2014 Smart Grid R&D Program
Peer Review Meeting

DOE - Integrated Smart Distribution RD&D Project

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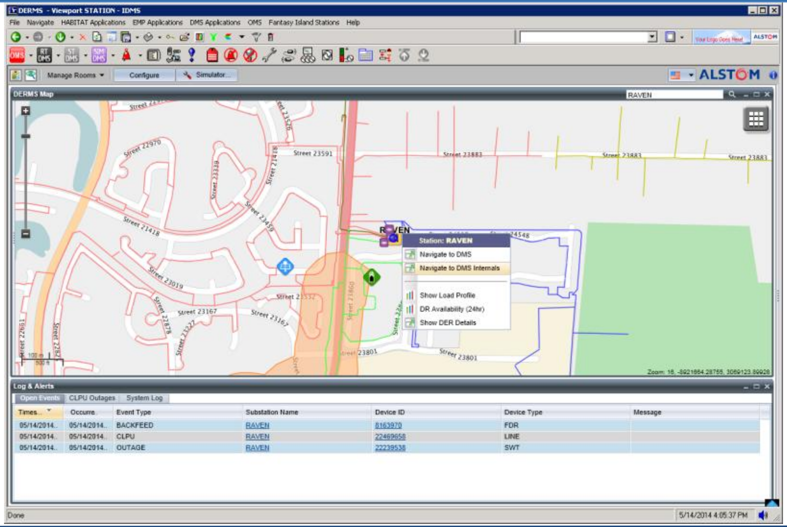
DOE Integrated Smart Distribution (ISD) Project

Objective

The primary objective of this project is to leverage the intelligence of, and information provided by, sensors, energy boxes and smart meters to integrate DER for developing next generation DMS to enhance optimal performance of the emerging distribution system. This builds on the DOE Vision towards an Intelligent North American Grid by 2030.



Life-cycle Funding Summary ($K)

Prior to FY 14 (k$)	FY14, authorized (k$)	FY15, requested	Out-year(s)
4,440	1,560	0	0

Technical Scope

- Advanced distribution modeling capability to accurately simulate/model smart grid operations.
- Accurate representation of the distribution system in real- or near real-time (capture real-time topology).
- Interoperability with and seamless communication between other management systems and data bases used by the utility
- Simulation of distribution systems based on real-time operational planning to analyze the benefits of smart grid assets.
- Integration of network, market, and renewable resource models for next generation DMS.
- Management and forecasting of DER (DG, storage, DR)

Significance and Impact

Project's Cost/Performance Targets Supporting the Smart Grid R&D Goals and 2020 Targets
(Project milestones shown in the backup slides)

Year	2011	2012	2013	2014	2020
Performance Targets					
Efficiency (%) National	94	94.15	94.30	94.45	97
Load Factor (%) Duke Energy	65	65.62	60.71	67	78 (↑20%)
SAIDI (min) Duke's McAlpine Substation	144	125.83	85.33	135.36	118.08 (↓20%)
Outage Reduction for Critical Loads (%) Duke's McAlpine Substation	98.6	98.62	98.65	98.68	>98 98.85

Significance and Impact

Alstom Grid:

- Integrated: Conventional energy & grid resource integrated with new distributed energy resources & grid devices for holistic system performance.
- Smart: Intelligence in devices and resources.
- Distribution: DMS extended to provide advanced tools (effective UI with advanced analytics) to ensure effective solutions for distribution system operation.

Duke:

- Capture grid network modeling and real-time topology.
- The operational philosophy, changes, and challenges with increasing DER penetration and emerging technology and devices are truly fundamental and transformational.
- Requires quick and automated response to meet new operational changes at higher level.
- Safety is built into the design of the system as foundation for new technologies.
- Create an understanding of the grid's operational value once they have all the new technologies integrated. Customer focus is the key.

U.S. Utilities:

- This project will pave the way for the next generation of DMS with DER integration.
  - Facilitate technical and market development for emerging technologies.
  - Explore new operational requirements and business models.
- Verify the capability to integrate DER in real-time software and control systems and monitor/analyze distribution circuits.
- Verify interoperability of solution using smart grid test tools.

Research and Development Areas

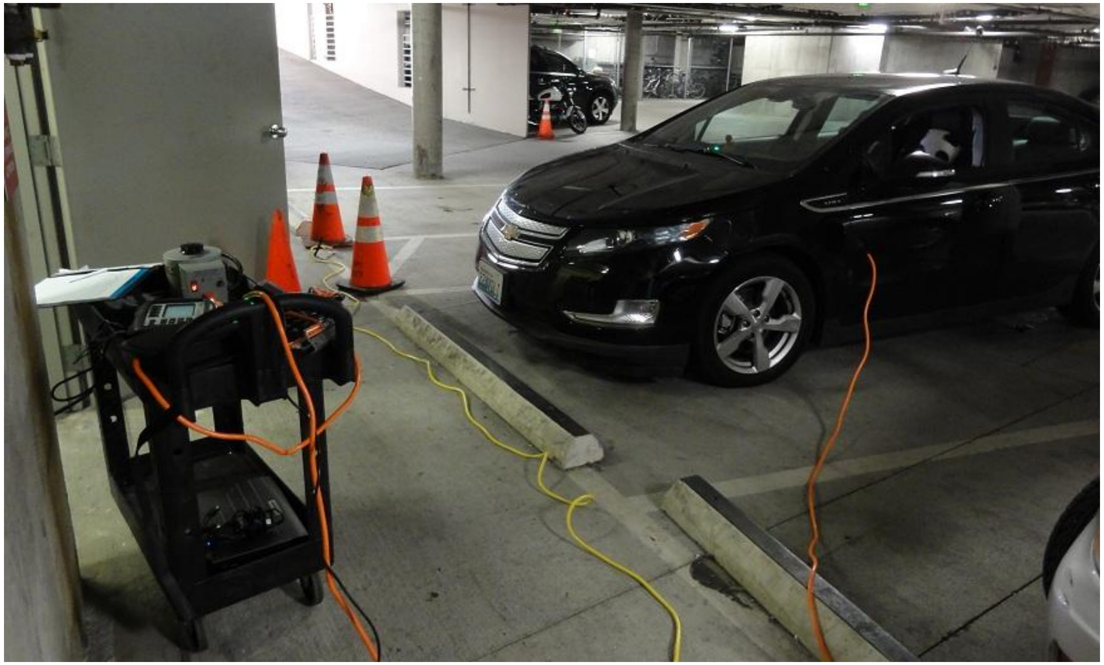
- **Research**
  - DER Modeling
  - Advanced and Adaptive Protection
  - Microgrid Protection
  - Fault Location Using PMUs
  - Optimal Real and Reactive Power (VVO) Management Using PMUs and µPMUs
  - Short Term Load Forecasting
  - Communication Architectures
  - Market Integration of DER

Research and Development Areas

- **Research**
  - Secondary Distribution Modelling
  - Solar Swing Mitigation
  - Grid and Microgrid Solar Penetration Investigation via Simulations
  - Robust Power Flow and Short Circuit Algorithms
  - Three-phase State Estimation
- **Research and Development for Pilot System**
  - Cold Load Pickup
  - DG Back feed Mitigation

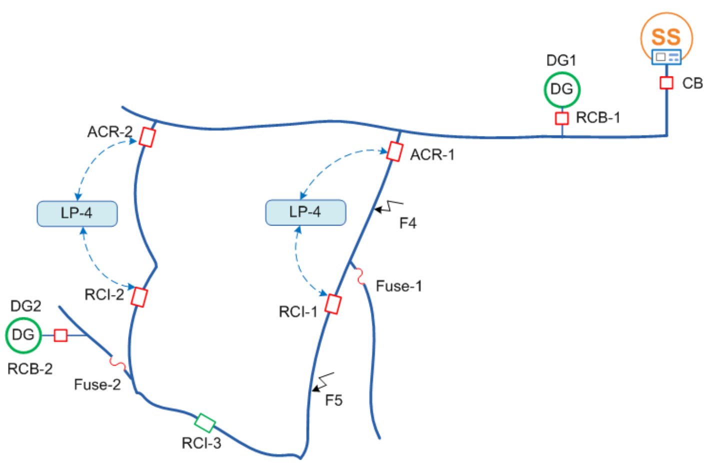
Technical Approach and Results

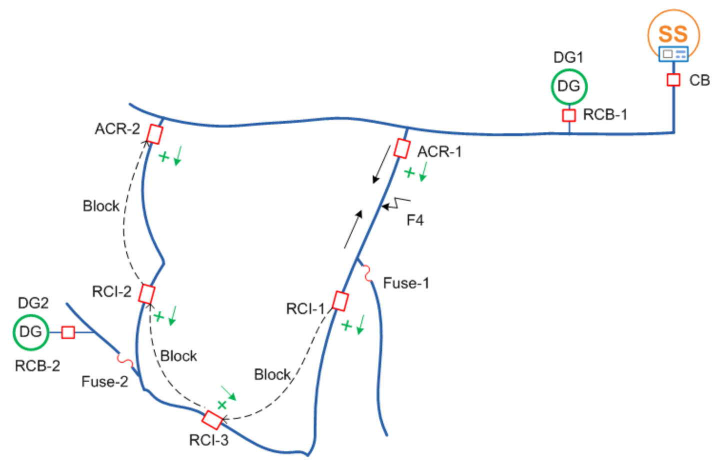
- **DER Modeling:**
  - Refined EV models by measuring EVs charging at different voltage levels, states and voltage response characteristics not previously known in the literature.
  - CIM based Solar & Battery models (to meet interoperability standards).



Technical Approach and Results

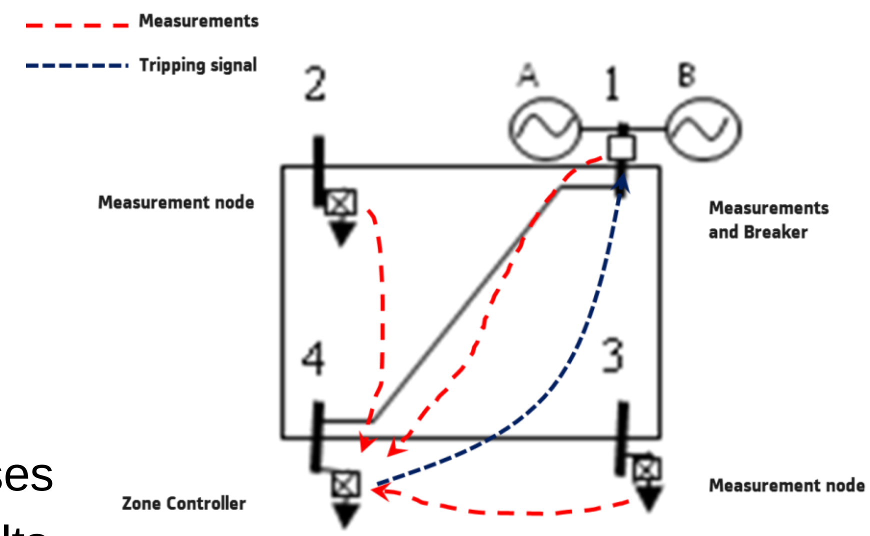
- **Advanced and Adaptive Protection**
  - Analyzed problems and issues in smart distribution grids introduced by distributed generations and energy resources.
  - Explored and studied features of new intelligent protection devices, such as digital relays, pulse reclosers, PMUs, logic processor, and advanced communication infrastructure.
  - Designed a new protection system which consists of several customized schemes for various conditions and scenarios for a distribution system.





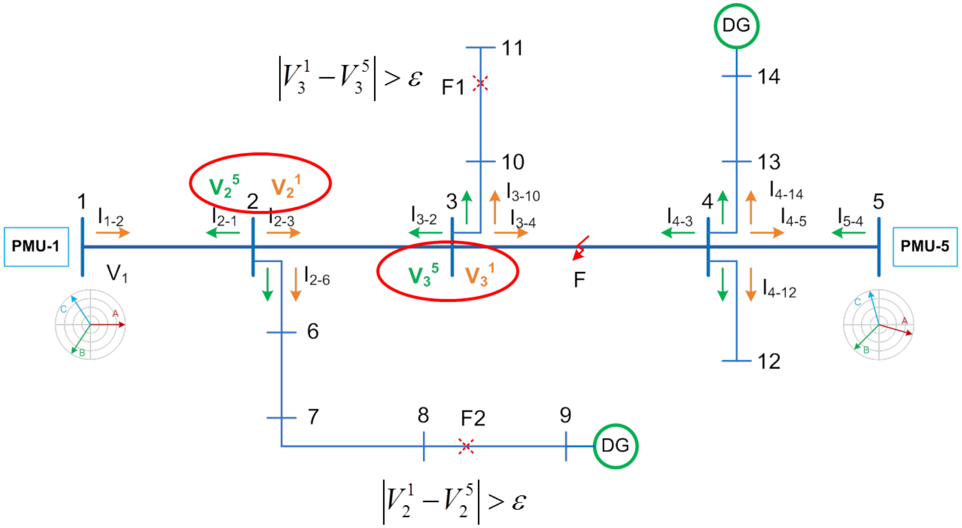
Technical Approach and Results

- **Microgrid Protection**
  - Proposed method based on distributed differential protection
    - Sums all currents or powers from devices within a given zone
    - If the summation is above some threshold, a fault is present
  - It can leverage existing devices
  - It can adaptively set the threshold according to the operating state and automatic coordination with legacy fuses
  - It is able to detect high impedance faults and other low current conditions
  - It can be implemented using PMUs, digital relays, and other measurement devices



Technical Approach and Results

- **Accurate Fault Location Using Phasor Measurement Units (PMUs)**
  - Developed accurate synchrophasor based fault location methods
  - The methods include three-phase apparent impedance based fault location estimation, iterative approach for resistive fault and differential diagnosis based fault location identification
  - Prototyped and implemented on a real distribution system
    - Validated the approach in simulations.
    - Validate using real measurements.

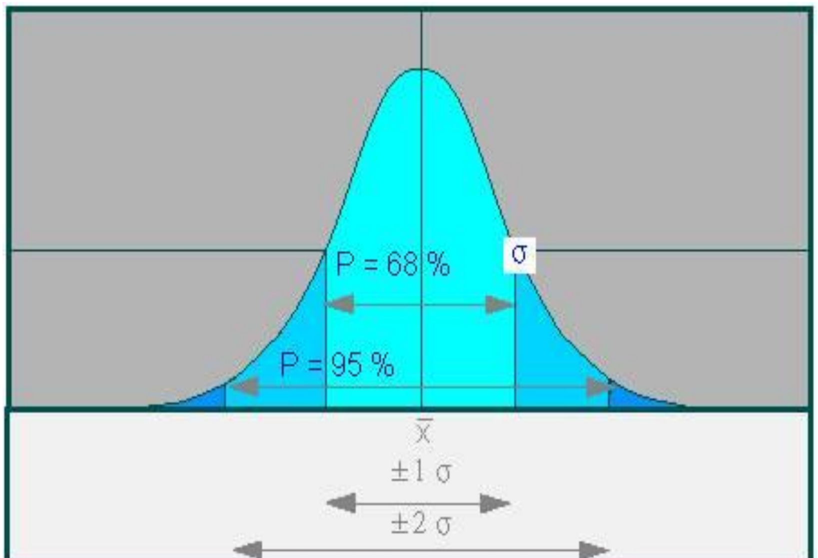


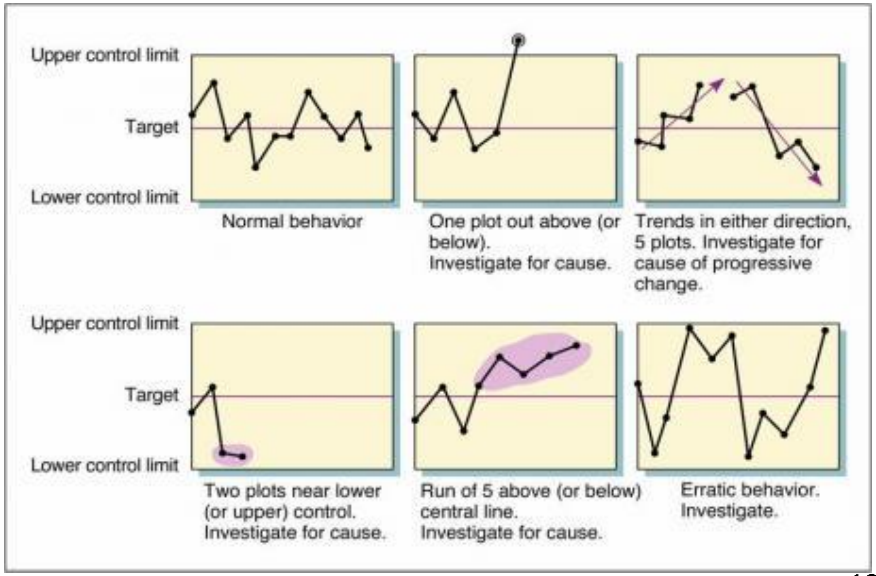
Technical Approach and Results

- **Optimal Real and Reactive Power (VVO) Management Using PMUs and μPMUs**
  - Comprehensive analysis of new requirements pressed on smart distribution grids and deficiency of existing approaches.
  - Leverage the characteristics of measurements from PMUs, such as high resolution and accuracy, phase angle information for both voltage and current signals.
  - Optimal plan considers all types of equipment with capability of voltage and/or reactive power regulation.
  - Optimal plan includes coupling of real and reactive power.
  - Aim to reduce computational burden compared to optimal power flow based methods.

Technical Approach and Results

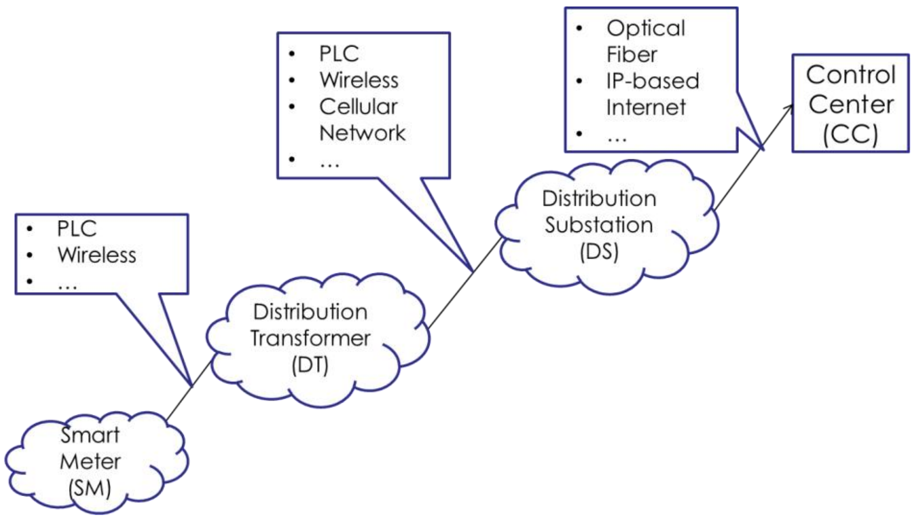
- **Short Term Load Forecasting:**
  - Short-term load forecasting of each feeder and substation that captures the spatial and temporal correlations using neural networks trained by Kalman filters
  - Solar power forecasting using weather, actual load history



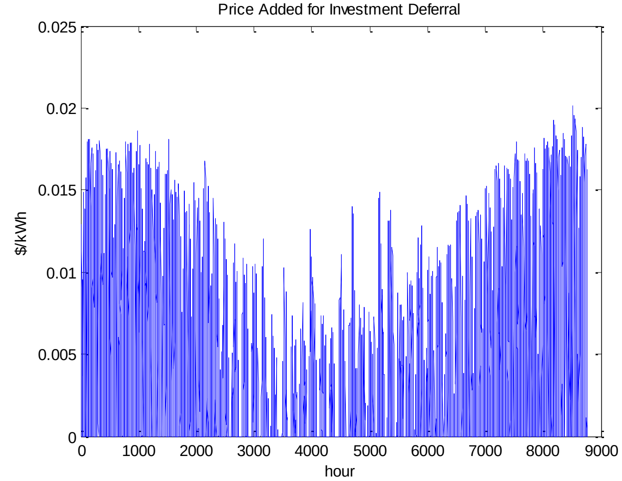


Technical Approach and Results

- **Communications Architecture:**
  - Developed multi-tier, distributed intelligent communication nodes and corresponding architecture. This requires deeper understanding and selection of proper communication schemes, protocols and interoperability standards.

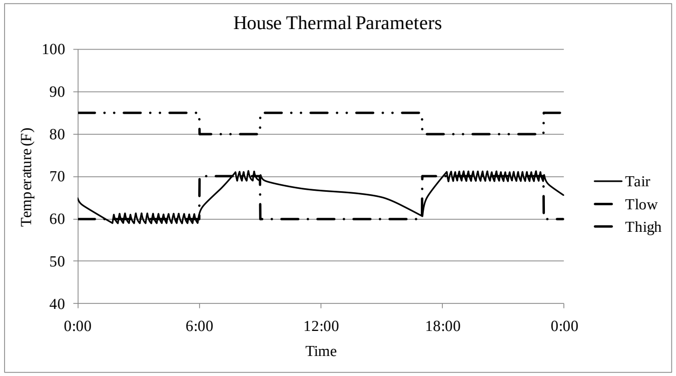


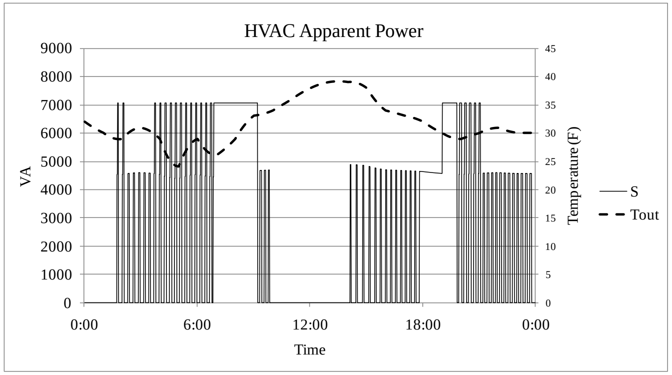
- **Market Integration of DERs**:
  - Analyzed the market rules and data flows to determine the impacts and necessary changes to facilitate the integration of DERs.
  - Allows market models for the integration of DERs.



Technical Approach and Results

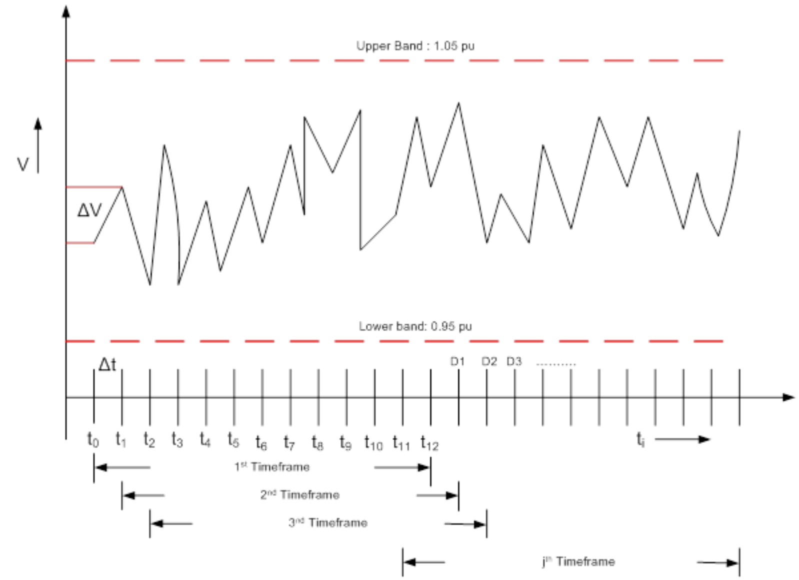
- **Secondary Distribution Modeling**
  - Converted feeder models of McAlpine substation and imported to GridLAB-D.
  - Investigated the GridLAB-D simulation model to be capable of handling weather-driven time-series power flows.
  - Time-series models are being developed for: customer loads, demand response, and selected other smart grid assets such as electric vehicles, storage devices and distributed generations.
  - The purpose of this simulation model is to develop a smart grid simulation test bed enabling predictive control strategies and decision support tools for advanced DMS.





Technical Approach and Results

- **Solar Swing Mitigation**
  - Implemented distributed communications utilizing communication nodes
  - The solution handles the impact of photovoltaic (PV) active power and voltage swings within a distribution system
  - Developed an algorithm to mitigate impacts of Solar Swing on the Distribution Grid per Duke Energy’s requirements:
    - Disconnect the PV unit(s) if voltage variations, caused by solar swing, are deemed harmful to the system
    - Reconnect the PV units(s) back to the system once the irradiance/PV open circuit voltage is stable (final implementation pending)

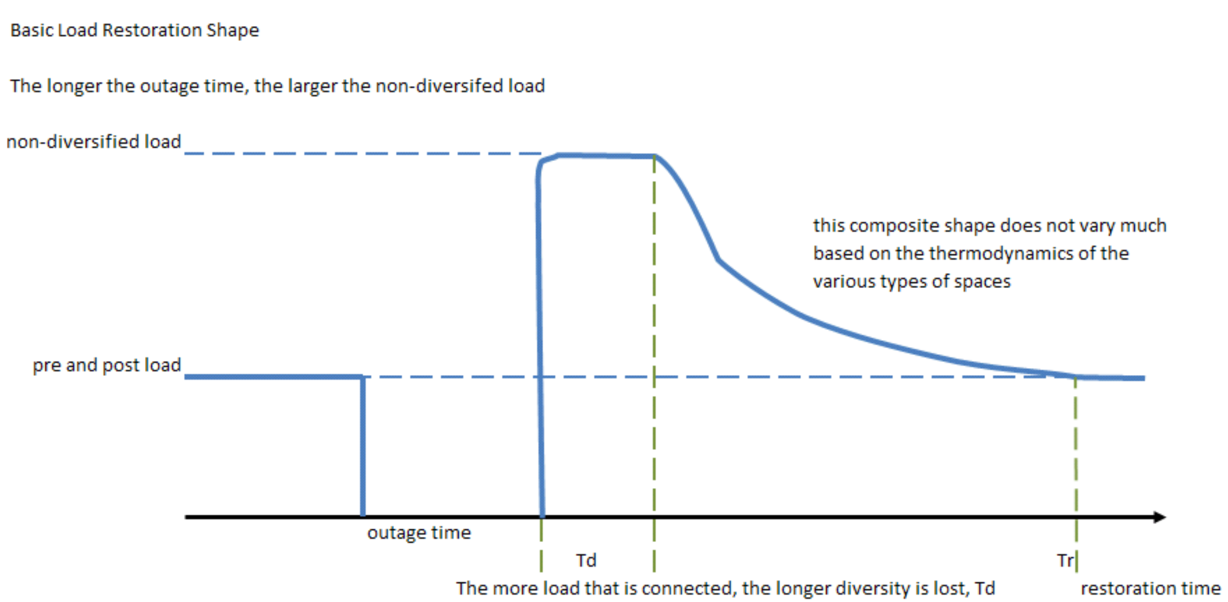


Technical Approach and Results

- **Grid and Microgrid Solar Penetration Investigation via Simulations**
    - Different geographic solar placements
        - Evenly disburse solar penetrations across all circuits
        - Place all solar penetration at one bank
        - Place all solar at the station (or all at the end of the circuits)
    - Different penetration levels
        - 5%, 10%, 20%, 30% of nominal substation load
        - 120 MVA substation – 3 banks of 40 MVA each – 6 feeders, evenly distributed
    - Simulation studies underway with Distribution Operator Training Simulator (DOTS) and/or GridLAB-D (two excellent planning tools)

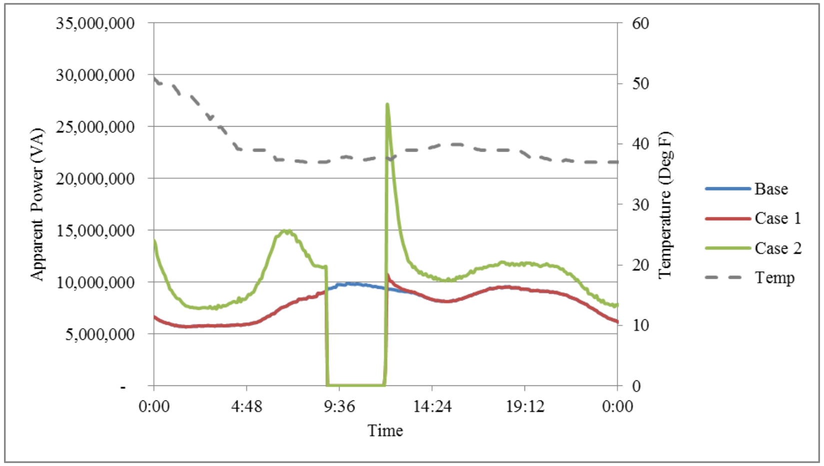
Technical Approach and Results

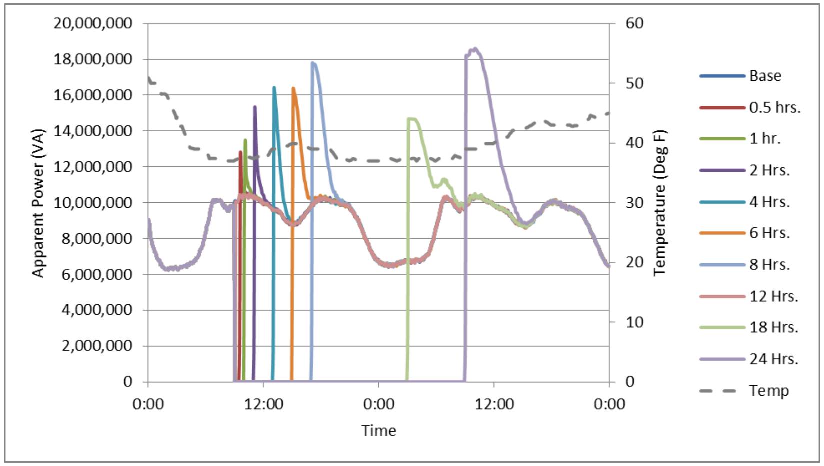
- **Cold Load Pickup (CLPU)**
  - Software analyzes outage areas and estimates load growth from loss of diversity.
  - It estimates the time it will take for the load growth to reach a level that will cause an overload at restoration
  - It shows how the addition of DERs can help restore from a CLPU situation
    - Reducing the peak load at restoration
    - Islanding portions of the load to maintain diversity



Modeling Cold Load Pick-Up Effects with GridLAB-D

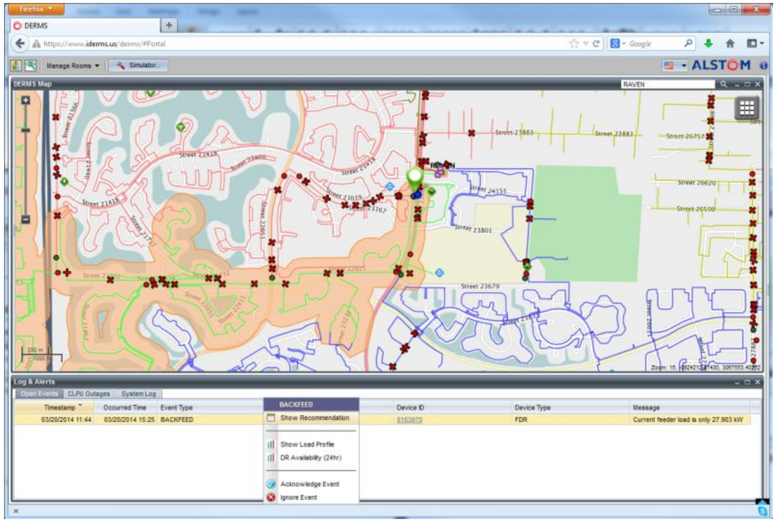
- **Problem**: Cold Load Pick-Up (CLPU) occurs when there is a loss of load diversity during an outage, which can lead to equipment damage and/or increased outage times.
- **Current Practices**: traditional methods of CLPU analysis use static curves or models that are accurate at only a single point in time, for a single set of conditions.
- **Technical Approach**: Multi-State load models are being developed in GridLAB-D to better represent the CPLU phenomena. The results from these models will then be used to populate the existing look-up tables in the Alstom DMS. This will provide a more accurate basis for restoration from an outage, reducing restoration times and minimizing equipment damage.
- **Progress**: in FY13 calibrated GridLAB-D models of the distribution feeders at the McAlpine substation in North Carolina were developed. These were used to evaluate demand response, energy storage, and solar PV. In FY14 work has focused on developing models that properly represent the CLPU effects. This work is 85% complete. No FY15 work is planned.
- **Transfer**: A new method of evaluating CLPU has been developed, which can be the foundation for improved restoration schemes. Additionally, the ability to use off-line DOE tools to augment the capabilities of on-line commercial operational tools has been proven.





Technical Approach and Results

- **DG Back feed Mitigation**
  - Alerts the operators if a back feed onto the transmission grid is about to occur on a feeder that is not configured for back feed.
    - When feeder load drops below a certain threshold, a check is made to see if there are any DERs which could cause reverse power flow
  - Optimizes available DERs to eliminate the back feed and keep the load above the threshold if possible.
  - Shows the operator the recommended course of action.



Project Team Capabilities & Funding Leverage

List organizations that this project interacts and collaborates with, describing their expertise and complementary roles to this project.

Primary Contractor:

- Alstom Grid

Host Utilities:

- Duke Energy

Subcontractors:

- University of Washington
  - Communication infrastructure and interoperability standards, network and market models.
- PNNL
  - Development of DER assets and load models within GridLAB-D.
  - Expanded to include CLPU schedules within GridLAB-D
- University of Connecticut
  - Development of bottom-up load forecasting techniques for integration of DERs.

Project Team Capabilities & Funding Leverage

1. Present what unique role DOE is playing and what the added value is.

- The DOE initiative and funding opportunity enabled this investigation to pave way for the next generation of DMS with DER and other technologies that would not have been otherwise initiated. The funding provided an unique opportunity to bring all the teams listed in the previous slides together with complementary skills and expertise needed to undertake this complex task.

2 **Present the project leveraging the DOE funding with other resources.**

- Alstom is providing almost 75% matching to the tune of $4.5 million.
- Duke Energy participation is truly priceless.
    - They making the McAlpine, Sherril's Ford, and Ruffin facilities available for this investigation.
    - They are also making more than 30 technical personnel to be part of the team.
    - They are also providing real-time data as and when required.

3. Present how the DOE funding catalyzes the industry/business. If not, why not?

- The results of this project should provide a business model and agile process for other electric utilities in the U. S. to meet the real-time operational needs of their smart distribution grid.

Technology Transfer: Publications

1. E. Sortomme, J. Ren, and S. S. Venkata, **"**A Novel Approach to Holistic Microgrid Protection", IEEE Transactions on Power Delivery, 2014. (Under revision).
2. J. Ren, E. Sortomme, and S. S. Venkata, **"**An Accurate Synchrophasor Based Fault Location Method for Emerging Distribution Systems", IEEE Transactions on Power Delivery, Vol. 29, No. 1, pp. 297-298, 2014.
3. E. Sortomme, A. I. Negash, S. S. Venkata, D. S. Kirschen, "Voltage Dependent Load Model of Charging Electric Vehicles," IEEE PES General Meeting, July 2013, pp. 1 – 5, Digital Object Identifier: Digital Object Identifier: 10.1109/PESMG.2013.6672752.
4. S. S. Venkata, D. Wilson, J. Ren and M. Miller, "Advanced and Adaptive Protection for Active Distribution Grid ", 2013 CIRED International Conference and Exhibition on Electricity Distribution, Page(s): 1 – 4, Digital Object Identifier: 10.1049/cp.2013.1174.
5. D. Wang, D. Wilson, S. S. Venkata, G. Murphy, "PMU Based Angle Constraint Active Management of 33-kV Networks", 2013 CIRED International Conference and Exhibition on Electricity Distribution, Page(s): 1 – 4, Digital Object Identifier: 10.1049/cp.2013.1092.
6. E. Sortomme, S. S. Venkata, "Mitigation Cold load pickup problems with Distributed Energy Resources", Proceedings of 2013 DistribuTECH Conference, San Diego, January 28-31, 2013.
7. E. Sortomme, A. I. Negash, S. S. Venkata, D. S. Kirschen, "Multistate voltage dependent load model of a charging electric vehicle," Proceedings of IEEE Transportation Electrification Conference and Expo, June 2012, pp. 1-5.
8. E. Sortomme, E. ; J. Ren, and S. S. Venkata**,** "A differential zone protection scheme for microgrids", IEEE PES General Meeting, July 2012, pp. 1 – 5, Digital Object Identifier: , 10.1109/PESMG.2013.6672113.
9. M. Miller, M. B. Johns, E. Sortomme, S. S. Venkata, "Advanced Integration of Distributed Energy Resources", IEEE PES General Meeting, July 2012, pp. 1 – 2, Digital Object Identifier: 10.1109/PESGM.2012.6345573.
10. D. Wang, D. Wilson, S. S. Venkata and A. Jayantilal, "A Synchrophasor Application for DER Connection and Efficient Operation", 2012 CIRED International Conference and Exhibition on Electricity Distribution, June 2012, Portugal, Page(s): 1 – 4.
11. S. S. Venkata and E. Sortomme, "Using Advanced Measurement Systems for Microgrid Protection," IEEE PES Innovative Smart Grid Technologies Conference, p. 1, January 2012, Washington DC.

Lessons Learned

- The partnership with Duke Energy has been a positive influence and the interaction with more than 30 Duke personnel via 20 workshops has been invaluable.
    - It enabled the team to concentrate on problems, with a real-world context, that needed immediate attention in the "Smart Distribution System".
    - Our project workshops continue to be very fruitful and will continue throughout the project phases as the requirements of Integrated Smart Distribution continue to evolve.
- It was a challenging experience for the entire team to tackle R&D areas that were not even on the radar screen when the project was started.
    - We underestimated the amount of workshops and brainstorming required.
    - Duke have acquired and installed new devices to provide scarce data in sufficient quantities to facilitate research.
    - Adoption of customer owned equipment slower than anticipated
- Demonstrated a strong partnership between a Utility, Vendor, Universities & National Labs to achieve project goals.
- The use of GridLAB-D as a planning tool is extremely useful for the project investigation along with Alstom's Distribution Operator Training Simulator (DOTS).

Contact Information

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