improved load shedding schemes
- High-accuracy fault detection and location
- Distribution load, DER, and EV forecasting
- DER integration
- Asset management of critical infrastructure
- Advanced monitoring of distribution grid (linear state estimation)
- Advanced microgrid applications and operation
- Advanced Dx system planning
- Advanced Dx protection and control

The Problems with Use Cases

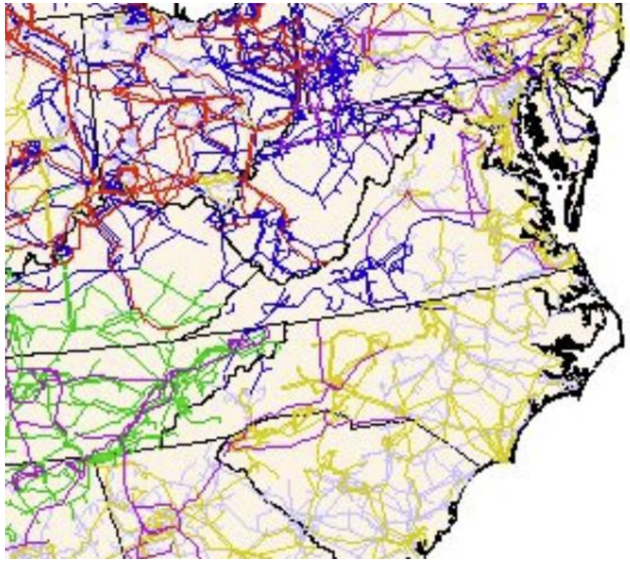
Everyone wants them, no one really understands them.

- We can only enumerate use cases retrospectively.
- Language for use cases is lacking.
    - We don’t have terms for novel use cases.
    - Many terms are overloaded with multiple meanings (ex: event detection).
- Use cases exist at greatly varying levels of abstractions:
    - from broad capabilities (event detection)
    - to highly specific engineering calculations (impedance calculations).
- Applications tackling the same challenge can do so in radically different ways, yielding vary different use cases.

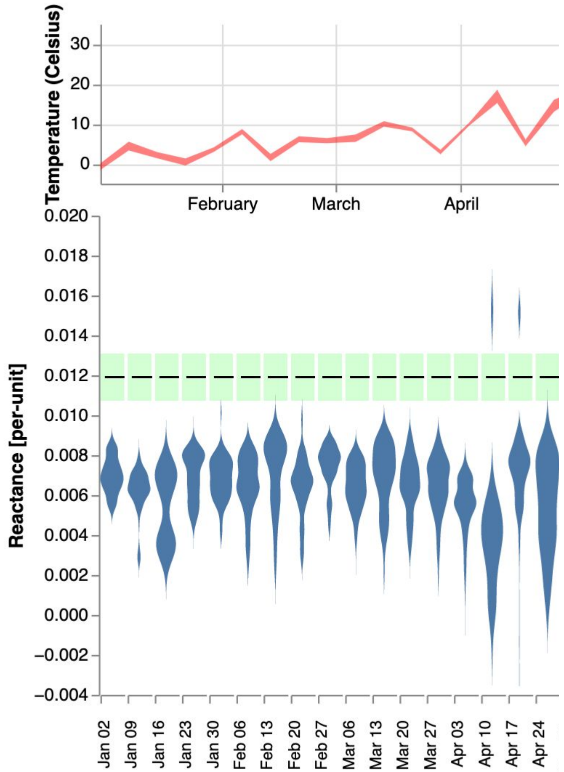
Line Impedance

Are these all the same use case?

Calculate transmission line impedance for a single line at a particular point in time.



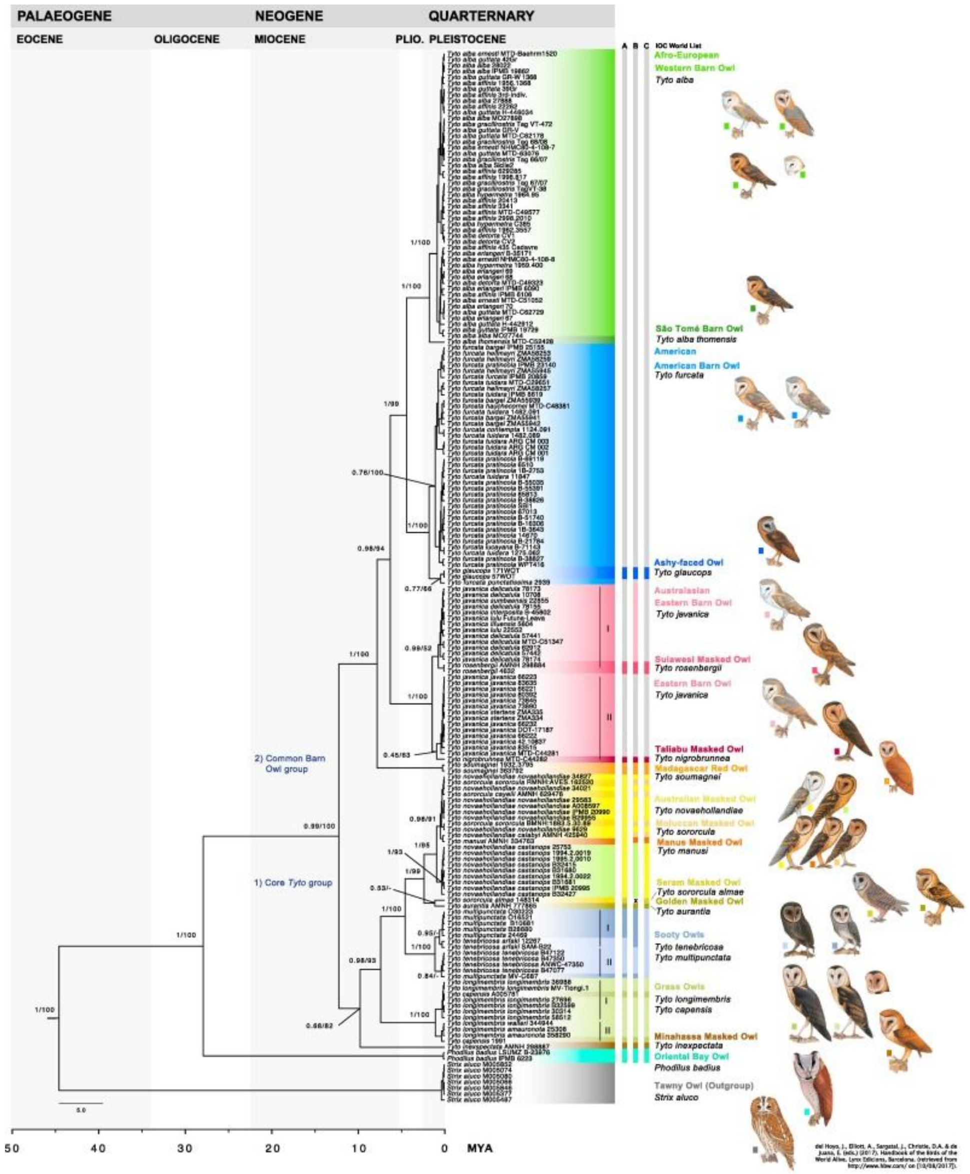
Examine transmission line impedances across the grid at a particular point in time.



Explore transmission line impedance dynamics across time as a function of environmental conditions.

Motivation and Objectives

- Provide a framework to structure thinking about use cases
- Enumerate and explain characteristics that can describe and categorize data-driven use cases
- Understand how existing use cases fit into this framework and can be characterized
- Identify broad areas that are under explored and ripe for exploitation



del Hoyo, J., Elliott, A., Sargatal, J., Christie, D.A. & de Juana, E. (eds.) (2017). Handbook of the Birds of the World Alive. Lynx Edicions, Barcelona. (retrieved from http://www.hbw.com/ on [10/08/2017]).

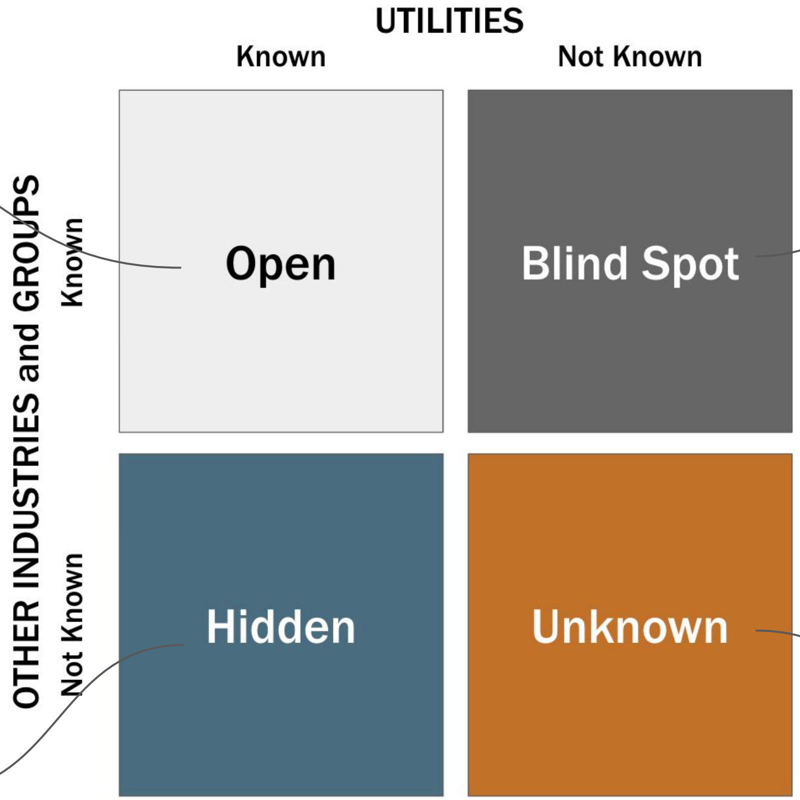
The Johari Window

*The **Johari window** is a technique*[1] *designed to help people better understand their relationship with themselves and others. It was created by psychologists Joseph Luft (1916–2014) and Harrington Ingham (1916–1995) in 1955, and is used primarily in self-help groups and corporate settings as a heuristic exercise.*[2][3]

https://en.wikipedia.org/wiki/Johari_window

		SELF	
		Known	**Not Known**
OTHERS	**Known**	**Open**	**Blind Spot**
	Not Known	**Hidden**	**Unknown**

The Johari Window - Examples

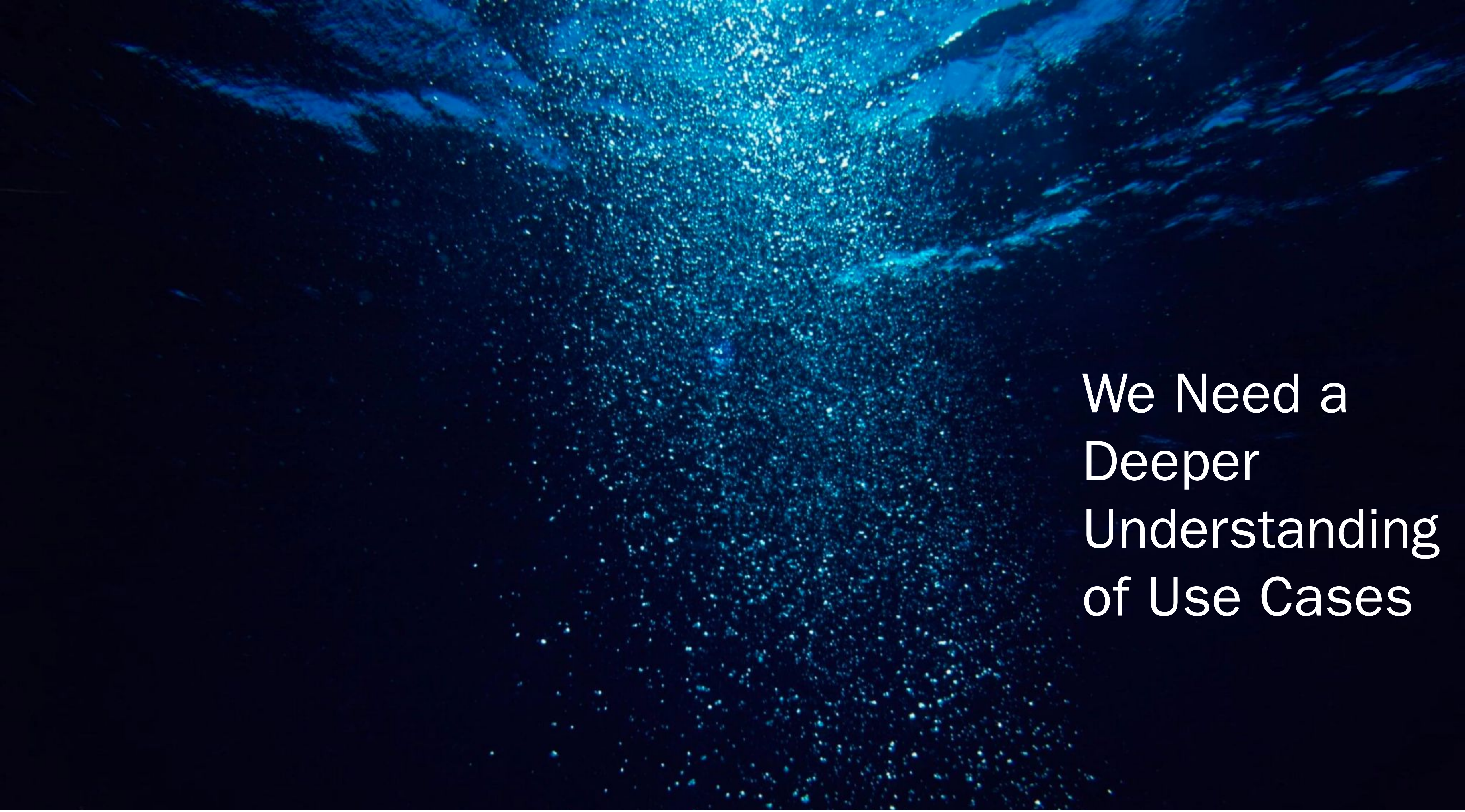


Impedance Calculations

Event Detection

Understood industry needs not yet supported by available tools

Most likely data-driven or hybrid approaches waiting to be developed (the fun stuff).



We Need a Deeper Understanding of Use Cases

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The Owner/Provider

- Who is responsible for the use case?
  - Is this an existing, well understood need?
  - Is this a new need?
  - Does the owner recognize this need?
- What happens if the owner doesn't perform the use case?

The Consumer/Audience

- Who needs to consume this use case?
  - Internal or external?
  - Which groups & departments?
  - Which users specifically?
  - How technical are they?
- If the answer is always the “Control Room,” something is wrong.

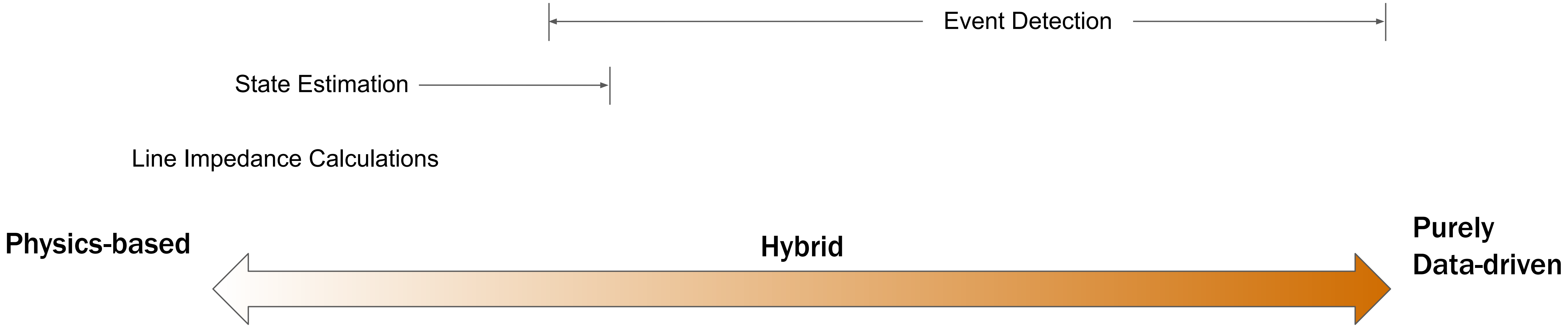
The Objective(s)

- Why is this use case needed?
- What are the associated KPIs?
- What is the ROI?
- How is the ROI calculated?
- ROI takes time and effort into calculating.
- Many business processes don’t have a known ROI, they just are “how things are done.”

The Modeling Methodology

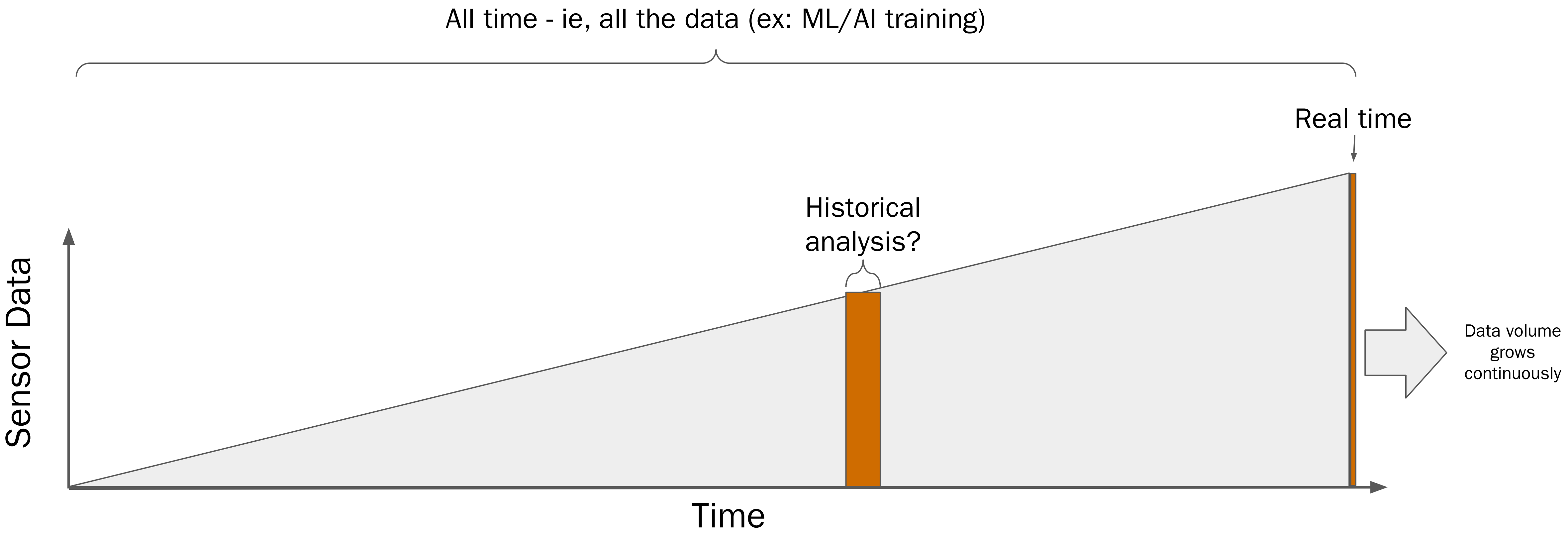
How do we choose to represent the world?

- Strong bias toward traditional, physics-based approaches.
- Purely data-driven models (AI/ML) are underexploited.
- Hybrid approaches are likely to dominate in the future.



The Temporal Location of the Data

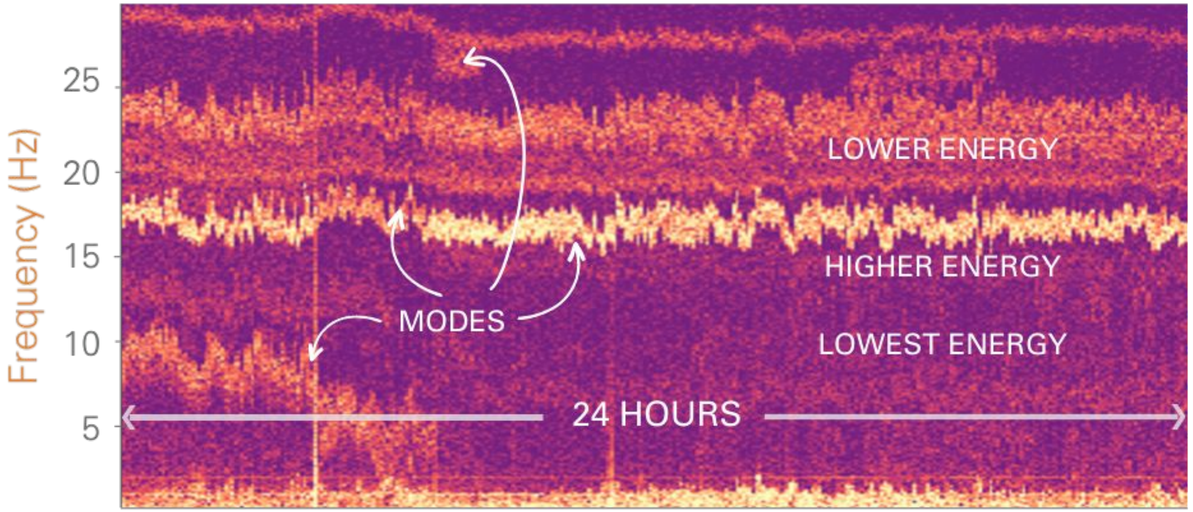
When did the data needed for the use case occur?



(1) We lack appropriate terminology. (2) Enormous bias toward real time to shrink the size of the data analyzed.

Oscillation Detection vs Oscillation Management

Are these the same use case?



Oscillation Detection

- Are oscillations of sufficient magnitude happening right now?

Oscillation Management

- How have the dynamics of the system evolved over time?
- How close to an impactful oscillatory event are we?
- What is causing each oscillation?
- What is the permanent or seasonal solution to the oscillation?
- What are the operational recommendations to mitigate the event?

The Scope of the Data

Data from how much of the physical world is required for the use case?

- Does the use case apply to:
    - 1 sensor/asset
    - a regional set of devices
    - or the entire system?
- Measurements are time synchronized and meant for comparison

De-energize a line for a conductor break

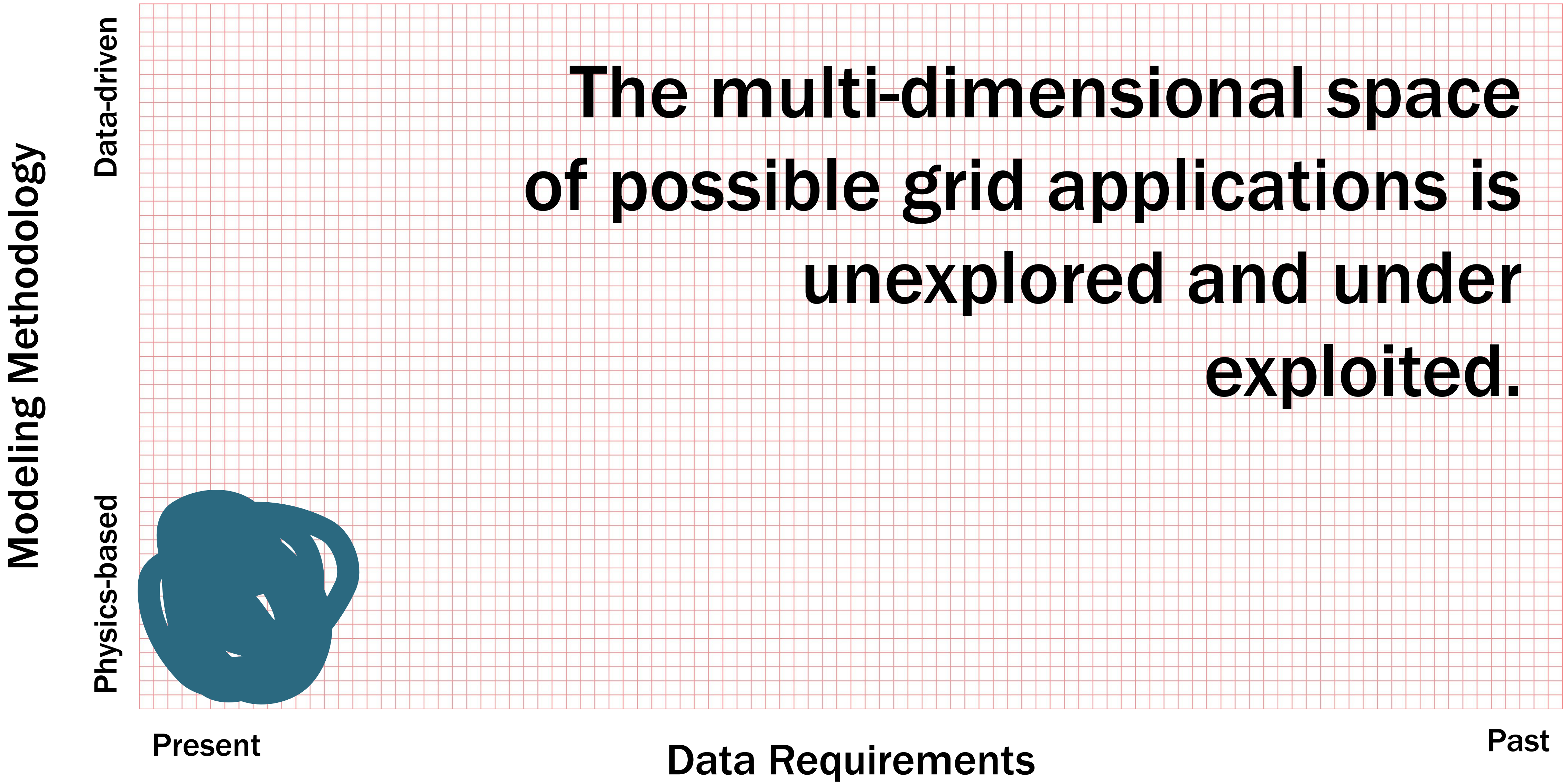
State Estimation

Local
“Edge”
Less Information

Regional

Global
“Centralized”
More Information

Implications for the Future



The multi-dimensional space of possible grid applications is unexplored and under exploited.

Conclusion

- Use cases are the transformation of data and process into some form of business value.
- An industry-wide shared understanding of use cases is critical for ultimate sensor acceptance by utilities.
- The adoption of use cases is the basis for any “digital transformation.”
- These are not the only characteristics that can describe use cases.
- Shared language must be developed to provide clarity for use cases that share a similar calculation or technical foundation.

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