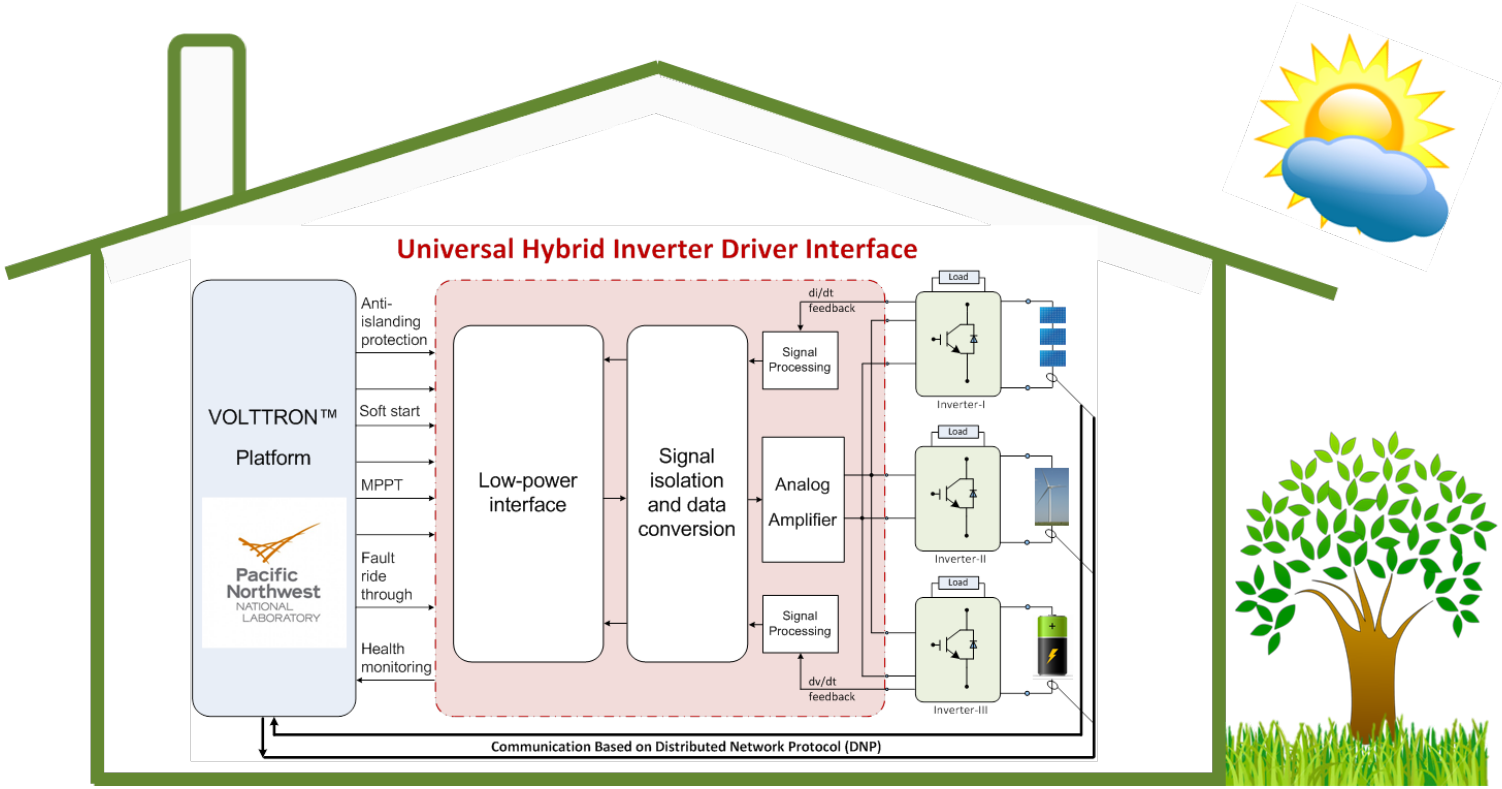
GM0204: Universal Hybrid Inverter Driver Interface for VOLTTRON™ Enabled DER Power Electronics Applications

2017 Building Technologies Office Peer Review



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Madhu Chinthavali, chinthavalim@ornl.gov
Oak Ridge National Laboratory

Project Summary

Timeline:

Start date: FY16

Planned end date: FY19

Key Milestones

1. Emulate functionality of advanced VOLTTRON™ platform to validate the control architecture; 12/30/2016
2. Validate functionality of the hybrid interface using a commercial inverter; 12/30/2017
3. Test the advanced VOLTTRON™ platform using the developed universal hybrid inverter driver interface; 12/30/2018

Budget:

Total Project $ to Date: $350K

- DOE: $350K
- Cost Share: $0

Total Project $: $1.35M

- DOE: $1.35M
- Cost Share: $0

Key Partners:

AgileSwitch (PE Vendor)	AgileSwitch
ROHM (Electronics Vendor)	ROHM SEMICONDUCTOR

Project Outcome:

This project will address needs for the Open-architecture control platforms for transactive energy ready buildings [DOE BTO MYPP Pages 98-99].

The project will assess the impact that the VOLTTRON™ platform can have on the grid-tied inverters for transactive control.

Purpose and Objectives

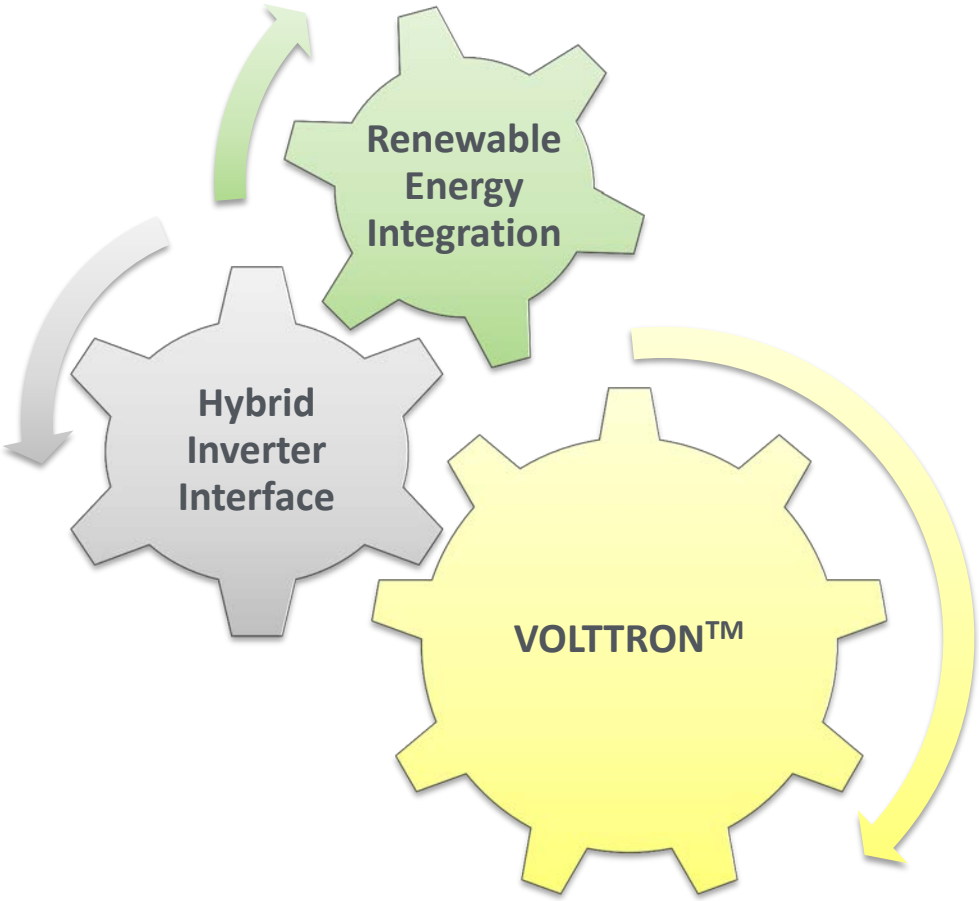
Challenges

- No open-source transactional network software platform for grid-tied inverters
- Legacy hardware and software solutions
  - Vendor base software cannot be modified for providing advance grid functions
  - Commercial inverters need an hardware interface for interacting with open-source platforms (VOLTTRON™)

Gaps

- No power electronics agent in VOLTTRON™ to control inverters
- No grid service agents that allow them to easily communicate with physical inverter and other resources

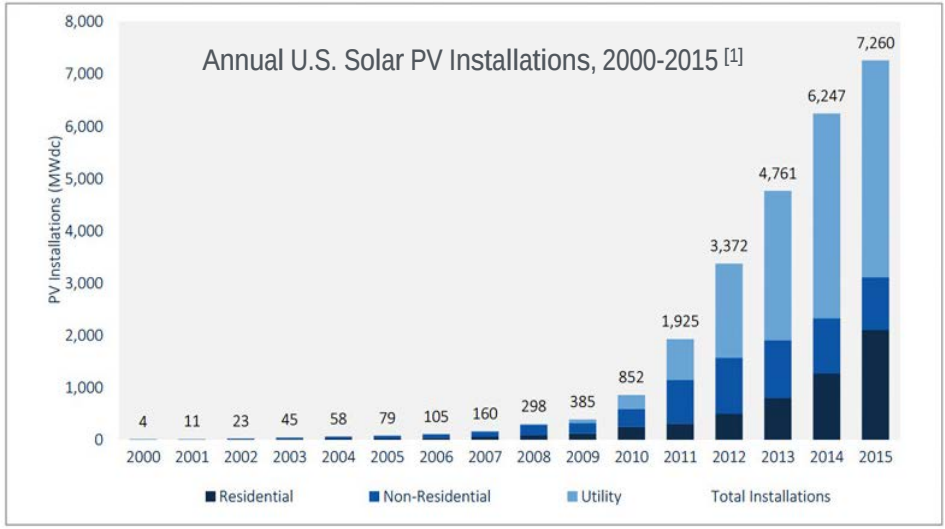
Renewable energy integration into building based on VOLTTRON™ platform



Purpose and Objectives (continued)

Target Market/Audience

- Consumer smart grid interface market for DER
  - PV
  - Energy storage
  - Wind



Impact of Project

Outputs: Enabling near real-time control and integration of renewable-energy-based power electronics inverters in green buildings by developing a universal driver interface for VOLTTRON™ platform

Near-term

- Implementing VOLTTRONTM based power electronics system for building integrated renewable energy

Long-term

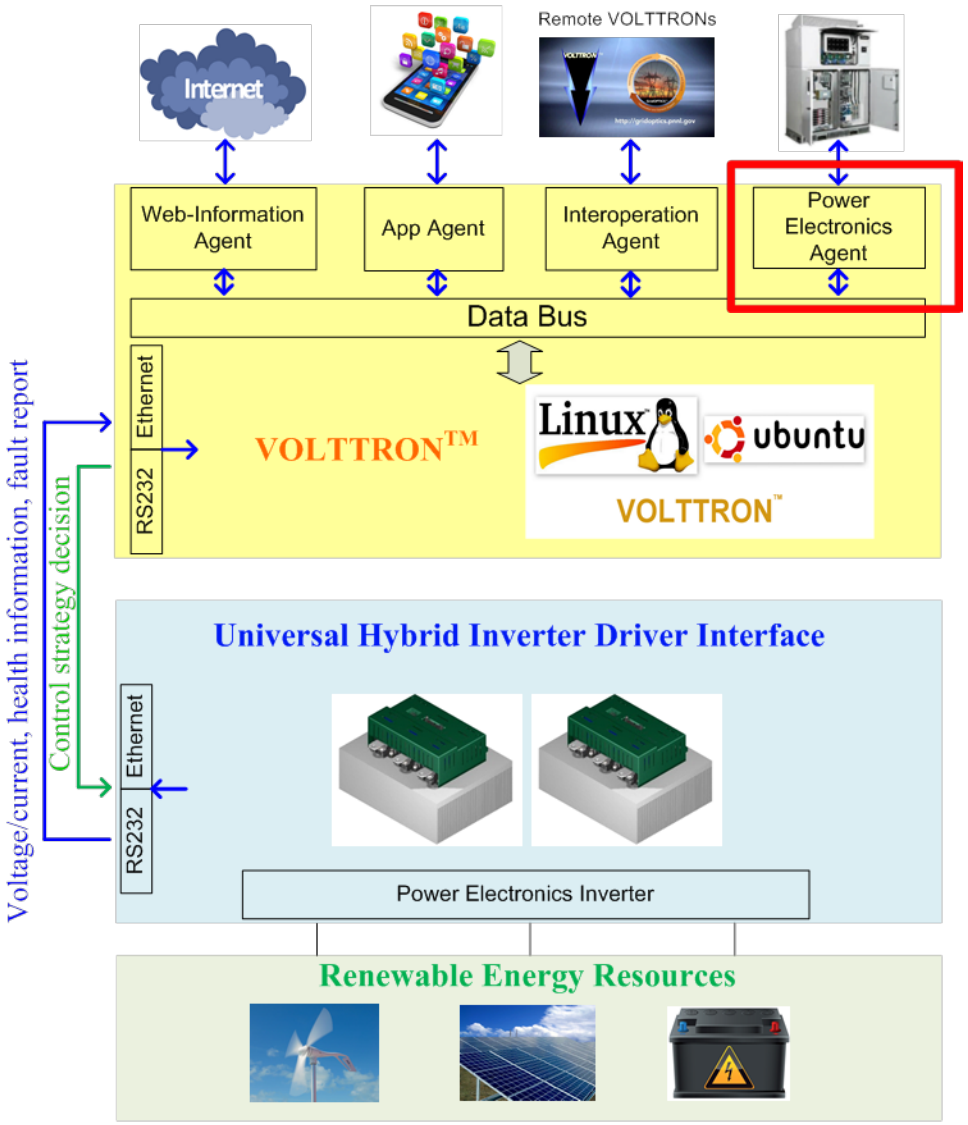
- Optimizing and exploring VOLTTRON™ functionality in energy management for large-scale electrical grid

Intermediate-term

- Providing design guidelines for industry to manufacture their inverters with proper interfaces for VOLTTRON™ platform

[1] http://www.seia.org/research-resources/us-solar-market-insight

Approach



Advanced VOLTTRON™ Control Platform(Software)

- New Power Electronics Agent Interface
- Control strategy decision maker
- Inverter status monitoring
- Communicate with other control platforms

Universal Hybrid Driver Interface (Hardware)

- Control strategy executor
- Online inverter health monitoring
- Communication interface between RES and VOLTTRON™

Summary of Tasks and Accomplishments FY16 - FY17 Q2

Advanced VOLTTRON™ Control Platform

Accomplishments:

- Completed the overall hardware and software requirements for VOLTTRON™ and hybrid driver interface
- Developed IEEE 1547 and IEEE 2030 functions for grid-tied operation of the inverter
- Simulated the control architecture to realize the functions
- Emulated the functionality of advanced VOLTTRON™ platform to validate the communication and overall architecture

Universal Hybrid Inverter Driver Interface

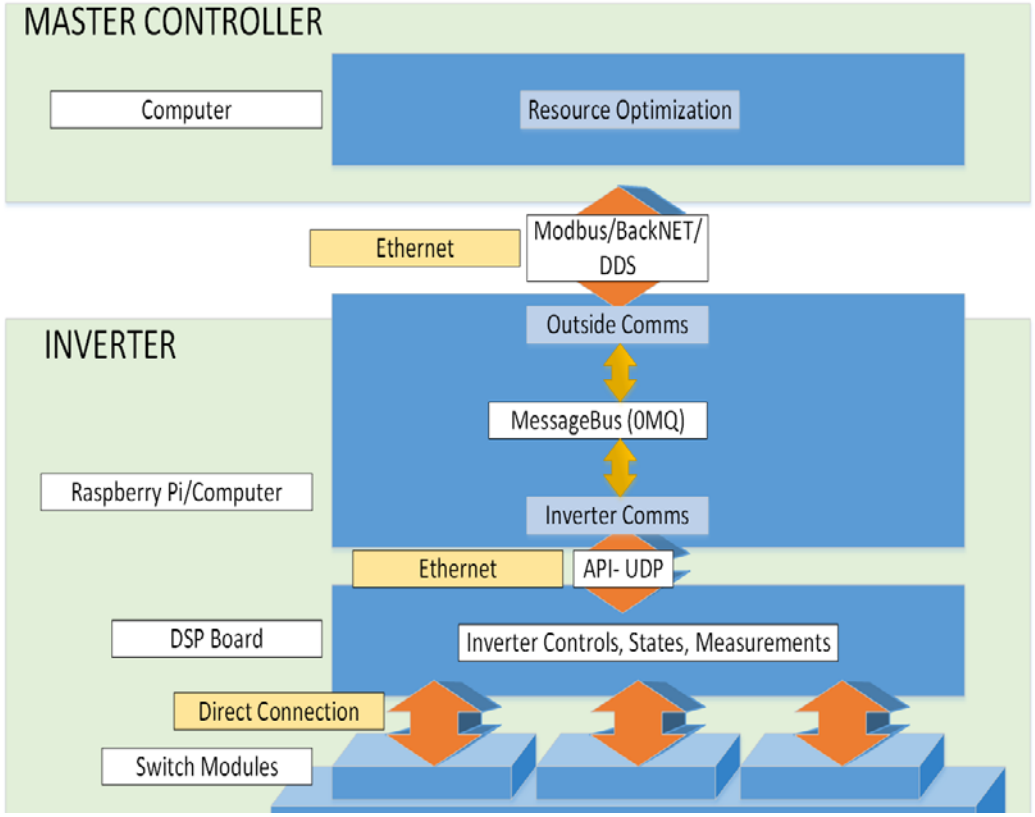
Accomplishments:

- Designed and tested advanced gate drive for short circuit and cross-conduction protection
- Completed the testing of the hybrid interface with basic functions (version 1.0)
- Evaluated a commercial inverter and identified the technical gaps SMART inverter operation
- Simulation of the hybrid interface functions and their impact on the system performance

Progress and Accomplishments

Detailed View of Overall Inverter Architecture

- Agent Inverter Comms converters the 0MQ schema to UDP for communication to the DSP board through Ethernet
  - This communication consists for inverter control states and set-points and inverter control status and measurements
- Agent Outside Comms converts the 0MQ schema to Mobus or other industry interface for communications by optimizer
  - This communication allows for any open-source communication interface to be constructed
- DSP provides all the direct control commands to the switch modules

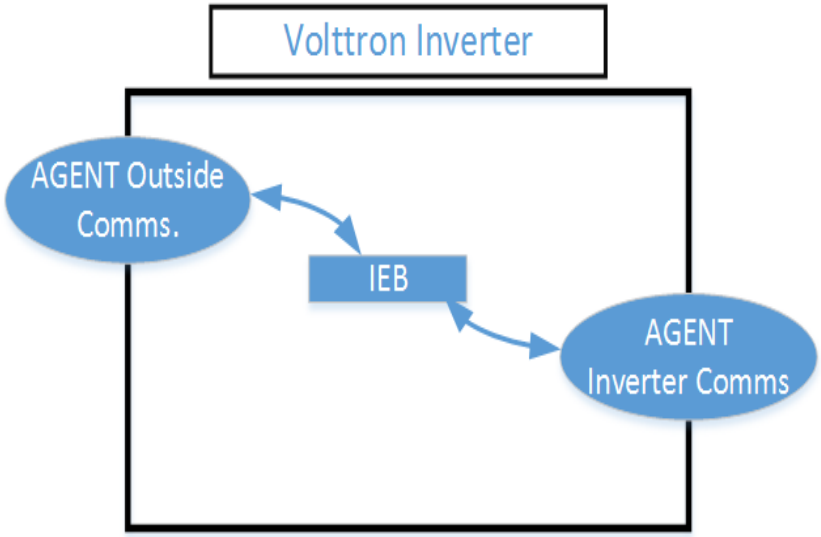


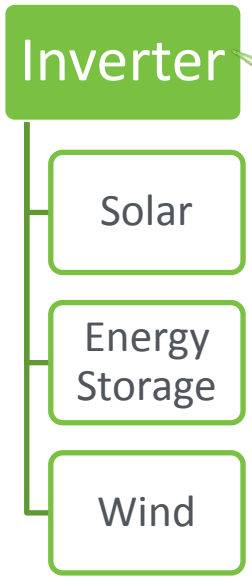
Progress and Accomplishments

Basic Layout of VOLTTRON™ Inverter Agent

- VOLTTRON™ deployed on computer or a Raspberry Pi will act as interface agent for communications to the outside

- Communication to the information exchange bus utilizes developed schema that incorporates class structure for inclusion of different inverter based resources such as:
  - Solar
  - Energy Storage
  - Easily Expandable to other…





Inverter Example Topics:

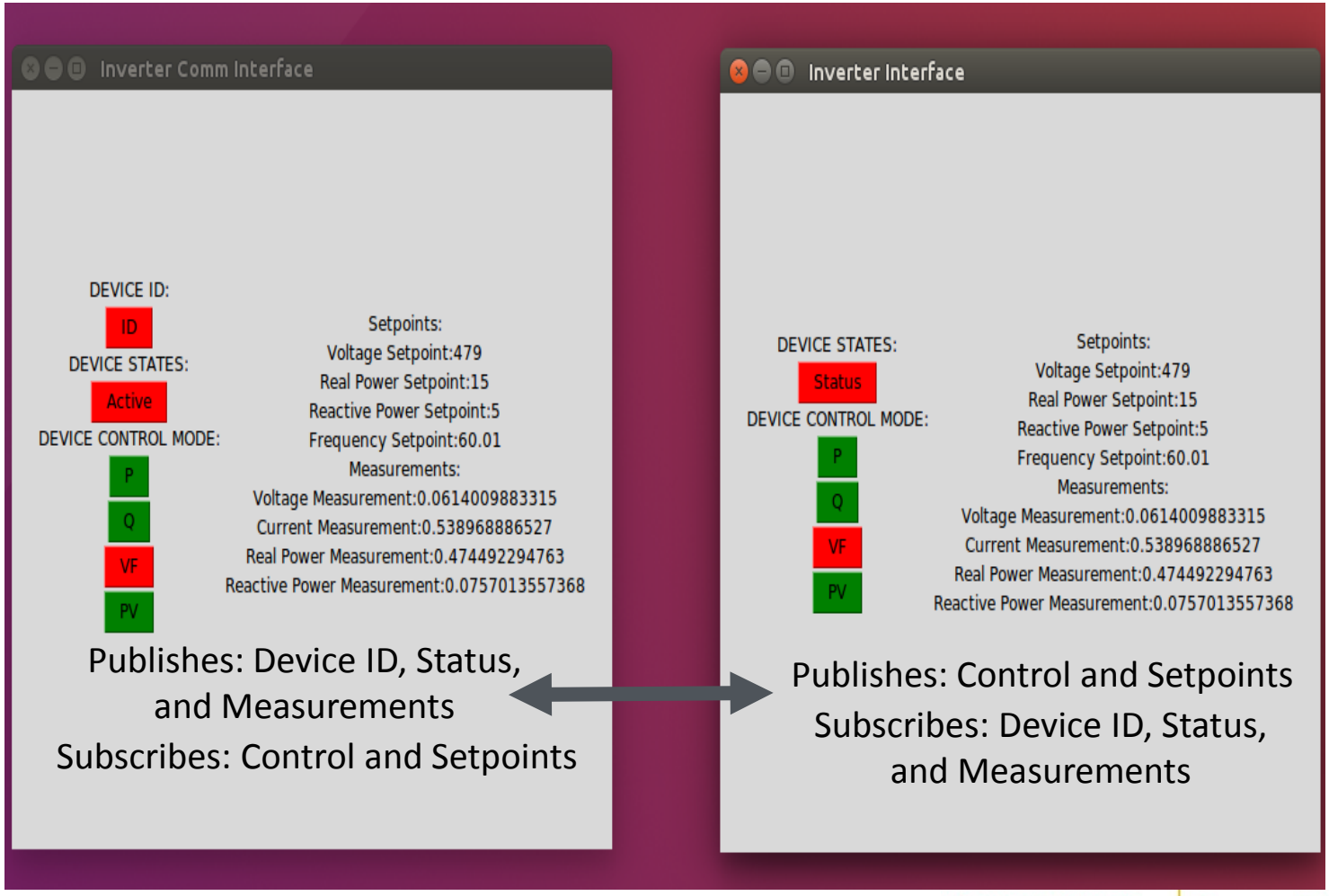
- Devicetype[1]/DeviceID#[2]/DER_Measurement /Voltage(V)
- Devicetype[1]/DeviceID#[2]/DER_Measurement /Current(A)
- Devicetype[1]/DeviceID#[2]/DER_Measurement /Real Power (kW)
- Devicetype[1]/DeviceID#[2]/DER_Measurement /Reactive Power (kVar)

Progress and Accomplishments

VOLTTRON™ Communication Emulation with Inverter Interface

Inverter Agent (Communicates Via Message Bus and Ethernet)

Inverter Agent Tester (Communicates Via Message Bus)



Technical Accomplishments

Hybrid Interface Hardware (version 1.0)

Advanced functions

- Gate drive channels with galvanic isolation
- High sinking and sourcing current

  (up to ±30 A peak, ±8 A continuous)
- Active miller clamping/crosstalk suppression
- Fault signal output function

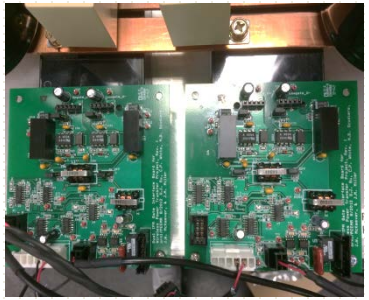
  (adjustable output holding time)
- Undervoltage lockout (UVLO) function
- Thermal protection function
- Short circuit protection function

  (adjustable reset time)
- High-precision real-time voltage and current sensing and processing
- Over-/low- AC/DC voltage/current protections
- Differential PWM signal for noise elimination
- Ethernet/CAN/RS-232 Communications

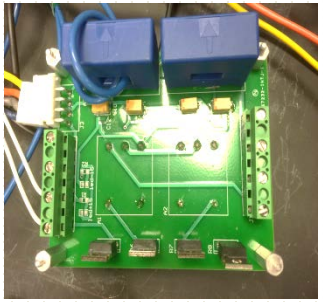
ORNL Universal Interface Board

Signal conditioning and processing

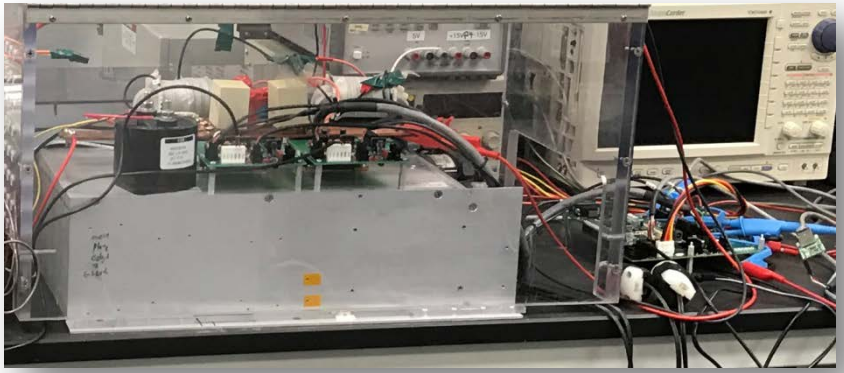
Logic translation and level shifter



Voltage/current isolation and sensing



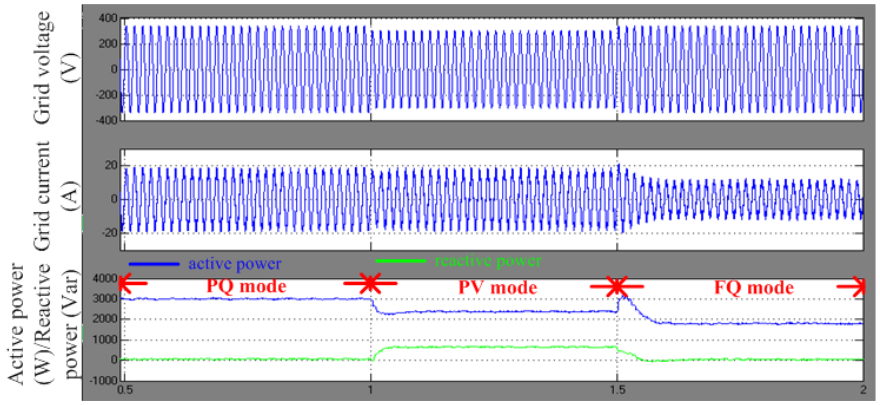
ORNL Single Phase Inverter



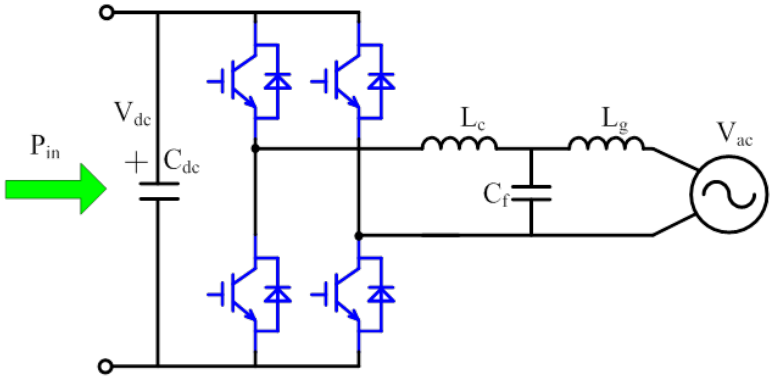
Technical Accomplishments

IEEE 1547 and IEEE 2030 Inverter Functions

Function	Role of proposed hybrid interface	Simulation verified	Coding verified
Grid-tied operation	Adaptive grid voltage tracking	✓	✓
PQ/PV/FQ mode	Power flow management	✓	✓
Islanding operation	Reconstruct a virtual grid	✓	✓
Anti-islanding protection	Seamless mode transfer through islanding detection	✓	✓
Fault ride through	Fault tolerant control	✓	✓



PQ/PV/FQ operation modes



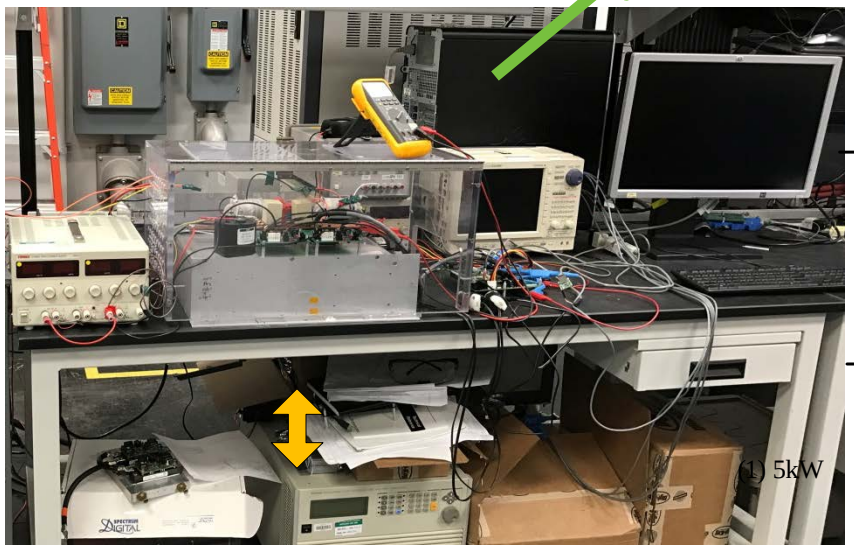
Inverter configuration

Technical Accomplishments- TEST BED

- Completed the integration of the universal hybrid interface and the single phase inverter developed at ORNL
- Completed the test bed for evaluation of the hybrid inverter interface

VOLTTRON™ EMULATOR ON A COMPUTER

DC Side



AC Side

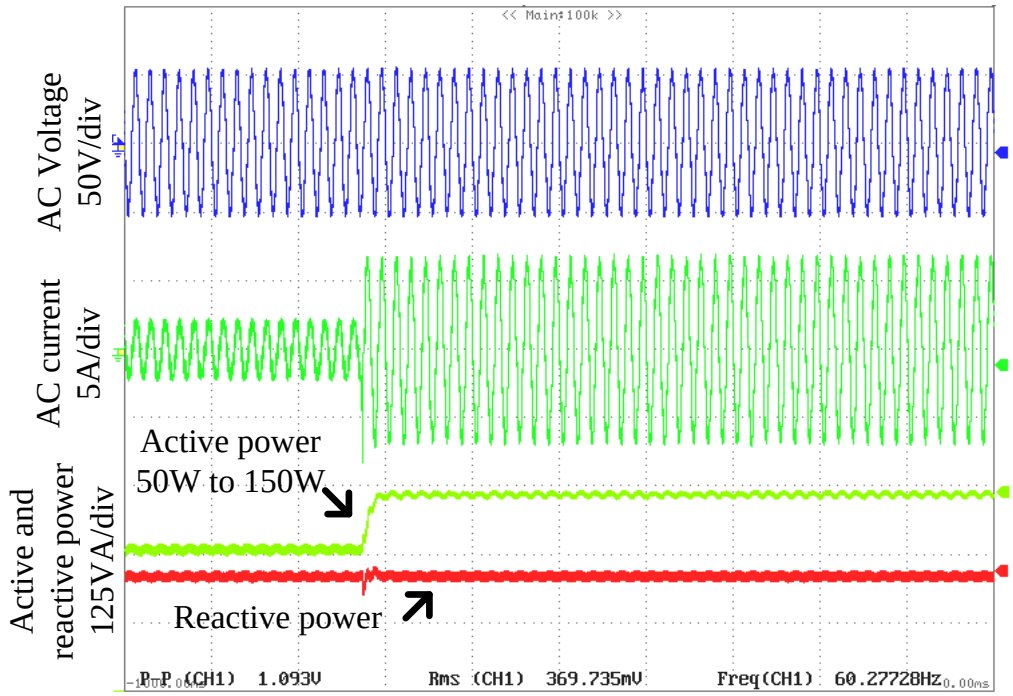
DC POWER SOURCE EMULATING DER

ORNL SINGLE PHASE INVERTER WITH THE HYBRID INTERFACE

GRID EMULATOR

Technical Accomplishments

- The simulations performed in FY16 were verified on the test bed
- The grid-tied operation was achieved on the universal hybrid driver interface prototype with closed loop control
- The active power steps up from 50 W to 150 W and the reactive power is at zero



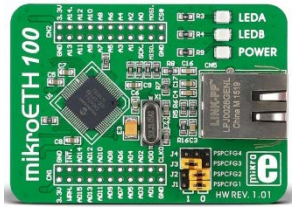
AC voltage: 50V/60Hz (peak); DC voltage: 100V; Power: 150W

Technical Accomplishments

Technology Gaps

- **Ethernet based solution for DSP controller boards**
  - No Ethernet module in the DSP boards available
  - No official recommendation solution from commercial products
  - No mature demonstration from third parties
- **Solutions**
  - **Scheme 1: Commercial Serial-to-Ethernet module**
    - Too expensive and not easy to combine into the DSP interface board due to the large size
  - **Scheme 2: Individual Ethernet chips**
    - Much cheaper chip based design, easy to combine into the DSP interface board
  - **ORNL proposed solution**
    - Use the cheaper hardware Ethernet chip from WIZnet and integrate into the interface board
    - Develop custom software for communication protocol interface in the DSP

Scheme 1[1]



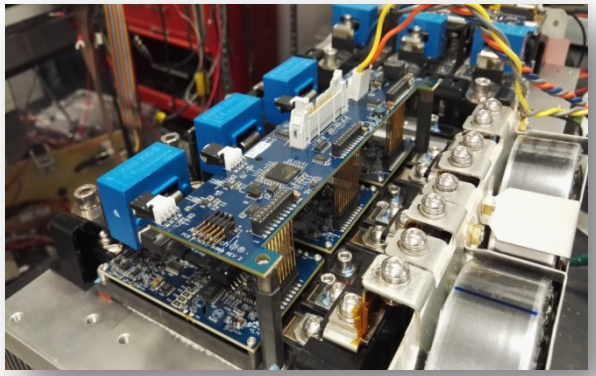
Scheme 2[2]

ORNL solution[3]

[1] Source: http://www.bb-elec.com/Products/Ethernet-Serial-Servers-Gateways/Ethernet-Serial-Device-Servers/PoE-Ethernet-to-Serial-Converters.aspx
[2] Source: http://www.digikey.sk/catalog/en/partgroup/mikroeth100-board/56675
[3] Source: http://www.digikey.com/product-detail/en/wiznet/W5500/1278-1021-ND/4425702

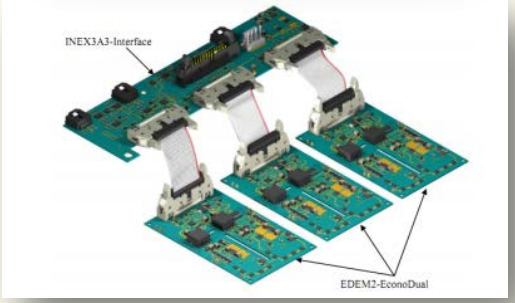
Project Integration and Collaboration

Update on Vendor Discussion

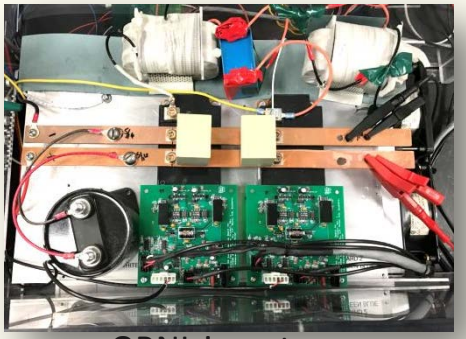


AgileStack™-Full Version

ORNL Universal Interface Board



AgileStack™-Analog Version Interface



ORNL inverter

Barriers:

- Incompatible communication protocol
- Incompatible hardware interface for digital version

Solution:

- Vendor will send analog inverter interface
- ORNL will integrate the universal hardware interface into the commercial interface demonstrate the functionality

Next Steps and Future Plans

Advanced VOLTTRON™ Control Platform

- Finalize VOLTTRON™ platform and its associated configurations
- Develop the software to integrate the control strategy in VOLTTRON™ platform
- Test the advanced VOLTTRON™ platform (with the PE agent) using the universal hybrid inverter driver interface (Version 1.0) developed in FY16

Universal Hybrid Inverter Driver Interface

- Design and test communication interface (Ethernet based)
- Design the hybrid interface hardware and validate the advance functions
- Validate the functionality of the hybrid interface using a commercial inverter

Publications

- **Pending Invention Disclosure**
  - Title: Adaptive DC-BUS Stabilizer for Building Integrated Renewable Energy Sources
  - Inventor: Rong Zeng, Zhiqiang Wang, Madhu Sudhan Chinthavali
  - Affiliation: Oak Ridge National Laboratory

- **ECCE 2017 Conference**
  - Paper ID: EC-0417
  - Title: An adaptive DC-bus stabilizer for single-phase grid-connected renewable energy source system
  - Authors: Rong Zeng, Zhiqiang Wang, Madhu Sudhan Chinthavali
  - Affiliation: Oak Ridge National Laboratory

REFERENCE SLIDES

Project Budget

Project Budget: $ 1.35 M

Variances: $150 K less than planned budget

Cost to Date: $ 280 K

Additional Funding: None

Budget History					
April – FY 2016 (past)		FY 2017 (current)		FY 2019 –March (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$350 K	0	$500 K	0	$ 500 K	0

Project Plan and Schedule

Project Schedule												
Project Start: FY16	Completed Work											
Projected End: FY18	Active Task (in progress work)											
	Milestone/Deliverable (Originally Planned)											
	Milestone/Deliverable (Actual)											
	FY2016				FY2017				FY2018			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Task 1 - Project Coordination												
Task 2.1: Identify basic hardware and software requirements												
Task 2.2: Hardware and software configuration												
Task 2.5: Core control algorithm implementation												
Task 2.6: System-level control debugging with virtual power electronics load												
Task 3.1: Determine the specification of basic and advanced driving functions and schemes												
Task 3.2: Design and fabricate circuit board with all necessary sub-interface elements												
Task 3.3: Develop low-power interface with embedded digital controller												
Task 3.4: Implement determined driving functions and schemes into low-power interface												
Task 3.5: Electrical testing of universal driver interface using various commercial power semiconductor modules												
Task 4.1: Determine the specification of DER-based power electronics inverters												
Task 4.2: Design necessary feedback interface												
Task 4.3: Power stage development and assembling												
Task 4.4: Static and dynamic characterization of power semiconductors												
Task 4.5: Electrical testing of inverters in single phase and multiphase using commercial driver interface												
Task 5.1: Integrate developed universal driver interface with power electronics inverters												
Task 5.2: Integrate driver interface and inverters with VOLTTRON™ platform												
Task 5.3: Offline static testing of inverters using VOLTTRON™ platform and universal driver interface												