

Situational Awareness in Distribution Grid Using Micro-PMU Data

(Tasks 1.1 and 1.2)

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Situational Awareness Using Distribution Synchrophasors

- Events in Distribution Systems
- Event Detection
- Event Classification



Use-Cases:

- Asset Monitoring
- Protection System Diagnosis



Cyber Security & Situational Awareness



Our Focus: Sensors and Measurements

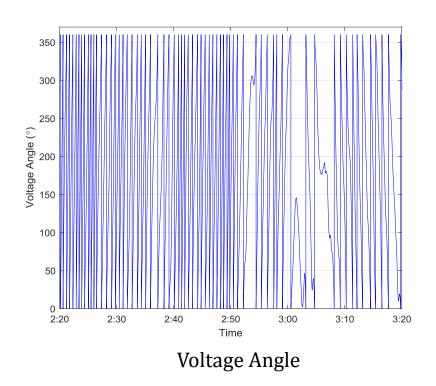
Data Recording:

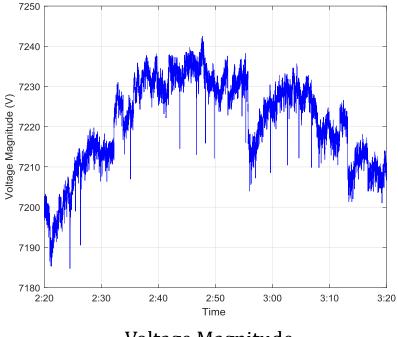
- Voltage Phasor
- Current Phasor



Features:

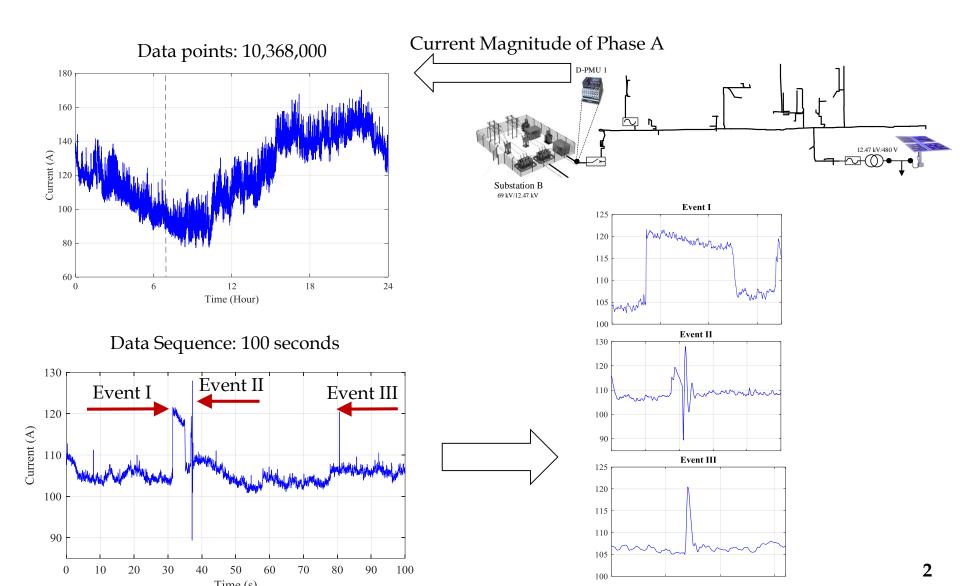
- Millisecond Reporting (120 Hz)
- 0.1 Accuracy







Events in Distribution Systems



Application of Micro-PMUs:

- Capacitor Back Switching
- Fault Analysis
- Lightning Analysis
- **Inverter Misoperation**
- **Event Detection**

. . .

- **Event Classification**
- Impedance Calculation
- **Topology Identification**
- **Event Source Location Identification**

Our Focus: Situational Awareness with Application to Cybersecurity

Situational Awareness in Distribution Grid Using Micro-PMU Data: A Machine Learning Approach

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Associate. The second at velopses of distintions let of home measurements that loss loss second loss loss loss of the second step is north, achieving, initiational ansaresses in power distri-bution networks. The challenge however is to transform the large amount of data data it generated by micro-PHUs to large amount of data data it generated by micro-PHUs to cases with gratical value to youth organizes. This open problem is addressed in this paper. First, we introduce a new data-data oreal data-data testings to job, and we shade portion of data second production of data data is and the production of data the second data testing of the production of data testing and the second vers detection technique to pick out valuable portion of data remorthemely large moins-TMU data. Subsequently, a data differences in constraints, and the subsequently and public vectoria. Inspectation, we use field expert havershold and differences in constraint data direction analysis are to find the subsequent and the subsequence of the sub-lament of the subsequence of the subsequence of the baseline trained and tested over 15 days of real-world data matters in testing the subsequence of the direction distribu-liantifier in trained and tested over 15 days of real-world data TU-700 exests. The effectiveness of the direction distribu-ion data data and tested over 15 days of real-world data fully baseline in testing and the direction distribution the data data and tested over 15 days of real-world data fully because the distribution of the distribution methods, making the subsequence of the distribution methods, making the subsequence of the distribution of the distribu-tion data matters analytics tools, interling remeta areas of the proposed data analytics tools, interling remeta areas of the distribution of the distribution data data subsequence of the distribution of the distribut ywords: Machine learning, distribution synchrophasors, sit-nal awareness, event detection, event classification, Big-Data.

L INTRODUCTION

vehicles, and controllable loads has introduced new and unmedictable sources of disturbance in distribution networks

This calls for developing new monitoring systems that can

upport achieving situational awareness at distribution-level

best operational decisions in response to such disturbances. Traditionally, there have been three major challenges in

chicving situational awareness in power distribution systems

First is the lack of high resolution measurements. Metering in distribution systems is often limited to supervisory control and

data acquisition (SCADA) at substations with minutely report

ing intervals. As for smart meters, their report measurements

once every 15 minutes or hourly. Second is the lack of accurate

and up-to-date models for most practical distribution circuits

Third, due to the lower voltage and the larger number and

A. Shahavari, M. Yangislahi, and H. Mohessian-Rad at: with the De-parameter of Recircal and Cimputer Engineering. Unbersity of Califeria Roverski, C., USK, Sawari is with the Intravacture Systems, Cyber and Physical Residence, Lawrence Lawrence National Laboratory, Lawrence C., USA, I. Cretter is with Strends Police Ullators, Recenting, C., A. USA, This work is supported by UCOP strat. USK 1544175, Doil grant 107 2008011, and MASK Mick Ogant SNRSL/1994A. The composition gamma

Mohemian Rad, e-mail ha

as, allowing the distribution system operator to make the

The proliferation in distributed energy resources, electric

variety of utility and customer equipment, dist are subject to a huge number of events on a daily basis. The first challenge above has recently been resolved by the advent of micro-PMUs [1]. A typical micro-PMU is connected to single- or three-phase distribution circuits to measure GPS time-referenced magnitudes and phase angles of voltage and current phasors at 120 readings per second. Since 2015, several micro-PMUs have been installed at pilot test sites in the state

of California, including some in the city of Riverside [2]. This paper makes use of real-world micro-PMU data from a feeder in Riverside, CA, see Fig. 1. It seeks to address the second and the third challenges listed above. Specifically, w propose a novel model-free situational awareness framework or power distribution systems to turn micro-PMU data in to ctionable information for tangible use cases. This is done by introducing a novel data-driven event detection technique as well as a novel data-driven event classification technique Event detection is applied to eight non-linearly dependent data streams for each micro-PMU, including voltage magn current magnitude, active power, and reactive power. Even classification is done by extracting the inherent features of detected events, and by constructing an algorithm that can learn from and make predictions of various events. The main contributions in this paper can be summarized as follows:

1) A novel situational awareness framework is introduced for power distribution systems using micro-PMU data,

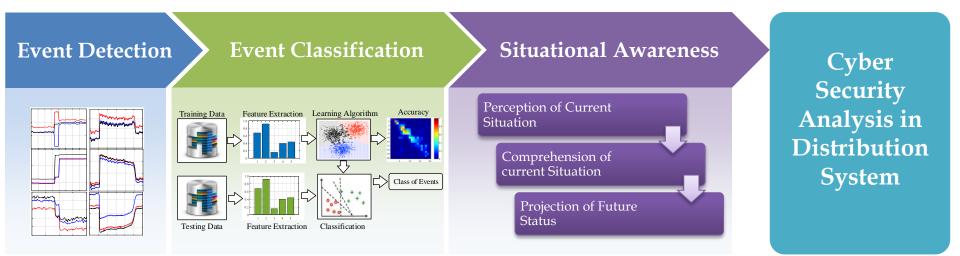
that is model-free; it works by going through a se-quence of event detection, event classification, and event scrutinization efforts to transform the large amount of measurement data from micro-PMUs to information that are useful for distribution system operators

- The approach in this paper makes use of field expert knowledge and utility records in order to conduct an extensive data-driven event labeling for micro-PMU data. The detected events are labeled according to event cone and event type. As for the event detection phase prior to event labeling, our approach is comprehensi it involves moving windows to help compensate the lack of information about the start time of each event. It also involves dynamic window sizes to help compensate the lack of information about the duration of each event. Different feature selection approaches and different classification methods are examined and compared, includ ing multi-SVM, k-nearest neighbor, and decision-tree. with considering certain aspects of events from micro
- PMUs, e.g., uneven datasets and features of multi-stream signals. It is shown that the use of the proposed detection features, such as detection window and detection indica-tor, is critical, regardless of the method of classification

IEEE Power and Energy IEEE Trans. on Smart Crid, Magazine, May 2018



Situational Awareness and Cybersecurity in Distribution Systems



Agenda



Situational Awareness Using Distribution Synchrophasors

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Practical Use-Cases:

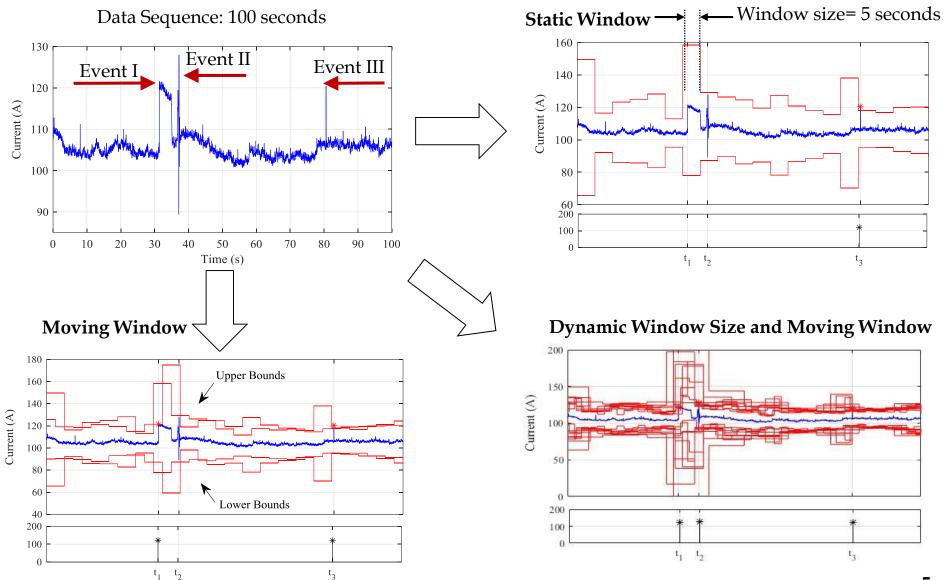
- Asset Monitoring
- Protection System Diagnosis



Cyber Security & Situational Awareness

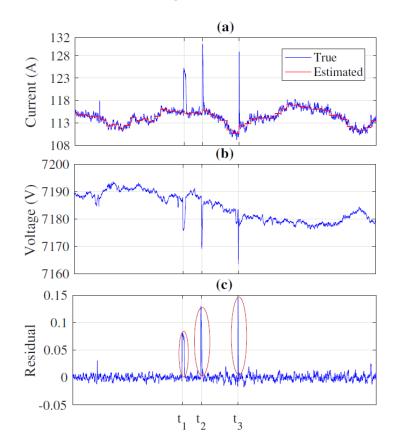


Events Detection: Method I, Absolute Deviation Around Median





Events Detection: Method II, Residual Test on Non-Linear Estimation



Current Magnitude Estimation

(a) 140 Current (A) 130 120 110 100 (b) 7240 7240
7220
7220
7200
7200
7180 True Estimated (c) 0.75 Residual 0.5 0.25 0 -0.25 t_2

Voltage Magnitude Estimation

Agenda



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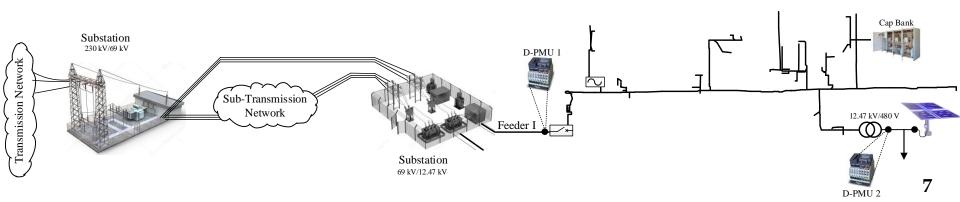
Cyber Security & Situational Awareness

Event Classification

Event Labeling: Field Expert Knowledge and Utility Records

Provisions:

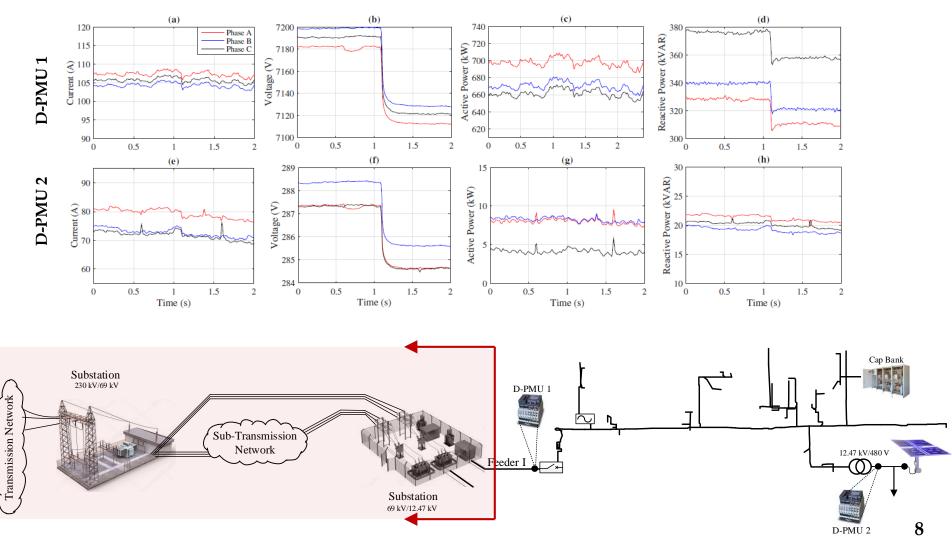
- Field knowledge of utility crew members
- Reviewing more than 1000 utility event logs for one year
- Computer simulation of the understudy feeders.
- Analysis of field data over three years.



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Event Labeling

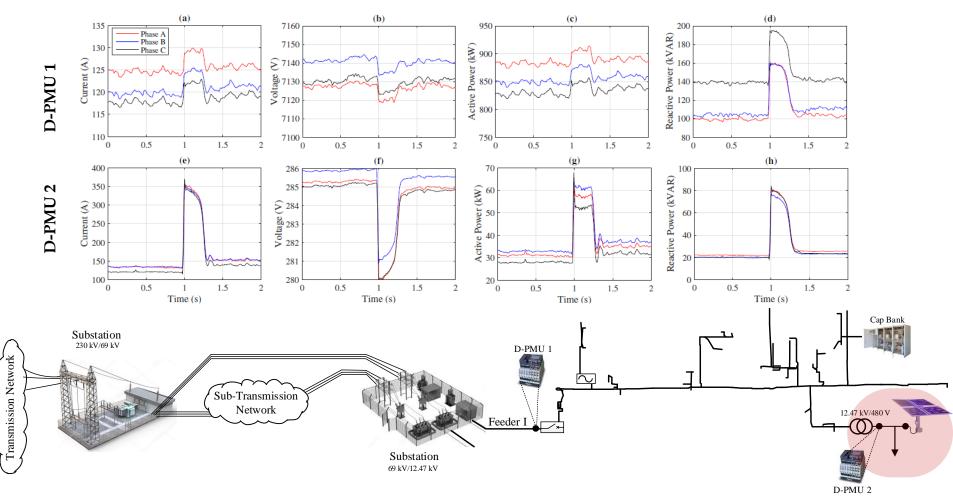
Class I: Events initiated from upstream of D-PMU 1:



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Event Labeling

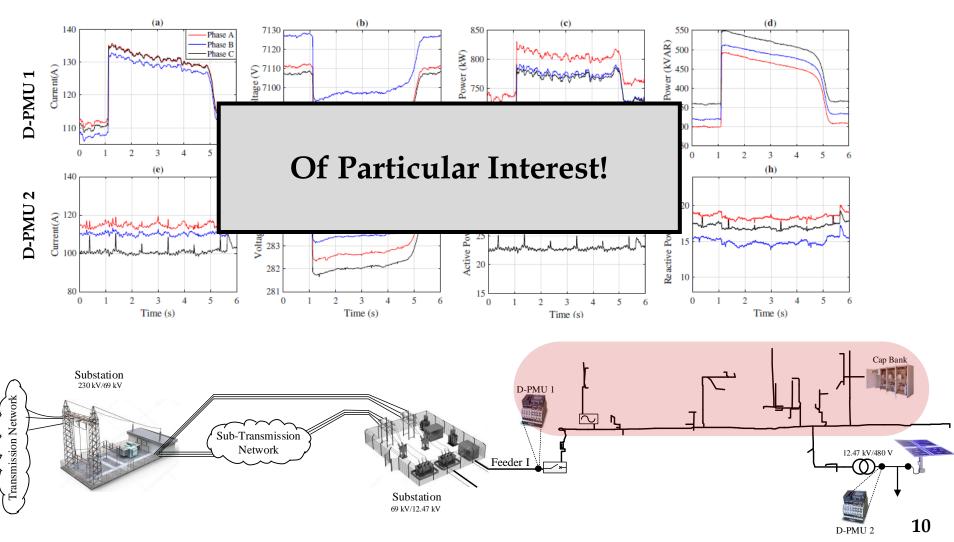
Class II: Events initiated from downstream of D-PMU 2:





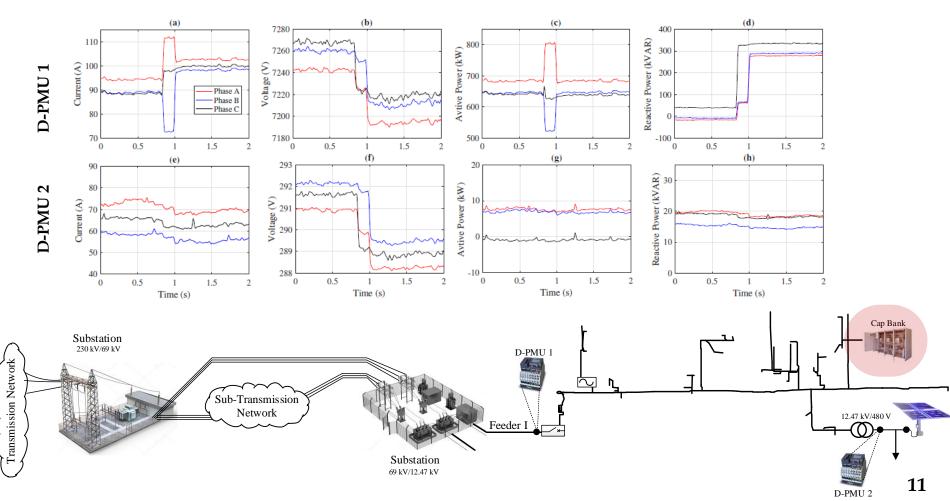
Event Labeling

Class III: Events initiated from somewhere between the two D-PMUs:



Event Labeling

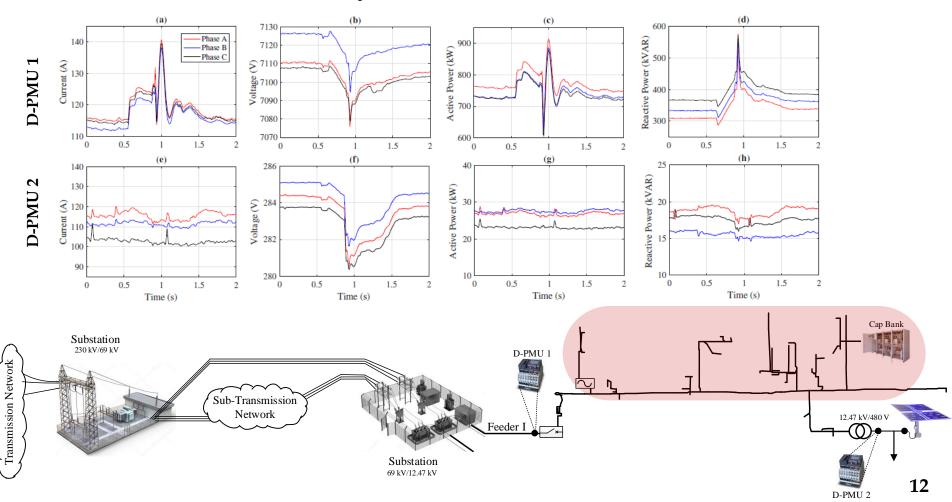
Class III: Events initiated from somewhere between the two D-PMUs: Class III.A: Capacitor Bank Switching



Event Labeling

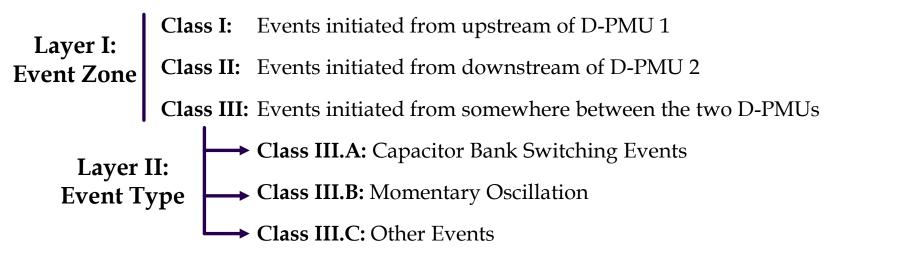
Class III: Events initiated from somewhere between the two D-PMUs:

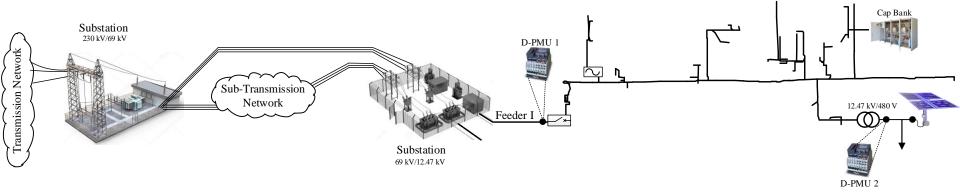
Class III.B: Momentary Oscillation



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Event Labeling Summary





Feature Selection

- Single-Stream Features
 - Statistics, e.g., standard deviation
 - Difference, e.g., post-event and pre-event
- Multi-Stream Features
 - Correlation between any two signals
- Event Detection Features
 - Detection window size
 - Detection indicator

We consider data from two D-PMUs: Total number of signals is 8

Feature	Feature Description		Number
Single-stream	Statistics	$std(D_i)$	8
	Difference	$ d_n - d_1 $	8
Multi-stream	Correlation	$corr(D_i, D_j)$	28
Detection	Detection Window	ω	1
	Detection Indicator	$\mathbb{I}\{D_i\}$	8

Total number of features: 53

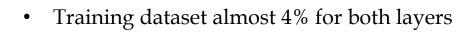
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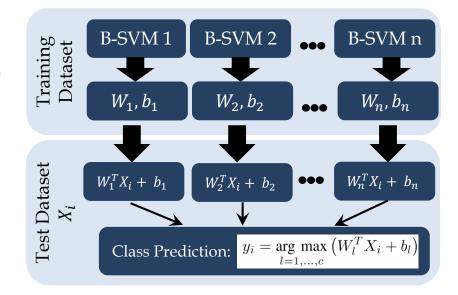
Event Classification Method:

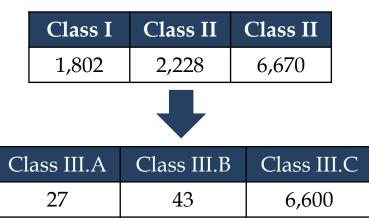
- 1- Multi-Support Vector Machine (Multi-SVM)
 - Binary Decomposition: One-against-all (OvA)
- 2- k-Nearest Neighbors (k-NN)
- 3- Decision-Tree (DT)

Summary of Analyzed Database:

- Data from two D-PMUs, during 15 days
- In total, 1.2 billion measurement points
- In total, 10,700 events (only 1% of the data points)
- Number of Events from Event Labeling



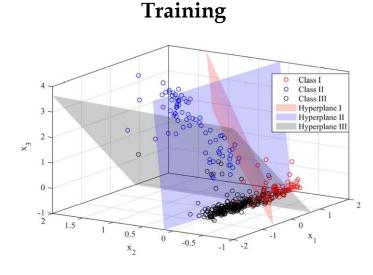






Illustrative Example of Multi-SVM Classification Results for Layer I:

Three dominant features among 53 features are selected to train and test classifier.



Accuracy: 91.55%

ass	Class I	82.7% 67	5.8% 5	5.9% 16
Predicted Class	Class II	0.0% 0	93.0% 80	0.4% 1
Pre	Class III	17.3% 14	1.2% 1	93.7% 254
	·	Class I	Class II	Class III

Target Class

00 00 0 Class I Class II 0 Class III 0 Hyperplane I 3 Hyperplane II Hyperplane III 2 x₃ 2 2 1.5 0.5 0 -0.5 -1 -2 x2

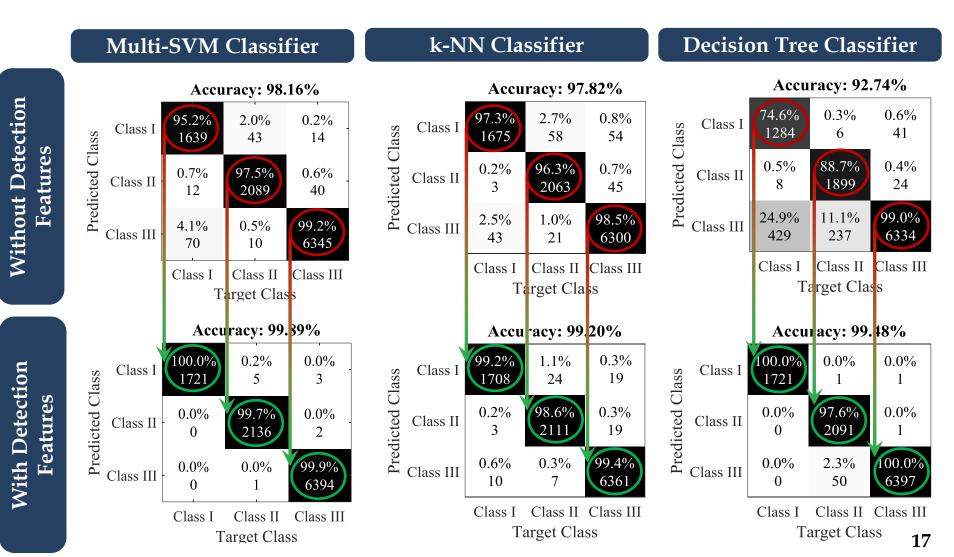
	Accuracy: 89.57%		
Class I	70.7%	4.8%	6.3%
	1216	102	404
Predicted Class	0.1%	94.2%	0.6%
II support	2	2018	37
Class III	29.2%	1.0%	93.1%
	503	22	5958

Class I Class II Class III Target Class

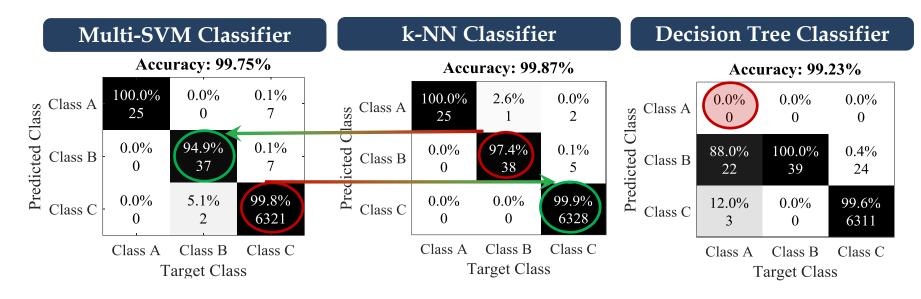
Test

Classification Results for Test data of Layer I:

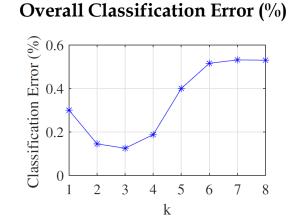
Impact of Detection Features



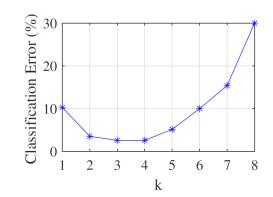
Classification Results for Test data of Layer II



• The performance of k-NN classifier is highly sensitive to the choice of parameter k.



Classification Error in Class III.B (%)



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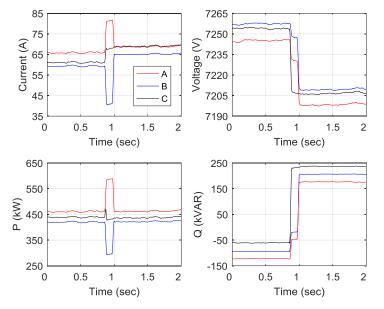


Cyber Security & Situational Awareness



Three-Phase Switched Capacitor Bank:

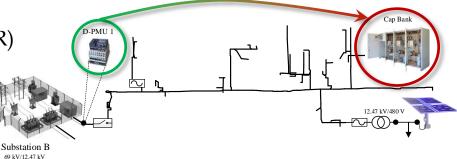
- Switched capacitor bank three-phase (900 kVAR)
 - Controller: Volt-VAR Controller.



Switch off Event

- Two-Step 3-Phase Switch
 - Step 1: Phase C (Zero Crossing)
 - Step 2: Phase A/B (Possible Malfunction)
- Slightly Unbalanced Operation
 - Likely fuse blowing on A and C

Remote Monitoring



Transient Current Magnitude

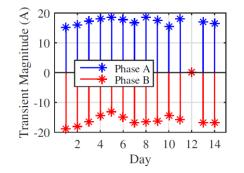
Duration of Transition

8

Day

10

12 14

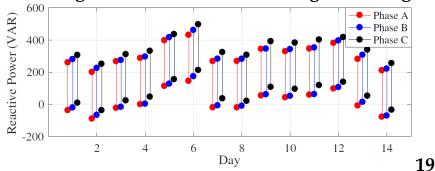


150 *** * * * 150 50 * * *

2

4 6

Change in Reactive Power During Switching



Agenda



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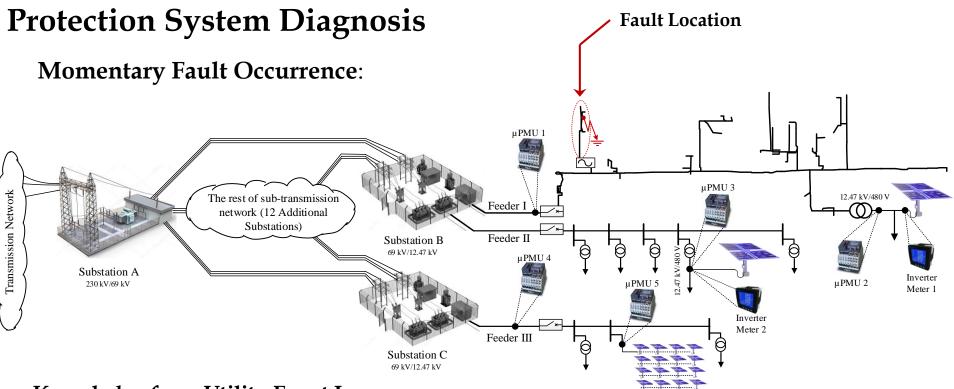


Use-Cases:

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Over Security & Situational Awareness





Knowledge from Utility Event Log:

- Fault Location: Feeder I, in November 2016, almost 0.3 mile away from Substation B.
- Event Source: Blown fuse is founded in phase B and a diseased bird on pole.

We are interested in answering the following questions

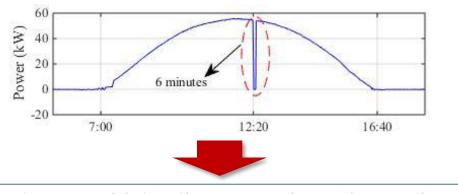
- What is the time-line of the fault?
- Possible miscoordination between lateral fuse and auto-recloser?
- Possible miscoordination between auto-recloser anti-islanding relay?



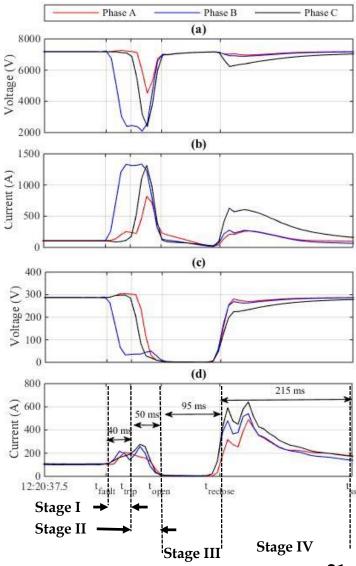
Fault Time-Line:

Stage I	Voltage on phase B dropsDeviation in voltage on phases A and C
Stage II	Recloser sends trip command to the circuit breakerThree-phase circuit breaker operation transient
Stage III	Feeder I is isolatedCurrent of D-PMU 1 decreases to zero (RLC circuit)
Stage IV	First shot of recloser is finishedFeeder is reconnected to substation

Recloser-fuse coordination is Verified



Recloser Anti-islanding protection Miscoordination



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Use Cases:

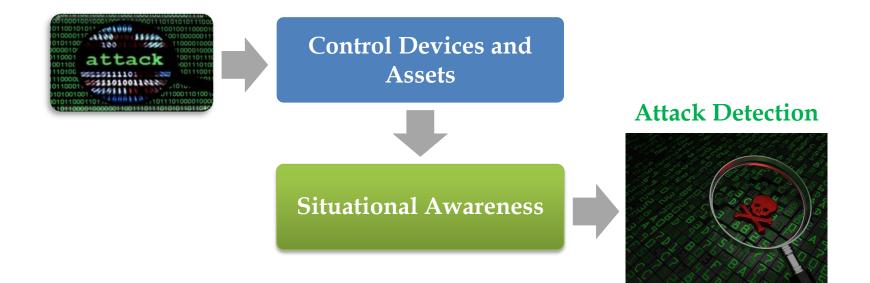
- Asset Monitoring
- Protection System Diagnosis



Cyber Security & Situational Awareness



• <u>Aspect 1</u>: Attack Detection through Situational Awareness



• <u>Aspect 2</u>: Vulnerability in Sensors and Monitoring System



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References:

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Thank You!

Alireza Shahsavari