UI-ASSIST: US-India collaborative for smart distribution system with storage

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Objectives & Outcomes

To evolve the future distribution grid that will allow the continuing increase of Distributed Energy Resources (DER) penetration towards improving reliability, resiliency, flexibility, and sustainability of electricity delivery.

Project work will lead to the fully conceptualized smart distribution grid that optimally utilizes energy storage and distributed generation supported by well-planned workforce development and policy recommendation. Our team will validate developed solutions using ten different unique test beds and deployed in pilot phase at 10 different field demonstrations sites in the US and India.

Technical Scope

To develop and demonstrate the DSO functions for optimal utilization and management of DER by interfacing with DER and microgrid control systems with high penetration of energy storage.

Life-cycle Funding Summary ($M)

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<tr>
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<th>FY17 &amp; prior, authorized</th>
<th>FY18, authorized</th>
<th>FY19, requested</th>
<th>Out-year(s)</th>
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UI-ASSIST Phases and Themes (2017-2023)

Phase 1: Kickoff/Finalizing Overall Project Management Architecture

Phase 2: Research and Development Activities

Phase 3: Lab Testing and Validation

Phase 4: Pilot Level Field Implementation

Phase 5: Impact Analysis and Policy Recommendations

Phase 6: Capacity Building and Workforce Training

Theme 1: Finalizing Overall Project Management Architecture

Theme 2: Distribution System Modeling & Benchmark System Development

Theme 3: Energy Storage Modeling and Optimization

Theme 4: Microgrid and Active Distribution System

Theme 5: Cyber Security and Infrastructure

Theme 6: DSO Functions/Energy Management

Theme 7: DSO – Market and Regulatory Issues

Theme 8: Lab Testing and Validation

Theme 9: Field Demonstration

Theme 10: Impact Analysis and Policy Recommendations

Theme 11: Workforce Development
Theme 1: Overall Project Management

Key Activities:

• Paperwork done for all partners including National Laboratories.
• UI-ASSIST Joint meeting-cum-workshop held Dec 18-19, The India Habitat Centre, New Delhi, India
• UI-ASSIST 3rd Annual Meeting (Virtual) is planning to held during July 29-31, 2020
  • US-India technical progress reporting and discussions
  • US-India Theme wise meetings and mini-workshops
• Updating theme-wise reporting and monthly meetings
• Finalized few Fact sheets and rest are in progress.
• Monthly webinars sharing information between partners
**Theme 2: Distribution System Modeling and Benchmark System Development**

**Key Activities:**

- WSU studied gap analysis and developing Pullman distribution system as semi-urban case study and Spokane distribution system modelling (i.e. Urban pilot) as well as cyber modeling.

- WSU completed framework for developing synthetic feeder models and identified the technical requirements of smart grid communication networks, including traffic-forwarding and end-user devices.

- Burns and McD, ETAP and TAMU are developing rural, semi-urban and urban synthetic distribution system models.

- VCS supporting in finalizing feeder model plan.

- NRECA will explore developed models in this project and adopt them as per the requirements.
Theme 3: Energy Storage: Modeling and Optimal Management

Key Activities

- A Fuzzy EV battery charging management system has been developed and validated by TAMU. A decision-making algorithm for the distribution grid operator has been developed.
- WSU is working on selection of storage system model to incorporate in WSU distribution system for demonstration.
- MIT is making progress on Li-Ion equivalent circuit model for estimating SOC and parameters using recursive least squares.
- LBNL and PNNL are contributing towards detailed storage models and DER-CAM based analysis.
- ETAP is supporting to explore the analysis for storage application.
- Field experience with industry partners (AVISTA and SnoPUD)
Theme 4: Microgrid and Active Distribution System: Converter, Controller and Protection

Simulation of multi-inverter AC microgrids is performed by TAMU to study of the protective relaying implementation.

Analysis of LV microgrids was conducted under steady state and faulty conditions for different scenarios.

Implementation of the digital protection system for microgrid is underway.

Expansion of the grid with different types of inverters and different types of load is in progress.

Different control modes of inverters were implemented on simulation testbed.

Fig. Simulation testbed for multi-inverter AC microgrids

Fig. Results of Phase-to-Phase Fault
Theme 4: Microgrid and Active Distribution System: Converter, Controller and Protection

WSU team developed voltage control and energy management strategy for active distribution system with grid connected DC microgrid (DCMG) with hybrid energy resources.

Architecture of test system is shown in top figure. It is explored under grid connected and islanded mode of operation.

Simulations of system is explored under worst conditions and result is shown in bottom figure.

Key Activities:

- WSU implemented droop primary control in the designed islanded microgrid system for rural electrification.
- WSU is discussing with IIT-Roorkee about possibly modeling the system in their test bed.
- Burns & McDonnell working on microgrid controller capabilities.

Fig. Operational diagram of DC microgrid connected 13 bus distribution system.

Fig. Voltage improvement at bus 671 with and without voltage control from DCMG.
Theme 5: Cybersecurity: Infrastructure and Measures

Cyber-Physical simulation environment for distributed DER operation (WSU)

- The platform integrates both the OpenDSS physical system simulator and the Mininet network emulation software.
- Platform enables the monitoring and control of smart inverters through the IEEE 2030.5 network protocol.
- WSU modeled DER devices within the Miramar feeder model. Malicious 2030.5 network messages sent to the DER devices to impact the feeder.
- Bottom figures demonstrate the voltage profile at the PV, Q and S behavior at the feeder, and P behavior at the PV resulting from an incorrect VAR-VOLT response.

Key Activities:

- WSU is planning to include network-based communication and control of additional grid components, such as circuit breakers.
- TAMU team developed a cybersecurity framework for the verification of energy/monetary transactions using blockchain technology.

Fig. OpenDSS/Mininet based co-simulation platform.

Fig. System response voltage and power injections at POI
**Theme 6: DSO Functions/Energy Management: Forecasting, MEMS, ADMS, Control and Optimization and Planning**

- **HNEI/ETAP:** Solar/PV monitoring
  - ETAP: probabilistic forecasting with confidence level
  - HNEI: solar forecasting system using 3D camera.

- **WSU/HNEI:** Machine learning
  - Disaggregation of behind-the-meter (BTW) PV from net load with Hawaii.
  - HNEI: solar forecasting system using 3D camera.

- **WSU/MIT:** Distributed VVC
  - Distributed Volt/Var Control using Proximal Atomic Coordination (PAC)

- **WSU:** Network clustering
  - Distributed OPF for IEEE 123 bus system.

- **TAMU:** Reliability
  - Distribution system with PV systems at the customer end.

- **WSU:** Data analytics
  - Using sensor data (i.e., anomaly detection using µPMU)
PV/Load Disaggregation

- Customer PV is behind the meter with limited monitoring and thus generally invisible to utilities and system operators.
- Data-driven algorithm to estimate the power generation output of invisible solar panels.
Load and PV Forecasting

ETAP has developed quantile or probabilistic forecasting successfully.

Least Absolute Deviation (LAD) is used for development.

Load forecasting using hyper deep learning method is also performed by ETAP.

Results are comparable and slower than linear regression.

Key Activities:
- ETAP is continue to develop different load forecasting models.
- HNEI has converted satellite-based irradiance forecasts from the period of October 2019 to January 2020 into animated gifs for sharing.
- HNEI planning to use micro synchrophasor data to detect solar-induced variations between areas of the island.

Fig. Quantile or probabilistic load forecasting
Volt-Var Control

- WSU implemented a centralized AC Optimal Power flow (ACOPF) for three-phase unbalanced distribution power systems in MATLAB and validated using OPENDSS-distribution power system solver (i.e. top figure).
- WSU also developed localized volt-var control and optimization algorithm.
- MIT developed distributed optimization based on proximal atomic coordination (PAC) and current injection (CI) method.
- Convergence results from distributed CI optimization on IEEE node network are shown in bottom figure.

Key Activities:
- WSU is working on centralized, localized and distributed volt-var techniques.
- MIT is planning to expand distributed PAC optimization to Mesh and unbalanced networks.
Reliability Assessment

- TAMU performed an analysis of the load on the distribution system from the residential systems with and without the PV systems.
- The average annual load is reduced by 40% with 100% penetration of rooftop PV systems.
- Results with and without PV penetrations shown in below figures
- TAMU developed a two-state model for the battery system and the bi-modal inverter to assess the reliability of battery storage systems.

Fig. No PV penetration.

Fig. 100% PV penetration.
### Theme 7: DSO- Market and Regulatory Issues

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<th>Institution/Project</th>
<th>Description</th>
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<td>MIT: Retail market mechanism</td>
<td>• Optimally managing and scheduling DERs.</td>
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<td>WSU and MIT: Retail Market Regulation (Clearance)</td>
<td>• If distribution connected resources are cleared by ISO markets, how will federal and local regulations overlap?</td>
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<td>WSU: TES environment</td>
<td>• Multiple possible transactions (centralized, peer-peer).</td>
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<td>MIT: Proximal Atomic Coordination algorithm (PAC)</td>
<td>• Focusing on the privacy for market applications.</td>
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<td>MIT and IITD: Retail market</td>
<td>• Interactions of the DSO and TSO.</td>
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<td>MIT: Testbed</td>
<td>• BeagleBone Blacks to run the proposed retail market.</td>
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<td>WSU: Separate Retail Market Regulation</td>
<td>• If separate retail markets are set up, should the market rules be under local government only?</td>
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<td>n-Grid market participation</td>
<td>• Participation of aggregator-nano grid interaction in the wholesale market</td>
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DSO Market: Retail Market Mechanism

- DER scheduling and real-time market settlements at distribution-level Locational Marginal Price (d-LMP)
- Each primary feeder has a DSO, which coordinates an energy market
- Bi-lateral agreement between agents and DSO
- Enabled by distributed optimization algorithm: Proximal Atomic Coordination (PAC)

**Market Steps:**
- Agents negotiate with neighbors to determine d-LMP and load/generation
- Upon reaching agreement, enter into bilateral contract with DSO
- Market clears every $\Delta t$ minutes
- DSO pays DERs (DGs and DRs) at d-LMP
- Loads pay DSO at d-LMP for consumption
Results: Retail Market

Case Study: An 84-node Distribution Grid in Komae City, Japan
- 7 DGs, 24 hour simulation
- Potential Savings from the Retail Market

Komae-city, Tokyo, Japan

Increase in Revenue for DSO with Energy Market:
\[ P_{DSO-increase} = P_{DSO} - P_{no-DSO} \]

Where:
\[ P_{DSO} = R_{DSO}^L - C_{flex}^{DSO} - C_{DG}^{DSO} - C_{WEM}^{DSO} \]
\[ P_{no-DSO} = R_{no-DSO}^L - C_{WEM}^{no-DSO} \]

At d-LMP

At utility retail price

Increase in Revenue for DSO with Energy Market

Theme 8: Lab Testing and Validation

Validate component model, network model and algorithms in offline validation.

Validate component model, network model and algorithms in real time validation.

Validate component model, network model and algorithms using lab-scale distribution system validation.

TAMU: Hardware-in-the-loop simulation using OPAL-RT. A control model for battery charger and PV quasi-Z-source inverter is implemented in DSP board TMS320F28379D.

WSU: Developing models and simulations for test systems in multiple platforms.

Burns & McDonnell: Smart Grid Labs in KC & Houston.

WSU/NREL: Evaluation of different simulation frameworks and control strategy:
- Software simulation
- Hardware-in-the-loop
- System-in-the-loop

WSU/HNEI: Enhancing existing testbed and development of HIL testbed at HNEI and WSU.
Theme 9: Field Demonstration

Field Implementation for Rural Feeders
Field Implementation for Semi-Urban Feeders
Field Implementation for Urban Feeders

Pilot Projects

US Semi-Urban Distribution Pilot 1 at WSU
US Semi-Urban Distribution Pilot 2 at TAMU
US Urban Distribution Pilot 1 at Spokane, WA
US Urban Distribution Pilot 2 by GE/ PNY for ADMS-MEMS integration
Theme 10: Impact Analysis and Policy Recommendations

Impact Analysis

- WSU completed survey data collection in California and began cleaning and analyzing the data.
- WSU analyzing data on household adoption of battery storage.
- WSU is analyzing the data to identify normative, attitudinal, and sociodemographic correlations with interest in adoption of household solar, as well as factors associated with trust in utility companies and PV providers.

Classification includes

- Motivations for adoption (financial, environmental, and self-sufficiency),
- Obstacles to adoption (aesthetics, cost, residential instability, difficulty of the process),
- The rebound effect (self-reported increase in electricity use when it was “free”),
- Views of utility companies, and other more minor themes.
Progress on Policy Recommendations

- Recommending ideal structure of microgrids for rural, urban, and semi-urban areas in Indian context
- Suggesting regulatory changes required to promote and accelerate microgrid installations and their integrated operation with grid
- Suggesting suitable DSO model in the Indian as well as US context
- Technical due-diligence of energy storage at mini-grids and microgrids
- Policy for workforce development and training in evolving distribution system
Theme 11: Workforce Development and Educational

Key Activities:

- **K-12 Outreach**
  - In partnership with ENGIE Hawai‘i, UH prepared and presented an interactive exhibit titled “Operation of the Electric Grid with Renewable Energy” for K–12 students at the UH SOEST Open House on October 25 and 26, 2019.

- Classroom and lab activities for college students
- Training the students for research
- Training for existing power engineering professionals
- Multiple panels and tutorials at IEEE PESGM 2020 and ICPS 2019
Publications List (from last two quarters)

1. M. Soleimani, M. Kezunovic, "Mitigating Transformer Loss of Life and Reducing the Hazard of Failure by the Smart EV Charging," IEEE Transactions on Industry Applications, page(s): 0, Print ISSN: 0093-9994, Online ISSN: 1939-9367, Digital Object Identifier: 10.1109/TIA.2020.2986990 [Accepted, In press]


Publications List (from last two quarters)


Thanks for the opportunity to share about UI-ASSIST

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