2017 ADMS Program
Steering Committee Meeting

Multi-Scale Integration of Control System (EMS/DMS/BMS Integration)

Liang Min, LLNL (PI) and Mark Rice, PNNL (Plus 1)

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Sidhant Misra/LANL, and Zhi Zhou/ANL

Multi-Scale Integration of Control Systems

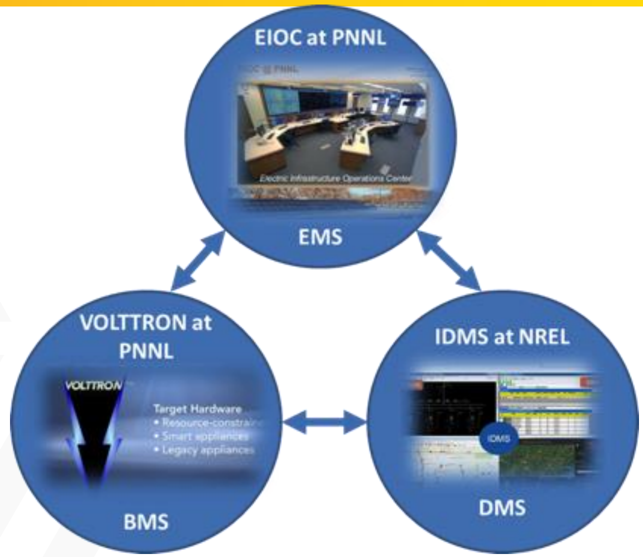
High-Level Project Summary

Project Objectives

Create an integrated grid management framework for the end-to-end power delivery system – from central and distributed energy resources at bulk power systems and distribution systems, to local control systems for energy networks, including building management systems.

Problem Statement

- ✓ The current grid operating systems were developed over the last three to four decades using a piecemeal approach, within narrow functional silos.
- ✓ The rapid growth of DERs and the increased need to integrate customers with the power system are rendering the current generation of grid operating systems obsolete.



Technical Scopes

- ✓ Develop an open framework to coordinate EMS, DMS and BMS operations;
- ✓ Demonstrate the new framework on a use case at GMLC national lab facilities.
- ✓ Deploy and demonstrate new operations applications on that framework.

Multi-Scale Integration of Control Systems
Project Team/Life-cycle Funding Summary

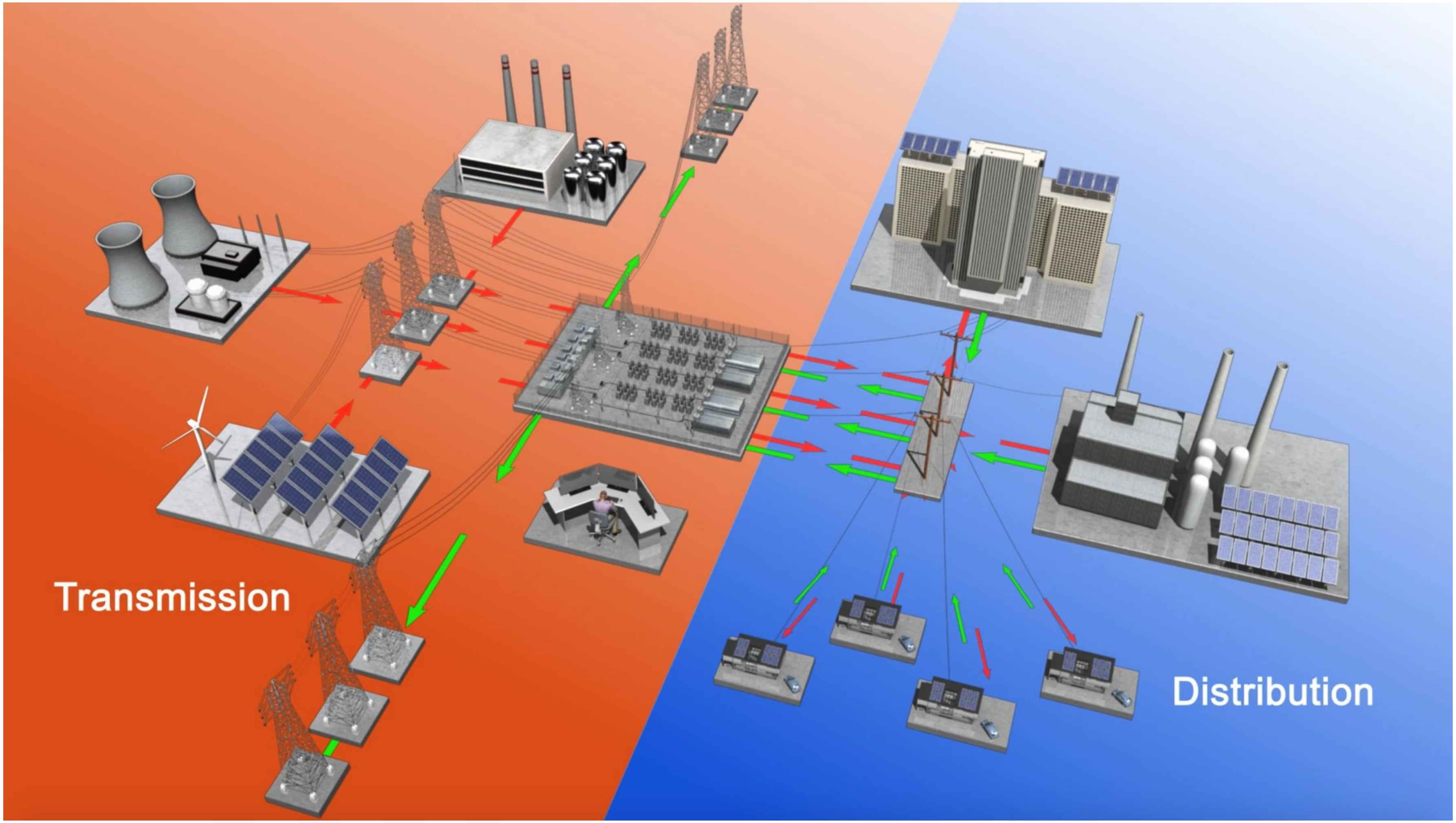
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Participants and Roles

- LLNL – PI, Task 1 lead
- PNNL – Project "+1", Task 2 lead
- NREL – Key contributor to the task 1 and 2
- SNL – Task 3 lead
- LANL – Key contributor to the task 3
- ANL – Task 4 lead
- Industry partners:
  - GE– e-terra EMS and DMS providers;
  - Duke Energy – Distribution feeder data;
  - PJM Interconnection LLC – Transmission Data.

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
LLNL	300	266	290
SNL	100	187	170
LANL	70	82	75
PNNL	380	276	270
ANL	150	142	150
NREL	200	197	195
Total	1200	1150	1150

Decoupled transmission and distribution operations are insufficient for complex smart grid systems



Specific improvements/advancements targeted by the project

Key innovations and project uniqueness

- An framework to coordinate EMS, DMS, and BMS operations, and being the FIRST in the industry to demonstrate the new framework on an industry test system.
- New transformative operations applications (probabilistic risk-based operations and forecasting data integration and decision support) that transform or extend existing EMS and DMS applications.

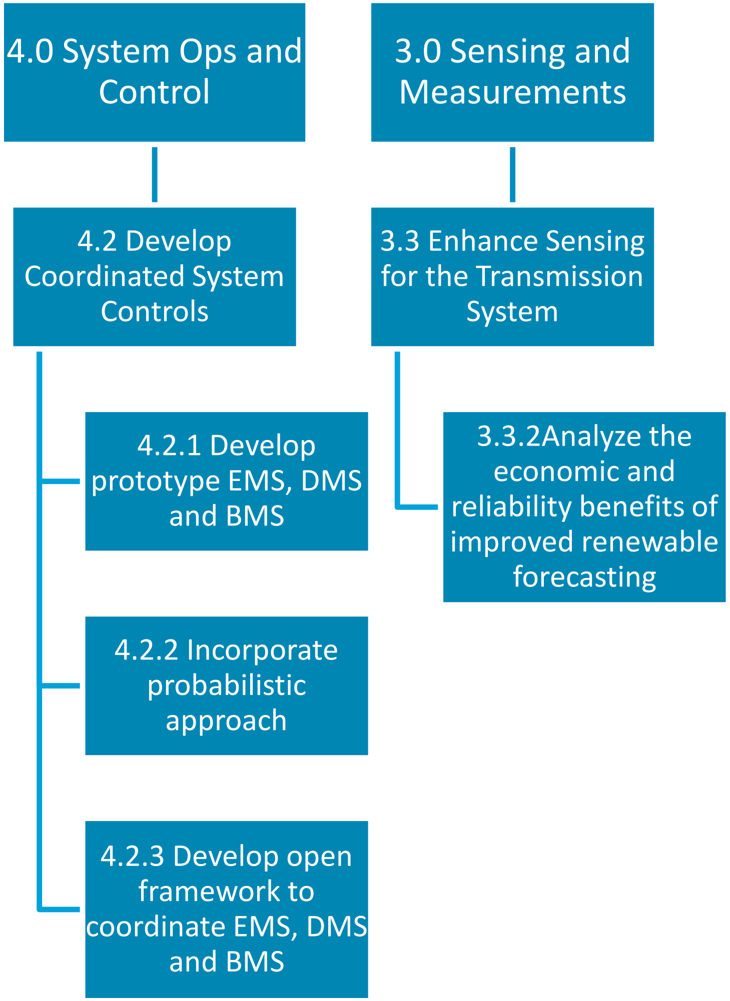
Technical tasks

- Task 1: Use case development
- Task 2: Open framework development for EMS/DMS/BMS integration
- Task 3: Integration of new DMS/BMS applications into EMS operations models
- Task 4: New application: EMS/DMS/BMS uncertainty modeling and forecasting method

Expected benefits to electric utilities

This project will support DOE's GMI to accomplish the following three Major Technical Achievements that will yield significant economic benefits of a modernized grid

- **Reduce the economic costs of power outages.** It will help grid operators leverage distributed energy resources and avoid conditions that could lead to load shedding or cause outages.
- **Decrease the cost of reserve margins while maintaining reliability.** It will substantially reduce the amount of system reserve capacity needed to cope with generation and load fluctuations, while maintaining and even increasing system reliability.
- **Decrease the net integration costs of distributed energy resources.** EMS/DMS/BMS coordination with controllability to engage response loads will help balance the variability of DERs.



Multi-Scale Integration of Control Systems
Key Project Milestones and Status

Milestone (FY16-FY18)	Status	Due Date
FY16 Mid-year Milestones: Completed the use case report and data exchange requirements/protocols report.	Done	12/1/2016
FY16 Annual Milestones: Complete integration of LANL ED with SNL UC engine; Complete integration of renewable forecasting into UC and ED.	Done	3/30/2017
FY17 Annual Milestones: Demonstrate integration of DMS and BMS information on the use case proposed under task 1; Complete the implementation and testing of UC and ED into EIOC.	40%	3/30/2018
FY18 Annual Milestones: Successfully demonstrate integrated EMS/DMS/BMS platform; Demonstrate new DMS/BMS applications in UC/ED EMS; Demonstrate the uncertainty modeling and forecasting method in the integrated EMS/DMS/BMS system.	Not started	3/30/2019

Multi-Scale Integration of Control Systems

Overall Project Budget (Planned vs Spending)

FY17 Planned	FY17 Spending	Variance
$1150K	$1093K	+$57K (<5%)

Multi-Scale Integration of Control Systems

FY16 Mid-year Milestones Accomplishments Summary

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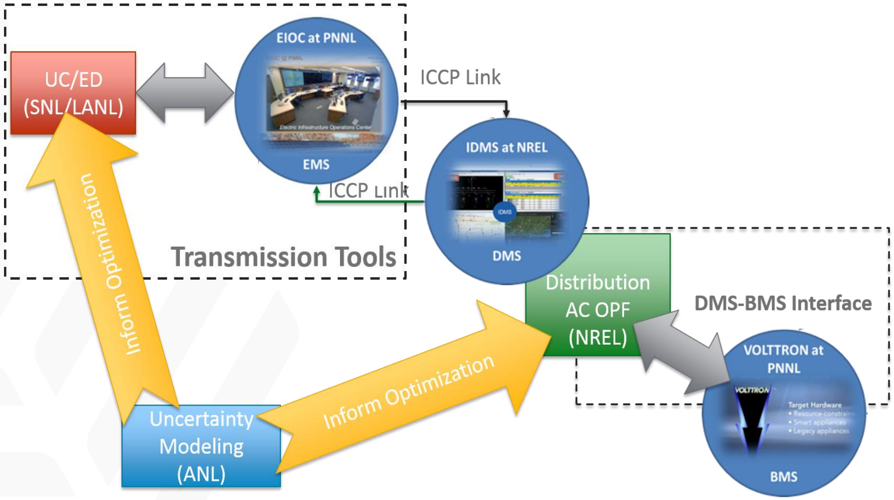
- Completed Version 1 of use case document and communication/control requirements document (Go/No-Go Milestone).
  - the connection between EIOC at PNNL and IDMS at NREL through the ICCP link (engaged the vendor, coordinating with another two GMLC projects.)
  - the connection between VOLTTRON™ at PNNL and IDMS at NREL through VOLTTRON™ Internet Protocol (Standardization is important)
- Collected Duke distribution data and Identified PJM transmission data for the demo.

Interface Definition



We have completed the use case report

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Use Case Description

- Multi-scale integration of controls systems (EMS/DMS/BMS integrations) help coordinate and operate new distributed control schemes which utilize PV inverters and demand response programs to mitigate voltage instability issues.
- EMS - Out of the 10 PJM IROLs, 8 of them are reactive power interfaces. We will use VSA (Voltage Stability Assessment) tool to assess system status and provide control suggestions.
- DMS - When voltage instability occurs, each PV inverter supplies the maximum available reactive power output and supports transmission Var emergency demand.
- BMS - Demand response programs can also be called to reduce air-conditioner compressor induction motor load. This helps recover system voltage to acceptable level instantly and prevent system voltage collapse.

Multi-scale Integration of Control Systems (EMS/DMS/BMS Integration)

1 Descriptions of Simulation Case

1.1 Background

Our of the 10 PJM IROL facilities, 8 of them area reactive power interfaces. PJM dispatch utilizes the PJM Security Constrained Economic Dispatch (SCED) system to assist operators in making cost-effective decisions to control projected constraints and Reactive Interfaces. PJM Real-Time Market uses the same SCED reactive interface constraints in calculating the real-time LMP. In case of voltage instability, the online VSA tool installed will provide control suggestions, for example, switching on/off capacitors and reactors, adjusting generator var output, re-dispatching generator MW output or load shedding. Besides these types of transmission level control schemes, we may also utilize distributed energy resource (such as smart inverters and demand response)-based distributed control scheme to prevent system instabilities.

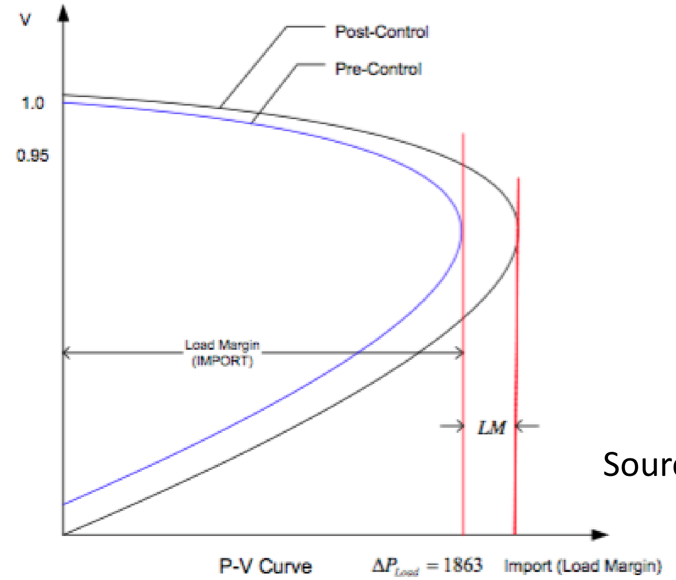
Reactive Transfer Limit / Thermal Rating	Reportable IROL Violation
Eastern Reactive Transfer Interface	Flow exceeds Last Convergent Case Limit for 30 minutes (T_v)
Central Reactive Transfer Interface	Flow exceeds Last Convergent Case Limit for 30 minutes (T_v)
5004/5005 Reactive Transfer Interface	Flow exceeds Last Convergent Case Limit for 30 minutes (T_v)
Western Reactive Transfer Interface	Flow exceeds Last Convergent Case Limit for 30 minutes (T_v)
AP South Reactive Transfer Interface	Flow exceeds Last Convergent Case Limit for 30 minutes (T_v)
Bedington – Black Oak Reactive Transfer Interface	Flow exceeds Last Convergent Case Limit for 30 minutes (T_v)
AEP-DOM Reactive Transfer Interface	Flow exceeds Last Convergent Case Limit for 30 Minutes (T_v)
Cleveland Reactive Transfer Interface	Flow exceeds Last Convergent Case Limit for 30 Minutes (T_v)
Kammer 765/500kV Transformer Thermal Rating	Post-contingency Simulated Flows exceed the Load Dump Limit for 30 Minutes (T_v)
Belmont #5 765/500 kV Transformer Thermal Rating	Post-contingency Simulated Flows exceed the Load Dump Limit for 30 Minutes (T_v)

1 9/27/2016

Use Case: Leveraging scaled-up smart inverters and DR to mitigate transmission voltage stability problems

We will use VSA (Voltage Stability Assessment) tool to assess system status and provide control suggestions in two categories:

- Reactive power control
  - Switch on/off capacitors and reactors. Adjust LTC and PAR tap positions.
  - Adjust generator var output.
  - Distributed var support from smart inverters.
- Real power control
  - Redispatch generator MW output.
  - Provide load shedding suggestion based on buses and TOs
  - Demand response from DMS/BMS



Source: PJM

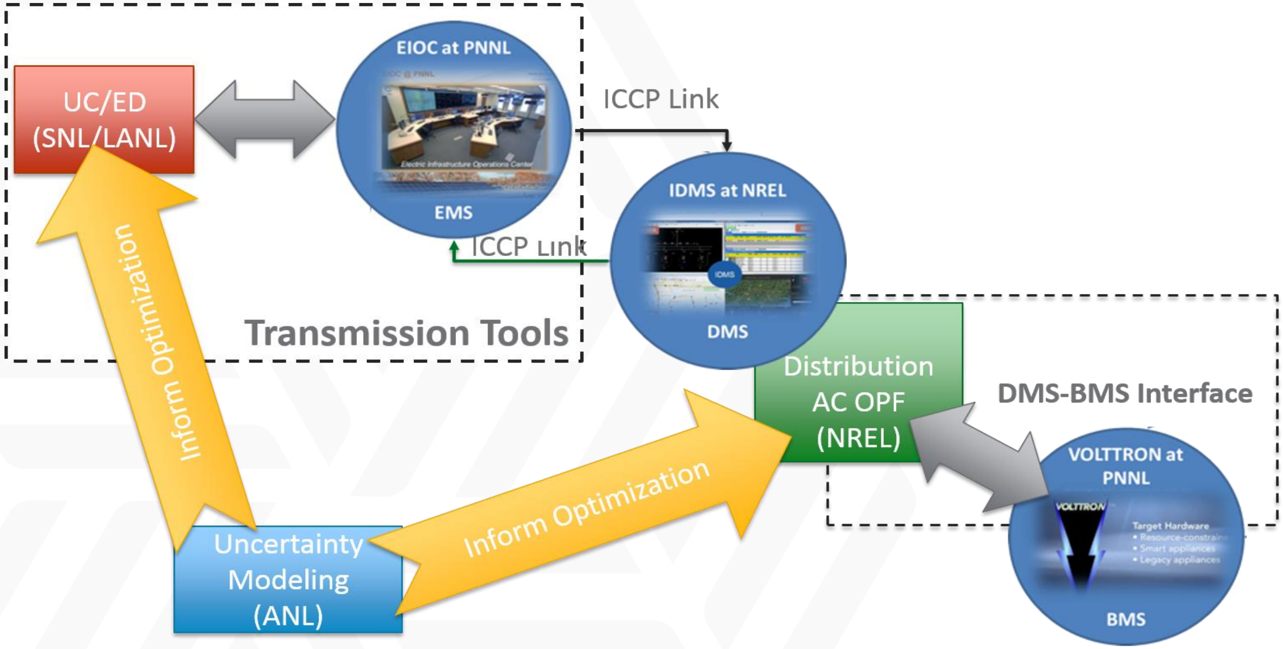
Example: Increase Load Margin Interface through extra Var support
Limiting Contingency: Contingency 1234
Pre-Control Load Pre-control load margin: *1863 MW*
VSA Control Solution:

- T option: change gen terminal voltage
- D option: send X Mvar reactive request command to DMS

Post-control load Margin: *1883 MW*

We have completed communication/control requirements document

Interface Definition



- the connection between EIOC at PNNL and IDMS at NREL through the ICCP link (engaged the vendor, coordinating with another two GMLC projects.)
- the connection between VOLTTRON™ at PNNL and IDMS at NREL through VOLTTRON™ Internet Protocol (Standardization is important)

Multi-Scale Integration of Control Systems

FY16 Annual Milestones Accomplishments Summary

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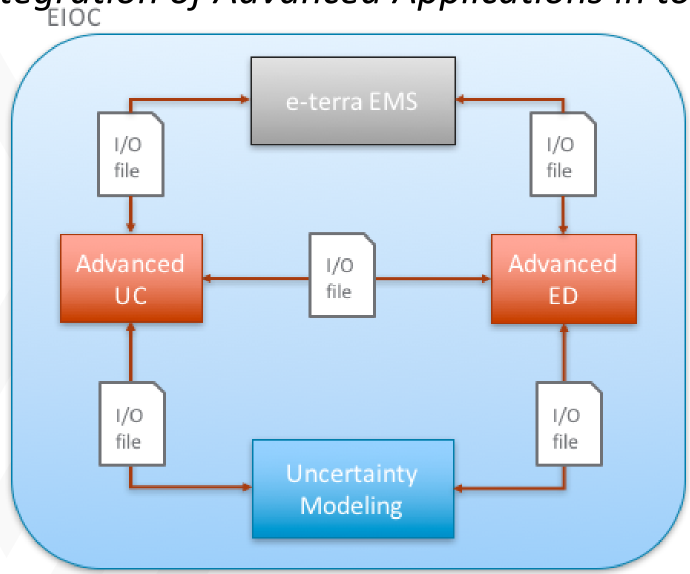
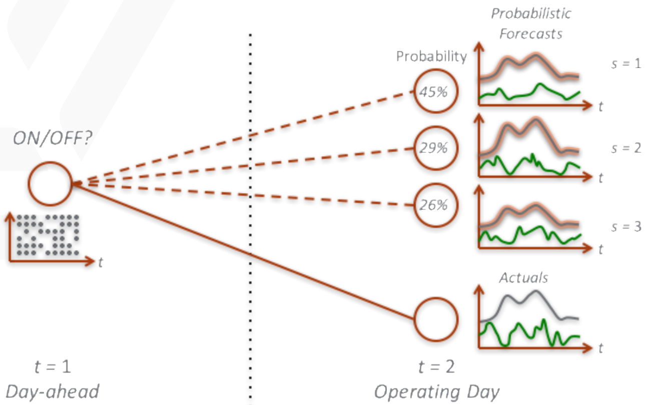
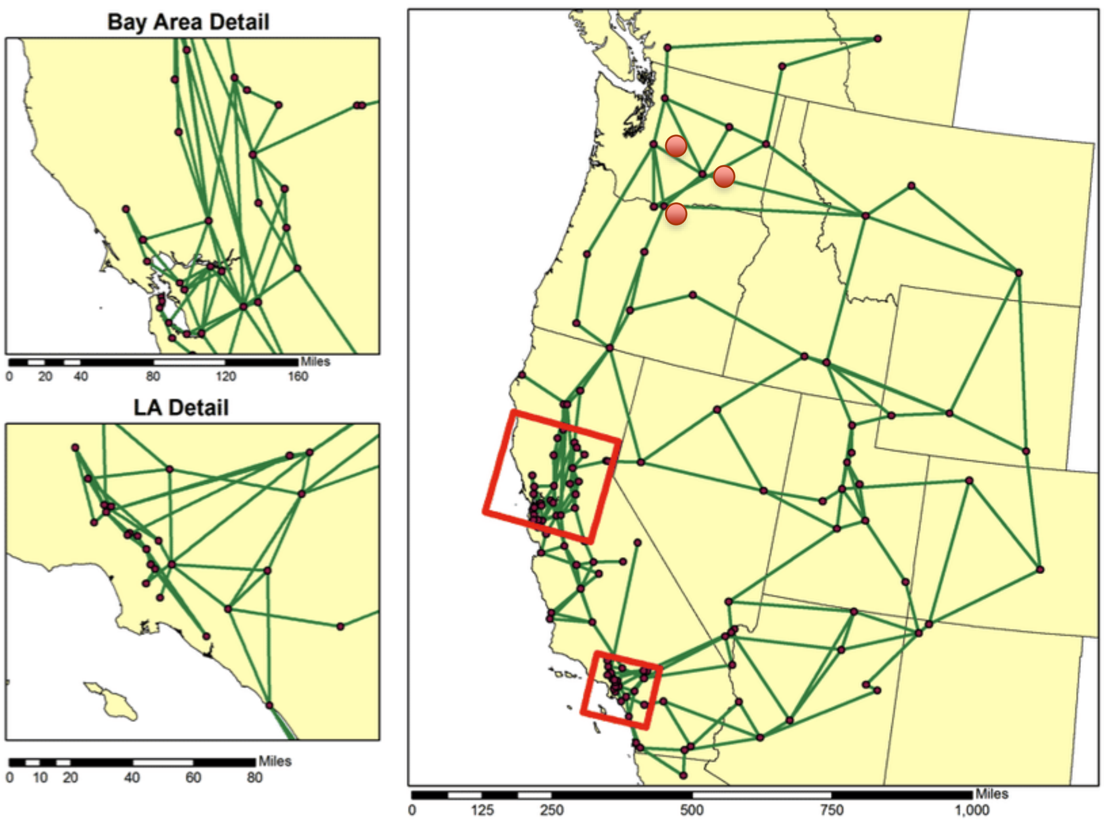
- Completed the benchmarking of stochastic unit commitment and economic dispatch;
- Completed the report of a summary on major uncertainty sources for grid operations;
- Completed integration of LANL ED with SNL UC engine; Complete integration of renewable forecasting into UC and ED;
- Completed interface definition of integrating stochastic wind forecasting, stochastic UC and ED into EIOC.

Integration of Advanced Applications in to EIOC





We used WECC-240 Bus Case for testing UC and ED integration



- Full PJM case is problematic for testing EMS-UC/ED
  - Solve time
  - Data issues
- Leveraging reference UC case being developed in ARPA-E Grid Data project
  - First of its kind

1. Munoz, F. and Watson, J.P, Comp. Management Science 12(4), March 2015

WECC-240 (with ARPA-E Grid Data)

Basic copperplate ED data (loads, gen cost curves etc.)

Network Data

UC specific data (ramp rates, startup/shutdown cost etc.)

Wind data (BPA – actual hourly realizations + hourly forecasts upto 24 hours for 14 months)

Available data

ED test case
DATA READY

UC test case
DATA READY

Stochastic UC/ED test case
Data in progress

We have completed integration of renewable forecasting into UC and ED

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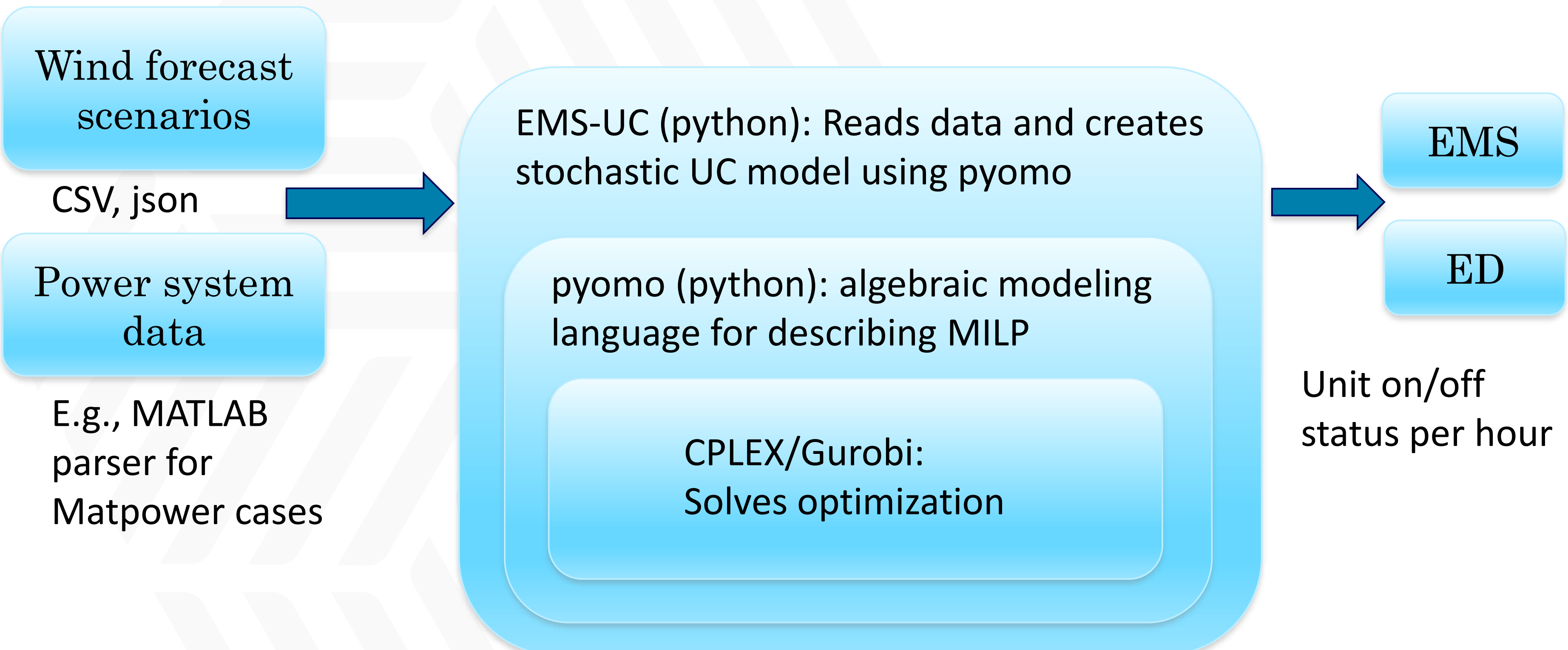


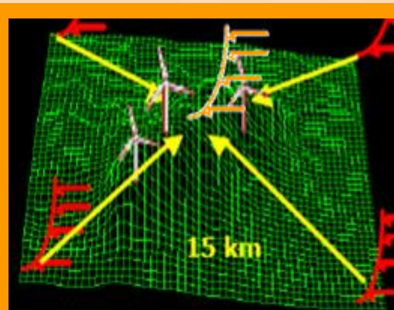
Uncertainty / Wind Power Forecasting

NWP Output Data

Weather Data

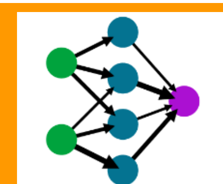
Off-site
Met Data

Site Power Gen
& Met Data



Physical Models

$$X_t = c + \sum_{i=1}^{p} \varphi_i X_{t-i} + \varepsilon_t.$$



Statistical Models

Forecast Results

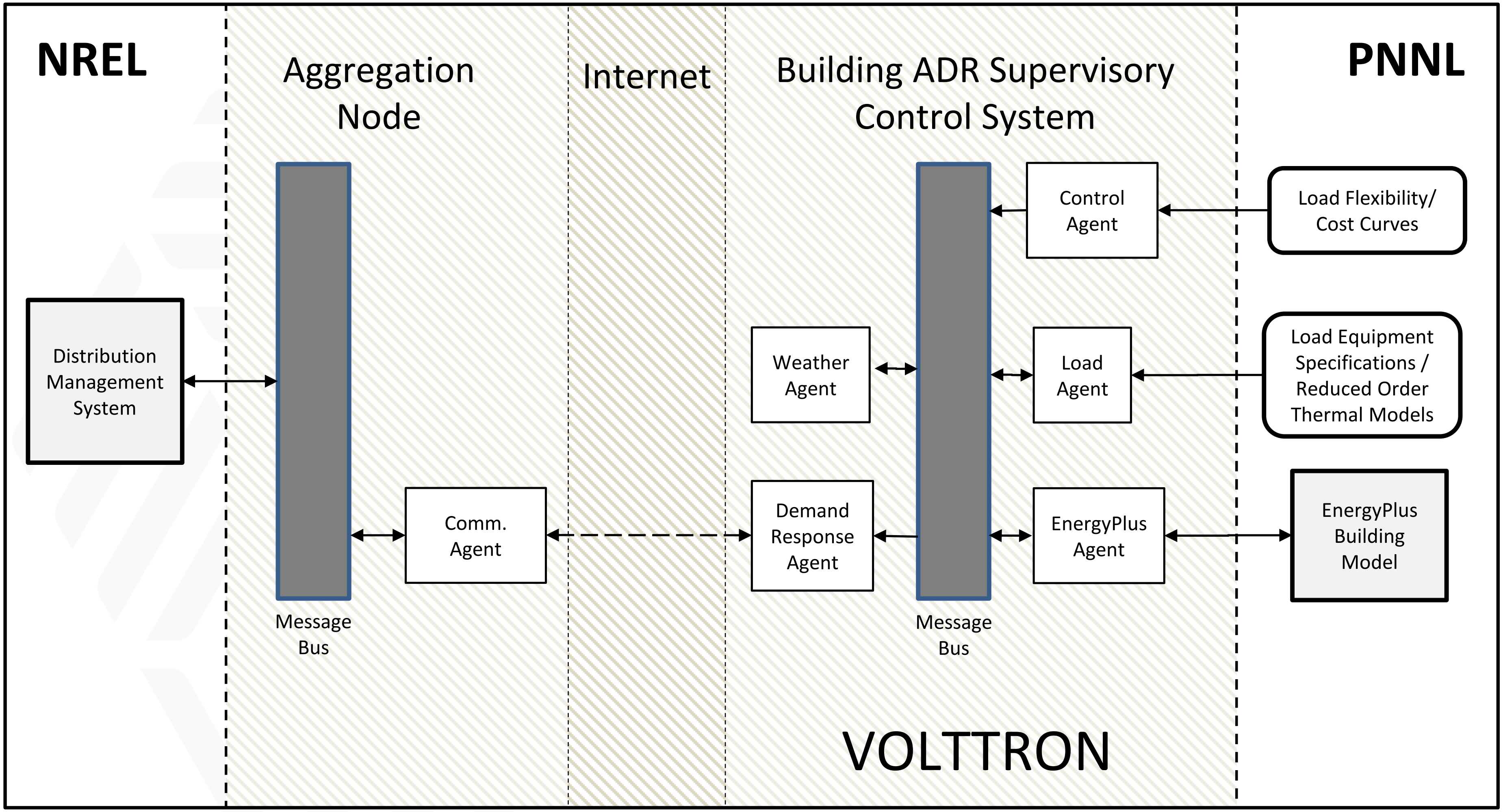
Wind Forecasts are the Result of Combination of a Diverse set of Models and Input Data

We are working on the integration of DMS and BMS information for the proposed use case.

Progress to Date

- BMS ADR Supervisory Controller developed and tested to support the initial use case
- Script developed allowing us to adapt any EnergyPlus model for integration with the BMS ADR Supervisory Controller
- BMS ADR Supervisory Controller tested with a prototypical DOE EnergyPlus models as well as a model of PNNL's SEB
- Connection verified over VIP between the DMS and BMS

DMS-BMS Implementation



DMS-BMS Integration to support the Use Case

- Scenario
  - DMS provides advance notification of a curtailment need
  - BMS increases all air conditioning set points by X °F for duration of the event
  - BMS provides indication of intent to participate for the duration of the event
  - We can explore a variety of mechanisms to relay anticipated power implications of the load actions planned
  - Evaluate the impacts of building's responses on the distribution system

DMS-BMS Interface Message Content

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messageType	Type of message being transmitted (e.g. “event notification,” “diagnostics,” “event response,” “bid,” “bid response,” etc.)
responseRequired	Required message response (e.g. “no response required,” “provide status,” “event participation,” etc.)
eventID	A unique identifier for the event within the context of the DMS
modificationNumber	A value that is incremented with each modification of the event message by the DMS
rID	Resource unique identifier
responseIndicator	Logical indicating that the message is a response to event message
eventType	Indicates event context or type and may dictate which programmatic group of participants will be affected
priorityLevel	Numerical value giving the event priority (i.e. from advisory to critical)
createdDateTime	Date time when message was created
eventDateTime	Date time of anticipated or active event
responseTime	Speed of response required
eventDuration	Duration of event
eventStatus	Status of the event (e.g. “near,” “far,” “active,” “canceled,” “completed”)
responseAction	Requested load action (e.g. “curtail load,” “increase load”)
incentiveStructure	Message indicating the type of price-based incentive or penalty during event (e.g. “price multiple,” “absolute price,” “cost curve,” etc.)
Incentive	Value of incentive or penalty
currentPower	Current power demand of the resource
Participation	Logical indication of participation
parDuration	Duration of participation
powerResponseType	Type of power response provided
powerResponse	Estimate power implications of response action.

Distribution Test System/DMS Functionality

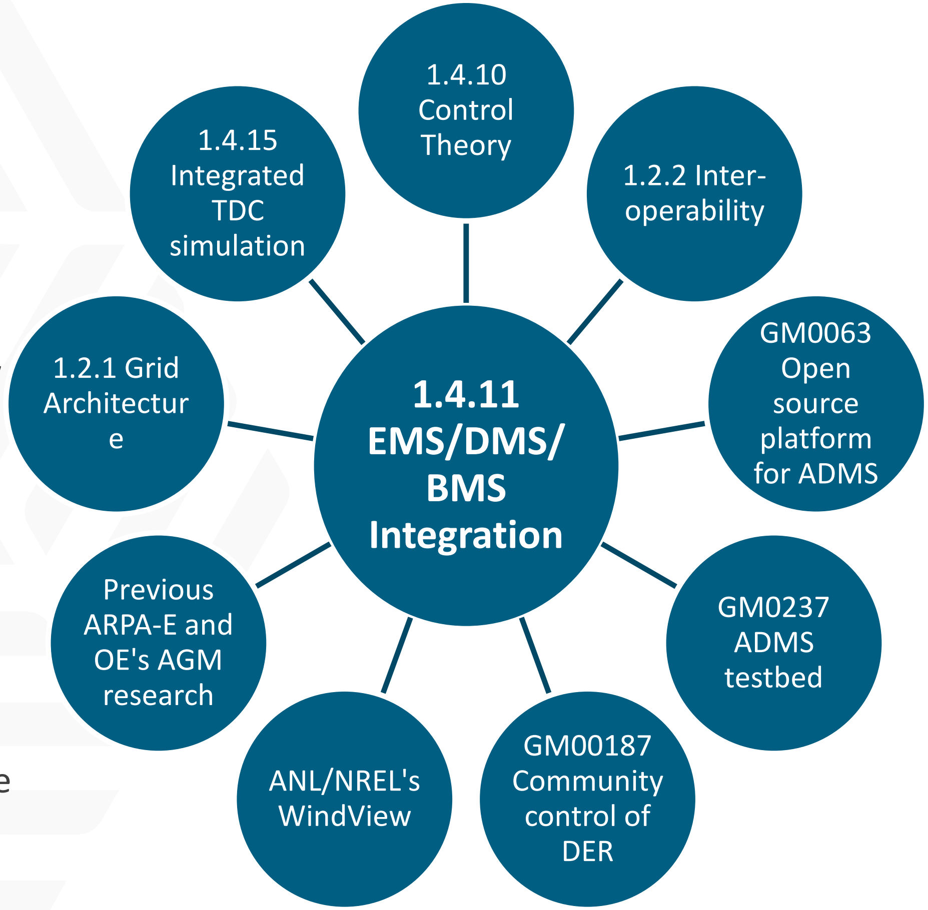
- Duke's Test Feeder
  - In Duke's North Carolina service territory
  - Nominal voltage is 12.47 kV
  - Native winter peak load of 5.26 MW
  - One 5-MW PV plant
- Existing Utility Equipment
  - Substation load tap changer
  - Two capacitor banks
  - Three sets of voltage regulators
- Data – 1 year of 1-minute resolution data
  - Feeder head substation
  - Reclosers
- Bus Load Allocation
  - Allocate the active and reactive power consumption of all loads
  - Closely match the available measurement values
- Distribution Power Flow
  - Voltage magnitude and angle at all nodes
  - Power flows through all feeder segments
- Integrated Volt/VAR Control (IVVC)
  - Determine an optimal set of control actions for voltage regulating devices
  - Achieve one or more specific operating objectives
  - Avoid violating any of the fundamental operating constraints
  - Devices include LTCs, voltage regulators, capacitors, and PV inverters

Multi-Scale Integration of Control Systems

Project Integration and Collaboration

- This project coordinates with another foundational projects -1.4.10 (control theory) and 1.4.15 (integrated TDC).
- This project coordinates with core areas 1.2.1 (grid architecture) and 1.2.2 (interoperability) to use appropriate future system architecture and interoperability standards to ensure project success.
- This project is a part of the DOE ADMS program and coordinates closely with other efforts under the program; this project coordinates with Cat 2 WindView project to visualize wind forecasting.
- This project leverages previous ARPA-E and OE's AGM research results on stochastic optimization area.

- Participated and presented at the Advanced Distribution Management System (ADMS) Industry Steering Committee kick-off workshop, April 2016
- Participated and presented at the 2016 IEEE Innovative Smart Grid Technologies ADMS panel, September 2016
- Will present at the 2017 IEEE Innovative Smart Grid Technologies ADMS panel, April 2017.



FY18 Plan

Key activities/milestones planned for FY18 include:

- Complete the implementation and testing of UC and ED into EIOC computational environment using WECC 240 bus model by the end Q1 of FY18.
- Demonstrate the integration of DMS and BMS using Duke Energy's data by the end Q2 of FY18.

Risks/Mitigation plans

Description	Severity	Response
The main risk associated with the integration of different control systems at different national labs (the EIOC and VOLTTRON at PNNL and IDMS at NREL) is network latency, which can impact communication between control systems.	Medium	PNNL and NREL have collaborated successfully in the past to remotely connect the Gridlab-D simulation at PNNL with the ESIF at NREL. The network latency issue has been discussed and considered.

FY18 Plan

Go/no-go decision

- **We have received both PJM-EMS and Duke-DMS data for this project**

Description	Criteria	Date
If the ESIF SCADA data and utility data from the virtual distribution feeder cannot be obtained by the end of the second quarter of FY18, will use existing data that PNNL and NREL previously acquired from another test site, such as AMI data from PNNL and the AEP gridSMART demonstration.	If utility testing data are obtained.	03/31/2018

Tech Transfer Activities

Industry Collaborators and Roles

- GE– e-terra EMS and DMS providers;
- Duke Energy – Distribution feeder data;
- PJM Interconnection LLC – Transmission Data.

Conference presentations/Reports

- DMS - BMS Interface Definition, PNNL Technical Report, Nov, 2016;
- Multi-scale Integration of Control Systems Use Case, LLNL Technical Report, LLNL-TR-712277, Nov, 2016;
- DOE GMLC Peer Review Presentation, April 2017;
- IEEE 2017 ISGT ADMS Panel Presentation Release number-LLNL-PRES-729081, April 2017;
- Proposed to participate in IEEE 2018 GM TSO-DSO panel;

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