Data-Driven Detection of Events in Distribution Power Systems

Oct 16 2018

REZA ARGHANDEH, WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCE, NORWAY

JOSE CORDOVA, FLORIDA STATE UNIVERSITY, USA

Acknowledgment

- This project is supported by Horizon 2020 grant 654113 ERIGrid
- Project collaborators:

Jose Cordova
PhD Candidate
FSU

Reza Arghandeh
Western Norway University

Matthias Stifter
OMNETRIC Group

Thomas Strasser
AIT

Christian Seitl
AIT

Christian Messner
AIT

Ravi Venugopal
Opal-RT

Nikola Stankovic
Opal-RT

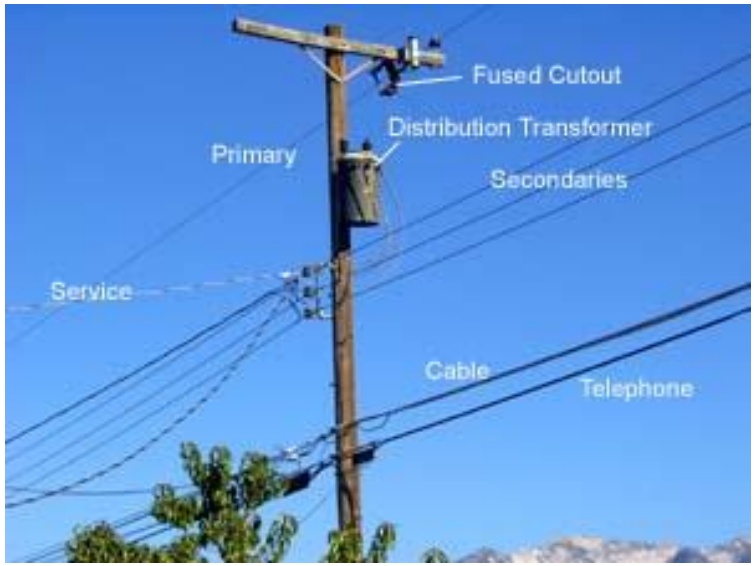
Jean-Nicolas Paquin
Opal-RT

Outline

- Motivation
- ERIGrid Project Objective
- TestBed Architecture
- Test Results Analysis

PMUs measurement are more challenging in Distribution compare to Transmission networks!

- Mostly radial architecture
- Very short lines
- Diversity among circuits and loads
- Subject to more external influences



Tallahassee, FL, Oct 11 2018

PMUs measurement are more challenging in Distribution compare to Transmission networks!

- Smaller voltage angle differences
- More noise in measurements
- Smaller X/R ratios (inductance/resistance of distribution lines)
- Unbalanced three-phase systems
- **Few PMU based monitoring are in the field, our knowledge is scant!**

Our ERIGrid Project Objectives

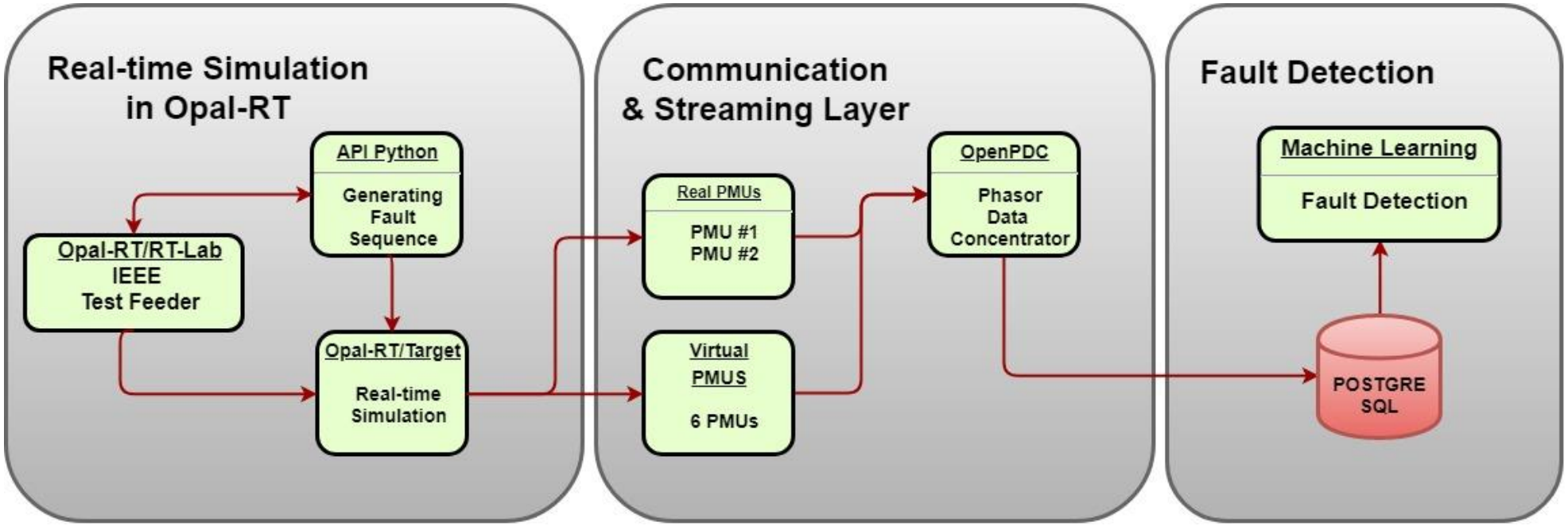
Objective 1, Create D-PMU Data: built a time-synchronized and scalable environment that includes multiple PMUs from different vendors.

Objective 2, Transfer D-PMU Data: developed the setup of a virtual communication layer that resembles the traffic and latencies inherent to our network of virtual and physical PMUs' data streams.

Objective 3, Analyse D-PMU Data: Use the developed HIL setup to produce actual PMU data from different devices and analyze the data.

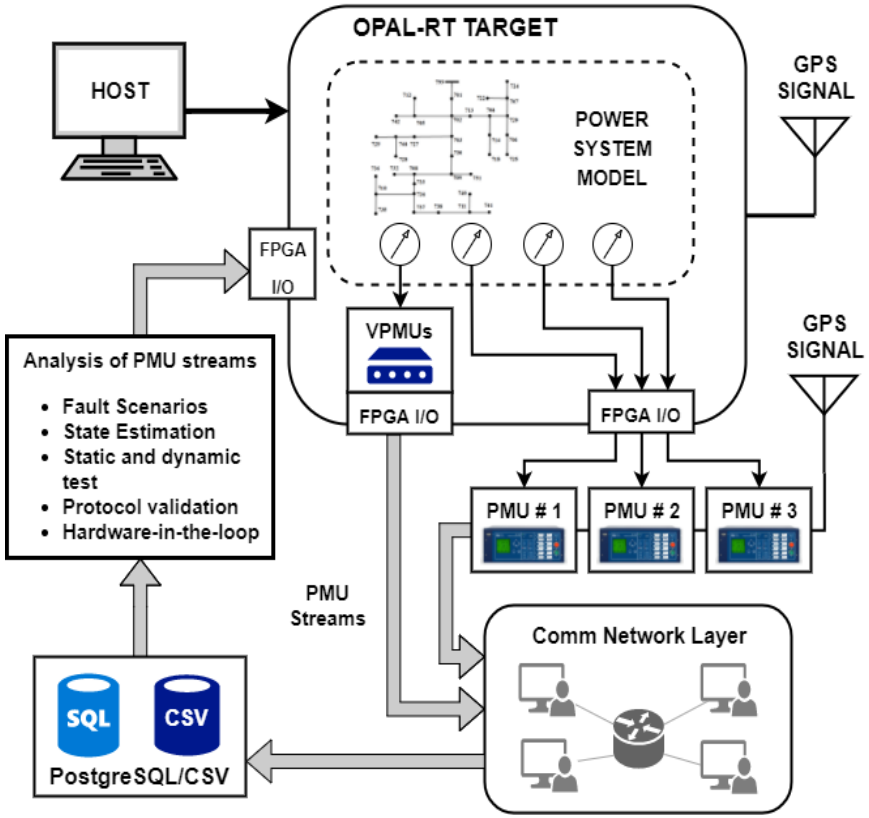
Overall Architecture

The main objective is fault detection in power distribution networks using PMU measurements in a real-time setup that resembles real-field conditions.



Testbed Overall Scheme

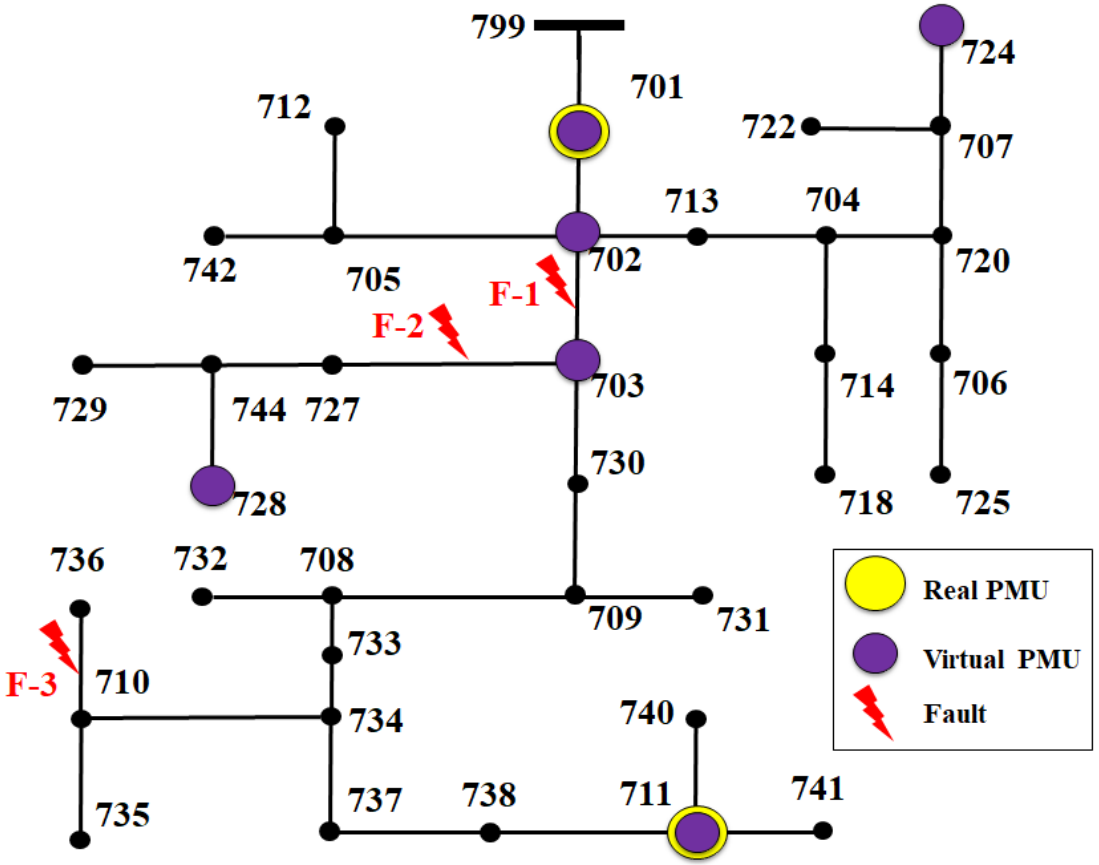
Testbed # 1: 3D-Power (Summer 2017)



- IEEE 37-nodes test feeder in Opal-RT
- Real PMUs from established vendors
- PMU & Opal-RT GPS clock synchronization
- Communication Network Layer Simulation

PSL POWER STANDARDS LAB ARTEMES ARBITER SYSTEMS Enabling Tomorrow's Technology Today

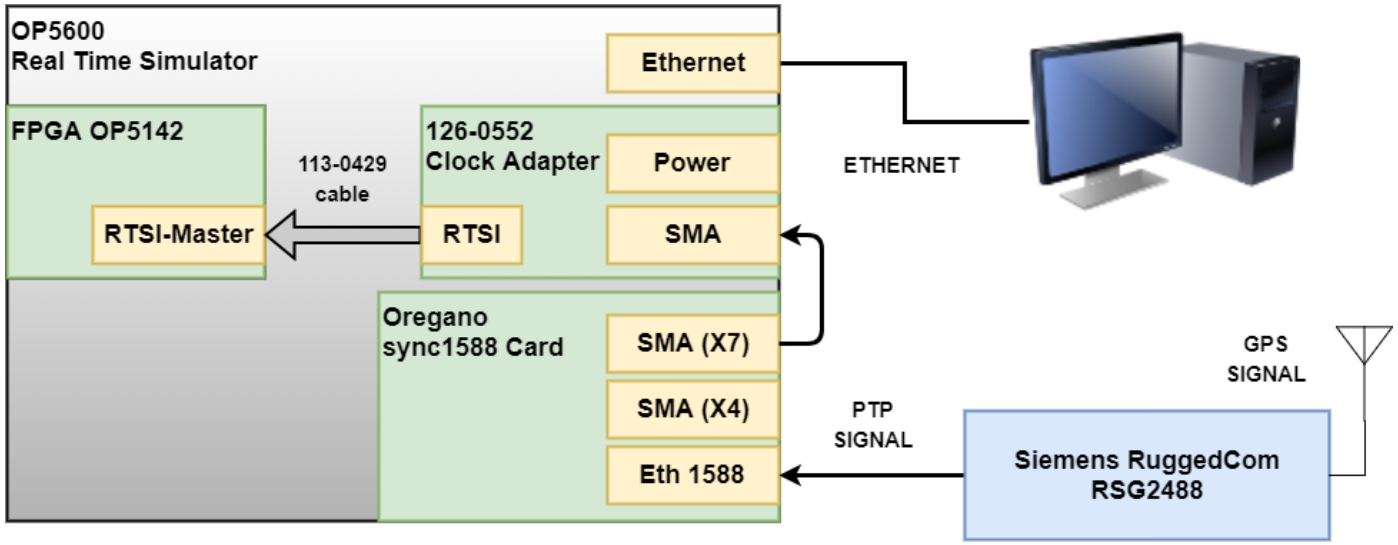
IEEE 37-nodes test feeder



Power System Model:

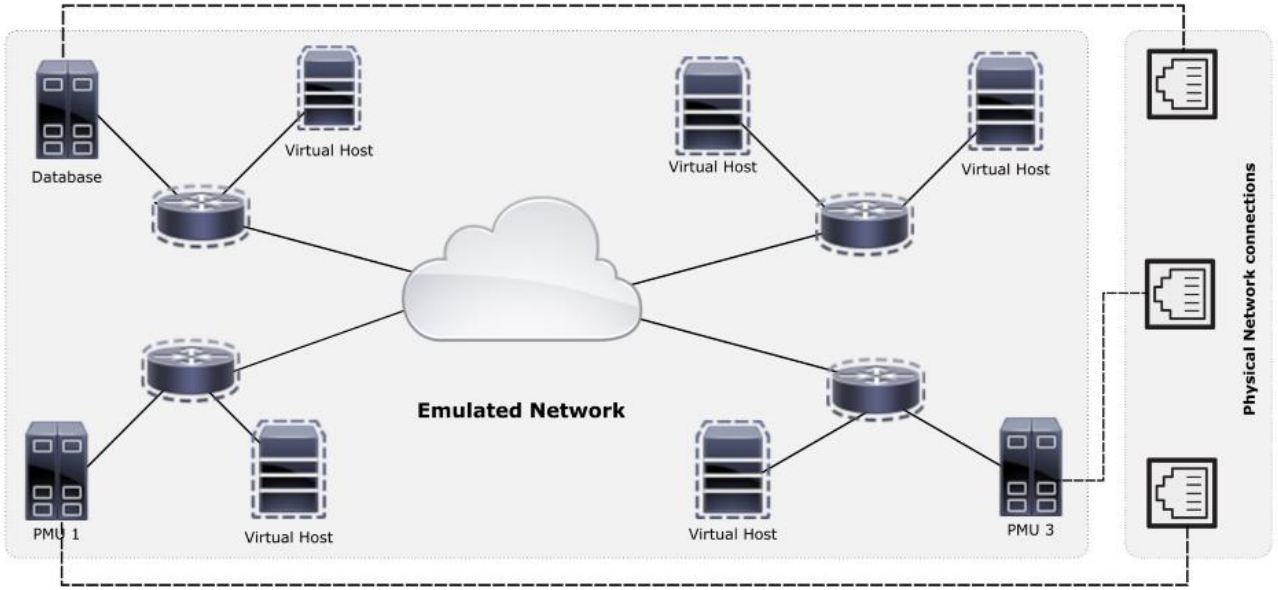
- IEEE 37-nodes with wye transformer at the feeder
- 3 Real PMUs in the network
- 6 Virtual PMUs in the network
- 3 Fault locations 3 fault types (AG, AB, and ABCG)
- Approx. 900 events produced and recorded

GPS Clock Synchronization



- Clock: Siemens Ruggecom PTP Source
- Use Oregano Card for Synchronization
- Opal-RT FPGA synchronized with PMU
- Setup was built to be able to have same timestamps between virtual and real PMUs.
- **A Big Practical Challenge, No-Body did it before with Opal-RT!**

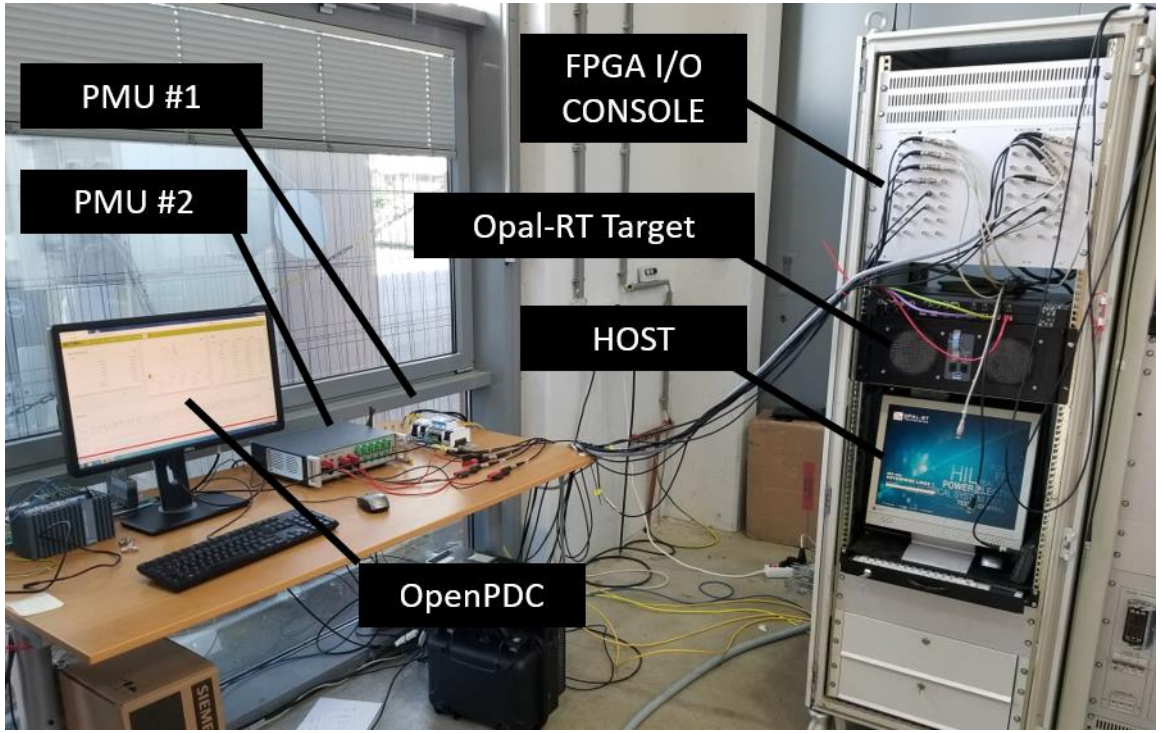
Communication Layer Modeling



Communication Network Simulated

- Use CORE Simulation Environment
- Emulates real monitoring system's latencies
- Applying to the PMU streams considering:
  - Bandwidth Limit
  - Packet Loss
  - Collisions
- Impact evaluation of delays and data availability.

Testbed # 2: 4D-Power (Summer 2018)

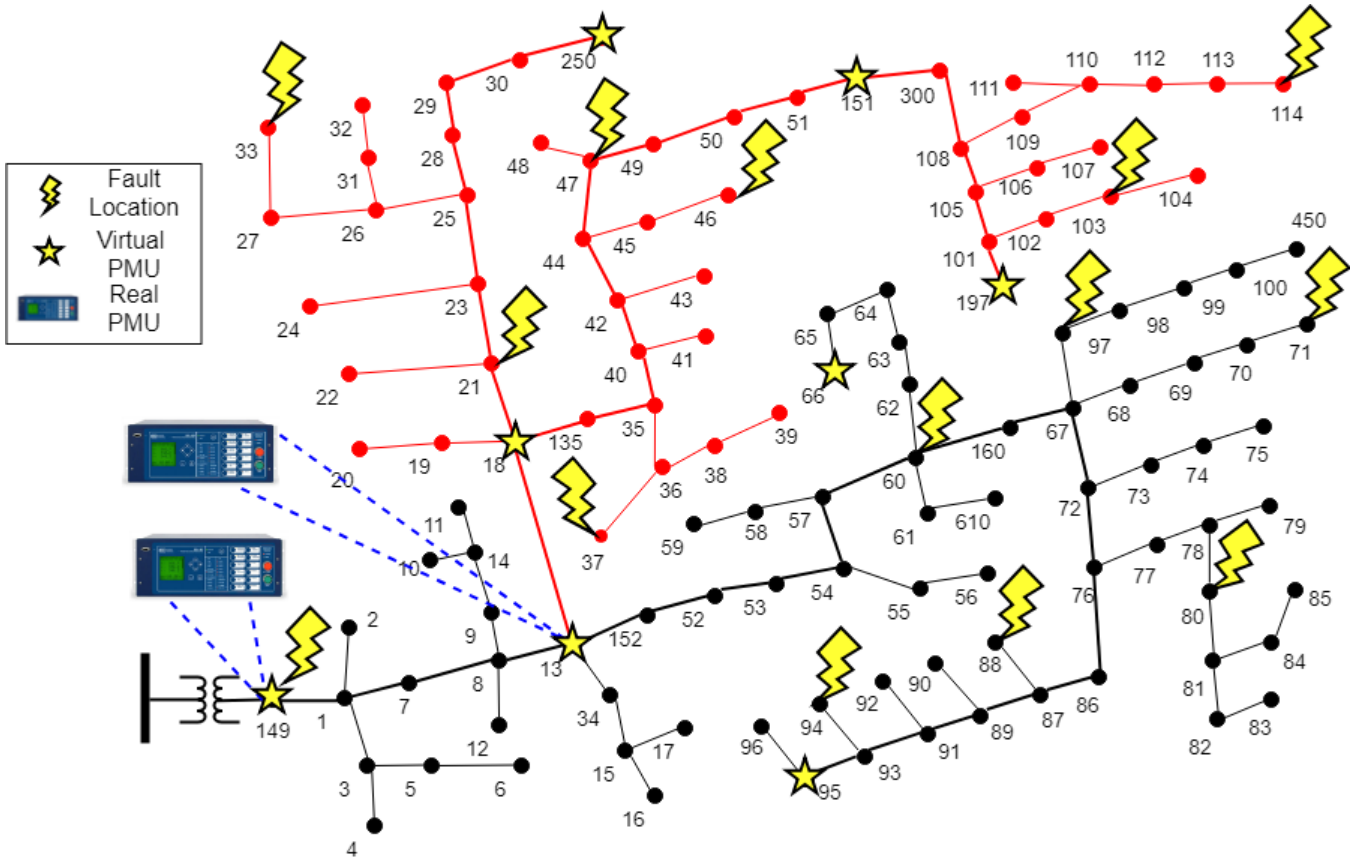


4D-Power Setup

- IEEE 123-nodes test feeder in Opal-RT
- Simulated with RT-Lab/ePhasorSim
- Real PMUs from established vendors
- Approx. 10,000 events simulated

EUROPEAN UNION'S HORIZON 2020 GRANT 654113 (ERIGRID) UNDER THE TRANS-NATIONAL ACCESS PROGRAMME

IEEE 123-nodes test feeder

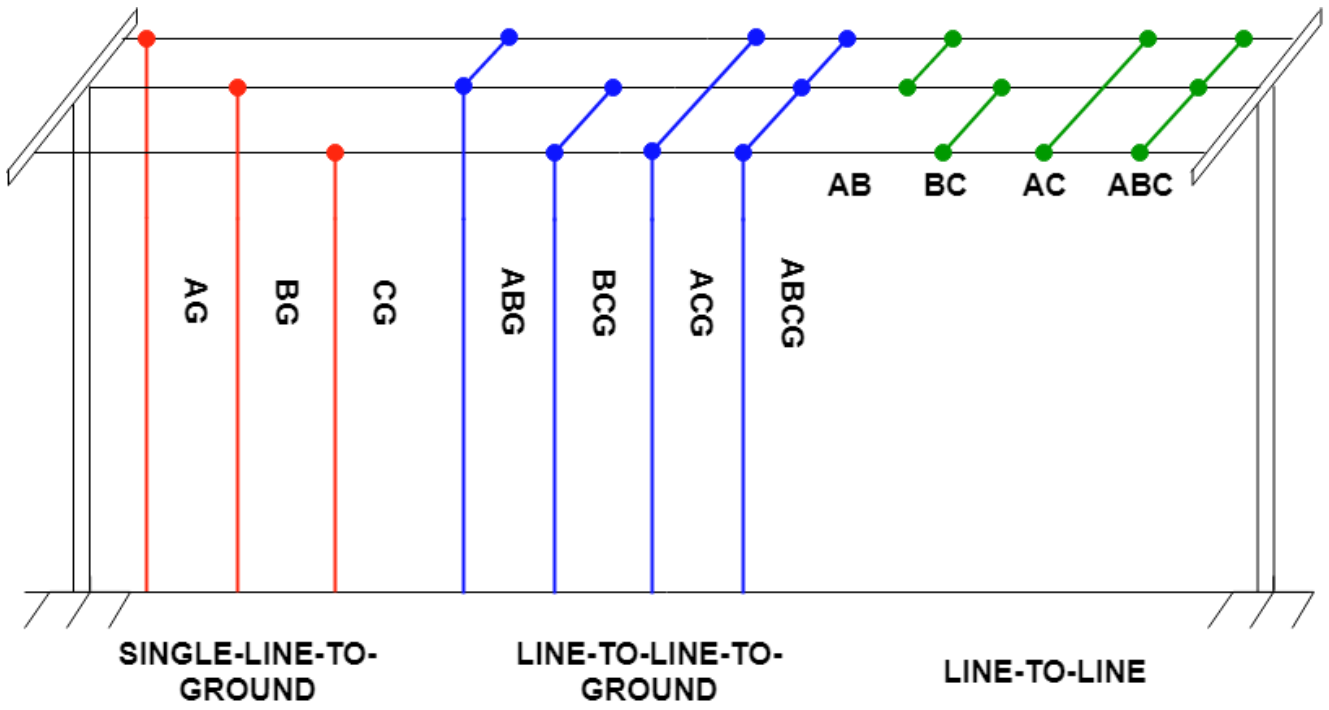


IEEE 123-nodes test feeder

- IEEE 123-nodes Network
- 2 Real PMUs in the network
- 8 Virtual PMUs in the network
- 14 Fault locations

EUROPEAN UNION'S HORIZON 2020 GRANT 654113 (ERIGRID) UNDER THE TRANS-NATIONAL ACCESS PROGRAMME

Fault Sequence



IEEE 123-nodes test feeder

- 14 Fault locations
  - 8 locations at three-phase branches
  - 6 locations at single-phase branches
- 7 fault types
  - Single-line-to-ground
  - Double-line-to-ground
  - Three-line-to-ground
- Changing fault impedance 0.1 – 50 Ohm

PMU Data Applications in Distribution System

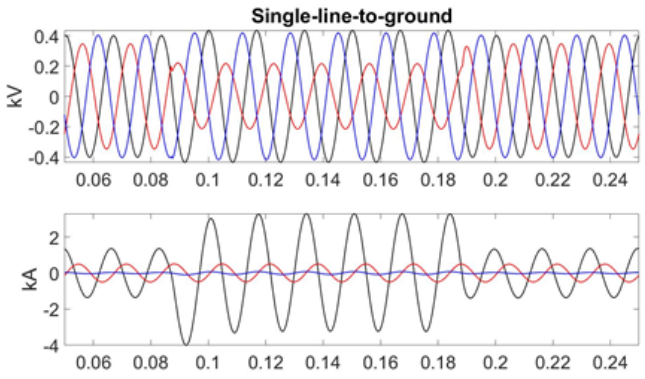
- ✓ Model validation
- ✓ Topology detection
- ✓ State estimation
- ✓ Fault detection
- ✓ Equipment health diagnosis
- ✓ Volt-Var optimization
- ✓ DER Management
- ✓ etc….

Data Application: Fault Detection with Shape Data Analysis

- We proposed a novel algorithm for fault detection **based on Shape Data Analysis (SDA).**
- SDA attempts to give insight into data by imposing a geometry on it.
- SDA uses shape as an abstraction or a feature of data.
- **Fault events with similar shape can be clustered together.**

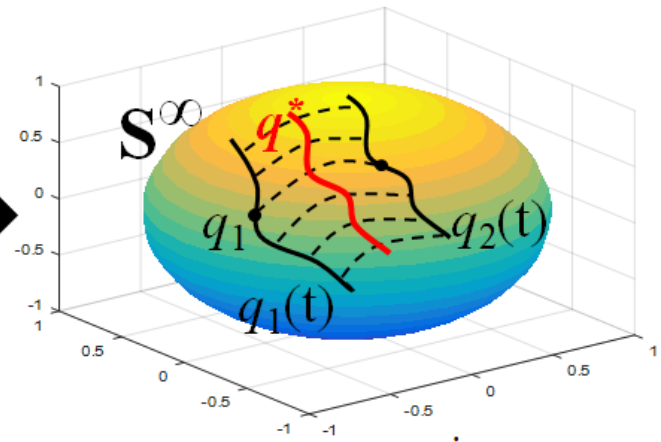
Fault Detection with Shape-based Clustering

Fault data represented by the function space $B = B(t)\colon [0,T] \mapsto \mathbb{R}^3$ (i.e. 3-phase voltage or current). Then it is transformed with a *Square-root Velocity Function (SRVF)* into a new event space where the fault similarities can be better extracted.



$B(t)\colon [0,T] \mapsto \mathbb{R}^3$

Time Domain



$$SRVF(B) = q(t) = \frac{\dot{B}(t)}{\sqrt{|\dot{B}(t)|}}$$

Function Space in a Hilbert Sphere

The SRVF transforms the event space (fault event streams) into a sphere space when similarities can be extracted in a more simple manner.

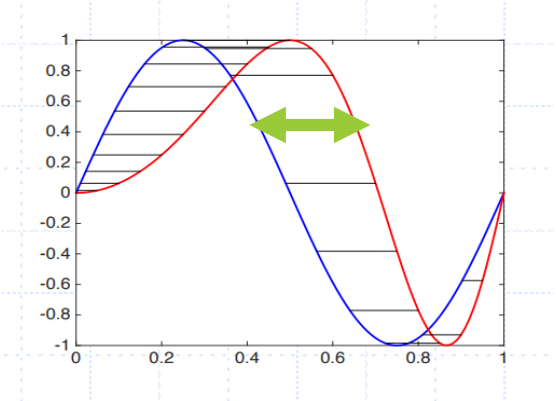
J. Cordova, C. Soto, M. Gilanifar, Y. Zhou, A. Srivastava and R. Arghandeh "Shape Preserving Incremental Learning for Power Systems Fault Detection," IEEE Control Systems Letters, Jan. 2019.

Fault Detection with Shape-based Clustering

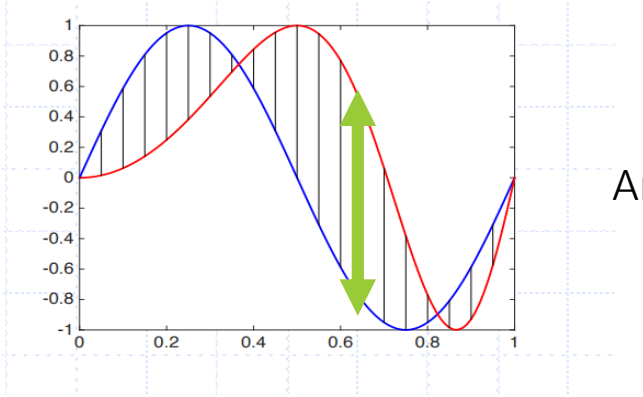
In the new function space after the SRVF transformation, for every signal B_1 and B_2, two distances will be calculated: *the* ***amplitude distance*** and the ***phase distance***.

The ***phase distance*** is the amount of warping γ (or horizontal shift) necessary to align the signal B_1 to B_2.

The ***amplitude distance*** between two the signal B_1 to B_2 is the distance (or vertical shift) for both time series to become fully aligned.



Phase distance

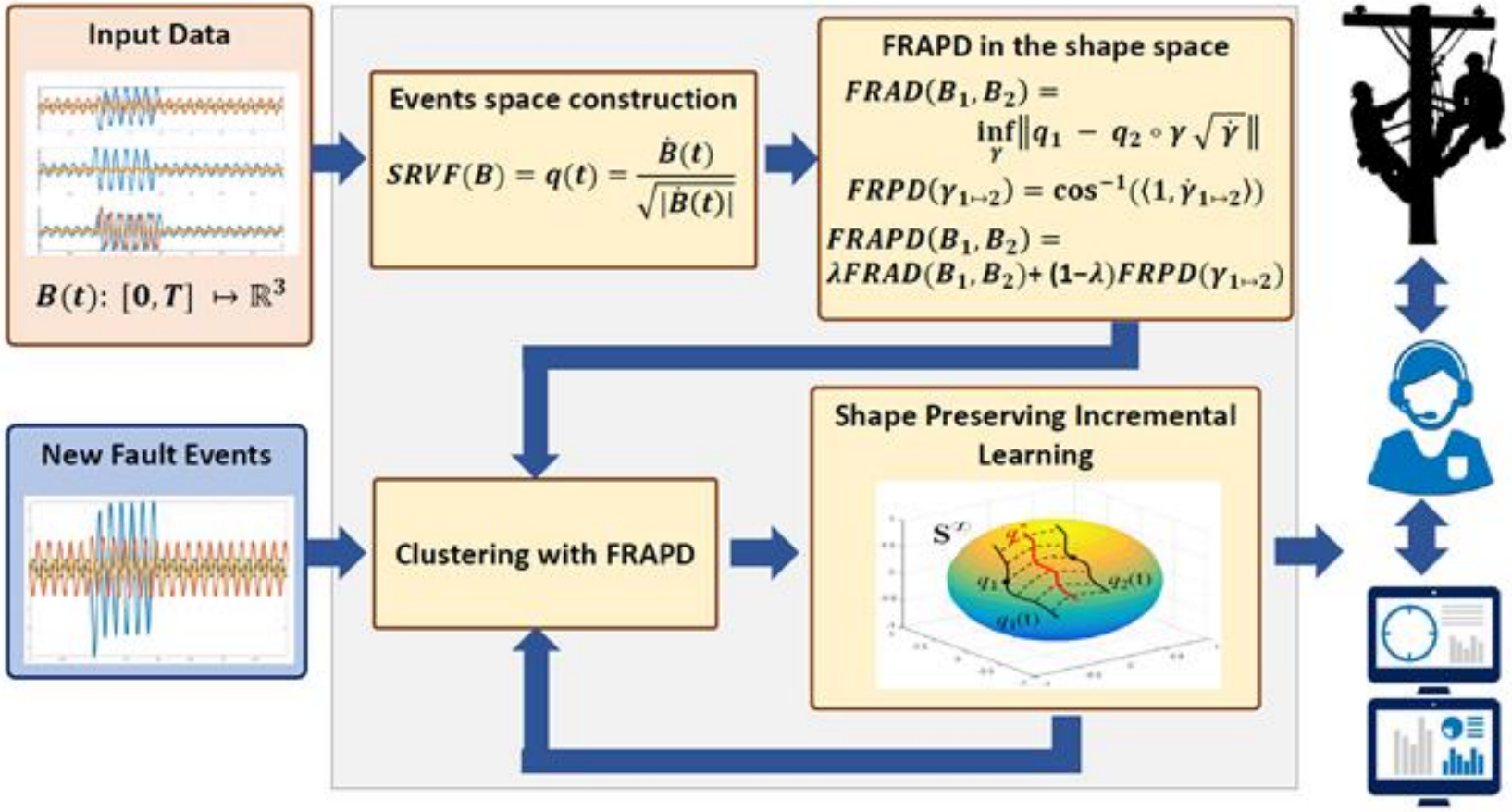


Amplitude distance

In general, fault events with similar shape should have an small distance.

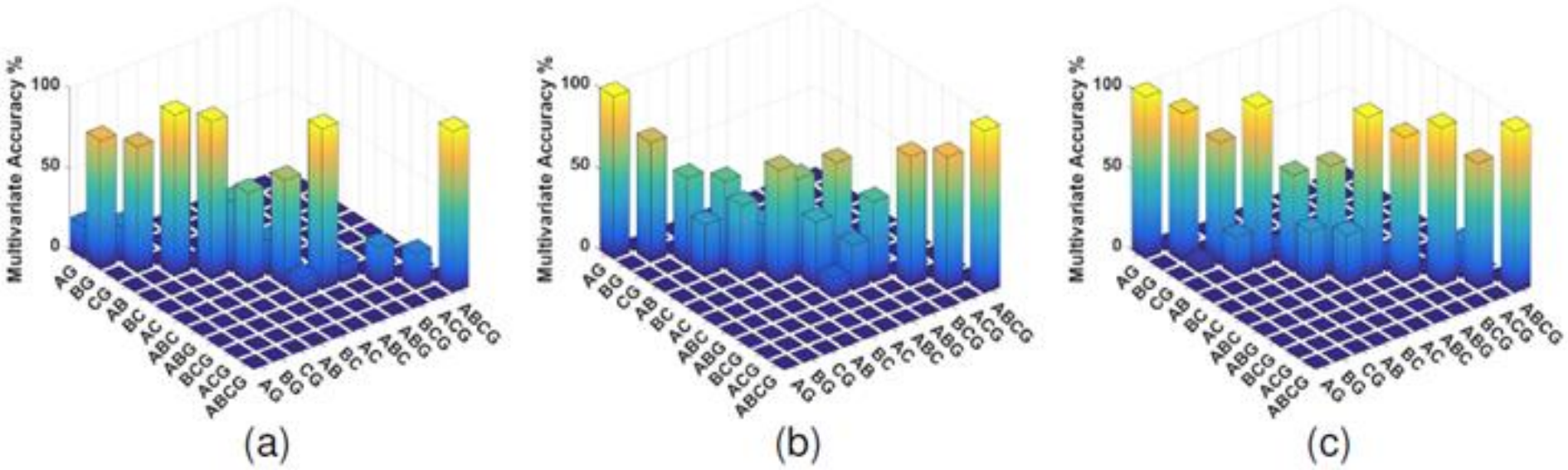
Image source: Dr. Anuj Srivastava, FSU.

Data Application: Fault Detection with Shape Data Analysis



Fault Detection with Shape-based Clustering

- The classification is performed by a hierarchical clustering process, resulting in similar events being grouped together for event detection purposes.



(a) Fault detection with proposed SDA methodology; (b) SVM ; (c) NN

Fault Detection with Shape-based Clustering

Misclassification Error % for different fault detection methods

Method	FRAPD	SVM	NN
False Positive	**2.69**	18.52	33.34
False Negative	**1.68**	16.16	33.33
Total	**4.37**	34.68	66.67

FRAPD: Fisher-Rao Amplitude Phase Distance

References & Publications

[1] J. Cordova, C. Soto, M. Gilanifar, Y. Zhou, A. Srivastava and R. Arghandeh, ”**Shape Preserving Incremental Learning for Power Systems Fault Detection**,”IEEE Control Systems Letters, vol. 3, no. 1, pp. 85-90, Jan. 2019.

[2] J. Cordova, C. Soto, M. Gilanifar, Y. Zhou, A. Srivastava and R. Arghandeh, ”**Shape Preserving Incremental Learning for Power Systems Fault Detection**,”57th IEEE Conference on Decision and Control, Miami Beach, FL, USA, December 17-19, 2018

[3] M. Stifter, J. Cordova, J. Kazmi, and R. Arghandeh, ”**Real-Time Simulation and Hardware-in-the-Loop Testbed for Distribution Synchrophasor Applications**”, Energies 11, no. 4 (2018). https://doi.org/10.3390/en11040876.

[4] J. Cordova, R. Arghandeh, Y. Zhou, S. Wesolowskiz, W. Wu, M. Stifter, ”**Shape-based Data Analysis for Event Classification in Power Systems**”, PowerTech 2017, Manchester, UK, June 2017.

Thank You

Reza Arghandeh

rajo@hvl.no

arghandehr@gmail.com