ADMS Testbed Development

1. Define question
   - Determine question/challenge to address
   - Define use case
   - Identify value proposition

2. Create test to answer question
   - Define test plan
   - Provide equipment capabilities

3. Run test
   - Provide field data (models, load data)
   - Configure test bed and execute test plan
   - Provide technical support

4. Get answer to question
   - Improve operations, reduce costs, gain new insights
   - Results analysis
   - Product performance insights
ADMS Applications

• 15 advanced distribution management system (ADMS) applications considered for discussion
  – Demand response (DR)
  – Short circuit analysis
  – Distributed energy management system (DERMS)
  – Standard outdoor measurement (SOM)
  – Etc.
ADMS Applications Continued

- Volt-VAR Optimization (VVO)
- Fault Location Isolation & Service Restoration (FLISR)
- Online Power Flow (OLPF)/ State Estimation (DSSE)
- Market Participation
OLPF/DSSE Use Cases

• **Data Remediation**
  – Data needs for feeder models; specifications and locations for adding new telemetry points; impact on ADMS applications

• **Calibrate OLPF/DSSE functions**
  – Comparing the states’ testbed measurements, tuning algorithms

• **Evaluate performance of hierarchical distributed sensing**
  – Integrating sensing technologies like advanced metering infrastructure (AMI), OpenFMB, OpenADR, grid-edge smart controls, distribution phasor measurement units (PMUs)

• **Modeling loss of photovoltaic (PV) generation**
  – Behavior of behind-the-meter components for PV, net load allocation, integrating forecasting, customer facility data, load models, etc.
VVO Use Cases

• Voltage Regulation
  – Legacy voltage control assets, smart inverters, energy storage, autonomous controllers

• Peak Load Management
  – Conservative voltage regulation (CVR) for peak load management and interaction with “aggregators” like a DERMS and Demand Response Management System (DRMS)

• Performance evaluation
  – Multi-objective VVO, different control architectures

• Interaction with Active Grid Edge Devices
  – Centralized VVO with grid-edge controllers
FLISR Use Cases

• High penetration of distributed energy resources (DERs)
  – Upstream and downstream DERs; line loading before and after fault; intermittency and visibility challenges
• Interaction with microgrids
  – Impact of temporary fault, black start capability, need for direct communication
• Very high loading conditions
  – Unnecessary backup feeder trip; use of load forecasting
• Multiple simultaneous faults
  – Severe thunderstorms leading to multiple faults, feeder re-tripping and lockouts
• Widespread outages
  – Uncertain distribution configurations, assessment of communication status and feeder outages
Market Participation Use Cases

- Maintaining power quality while providing bulk grid services
- Distribution system operations (DSOs) providing market functions
- Estimating available capacity for bidding in energy markets
## Simulation time scales

<table>
<thead>
<tr>
<th>Application</th>
<th>Use Case</th>
<th>Simulation Time Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>VVO (sub-second simulations</td>
<td>Traditional VVO</td>
<td>1 second</td>
</tr>
<tr>
<td>with hardware)</td>
<td>Inverter Controls</td>
<td>Milliseconds</td>
</tr>
<tr>
<td>FLISR</td>
<td>High resolution Electromagnetic Transients Program (EMTP) simulations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>to characterize protection system; second-scale for ADMS</td>
<td></td>
</tr>
<tr>
<td>Market Participation</td>
<td>Frequency Regulation</td>
<td>1 second</td>
</tr>
<tr>
<td></td>
<td>Demand Response</td>
<td>1 second</td>
</tr>
<tr>
<td></td>
<td>Synthetic Inertia</td>
<td>Milliseconds</td>
</tr>
<tr>
<td></td>
<td>Peak load management</td>
<td>A few seconds to minutes</td>
</tr>
</tbody>
</table>
ADMS Use Case 1
ADMS Testbed Capabilities

• Use Case 0
  – ADMS internal power flow with power hardware-in-the-loop (PHIL) with a PV inverter

• Use Case 1
  – Multitime scale simulation as external power flow
  – Integrated data collection and management system

• Use Case 2
  – Integrated application
Use Case 1 - Objective

Evaluate performance of the ADMS VVO application for different levels of model quality and different levels of measurement density

– Performance improvements from accurate model
– Offset model inaccuracies with additional telemetry
– Tradeoff between model quality and telemetry density
Model Quality & ADMS Deployment

• Model quality is essential for accurate ADMS performance
• A geographical information system (GIS) is a typical source for ADMS
• Model and data cleanup = up to 25% of ADMS costs
• Upkeep of models during operation is a critical need
Important Questions

• What level of data cleanup needs to be performed for successful deployment?

• Can the need for data cleanup be offset by deploying additional sensors?

• Can sensors such as AMI be used in addition to supervisory control and data acquisition (SCADA) points to improve ADMS performance?

• What is the impact of the reduced data quality on the performance of ADMS and its applications?
Use Case Setup

Levels of Model Quality

- **Level 1** – Base level GIS data
- **Level 2** – Field verification at select locations
- **Level 3** – Tap phase verifications
- **Level 4** – Field confirming each primary pole line

Levels of Measurement Density

- **Level 1** – Feeder head
- **Level 2** – Level 1 + utility assets + 1 tail-end AMI sensor
- **Level 3** – Level 2 + additional 9 AMI sensors
- **Level 4** – Level 3 + additional 20 AMI sensors
Test Setup

Phase I: Software-based simulations
Phase II: Hardware-in-the-loop (HIL)-based evaluation
## Test Metrics

<table>
<thead>
<tr>
<th>Test Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVR Energy Reduction</td>
<td>Feeder energy consumption before and after application of CVR</td>
</tr>
<tr>
<td>System Average Voltage Fluctuation Index</td>
<td>Average voltage fluctuations for all nodes within the time period. Represents the flatness of the voltage profile.</td>
</tr>
<tr>
<td>System Control Device Operation Index</td>
<td>Number of times the capacitor banks were turned on or off</td>
</tr>
<tr>
<td>Capacitor bank operations, load-tap changing (LTC) or voltage regulator operations</td>
<td>Number of times the LTC/voltage regulators were operated</td>
</tr>
<tr>
<td>System Energy Loss Index</td>
<td>Ratio of total energy loss during the entire simulation time to the total load</td>
</tr>
<tr>
<td>Power factor</td>
<td>Power factor computed at selected nodes</td>
</tr>
</tbody>
</table>

![Impedance Model Improvement](image)
Phase I - Initial Results

 réalisation graphique

Tail-End Voltage

Measurement Density →
Phase I – Initial Results

Voltage Spread For one day

<table>
<thead>
<tr>
<th>Measurement Density</th>
<th>Tail-End Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>8</td>
</tr>
<tr>
<td>L2</td>
<td>6</td>
</tr>
<tr>
<td>L3</td>
<td>2</td>
</tr>
<tr>
<td>L4</td>
<td>0</td>
</tr>
</tbody>
</table>
Performance Against Model Quality

Level 1

Level 4
Test Setup
Model Conversion

- Xcel Energy feeder converted from CIM to OpenDSS
  - Validating against Synergi model from Xcel
  - Tool to convert from OpenDSS to ePHASORSIM completed
Configuring the ADMS
## Use Case 1 - Summary

<table>
<thead>
<tr>
<th>Test Metric</th>
<th>Description</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVR Energy Reduction*</td>
<td>Feeder energy consumption before and after application of CVR</td>
<td>Feeder head voltage and current measurements</td>
</tr>
<tr>
<td>Average Absolute Deviation*</td>
<td>Sum of absolute voltage deviation at each node divided by number of nodes.</td>
<td>RMS voltage at every node collected from software-based simulation platforms</td>
</tr>
<tr>
<td>Voltage Excursions</td>
<td>Number of voltage violations (beyond the acceptable range of 0.95-1.05pu)</td>
<td>RMS voltage at every node collected from software-based simulation platforms</td>
</tr>
<tr>
<td>Capacitor bank operations</td>
<td>Number of times the cap banks were turned on or off</td>
<td>Cap operations as recorded from the cap bank controller</td>
</tr>
<tr>
<td>Voltage Regulator operations</td>
<td>Number of times the voltage regulators were operated</td>
<td>Regulator operations as recorded from regulator controller</td>
</tr>
<tr>
<td>Cost of operation</td>
<td>Cost of voltage regulation; incurred from operation of cap banks, regulators, etc.</td>
<td>ADMS output</td>
</tr>
<tr>
<td>Power factor</td>
<td>Power factor will be computed at selected nodes</td>
<td>Voltage and current or power measurements collected from software-based simulation platforms</td>
</tr>
</tbody>
</table>

* primary test metrics
Next Steps

• Completing Phase I simulation studies
• Identify two scenarios from Phase I for validation with HIL Evaluation
• Develop methodology to enable equitable comparison of Phase I and Phase II results
Use Case 2: Integrated Use Case
ADMS Testbed Capabilities

• Use Case 0
  – ADMS internal power flow with PHIL (PV inverter)
• Use Case 1
  – Multitime scale simulation as external power flow
  – Integrated data collection and management system
• Use Case 2
  – Integrated application (EMS + ADMS + DERMS)
Integrating DERMS with ADMS – Opportunities

• Controls aggregation
  ✓ ADMS can exercise control over additional assets
• Model and data abstraction
  ✓ Limit what details are needed to model/observe the DERs
• Performance improvement
  ✓ Allow grid-edge control for improved performance
• Advanced capabilities
  ✓ DSO-type functionalities with multiple DER aggregators
Integrating DERMS with ADMS – Challenges

• Model abstraction
  – Extent of abstraction can very based on application
• Data exchange
  – How often and what data needs to be exchanged?
  – Communication speed is a constraint when designing applications
• Interfaces and messages
  – Lack of mature standards
• Customer participation
  – Value case, incentives, multiple controllers at home level
• Measurement vs model-based DERMS
  – Different needs based on the DERMS technology
Potential Applications

• Service Restoration (FLISR + DERMS)
  – Passive: FLISR uses DERMS-estimated group DER capacity to plan reconfiguration
  – Active: DERMS provides requested group DER capacity for specified duration
  – FLISR is restricted; other assets used for reconfiguration; load relief

• Peak Management (dynamic voltage regulation (DVR) + DERMS)
  – ADMS uses DVR to clamp voltages at 114 V; DERMS dispatches DERs to lower peak demand
Other Potential Integrated Applications

• Adaptive relay protection: Issue adaptive settings for relays based on DERMS forecast.
• Load Shedding/Emergency Response Service (ERS) programs: DER assets as first resort before load shedding through DERMS; some programs are a requirement while some are incentivized; DERMS can improve operations for both.
• DERMS for maintaining grid reliability: Under Frequency Load Shedding (UFLS), Under Voltage Load Shedding (UVLS), Emergency Voltage Reduction (some voltage violations acceptable for deeper MW cut).
• Instabilities (angular, voltage) from the transmission side: DERMS as a lever for bulk grid operators; DERMS for increasing Available Transfer Capacity (ATC) along transmission corridors by addressing instability criteria.
• Market applications: Ancillary markets; large area restoration; black start.
Objective

- Evaluate performance of peak load management use case coordinated across ADMS, DERMS & EMS
  - Communication interface between ADMS & DERMS
  - Reference controls architecture for interoperability
  - Effectiveness of DERMS in complementing ADMS operations
  - Focus on municipal and cooperative utilities
Peak Load Management - Questions

• How effective is DERMS in augmenting ADMS performance? (Performance evaluation: DVR only; DERMS only; DVR + DERMS)

• Are certain types of DERs better for this application? (types of DER: PV only, PV+ES, PV+ES+DR, etc.)

• How much controllable DER assets are needed to make a difference? (% controllable DER penetration)

• What information needs to be exchanged, and how often?
Use Case 2 Summary

• General Electric’s EMS initiates peak load management
• Survalent’s ADMS controls legacy assets to lower voltage
• DERMS dispatches the DER assets (PV, Energy storage and load) to reduce load
• Utility partner: Holy Cross Energy (HCE)
• ADMS/DERMS enterprise-level interface: National Rural Electric Cooperative Association’s (NRECA’s) MultiSpeak
Use Case 2 – Test Setup
NREL’s Real-Time Optimal Power Flow DERMS

Reserve provisioning
\[ \{ r_{n+1}^{T+1}, \ldots, r_{n+T}^{T+T} \} \]

Real-time module
\[ (P_{n}^{t}, Q_{n}^{t}) = C_n(P_{n}^{t-1}, Q_{n}^{t-1}, d^t) \]

Commands to DERs

Reserve provisioning
\[ \{ r_{n+1}^{T+1}, \ldots, r_{n+T}^{T+T} \} \]

Real-time module
\[ d^t = D(y^t, P_{0,\text{set}}^t) \]

Measurements
\[ y^t = \{ V^t, I^t, P_0^t \} \]

Power Substation

Set Point

Past Present Future

M Up M Down

Voltage magnitude [pu]

9:00 10:00 11:00 12:00 13:00 14:00 15:00

Node 2 Node 28 Node 35
Use Case 2 Status

- CRADA between NREL and utility partner Holy Cross Energy; data received from Holy Cross Energy
- Multi-party NDA between the project partners
- Multiple cooperative/municipal advisory partners identified
  - Subcontracting underway with Survalent Inc, NRECA & Heila
  - Scoping discussions with partners
Synergistic Efforts around Use Case 2

Drivers
- Increasing DER Penetration
- Lack of Observability/Controllability for Behind-The-Meter DERs
- Economics

Resources
- AMI Measurement
- Solar PV
- Electric Vehicle
- Distributed Control
- Flexible Building Loads

Advanced Modeling and Techno-Economic Study

ESIF HIL Evaluation using ADMS Test Bed

Field Deployment

Outcomes
- Visualization of grid operations and impact of DERs
- Controllability of DERs to provide grid and customer benefits
- Business Model to demonstrate the values of DERs

Grid Modernization via non-wires alternatives
Other ADMS Projects
Use Case 3: ENERGISE ECOIDEA

Data-enhanced architecture for integration of centralized and distributed controls for VVO

- Utility enterprise
- Varentec ENGO® devices
- Real-time optimal power flow
- State estimation, forecasting
- Cybersecurity and interoperability
Use Case 3: ENERGISE ECOIDEA

Test plan execution starting June 2019
Use Case 5: Evaluation of centralized and decentralized FLISR using Flexible DER and Microgrid Assets Enabled by OpenFMB

– Test plan execution starting April 2020