Reconfigurable instrumentation for monitoring and control of energy systems

Vidar Grønås, National Instruments

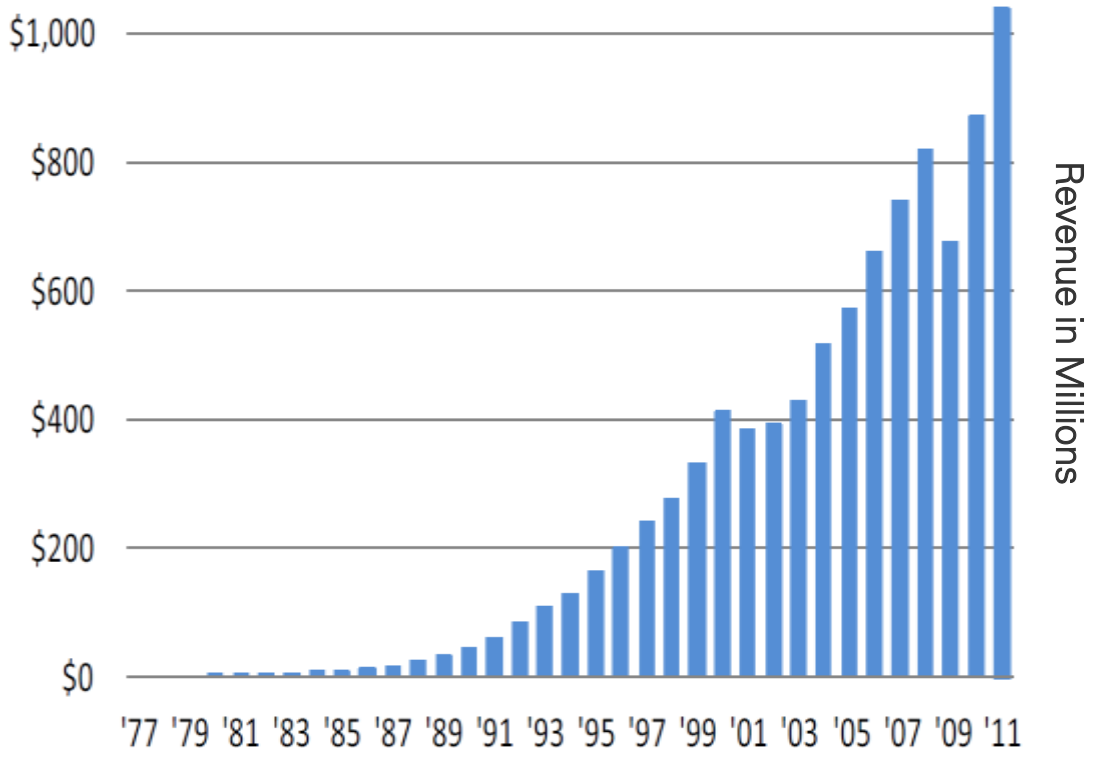
Energy Segment Manager Europe

Jan/2012

National Instruments

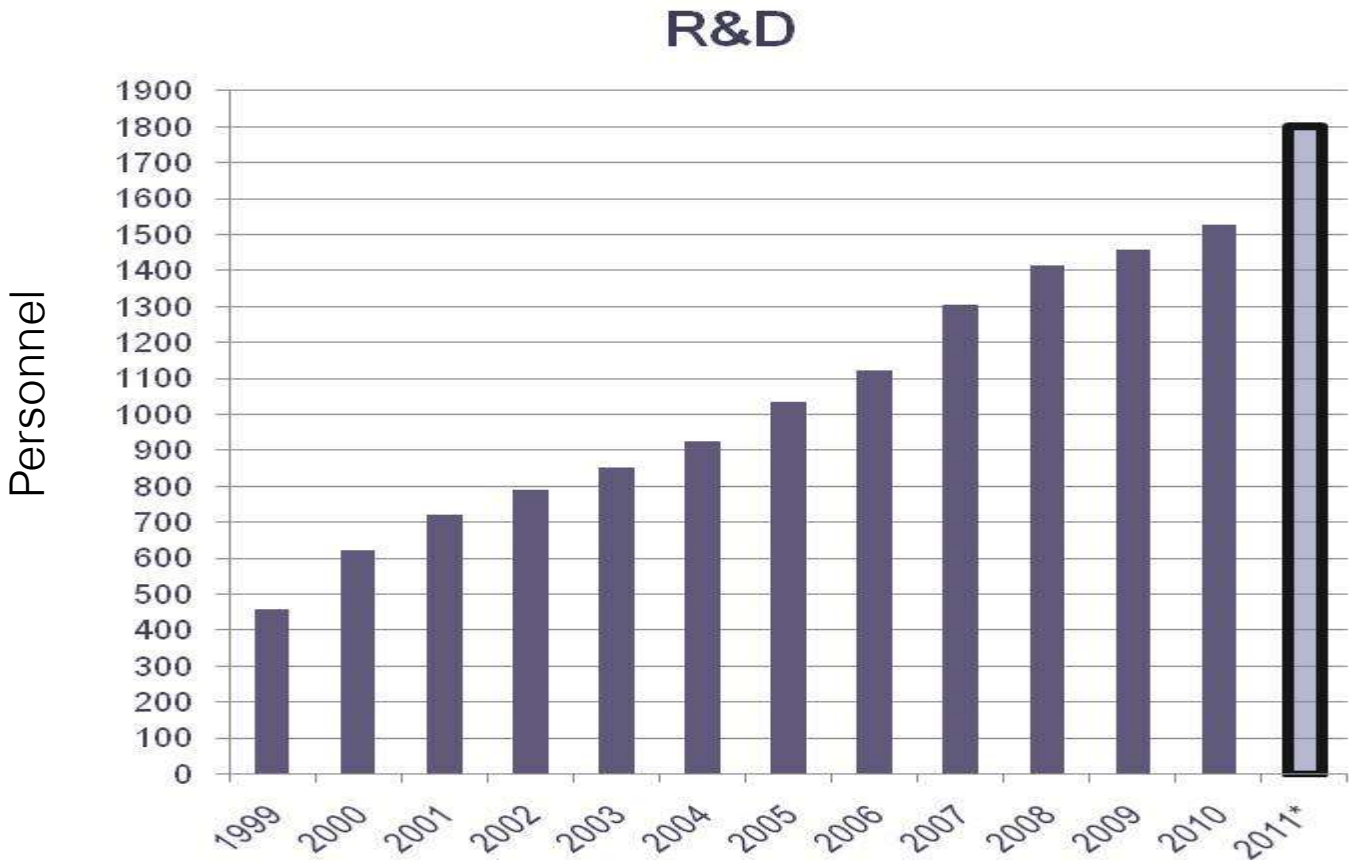
Leader in measurement and automation

- Long-term track record of growth and profitability
- $1.02B revenue in 2011
- More than 5,200 employees; operations in 40+ countries
- Sales to More than 30,000 companies
- No Industry >15% of Revenue
- *FORTUNE's* 100 Best Companies to Work For list for 12 consecutive years
- 16% or More Investment in R&D



Investing for the Future

NI R&D headcount has grown over 50% in the last 5 years
Over $200M/yr in R&D Investment



Our Challenges

- Smart Grid is an umbrella term defining multiple efforts for modernizing power systems
  - *Utilities are learning as they go, so flexibility is paramount*
- Technology and Standards are constantly evolving
  - *Instruments are designed for functions and standards of an specific/fixed point in time (obsolescence risks)*
- Computerized systems require enhanced/flexible security approaches
  - *Special technology and costly components must be developed making existing instrumentation expensive and slow to adopt*
- Global Economy Decline
  - *Shrinking budget and resources and favors, high efficiency, multi-purpose/field-configurable instrumentation*

Grid: Measurement – Visualization – Automation

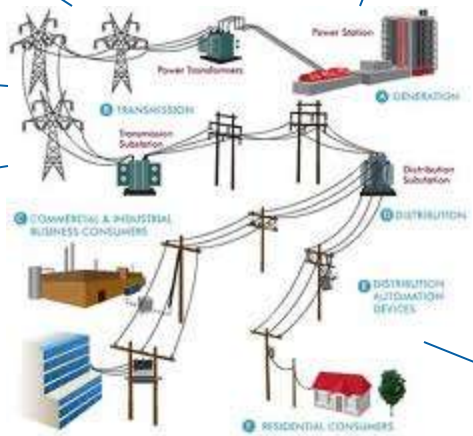
Transformer Monitoring

Alarm Event Recorder

Recloser Control

Sectionalizer Control

Phasor Measurement Unit



Capacitor Control

Substation Automation

Demand Response

Metering

Power Quality Analyzer

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Grid: Measurement – Visualization – Automation

Transformer Monitoring

Alarm Event Recorder

Recloser Control

Sectionalizer Control

100's of Devices

Multiple Protocols

Multiple Buses

Fixed Functionality

Hundreds of Vendors

Poor Data Visualization Tools

Phasor Measurement Unit

Capacitor Control

Substation Automation

Demand Response

Metering

Power Quality Analyzer

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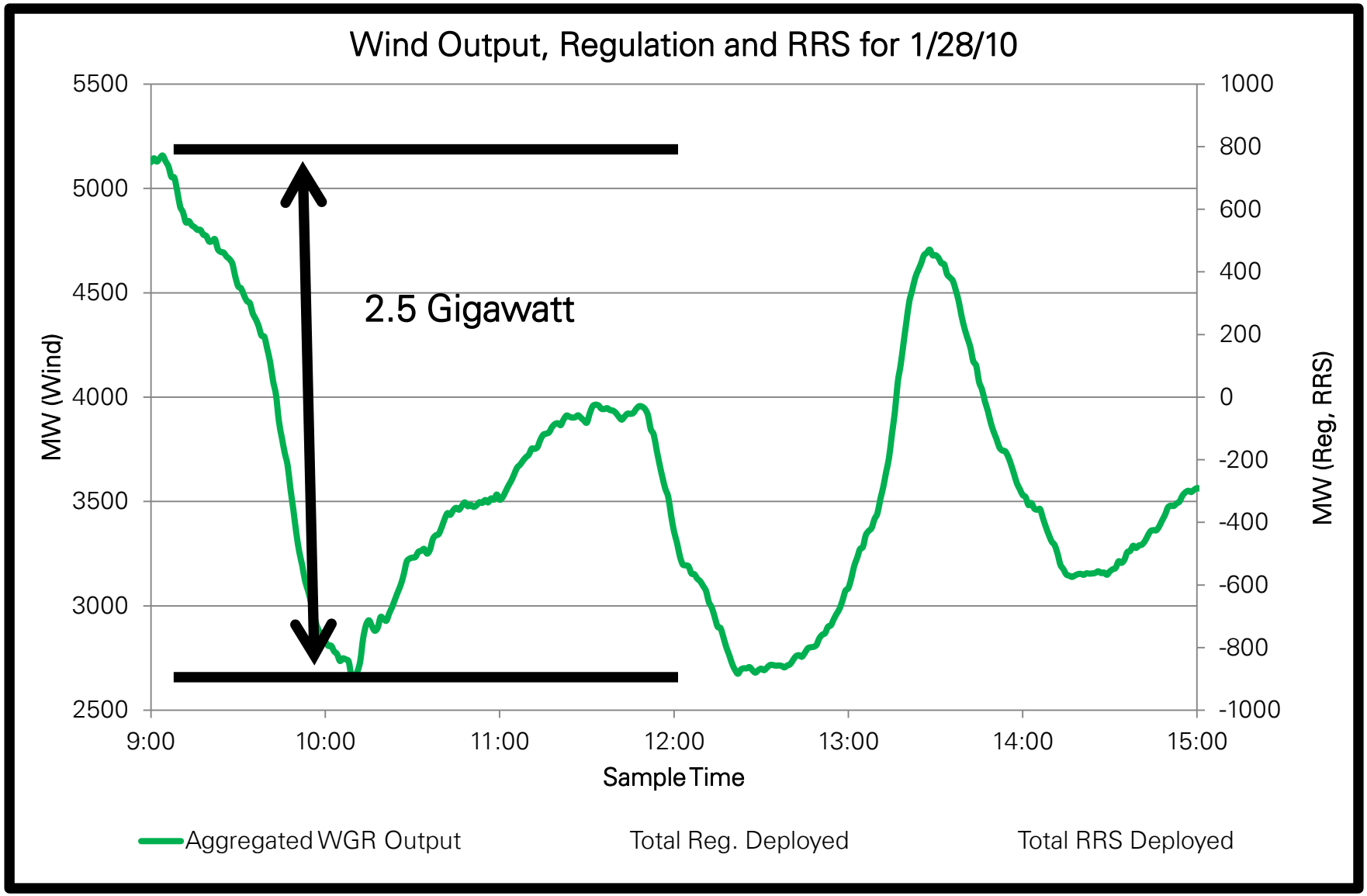
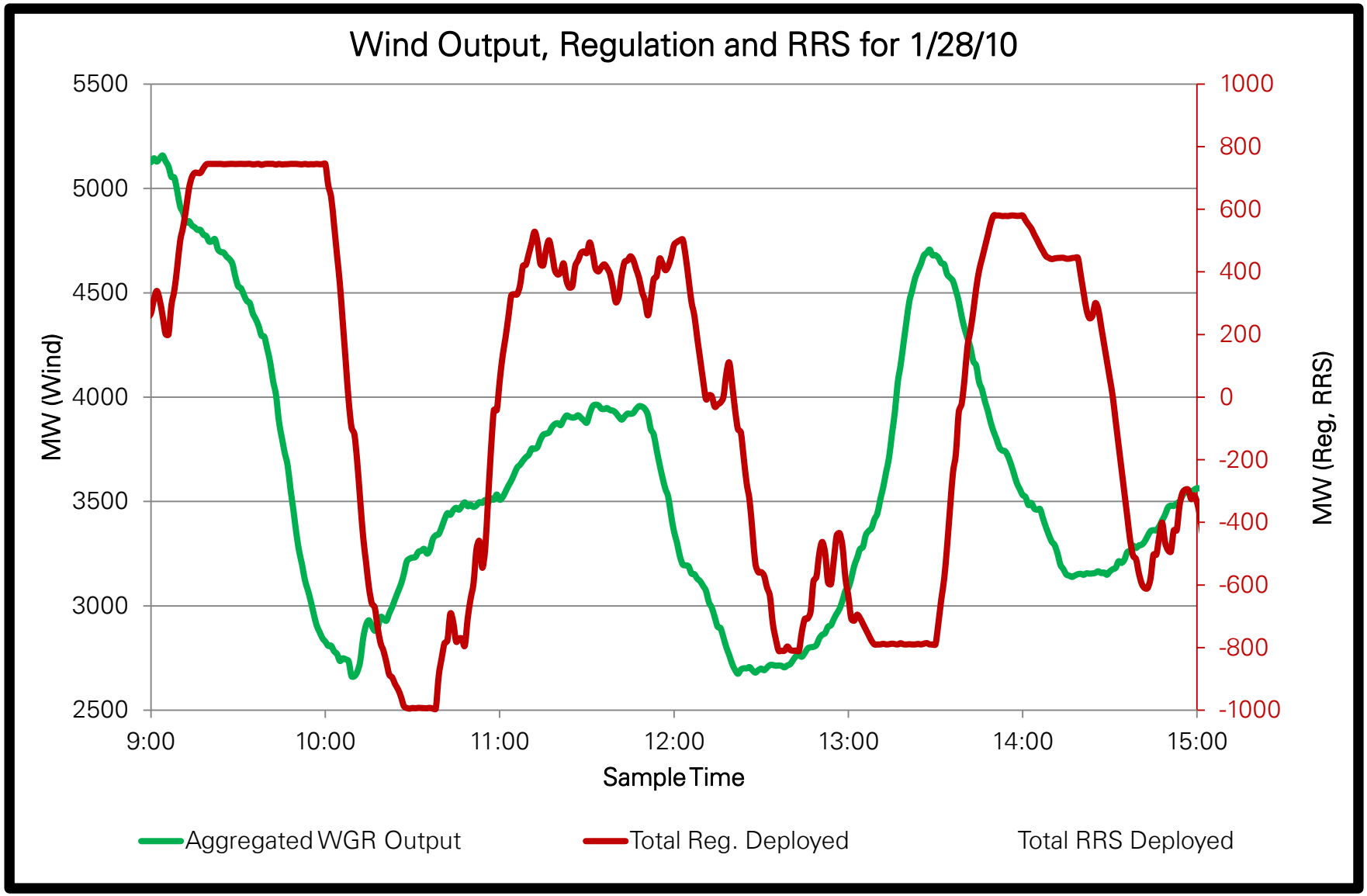
Intermittent Generation

West Texas Wind Farms (9 Gigawatt)


Wind Output, Regulation and RRS for 1/28/10
5500
5000
4500
4000
3500
3000
2500
MW (Wind)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
MW (Reg, RRS)
2.5 Gigawatt
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Sample Time
Aggregated WGR Output
Total Reg. Deployed
Total RRS Deployed

Regulation Service

- Capacity Reserved by the Grid Operator
- Under Automatic Generation Control
- Provides second by second Load following Capability (usually 800 – 1000 MW)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-600
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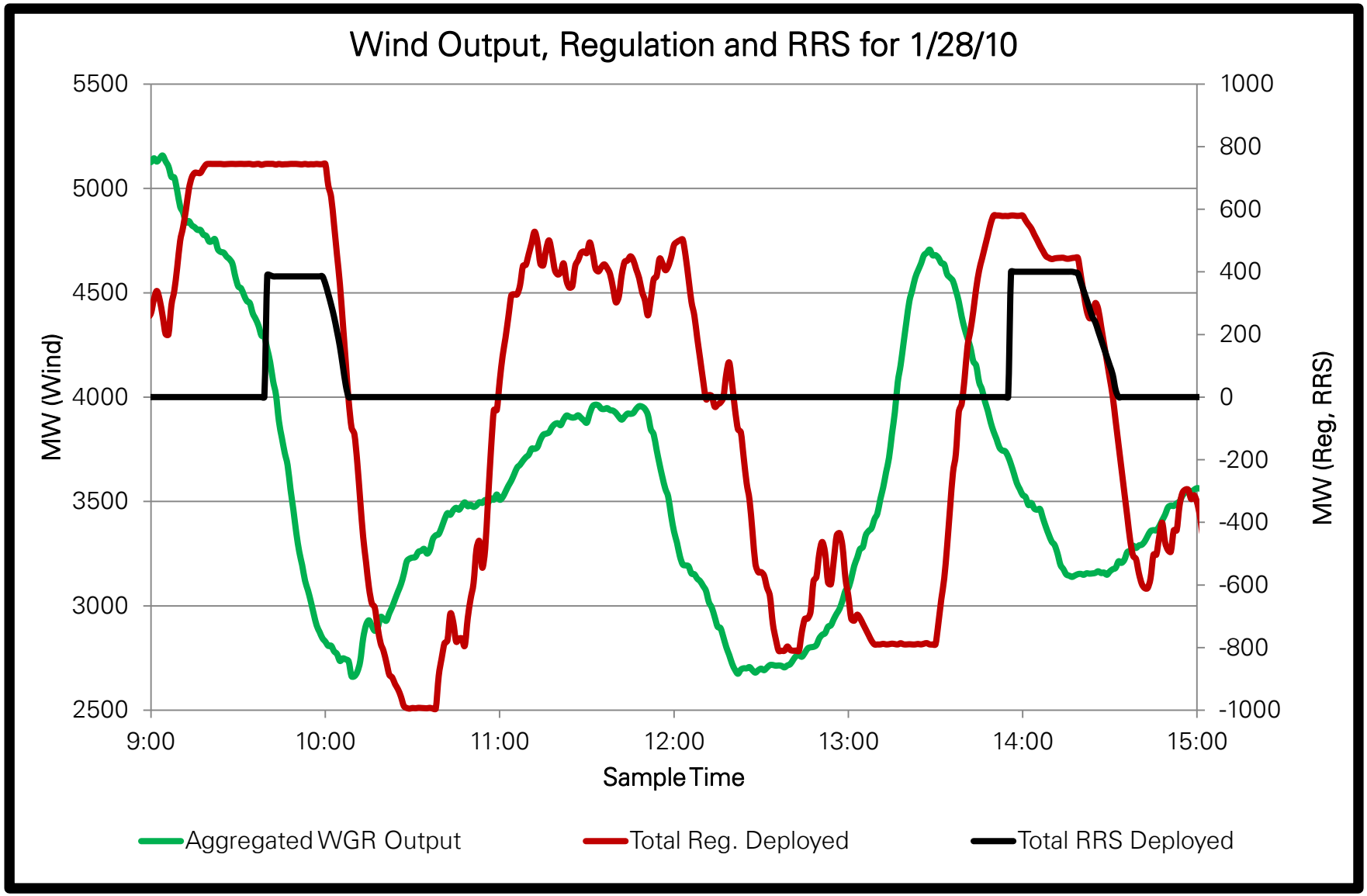
-1000
MW (Reg, RRS)
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Sample Time
Aggregated WGR Output
Total Reg. Deployed
Total RRS Deployed

Responsive Reserve Service

- Capacity Reserved by the Grid Operator
- Arrest Frequency Decay and/or provide a Short Term Replacement for Capacity Lost
- Loss of Capacity could be due to Unit Trips and other Unforeseen Events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5500
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MW (Reg, RRS)
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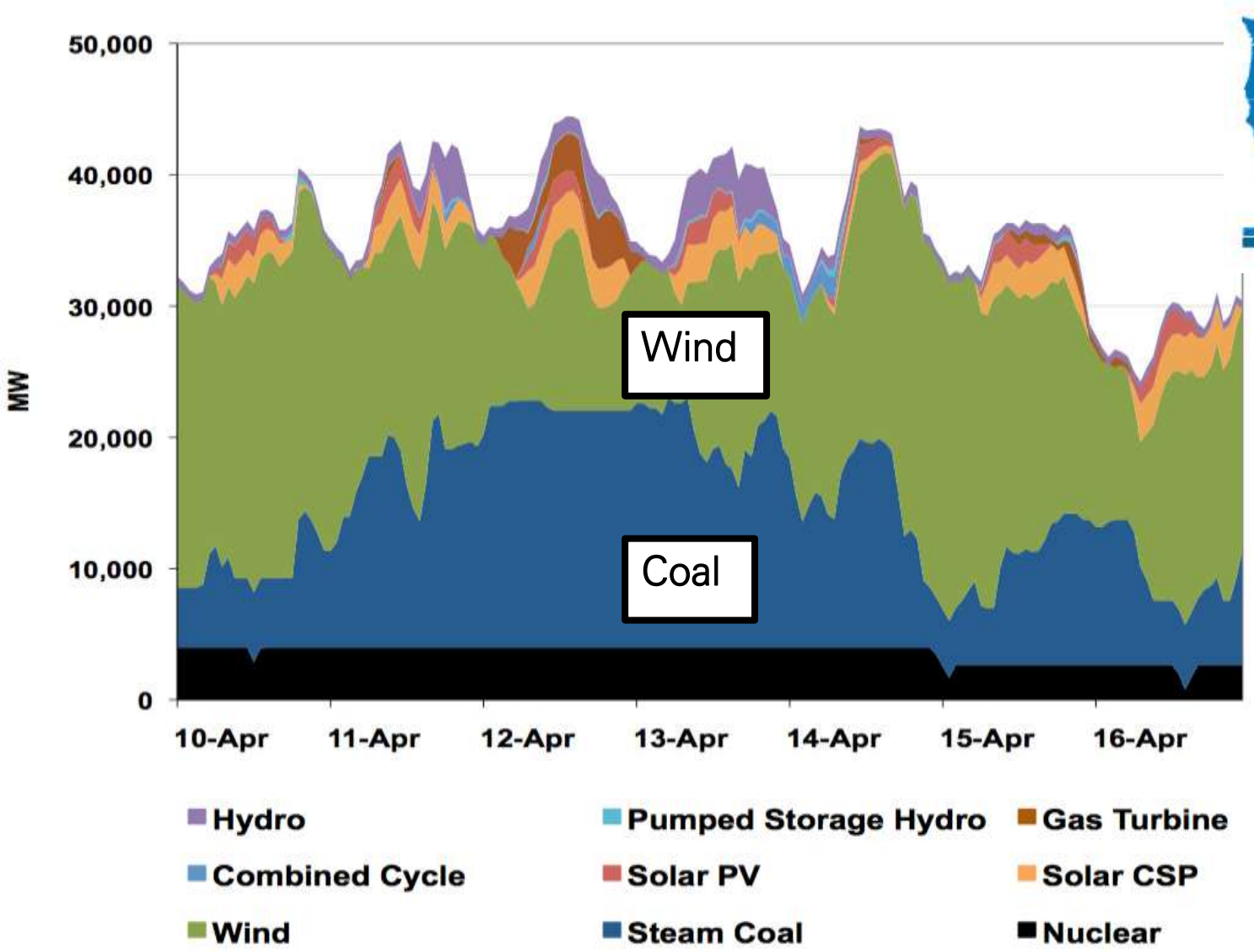


Western Electricity Coordinating Council

Due to Cycling of Coal Fired Plants

SO_2 NO_X CO_2

INCREASED !!

Smart Grid Instrumentation Requirements

- 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 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*
- Security
  - *NERC/CIP, SSL*

Converging instrumentation

Computers

- Processing Power
- Open Source
- I/O Expandable
- Programmable
- Software-Defined

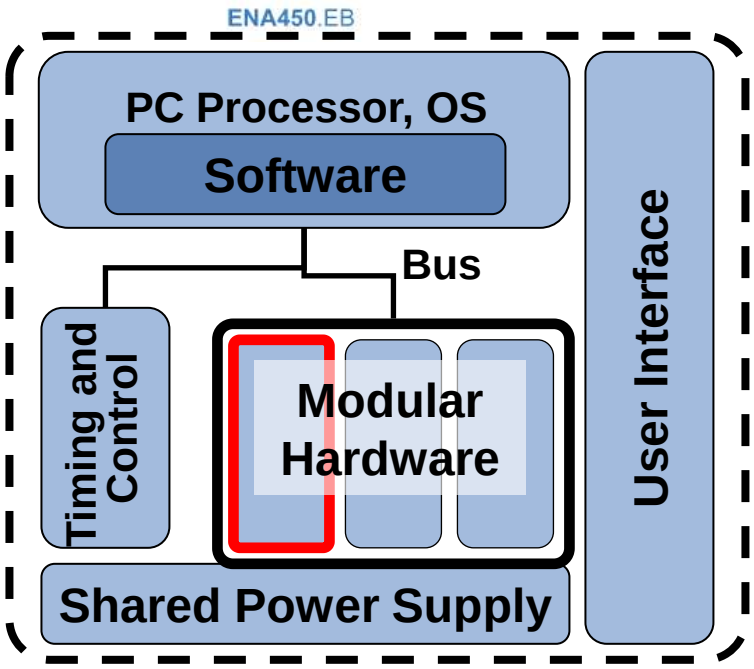
- Measurement Quality
- Embedded Processing Power
- Reliable and Robust
- Open source and Programmable
- I/O Expandable and Standards-Based
- Software-defined

T&D Instrumentation

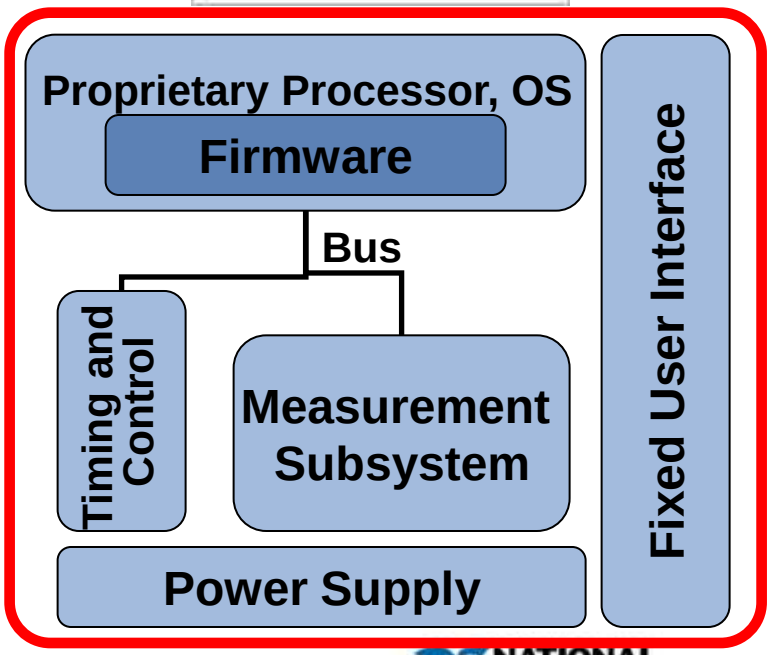
- Measurement Quality
- Embedded
- Reliable and Robust
- Standards-based
- Vendor-Defined

Converging instrumentation

Software defined Instrumentation



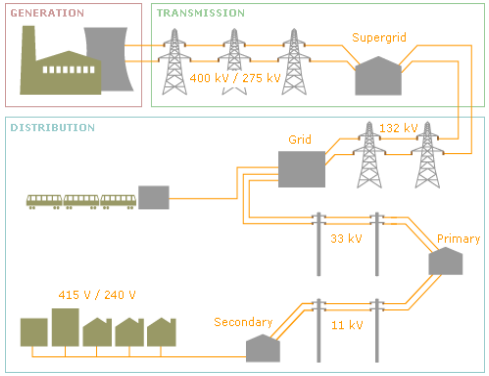
T&D Instrumentation



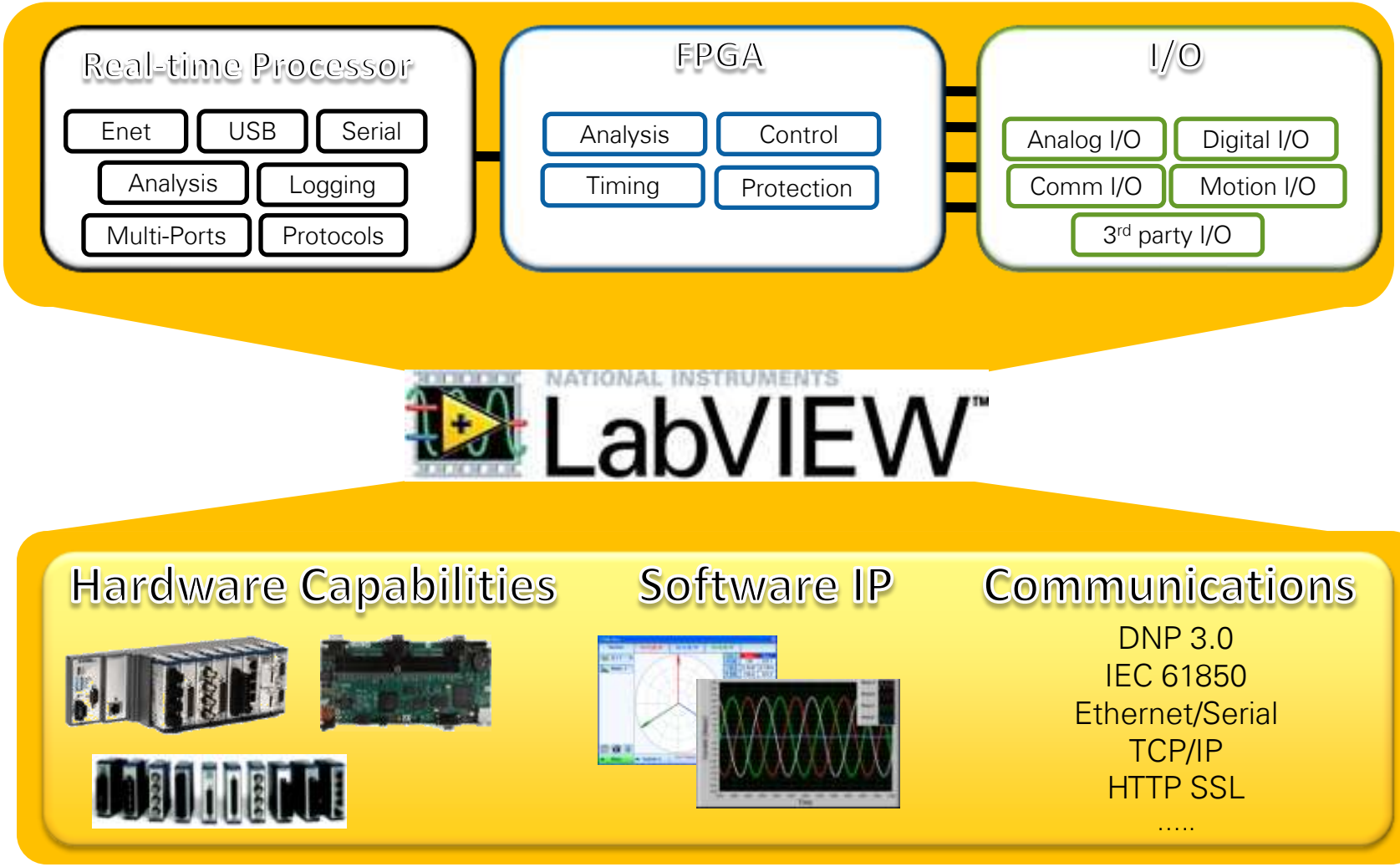
NI's Value Proposition

Convergence of technology into a single device

- Cost reduction
- High Performance
- Distributed Processing
- Small Footprint
- Flexible & Reconfigurable
- Scalable
- Easily upgraded
- User-defined functionality



NI compactRIO Platform

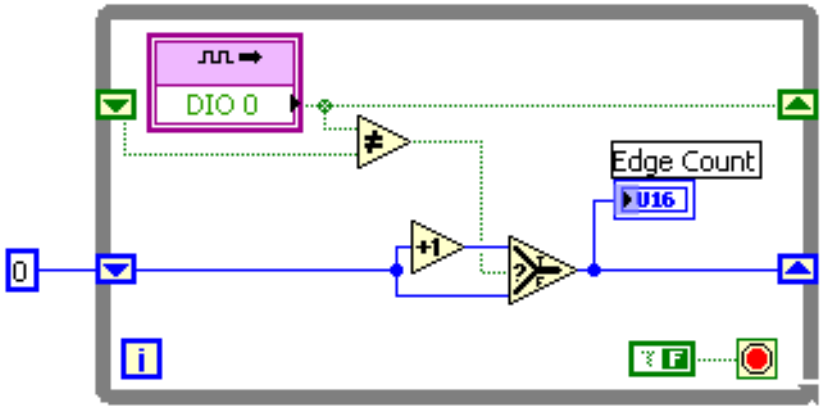


Productivity: LabVIEW FPGA Code Abstraction

Counter

Analog I/O

I/O with DMA



LabVIEW FPGA

```
-- First we sychronize the asynchronous digital input to our clock
-- by inserting two flip flops.
SynchronizationFFs:
process( aReset, Clk )
begin
  if aReset then
    cDigitalInput_ms <= false;
    cDigitalInput <= false;
  elsif rising_edge(Clk) then
    cDigitalInput_ms <= aDigitalInput;
    cDigitalInput <= cDigitalInput_ms;
  end if;
end process SynchronizationFFs;

-- Then we keep track of what the digital input was on the previous
-- clock cycle by inserting another flip flop
PreviousDigitalInputFF:
process( aReset, Clk )
begin
  if aReset then
    cPrevDigitalInput <= false;
  elsif rising_edge(Clk) then
    cPrevDigitalInput <= cDigitalInput;
  end if;
end process PreviousDigitalInputFF;

-- Then we have a little combinatorial logic to detect a rising edge
cRisingEdgeDetected <= cDigitalInput and not cPrevDigitalInput;

-- And finally we have a register that increments when that rising
-- edge is detected.
CounterRegister:
process( aReset, Clk )
begin
  if aReset then
    cCountReg <= (others=>'0');
  elsif rising_edge(Clk) then
    if cRisingEdgeDetected then
      cCountReg <= cCountReg + 1;
    end if;
  end if;
end process CounterRegister;
cCount <= cCountReg;

end rtl;
```

VHDL

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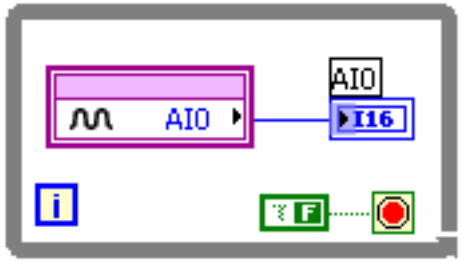
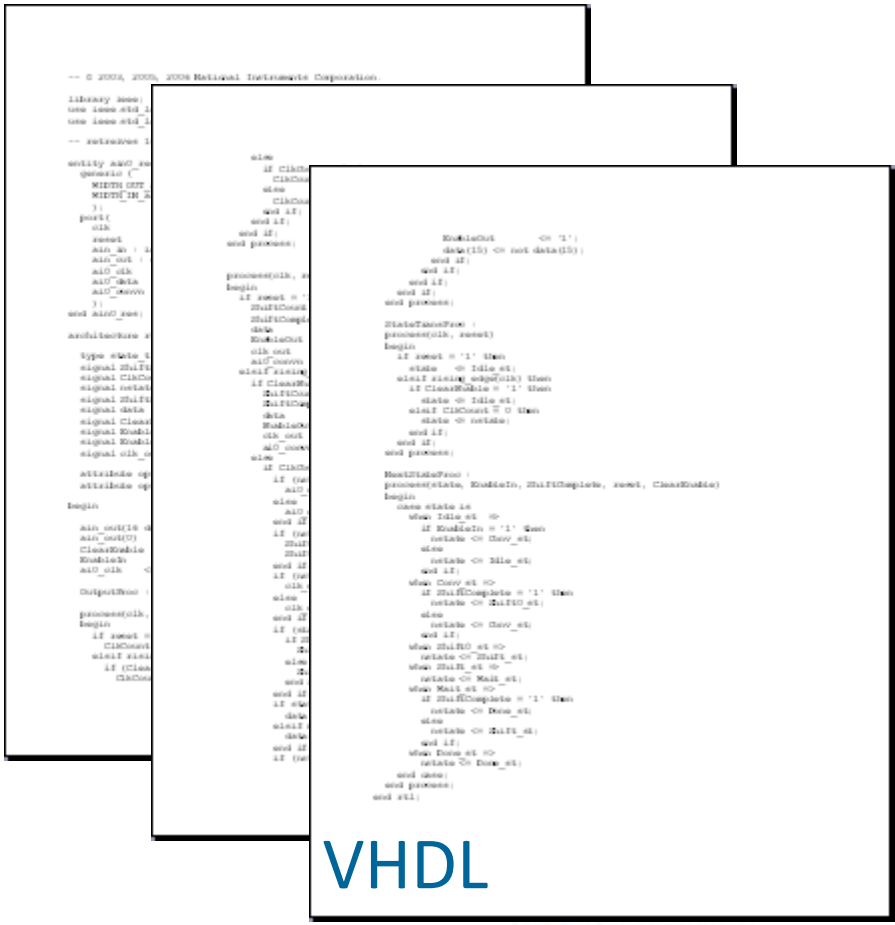
Productivity: LabVIEW FPGA Code Abstraction

Counter

Analog I/O

I/O with DMA





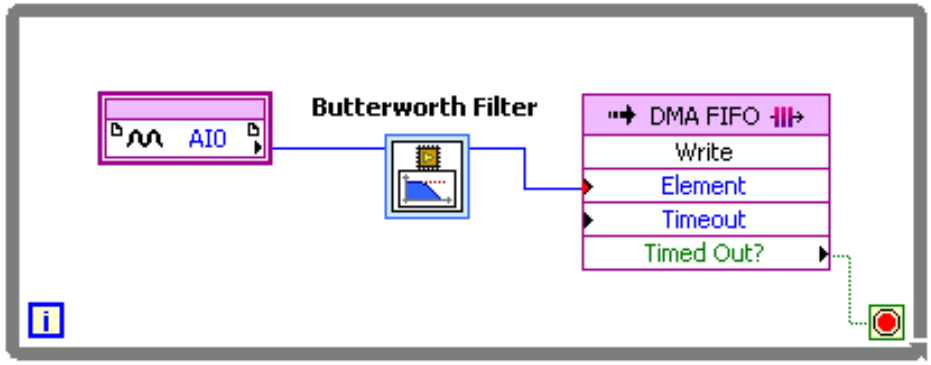
LabVIEW FPGA

VHDL

NATIONAL INSTRUMENTS

Productivity: LabVIEW FPGA Code Abstraction

Counter **Analog I/O** **I/O with DMA**



LabVIEW FPGA

VHDL ~4000 lines

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Precision and Accuracy: Hardware Based Timing and Analysis

High Accuracy

- Up to 24bit resolution
- NIST Traceable Calibration

High Speed

- Up to 1 MS/s/ch in C series
- Up to 12.5GS/s in other form-factors

Timing and Synchronization

- GPS, IRIG, 1588 support
- 1nS resolution timekeeper on FPGA

Quality and Ruggedness

Confidence to build reliable and rugged systems that last

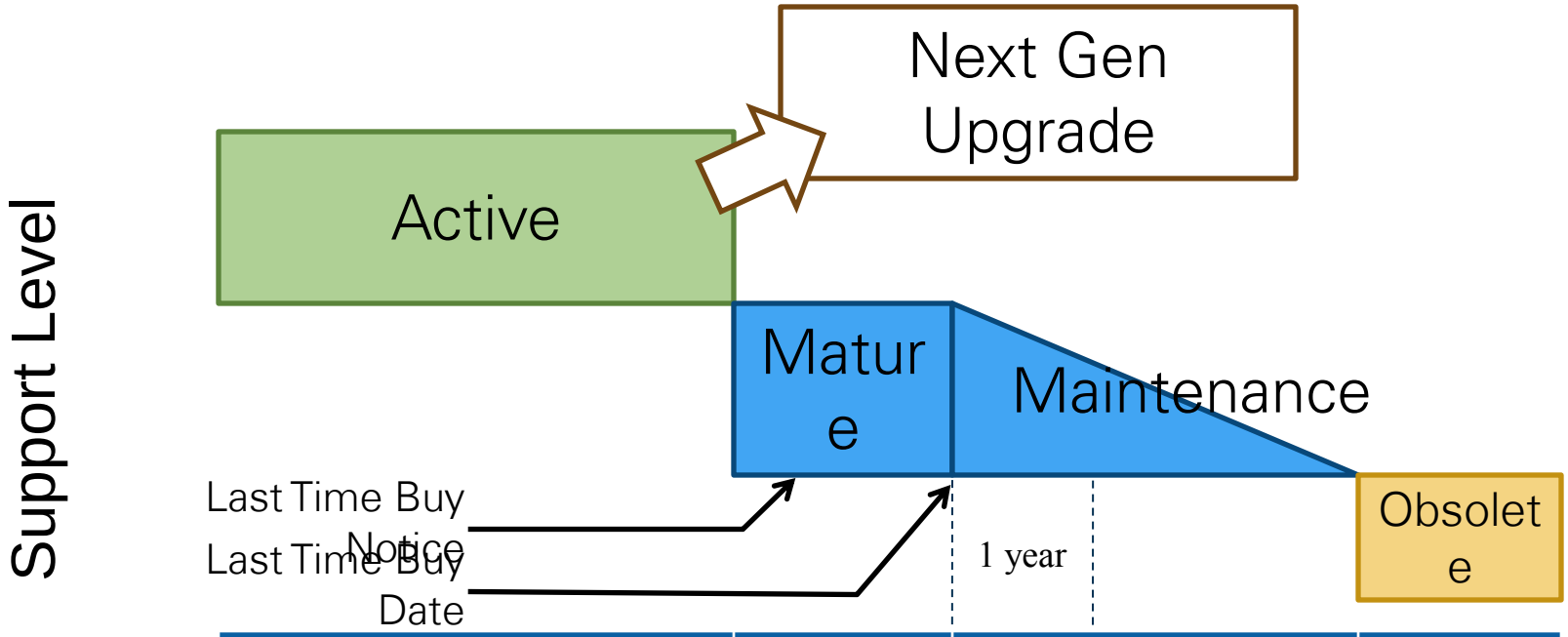
NI stringently builds and tests embedded hardware and software to ensure you can deploy reliable systems that last. NI RIO hardware can survive in the harshest of environments.

- **Hidden Costs of Embedded Design**–Small design teams eliminate the need to spend time and money certifying and maintaining their product over its lifetime by leveraging high-quality, off-the-shelf tools from National Instruments.
- **Electrical Quality**–Through stringent testing and certification, NI ensures that products meet the highest standards of electrical design with high-quality PCBs and components.
- **Mechanical Ruggedness**–NI embedded systems and PACs provide packaged and board level solutions with fanless cooling that can handle extreme temperatures (-40 degC to 85 degC) and vibrations (50G shock, 5G vibration).
- **Software Stability**–LabVIEW meets the strict stability requirements of mission-critical applications

SRL cRIO Testing

- 40 systems
  - 32 systems at room temperature and 8 systems in temperature chamber (cycles between -40 and 70°C three times per day)
  - 8 systems running on dirty power
- 4 unique cRIO applications written for RT and FPGA (10 systems for each)
- 24/7 execution during mission
  - We run one or two missions per year
  - Mission time ranges from 3 to 12 months

Longevity: Standard Hardware Life Cycle



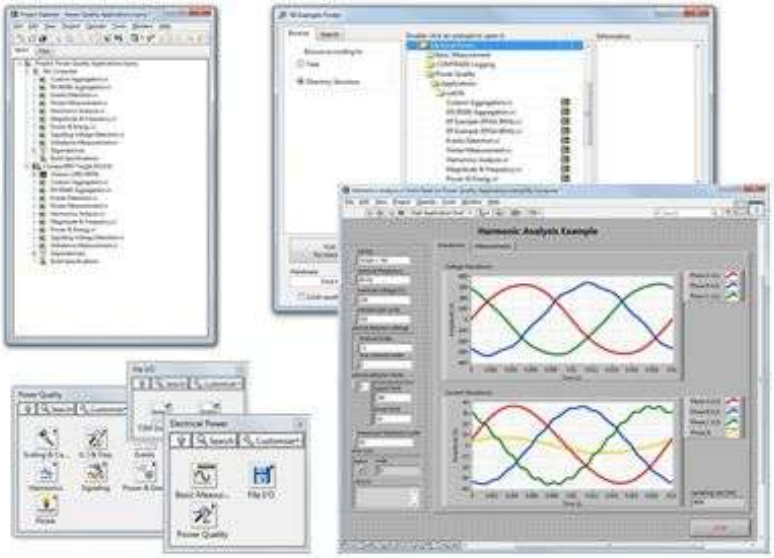
	Active	Mature	Maintenance		Obsolete
Buy new products	Yes	Yes	No	No	No
Repair services	Yes	Yes	Yes	Yes	No
Calibration services	Yes	Yes	Yes	Yes	No
Service Agreements	Yes	Yes	Yes	Yes	No

Longevity: NI Partner Advantage

Processor	• Intel, Freescale, Wind River • Multi-core and real-time technology
Bus	• PCI/PCIe, Enet, USB, wireless, deterministic Enet • Open architecture
FPGA	• Xilinx Virtex & Spartan • Reconfigurable hardware
IP	• Control & signal processing IP & I/O drivers • Built-in graphical IP, integrate existing IP
I/O	• Analog Devices, Texas Instruments • Connect to any sensor & actuator

2012-2013 Energy Products

Electrical Power Suite - Software



- Electrical Power Suite 1.0 – Released
  - *Measure power quality and energy features to IEC, EN, and IEEE standards*
  - *Harmonics (IEC 61000-4-7)*
  - *Flicker (IEC 61000-4-15)*
  - *Sag/sell/interruption with standard or custom levels (IEC 61000-4-30)*
  - *Rapid voltage change with standard or custom levels (IEC 61000-4-30)*
  - *Compatibility with the COMTRADE (IEEE 37.111) file format*

Electrical Power Measurement Suite

Voltage and Current	Power and Energy	Power Quality
Three Phase RMS (V and I)	Power per Phase	Voltage Sag (dip)
THD	Three Phase or Total	Voltage Swell
Harmonic (up to 64th)	Once per sec and once per cycle	Impulsive Transient (V + I)
Interharmonics (0.5 to 63.5th)	Power Factor	Oscillatory Transient (V + I)
Voltage Unbalance	Active Power Total	Overvoltage and under voltage
Frequency Oscillation	Active Power Harmonic	Overcurrent
Flicker	Apparent Power Total	Phasor Imbalance
DC Portion	Apparent Power Harmonic	Three Phase Voltage Harmonic
	Reactive Power	Four Current Harmonic
	Reactive Power Harmonic	Harmonic per sec and per cycle
	Energy Active Total	Synchrophasor IEEE-C37.118
	Energy Apparent Total and +/-	
	Energy Reactive Total and L/C	

Electrical Power Measurement Suite

Voltage and Current	Power and Energy	Power Quality
Three Pha	Power per Phase	Voltage Sag (dip)
THD		
Harmonic		+ I)
Interharm		+ I)
Voltage U		voltage
Frequenc		
Flicker		
DC Portio		armonic
		per cycle
		37.118
Energy Reactive Total and L/C		

- **Power Quality**
  - *IEC 61000-4-7 (harmonics)*
  - *IEC 61000-4-15 (flicker)*
  - *IEC 61000-4-30 (Event Measurement Class A)*
  - *EN 50160 (Data Aggregation)*
- **PMU**
  - *IEEE C 37.118*
- **File Format**
  - *COMTRADE IEEE C37.111*

EPS 2013 Additions

- Protection Features
  - *Fundamental Protection Features*
    - *Fundamental magnitude and phase*
    - *Definite time delay*
    - *Trip Logic*
  - *Fundamental Devices Support*
    - *27, Under voltage*
    - *50, Instantaneous Overcurrent*
    - *51, Inverse Time Overcurrent Support*
    - *59, Overvoltage Relay Support*
    - *79, Reclose Logic*
- PMU 2011 Support, Class M (C37.118-2011)

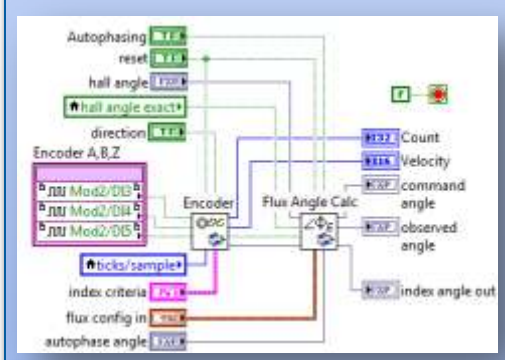
Communication Protocol Support

- NI DNP3 Toolkit
  - *Level 2 (Certified)*
  - *Level 3*
- NI IEC 61850 Toolkit
  - *MMS*
  - *GOOSE*
  - *SMV*
- IEC 60870-5 Toolkit
  - *101*
  - *102*
  - *103*
  - *104*

NI Single-Board RIO 960x

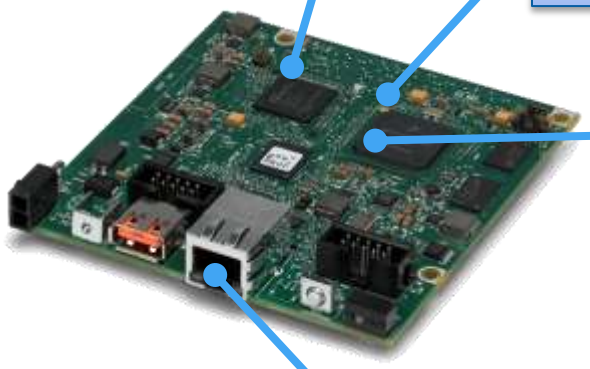
LabVIEW Tool Chain

- *Rapid commercialization of differentiated, high performance products*
- *Complete, industry proven graphical system design tools*
- *Available IP block libraries and reference design examples*
- *Fully integrated support for processor, FPGA , I/O and networking in single language*
- *Integrate existing C, VHDL, simulation or text-based math code*



Reconfigurable FPGA
Silicon level re-configurability, lifetime upgradability, true parallel execution in dedicated hardware

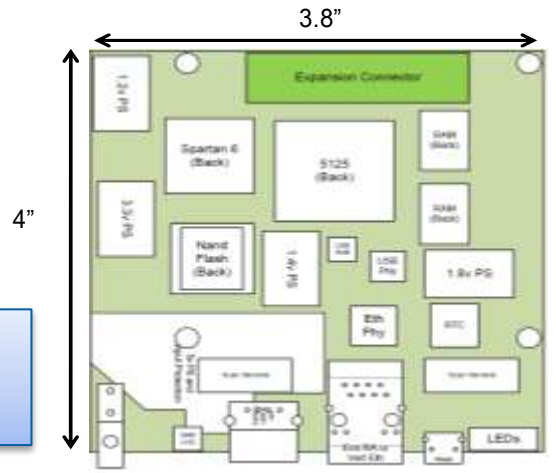
RIO Mezzanine Connector (RMC)
High density, high bandwidth connector gives direct access to FPGA and processor I/O



Real-Time Processor
400 MHz PowerPC for floating-point control, analysis, logging and network communication

Networking Peripherals
Ethernet, RS-232, CAN, USB
Modbus, DNP3, HTTPS and SSL support

Small Size, Low Power
10.3 x 9.6 cm (4 x 3.8 in.)
9-30 VDC power



ni.com/singleboard

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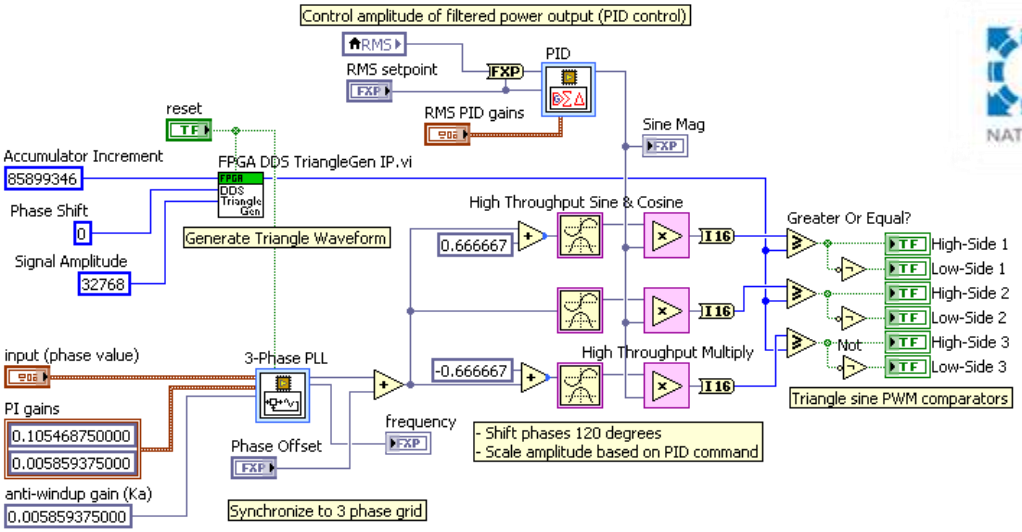
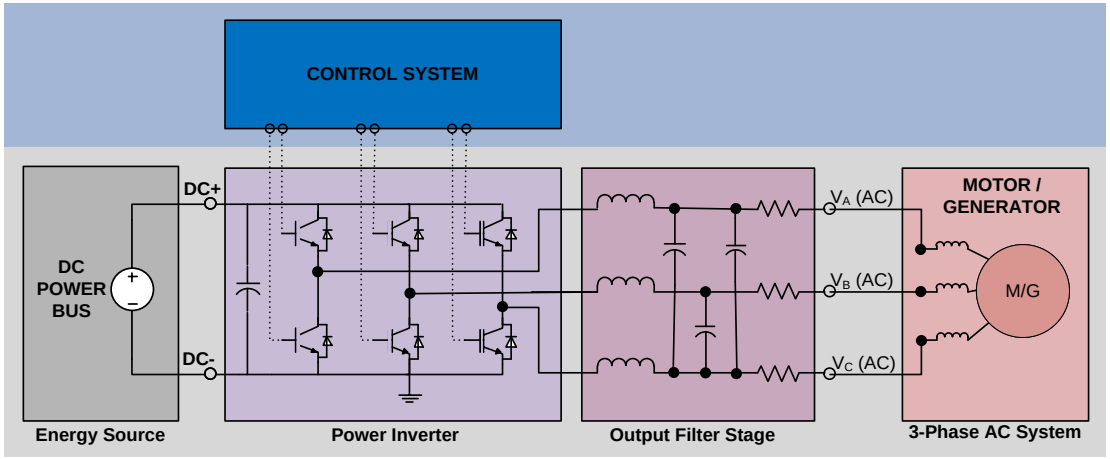
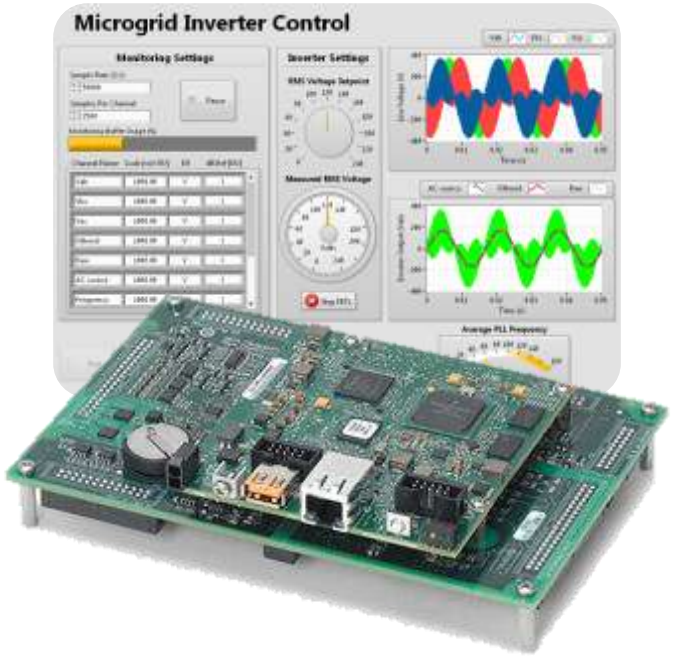
NI Single-Board RIO General Purpose Inverter Controller







cRIO Enclosures

NI Advanced Phasor Measurement Unit

- Multichannel Synchrophasors
  - Expandable up to 32 channels (Voltage and Current)
  - Data/Message rates up to 240 /sec
  - IEEE C37.118
  - Stand-alone or control capable
  - Built-in or external GPS (IRIG-B)
- Remote Firmware Upgrade
  - HTTPS using SSL
- Advanced Features
  - Hybrid: PMU and Power Quality algorithms in one unit
  - Flexible open software architecture
  - Logging and event recording
    - Up to 833/1000 Samples/cycle
    - 24-bits ADC with Filtering Capabilities
    - Multi-Protocol TCP/IP, DNP3, Modbus
  - Dual-Ethernet, Serial Ports and Digital Communication
  - Built-in and expandable storage capabilities
  - Rugged Design (-40 to 70 C)

NI SmartGrid Analyzer ™

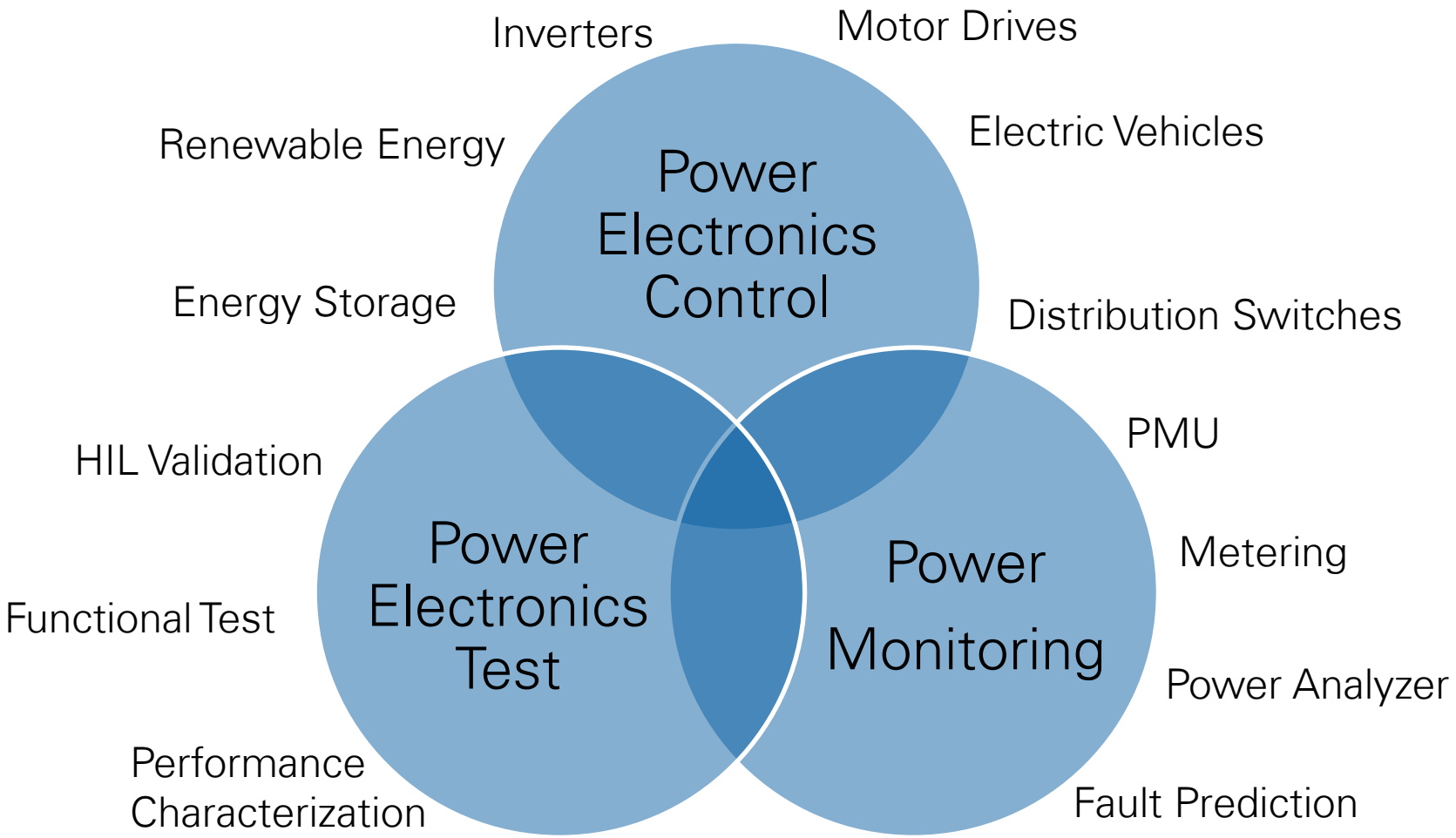
Applications

- *Power Quality Analyzer – IEC 61000*
- *Flicker Meter - EN 50160 / IEC 61000-5-15*
- *PMU – IEEE C37.118 (optional)*
- *Transient Analysis – 512 S/cycle*
- *Energy Metering and Power Flow Monitoring*
- *Control , Alarming, and Recording*

Features

- *Reconfigurable Real-Time Processor*
- *Multi-port & multi-protocol communication*
- *DNP3.0, Modbus RTU, and IEC Protocols*
- *GPS 1us time stamp resolution (optional)*
- *24 bits resolution*
- *4GB Storage built-in*

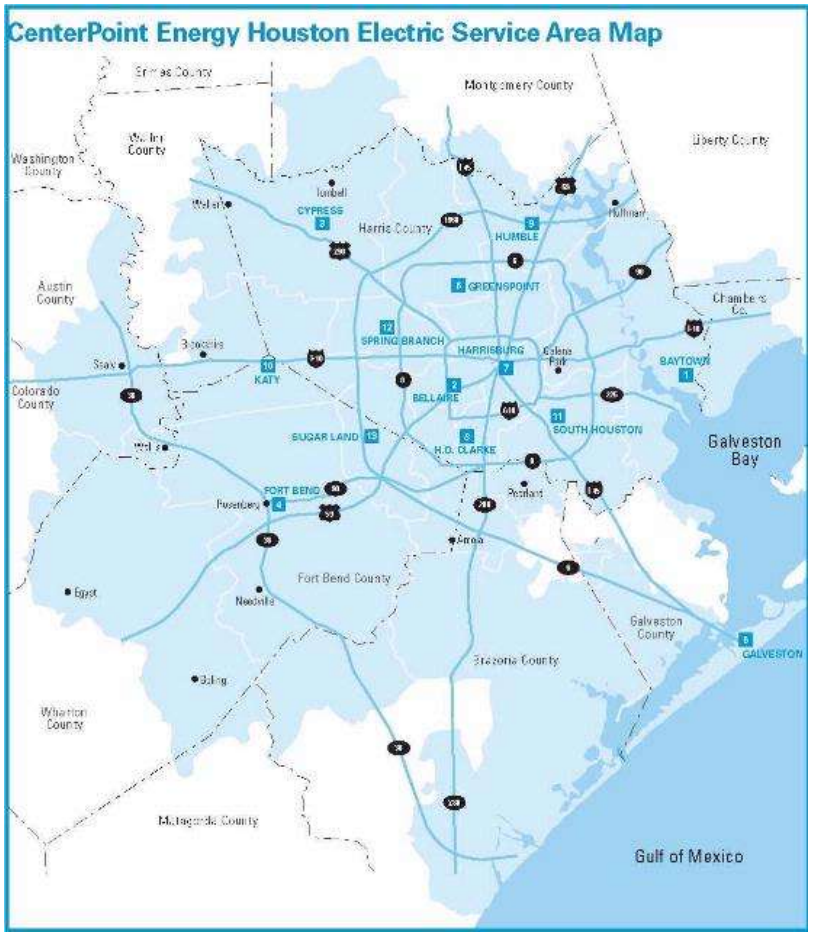
NI Role in Power Electronics



CenterPoint Energy

Houston, Texas

4th Largest City in the U.S.



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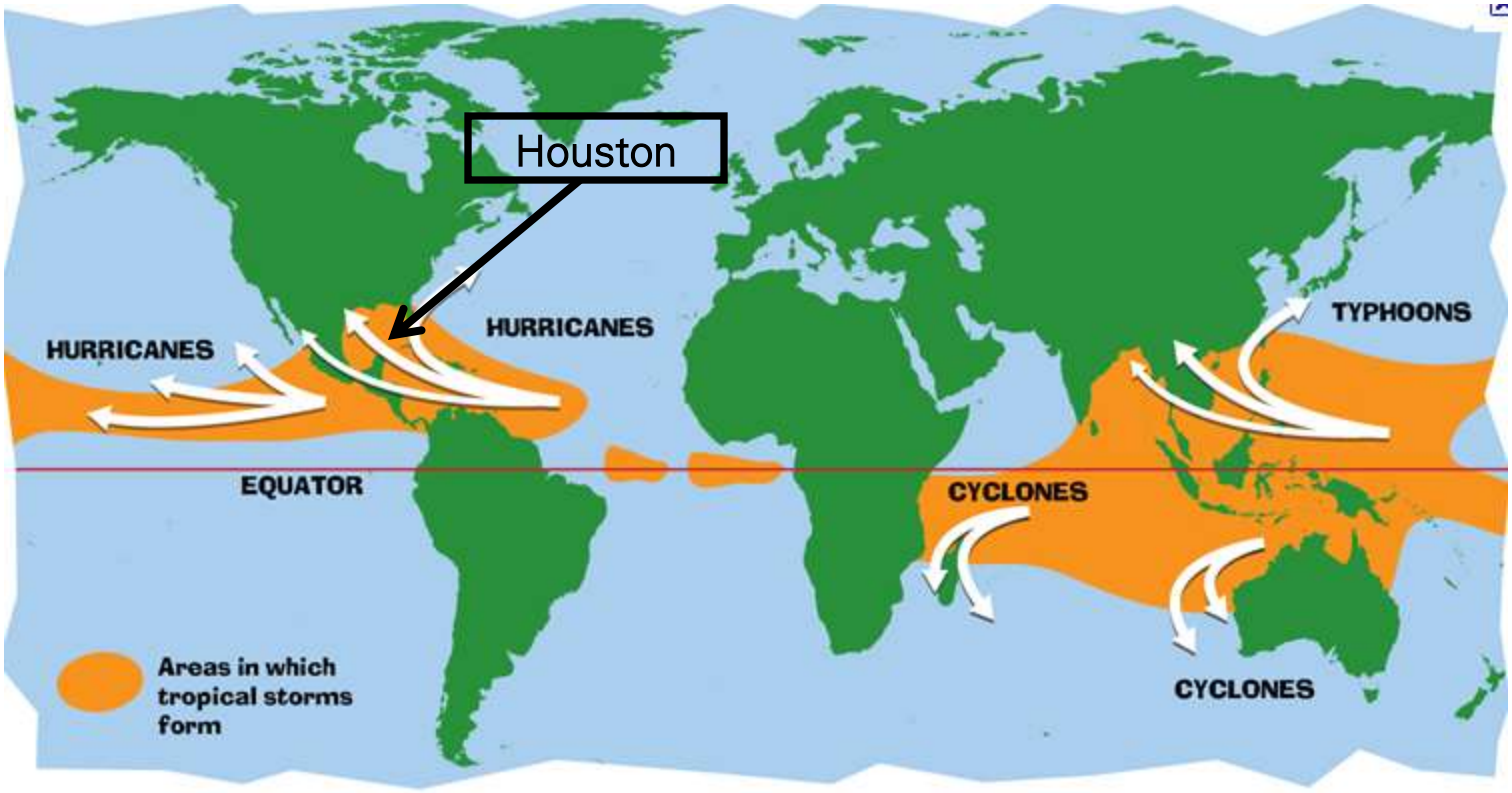
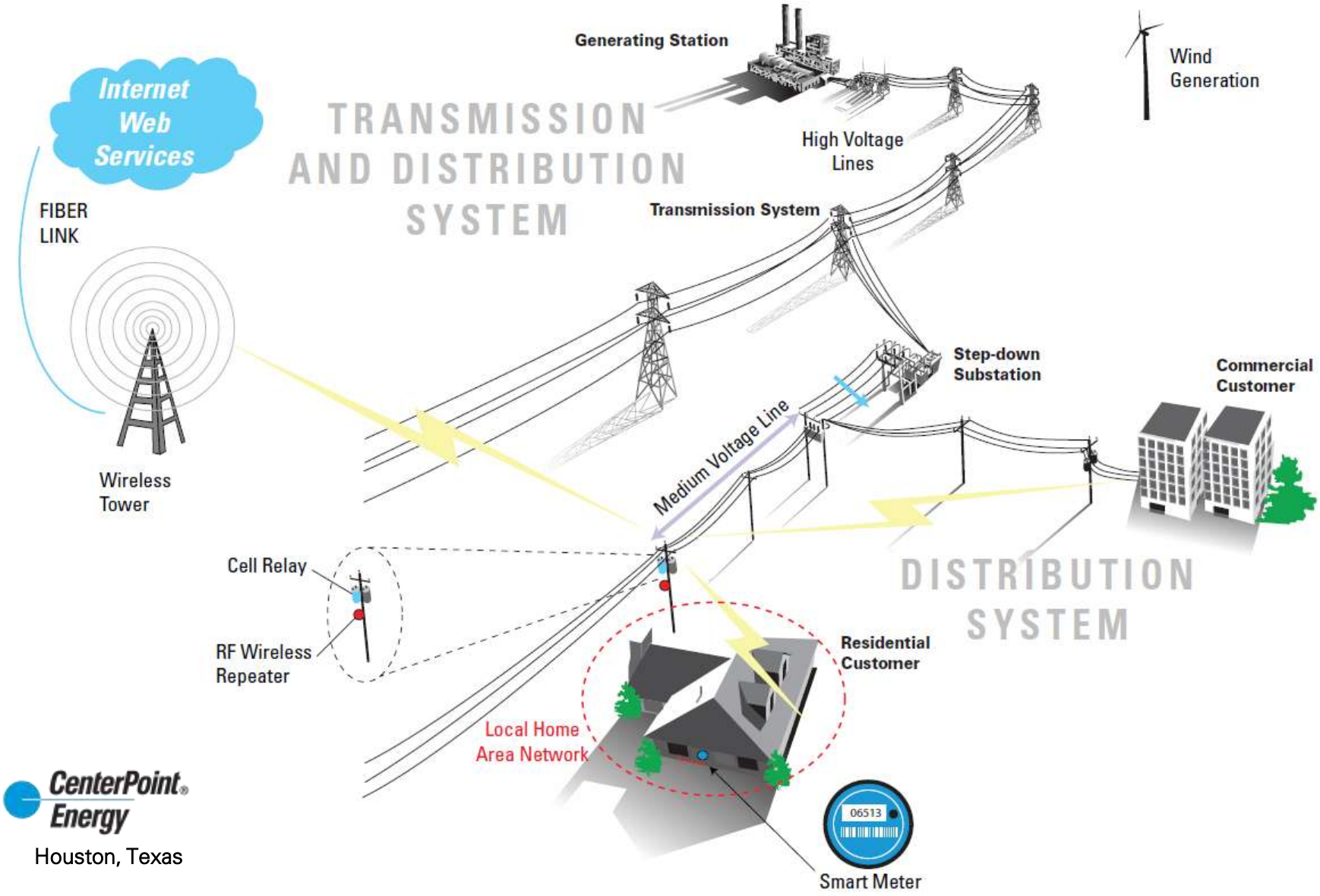
Houston is Located in "Hurricane Alley"

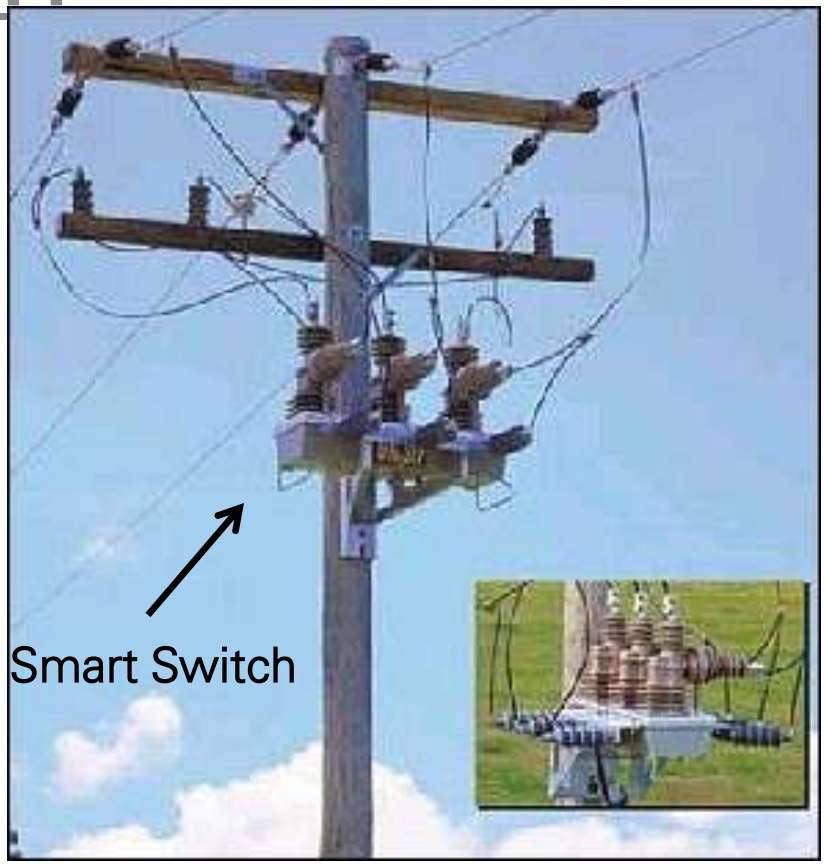



Internet
Web
Services
FIBER
LINK
TRANSMISSION
AND DISTRIBUTION
SYSTEM
Generating Station
Wind
Generation
High Voltage
Lines
Transmission System
Step-down
Substation
Commercial
Customer
Wireless
Tower
Medium Voltage Line
Cell Relay
RF Wireless
Repeater
DISTRIBUTION
SYSTEM
Residential
Customer
Local Home
Area Network
06513
Smart Meter
CenterPoint
Energy
Houston, Texas

CenterPoint Smart Switch

Reliability and System Efficiency

Distributed Sensing
Self Healing
Distribution Automation
Fault Location / Anticipation



SIEMENS

- NI-SGA brings advanced capabilities to Siemens SDR enclosure controller
  - *Analytics + Switch Functionality*
  - *With optional future upgrades*

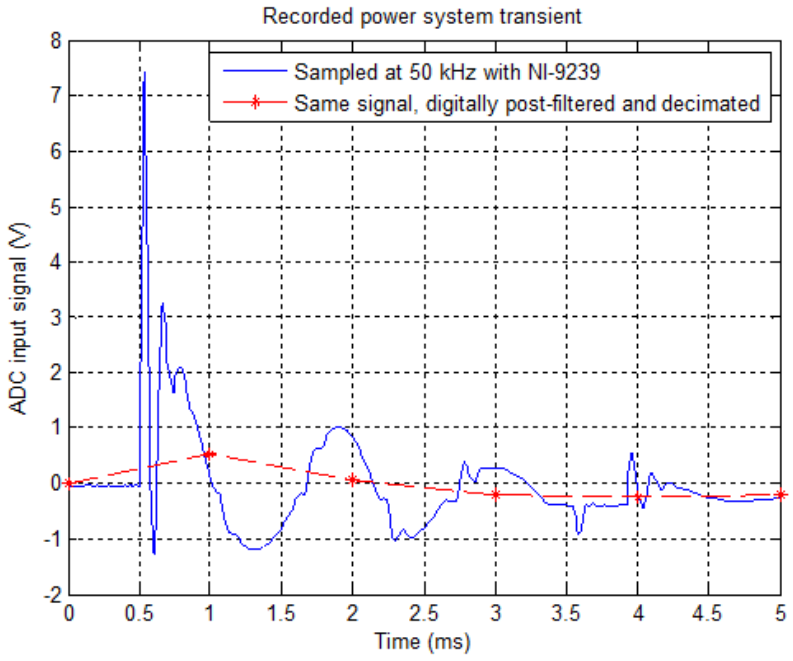
E.On and DLAB – Ground Fault Detector

- Jan 8th-9th 2005 the hurricane Gudrun struck south of Sweden
- 9 people were killed
- 730,000 people lost electricity
  - 350,000 got it back within a day
  - 160,000 without electricity for 3 days
  - 82,000 for a week
  - The remaining had to wait for several weeks
- 75 million cubic meters of timber
- Estimated cost of 2,3 Billion Euros

Ground fault detector

- Detect short circuits
  - Water coming through the isolation
  - Destroying the isolation barrier little by little

  Ground Fault Detector



Putrajaya - Malaysia

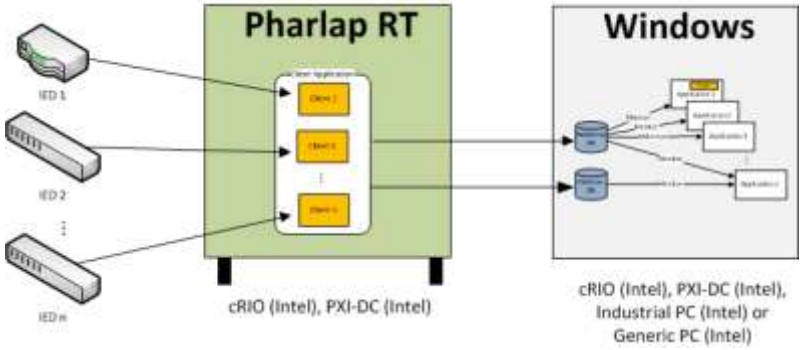
61850 DATA CONCENTRATOR FOR SUBSTATION AUTOMATION

Who is Tenaga Nasional?

- Early Predecessor, Central Electricity Board founded in 1949
- Manages & operates the National Grid, a comprehensive transmission network that is also interconnected to Thailand & Singapore
- Largest Utility in Malaysia
  - *12,000 MW Installed*
  - *28,000 Employees*
  - *7 Million Customers*
- Businesses
  - *Core Activities: Generation, Transmission & Distribution*
  - *Other diversified activities: Manufacturing of transformers, high-voltage switchgears & cables*

61850 Concentrator

- Development of transmission substation automation system based on IEC 61850
- High performance, expandable platform
  - *Memory and disk space can be added as needed*
  - *FPGA and I/O can be added as needed*
- Reliability (two independent boxes)



Distribution Monitoring

NexGEN

Rajasthan is situated in the North Western part of India

Area of 342,214 sq. km

District - 32

Population - 56 million

Total no of consumers – 6,701,017

Domestic consumers – 4,894,726

33kV lines (kms) – 31,560

Temperature various from -5°C to 45°C

Rajasthan Utility

NATIONAL INSTRUMENTS

Distribution Monitoring

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Domestic consumers – 4,894,726

33kV lines (kms) – 31,560

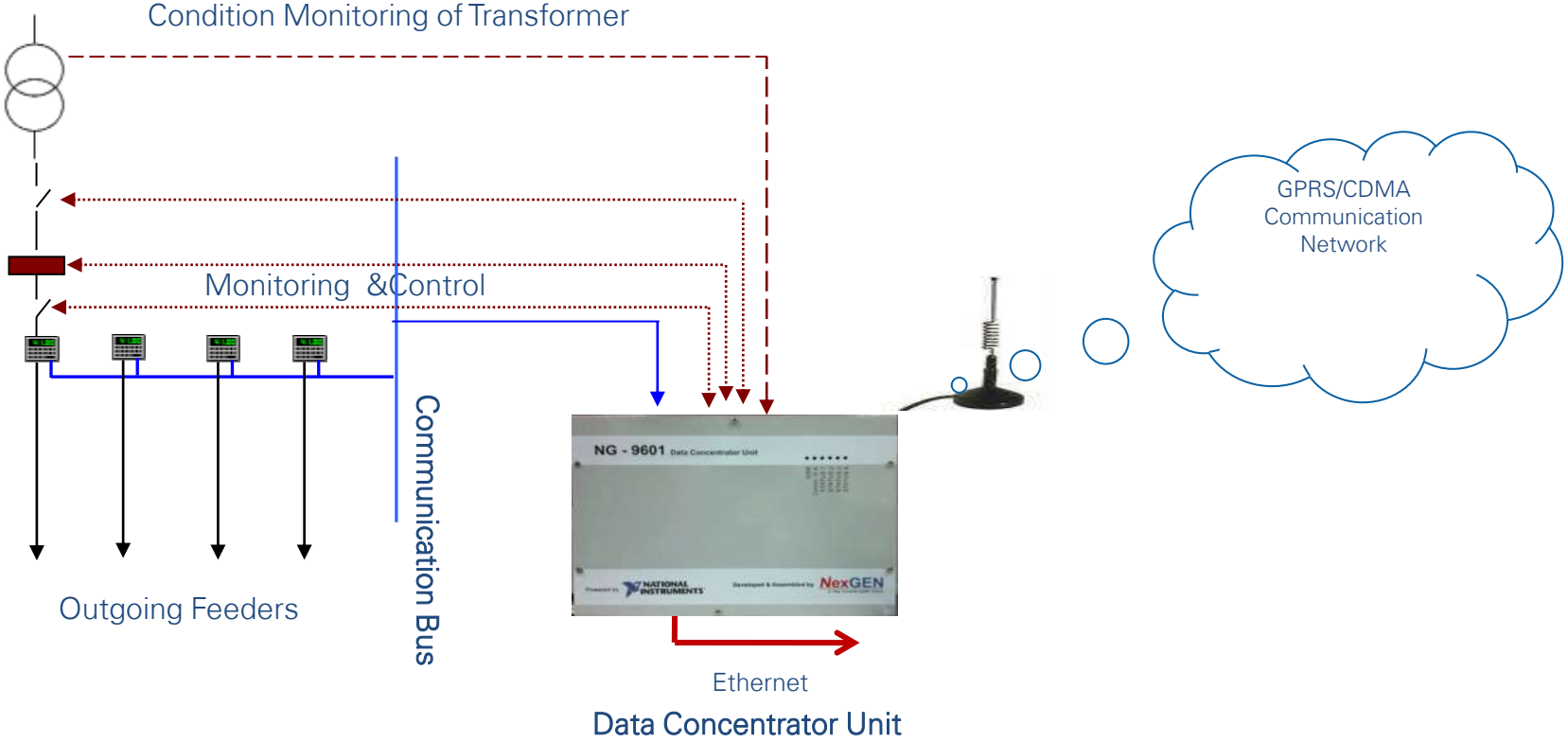
Temperature various from -5°C to 45°C

Number or RTUs: 2820

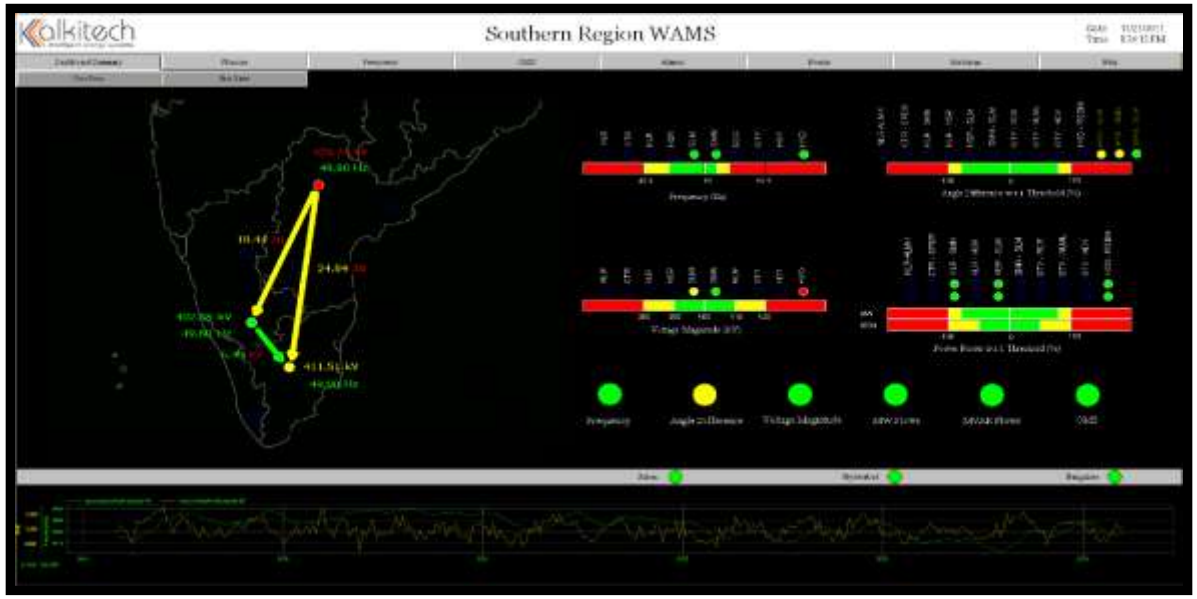
Rajasthan Utility

NATIONAL INSTRUMENTS

Data Concentrator Unit: Monitoring & Control



Application Area - Power - Transmission Line Monitoring

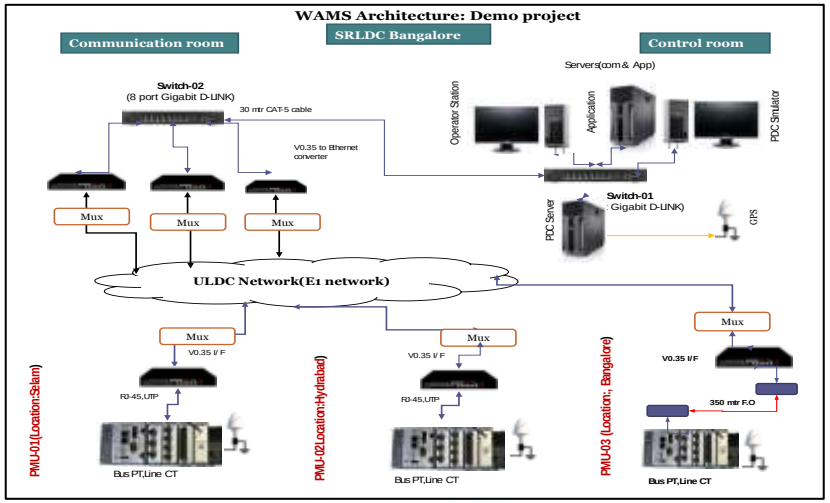


Kalkitech intelligent energy systems

Project Size

- *700+*

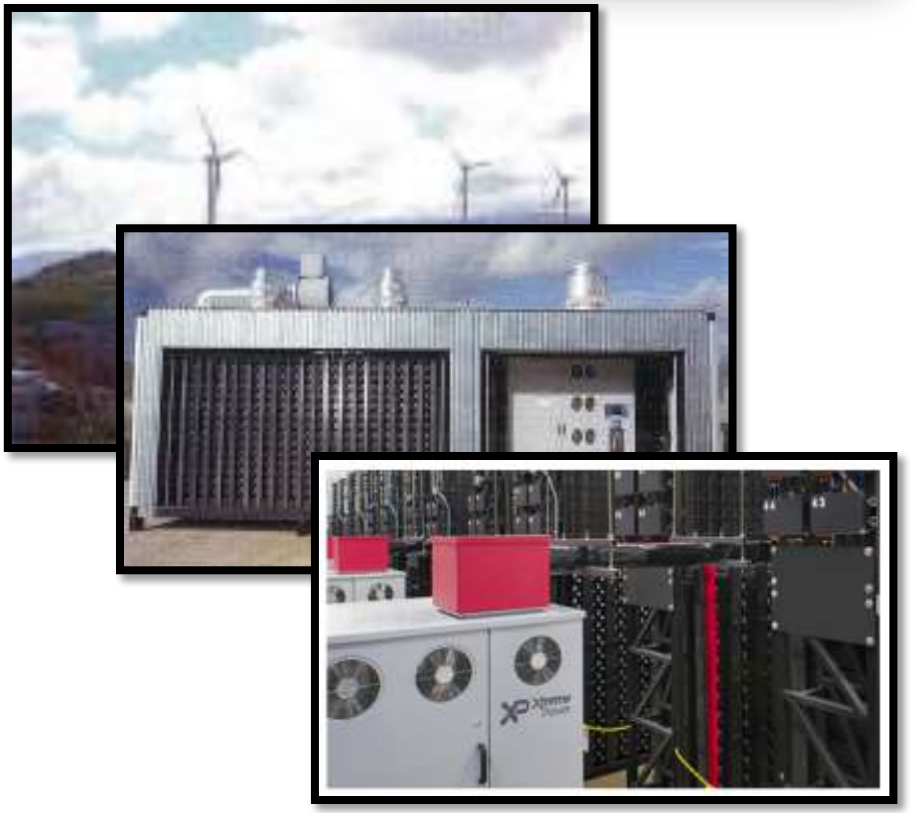
- Application:
  - *PMUs for wide area monitoring, real-time dynamic system information, planning and operation.*
- Key Differentiator:
  - *Build-in GPS, Protocols Support*

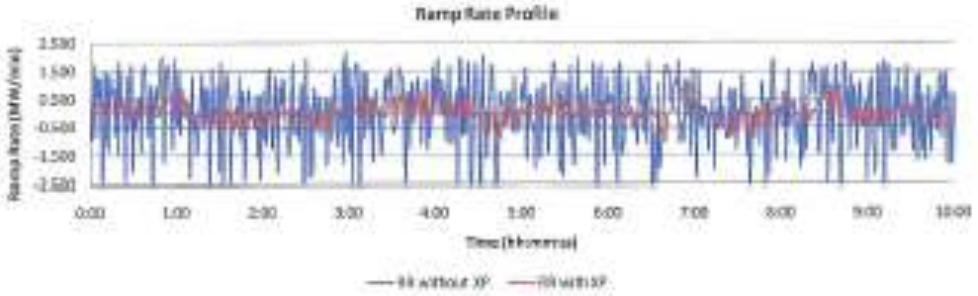


Energy Storage

Grid-tied Megawatt Storage for Wind Energy

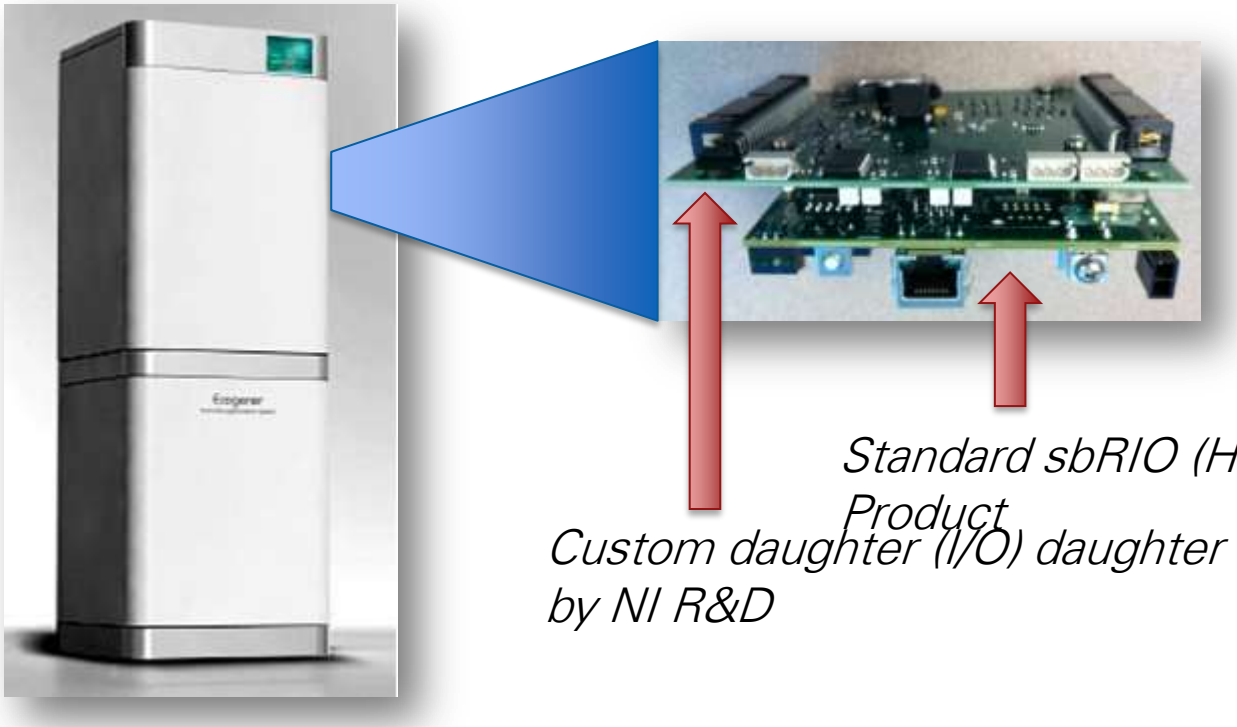
- First full utility-scale deployment in 2009
  - 1.0 MWh storage coupled with 30 MW wind farm on a 80-200 MW grid
- Energy storage platform capable of:
  - Transmission Curtailment
  - Ramp Control / Time Shifting
  - Grid Frequency / Voltage Regulation Support
- National Instruments platforms used for:
  - Battery management and monitoring
  - High speed / subcycle supervisory control





Fuel-Cell Control and Monitoring

Major Supplier of Residential Fuel Cells



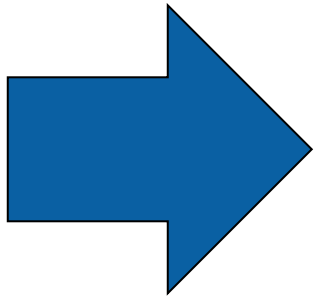
Standard sbRIO (Half Moon) Product

Custom daughter (I/O) daughter board developed by NI R&D

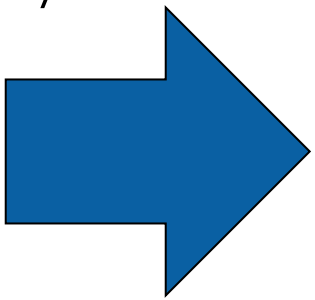
- 1 to 5kW power using Polymer Electrolyte Fuel Cell Technology
- Control and monitor air/water flows, temperature, inverter and gas valves
- Project based on sbRIO, 11,000 sbRIO deployments by 2015
- Development completed in less than one year

Strengths of NI FPGA platform

- Measurement quality
  - High-accuracy A/D
  - High sampling rates
  - High-resolution timestamp
- Computing power
  - Local, multi core/parallel analysis
- Flexibility
  - Modular I/O
  - Software-defined device



Better fault location and prevention



Install once, upgrade remotely

Questions

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind."

- Lord Kelvin, 1894