PMU-Based Real-Time Applications: Steady State Model Synthesis, DLR and Modal Analysis of Active Distribution Networks

IDE4L
ideal grid for all

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Luigi Vanfretti

KTH Royal Institute of Technology,
Smart Transmission Systems Laboratory,
Sweden
luigiv@kth.se

KTH VETENSKAP OCH KONST

SmarTS Lab
Smart Transmission Systems Laboratory

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- SUPPORT -

COOPERATION

Introduction

- 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-synchonization and speed of data acquisition

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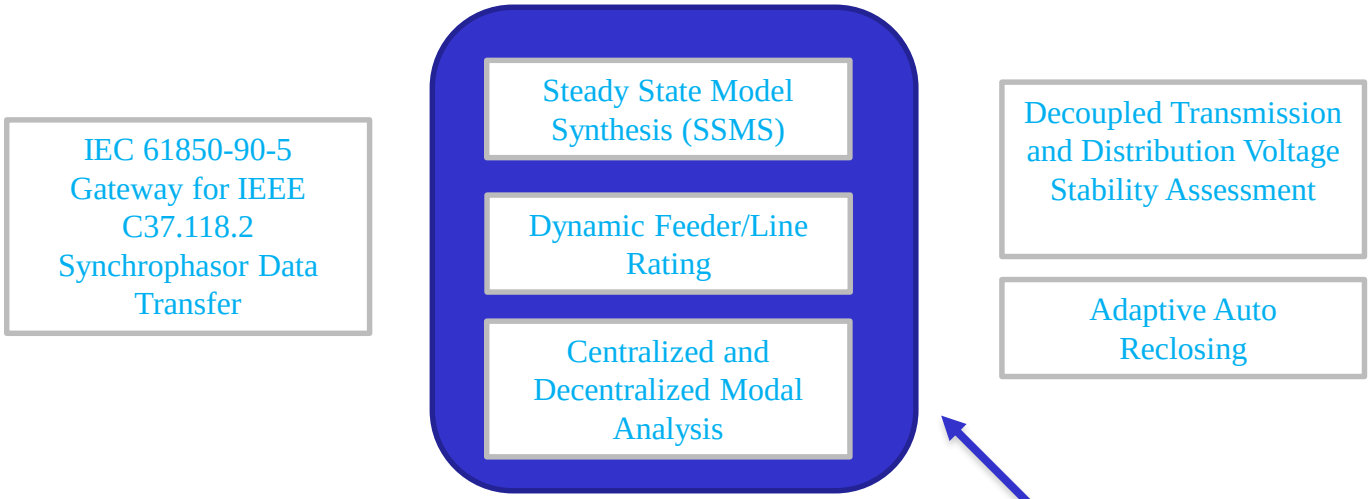
- There is great potential of utilizing real-time Synchrophasor data from PMUs (Phasor Measurement Unit) to extract key information related to fast changing conditions and dynamic behavior
- Example of applications to extract such key information are presented in this presentation.

Previous Work

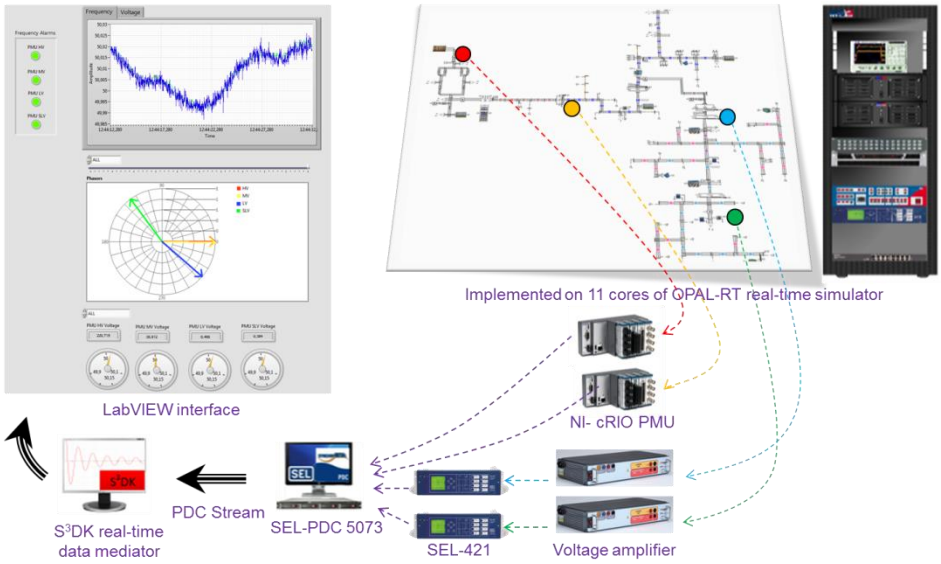
- Within IDE4L, KTH has developed concepts, methods and tools to utilize PMUs in ADNs



- Additional work has been carried out to demonstrate and enhance these applications.
- Results from work on three applications is presented herein.

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
  - A real-time simulation model of active distribution networks has been developed to test the applications
  - The real-time simulation model is interfaced with PMUs in HIL
  - PMU data is streamed into a PDC, and the concentrated output stream is forwarded to an application development computer
  - The computer makes available software development tools within the LabVIEW environment that allows for the testing of the applications using real-time measurements from the HIL simulation
  - All data acquisition chain is carried out using the corresponding PMU standards



Real-Time Steady State Model Synthesis of Distribution System

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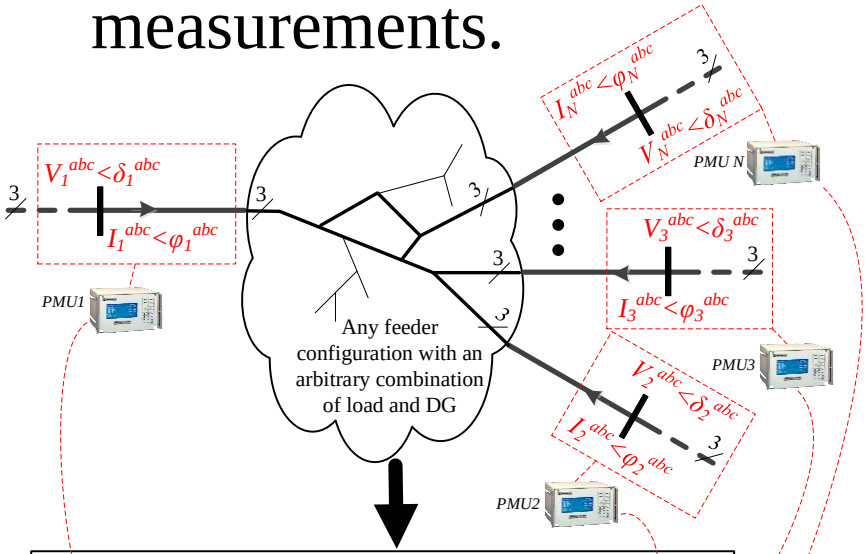
  - The models covers limited portions of the distribution network due to the lack of network observability (measurement points) and computational burden associated with simulating large joint T&D models.
  - The models are not updated frequently.
  - The reduction methods, used by TSOs, often make assumptions 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.



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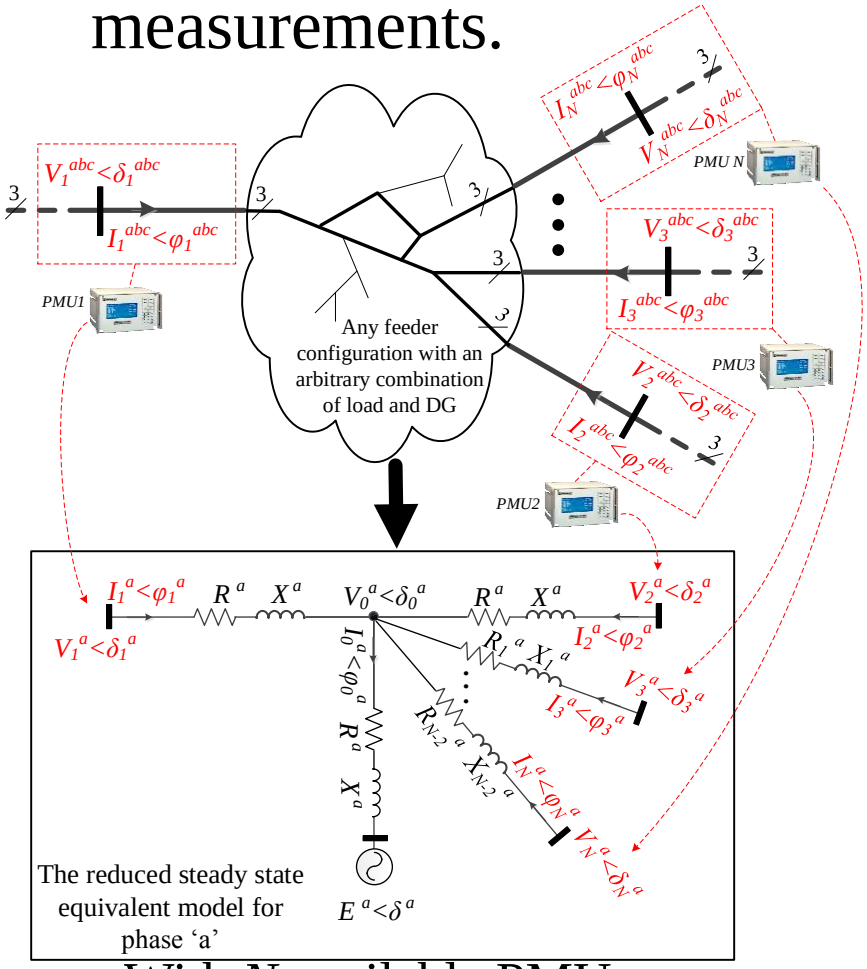
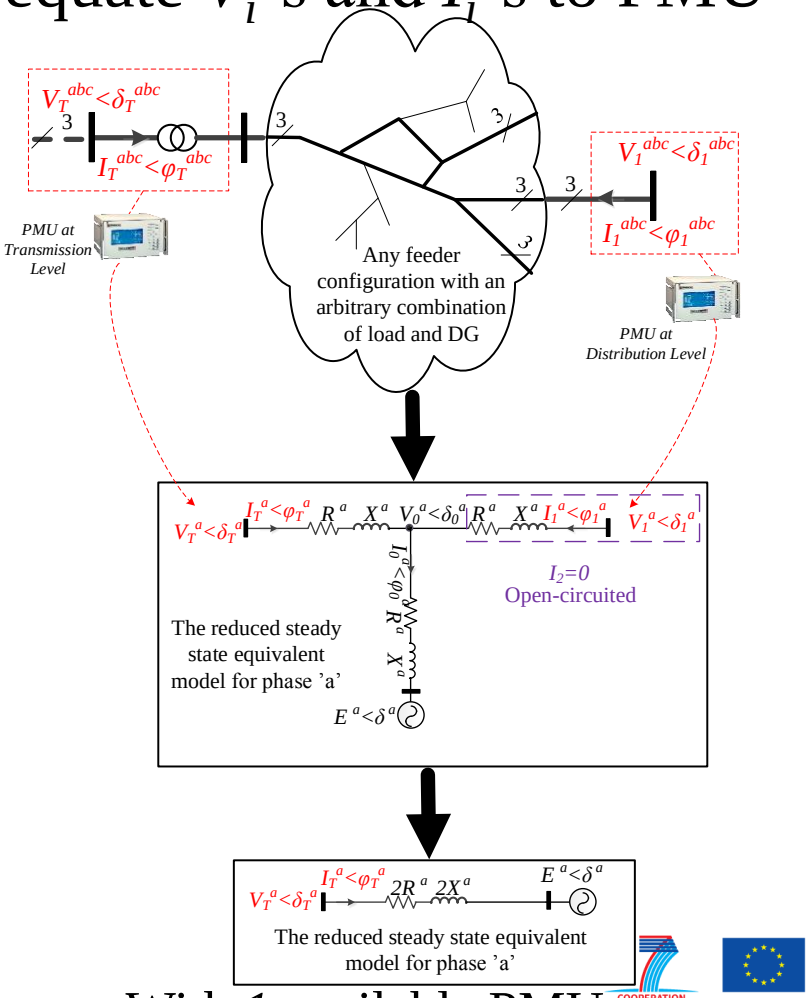


With N available PMUs



With 1 available PMU

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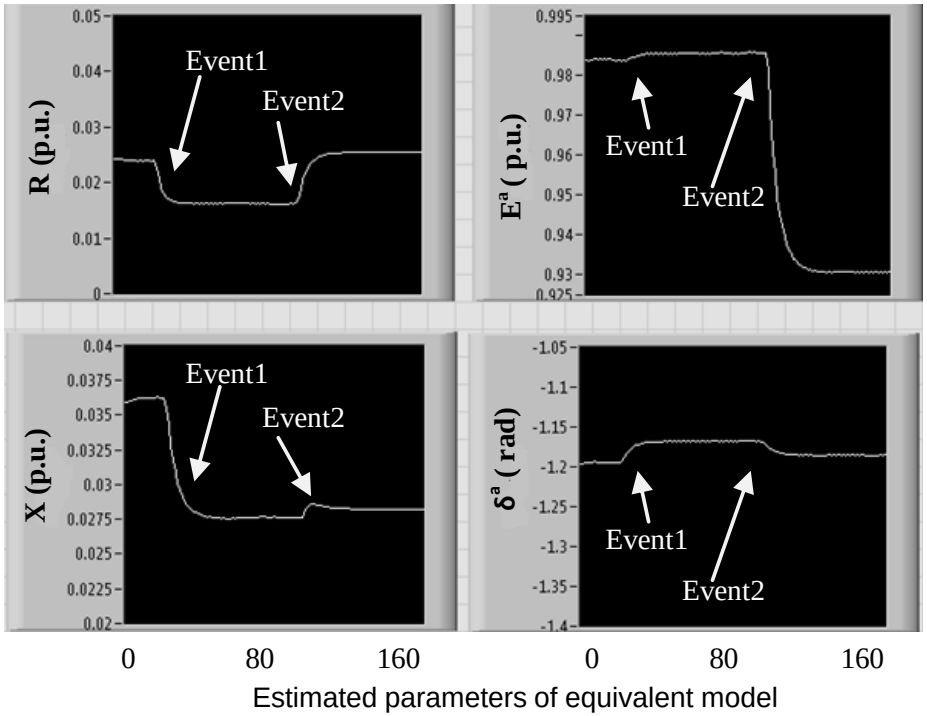
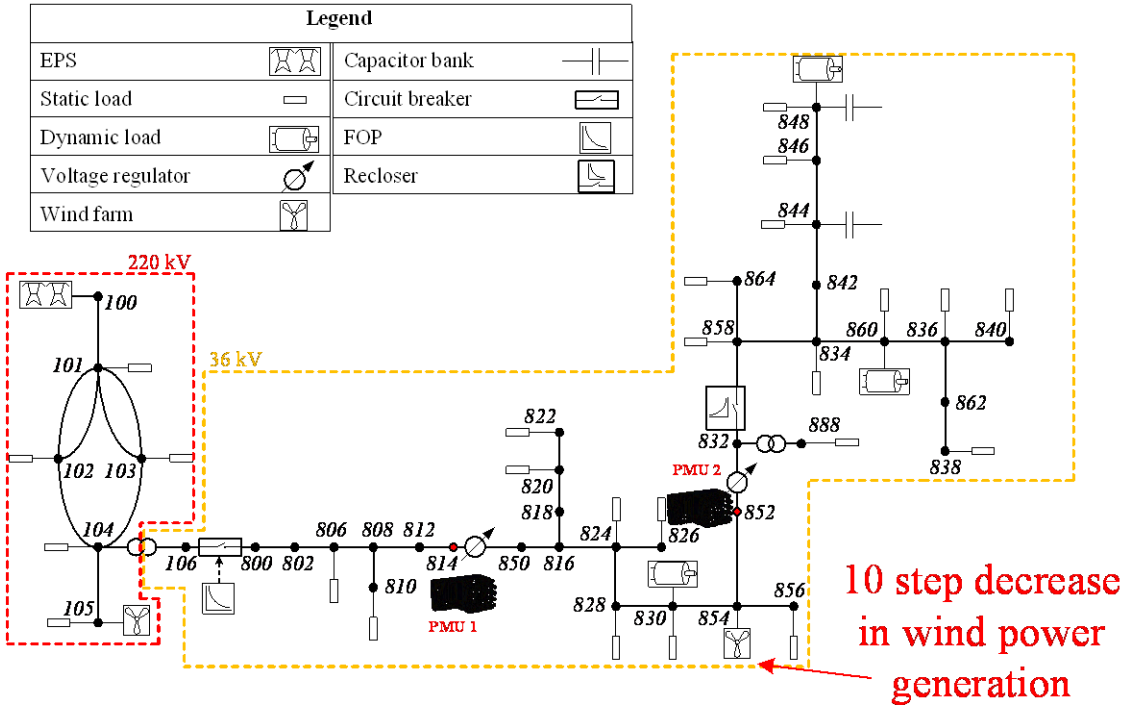


LabVIEW Application

Illustration Example

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



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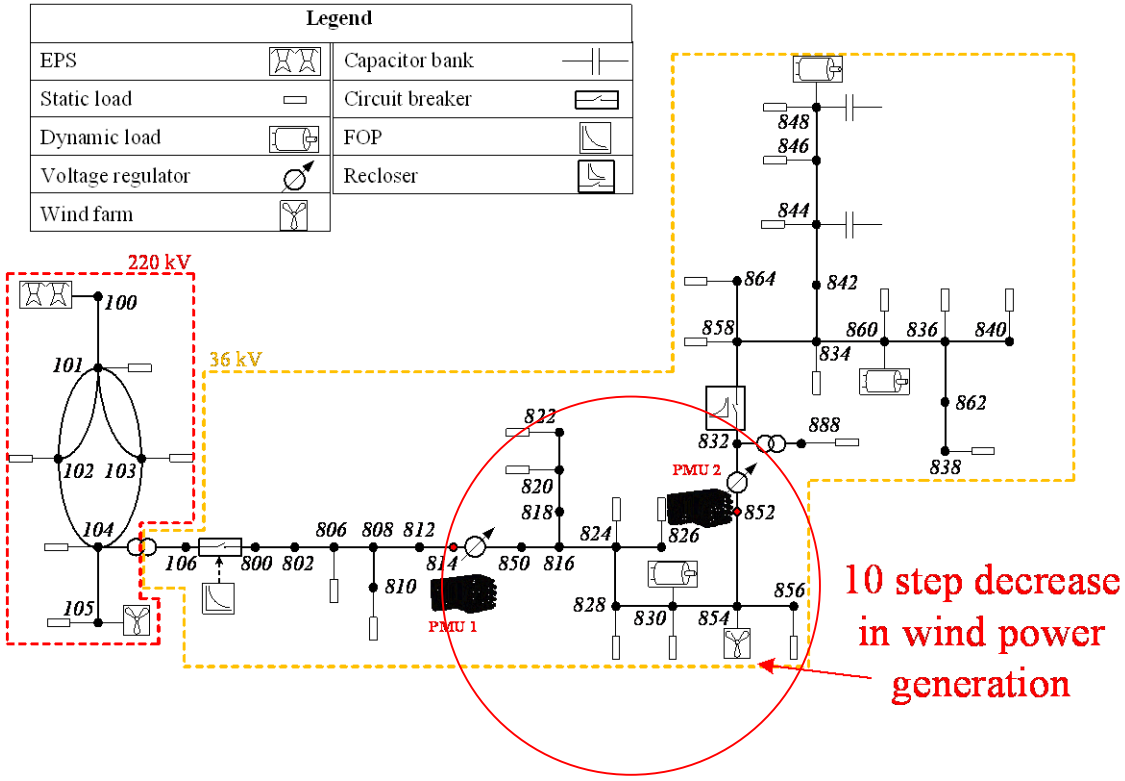

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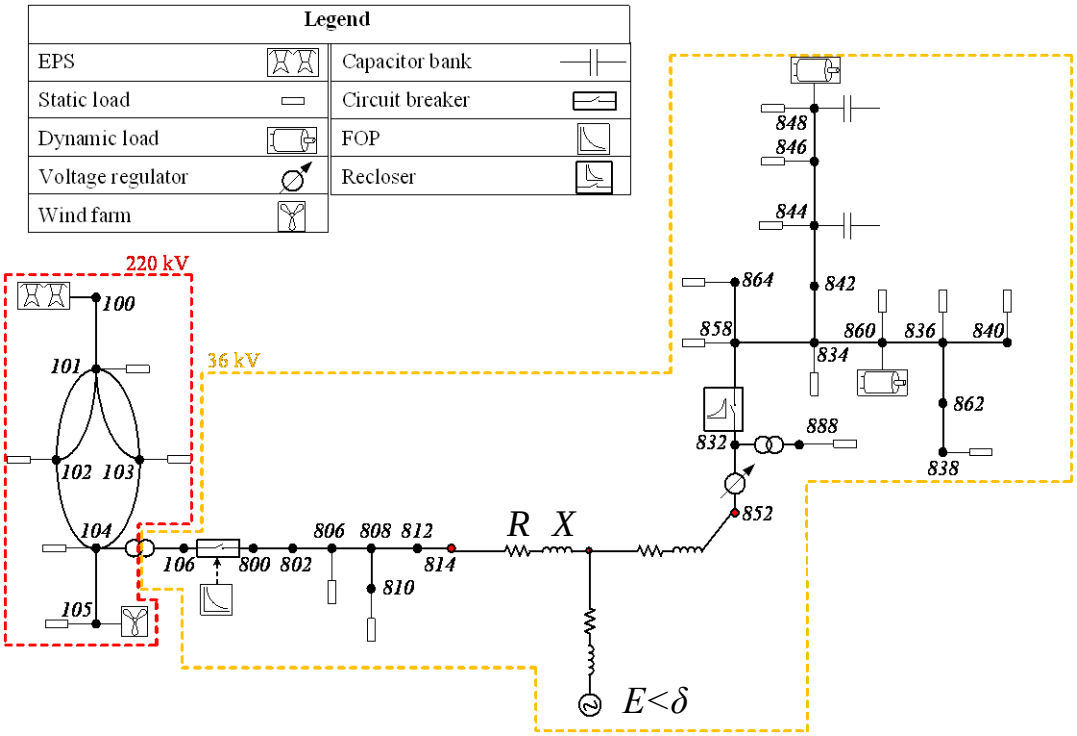

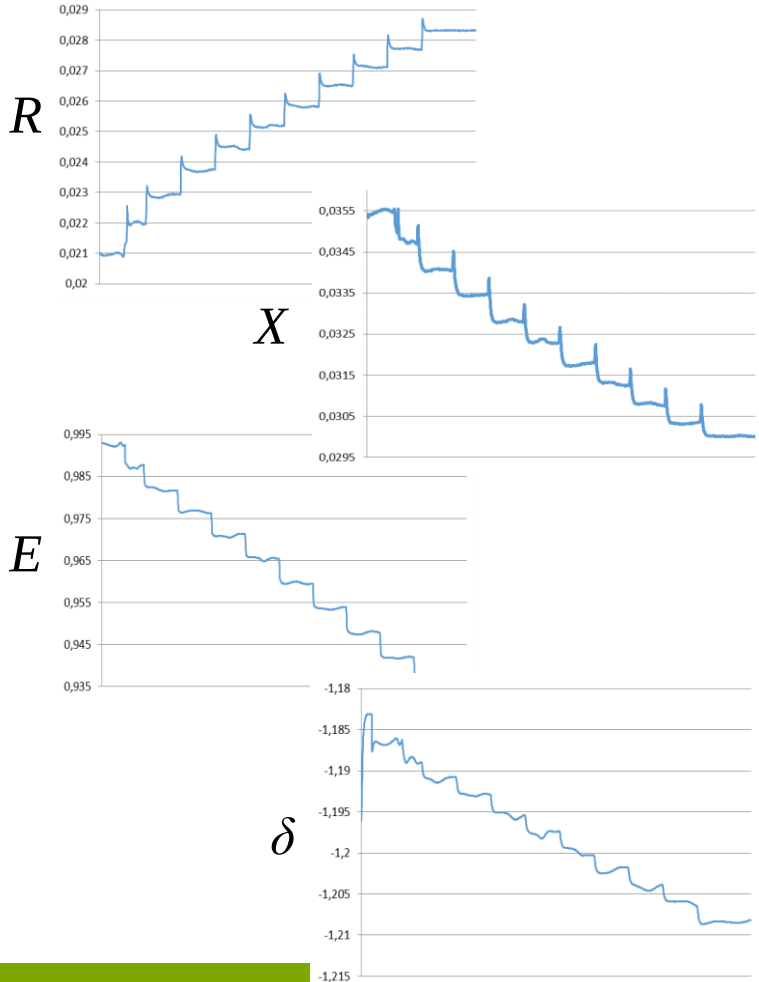

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- True and reproduced current and voltage phasors are compared using *TVE*.

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

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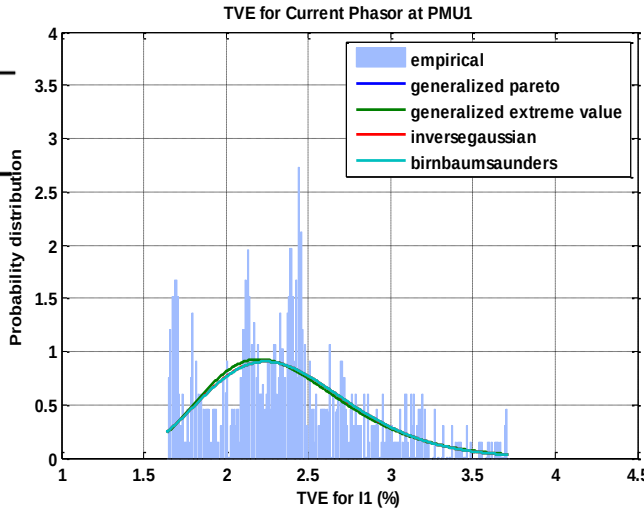
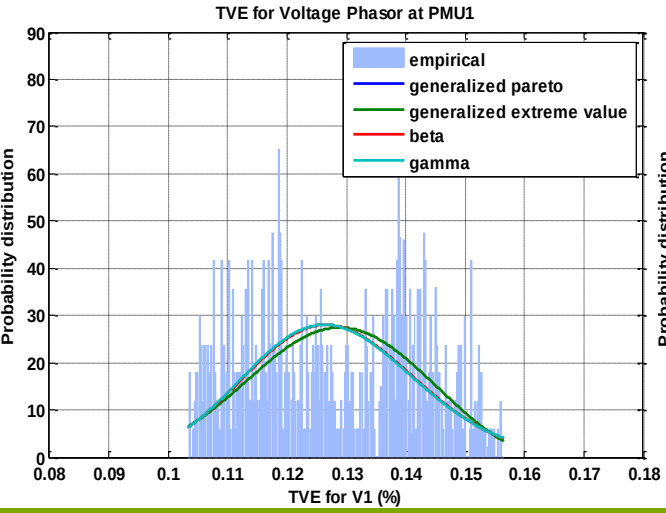
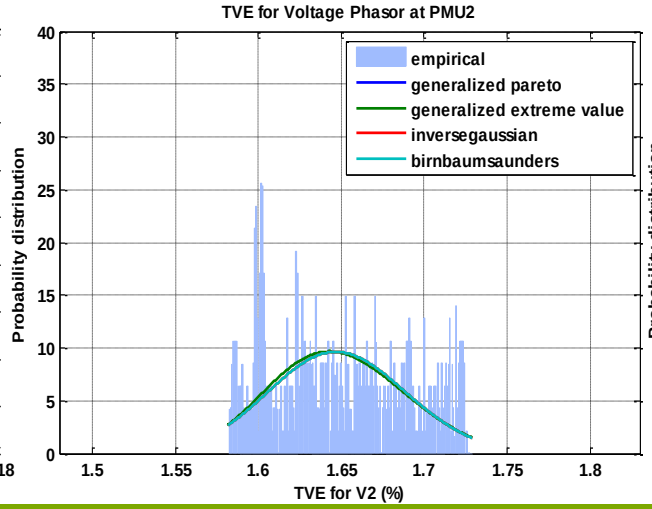
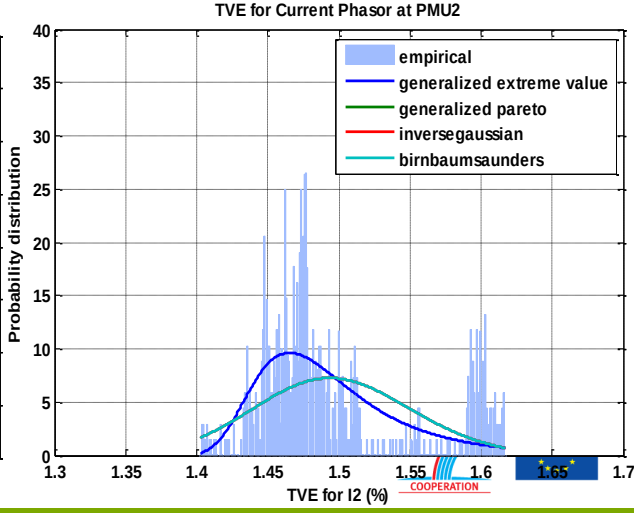
- The mean TVE is less than 2.5%.









Dynamic Line Rating for Distribution Feeders

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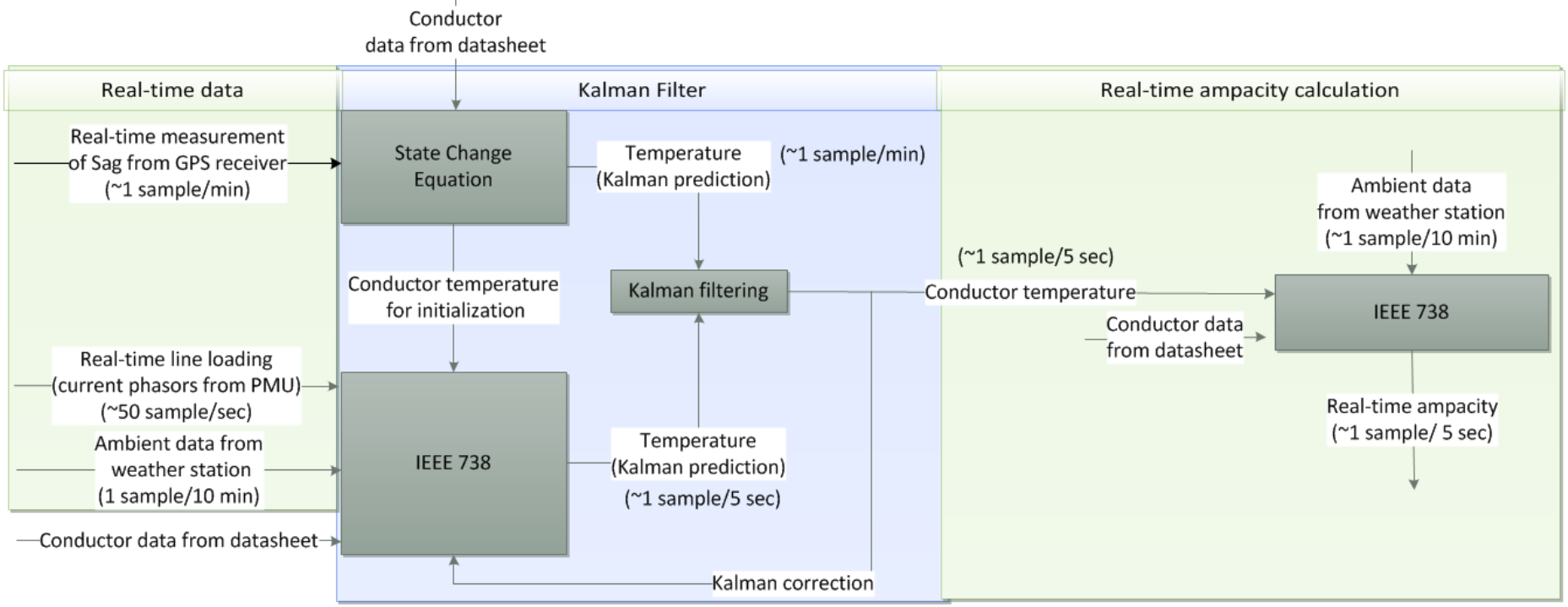
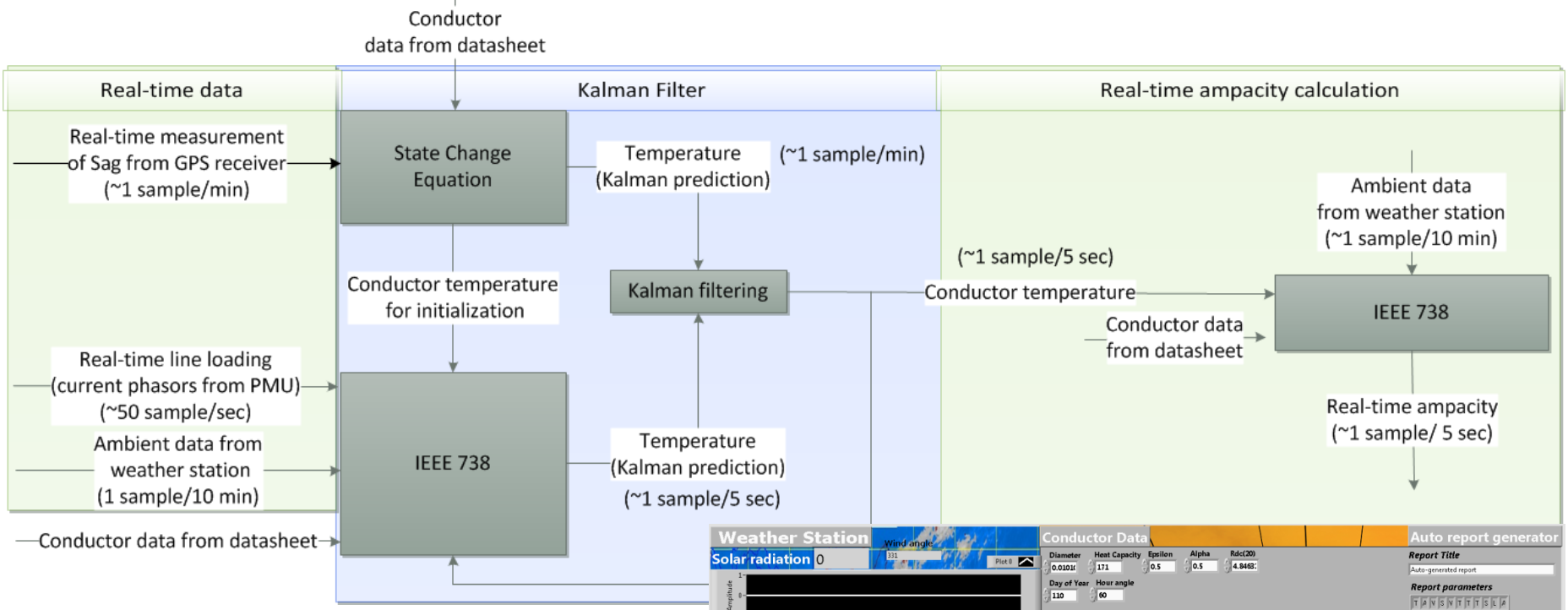
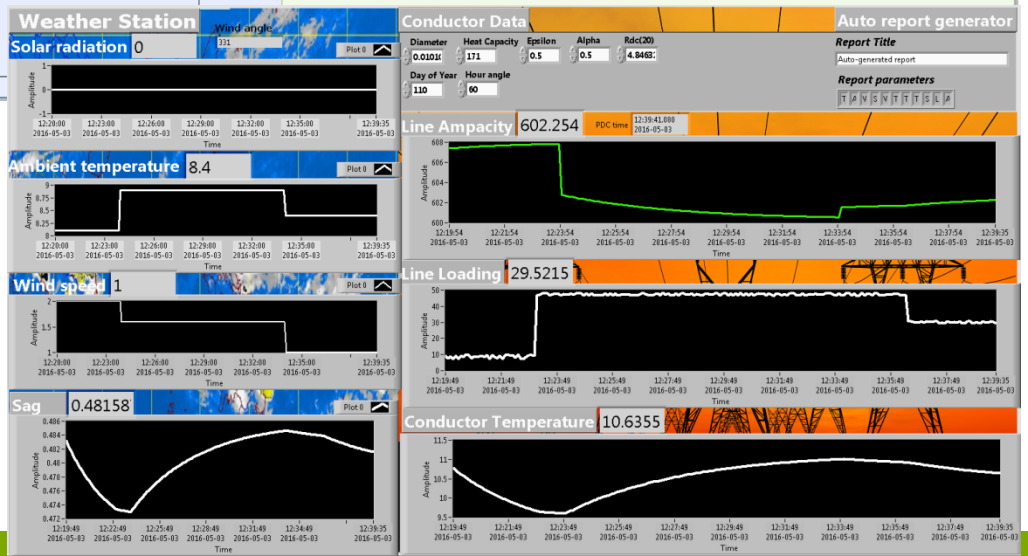
  - Line loading => provided by PMU
  - Real-time sag => provided by a GPS-based measurement device.

Methodology and Application



Methodology and Application

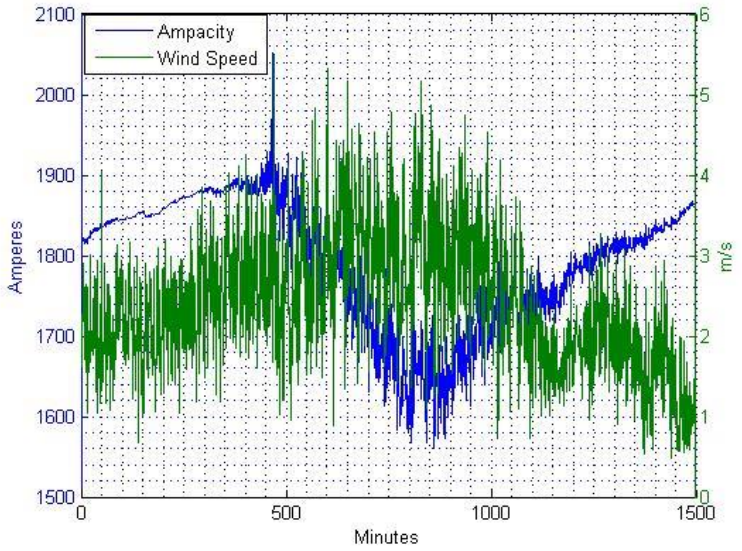


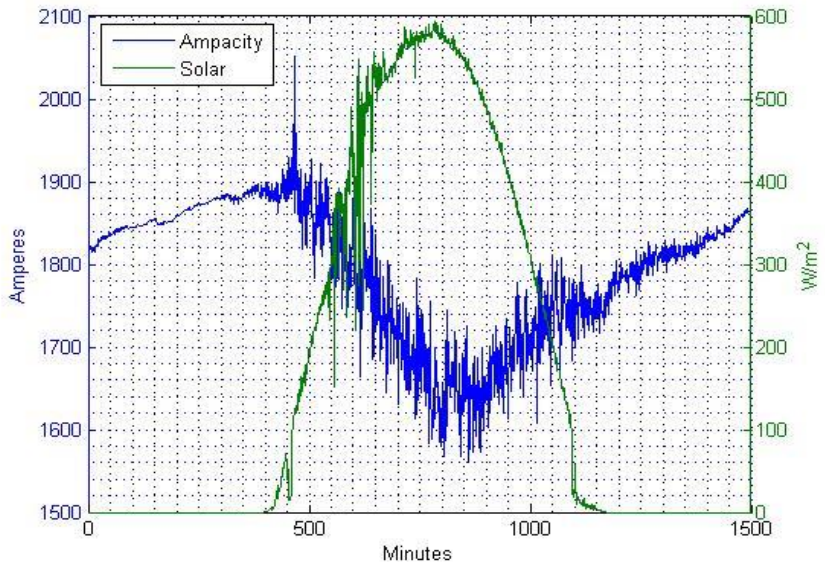


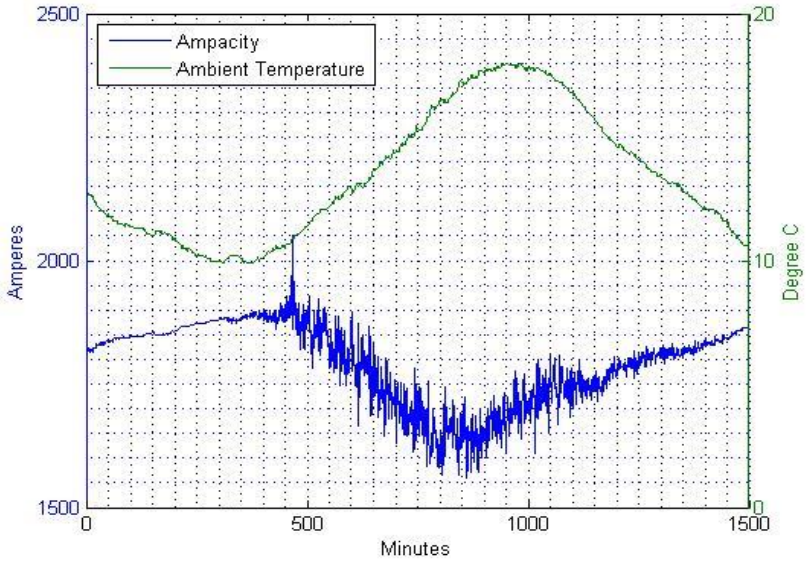
LabVIEW Application

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

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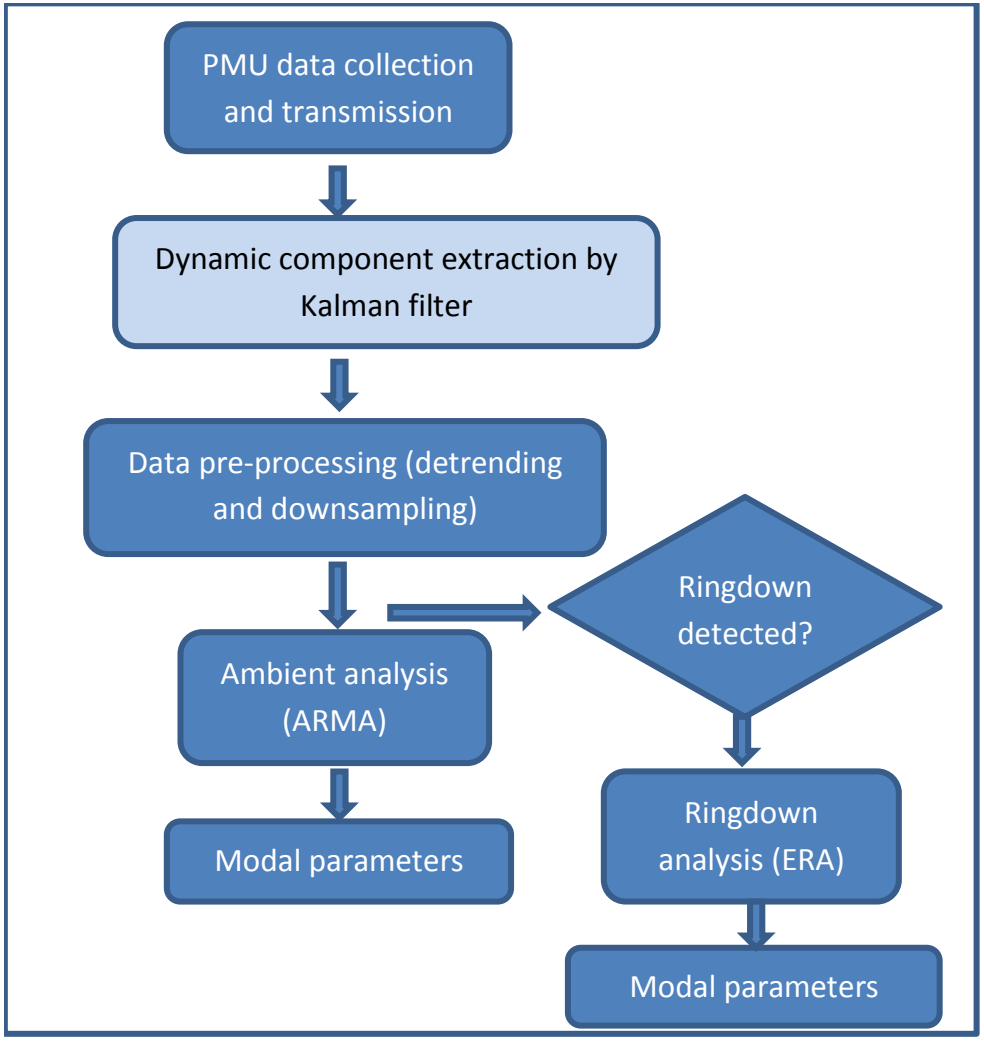
- Accurate and real-time estimates of active distribution networks oscillatory modes has become ever so important.
- Timely extraction of these modes and related parameters from network measurements has considerable potential for near real-time dynamic security assessment.

Methodology and Application



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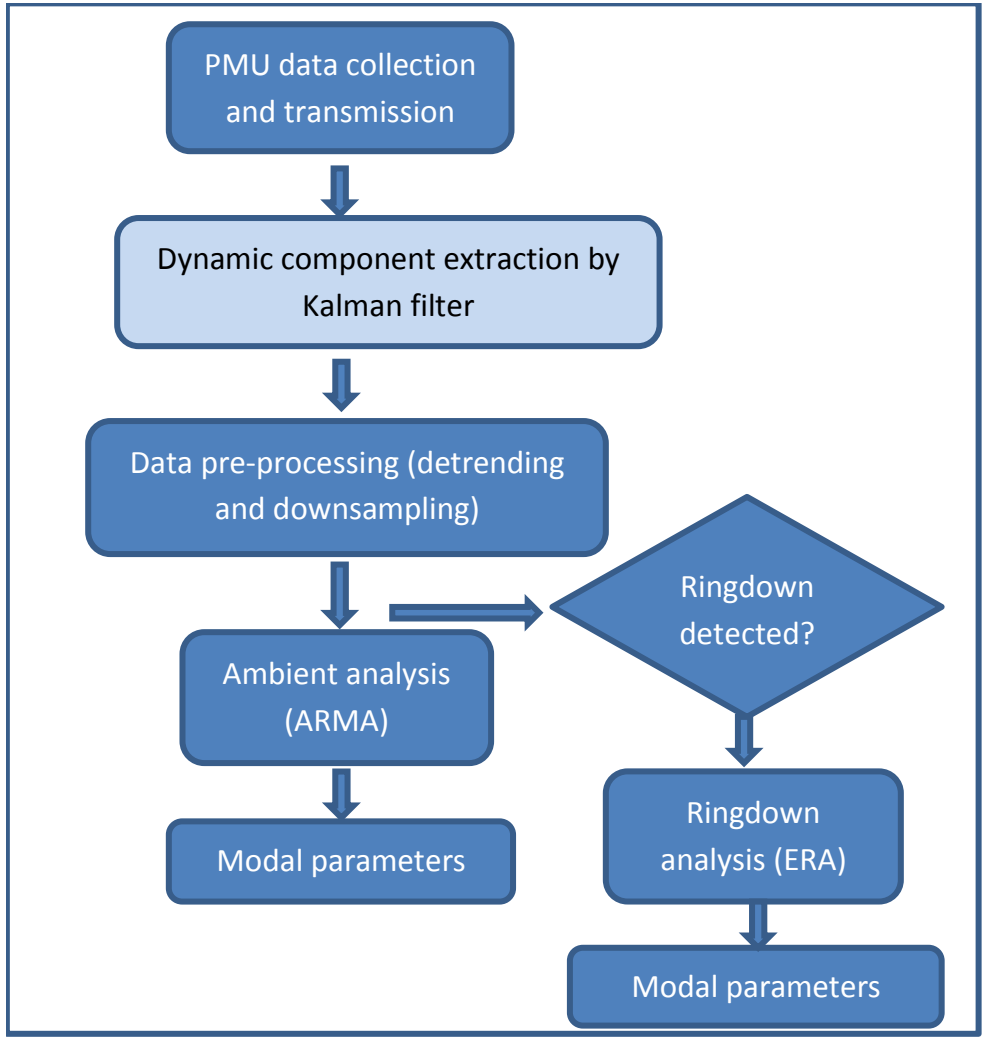
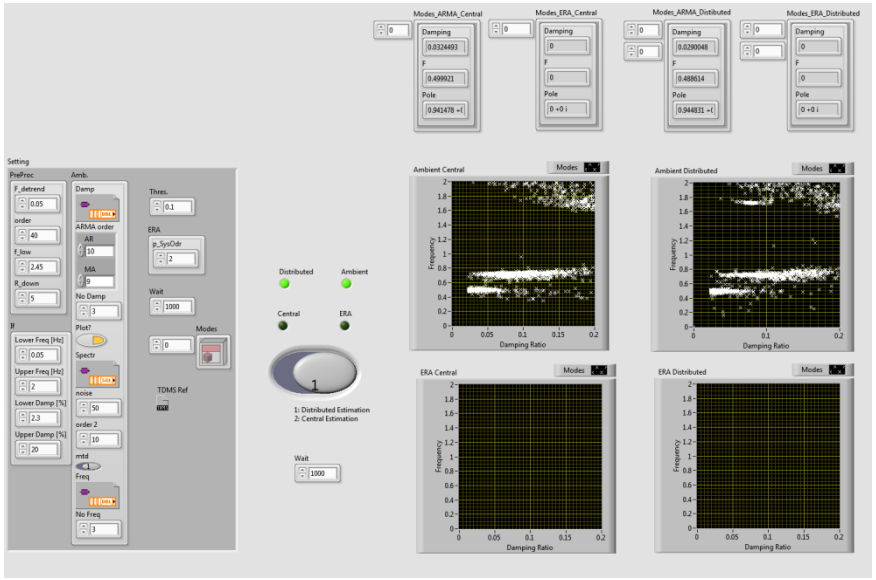
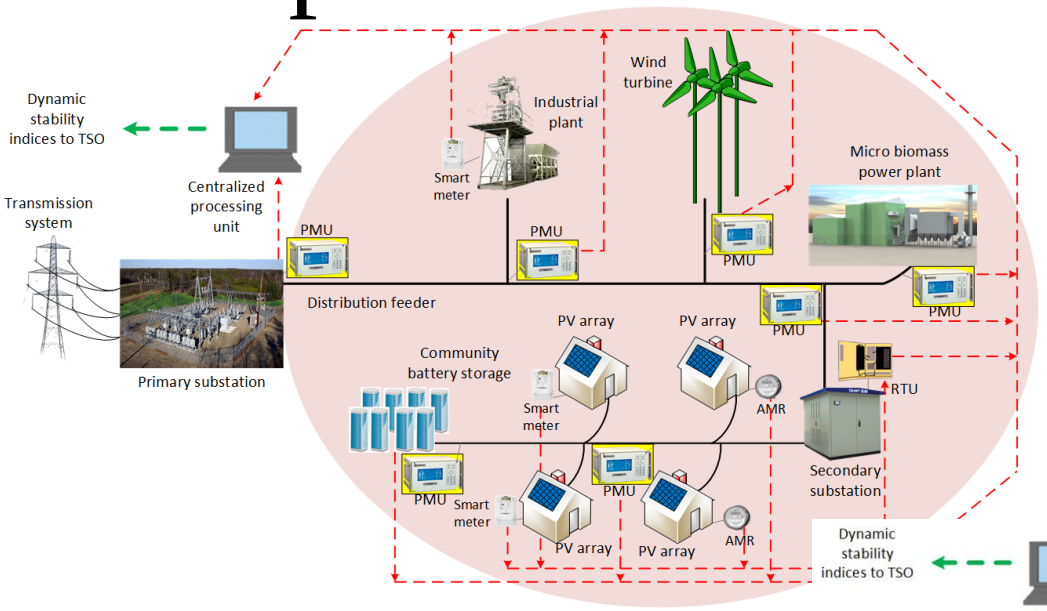




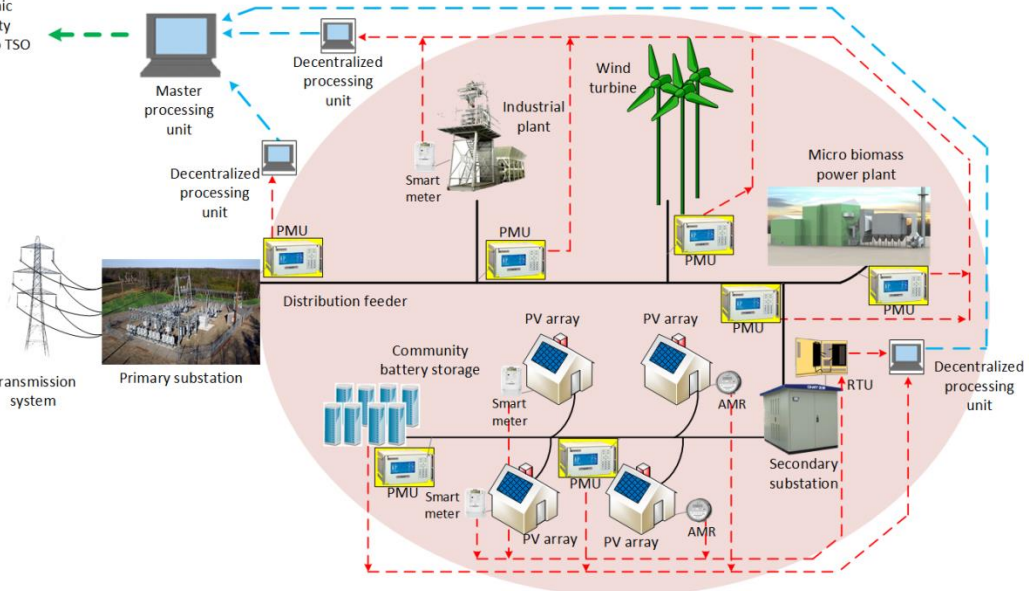
LabVIEW Application

Implementation Architectures



Centralized

Decentralized



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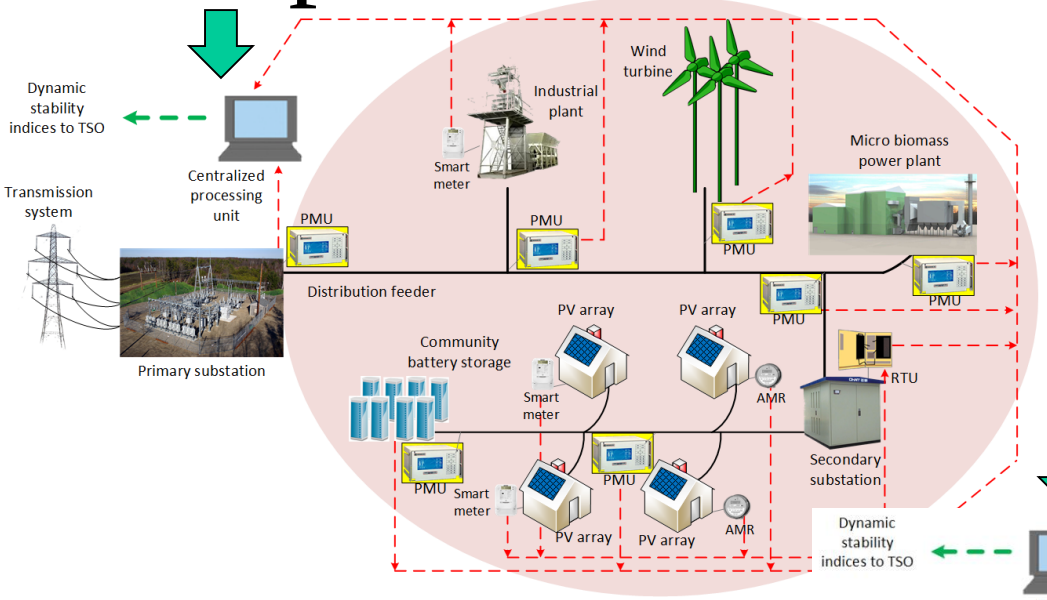

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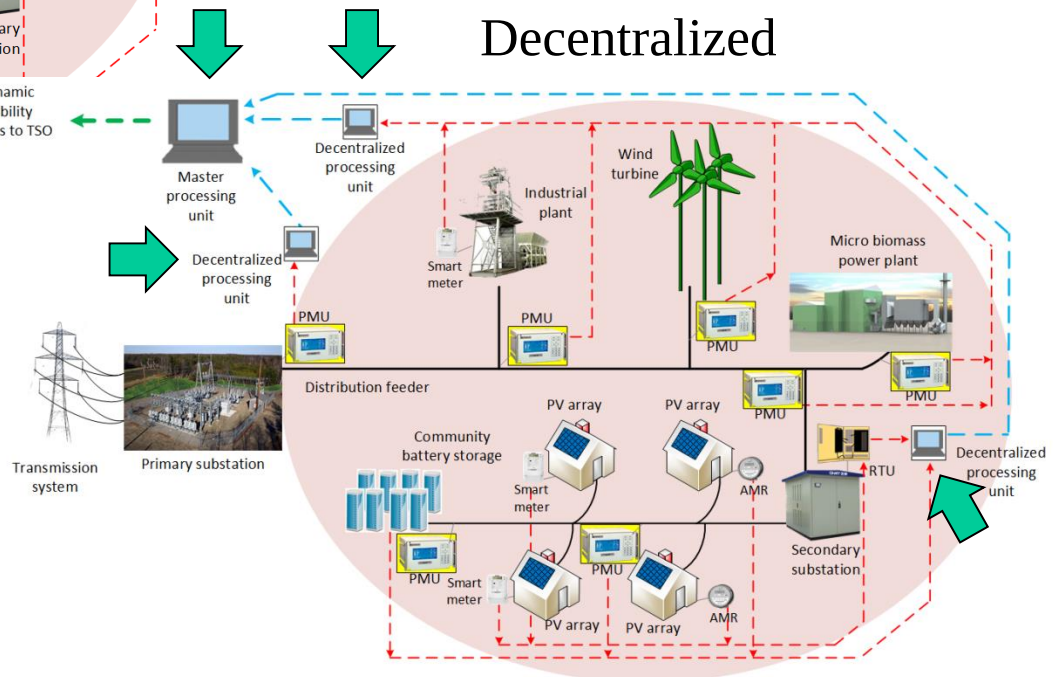
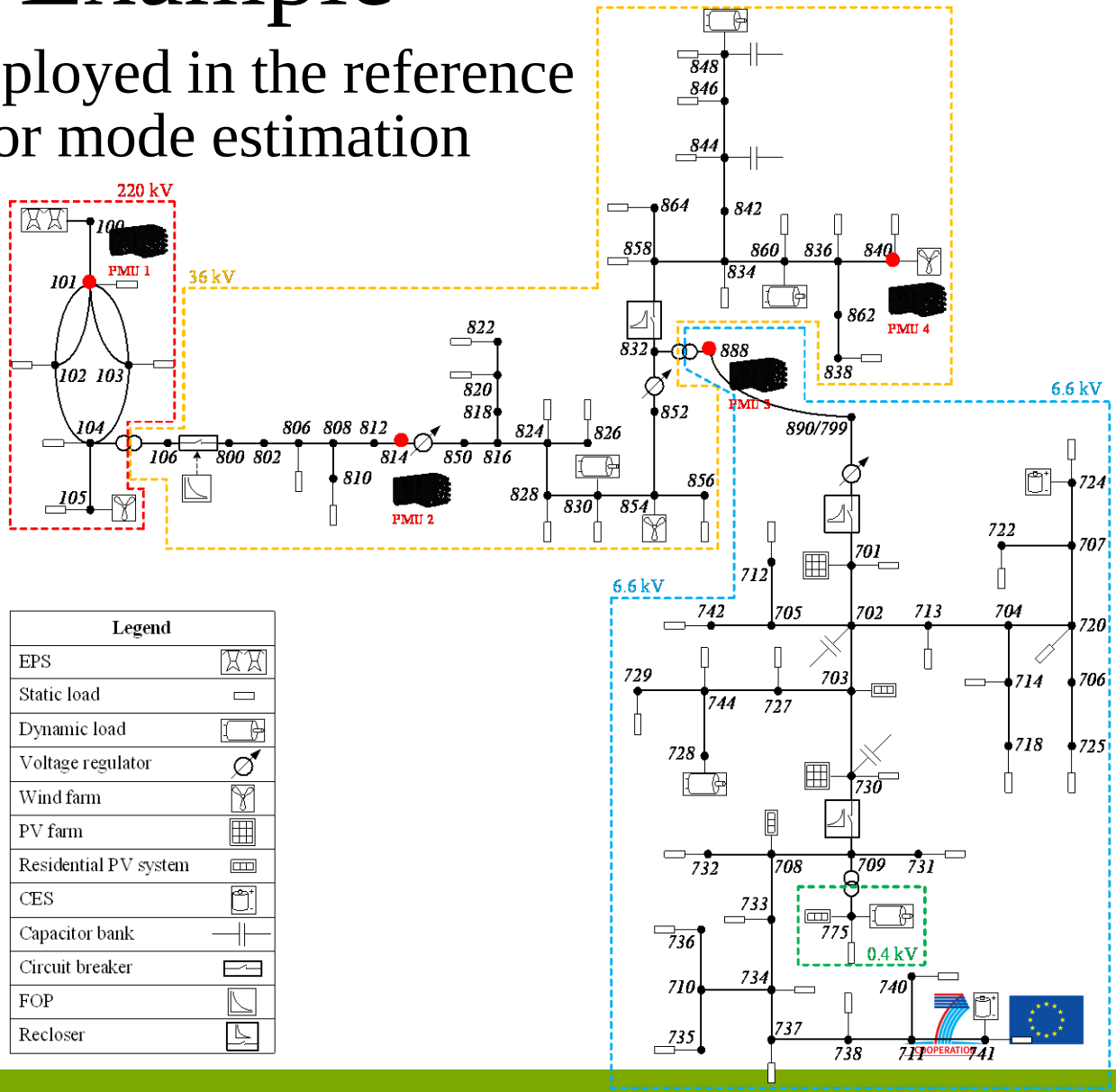


Illustration Example

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



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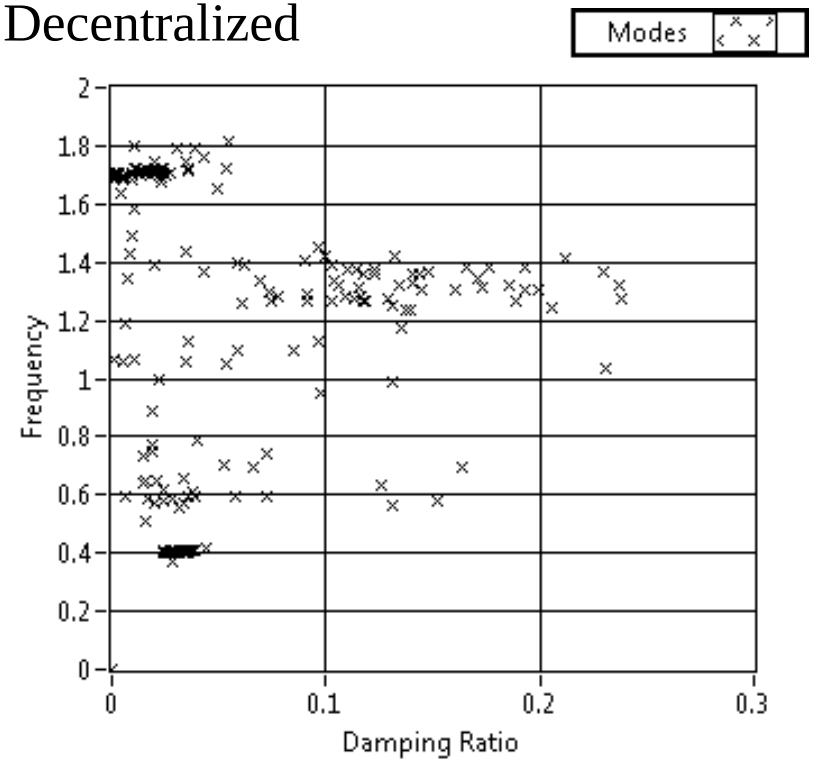

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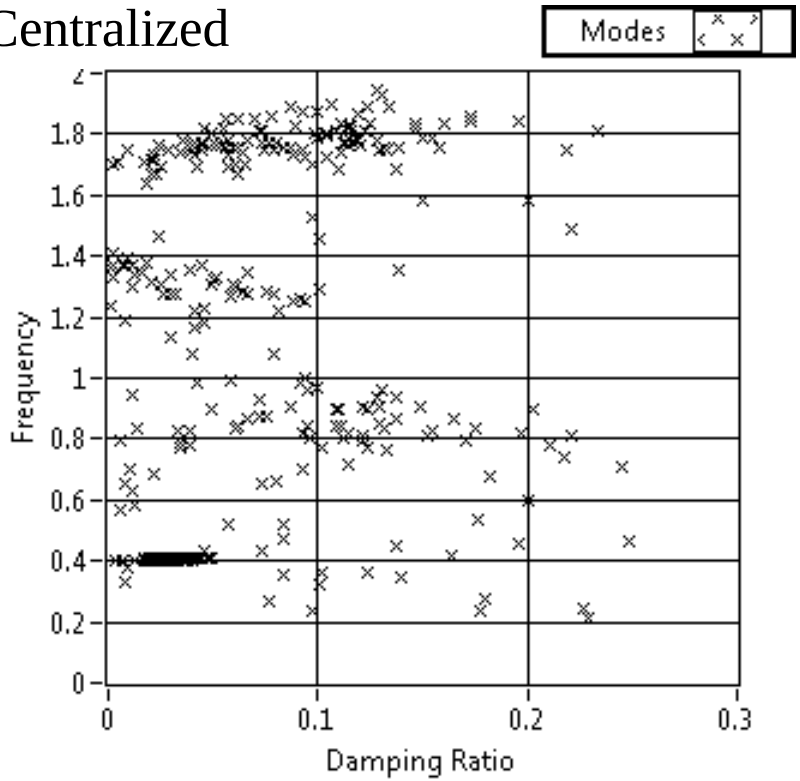

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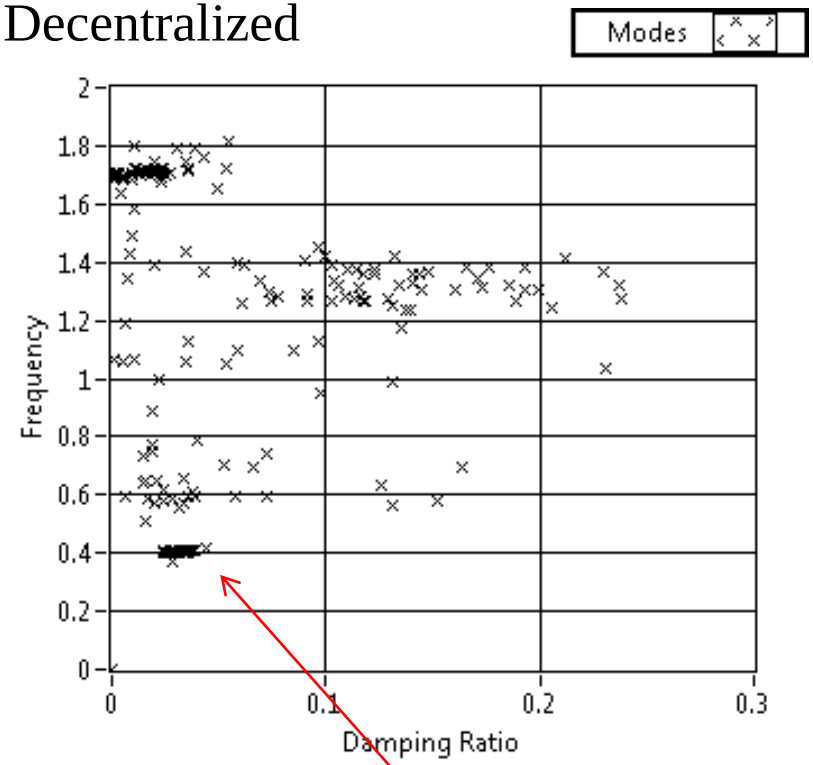

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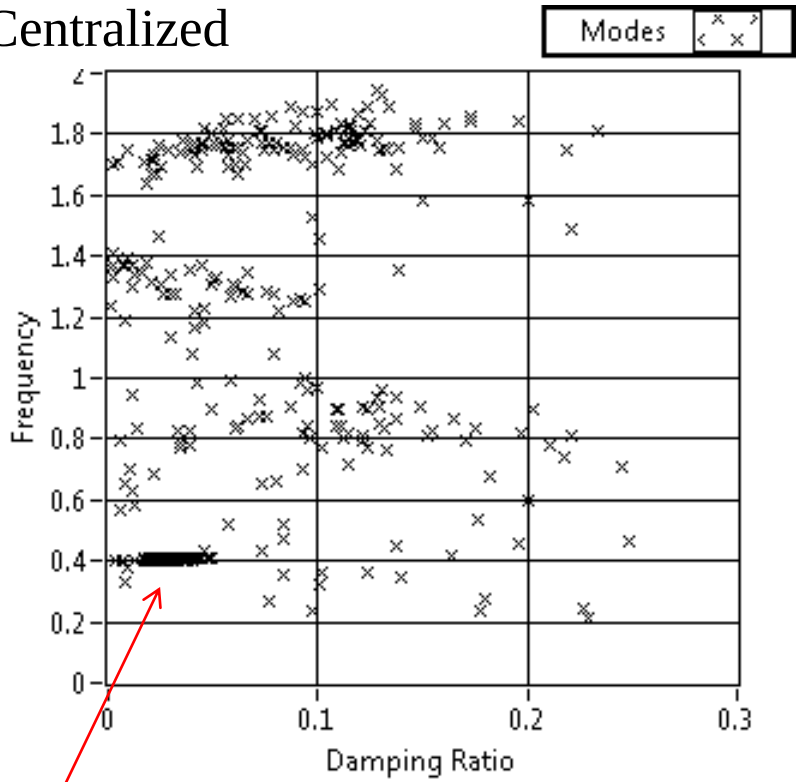
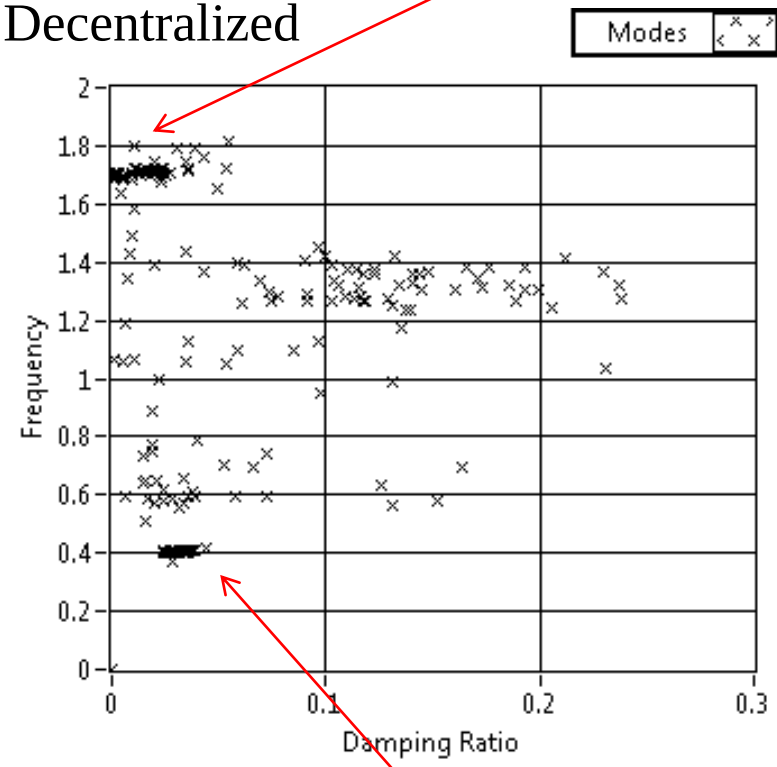


Inter-area oscillatory mode between HV section and rest of the grid

Illustration Example

Forced local oscillatory mode detectable in decentralized architecture

Decentralized



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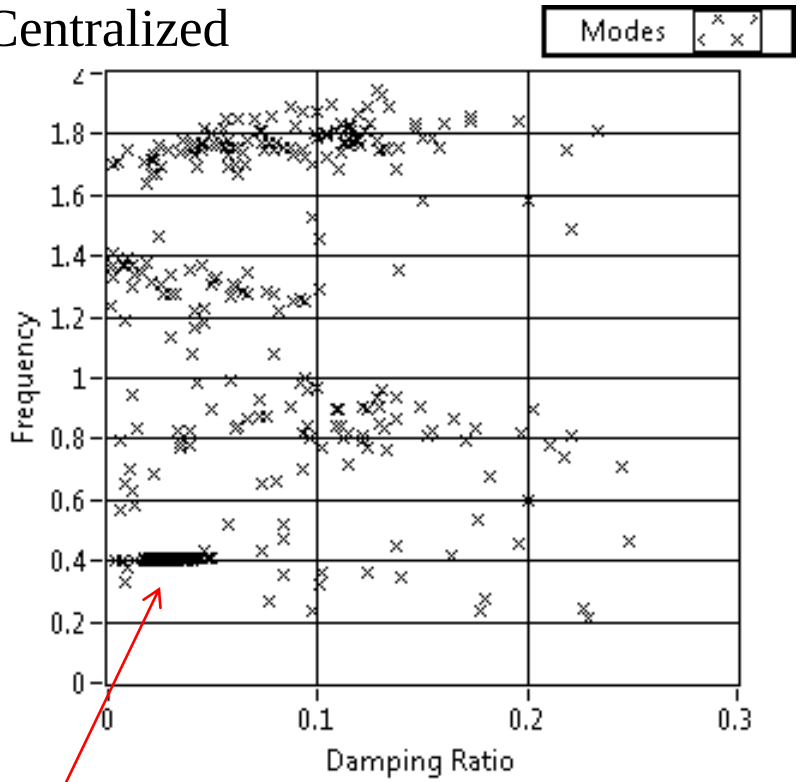

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