Development and Testing of Wide-Area Protection Applications
STRONG²rid Project Results

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Outline

- PMUs: Smart Grid Enablers
- SmarTS-Lab
- Wide-Area Protection Applications
  - Anti-Islanding Protection
- Future focus
  - Vulnerabilities of WAMPAC Apps
- Conclusion
Enabler of the evolving Smart Grid

PHASOR MEASUREMENT UNITS (PMUs)
Synchrophasor Fundamentals

Sinusoidal waveform

Represented as
Phasors

• Data rate upto 50 / 60 msgs per sec
• Numerous potential applications like islanding detection, state estimation, early warning systems, model validation, SIPS, RAS, etc

Typical Hierarchical Communication Layout of PMUs and PDCs
Platform for developing WAMPAC Applications

SMART TRANSMISSION SYSTEM LABORATORY (SmarTS-Lab)
Architecture

Legend
- GPS Signal
- Hardwired
- Station Bus
- Process Bus
- PMU Stream
- PDC Stream
- Feedback Signal

National Instrument Controllers (cRIOs) which are programmed as PMUs. Some cRIOs are used as external power system controllers to send feedback signals to RTS.

SEL-5073 takes synchrophasor data from SEL and NI-cRIO PMUs, time align them and outputs a single concentrated stream.

NTNU Lund Aalto DTU TuT

Babel Fish and S3DK unwraps the PDC streams and provide raw measurements to the N-cRIOs in Labview. The cRIOs are programmed to perform power system operation applications.
Our Smarts Lab Architecture
RT-HIL Design and Testing

WAMPAC APPLICATIONS
Application developments

- Large number of PMU-assisted WAMPAC applications have been developed within the STRONg²rid project.
- All these applications have been tested using Real-Time Hardware-in-the-loop (RT-HIL) facility at SmarTS-Lab.
RT-HIL Setup: Minimum Requirement

Legend:
- GPS Signal
- PMU stream
- Hardwired
- PDC stream

1. Remote UDP clients on different programming platforms using user selected synchrophasor data from BF for further data manipulation.

2. Selected synchrophasor data being received in National Instrument controllers using UDP for performing power system control applications.

3. User selected synchrophasor data through BF being used in a power system monitoring application.

Important piece of the puzzle
WIDE AREA PROTECTION APPLICATIONS

• Anti-Islanding Protection
1. Anti-Islanding Protection
(Local and Wide Area Measurements)

- IEEE Std. 1547-2008 states that the DG must be disconnected from the isolated grid within 2 seconds after an unintentional islanding event.

- This maximum delay of 2 seconds includes islanding detection, trip signal generation, trip signal transfer and breaker opening for the connected DG.

Simulink Model
IEEE 3 Machine, 9 bus System
1. Anti-Islanding Protection (Local and Wide Area Measurements)

Latencies in PMU-based applications

- PMU filtering delay
- Synchrophasor computation delay
- PMU Data Packaging Delay
- Link propagation delay
- Router delay
- PDC delay
- Feedback loop delay

<table>
<thead>
<tr>
<th>Cause of Delay</th>
<th>Typical Range of Delay</th>
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</thead>
<tbody>
<tr>
<td>Sampling Window</td>
<td>17 ms to 100 ms</td>
</tr>
<tr>
<td>Measurement Filtering</td>
<td>8 ms to 100 ms</td>
</tr>
<tr>
<td>PMU processing</td>
<td>0.005 ms to 30 ms</td>
</tr>
<tr>
<td>PDC processing Delay</td>
<td>500 ms to 2 s</td>
</tr>
<tr>
<td>Communication Distance</td>
<td>6 µs / km</td>
</tr>
</tbody>
</table>
1. Anti-Islanding Protection (Local and Wide Area Measurements)

- ROCOF-based schemes are effective for both active and reactive power mismatch, and result in faster operation.
- Wide-area schemes not only perform faster, but also have smaller NDZs.
If latencies are kept to a minimum, wide-area passive islanding detection schemes reduce the NDZ to half or two-third of the one using local synchrophasors.

Reference: M. S. Almas and L. Vanfretti, “RT-HIL Implementation of Hybrid Synchrophasor and GOOSE-based Passive Islanding Schemes”, Accepted for publication in IEEE Transactions on Power Delivery, DOI: 10.1109/TPWRD.2015.2473669
Cybersecurity

VULNERABILITY OF PMU-BASED APPLICATIONS
On December 23, 2015, Ukrainian power companies experienced unscheduled power outages impacting a large number of customers in Ukraine.
GPS Spoofing/Jamming

Jamming attack to deny the GPS signals to the receivers (PMUs / IEDs)
GPS Jamming resulted in

- Erroneous increase in line loading from 80% to 92%.
- Increase from 625 MW to 752 MW.
- Changes occurred within a span of 550 s once the jamming is launched.
Due to jamming, the protection operation time has increased by 1.022 s for 20 % active power mismatch and 0.62 s for 30 % active power mismatch.

Reference: M. S. Almas, and L. Vanfretti, “Impact of Time-Synchronization Signal Loss on PMU-based WAMPAC Applications”, accepted for presentation in IEEE PES GM 2016, July 17-21, Boston, Massachusetts, USA
Conclusions/Recommendations

Conclusion

– Demonstrated the utilization of synchrophasor measurements for developing Wide-Area Protection Applications.
  – Wide area measurements can decrease the tripping time and reduce the Non Detection Zone (NDZ) for the scheme
– The test-bench demonstrated is useful for a myriad of applications in which simulation exercises in power system CAD software provides no realistic insight into the practical design and implementation challenges
– Real-Time QoS requirements (end-to-end delay) needs to be addressed for each type of WAMPAC applications
– A protocol parser is required to translate / unwrap legacy protocols into raw measurements.
– With more automation and dependence on IT infrastructure, cyber-security threats are a real concern.
Acknowledgements

• The work presented here is a result of the collaboration between iITC, KTH SmarTS Lab (Sweden), Statnett SF (Norway)

• This work has been financed by:
  – Statnett SF, the Norwegian transmission system operator, through its Smart Operation R&D program.
  – The Nordic Energy Research through the STRONG2rid project.

- KTH SmarTS Lab: Luigi Vanfretti, M. Shoaib Almas, Maxime Baudette, Gudrun Jonsdottir, Eldrich Rebello

- Statnett SF: Stig Løvlund, Jan O. Gjerde, Luigi Vanfretti
Thank you!

• Questions?
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The scientific man does not aim at an immediate result. He does not expect that his advanced ideas will be readily taken up. His work is like that of the planter - for the future. His duty is to lay the foundation for those who are to come, and point the way. (Nikola Tesla)