IDEAL
ideal grid for all

Synchrophasor Applications for Distribution Networks Enhancing T&D Operation and Information Exchange

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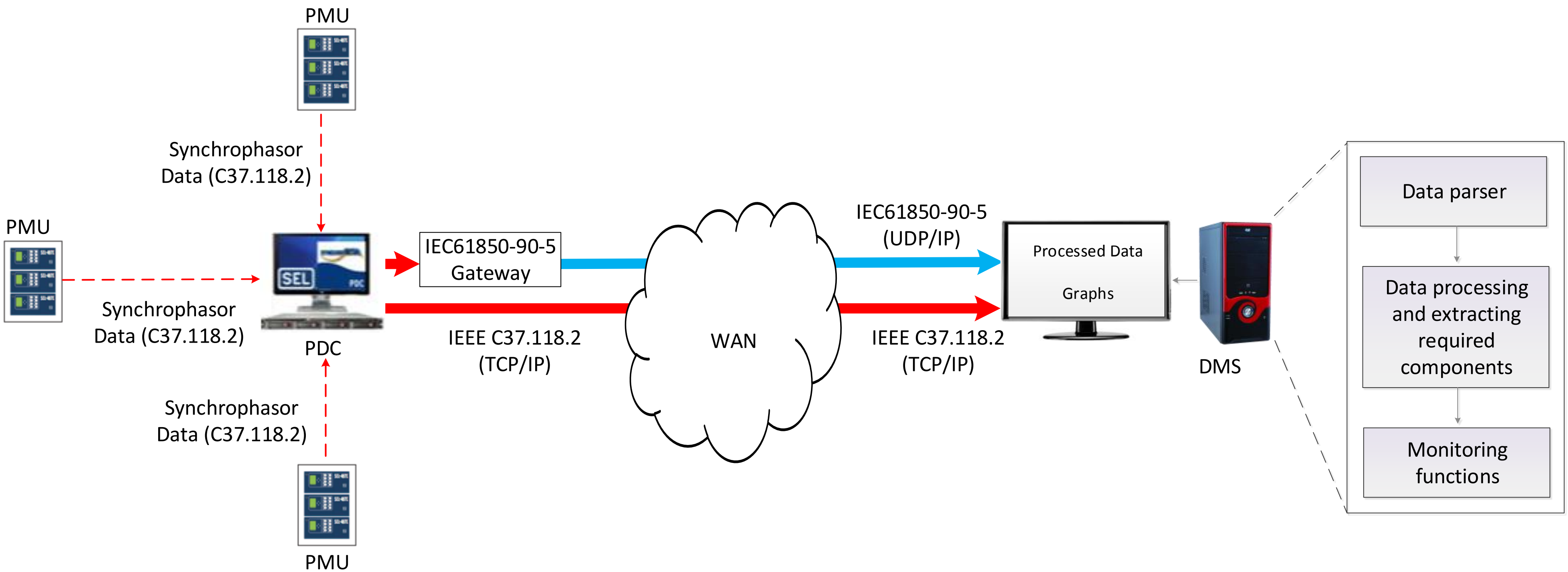
COOPERATION

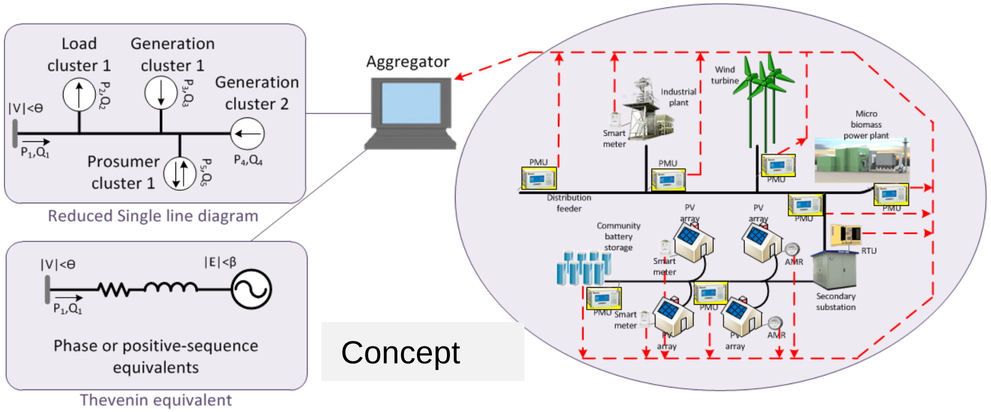
Laboratory Implemented Architecture



Applications

Providing Dynamic Information

Steady State Model Synthesis (SSMS)



$$V_1^a\angle\delta_1^a - V_2^a\angle\delta_2^a = \left(R^a + jX^a\right)\left(I_1^a\angle\varphi_1^a - I_2^a\angle\varphi_2^a\right)$$

↓

R^a & X^a

$$V_0^a\angle\delta_0^a = V_1^a\angle\delta_1^a - \left(R^a + jX^a\right)I_1^a\angle\varphi_1^a$$

↓

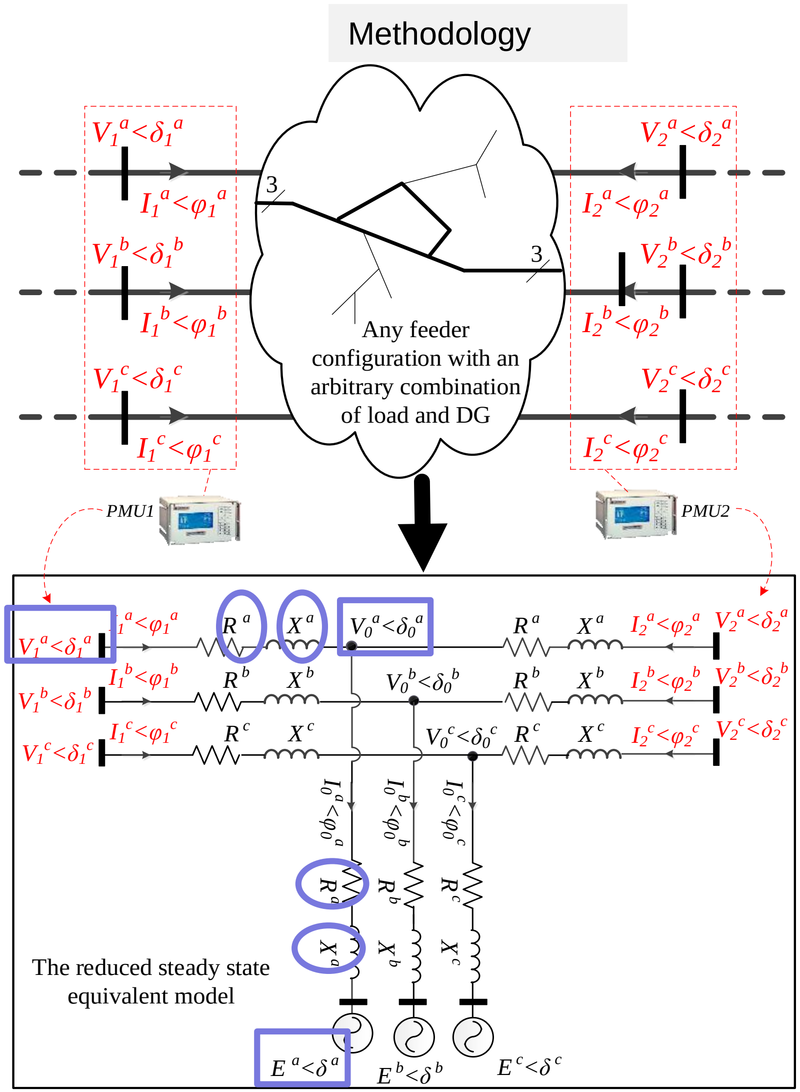
V_0^a & δ_0^a

Assumption: R1a=R2a=R3a & X1a=X2a=X3a

$$E^a\angle\delta^a = V_0^a\angle\delta_0^a - \left(R^a + jX^a\right)I_0^a\angle\varphi_0^a$$

↓

E^a & δ^a



HIL RT Simulation Setup

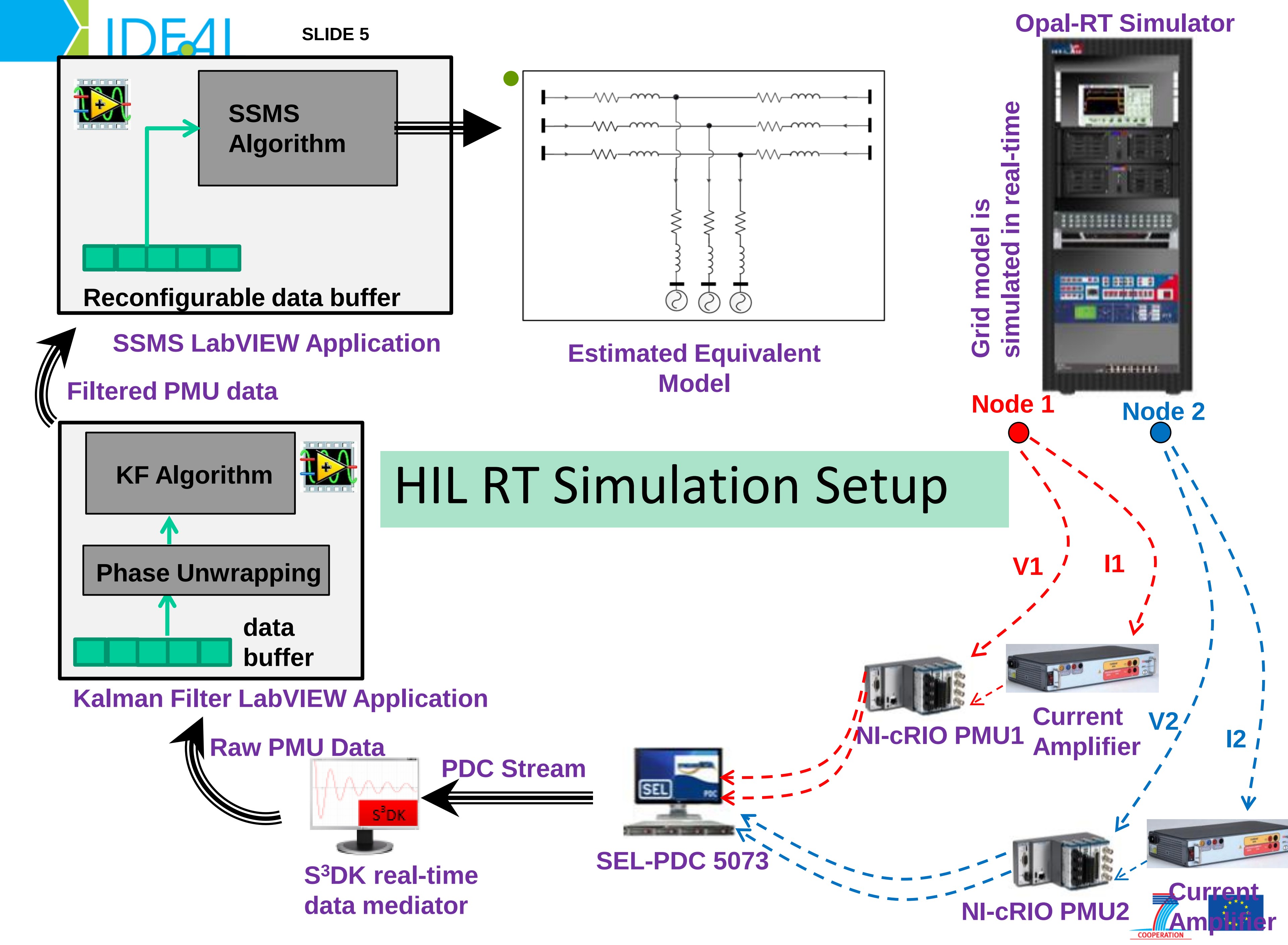
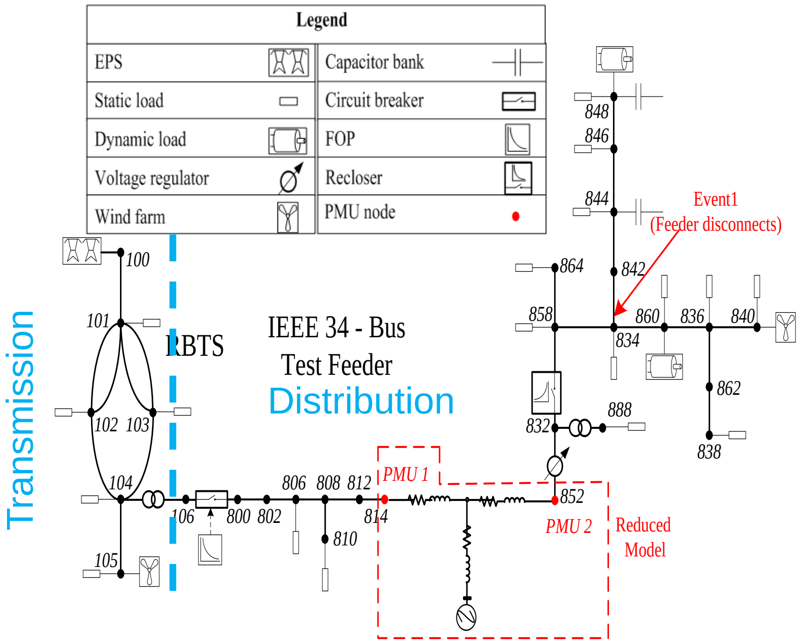


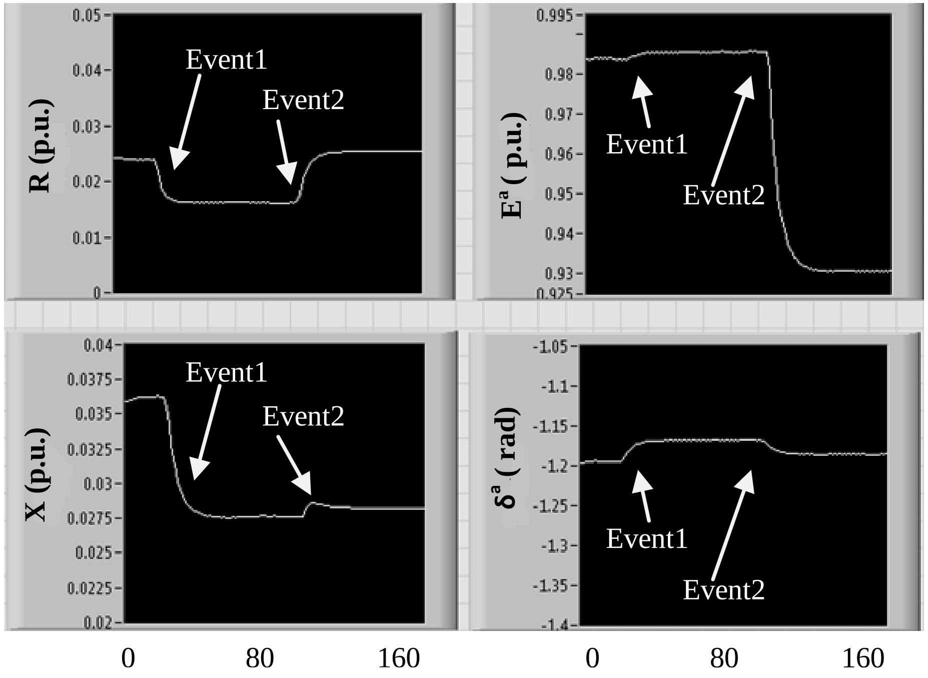
Illustration Example: Model synthesis of sample active distribution network

Event 1: *A lateral MV feeder disconnects at Node 834 at t = 40 s*

Event 2: *A wind farm generation of 1 MW (0.2 p.u.) disconnects at Node 854 at t = 70 s.*



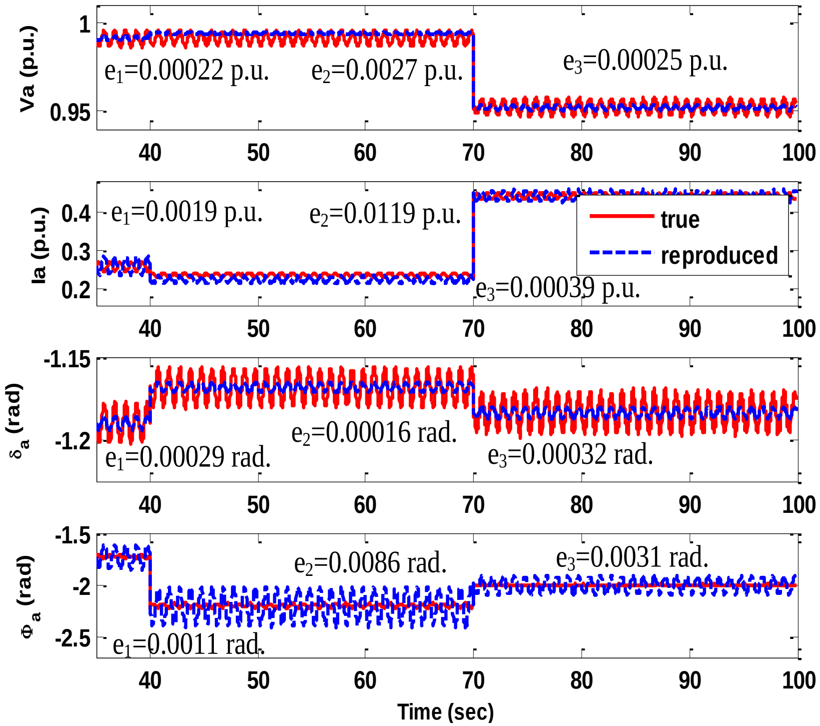
Sample network with synthesized model



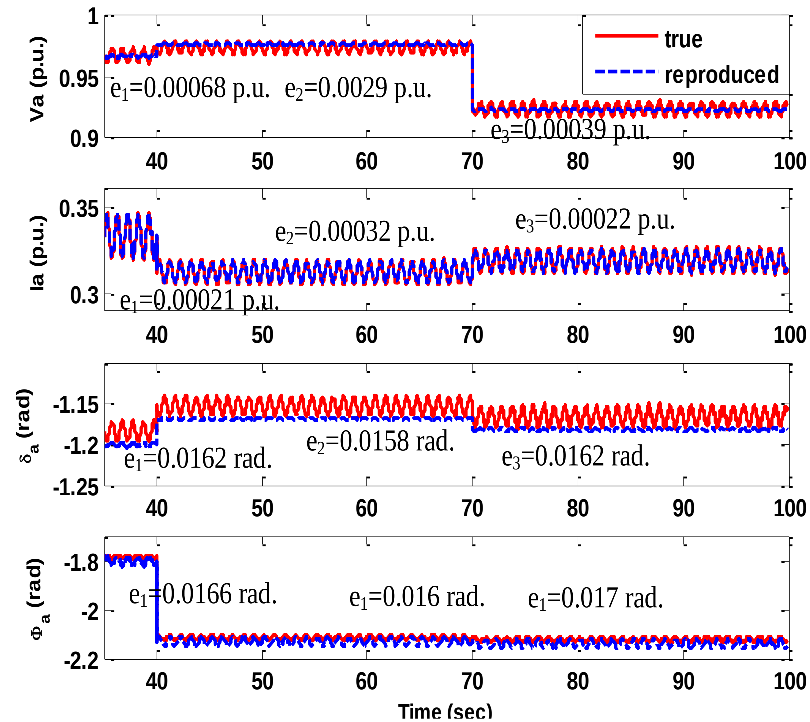
Estimated parameters of equivalent model

Illustration Example: Model synthesis of sample active distribution network

True phasors vs Reproduced phasors at PMU 1 and PMU 2



True phasors vs Reproduced phasors at PMU 1

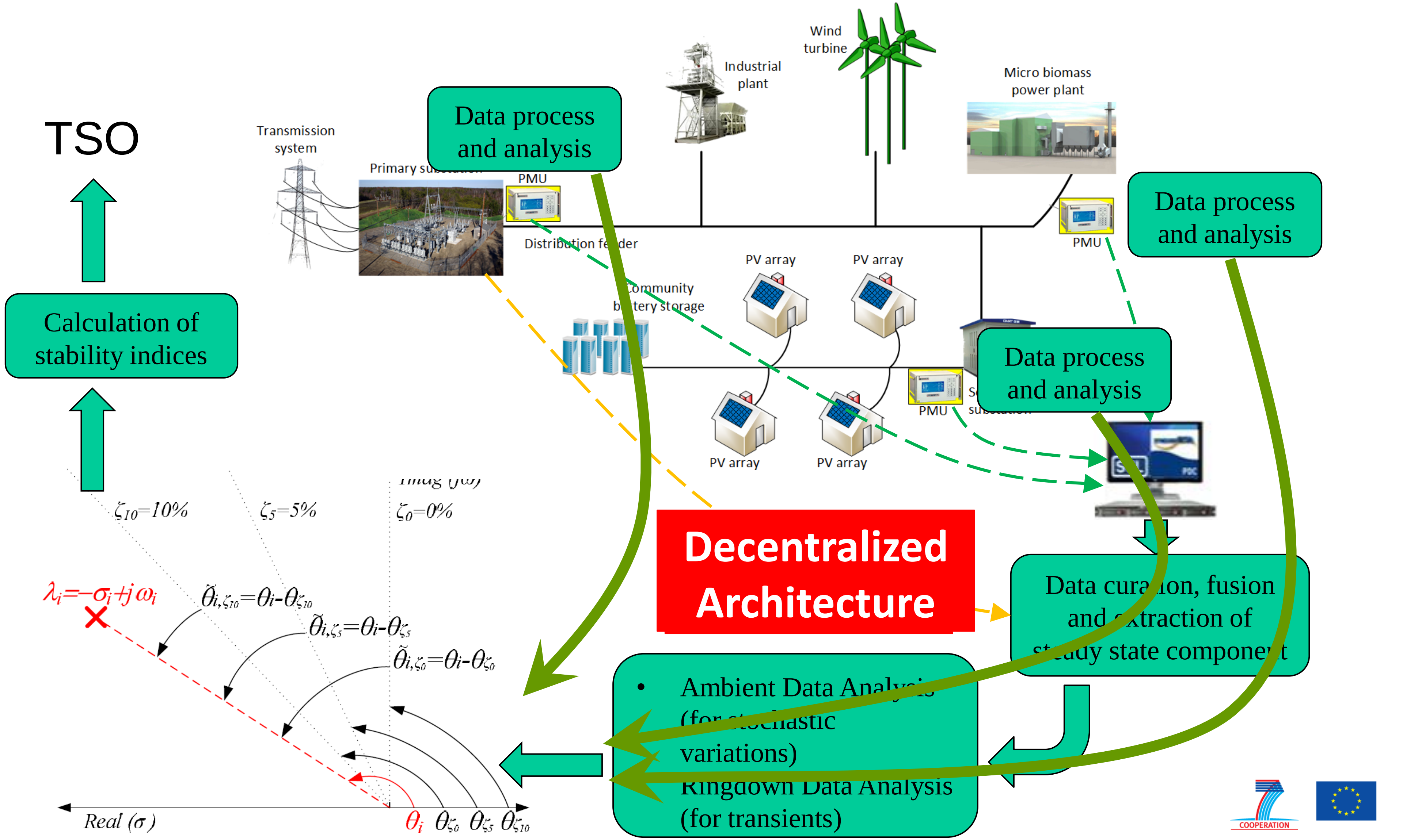


True phasors vs Reproduced phasors at PMU 2

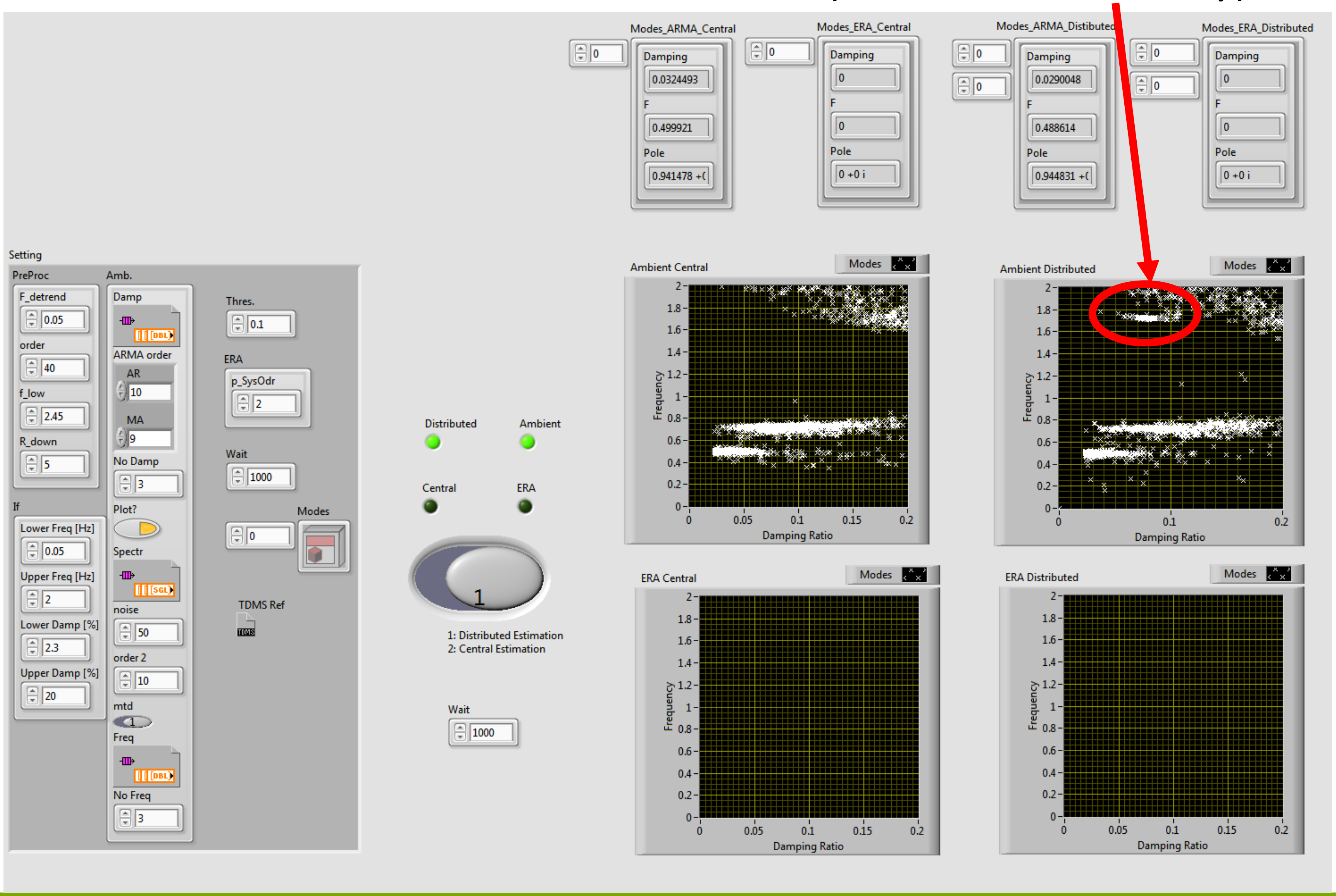
The end-to-end TVE is less than 3%.

Submitted to IEEE Transaction on Power Delivery (2nd review):
F. Mahmood, H.Hooshyar, L. Vanfretti, “Real-time Reduced Steady State Model Synthesis of Active Distribution Networks Using PMU Measurements”

Dynamic Model Synthesis of Distribution System



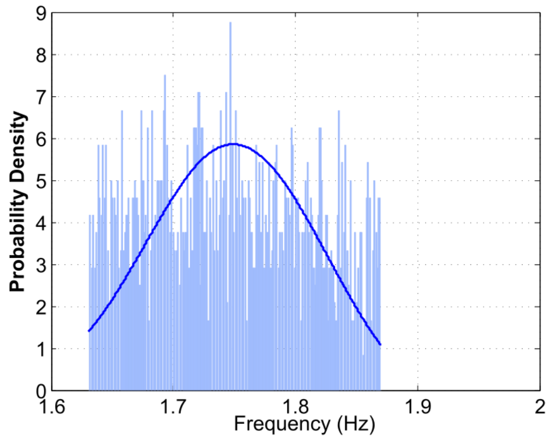
Centralized vs decentralized architecture (local mode visibility)



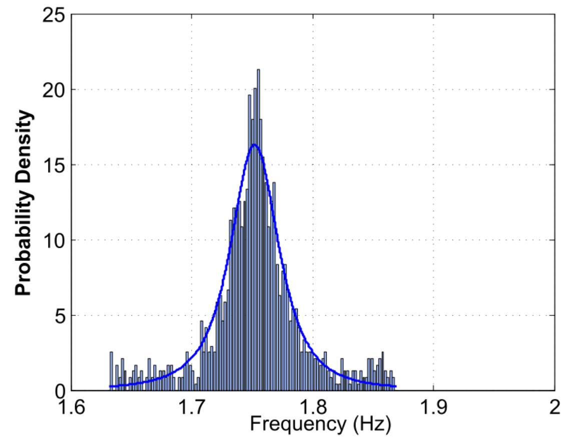
Centralized vs decentralized architecture (better observability)

Decentralized Mode Estimation

Better observability of local modes by using Decentralized Mode Estimation Architecture!

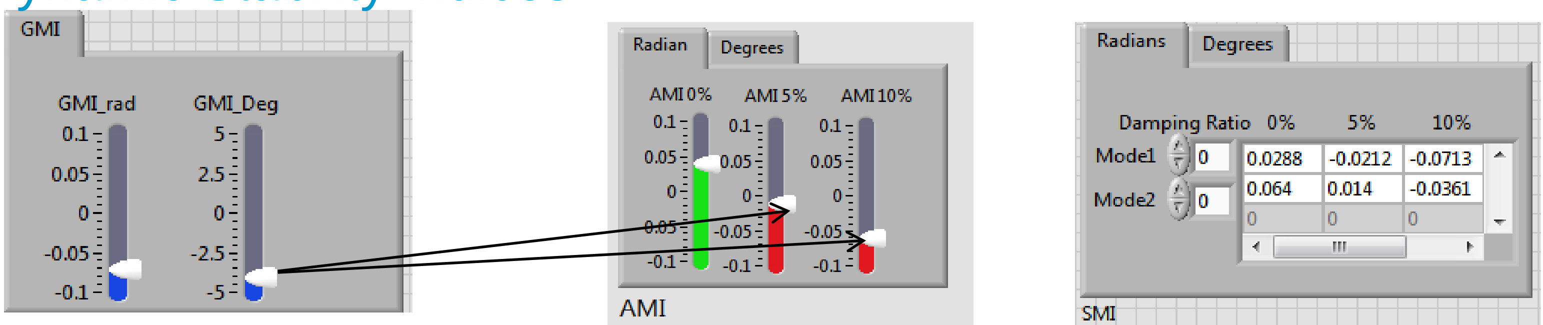


Centralized Mode Estimation (4 PMUs)



Decentralized Mode Estimation (PMU ID: 4)

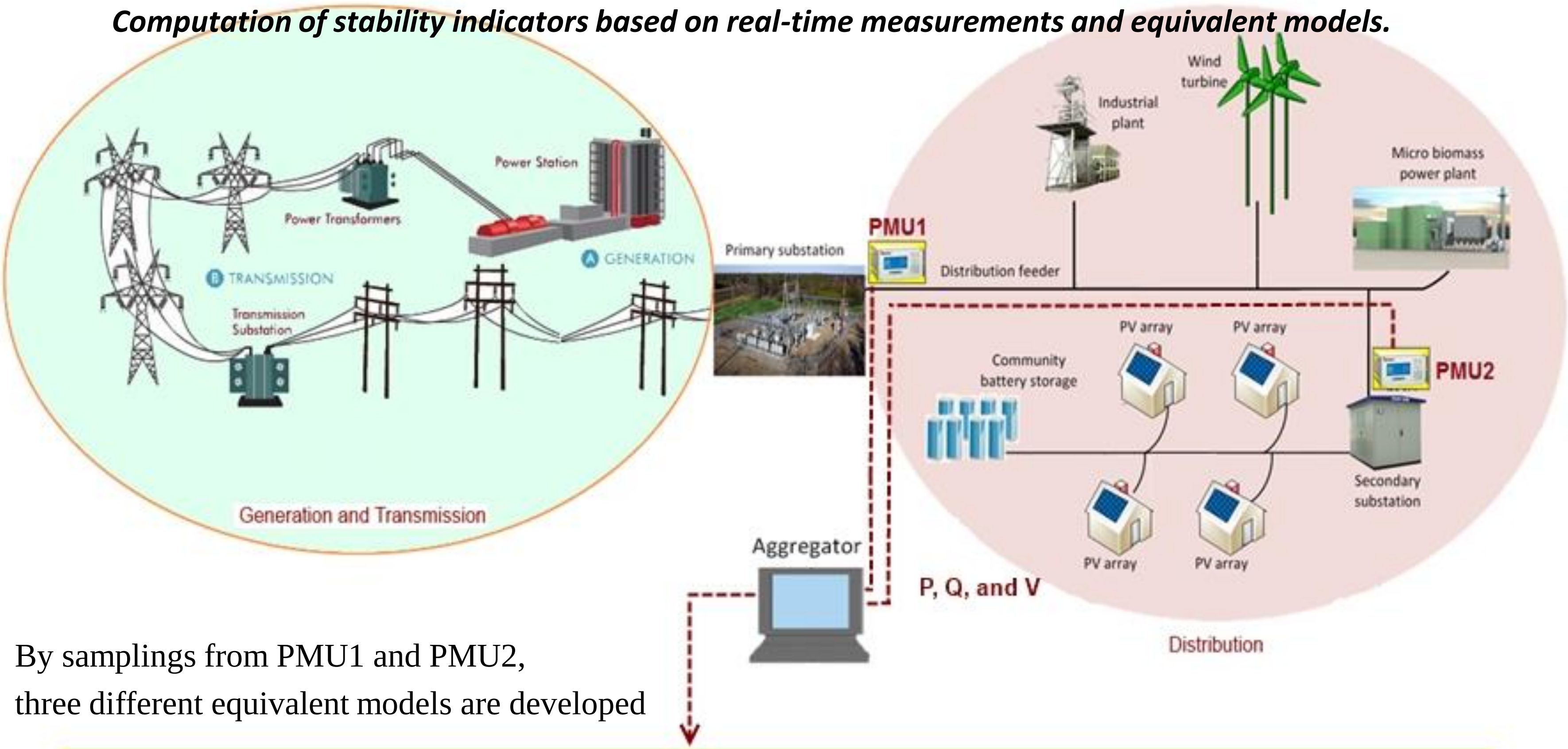
Dynamic Stability Indices



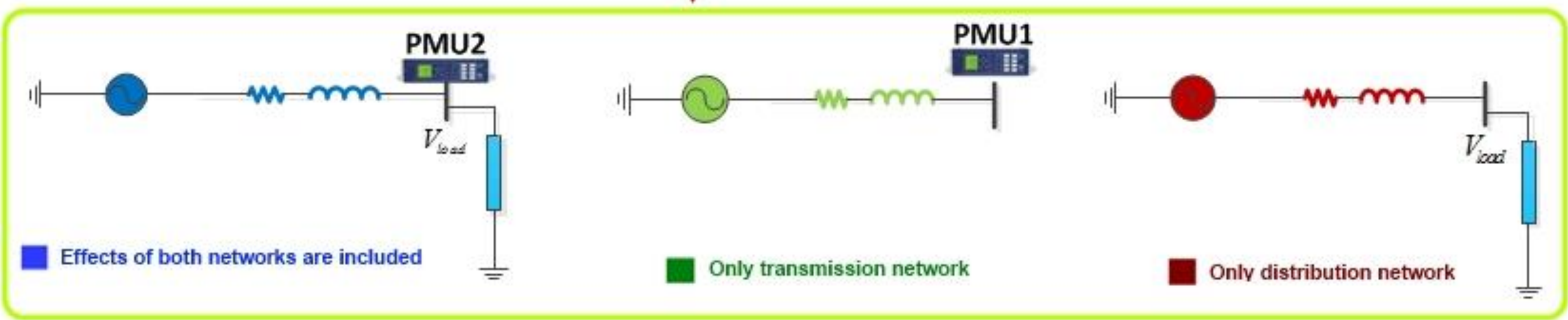
More information to appear in IEEE PES General Meeting 2016 in Boston:
R. S. Singh, M. Baudette, H.Hooshyar, L. Vanfretti, "'In Silico' Testing of a Decentralized PMU Data-Based Power Systems Mode Estimator"

Voltage Stability Analysis in Distribution Networks

Computation of stability indicators based on real-time measurements and equivalent models.

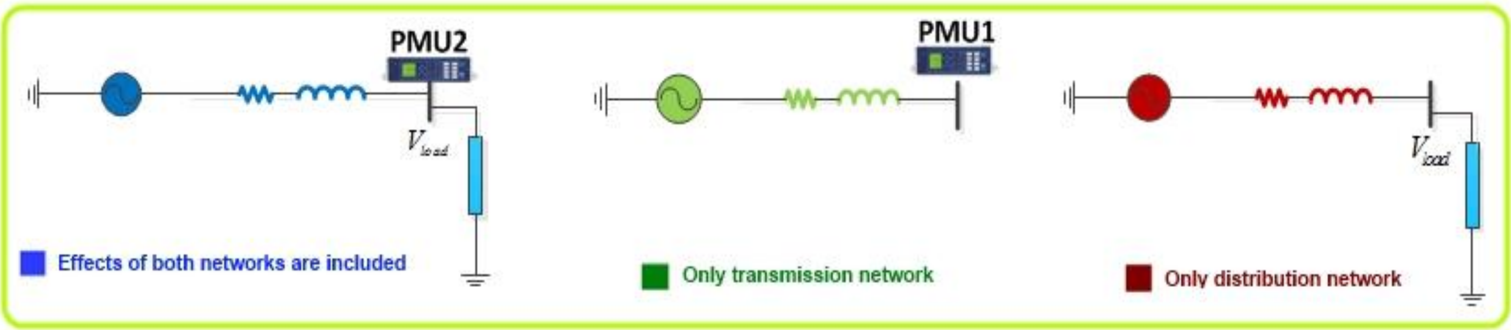


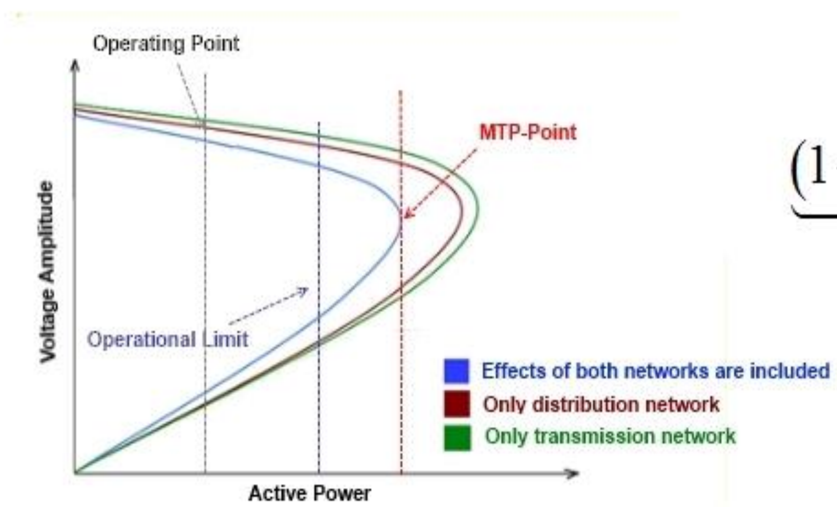
By samplings from PMU1 and PMU2,
three different equivalent models are developed



Three different PV curves are calculated from the three models.

The voltage stability and instability indices are calculated from these models to indicate the contributions of two networks on the voltage stability.

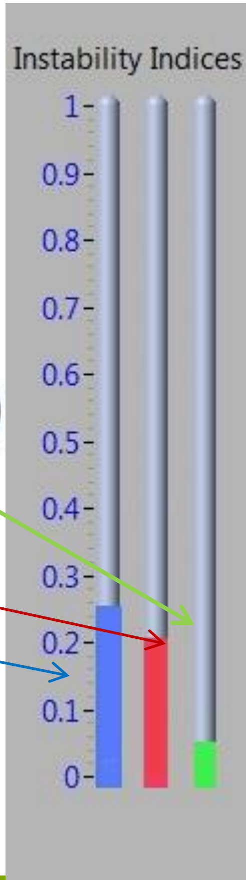




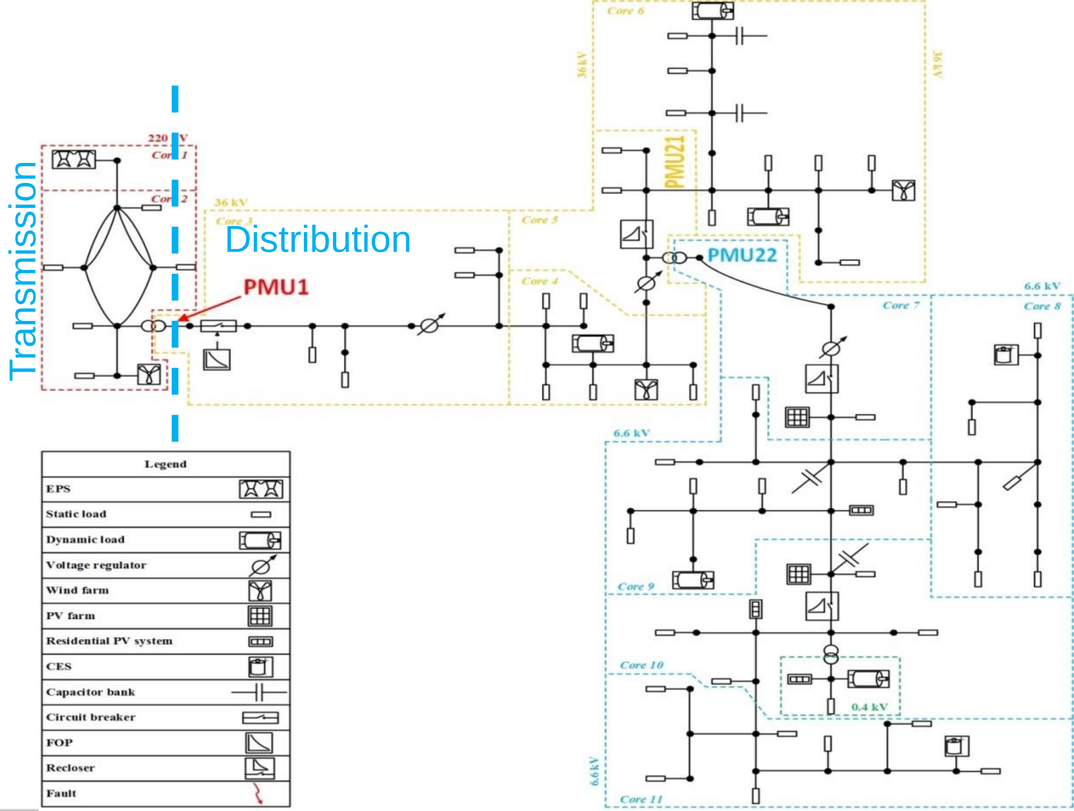
$$\underbrace{(1-VSI_{total})}_{VISI_{total}} = \underbrace{(1-VSI_{dist.})}_{VISI_{dist.}} + \underbrace{(1-VSI_{trans.})}_{VISI_{trans.}}$$

$VSI =$ Voltage Stability Index

$VISI =$ Voltage Instability Index



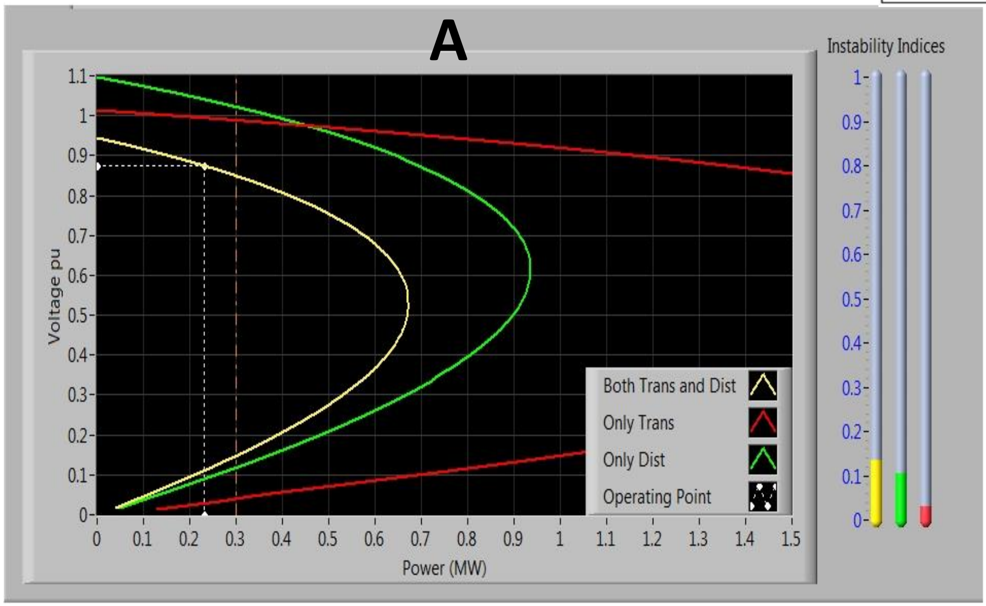
LABVIEW Application

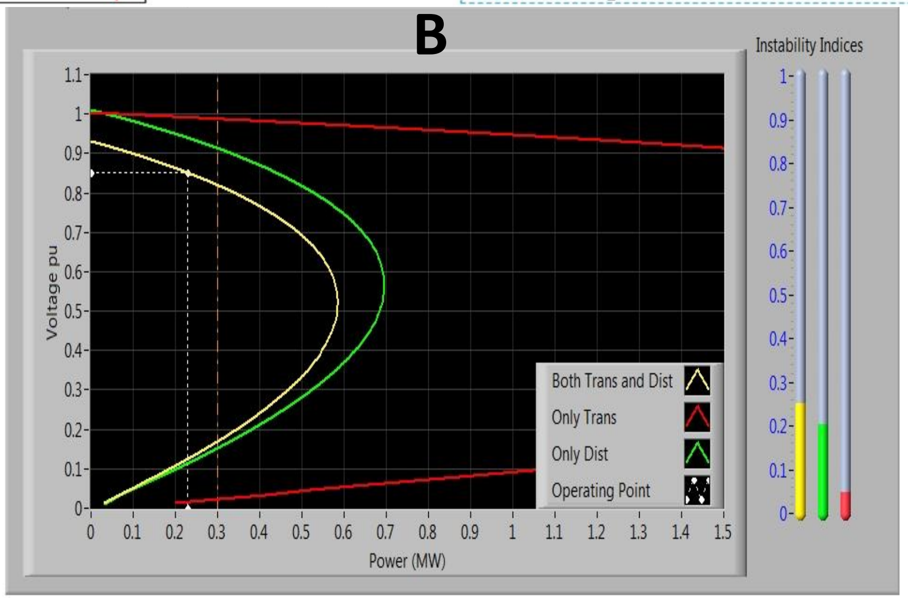


Real-time simulations results for aggregated load (LV network) seen from PMU22:

A. all distributed generations inside MV network are connected

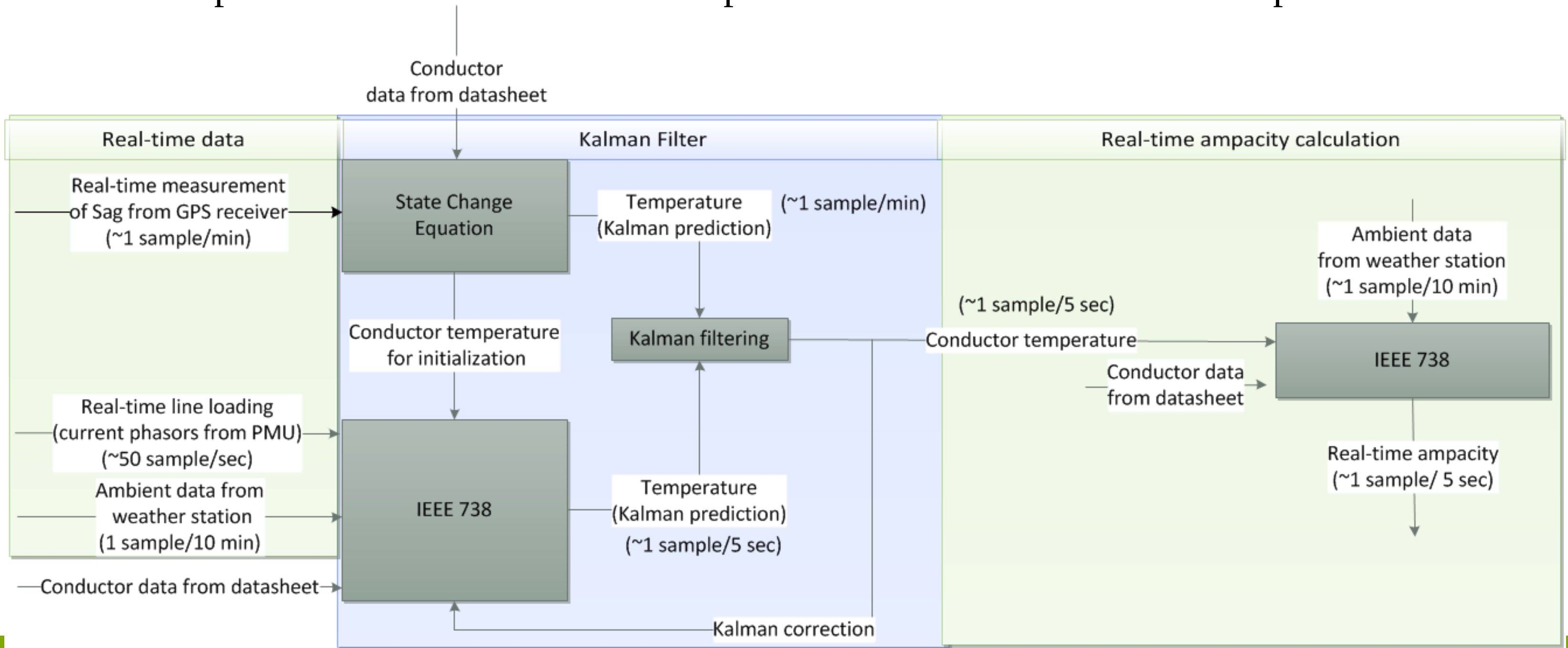
B. all distributed generations inside MV network are disconnected



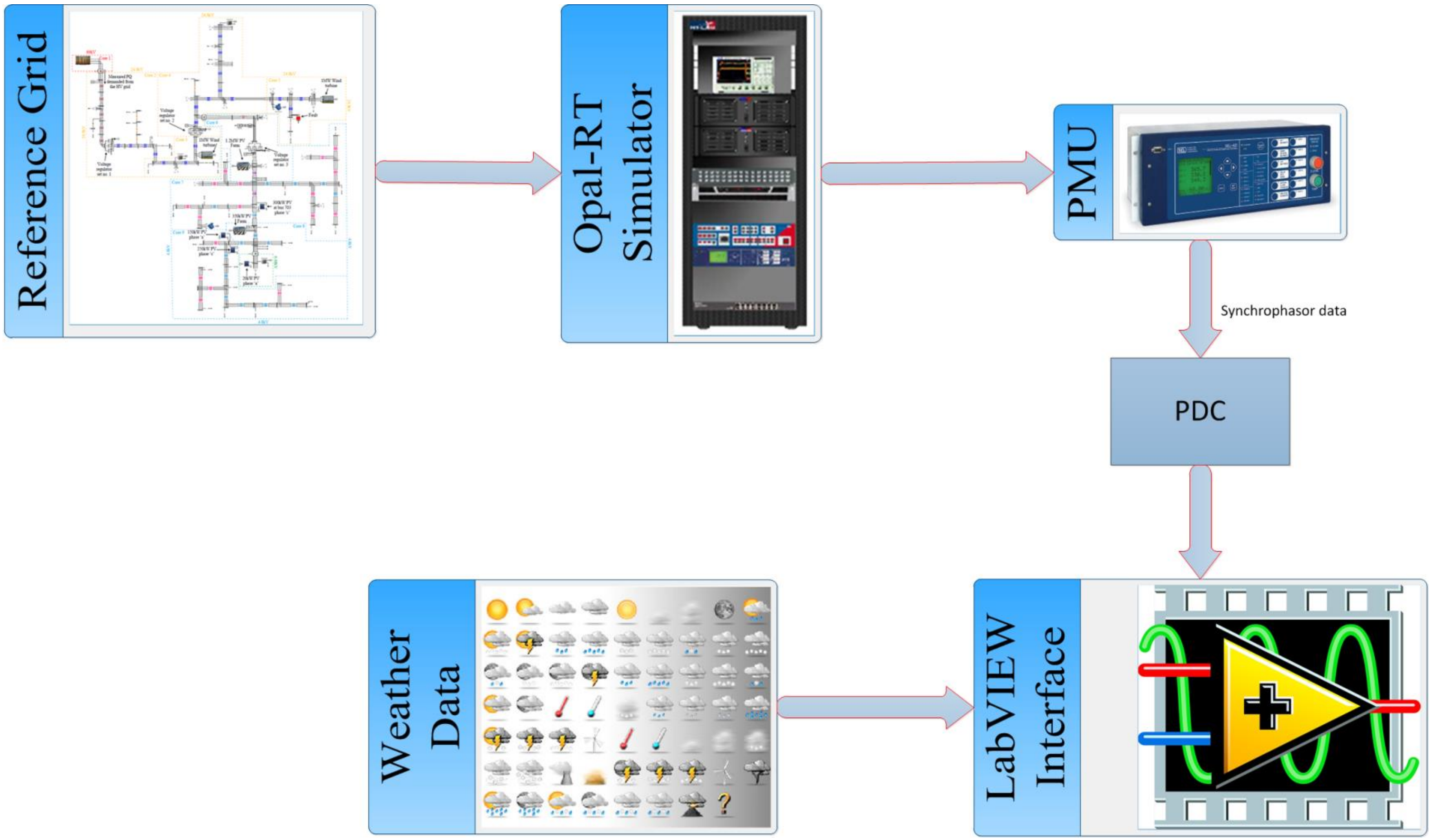


Feeder Dynamic Rating Application for Active Distribution Network Using Synchrophasor

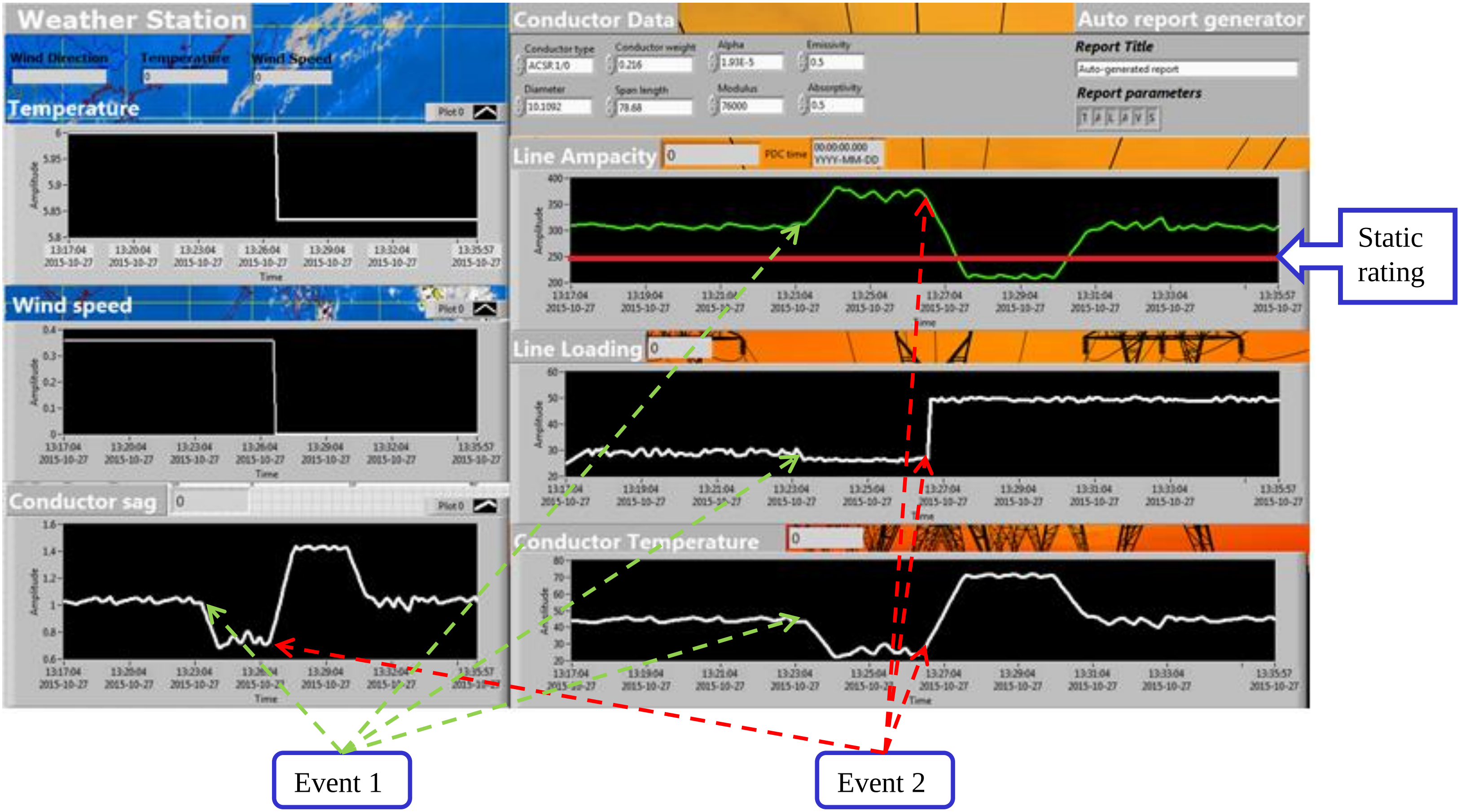
- Dynamic line rating (DLR) is a way to optimize the ampacity of transmission and distribution lines by measuring the effects of weather and actual line current.
- IEEE 738 Standard: Can be used to calculate conductor line Ampacity and Conductor temperature if conductor material properties, ambient weather conditions and actual line current is known GPS Time Source
- State Change Equation: Relates two different states of an overhead conductor. The values of conductor temperature and corresponding parameters in one state can be used to estimate the conductor temperature in another state.
- Kalman filter: A filtering technique that uses a series of measurements observed over time to produce a more precise estimate. Gives a more precise estimate of conductor temperature.



HIL Setup


Reference Grid
Opal-RT Simulator
PMU
Synchrophasor data
PDC
Weather Data
LabVIEW Interface

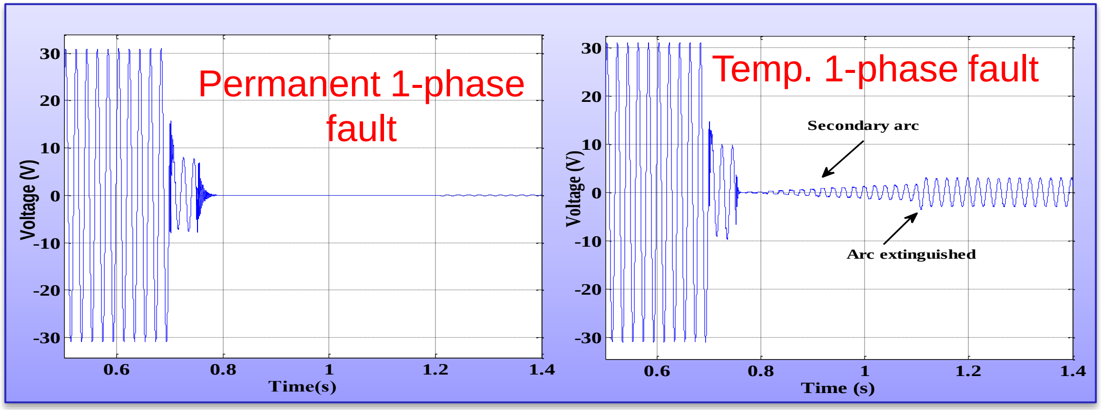
LabVIEW application and sample results

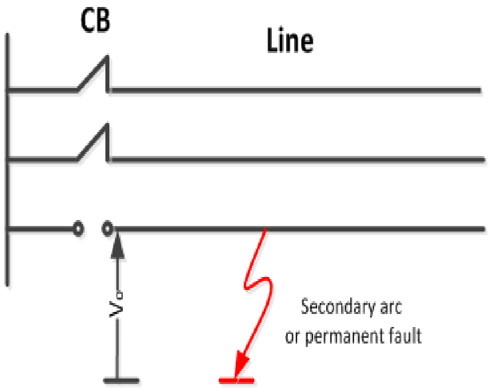


Event 1: Outage of a line.
Event 2: Outage of a wind generation (more power t be drawn from the grid).

Adaptive Auto-Reclosing (AAR)

- The proposed AAR scheme is capable to:
  - Firstly, in the case of single-phase faults discern between temporary and permanent faults. This is done by considering the voltage phasor of the opened-phase (shown below).
  - Secondly, in case of temporary single-phase faults, recloses when the secondary arc extinguishes (when TVD backs close to zero).
  - Thirdly, in the case of permanent or non-detectable faults, reclose only when the healthy part of the network is able to tolerate another reclosing attempt. In this case the Stability and Thermal indices are calculated based on the PMU's outputs.





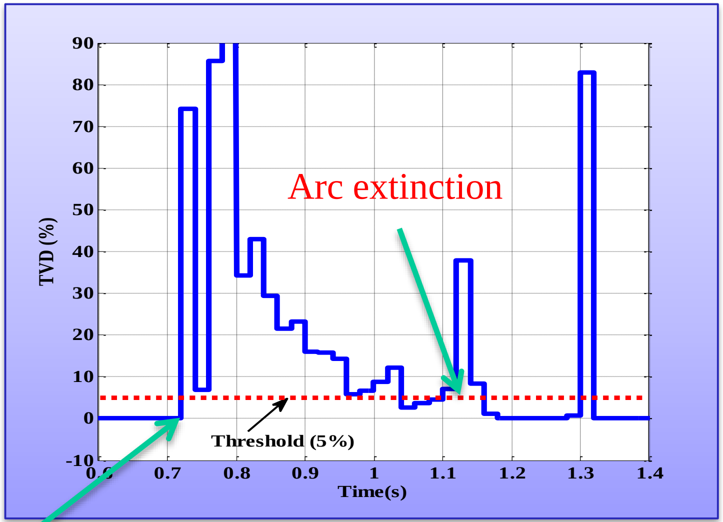
to determine the difference between two consecutive measured phasors, a total vector difference (TVD) index which is defined as:

$$TVD_{V_o} = \sqrt{\frac{(V_{or}(n+1)-V_{or}(n))^2-(V_{oi}(n+1)-V_{oi}(n))^2}{V_{or}(n)^2+V_{oi}(n)^2}}$$

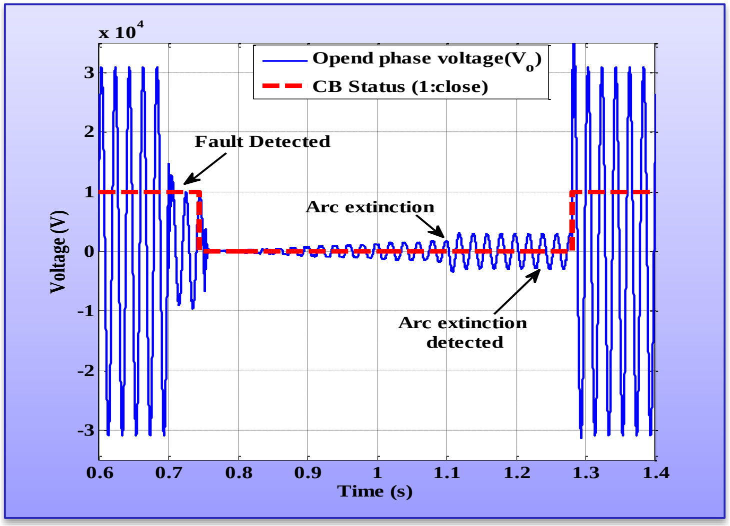
Results

Case Study: Occurrence of a single-phase fault at $t = 0.7s$.

The TVD index during and after the fault:

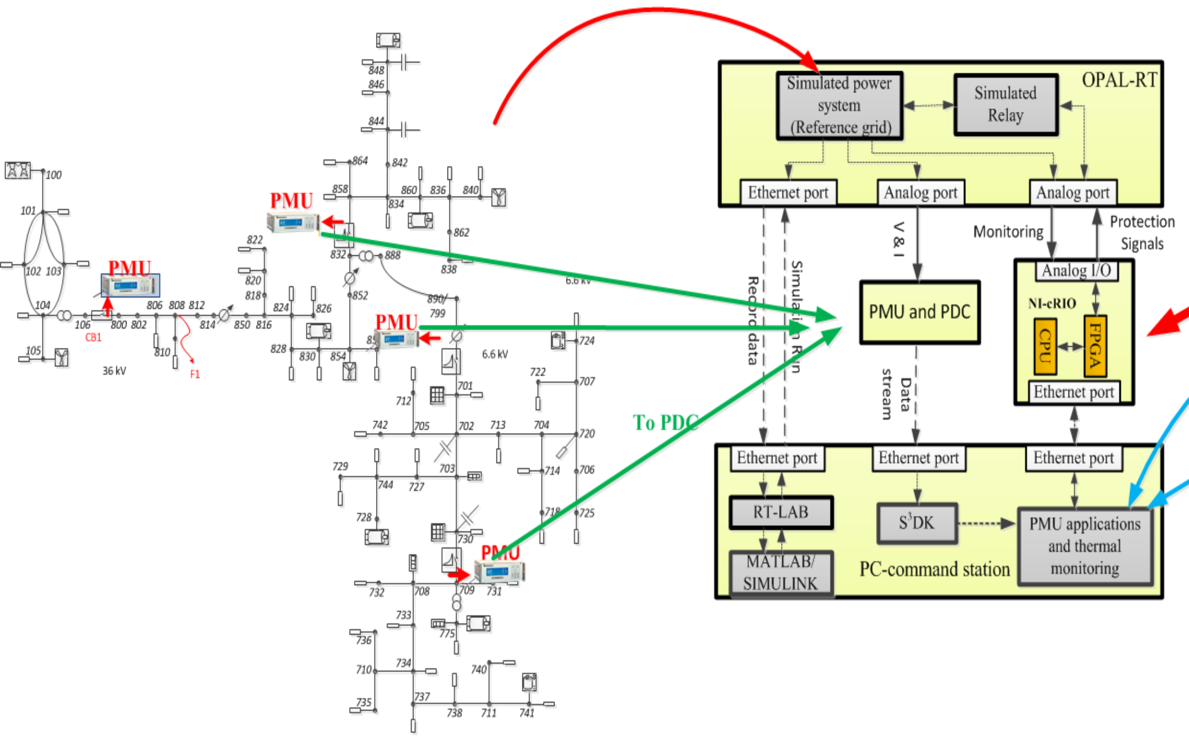


The voltage of the faulted phase and the CB status:



- Before the fault occurrence the TVD is close to zero.
- After fault, its value goes up dramatically.
- Finally, after the arc extinction TVD backs to zero.
- The proposed method send the close command after the arc extinction.

Proposed Method and Implementation



The study network and PMUs placement

The schematic diagram of the HIL Setup

Issuing the reclosing command

Providing information on different considerations:

- For 1-phase faults, whether the fault cleared.
- For 3-phase faults, whether the system operating point is far enough from the stability margins to tolerate another fault (in case the fault is not cleared).
- For 1-phase and 3-phase faults, whether the conductors are cooled down.

Thank You