PMU Emulator for Power System Electromechanical Dynamics Simulators

Evangelos Farantatos, Mahendra Patel
EPRI

Param Banerjee, Anurag Srivastava
Washington State University

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PMU Measurements vs Phasors from Dynamic Simulations

- Phasor values obtained from dynamic simulation tools may differ from synchrophasors measured by PMUs in the field
- How a PMU works:
  - Analog signal sampling - A/D Conversion
  - Digital filtering → magnitude attenuation & phase offset
  - Phasor estimation
    - algorithm e.g. DFT
    - window length - P & M class PMUs
PMU Emulator

- PMU Emulator: interfaced with power system dynamics simulators, and produces “simulated synchrophasors” taking into account PMUs internal signal processing.

Dynamics Simulation Software (PSS/E, PSLF, TSAT etc)

Synchrophasor Application

Proof-of-concept software
PMU Emulator - Algorithm

- Point On Wave based (POW) compensation
  - POW signal reconstruction
  - Application of phasor estimation algorithm and filters on reconstructed signal
  - Reported synchrophasors time stamped at the center of the data window.

\[
\begin{align*}
\phi(t) &= \phi_0 + \phi f + \phi t^2 \\
\alpha(t) &= \alpha_0 + \alpha f + \alpha t^2
\end{align*}
\]
Demonstrating Results – Voltage Phasors

M-Class - 15 cycles window

- Voltage Magnitude (p.u.)
  - Dynamic Simulator
  - PMU (15 cy, M class)
  - PMU Emulator (15 cy, M class)

- Voltage Magnitude Error (%)
  - Dynamic Simulator
  - PMU Emulator (15 cy, M class)

- Voltage Phase Angle (deg)
  - Dynamic Simulator
  - PMU Emulator (15 cy, M class)

P-Class - 6 cycles window

- Voltage Magnitude (p.u.)
  - Dynamic Simulator
  - PMU (6 cy, P class)
  - PMU Emulator (6 cy, P class)

- Voltage Magnitude Error (%)
  - Dynamic Simulator
  - PMU Emulator (6 cy, P class)

- Voltage Phase Angle (deg)
  - Dynamic Simulator
  - PMU Emulator (6 cy, P class)
Demonstrating Results – Current Phasors

**M-Class - 15 cycles window**

- **Current Magnitude (p.u.)**
  - Dynamic Simulator
  - PMU (15 cy, M class)
  - PMU Emulator (15 cy, M class)

- **Current Magnitude Error (%)**
  - Dynamic Simulator
  - PMU Emulator (15 cy, M class)

- **Current Phase Angle (deg)**
  - Dynamic Simulator
  - PMU (15 cy, M class)
  - PMU Emulator (15 cy, M class)

**P-Class - 6 cycles window**

- **Current Magnitude (p.u.)**
  - Dynamic Simulator
  - PMU (6 cy, P class)
  - PMU Emulator (6 cy, P class)

- **Current Magnitude Error (%)**
  - Dynamic Simulator
  - PMU Emulator (6 cy, P class)

- **Current Phase Angle (deg)**
  - Dynamic Simulator
  - PMU (6 cy, P class)
  - PMU Emulator (6 cy, P class)
PMU Emulator – Use Cases - Model Validation

Typical Practice

Use of PMU Emulator in Model Validation

Proposed Practice

Simulation Framework

PMU Emulator

Model Parameter Estimation

Power System

System Model

DAE Solver

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PMU Emulator – Use Cases - Model Validation - Example

• Parameter estimation of generator exciter model – IEEE T1
• Parameter estimation with and without PMU Emulator for different PMU settings

<table>
<thead>
<tr>
<th>PMU Settings (Cycle, Window)</th>
<th>True $K_A$ (p.u.)</th>
<th>True $T_A$ (sec)</th>
<th>Estimation with PMU Emulator</th>
<th>Estimation without PMU Emulator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$K_A$ (p.u.) Error (%)</td>
<td>$T_A$ (sec) Error (%)</td>
<td>$K_A$ (p.u.)</td>
<td>$T_A$ (sec) Error (%)</td>
</tr>
<tr>
<td>8 cycles, Triangular</td>
<td>7.9998 0.0024</td>
<td>0.0099 0.0413</td>
<td>7.9357 0.8034</td>
<td>0.0082 11.9543</td>
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<tr>
<td>15</td>
<td>14.9996 0.0026</td>
<td>0.0099 0.0393</td>
<td>14.8956 0.9362</td>
<td>0.0082 12.8717</td>
</tr>
<tr>
<td>15 cycles, Hamming</td>
<td>7.9998 0.0016</td>
<td>0.0099 0.0409</td>
<td>7.7702 2.8725</td>
<td>0.0067 43.0149</td>
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<tr>
<td>15</td>
<td>14.9997 0.0019</td>
<td>0.0099 0.0411</td>
<td>14.5378 3.0810</td>
<td>0.0063 46.6787</td>
</tr>
<tr>
<td>20 cycles, Hamming</td>
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<td>0.0099 0.0368</td>
<td>7.5875 5.1561</td>
<td>0.0019 81.0211</td>
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<tr>
<td>15</td>
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<td>0.0099 0.0411</td>
<td>14.2252 5.1656</td>
<td>0.0004 95.8872</td>
</tr>
</tbody>
</table>
PMU Emulator Software

- Also developed scripts for dynamic simulators (TSAT, PSS/E etc) to generate PMU Emulator input files (simulated voltage phasors and power) with the required format

https://membercenter.epri.com/abstracts/Pages/ProductAbstract.aspx?Productld=000000003002010741
Benchmarking PMU Emulator with Hardware PMU

RTDS

PMUs

PMU1
PMU2
PMU3
PMU4

PDC

C37.118.1 Data

Synchronizing phasor from PDC and PMU Emulator

Comparison

Voltage Mag.

Estimated Freq.

Voltage Ang.

Phasor compensated by PMU Emulator

PSS/E

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PMU Emulator – Vendor PMU Library

- Objective: Include in the PMU Emulator a library of commercial PMU models
- PMU vendors approached
- Required information is proprietary and requires NDA

Requested information sample

- Sampling frequency of the point of wave signal
- Transfer function of antialiasing filter
- Down sampling frequency, if any
- Length of the data window used for single phasor estimation
- FIR filters used
- Lengths of the FIR filters used (e.g. 8 cycles)
- …
Next Steps

• Tech Transfer: Case Studies

• Vendor Engagement: Collaboration with vendors for implementation of PMU Emulator in commercial platforms
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