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

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Laboratory Implemented Architecture

Synchrophasor Data (C37.118.2)

PMU

IEC61850-90-5 Gateway

IEEE C37.118.2 (TCP/IP)

Processed Data Graphs

Data parser

Data processing and extracting required components

Monitoring functions

DMS

PMU

Synchrophasor Data (C37.118.2)

PDC

IEEE C37.118.2 (TCP/IP)
Applications

Providing Dynamic Information
Steady State Model Synthesis (SSMS)

The reduced steady state equivalent model

Assumption:  \( R_1^a = R_2^a = R_3^a \) &  \( X_1^a = X_2^a = X_3^a \)
HIL RT Simulation Setup

- **SSMS Algorithm**
- **KF Algorithm**
- **Phase Unwrapping**

**S3DK** real-time data mediator
- **PDC Stream**
- **SEL-PDC 5073**

**Grid model is simulated in real-time**

- **Opal-RT Simulator**
- **Nodes 1 & 2**
- **Current Amplifiers**
- **NI-cRIO PMU1**
- **NI-cRIO PMU2**

**Filtered PMU data**
- **Kalman Filter LabVIEW Application**

**Reconfigurable data buffer**

**Estimated Equivalent Model**

**Raw PMU Data**

**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.
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%.

Dynamic Model Synthesis of Distribution System

Data process and analysis

- Ambiguous Data Analysis (for stochastic variations)
- Ringdown Data Analysis (for transients)

Centralized Architecture

Decentralized Architecture

Calculation of stability indices

TSO

Data curation, fusion and extraction of steady state component
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!

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”
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.

\[
\left(1 - \frac{VSI_{\text{total}}}{VSI_{\text{total}}}\right) = \left(1 - \frac{VSI_{\text{dist.}}}{VSI_{\text{dist.}}}\right) + \left(1 - \frac{VSI_{\text{trans.}}}{VSI_{\text{trans.}}}\right)
\]

\[
VSI = \text{Voltage Stability Index}
\]

\[
VISI = \text{Voltage Instability Index}
\]
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

More information to appear in IEEE PES General Meeting 2016 in Boston:
A. Bidadfar, H.Hooshyar, L. Vanfretti, “Decoupled Voltage Stability Assessment of Distribution Networks Using Synchrophasors”
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

Weather Data -> LabVIEW Interface

Synchrophasor data -> PDC
LabVIEW application and sample results

Event 1: Outage of a line.
Event 2: Outage of a wind generation (more power to 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.

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

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

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