GM0204: Universal Hybrid Inverter Driver Interface for VOLTTRON™ Enabled DER Power Electronics Applications
2017 Building Technologies Office Peer Review

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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)
ROHM (Electronics Vendor)

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
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 VOLTTRON™ 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

### 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 /DeviceID# /DER_Measurement /Voltage(V)
- Devicetype /DeviceID# /DER_Measurement /Current(A)
- Devicetype /DeviceID# /DER_Measurement /Real Power (kW)
- Devicetype /DeviceID# /DER_Measurement /Reactive Power (kVar)
Progress and Accomplishments

VOLTTRON™ Communication Emulation with Inverter Interface

Inverter Agent (Communicates Via Message Bus and Ethernet)

- Device ID
- Status
- Measurements

Inverter Agent Tester (Communicates Via Message Bus)

- Control and Setpoints

Publishes: Device ID, Status, and Measurements
Subscribes: Control and Setpoints

VOLTTRON™ Communication Emulation with Inverter Interface

Publishes: Control and Setpoints
Subscribes: Device ID, Status, and Measurements
Technical Accomplishments

Hybrid Interface Hardware (version 1.0)

Advanced functions

- Gate drive channels with galvanic isolation
- High sinking and sourcing current
  \(\text{up to } \pm30 \text{ A peak, } \pm8 \text{ A continuous}\)
- Active miller clamping/crosstalk suppression
- Fault signal output function
  \(\text{adjustable output holding time}\)
- Undervoltage lockout (UVLO) function
- Thermal protection function
- Short circuit protection function
  \(\text{adjustable reset time}\)
- 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

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

**Inverter configuration**

**PQ/PV/FQ operation modes**

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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
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

  – **ORNPL 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

**Project Integration and Collaboration**

**Update on Vendor Discussion**

**AgileStack™-Full Version**

**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 to 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

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<th>April – FY 2016 (past)</th>
<th>FY 2017 (current)</th>
<th>FY 2019 –March (planned)</th>
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<tr>
<td>DOE</td>
<td>Cost-share</td>
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### Project Schedule

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