

The logo graphic for IDEAL, featuring a blue and green geometric design with a stylized 'i' and 'd'.

ideal grid for all

Synchrophasor Applications Facilitating Interactions between Transmission and Distribution Operations

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EUROPEAN ELECTRICITY GRID INITIATIVE

- SUPPORT -





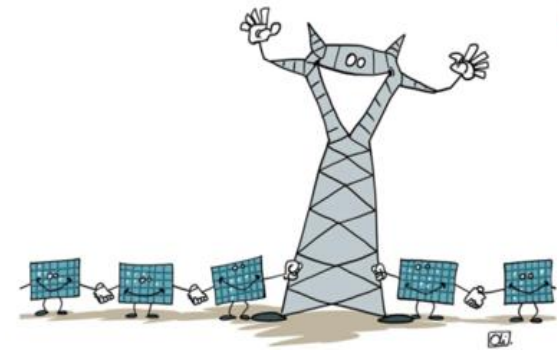
Thank you!

- Four years of sharing with us!
- Brazil has an enormous heart:
 - It's the *generosity* of it's people!





Acknowledgements



- The work in this presentation is result of the research carried @KTH SmarTS Lab in the FP7 IDE4L project (2014-2016) and other projects form 2011-2016.
- Special thanks to **Dr. Hossein Hooshyar**, who undertook the day-to-day project management of this project at KTH SmarTS Lab. with great dedication.
- All of the following students contributed to this presentation with their hard work!



Hossein



Farhan



Reza



Ali



Ravi



Narender



Maxime



Outline

- Introduction: PMUs in distribution networks?
- PMU Application Use Case Definition using SGAM
- Methods and Tools
 - Development, Implementation and Testing using RT-HIL Simulation
 - The Reference Distribution Grid Model
- Handling PMU Data:
 - PMU Data Feature Extraction
- Applications:
 - Steady State Model Synthesis
 - Dynamic Line Rating for Distribution Feeders
 - Small-Signal Dynamic Analysis
- Conclusions



Introduction (1/2)

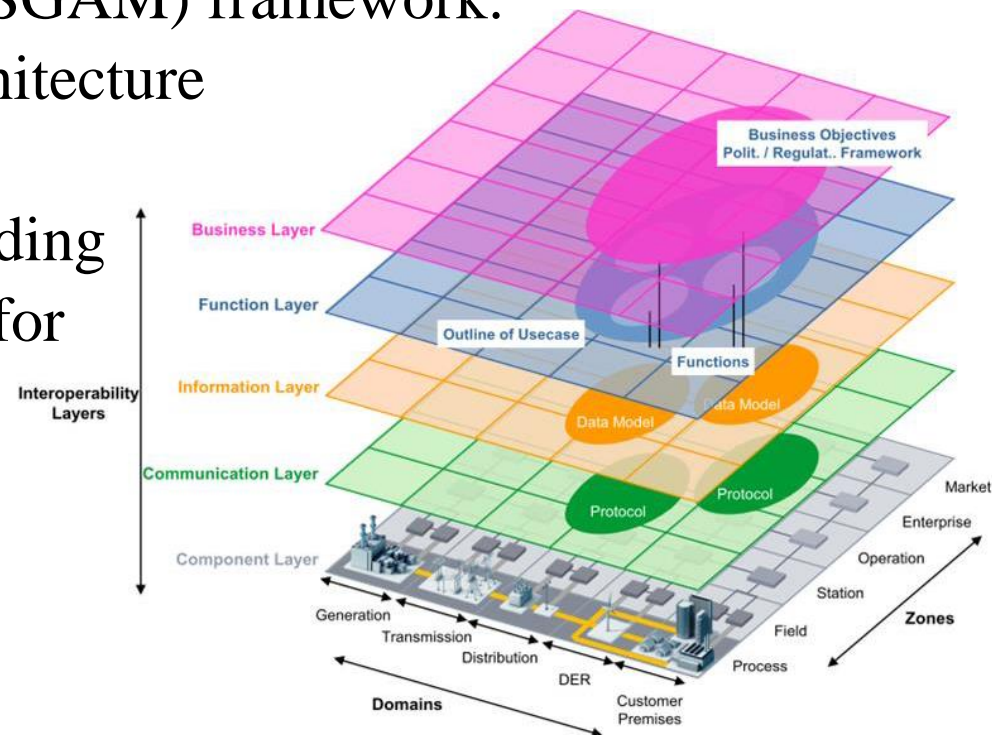
- It is becoming necessary to increase observability between T&D grids, because of emerging dynamics active distribution networks due to renewables
 - Fast changing conditions in the network
 - Fast behavior of components
 - Traditional monitoring technology not capable of satisfying requirements: types of signals, time-synchronization and speed of data acquisition
- There is great potential of utilizing real-time Synchrophasor data from PMUs (Phasor Measurement Unit) to extract key information related to fast changing conditions and dynamic behavior.
- The implementation of such PMU-based “information exchange” has to go through a properly designed and implemented architecture.



Introduction (2/2)



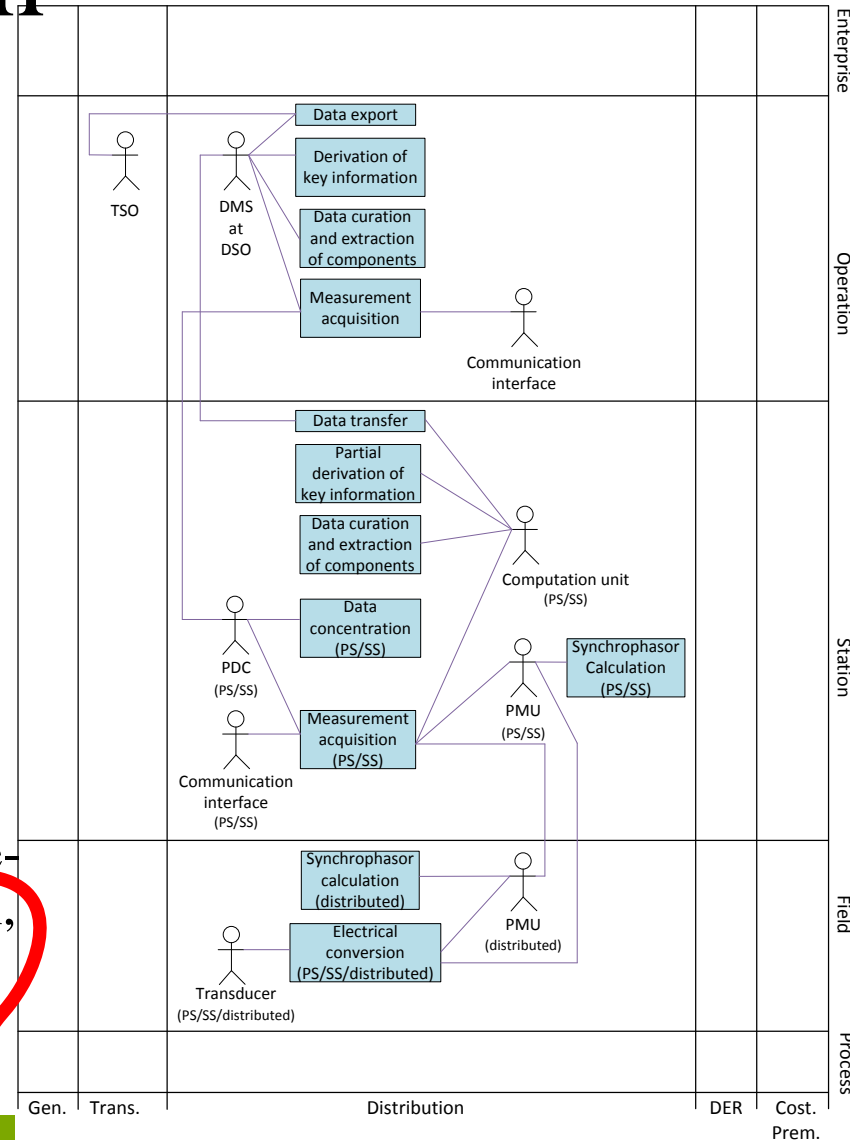
- The IDE4L architecture is built upon the 5-layer Smart Grid Architecture Model (SGAM) framework.
- The main inputs to the architecture design are the use cases.
- The IDE4L use case, including the PMU-based functions for dynamic information extraction, is presented in this presentation.





Use Case Definition

- Data flows from PMUs => PDC => Super PDC => DMS computers (where dynamic information is extracted) => TSO.
- Data processing and information derivation can occur at both the station (partially) and the operation (i.e. DMS computers) zones.
- Actors: Instrumentations, PMU, PDC, communication interface, DMS, and TSO
- Functions: electrical conversion, synchrophasor calculation, data acquisition, data concentration and time-alignment, data exporting, data curation, extraction of different time-scale components of the data, and derivation of key information out of the data.

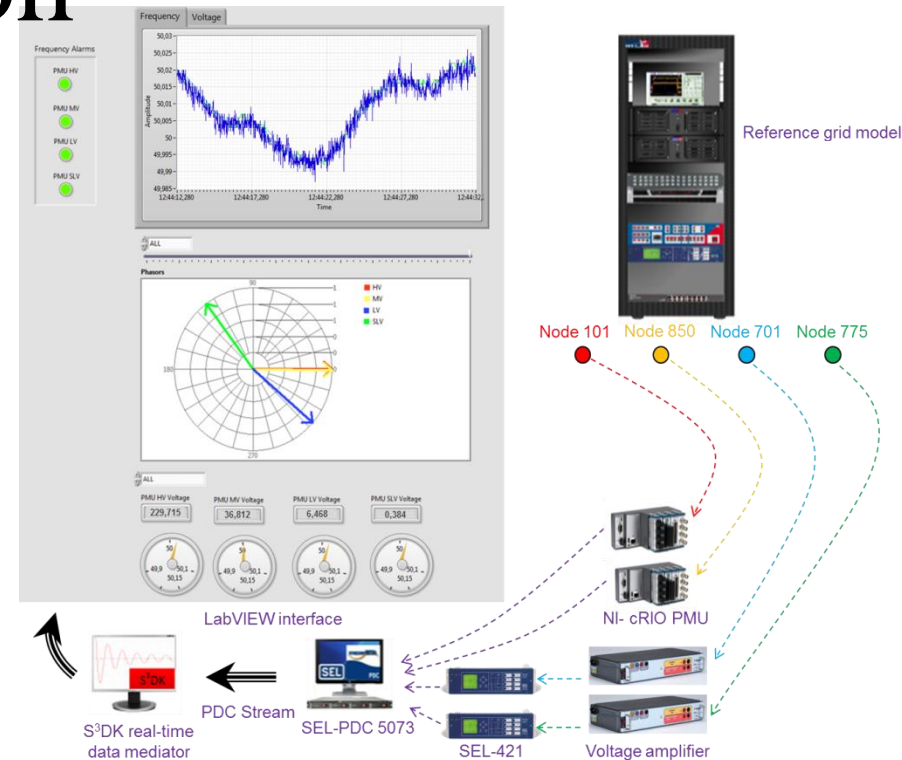




Development, Implementation and Testing using RT-HIL Simulation

- The development of the applications has been carried out using real-time hardware-in-the-loop simulation consisting of:

- A real-time simulation model of active distribution networks.
- The real-time simulation model is interfaced with PMUs in HIL.
- PMU data is streamed into a computer workstation through PDC.



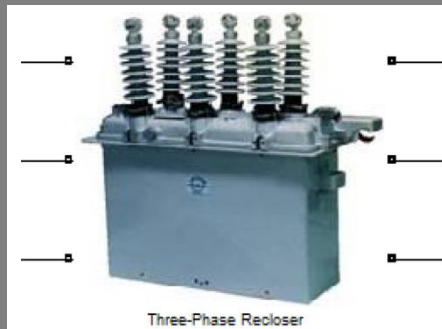
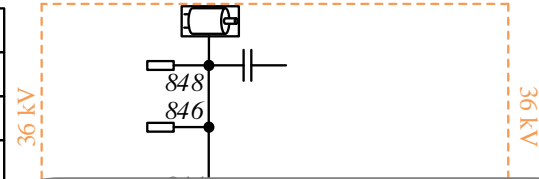
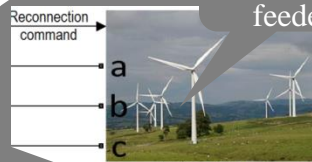
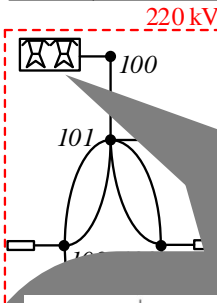
- The computer makes available software development tools within the LabVIEW environment.
- All data acquisition chain is carried out using the corresponding PMU standards.

The Reference Distribution Grid Model (1/2)

	Rated Voltage	No. of buses	Number of branches
HV	220 kV	6	7 three-phase
MV	36 kV		three-phase, 8 single-phase
LV	6.6 kV		39 three-phase
RLV	0.4 kV		1

Roy Billinton
Transmission
Test System

IEEE 34
bus test
feeder



Unity Energy Storage

Energy System (CES) (mask)

Protection

Total battery storage capacity (Ah)
200

Minimum SoC (%)
20

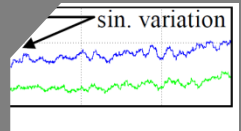
Maximum SoC (%)
90

Voltage levels [Vmin2 Vmin1 Vmax1 Vmax2] (pu)
[0.5 0.88 1.1 1.3]

Trip times [V<Vmin2 Vmin2<V<Vmin1 Vmax1<V<Vmax2 Vmax2<V] (s)
[0.24 4.8 4.8 0.24]

Frequency levels [fmin fmax] (Hz)
[49.3 50.5]

Trip times [f<fmin fmax<f] (s)
[0.24 0.24]



OG
oad



The Reference Distribution Grid Model (2/2)

- Runs on 4 cores using the State-Space-Nodal (SSN) solver with time-step of $100\mu\text{s}$.
- The two different implementations of the grid model can be downloaded from the KTH SmarTS Lab Github repository at

<https://github.com/SmarTS-Lab/FP7-IDE4L-KTHSmarTSLab-ADN-RTModel>

- The SSN implementation is also available in the ARTEMiS 7.0.5 demo section.

This repository: Search Pull requests Issues Gist

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Active Distribution Network Power System Model developed in the FP7 IDE4L Project by KTH SmarTS Lab — Edit

10 commits 1 branch 1 release 1 contributor

Branch: master New pull request Create new file Upload files Find file Clone or download

Ivanfretti committed on GitHub Add DOI from Zenodo Latest commit 2516633 4 days ago

File	Description	Time
V2	Uploading the two versions of the model.	6 days ago
V6	Add files via upload	6 days ago
LICENSE	Initial commit	6 days ago
README.md	Add DOI from Zenodo	4 days ago

README.md

DOI: 10.5281/zenodo.61183

FP7-IDE4L-KTHSmarTSLab-ADN-RTModel

This project contains an Active Distribution Network Power System Model developed in the FP7 IDE4L Project by KTH SmarTS Lab. The model was developed for use with the Opal-RT eMegaSim real-time power system simulator.

Model Versions

Two versions of the model are provided in this repository, along with a model description and a self-contained documentation (i.e. help file).

Details of the first version (V2) can be found in the open access publication in the following link:

- Ref. 1: H. Hooshyar, F. Mahmood, L. Vanfretti, M. Baudette, Specification, implementation, and hardware-in-the-loop real-time simulation of an active distribution grid, Sustainable Energy, Grids and Networks, Volume 3, September 2015, Pages 36-51, ISSN 2352-4677, <http://dx.doi.org/10.1016/j.segan.2015.06.002>

The second version of the model was developed to overcome several of the limitations in accuracy of the "stub-line" modeling used to decouple the model into different cores. Hence, V6 partitions each subsystem into state-space-nodal (SSN) groups so that parallel computations can be carried out with the ARTEMiS-SSN solver. More information about the model can be found on the "ReadMe.pdf" included in the V6 folder, and in the following paper:

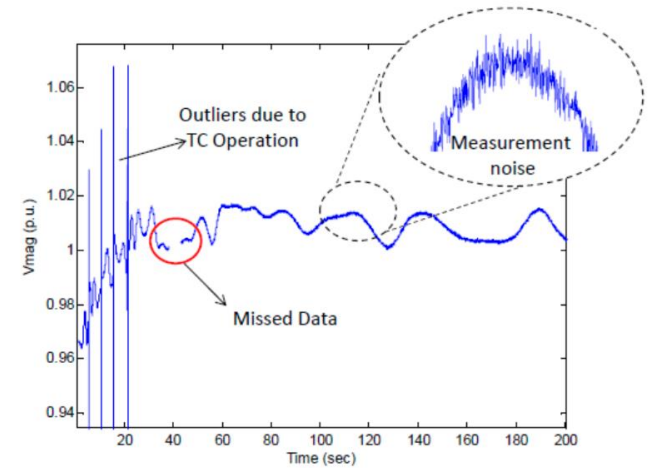
- Ref. 2: H. Hooshyar, L. Vanfretti, C. Dufour, "Delay-free parallelization for real-time simulation of a large active distribution grid model", in Proc. IEEE IECON, Florence, Italy, October 23-27, 2016.



PMU Data Curation, Extraction of Different Time-Scale Components of the Data (Data Processing)

PMU Data Processing

- PMU measurements are normally
- polluted with
 - Undesirable noise
 - Outliers
 - Missing data
- Measurements obtained from PMUs during different events in power systems contain different signal features at different time scales, i.e. features of different types of power system dynamics.
- So before being fed to the applications:
 - PMU measurements should be curated.
 - Signals required for each application should be extracted from the PMU measurements.





PMU Data Processing (2/3)

- An enhanced Kalman filtering technique has been utilized for both bad data removal, i.e. data curation, and extraction of the proper signal feature from the PMU data.

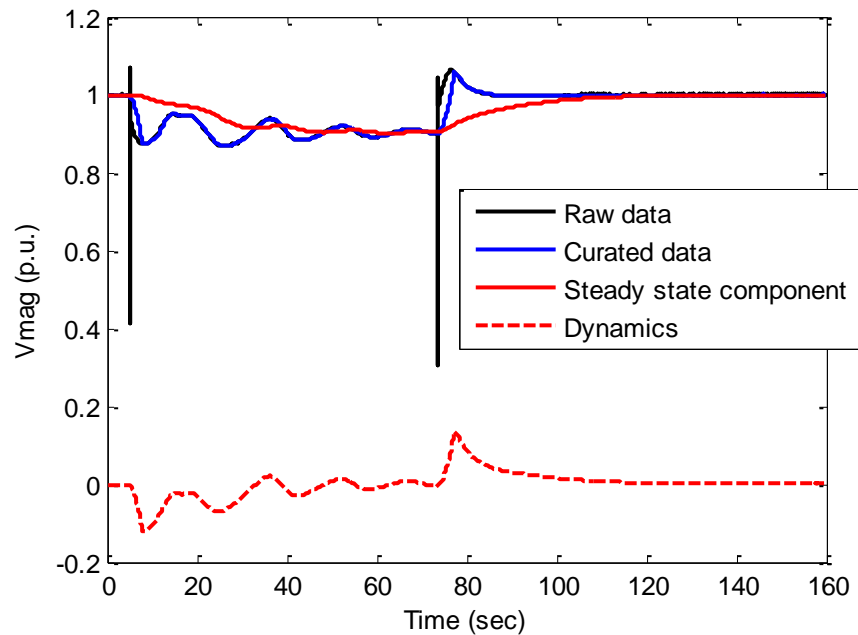
Step		Equation	Significance
1	Prediction	$\hat{x}_k^- = A\hat{x}_{k-1}^- + Bu_k$	Project the state ahead.
2		$P_k^- = AP_{k-1}A^T + Q$	Project the error covariance ahead.
3	Correction	$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1}$	Compute the Kalman gain.
4		$\hat{x}_k = \hat{x}_k^- + K_k(z_k - H\hat{x}_k^-)$	Update estimate with measurement z_k .
5		$P_k = (I - K_k H)P_k^-$	Update the error covariance.

- R and Q (the measurement and process noise covariance matrices), can be updated in real-time to perform the data processing.

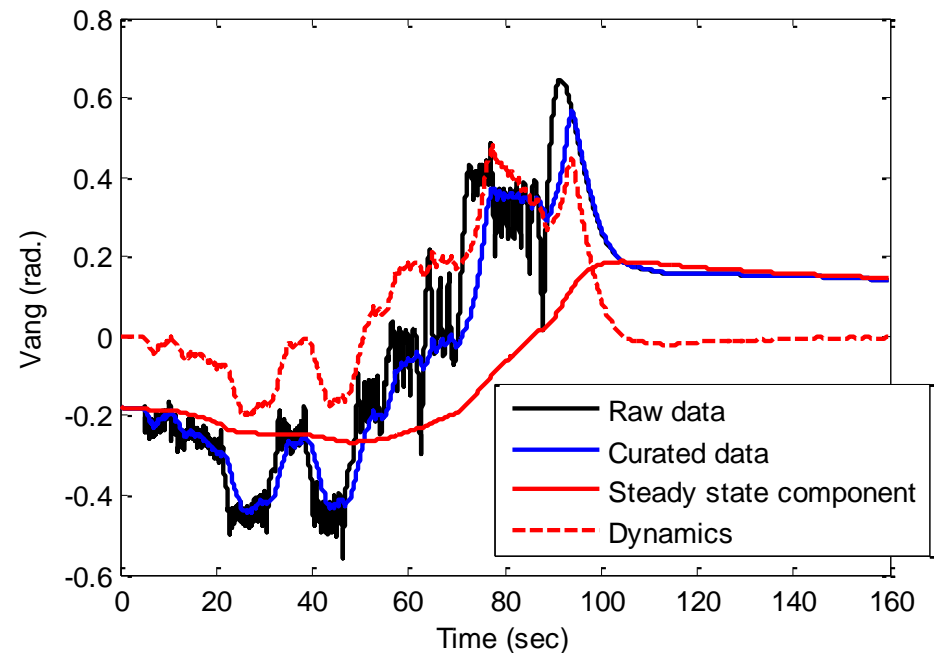


PMU Data Processing (3/3)

- Sample results.



voltage magnitude (per unit)



voltage angle (radian)



Real-Time Steady State Model Synthesis of Distribution System



Background

- Currently, TSOs maintain reduced models of portions of the distribution networks, however:
 - The models covers limited portions of the distribution network due to the lack of network observability (measurement points) and computational burden associated with simulating large joint T&D models.
 - The models are not updated frequently.
 - The reduction methods, used by TSOs, often make assumptions that are no longer valid for active distribution networks.



Methodology and Application

- Model parameters are obtained by writing KVL equations across the model branches and equate V_i 's and I_i 's to PMU measurements.

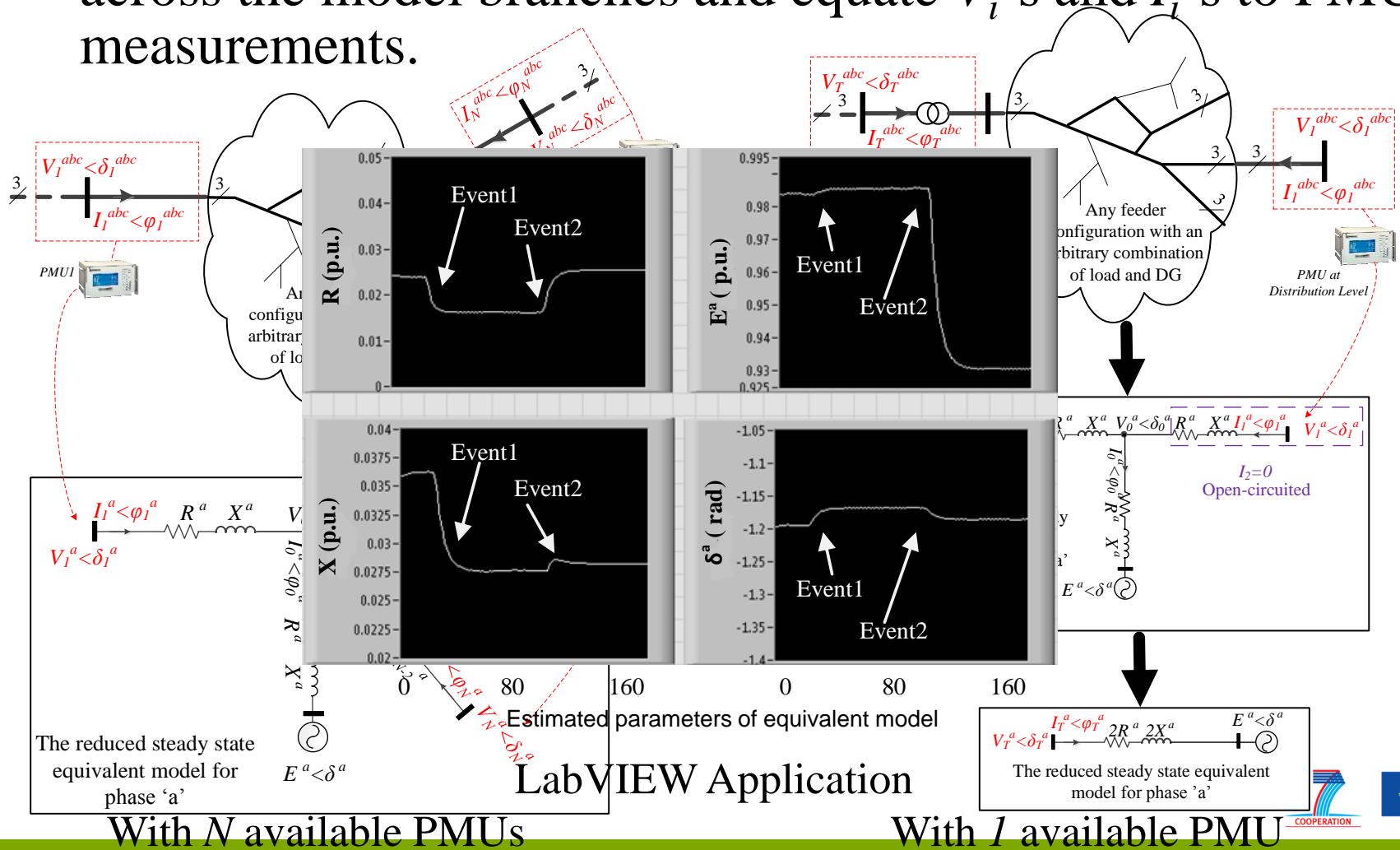
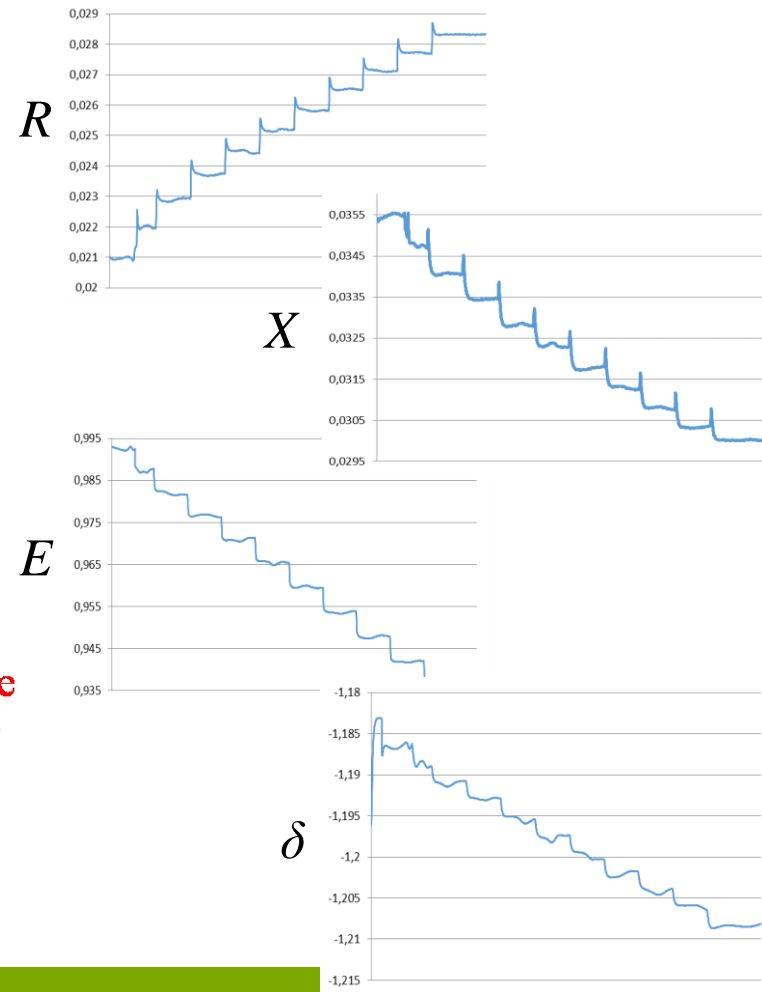
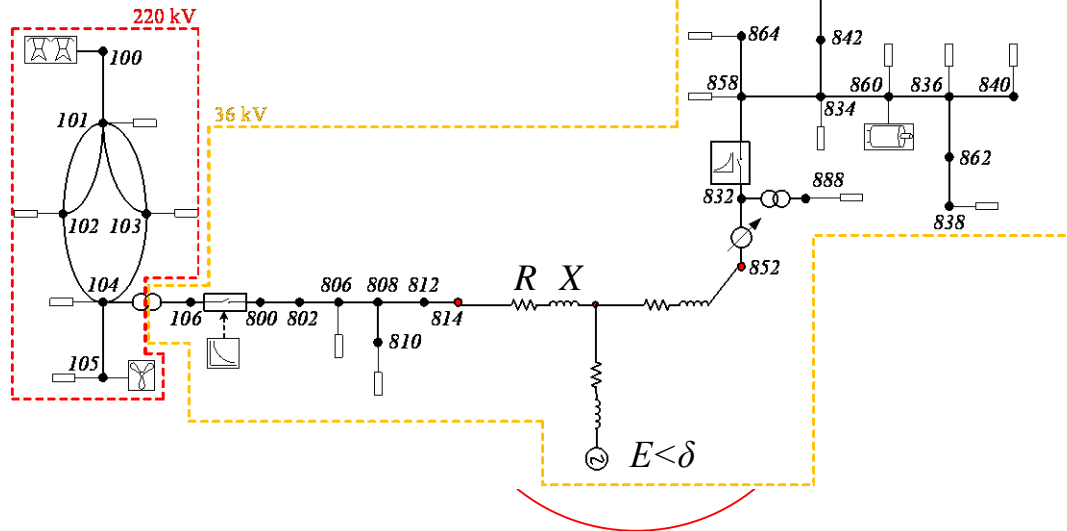




Illustration Example (1/2)

- Steady state model of a portion of the reference grid is estimated during wind curtailment at different dispatch levels.

Legend			
EPS		Capacitor bank	
Static load		Circuit breaker	
Dynamic load		FOP	
Voltage regulator		Recloser	
Wind farm			



use
or

δ



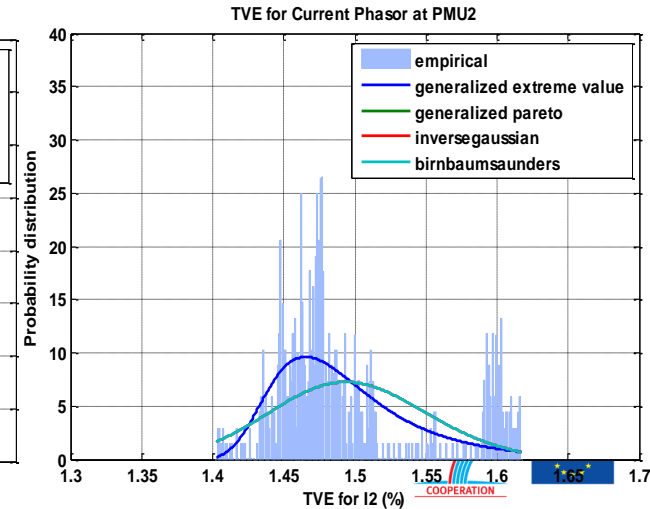
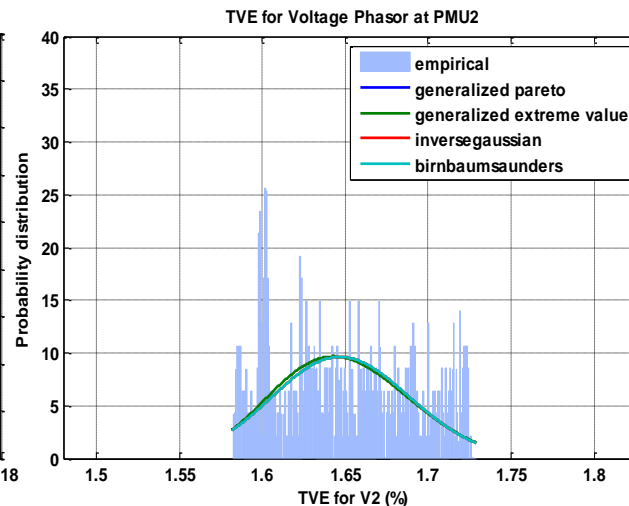
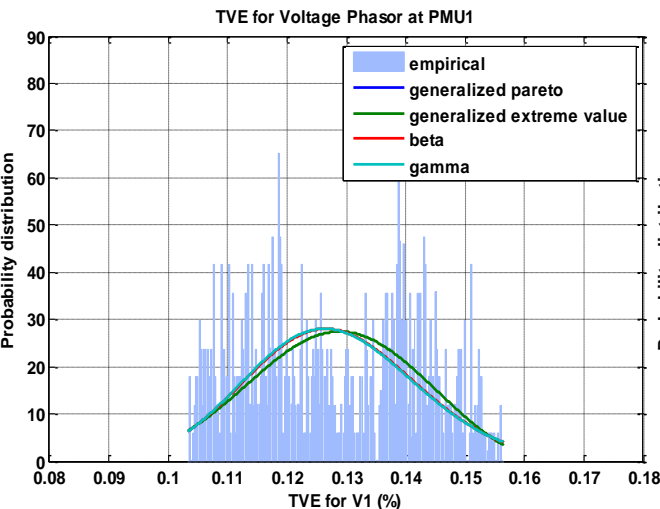
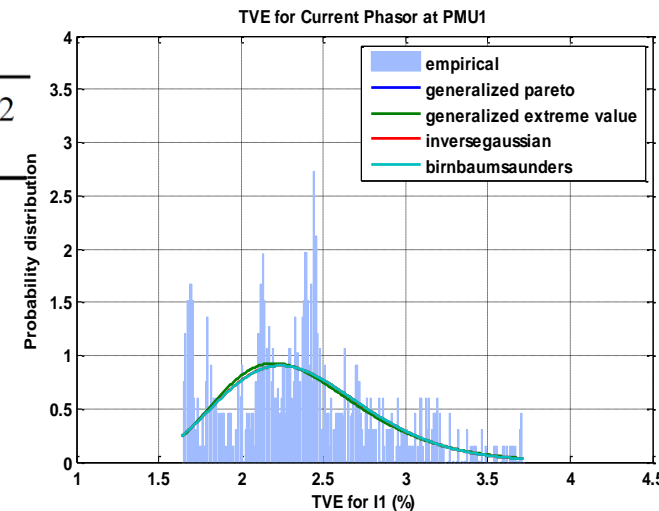
Illustration Example (2/2)

- True and reproduced current and voltage phasors are compared using *TVE*.

$$TVE(n) = \sqrt{\frac{(\hat{V}_r(n) - V_r(n))^2 + (\hat{V}_i(n) - V_i(n))^2}{V_r(n)^2 + V_i(n)^2}}$$

Variables with hat are reproduced ones.

- The mean TVE is less than 2.5%.





Dynamic Line Rating for Distribution Feeders

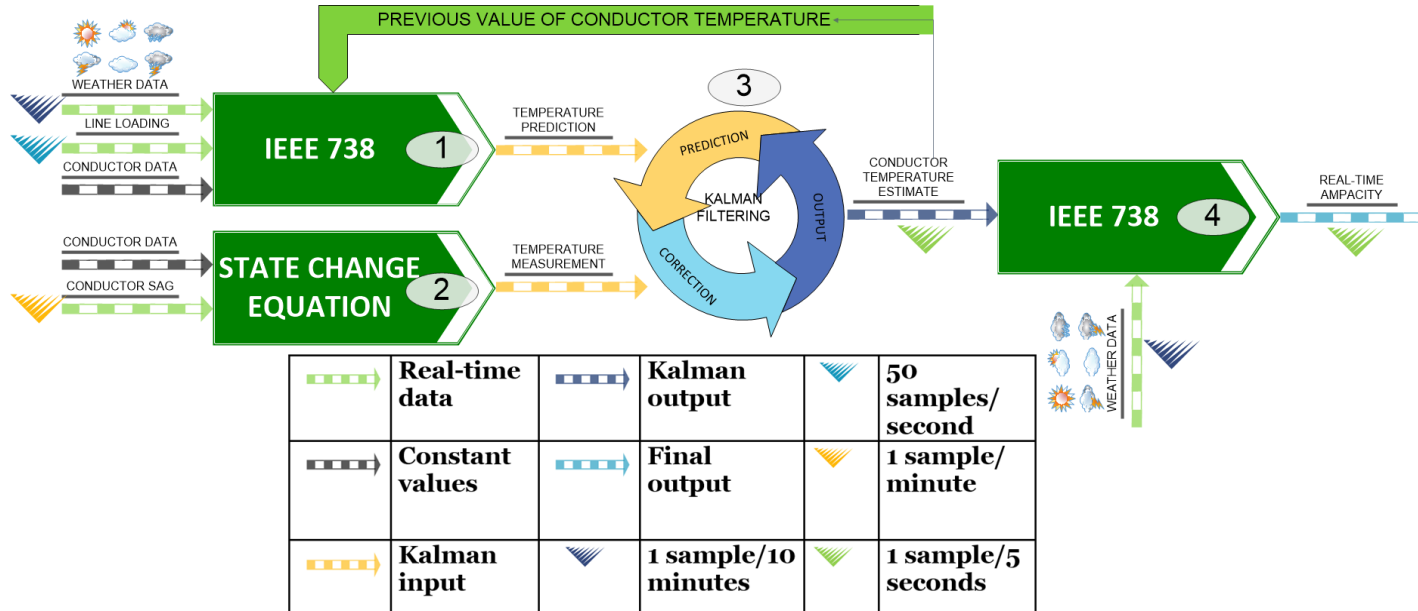


Background

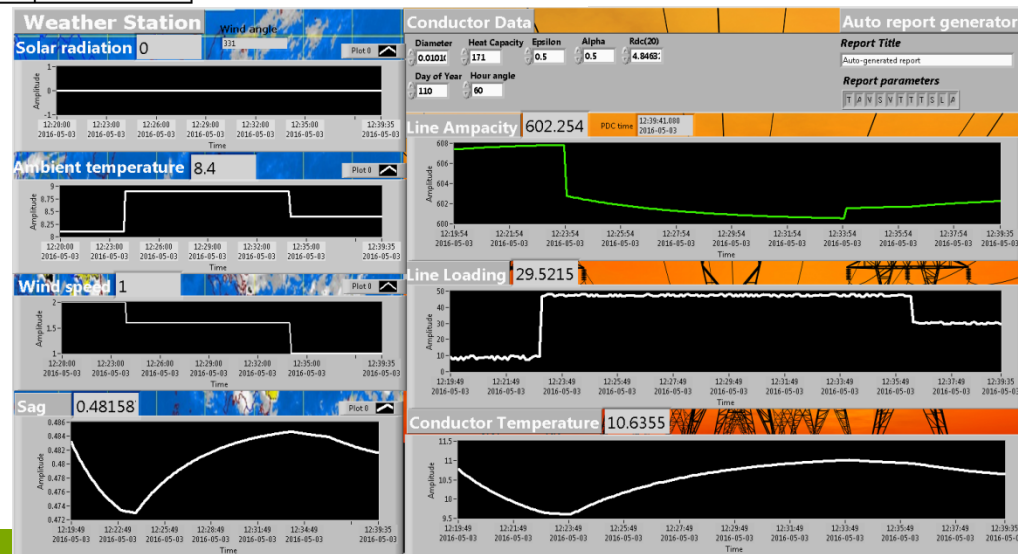
- Dynamic line rating (DLR) is a way to optimize the ampacity of transmission and distribution lines by measuring the effects of weather and actual line current.
- The inputs needed for the method:
 - Ambient data => provided by a close-by weather station.
 - Line loading => provided by PMU
 - Real-time sag => provided by a GPS-based measurement device.



Methodology and Application



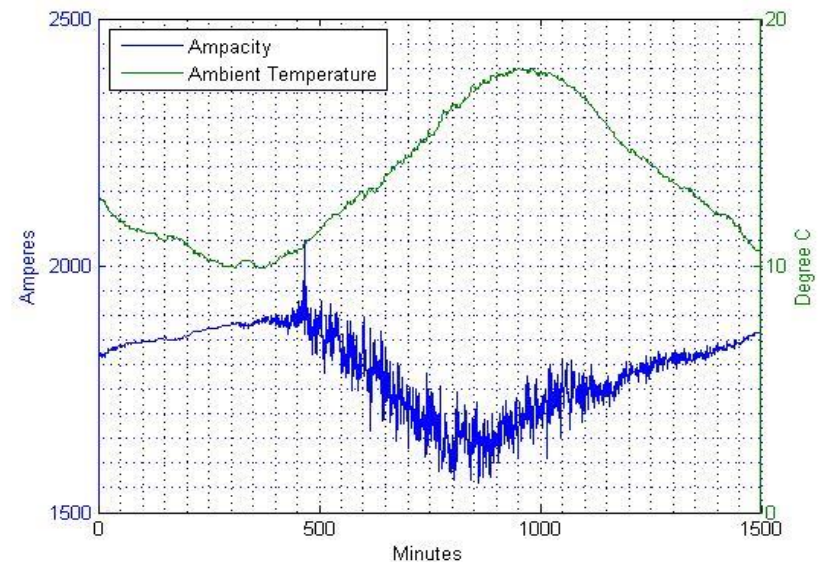
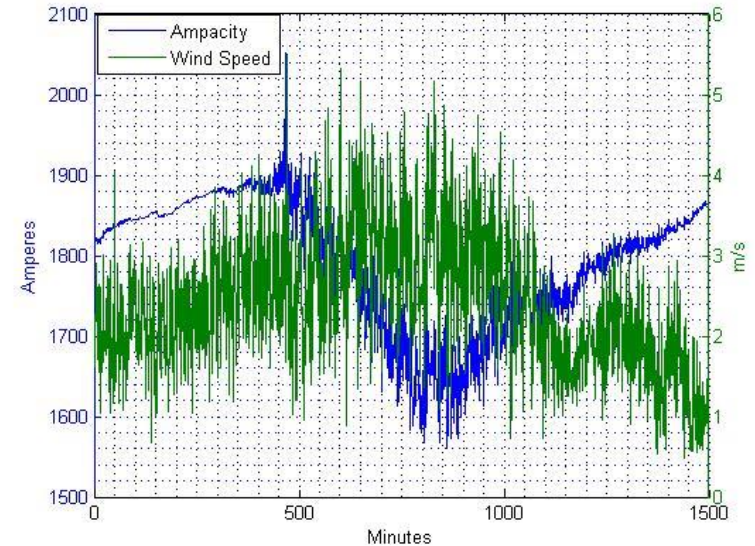
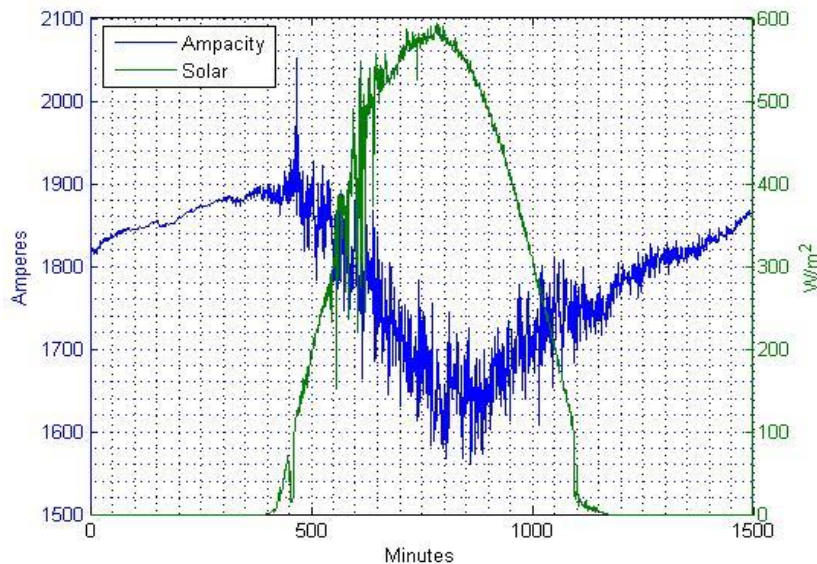
LabVIEW Application





Sample Results

- Results are obtained by applying the method on data from a real feeder.
- Output shows accurate correlation with different inputs.





Small Signal Dynamic Analysis of Distribution System

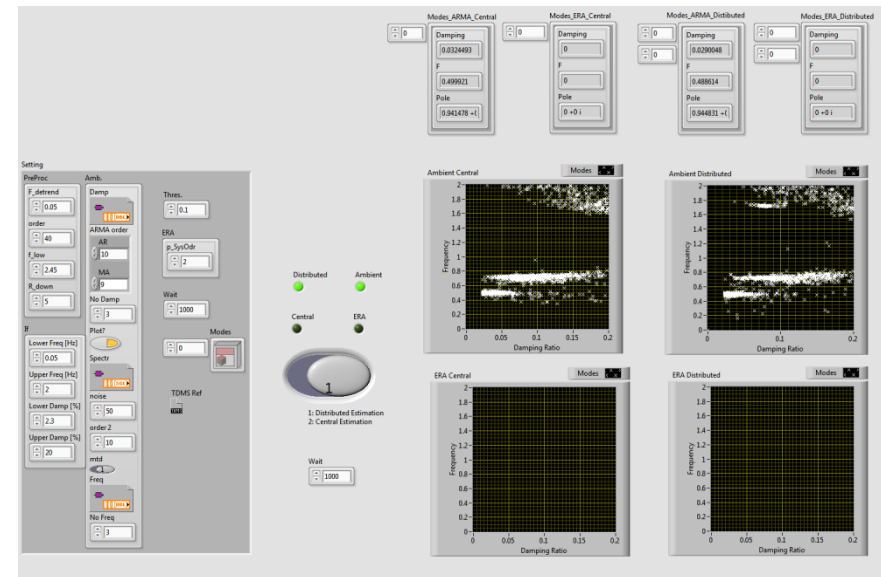
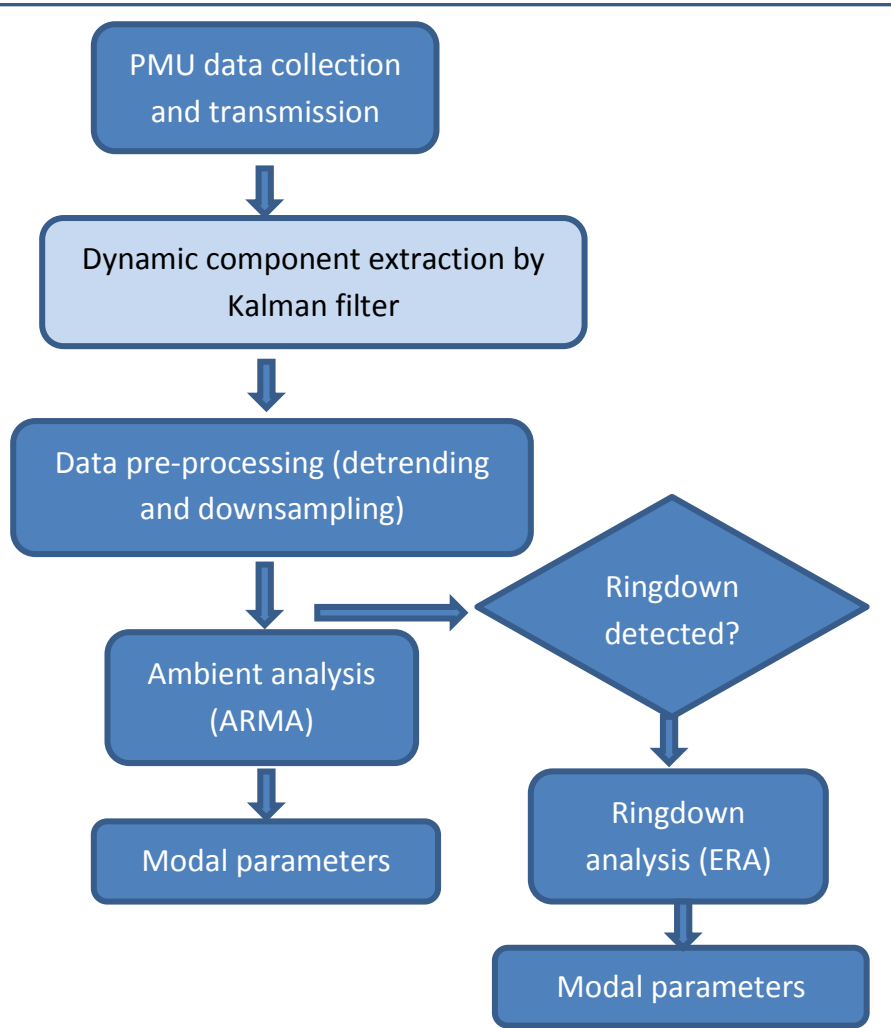


Background

- For reliable operation of the power system, oscillations are required to decay.
- Accurate and real-time estimates of active distribution networks oscillatory modes has become ever so important.
- Timely extraction of these modes and related parameters from network measurements has considerable potential for near real-time dynamic security assessment.



Methodology and Application



LabVIEW Application



Implementation Architectures

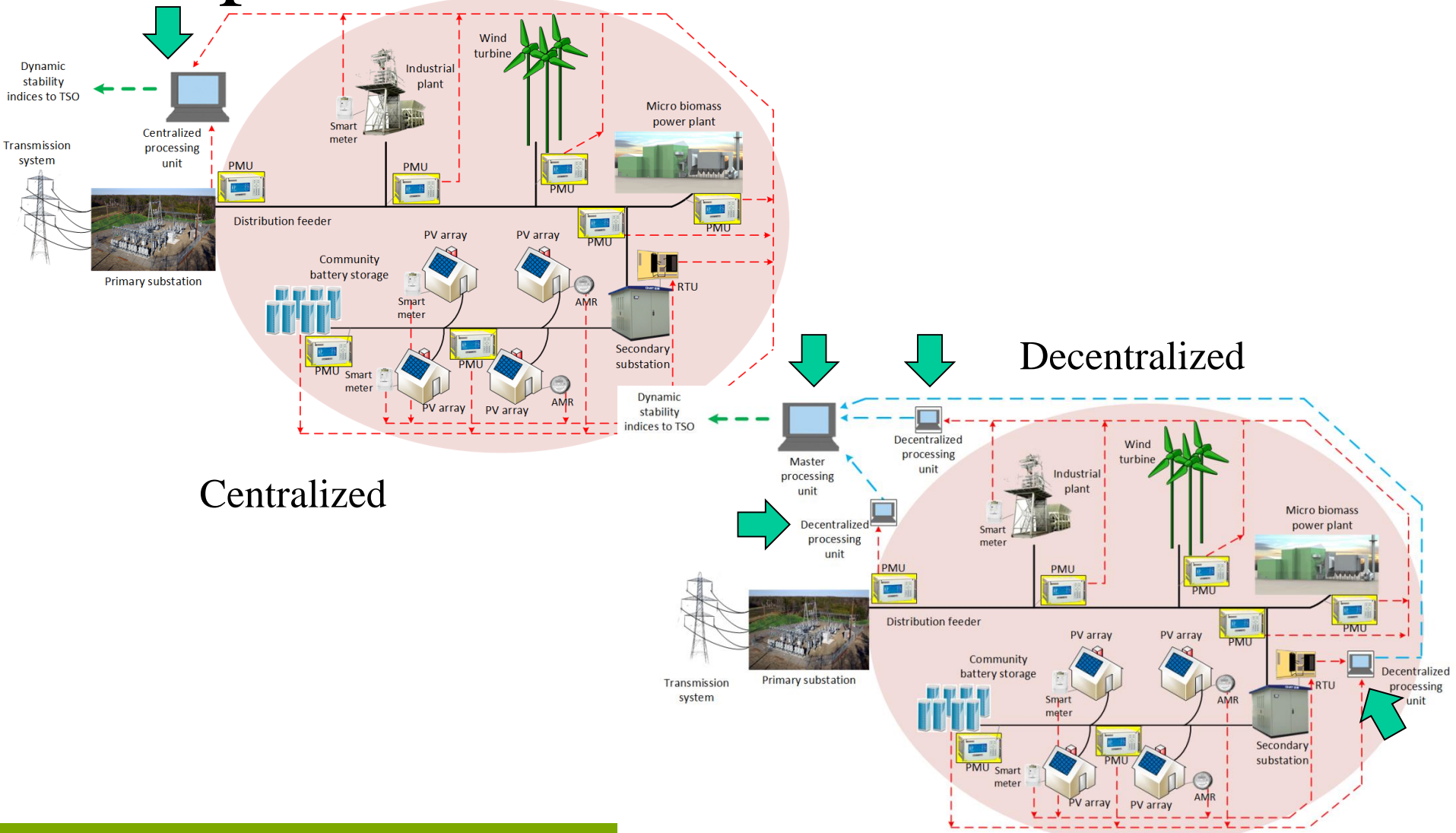


Illustration Example (1/2)

- 4 PMUs were deployed in the reference grid to be used for mode estimation under two different architectures of centralized and decentralized

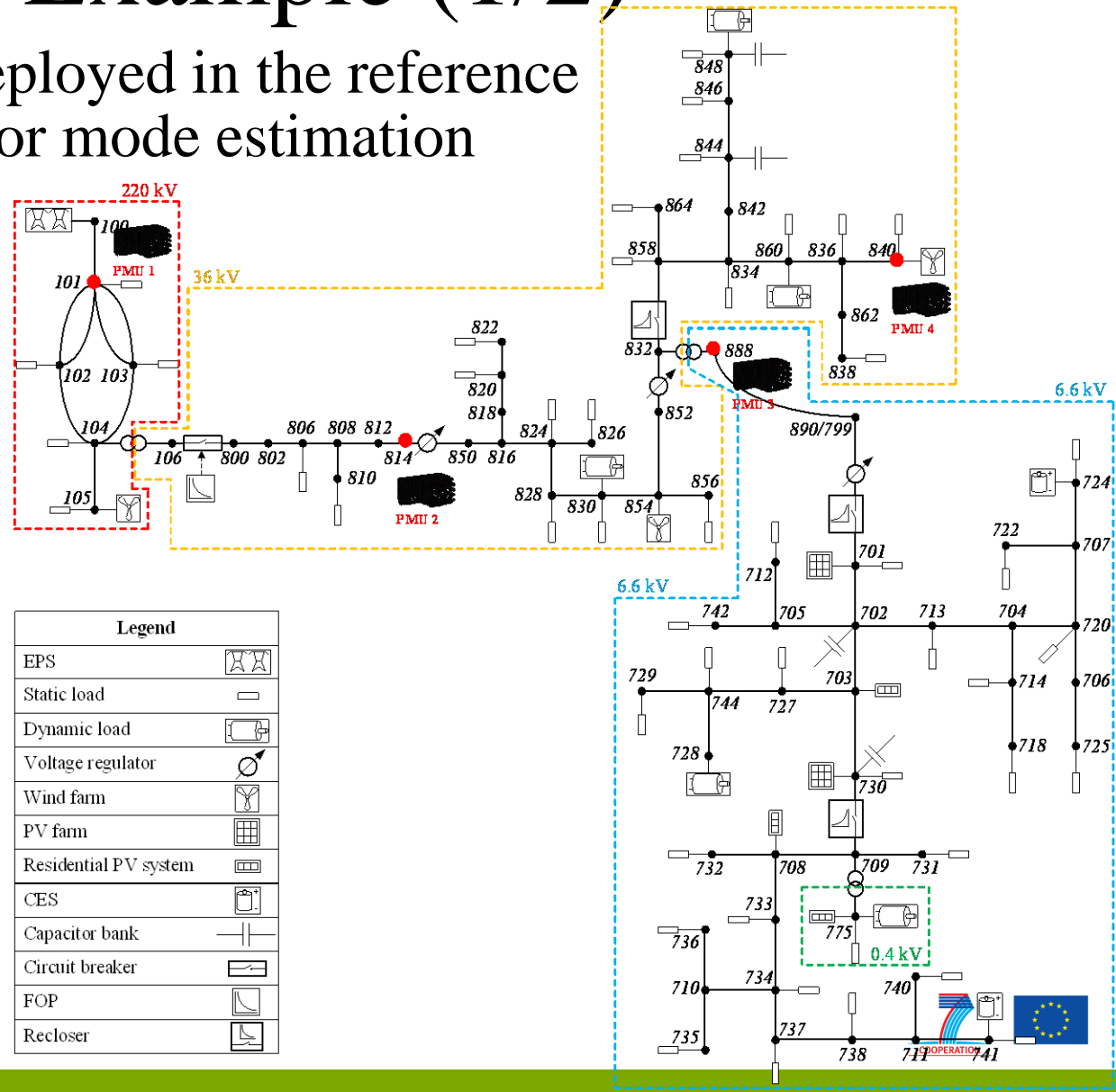
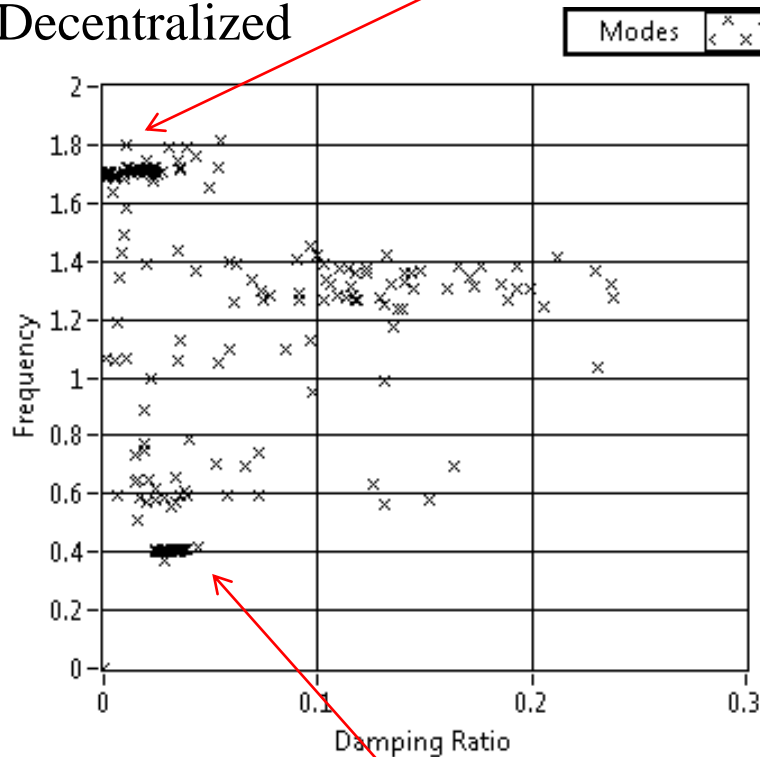




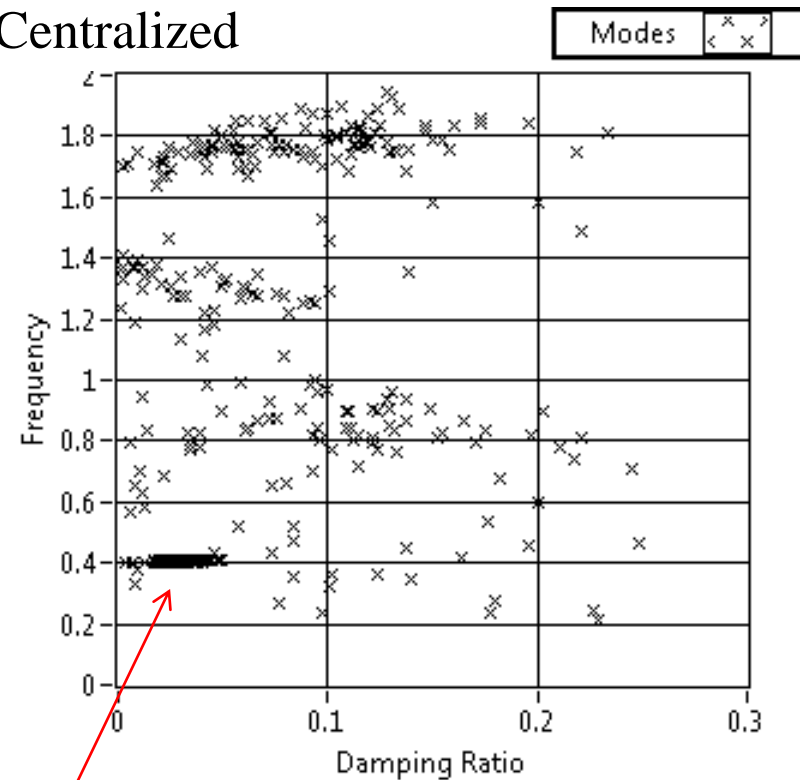
Illustration Example (2/2)

Forced local oscillatory mode detectable in
decentralized architecture

Decentralized



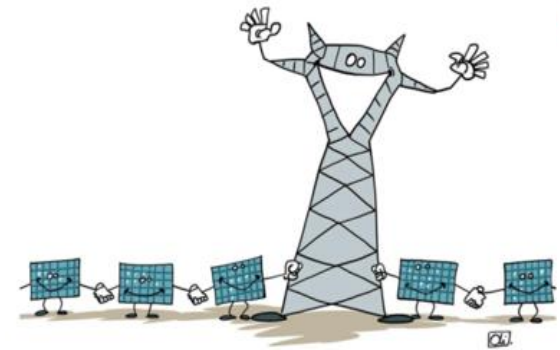
Centralized



Inter-area oscillatory mode between HV
section and rest of the grid

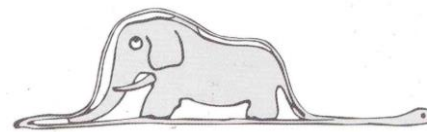
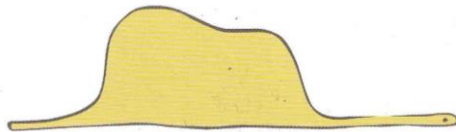


Conclusions



- The increase of intermittent renewable sources at the distribution network will bring challenges into DSO operations
- Synchrophasor measurements have a great potential in distribution networks
 - Applications will play the role of extracting key information about the operation of the grid
- TSOs-to-DSOs interaction
 - DSOs can enhance the way they operate by having better knowledge of the system's performance
 - TSOs can gain visibility of the phenomena at lower voltage levels

Thank you!



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