New Standards for Test and Calibration of Phasor Measurement Units

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Stability of the Smart Grid threatened

Real-time network of demand and supply

- Time-variant and non-inertial sources
- Loads want to source, too!
- Switching power supplies, adjustable speed drives push distortion onto the grid
- Complexity and variability threaten stability and reliability
- Real-time computer control required to keep the lights on
Real-time control begins with Phasors

What’s a Phasor?

• Rotating “Phase Vector”
• Alternative representation of a sine wave
• Expression of V or I in a power system
Real-time control begins with Phasors

What’s a Phasor?
• Rotating “Phase Vector”
• Alternative representation of a sine wave
• Expression of V or I in a power system

What’s a SynchroPhasor?
• Time-stamped V and I phasor data
From a PMU!

- Phasor Measurement Unit
- Specialized Test and Measurement equipment
- Standalone or integrated
- Uses UTC, Universal Coordinated Time, usually GPS-derived
- Synchronously captures V and I phasors at strategic points in Grid
- Concentrates and forwards data to a remote location
- Enables SynchroPhasor applications
PMUs enable SynchroPhasor Apps

Analysis
• Wide Area Situational Awareness (WASA)
• Steady-state and dynamic modeling
• Post-mortem fault analysis

Protection
• Early warning and backup protection
• Load demand variation (load shedding)
• Adaptive protection

Control
• Variable / intermittent source integration (e.g. wind and solar)
• Real-time wide-area system control
• Synchronization, loop closing assist
PMUs hold promise of greater reliability

• September 8, 2011, San Diego went dark for over 12 hours

• PMUs widely deployed in Western Electricity Coordinating Council
  • High sampling speed, GPS time synch offer insight into grid conditions
  • PMUs will to be used to identify and monitor for grid stress, grid robustness, dangerous oscillations, frequency instability, voltage instability, and reliability margins

• Not sufficiently integrated to have been used on September 8th
  • PMUs did not report the event in real time
  • PMU data was valuable in post-event analysis
Limitations of deployed PMUs

• “The reliable power sources, samplers and associated standards for PMU testing and calibration have become a major hurdle to the further development and implementation of PMU applications in power system. Utilities need the guarantee of reliability and accuracy of PMUs and also the seamless interchangeability among the PMUs from different vendors before they will invest heavily in them.”

IEEE Std C37.118.1™-2011

IEEE Standard for Synchrophasor Measurements for Power Systems
- Redefines and clarifies concepts
- Establishes clear performance limits for PMU test and calibration
- Revises static tests, adds dynamic tests.
- Companion standard C37.118.2 for data transfer
- Companion standard PC37.242 for “how to”
“Documentation shall be provided by any vendor claiming compliance with this standard that shall include the following information:

1. Performance class  \((M=\text{Measurement, } P=\text{Protection})\)
2. Measurements that meet this class of performance
3. Test results demonstrating performance
4. Equipment settings that were used in testing
5. Environmental conditions during the testing
Revised steady-state tests

<table>
<thead>
<tr>
<th>IEEE C37.118.1-2011</th>
<th>Test Parameter</th>
<th>Range</th>
<th>Metrics (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady-state</td>
<td>Signal frequency</td>
<td>±2 Hz for P = Protection class</td>
<td>TVE (%)</td>
</tr>
<tr>
<td>compliance tests</td>
<td></td>
<td>±5 Hz for M = Measurement class</td>
<td>FE (Hz)</td>
</tr>
<tr>
<td>Section 5.5.5</td>
<td>Signal magnitude: voltage</td>
<td>80 to 120 % of nominal</td>
<td>RFE (Hz/s)</td>
</tr>
<tr>
<td></td>
<td>Signal magnitude: current</td>
<td>20 to 200 % of nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phase angle</td>
<td>±π radians</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harmonic distortion</td>
<td>1%, to 50th harmonic (P class)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10%, to 50th harmonic (M class)</td>
<td></td>
</tr>
<tr>
<td>Interharmonics (M</td>
<td></td>
<td>10%, for Fs ≥ 10</td>
<td></td>
</tr>
<tr>
<td>class only)</td>
<td></td>
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</tbody>
</table>
New! Dynamic tests

<table>
<thead>
<tr>
<th>IEEE C37.118.1-2011</th>
<th>Test Parameter</th>
<th>Range</th>
<th>Metrics (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic compliance tests</td>
<td>Modulation of amplitude and phase, individually or in combination</td>
<td>0.1 to lesser of $F_s/10$ or 2 Hz (P)</td>
<td>TVE (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.1 to lesser of $F_s/5$ or 5 Hz (M)</td>
<td>FE (Hz)</td>
</tr>
<tr>
<td>Sections 5.5.6 through 5.5.8</td>
<td>Linear ramp of system frequency</td>
<td>1.0 Hz/s over ±2 Hz (P), ±5 Hz (M)</td>
<td>RFE (Hz/s)</td>
</tr>
<tr>
<td></td>
<td>Step changes in amplitude and phase.</td>
<td>Amplitude = ± 10% of nominal</td>
<td>Response time (s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phase angle ± 10° from nominal</td>
<td>Response delay (s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Overshoot (%)</td>
</tr>
</tbody>
</table>
Output of the PMU is compared and evaluated against the applied stimulus, often using TVE or Total Vector Error.
Total Vector Error

1. Source $V_{th}$ aka $V_{true}$
2. Capture $V_{ob}$ aka $V_{Meas}$
3. Calculate $V_{dif}$
4. Calculate TVE
5. Compare to test threshold

Target uncertainty of Cal System is:
- 1/40 of 118.1 standard,
- 1/10 of typical PMU spec

$$TVE = \frac{|V_{th} - V_{ob}|}{|V_{th}|}$$
PMU Calibration Today

- Few qualified sites
- Complex test setup
- Highly proficient operator
- Manual operation
- Two to six weeks per PMU configuration
  - Frequency, sample rate, class
- PMU can have up to 18 configurations

Fluke Calibration, under a grant from NIST, is developing an automated PMU Cal System
6135A/PMUCAL Cal System

- Server PC
- GPS Receiver
- 6135A/PMU Phasor Measurement Unit Calibrator
- 6105A Electrical Power Standard Master Unit
- 6106A Electrical Power Standard (Auxiliary #1 Unit)
- 6106A Electrical Power Standard (Auxiliary #2 Unit)
PMU calibration process

- Remotely operated sequence of tests controlled via Cal Software
- Client PC sends test parameters to the Server PC
- Server PC
  - receives test parameters and configures the Cal System
  - starts test and actively controls all Cal System outputs
  - records the true (stimulus) data from the 6135A System
  - Records measured data reported by the PMU.
- True and measured data are sent to the Client
- Maximum test values are saved to the active test results file.
## Impact of automated Cal System

<table>
<thead>
<tr>
<th>Manual</th>
<th>Criterion</th>
<th>Automated</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Operator Proficiency</td>
<td>Modest</td>
</tr>
<tr>
<td>Continuous</td>
<td>Operator interaction</td>
<td>Limited, at start</td>
</tr>
<tr>
<td>Complex</td>
<td>Test setup</td>
<td>Routine</td>
</tr>
<tr>
<td>Manual</td>
<td>Operation</td>
<td>Automated</td>
</tr>
<tr>
<td>2 to 6 weeks</td>
<td>Test time per configuration</td>
<td>1 to 2 days</td>
</tr>
</tbody>
</table>
Measurement traceability relies upon the demonstrated accuracy of
1) the electrical signal sources,
2) the maintenance of time accuracy and
3) the performance verification of the entire integrated system.
Maintenance of time accuracy

6135A Electrical Power Standard, governed per the schematic yields these Test Accuracy Ratios for the following time-dependent tests:

• Measurement bandwidth test accuracy expected to be < 0.025%  
  TAR > 100:1
• Amplitude step using Dip/Swell function, Pre/post step TVE ± 0.025%  
  TAR = 40:1
• Phase step by shifting DSP pointer, Pre/post step TVE ± 0.0142°  
  TAR = 70:1

Fluke 6105A
Maintaining traceability

• Each 6135A/PMUCAL System is delivered with a traceable certificate of calibration at time of manufacture.

• For regular calibrations at one-year intervals, a reusable shipping crate is provided for transport to one of three calibration depots;
  • Everett, Washington, USA
  • Norwich, England
  • Beijing, China
• New test and calibration standards for Phasor Measurement Units, when combined with automated test execution and sound metrology, will result in improved interoperability across various makes and models of PMU.

• This improved credibility as a measurement device, combined with better economics of initial type testing and ongoing calibration, will result in increased deployment of PMUs.

• SynchroPhasor technology will take its place as the real-time guardian of the availability and reliability of the Smart Grid.
Calibrate with speed and confidence


- The automated cal system completes the 600 tests that certify a single PMU configuration less than 1 day, versus 2 to 6 weeks with manual test methods.

- Sound traceability practices ensure the long-term accuracy of PMU assets.
## Automated PMU calibration system

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb 2010</td>
<td>NIST grant announced</td>
</tr>
<tr>
<td>July 2010</td>
<td>Requirements survey</td>
</tr>
<tr>
<td>Dec 2010</td>
<td>Product requirement spec</td>
</tr>
<tr>
<td>Aug 2011</td>
<td>System demo at NCSLI</td>
</tr>
<tr>
<td>Sept 2011</td>
<td>First system to NIST</td>
</tr>
<tr>
<td>2012</td>
<td>Beta tests, intercomparisons</td>
</tr>
<tr>
<td>2013</td>
<td>Commercial availability</td>
</tr>
</tbody>
</table>

- IEEE Std C37.118.1™-2011 compliant
- Fast, automated
- Accurate, traceable
- Fully documented
Going forward

• Interoperability across PMUs derived from new standards and procedures
  • IEEE C37.118:2011 Normative standard updated, published in two parts
    • 118.1 – Measurement; Dynamic tests added
    • 118.2 – Data Transfer
      Ratification September 2011, publication December 2011
  • IEEE C37.242 Informative Guideline created
    Publication late 2012

• Pathway to worldwide standard adoption
  • 118.1 to IEC via IEC TC57
  • 118.2 to IEC 61850

• Availability of automated PMU calibration system
  • Lowers development costs of PMU
  • Bolsters credibility of new PMUs
  • Lowers PMU ownership costs
  • Spurs deployment of PMUs into control and protection applications