Open Platform for Developing and Testing Smart Grid Automation Systems

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The Grid – Evolving Challenges

Color Key:
Black: Generation
Blue: Transmission
Green: Distribution

Generating Station
Generating Step Up Transformer

Transmission lines
765, 500, 345, 230, and 138 kV

Transmission Customer
138kV or 230kV

Substation Step Down Transformer

Subtransmission Customer
26kV and 69kV

Primary Customer
13kV and 4kV

Secondary Customer
120V and 240V
The Grid – Evolving Challenges

More DC sources, micro-grids...

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Transmission lines
765, 500, 345, 230, and 138 kV

Generating Station

Generating Step Up Transformer

Substation Step Down Transformer

Primary Customer
13kV and 4kV
One Platform, Multiple Applications

A Platform that accelerates:
- Application development/updates
- Hardware reconfigurability
- System deployment

- Intelligent Electronic Device (IED)
- Phasor Measurement Unit (PMU)
- Remote Terminal Unit (RTU)
- Programmable Automation Controller (PAC)
- General Purpose Inverter Controller (GPIC)
- Phasor Data Concentrator (PDC)
- Protection Relays, Reclosers
- Intelligent Gateway/Protocol Translators
- Power Quality Analyzer (PQA)
- Etc....
The Development Process

- Theory
- Curriculum Integration
- Design
- Real World I/O Integration
- Prototype
- Industry Relevant Integration
- Deploy
- Test

Equations:

\[ V_{sd} = P \cdot \omega_m \cdot Lq \cdot Iq \]

\[ V_{sq} = P \cdot \omega_m \cdot (Iq \cdot Iq + \lambda) \]

\[ T_e = \frac{3}{2} \cdot P \cdot (Iq \cdot (Iq \cdot Iq + \lambda) - Iq \cdot (Iq \cdot Iq)) \]
SIL/HIL/Real-Time Control Platform

- Data Acquisition/Signal Generation
- Signal Processing/Analysis
- Math/Linear Algebra
- Visualization

Physical Process (Model/Real)

Inputs (Sensors) → Real-Time Analysis & Control → Outputs (Actuators)

Timing/Sync
A Platform for Developing Reconfigurable Smart Grid Automation Systems

Embedded, Real-Time Measurement & Control System

Host

Comm Loop
Logging Loop

Real-Time

LOGGING

Disk

Comm Loop

Monitoring Loop
DMA Loop
Control Loop 1
Control Loop 2

RT FIFO

FPGA I/O
DMA FIFO
FPGA I/O
FPGA I/O
FPGA I/O

Monitoring Loop
I/O Module Loop 1
I/O Module Loop 2
I/O Module Loop 3

FPGA

Hardware-level algorithm implementation
System Level Design

Traditional Methodology
- Plant Model (Analog)
- Circuit Design & PCB Layout
- Mechanical Design
- Magnetic & Thermal Analysis

Proposed Methodology
- Plant Model (Analog)
- Circuit Design & PCB Layout
- Mechanical Design
- Magnetic & Thermal Analysis

Closed Loop Simulation
Continuous to Discrete Time
Float to Fixed-Point Math
System Level to Register Level Code
Closed Loop Simulation
Graphical Implementation Code w/ I/O (Discrete-Time, Fixed Point)

FPGA SW Cost
- I/O (70%)
- Algorithm

Full-Custom Circuit Design

FPGA SW Cost
- I/O
- Algorithm (90%)

Chip-On-Board with I/O Support
A Comprehensive Approach to the Smart Grid/Micro Grid

Legend: GPIC=General Purpose Inverter Controller; PMU = Phasor Measurement Unit; IED = Intelligent Electronic Unit; RTU = Remote Terminal Unit; PDC = Phasor Data Concentrator; OI = Operator Interface; HMI = Human-Machine Interface; SCADA = Supervisory Control and Data Acquisition
Developing Deterministic, Real-Time Smart Grid Automation Systems

• Easy implementation of power and signal processing algorithms
• RTOS: Linux Real-Time Operating System (Linux RT OS)
• Hybrid, System-on-Chip (SoC) with dual-core processor and FPGA
  – SoC: Xilinx Zynq*
    • Processor: 667 MHz dual-core ARM Cortex-A9 Processor
    • FPGA: Artix 7

(*) Note: Other options include Intel Core i7® and Atom® processors, Xilinx Kintex-7® and Spartan® FPGAs
Programming Tools, Drivers and API

NI LabVIEW

- NI LabVIEW Professional Development System:
  - LabVIEW for MS Windows
  - LabVIEW Real-Time
  - LabVIEW FPGA
  - LabVIEW Electrical Power Suite
    - IEC 61000-4-7 (harmonics)
    - IEC 61000-4-15 (flicker)
    - IEC 61000-4-30 (Event Measurement Class A)
    - EN 50160 (Data Aggregation)
  - Other Toolkits/Toolsets
- Drivers:

C/C++/Python/Eclipse

- Eclipse IDE
- C/C++ programming
- Python scripting
- HTTPS Comm.
- IPTables
- SSL, OpenVPN, Syslog-ng
An Open Platform for Developing & Testing Smart Grid Automation Systems

I/O Modules:
- 8x Voltage: $0-250\, \text{V}_{\text{RMS}}$ for PT input, 24-bit, 50kS/s
- 8x Current: $0-20\, \text{A}_{\text{RMS}}$ for CT input, 24-bit, 50kS/s
  - 100$\text{A}_{\text{RMS}}$ measurement for 10s, 500A$\text{A}_{\text{RMS}}$ withstand (1s), 1250A$\text{A}_{\text{RMS}}$ withstand (1 cycle)
- 8x Binary Input: 300 VDC with 2/3 ratiometric crossing threshold
- 1x Fiber ENET, 1x Copper ENET
- 1x GPS input
- Power Supply: 110-300 VDC, or 110-250VAC  50/60Hz

Xilinx ZYNQ SoC (dual-core ARM processor + Artix-7 FPGA)

- Incorporate readily available IP, VHDL and/or Verilog (HDL code)
Reconfigurable, Modular Architectures w/ Connectivity & Processing Power

- 667 MHz Dual-Core ARM Processor
- Xilinx Artix-7 FPGA
- 512MB DDR3 RAM
- 1GB Storage
- 2x Gigabit Ethernet
- 9-30 VDC Dual Input
- 5x Vibration, 50g Shock Tolerance
- USB 2.0
- RS-232
- RS-485
- 31.3cm*
- -40 to 70° C Operating Temperature

1 FPGA Specifications: 85K Logic Cells, 560KB Block Ram, 220 Multipliers

* 31.3cm x 10.1cm x 3.4cm
Modules for I, PT, GPS, DI; Embedded Touch Displays

- 1x **NI 9467** GPS Module
- 2x **NI 9242** Voltage Input for High voltage sensor connection (PT)
- 2x **NI 9238** Voltage Input for Shunts/Current
- 1x **NI 9437** HVDC Digital Input
- **Amulet** touch display
- **PULS PS-14** Power Supply
Custom I/O Module Development

- A Module Development Kit (MDK)
- The NI cRIO-9951 MDK Suite helps users, OEMs, and system integrators develop custom modules to meet unique system needs.
- The kit includes cRIO module development software and the cRIO Module Development Kit user manual.
- Additionally, the kit features housing module shells and testing to the NI cRIO electrical hardware power specification.
- A distribution agreement is available for reselling or marketing your module individually or stand-alone.
- PCB Design and Layout in NI Multisim/Ultiboard or other EDA/CAD tools
Enclosures for System Protection & Deployment in the Field
Grid Automation System

Web services and Dashboard

NI LabVIEW Programming
Easy Connectivity for Comms. & Signals

Analog Inputs (2-buses)

Digital Input
Current Input
Voltage Input

Copper  Fiber  GPS  System Power

Ethernet Connection
Grid/Substation Certifications

- IEC 61000-6-5 (2001)
- IEC 60255-22-3 (2007)
- IEEE 1613 (2009)

- ANSI C37.90.1
- ANSI C37.90.2
- ANSI C37.90.3
- C37.118
Type Tests and UL/CE Certifications

Table 1. NI 9725 Type Tests

<table>
<thead>
<tr>
<th>Description</th>
<th>Standards</th>
<th>Ports</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiated Emission</td>
<td>CISPR 22</td>
<td>Enclosure</td>
<td>Class A</td>
</tr>
<tr>
<td>Conducted Emission</td>
<td>CISPR 22</td>
<td>Enclosure</td>
<td>Class A</td>
</tr>
<tr>
<td>1 MHz Damped Oscillatory Wave</td>
<td>IEC 61000-4-15</td>
<td>Power, Digital Inputs, Analog Inputs</td>
<td>2.5 kV common mode, 1 kV transverse mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C37.90.1</td>
<td>2.5 kV common mode</td>
</tr>
<tr>
<td>100 kHz Damped Oscillatory Wave</td>
<td>IEC 61000-4-15</td>
<td>Power, Digital Inputs, Analog Inputs</td>
<td>4 kV common mode, 2 kV transverse mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Digital Inputs</td>
<td>4 kV common mode, 1 kV transverse mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GPS</td>
<td>2 kV common mode</td>
</tr>
<tr>
<td>Fast Transients</td>
<td>IEC 61000-4-4</td>
<td>Power, Digital Inputs</td>
<td>4 kV common mode and transverse mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C37.90.1</td>
<td>4 kV common mode, 2 kV transverse mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ethernet, GPS, Functional Earth</td>
<td>4 kV common mode</td>
</tr>
<tr>
<td>Surge</td>
<td>IEC 61000-4-5</td>
<td>Power, Digital Inputs</td>
<td>0.5 kV, 1 kV, 2 kV, 4 kV common mode; 0.5 kV, 1 kV, 2 kV transverse mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Digital Inputs</td>
<td>0.5 kV, 1 kV, 2 kV, 4 kV common mode, 0.5 kV, 1 kV transverse mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GPS</td>
<td>0.5 k V, 1 kV, 2 kV common modes</td>
</tr>
<tr>
<td>Electrostatic Discharge</td>
<td>IEC 61000-4-3</td>
<td>Enclosure</td>
<td>8 kV contact discharge, 15 kV air discharge</td>
</tr>
</tbody>
</table>

Type Tests in HW Manual
Built-in Security in Embedded, Measurement Systems

- **Linux-based Options**
  - OpenSSH
  - Firewall
  - VPN
  - Port Blocking
  - Strong OOB Security (ACLs)
  - Support for CPU privilege levels/modes
  - Secure file transfer (WebDAV)
  - Authentication, Encryption, SSL

- **Custom Security Support**
  - Safe mode security options
  - Secure remote software update
  - Secure industry standard Power protocols (IEC 61850)
  - Raw TCP hooks to add custom network security
Group Discussion