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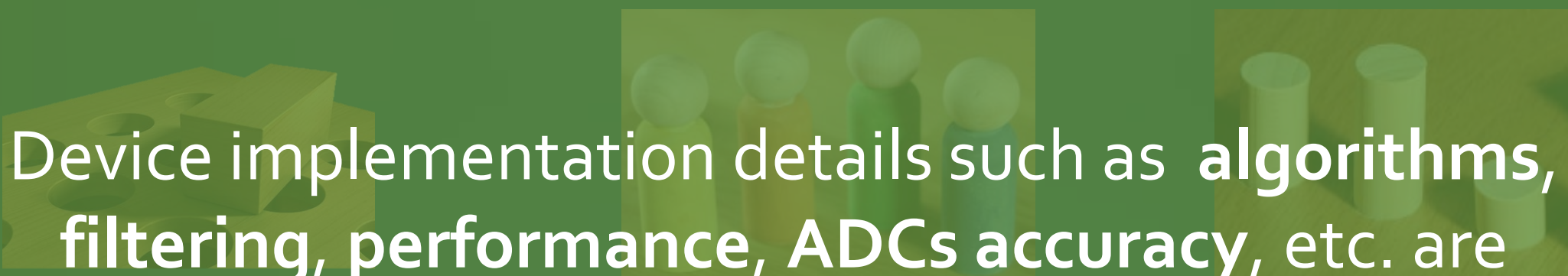
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Algorithms, Filters, Accuracy, etc.

Actual Impacts of Mixing PMU Standards

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"Standardization is a powerful tool to increase **interchangeability** and **reduction of variety**"

— United Nations, Industrial Development Committee

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Standards Objectives

Device implementation details such as **algorithms**, **filtering**, **performance**, **ADCs accuracy**, etc. are largely left to manufacturers to decide

Fitness for Purpose   Interchangeability   Variety Reduction

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Note on C37.118 Standards

Standard defined by IEEE for PMU that includes

- *Measurements*
- *Method of quantifying measurements*
- *Testing & Certification requirements*
- *Data transmission format and protocol for communication*

Available in two standards

- *C37.118-2005*
    - *Most existing installations*
    - *Defines phasor measurement performance only under steady-state conditions*
- *C37.118-2011*
    - *Introduced recently, mostly required for new installations*
    - *Defines class M (Measurement) and P (Protection) based on performance requirements*
    - *Defines phasor measurement performance under both steady-state and dynamic conditions*

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Building blocks of a Generic PMU

PMU implementation details such as **algorithms, filtering, performance, ADCs accuracy**, etc. are largely left to manufacturers to decide

Real-Time Processor and OS
- *Communication*
- *Time Synchronization*
- *Non-Critical Tasks*

Dedicated Reconfigurable HW
- *Phasor Calculation*
- *AD ⬌ DA Conversion*
- *GPS Management*
- *Critical Tasks*

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PMU Algorithm Extravaganza

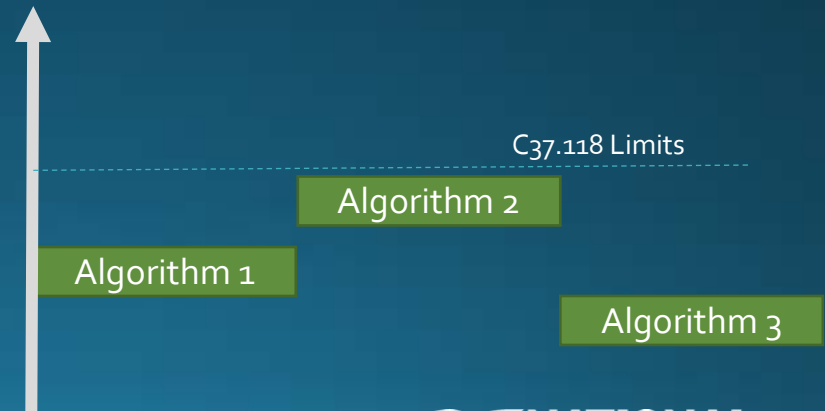**There's a variety of ways to calculate phasors…**

Re-Sampling

Reference Wave

Zero-Crossing

Spiral Vectors

Others…

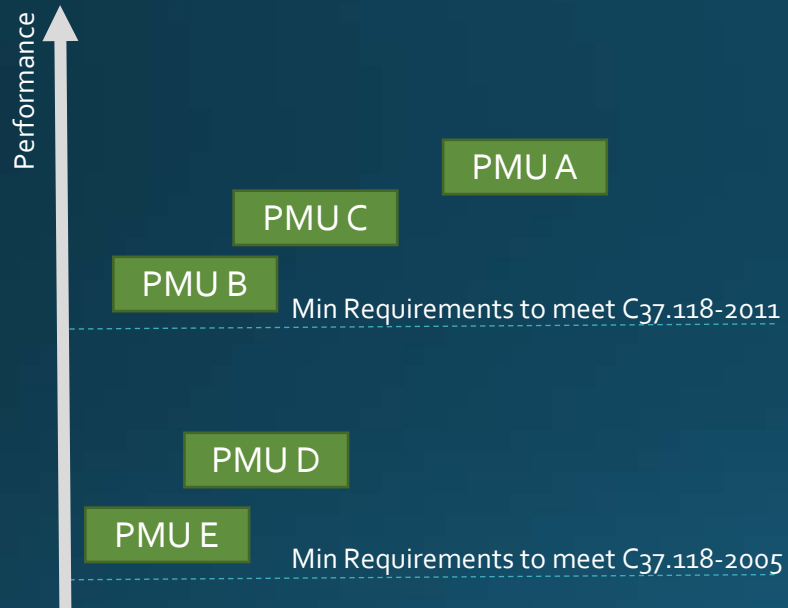**…and there's a variety of <u>different</u> results when multiple algorithms are used side-by-side**

C37.118 Limits

Algorithm 2

Algorithm 1

Algorithm 3

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Enhance Situation Awareness with PMUs

There's a variety of PMU Vendors...

Performance

PMU A

PMU C

PMU B

Min Requirements to meet C37.118-2011

PMU D

PMU E

Min Requirements to meet C37.118-2005

...and there's a variety of <u>different</u> grid state estimation results when dissimilar PMUs are used side-by-side

PMU A

PMU C

Stability Threshold

PMU B

PMU D

PMU E
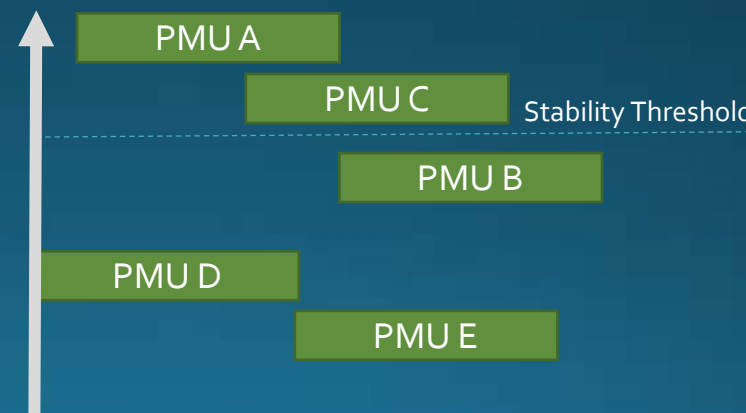
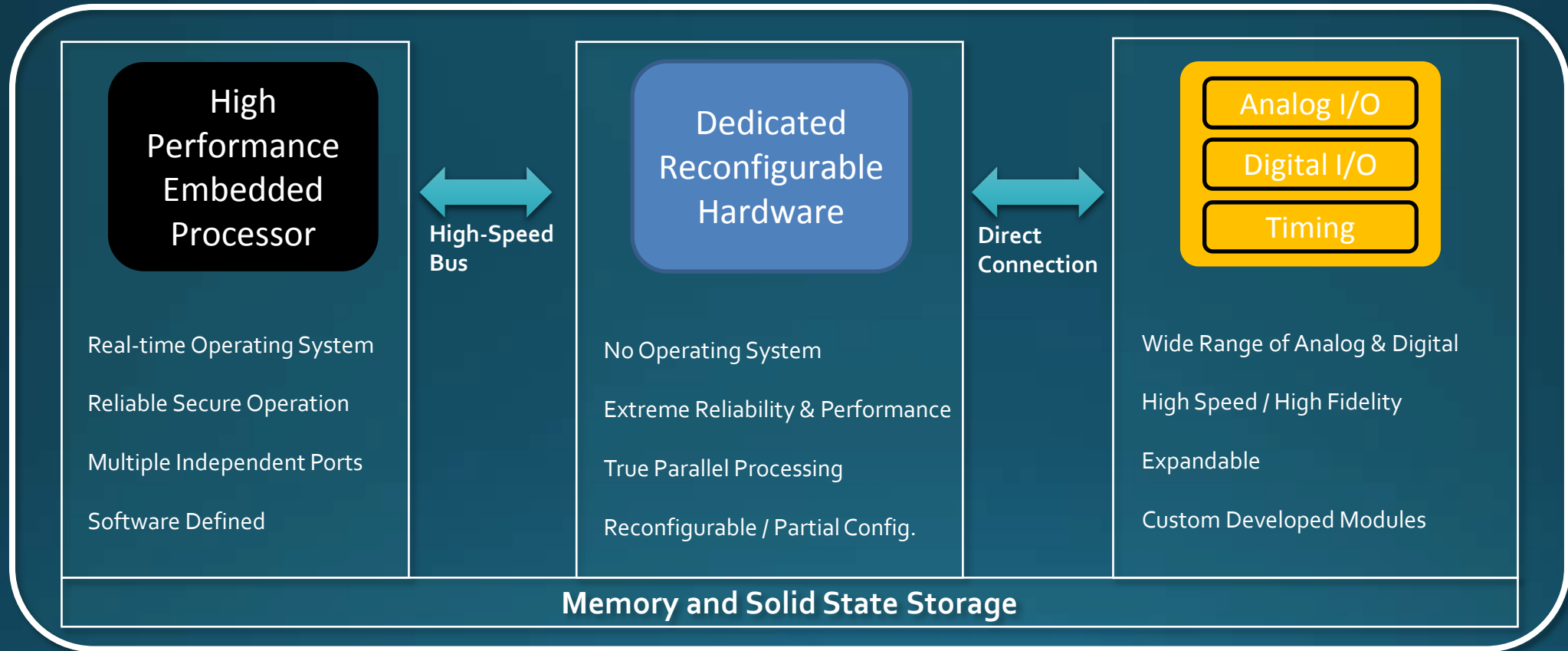# Other Considerations

- Technology and standards are constantly evolving
- Security compliance
- Reliability (i.e. Network and GPS Vulnerabilities)
- Calibration
- Multiple logical devices on the same physical unit
- …

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A novel approach: Advanced IED Platform

High Performance Embedded Processor

High-Speed Bus

Dedicated Reconfigurable Hardware

Direct Connection

Analog I/O

Digital I/O

Timing

Real-time Operating System

Reliable Secure Operation

Multiple Independent Ports

Software Defined

No Operating System

Extreme Reliability & Performance

True Parallel Processing

Reconfigurable / Partial Config.

Wide Range of Analog & Digital

High Speed / High Fidelity

Expandable

Custom Developed Modules

Memory and Solid State Storage

Operating Temp Range -40 C to +70 C | No Moving Components | Small Form Factor

Certified to IEEE C37.90/60, IEC 60255 | Secure Remote Upgrades

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Advanced IED Platform - Benefits

- **Distributed Intelligence**
  - *Promotes optimum network response times and bandwidth utilization*
  - *Allows unprecedented amounts of data and grid control operations to be seamlessly managed through the system*
  - *Enhances reliability through decentralized coordination instead of through the imposition of hierarchical control.*

- **Flexible communication protocols**
  - *Facilitates instrumentation interoperability*

- **Future-proof hardware architecture**
  - *Real-time platform that allows capture of fast moving data such as transients and line disturbances*
  - *High Fidelity ADCs with 24-bits and Filtering Capabilities for Quality Measurements*
  - *Common data file formats (Standards Based)*
  - *I/O Expandable and Remote Upgrades*
  - *Personality Swap*

- **Security**
  - *Micro-Processor based infrastructure combined with modern RT OS allows advanced security schemes to comply with NERC/CIP*
  - *VPN, Firewall, Port Blocking, Authentication, Encryption, etc.*
  - *IP Protection (develop $\Rightarrow$ certify $\Rightarrow$ lock)*

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About the Project

Customer   -   **Power Grid Corporation of India (PGCIL)**

Project   -   **PMU Based Wide area measurement for Dynamic measurement and State Estimation of the Power Grid**

Details   -   1750 PMU C37.118-2011 (Class M and P)

64 Servers (PDC and Hist.), 1 Central Operator Console

8 Voltages, 8 Currents, and 8 Digital Inputs

Robust Built-In GPS

Remote Upgradability

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NI Advanced PMU Platform

High-Performance Hardware

- **Dual-Core ARM A9 RT Processor (667Mhz) and Xilinx Artix 7 FPGA**
  - *RAM 512 Mb (DDR3), 1Gb Solid-State Storage (Expandable)*
  - *High-Fidelity ADCs 24bits @ 50kS/s/Ch (833/1000 Samples/Cycle @ 60Hz/50Hz)*
  - *Reporting rates up to 240 Msg/s*

- **Standards-Based I/O (C37.90, C37.60, IEC 60255)**
  - *9 Currents, 20A (continuous) , 100A (10s) | Withstand: 500A (1s) , 1250A (1/2 cycle)*
  - *8 Voltages, 800 V$_{RMS}$ L-E (continuous) | Withstand: 1000 V$_{RMS}$ L-E (10s)*
  - *8 Digital Inputs with programmable thresholds, up to 250 VDC @ 1mA*
  - *2x RS-232, 1x RS-485, 2x Gigabit Ethernet (Fiber upgradable), 1 USB 2.0*
  - *Built-in GPS with optional Anti-Spoofing technology (withstand attacks, or complete signal loss for up to 7 days)*

- **Programmable 4.3" Resistive–touch Display**

- **5U | 19" Substation Rack Mountable, -40C to 70C**

Flexible Software Framework

- **LinuxRT OS**
  - *NI LabVIEW , Eclipse (C-Style) or IEC 61131-3*
  - *Support for 3rd Party Libraries and Math scripts (.m)*

- **Hybrid Solution**
  - *PMU C37.118.2011.a Class M and P*
  - *Optional Power Quality (IEC 61000-4)*
  - *Optional Protection Relay (C37.60)*
  - *Optional Custom Algorithms*

- **Simultaneous Protocol Support**
  - *C37.118-2, DNP3, IEC 60870, IEC 61850, Modbus*

- **Security**
  - *Support VPN, Firewall, Port Blocking, Authentication, etc.*
  - *IP Protection (develop $\Rightarrow$ certify $\Rightarrow$ lock)*

- **Remote software updates, and personality "swap"**

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Lessons Learned

- **A couple of "firsts" for National Instruments:**
  - *First manufacturer to deploy C37.118-2011.a PMUs to power grids*
  - *First PMU to pass (and outperform) tests for C37.118-2011.a compliance (Class M and P)*
  - *First Advanced IED Platform allowing rapid design-prototype-deploy cycles. (From PMU concept to deployment in 3 Months)*

- **Mixing C37.118-2005 with C37.118-2011 PMUs**
  - *DO IT AT YOUR OWN RISK, as they produce different measurement reports*
  - *May lead to ambiguous grid-health estimation*
  - *May filter-out real grid events or oscillations during dynamic situations*

- **Other**
  - *Customer expectations for performance were more strict than the standard*
  - *The software-defined instrument approach of NI Advanced IED Platform allowed quick turn-around for updating algorithms and filter schemes to meet customer expectations*

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"Deploying NI PMUs that meet the latest standard in our pilot program has already helped us with **more accurate grid health monitoring**. The quality of measurements available in these systems are **able to detect perturbations and grid phenomena that otherwise would go unseen**. We are excited how these new tools will help us achieve continuous improvements through innovation and state of the art technology."

— **Power Grid Corporation of India (PGCIL)**

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