

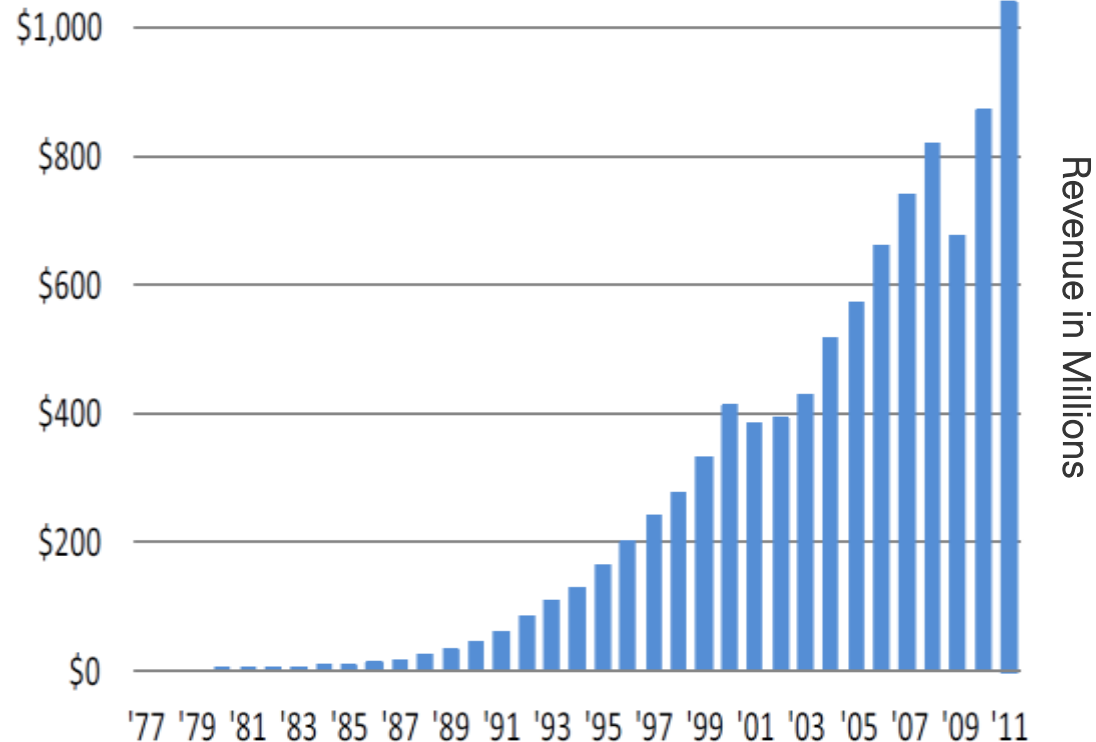
Reconfigurable instrumentation for monitoring and control of energy systems

Vidar Grønås, National Instruments
Energy Segment Manager Europe

National Instruments

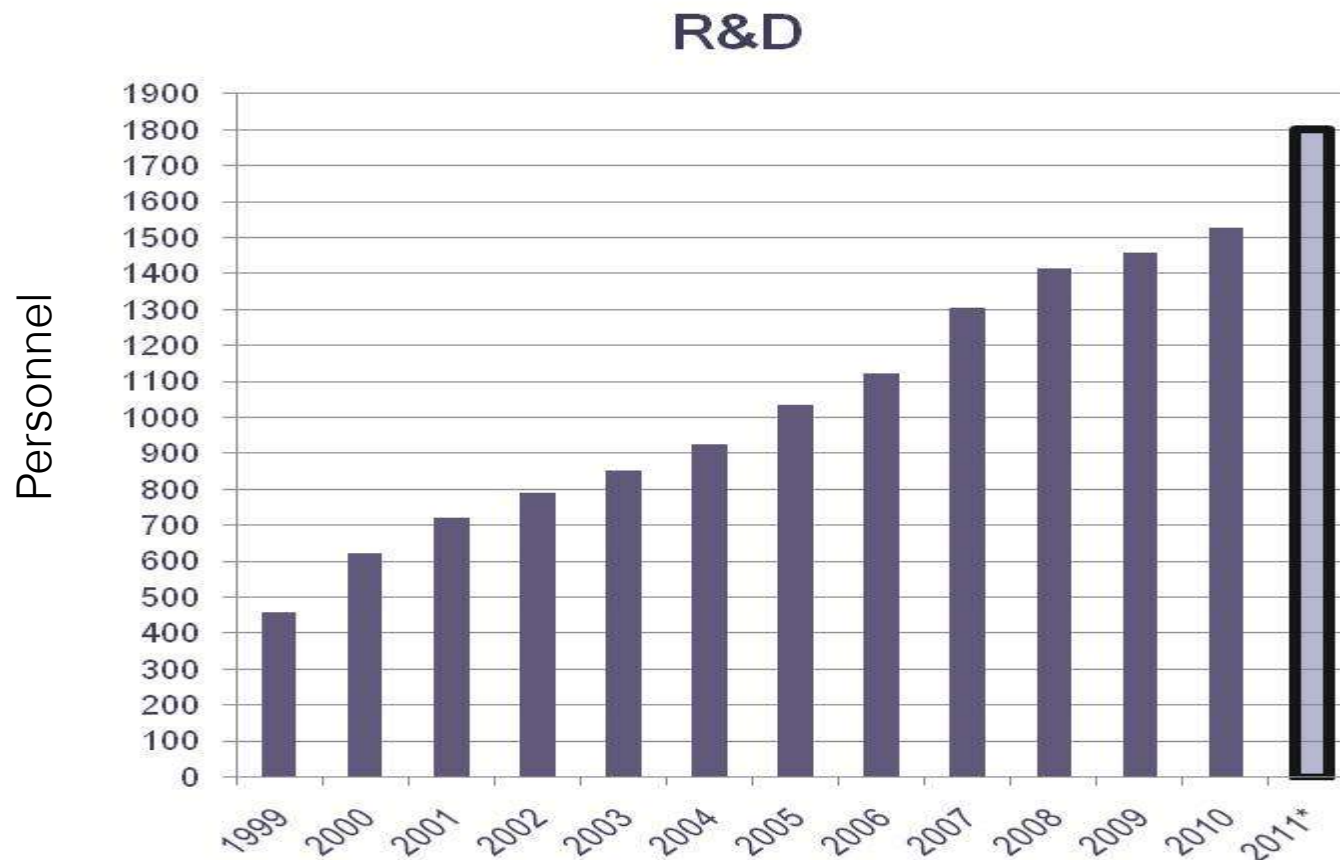
Leader in measurement and automation

- 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

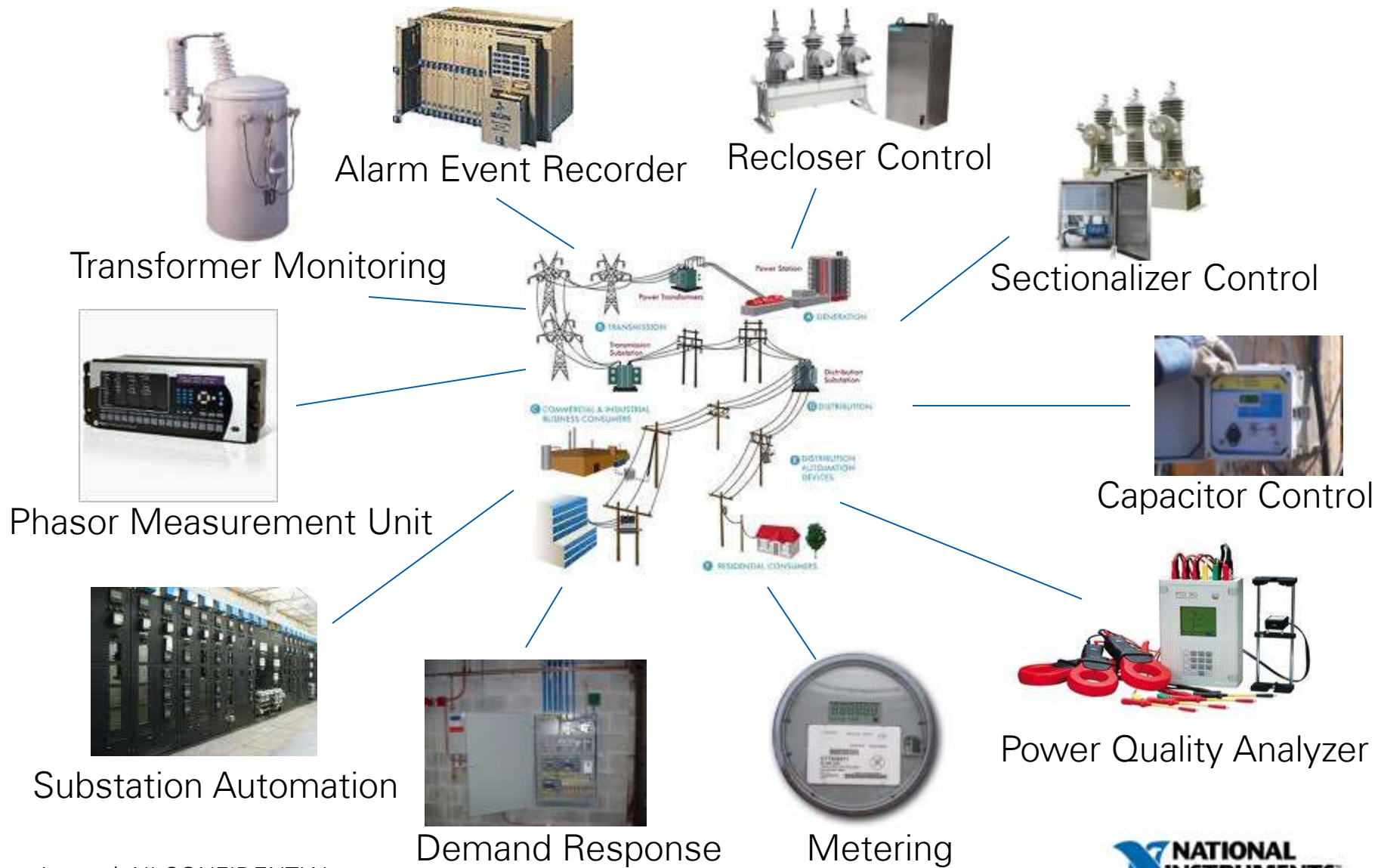
NI R&D headcount has grown over 50% in the last 5 years
Over \$200M/yr in R&D Investment



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 a 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



Grid: Measurement – Visualization – Automation

100's of Devices

Multiple Protocols

Multiple Buses

Fixed Functionality

Hundreds of Vendors

Poor Data Visualization Tools



Transformer Monitoring



Alarm Event Recorder



Recloser Control



Sectionalizer Control



Phasor Measurement Unit



Capacitor Control



Substation Automation



Demand Response



Metering



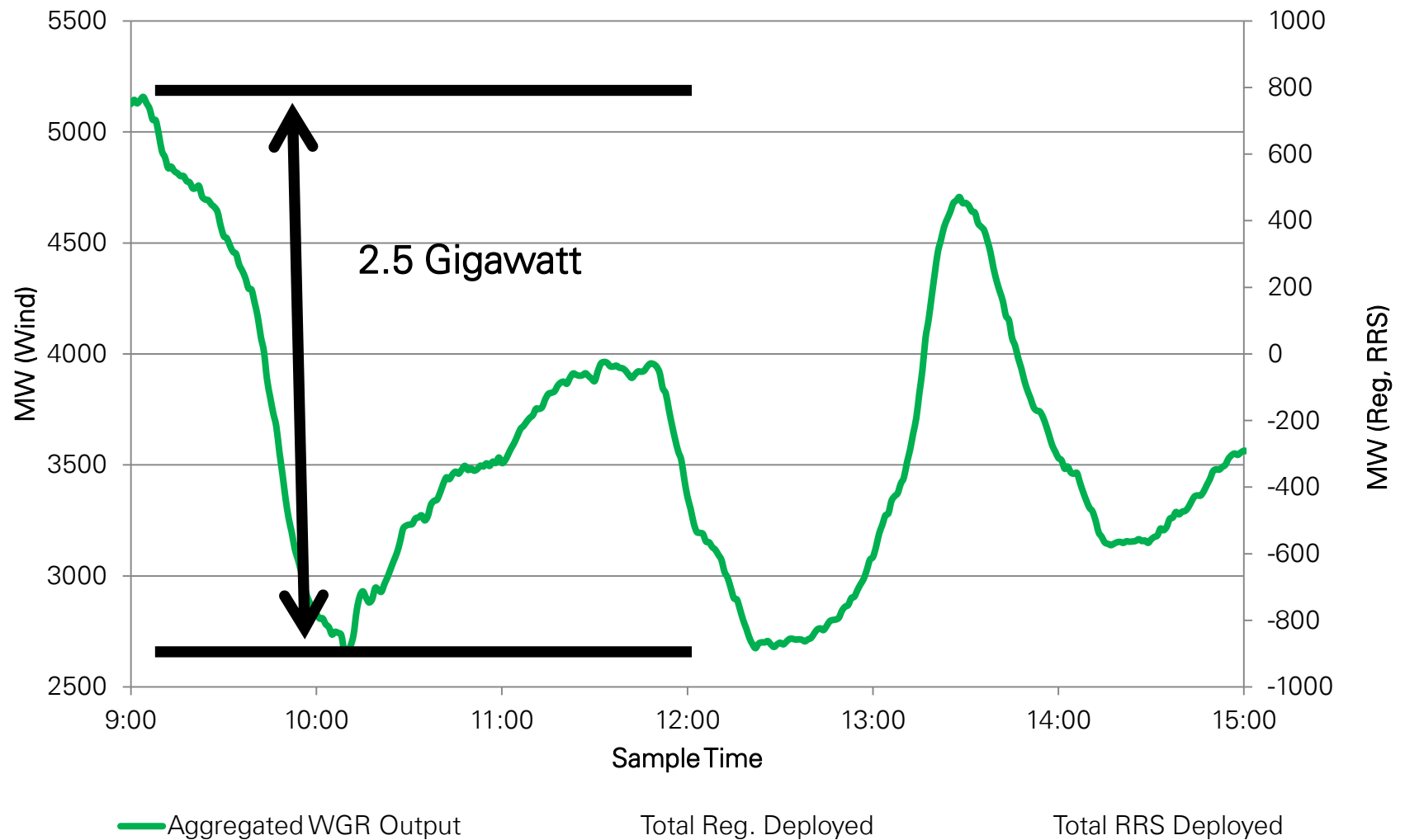
Power Quality Analyzer

Intermittent Generation



West Texas Wind Farms (9 Gigawatt)

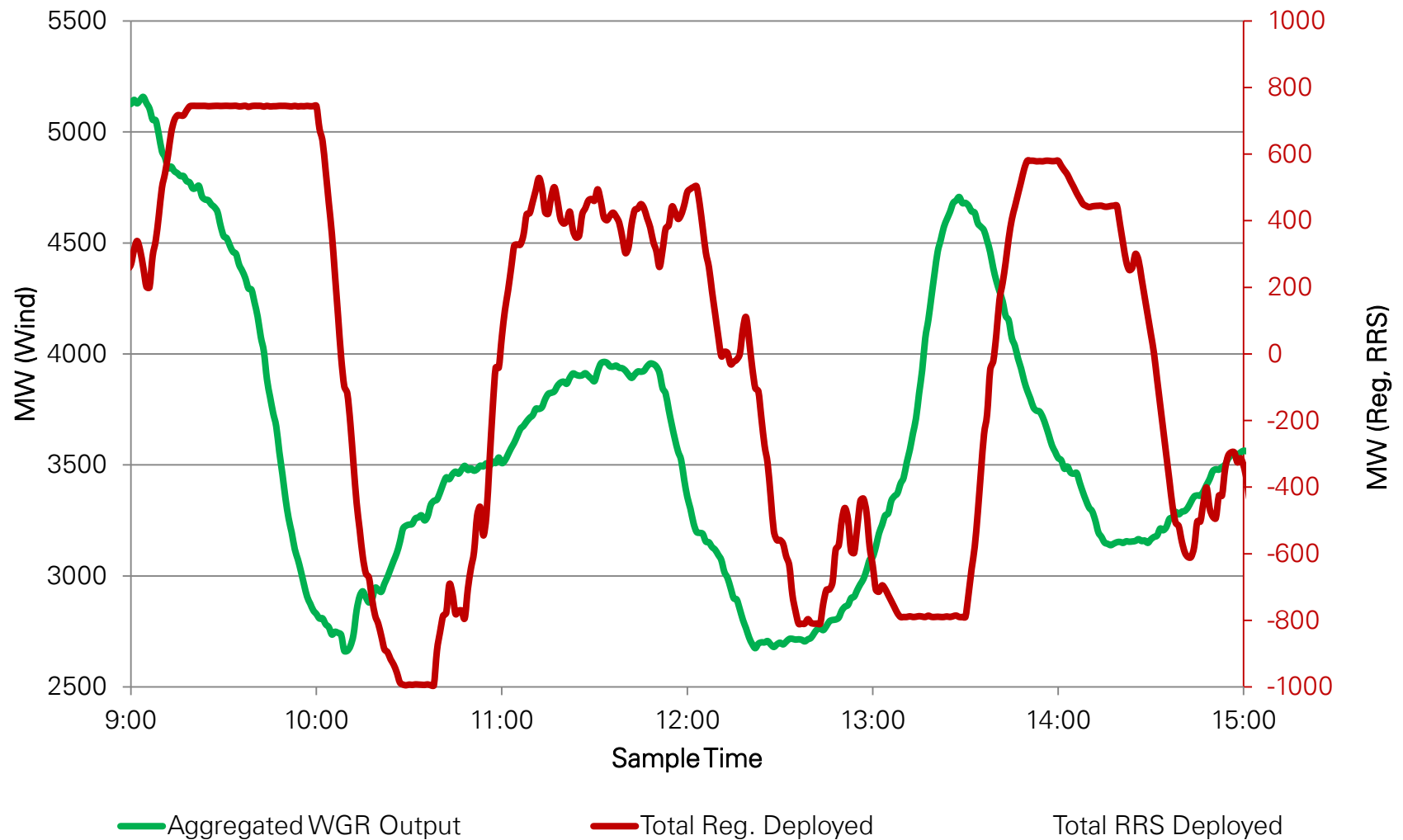
Wind Output, Regulation and RRS for 1/28/10



Regulation Service

- Capacity Reserved by the Grid Operator
- Under Automatic Generation Control
- Provides second by second Load following Capability (usually 800 – 1000 MW)

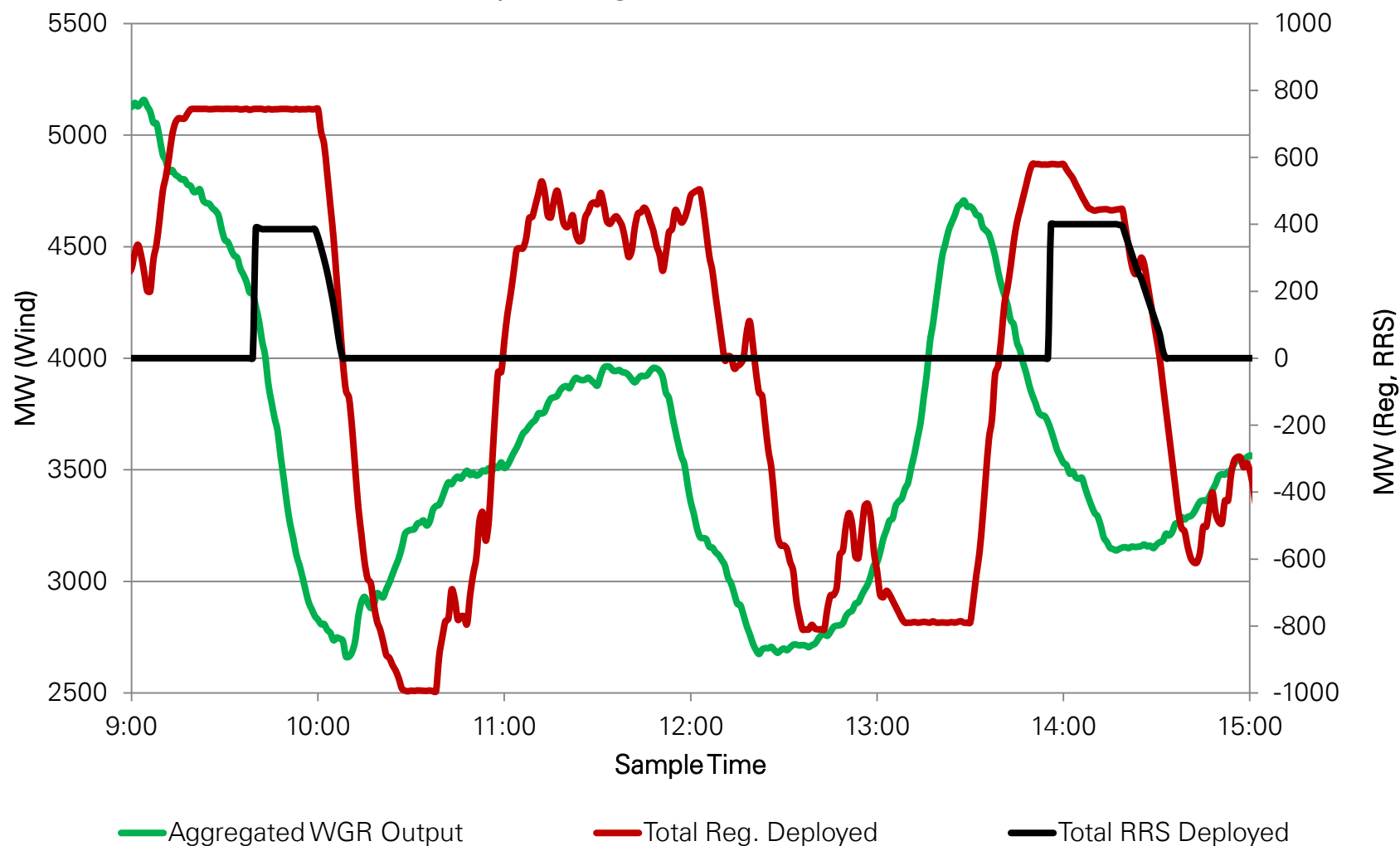
Wind Output, Regulation and RRS for 1/28/10

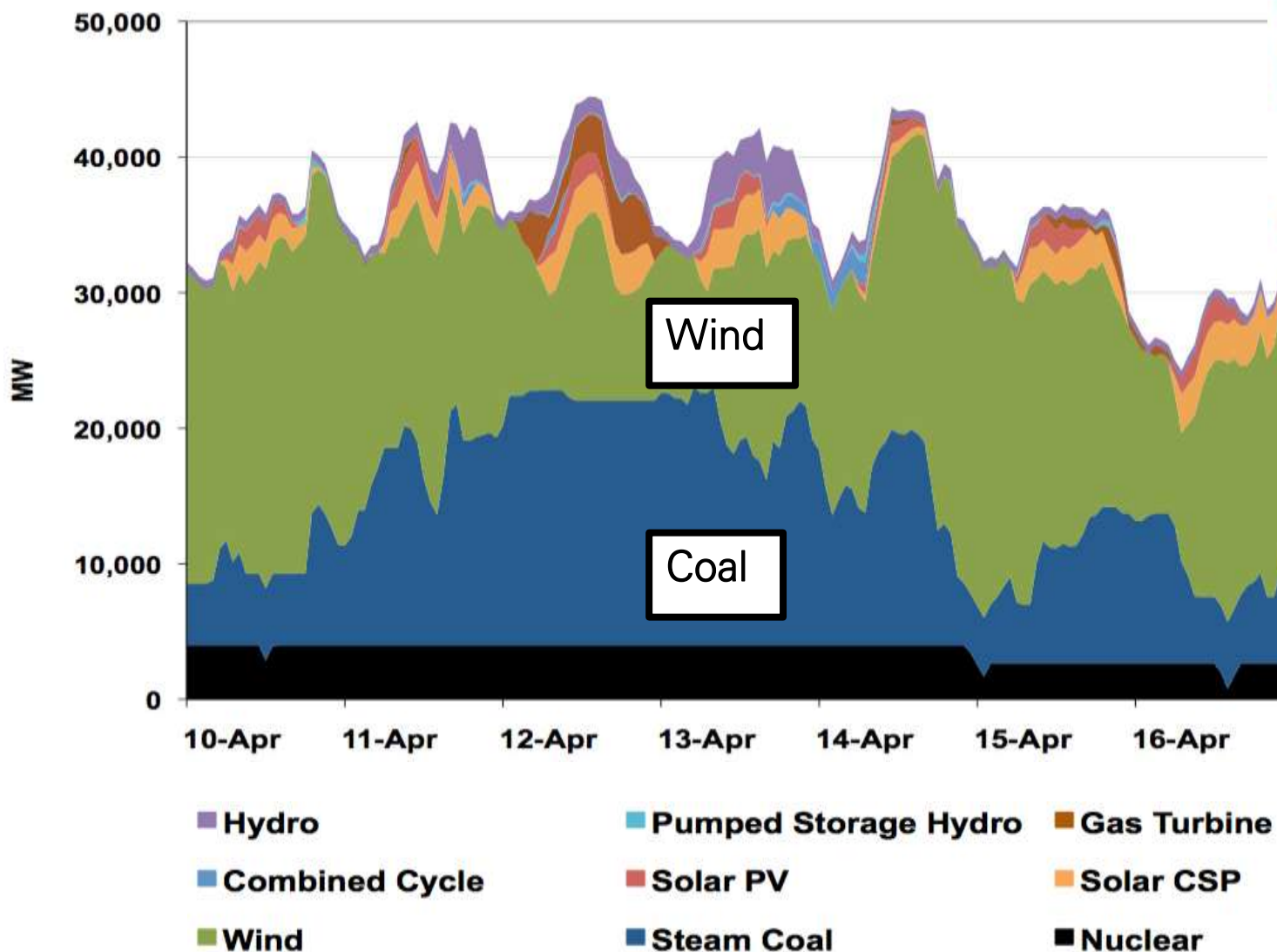


Responsive Reserve Service

- 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

Wind Output, Regulation and RRS for 1/28/10





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



GAP

T&D Instrumentation



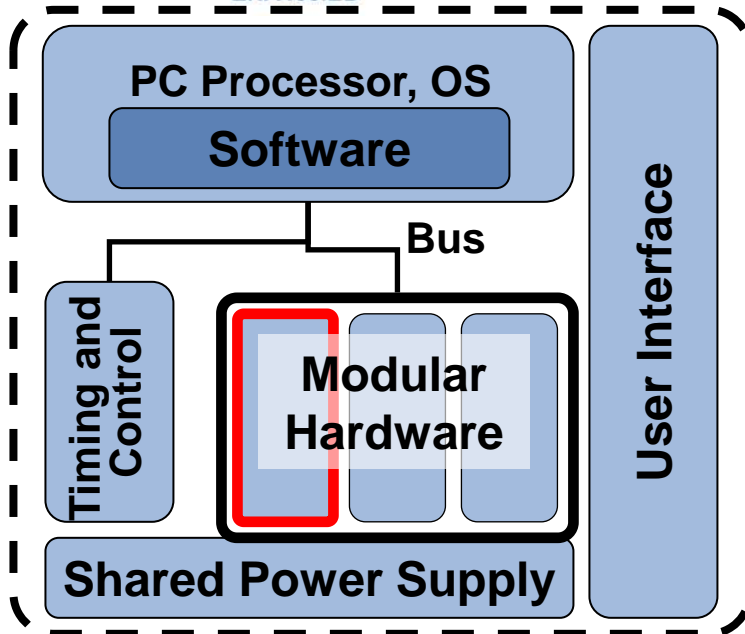
- Measurement Quality
- Embedded
- Reliable and Robust
- Standards-based
- Vendor-Defined

Converging instrumentation

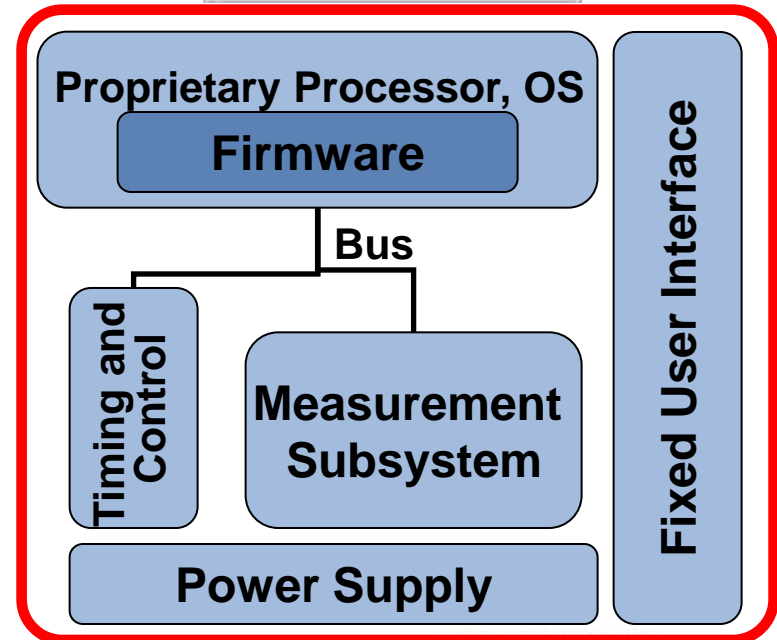
Software defined
Instrumentation



ENA450.EB



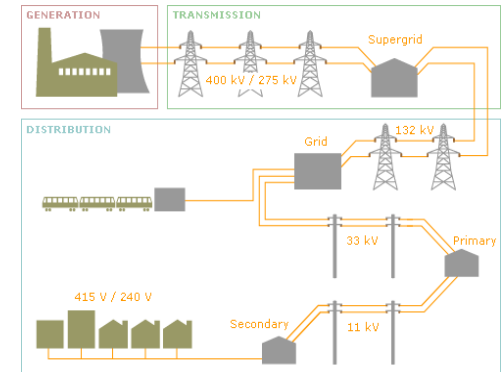
T&D Instrumentation



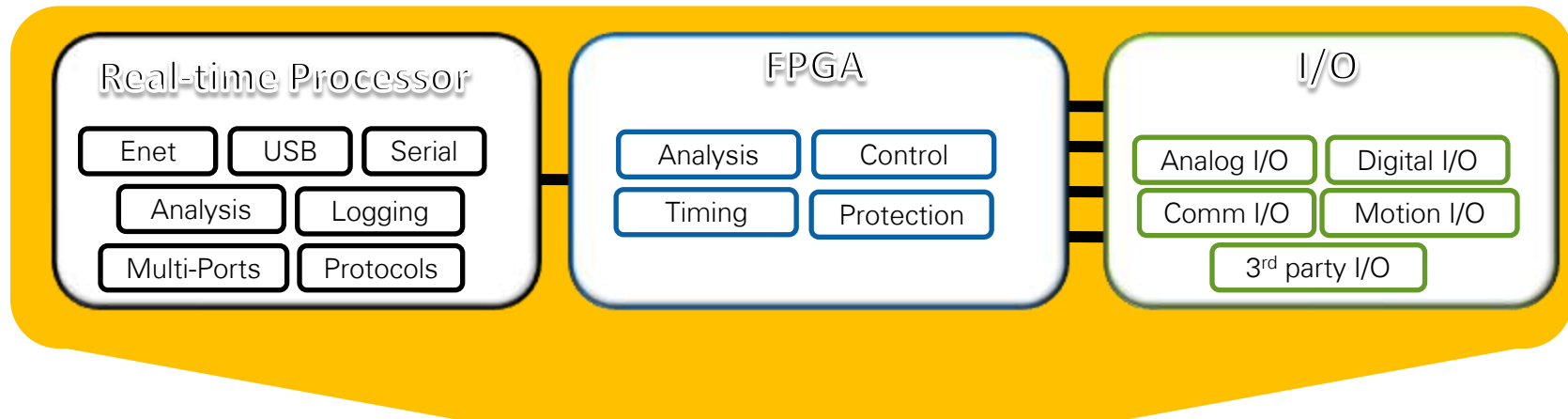
NI's Value Proposition

Convergence of technology into a single device

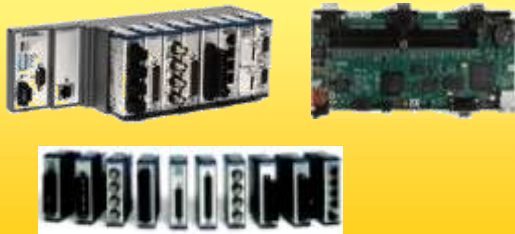
- Cost reduction
- High Performance
- Distributed Processing
- Small Footprint
- Flexible & Reconfigurable
- Scalable
- Easily upgraded
- User-defined functionality



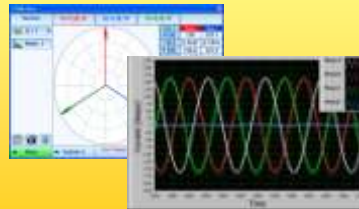
NI compactRIO Platform



Hardware Capabilities



Software IP



Communications

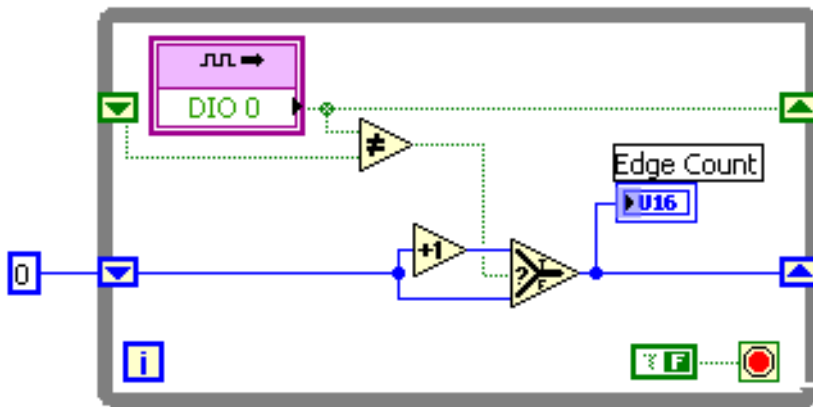
DNP 3.0
IEC 61850
Ethernet/Serial
TCP/IP
HTTP SSL
.....

Productivity: LabVIEW FPGA Code Abstraction

Counter

Analog I/O

I/O with DMA



LabVIEW FPGA

```
-- First we synthesize 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
        cCounter <= (others=>'0');
    elsif rising_edge(Clk) then
        if cRisingEdgeDetected then
            cCounter <= cCounter + 1;
        end if;
    end if;
end process CounterRegister;
cCount <= cCounter;

end rtl;
```

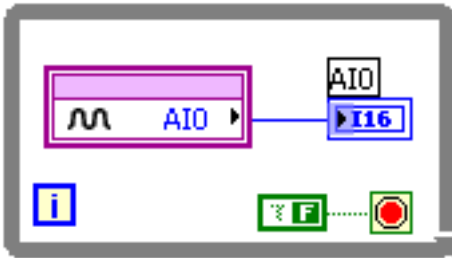
VHDL

Productivity: LabVIEW FPGA Code Abstraction

Counter

Analog I/O

I/O with DMA



LabVIEW FPGA

```

-- C 2004, 2005, 2006 National Instruments Corporation.

library ieee;
use ieee.std_logic_1164;
use ieee.std_logic_arith;

-- architecture 1

entity AIO_00 is
generic (
    WIDTH_OUT : integer := 16;
    WIDTH_IN : integer := 16;
)
port (
    clk : in std_logic;
    reset : in std_logic;
    aio_in : in std_logic_vector(WIDTH_IN-1 downto 0);
    aio_out : out std_logic_vector(WIDTH_OUT-1 downto 0);
    aio_data : in std_logic_vector(WIDTH_OUT-1 downto 0);
    and_aio_res : in std_logic;
    architecture_0 : in std_logic;
    type_state : in std_logic;
    signal_shift : in std_logic;
    signal_clk0 : in std_logic;
    signal_shift0 : in std_logic;
    signal_data : in std_logic;
    signal_clk00 : in std_logic;
    signal_clk01 : in std_logic;
    signal_clk : in std_logic;
    attribute_0 : in std_logic;
    attribute_op : in std_logic;
)
begin
    aio_out(0) <= aio_in(0);
    aio_out(1) <= aio_in(1);
    aio_out(2) <= aio_in(2);
    aio_out(3) <= aio_in(3);
    aio_out(4) <= aio_in(4);
    aio_out(5) <= aio_in(5);
    aio_out(6) <= aio_in(6);
    aio_out(7) <= aio_in(7);
    aio_out(8) <= aio_in(8);
    aio_out(9) <= aio_in(9);
    aio_out(10) <= aio_in(10);
    aio_out(11) <= aio_in(11);
    aio_out(12) <= aio_in(12);
    aio_out(13) <= aio_in(13);
    aio_out(14) <= aio_in(14);
    aio_out(15) <= aio_in(15);
    aio_out(16) <= aio_in(16);
    aio_out(17) <= aio_in(17);
    aio_out(18) <= aio_in(18);
    aio_out(19) <= aio_in(19);
    aio_out(20) <= aio_in(20);
    aio_out(21) <= aio_in(21);
    aio_out(22) <= aio_in(22);
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    aio_out(26) <= aio_in(26);
    aio_out(27) <= aio_in(27);
    aio_out(28) <= aio_in(28);
    aio_out(29) <= aio_in(29);
    aio_out(30) <= aio_in(30);
    aio_out(31) <= aio_in(31);
    aio_out(32) <= aio_in(32);
    aio_out(33) <= aio_in(33);
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    aio_out(36) <= aio_in(36);
    aio_out(37) <= aio_in(37);
    aio_out(38) <= aio_in(38);
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    aio_out(40) <= aio_in(40);
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    aio_out(46) <= aio_in(46);
    aio_out(47) <= aio_in(47);
    aio_out(48) <= aio_in(48);
    aio_out(49) <= aio_in(49);
    aio_out(50) <= aio_in(50);
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    aio_out(52) <= aio_in(52);
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    aio_out(201)
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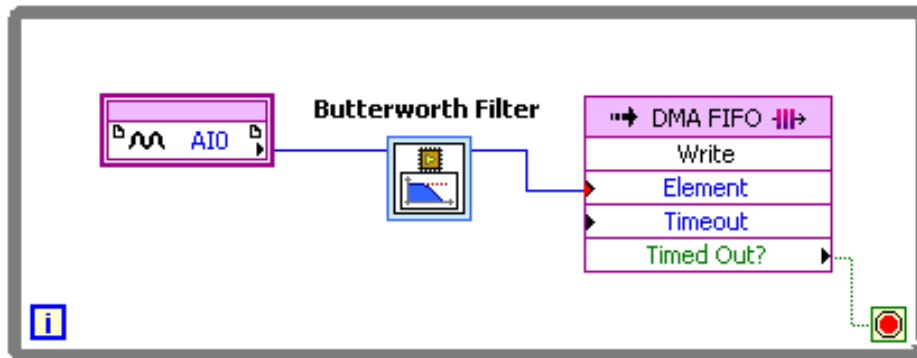
VHDL

Productivity: LabVIEW FPGA Code Abstraction

Counter

Analog I/O

I/O with DMA



LabVIEW FPGA

VHDL ~4000 lines

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.

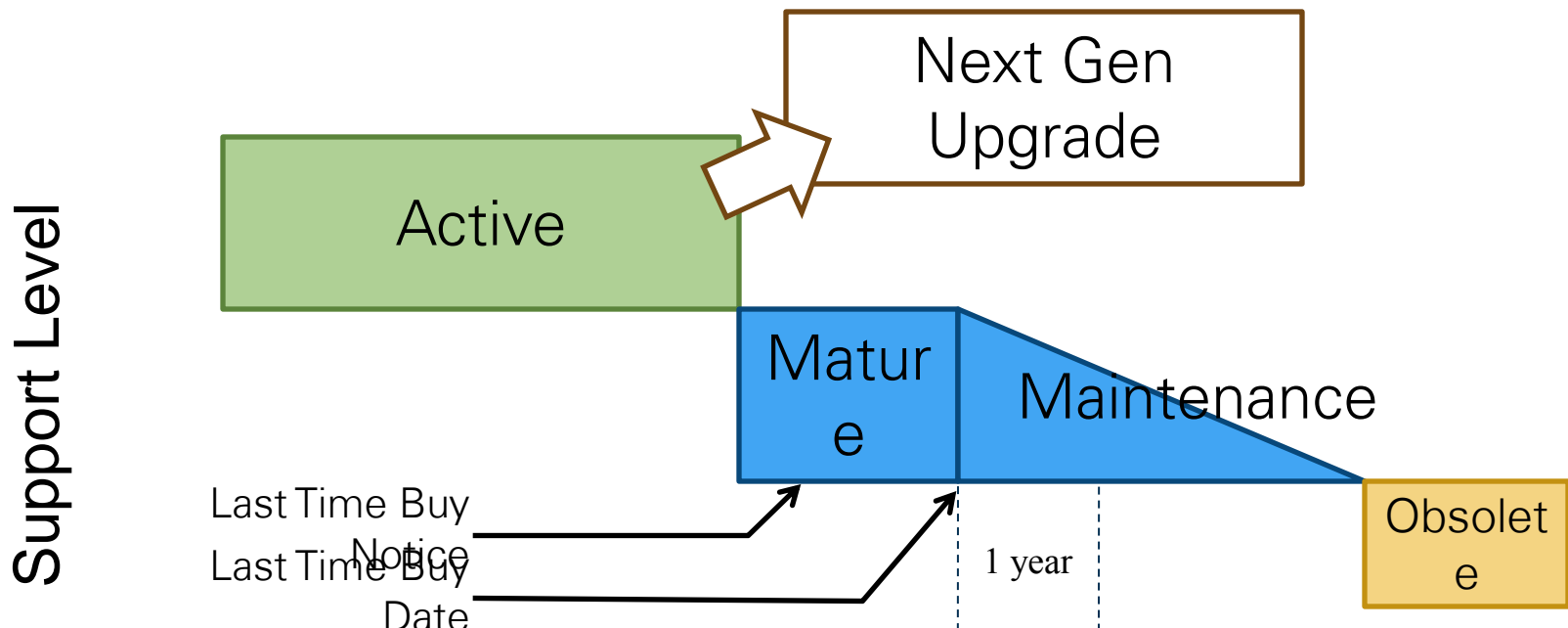
- **Hidden Costs of Embedded Design**—Small design teams eliminate the need to spend time and money certifying and maintaining their product over its lifetime by leveraging high-quality, off-the-shelf tools from National Instruments.
- **Electrical Quality**—Through stringent testing and certification, 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/PCle, 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



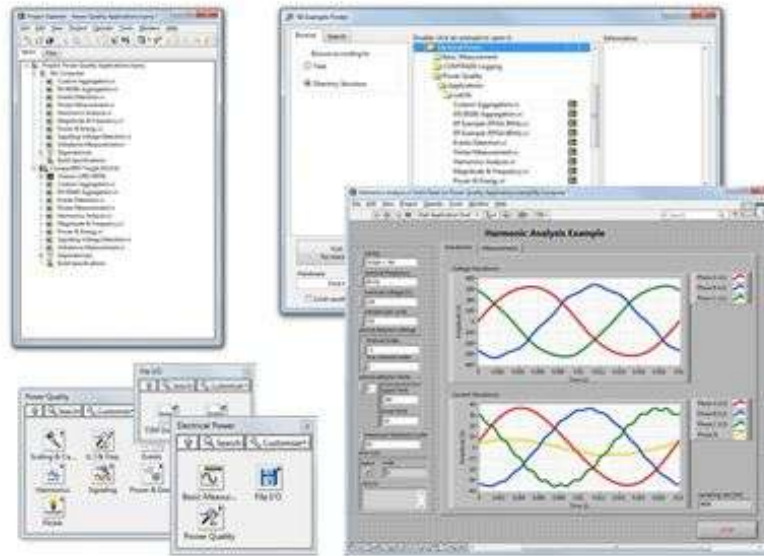
I/O

- 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/swell/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 64 th)	Once per sec and once per cycle	Impulsive Transient (V + I)
Interharmonics (0.5 to 63.5 th)	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 Phase RMS (V and I)	Power per Phase	Voltage Sag (di)
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)**

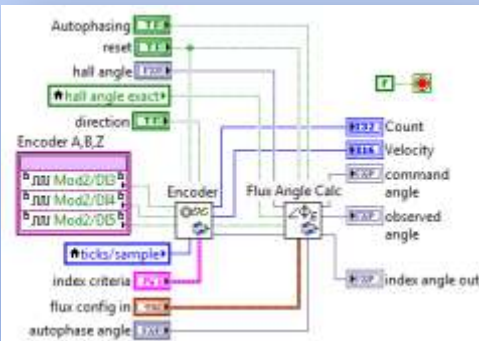
Communication Protocol Support

- 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

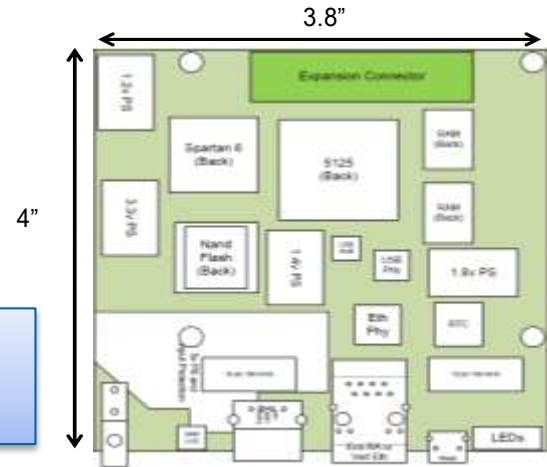
400 MHz PowerPC for floating-point control, analysis, logging and network communication

Networking Peripherals

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

Small Size, Low Power

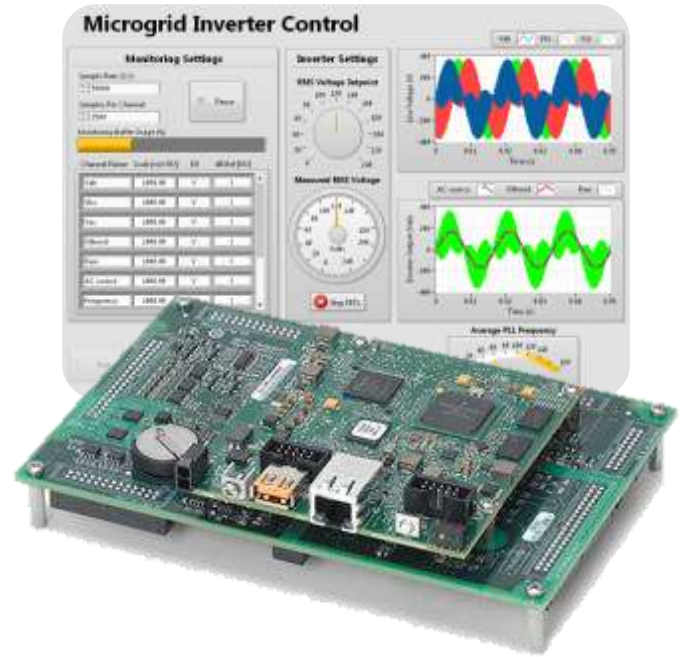
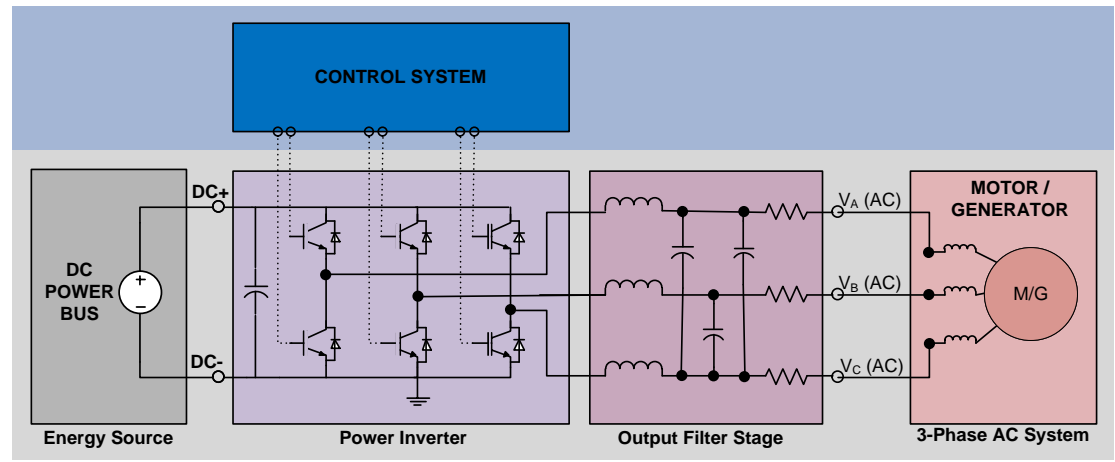
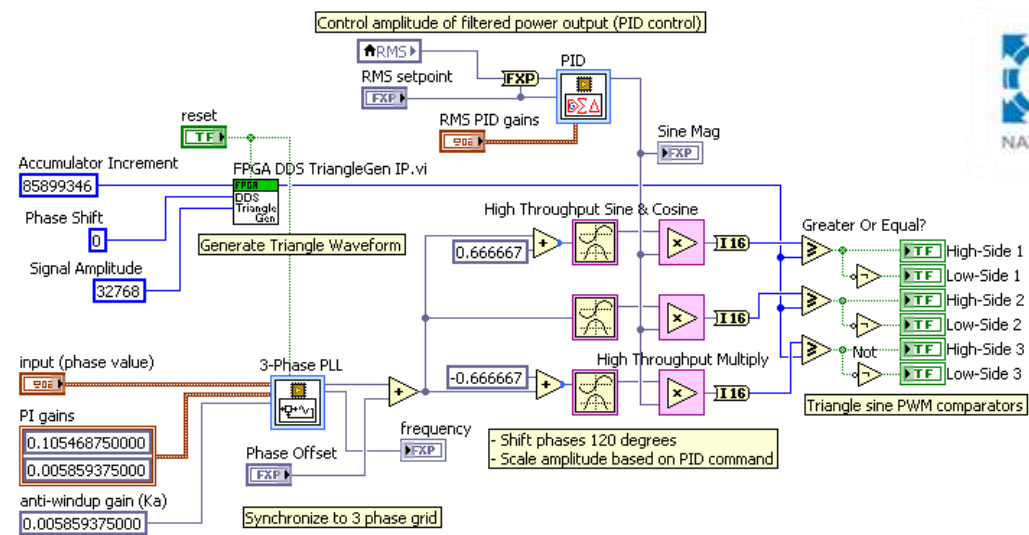
10.3 x 9.6 cm (4 x 3.8 in.)
9-30 VDC power



ni.com/singleboard



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

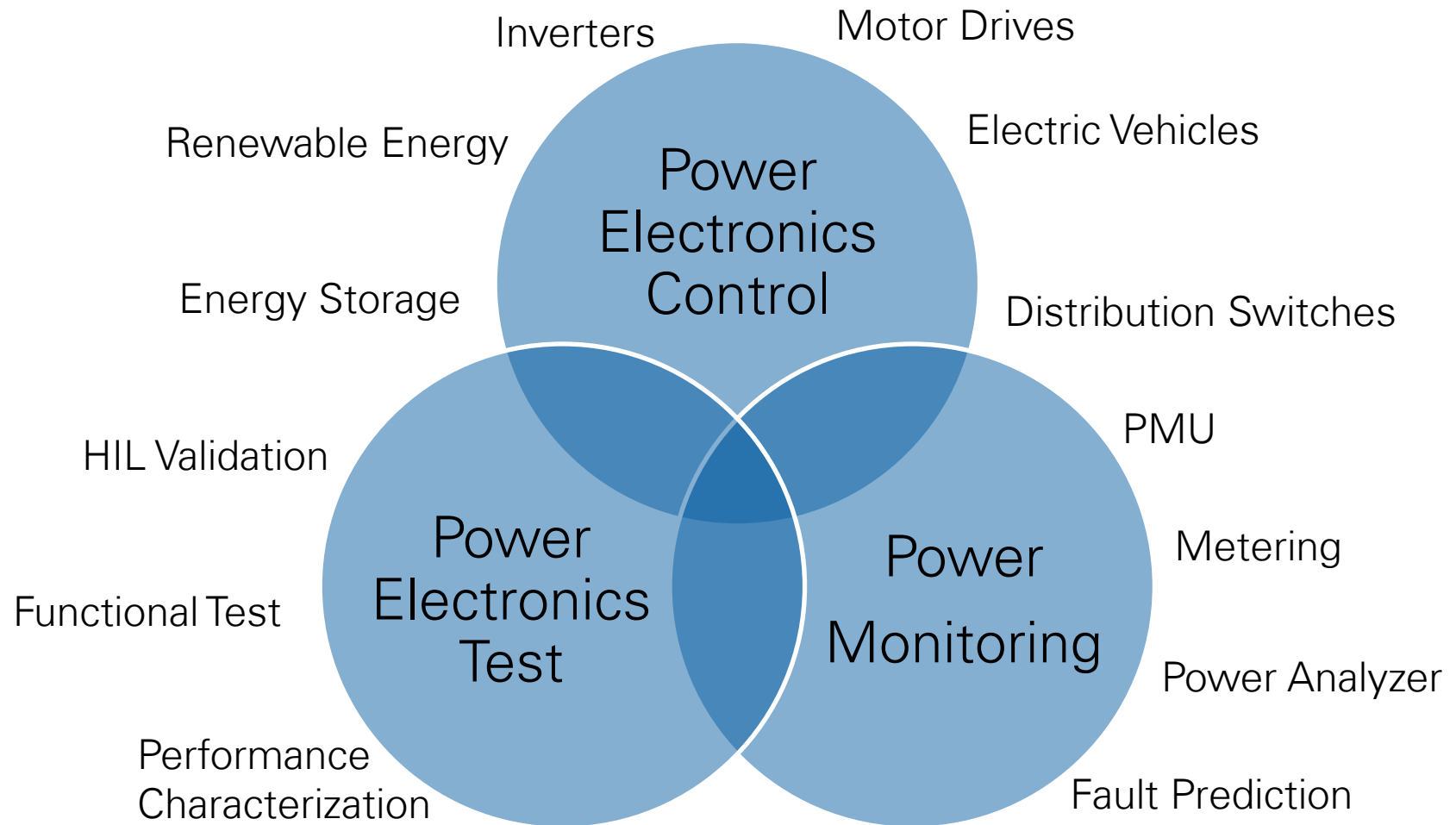
- *Power Quality Analyzer – IEC 61000*
- *Flicker Meter - EN 50160 / IEC 61000-5-15*
- *PMU – IEEE C37.118 (optional)*
- *Transient Analysis – 512 S/cycle*
- *Energy Metering and Power Flow Monitoring*
- *Control, Alarming, and Recording*

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*

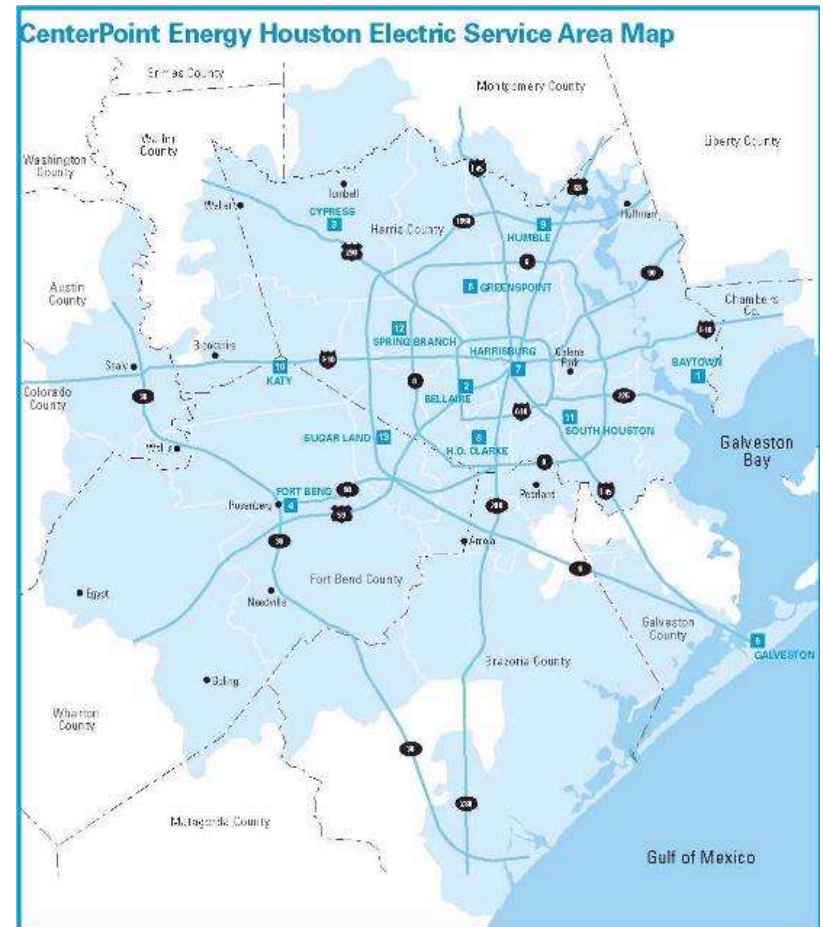


NI Role in Power Electronics

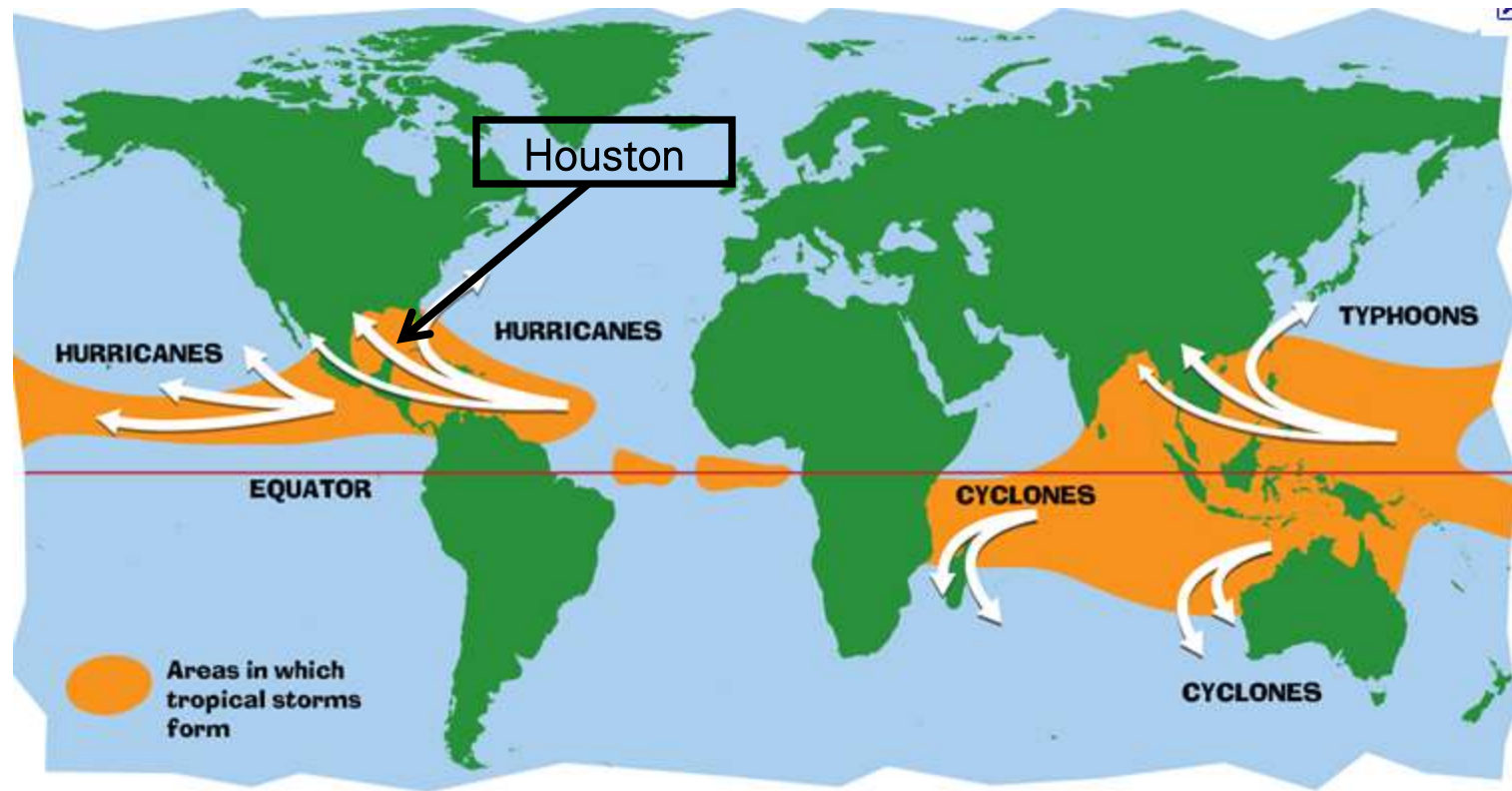


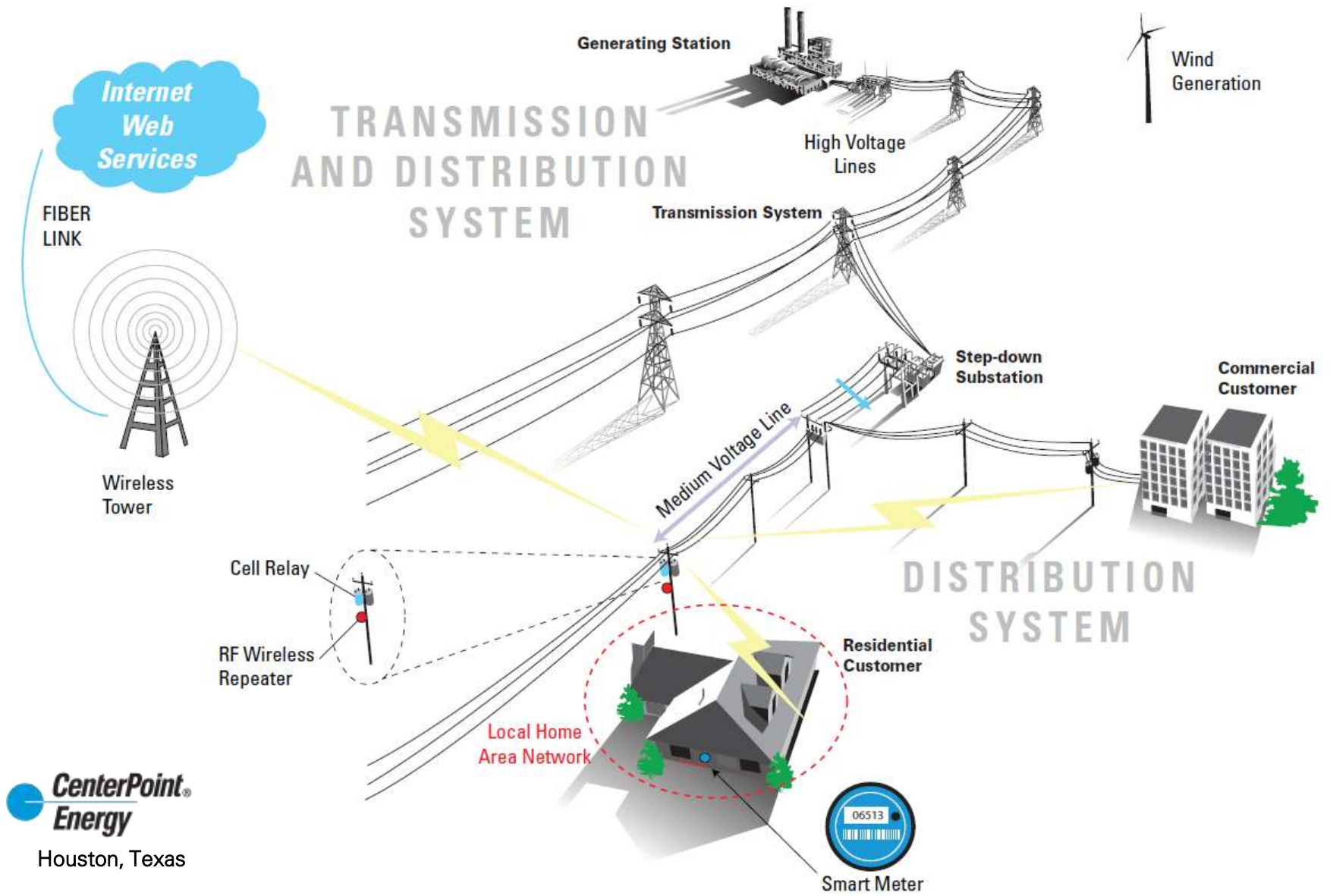


Houston, Texas
4th Largest City in the U.S.

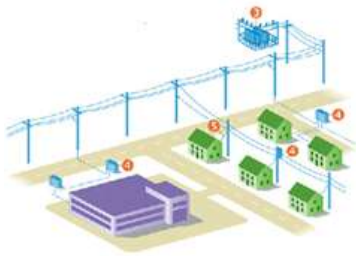


Houston is Located in "Hurricane Alley"





CenterPoint Smart Switch



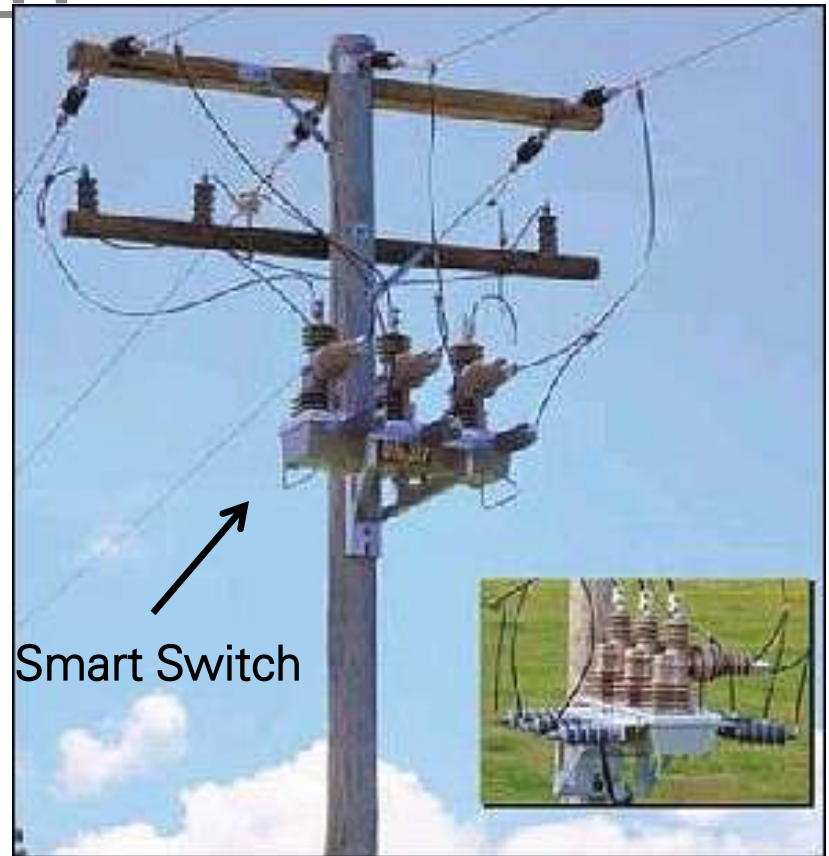
Reliability and System Efficiency

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

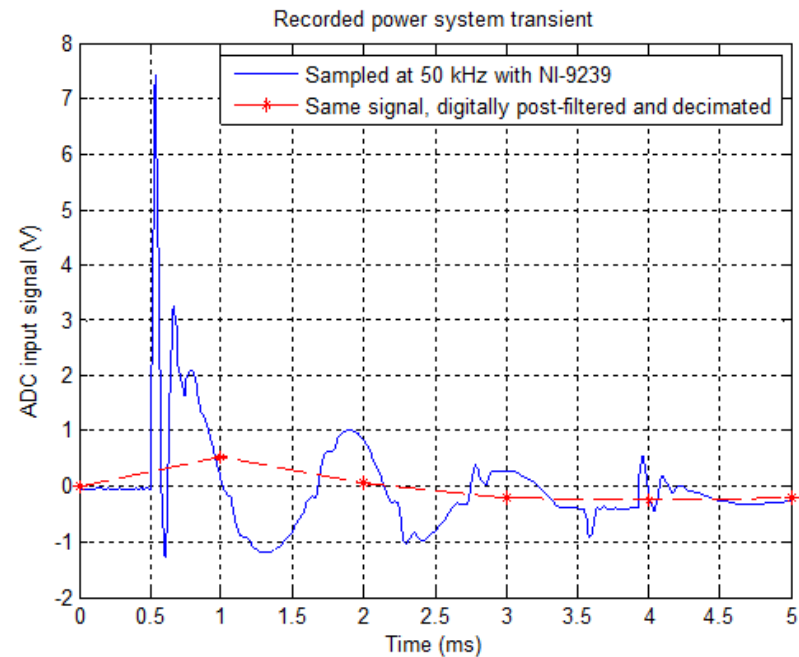
- Jan 8th-9th 2005 the hurricane Gudrun struck south of Sweden
- 9 people were killed
- 730,000 people lost electricity
 - 350,000 got it back within a day
 - 160,000 without electricity for 3 days
 - 82,000 for a week
 - The remaining had to wait for several weeks
- 75 million cubic meters of timber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





**TENAGA
NASIONAL BERHAD**

Putrajaya - Malaysia

61850 DATA CONCENTRATOR FOR SUBSTATION AUTOMATION

Who is Tenaga Nasional?

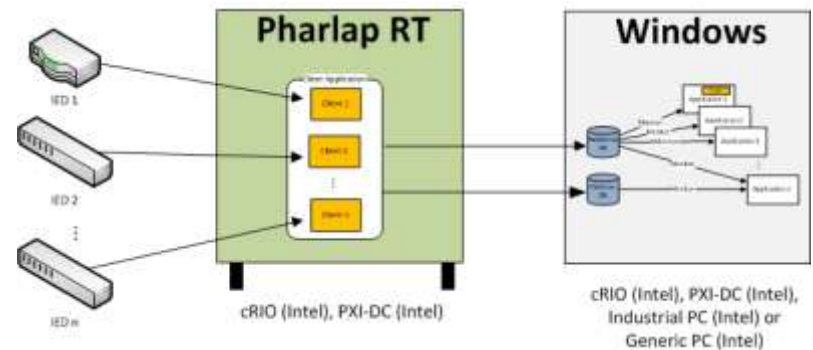
- Early Predecessor, Central Electricity Board founded in 1949
- Manages & operates the National Grid, a comprehensive transmission network that is also interconnected to Thailand & Singapore
- Largest Utility in Malaysia
 - 12,000 MW Installed
 - 28,000 Employees
 - 7 Million Customers
- Businesses
 - 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

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 varies from -5°C to 45°C



Rajasthan Utility

Distribution Monitoring



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Temperature various from -5°C to 45°C

Number of RTUs: 2820

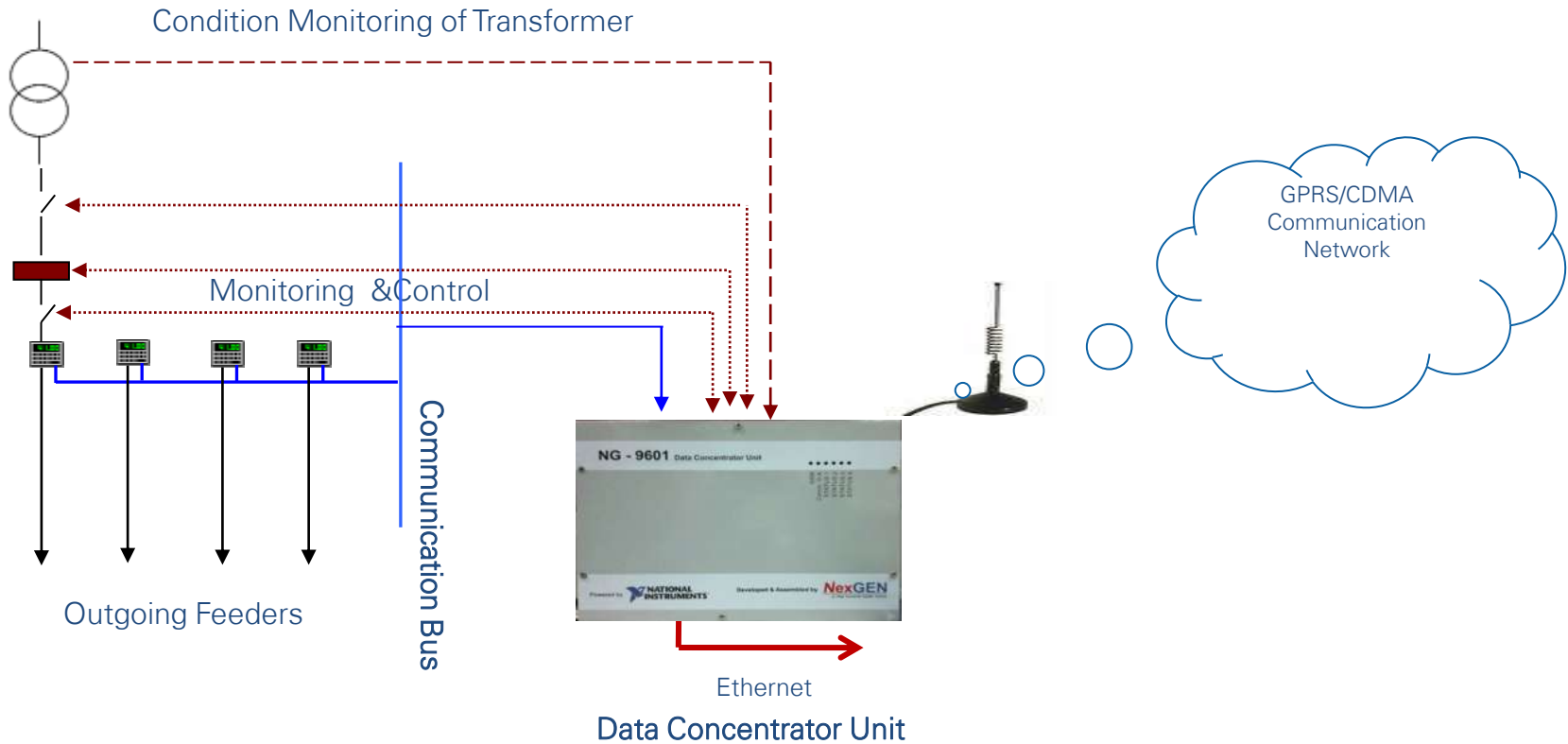


Rajasthan Utility

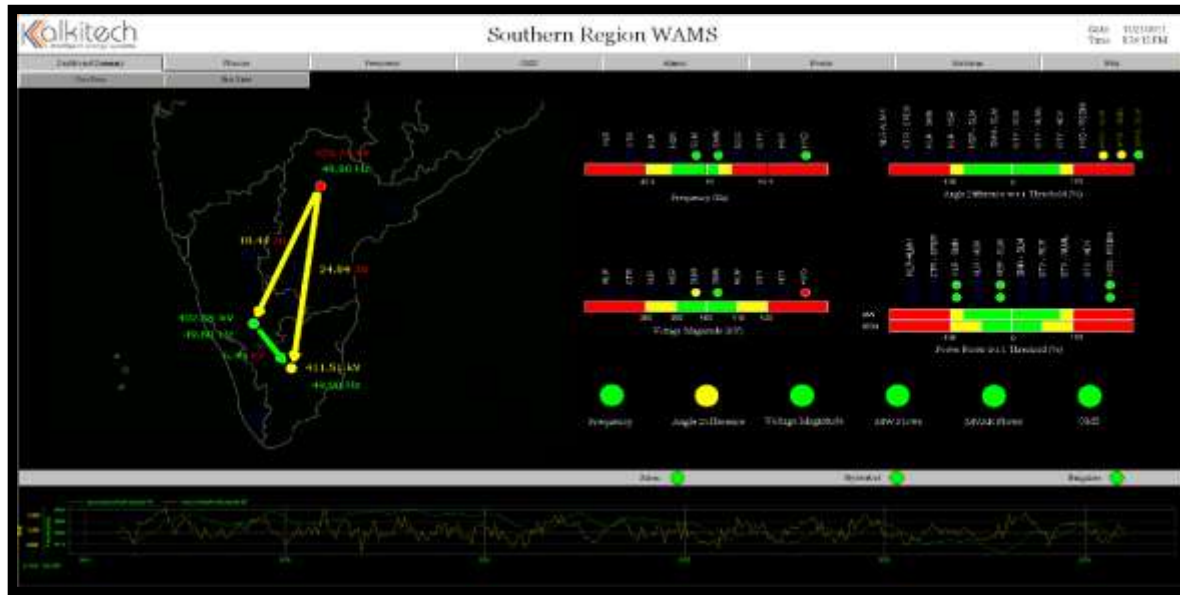


Data Concentrator Unit: Monitoring & Control

NexGEN



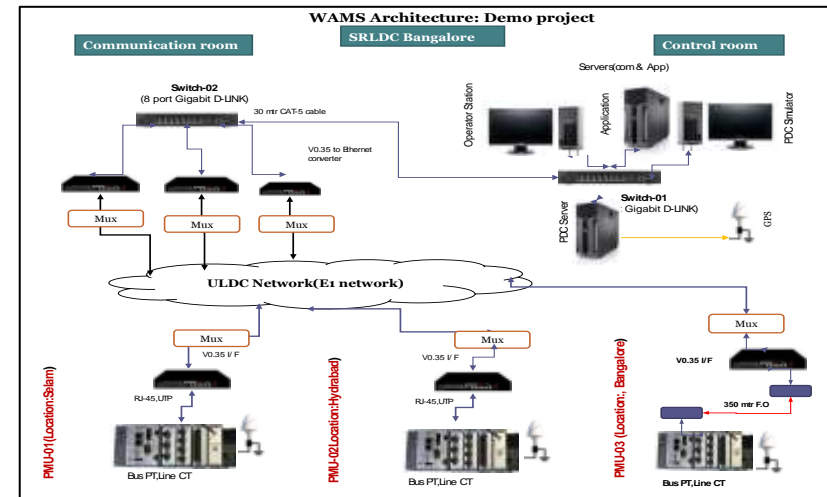
Application Area - Power - Transmission Line Monitoring



Project Size

- 700+

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

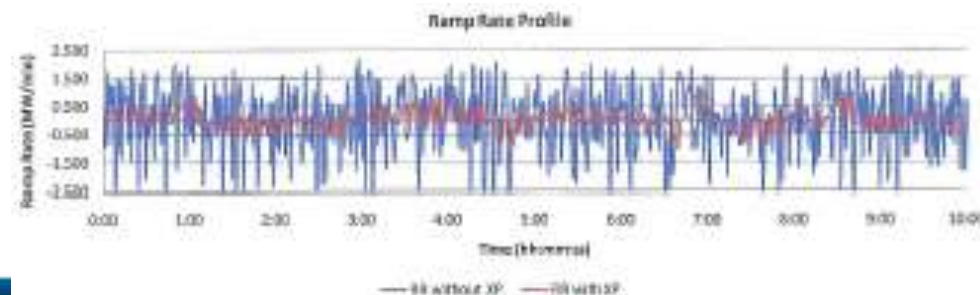


Energy Storage

Grid-tied Megawatt Storage for Wind Energy

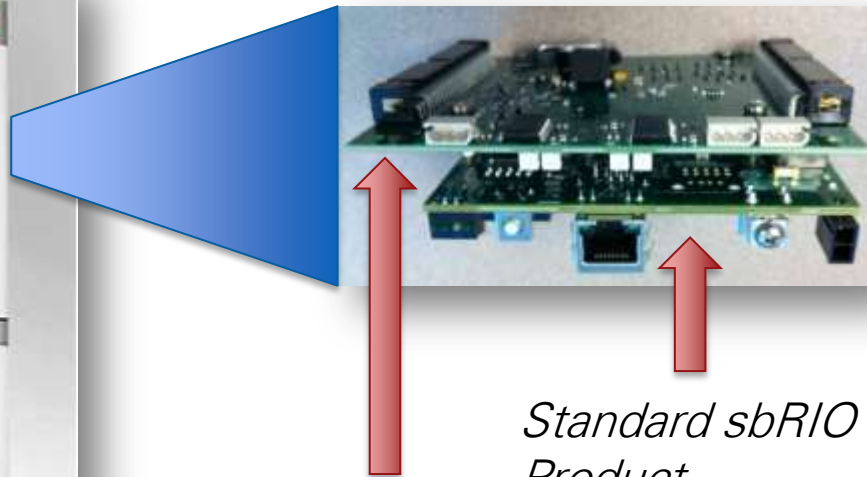


- First full utility-scale deployment in 2009
 - 1.0 MWh storage coupled with 30 MW wind farm on a 80-200 MW grid
- Energy storage platform capable of:
 - Transmission Curtailment
 - Ramp Control / Time Shifting
 - Grid Frequency / Voltage Regulation Support
- National Instruments platforms used for: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



Fuel-Cell Control and Monitoring

Major Supplier of Residential Fuel Cells

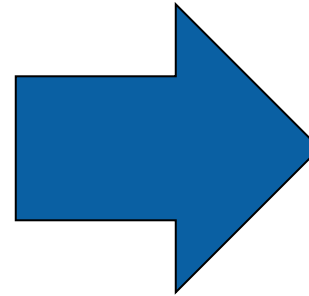


*Standard sbRIO (Half Moon)
Product
Custom daughter (I/O) daughter board developed
by NI R&D*

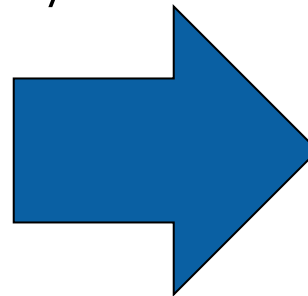
- 1 to 5kW power using Polymer Electrolyte Fuel Cell Technology
- Control and monitor air/water flows, temperature, inverter and gas valves
- Project based on sbRIO, 11,000 sbRIO deployments by 2015
- Development completed in less than one year

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