Power Systems Engineering Research Center

PSERC Projects Ending in 2017

Advanced Cyber-Physical Analysis for Smart Grid Distributed ICT and IED Resources at RTE France (S-63G)

Summary	The availability of a vast number of substation IEDs and distributed computational resources offers great potential for enhancing the smart grid. However, the distributed computing infrastructures in utilities today are nowhere near adequate to exploit this potential, being decades behind those in other industries. This project will lead to several technologies and tools, and analyze others, to help utilities and vendors to develop next- generation cyber-physical infrastructure using distributed ICT and IED resources. The problems addressed by this project, as well as the software released, will be widely applicable to utilities, ISOs, and vendors.
Academic Team	Project Leader: Dave Bakken (Washington State Univ., bakken@wsu.edu) Team members: Anurag Srivastava (Washington State Univ.)
Industry Advisors	Daniel Arjona (Idaho Power); Patrick Panciatici (RTE France); Juan Castaneda (SCE)

Monitoring and Maintaining Limits of Area Transfers with PMUs (S-64)

Summary	We will develop practical methods based on PMUs to detect and act on conditions in which transfer of power through areas of the power system should be curtailed to satisfy thermal line limits and small signal stability limits. Closed loop controls for robust stability will also be developed. The larger objective is to combine measurements with physical network models to turn PMU data into actionable advice for operators to improve the management of bulk power transfers and control instabilities.
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RTE DSE-Protection Demonstration (T-59G)

Summary	Georgia Tech and EPRI have been developing the Dynamic State Estimation based protection method (a.k.a. setting-less protection). This technology has been demonstrated in the laboratory and also a demonstration project with NYPA under NYSERDA sponsorship is in progress. The objective of the proposed project is to demonstrate the technology on the digital substation that RTE is developing. A DSE based relay will be developed for the protection of RTE's digital substation, factory tested at the Georgia Tech laboratory and it will be installed on RTE's digital substation.
Academic Team	Project Leader: Sakis Meliopoulos (Georgia Institute of Technology, sakis.m@gatech.edu
Industry Advisors	Patrick Panciatici,Thibault Prevost, Volker Leitloff, Aurelien Watare, Christian Guibout, RTE

PSERC Projects Ending in 2018

Robust and Decentralized Operations for Managing Renewable Generation and Demand Response in Large-Scale Distribution Systems (M-35)

Summary	The distribution system is becoming more complex and active. Distribution system operators may face a portfolio of an extremely large number of devices including distributed generators (DG), demand response (DR) resources, storage devices, and emerging proactive customers with various resources (electric vehicles, smart appliances, rooftop PVs, TCLs). Many of these devices may exhibit stochastic supply or consumption patterns. A portfolio of these devices can significantly increase the flexibility of the distribution system for system balancing and congestion management. The goal of this project is to develop new operational models and algorithms to efficiently operate such a large portfolio of controllable but uncertain resources in an active distribution system with the aim to increase flexibility and reliability of both distribution and transmission systems. The proposed models will provide the industry with computational tools to manage various types of uncertainties through robust optimization techniques and a mixture of centralized and decentralized control schemes in order to improve scalability of the operational algorithms. The project will also explore efficient solution methods for incorporating unbalanced multi-phase power flow models in the proposed scheduling algorithms in order to accurately model the distribution system.
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Analysis of Power System Operational Uncertainty from Gas System Dependence (M-36)

Summary	The heavier reliance on natural gas for electricity generation raises increasing power system security concerns because gas-fueled generators may be subject to gas supply shortages and/or high spot market prices. While under FERC directives the industry has undertaken appropriate steps to better align the gas supply plans with the forecast electricity loads, the gas supply issue has become a challenging uncertainty that must be considered explicitly in power system operations. The goals of this project are to analyze the impacts of the uncertainty created by gas supply vulnerabilities and to assess the risks that emanate from the unit commitment/dispatch schedules. The interpretation of the analysis and the risk assessment results with intuitively meaningful presentation of the information will allow the formulation of appropriate strategies to address the issues associated with the gas supply/cost uncertainty. Study of the impacts of the gas uncertainty on the grid operational flexibility (GOF) for systems with deep penetration of renewable resources will allow a practical assessment of the extent of GOF change due to gas shortage issues and the identification of GOF shortfalls that can result in power system insecurity.
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Leveraging Conservation Voltage Reduction for Energy Efficiency, Demand Side Control and Voltage Stability Enhancement in Integrated Transmission and Distribution Systems (S-70)

Summary	We propose a comprehensive framework that assesses energy saving, demand reduction and stability enhancement potential of conservation voltage reduction (CVR). A new algorithm based on load modeling is developed to assess real-time real/reactive load-reduction effects of CVR. A co-simulation framework for transmission and distribution systems is proposed to investigate the impacts of CVR on voltage stability margins of transmission systems. The identified time-varying load models are integrated into the co-simulation framework to capture CVR effects. The coordination between energy-oriented and stability-oriented CVR will be studied. The mutual impacts between voltage reduction and voltage control of DGs will also be investigated. The combination of these approaches will assist utilities to select feeders to implement voltage reduction, perform cost/benefit analyses, reduce the stress of transmission systems, and improve the operation of integrated transmission and distribution systems.
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Real-time Synchrophasor Data Quality Analysis and Improvement (S-71)

Summary	This project aims at developing strategies for real-time data quality management of streaming PMU data. With the recent impetus towards design and adoption of synchrophasor-based applications in the power industry, there is an urgent need to develop online techniques for detecting, analyzing, and mitigating bad as well as missing data in real-time streams. In this project, we will build a systematic online framework for identifying and handling typical data quality issues such as clock errors, transducer errors and network delays. Based on the synchrophasor data's spatio-temporal correlations, the proposed approach is capable of identifying bad data during both normal and fault-on conditions. Real-world synchrophasor data as well as synthetic dynamic grid models will be used to differentiate the root causes of data quality issues and to validate the proposed strategies.
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Attack-Resilient and Secure EMS: Design, Algorithms, Operational Protocols, and Evaluation (S-72)

Summary	The modern electric grid is a highly automated cyber-physical system (CPS) and is increasingly dependent on cyber-based automation systems for various monitoring, control, protection, and market functions. The DOE, DHS, and NERC have identified concerns that the grid is vulnerable to sophisticated coordinated cyber-attacks. This leads to the following fundamental question: can reasonably realistic (i.e., attackers with limited capabilities) cyber-attacks be modeled and tested on electric power system (EPS) simulation platforms to: (a) evaluate attack severity and consequences and (b) evaluate resiliency of energy management systems (EMSs) to such attacks? The goal of the proposed research is three-fold: (i) identify credible threats and develop attack-resilient control algorithms (countermeasures) that can be modularly integrated into energy management systems (EMSs); (ii) develop a realistic software-hardware simulation testbed comprised of EMS software platform (ASU) and a hardware SCADA system in conjunction with a power system simulator (ISU); and (iii) use the integrated software-hardware testbed to evaluate credible threats and countermeasures.
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Functional Assessment of DFIG and PMSG-Based Wind Turbines for Grid Support Applications (S-73G)

Summary	The specific objectives of this project are to i) investigate the capability of doubly-fed induction generator (DFIG) and permanent-magnetic synchronous generator (PMSG)-based wind turbine systems to provide reactive power support at low wind speed and/or in cases of voltage drop, ii) develop new reactive power control techniques for wind turbines, iii) assess the suitability of using DFIGs to regulate frequency without energy storage systems, and iv) explore the possibility of DFIG inertia sustaining network voltage and frequency immediately following fault occurrence and before fault detection, in systems with low physical inertia and high wind penetration. Experiments will validate proposed theories.
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Industry Advisors	Thibault Prevost (RTE), Florent Xavier (RTE)

Improving Voltage Stability Margin Estimation through the use of HEM and PMU Data (S-77G)

Summary	Voltage stability security is best ensured by complementing some form of system simulation with real-time measurements. Both approaches have their strong and weak points. For example, system simulations are able to predict the effects on voltage stability margin of contingencies while real-time-measurement-based Thévenin equivalents are not hampered by any erroneous data that may be part of the system model. Thévenin equivalent approaches however work well on small systems but fail on large systems. The objective of this proposal is to develop a set of theoretically-based rules for developing and using Thévenin-based equivalent approaches for estimating voltage stability margin on large systems and then demonstrate the effectiveness of these techniques on larger systems or understand their limitations. We also propose to develop a set of nonlinear equivalents, establish their properties and determine their fitness for use in measurement-based voltage-stability assessment approaches..
Academic Team	Project Leader: Daniel Tylavsky (Arizona State University, tylavsky@asu.edu)
Industry Advisors	Di Shi, Zhiwei Wang, Jidong Chai, Xiaohu Zhang, Xi Chen, Zhe Yu, Wendong Zhu, Xinan Wang, Janet Zhang (GEIRI North America)

Efficient modeling of modular multilevel converters for fast simulation of large-scale MMC-HVDC embedded power systems (S-78G)

Summary	Modular multilevel converters (MMCs) have become the most attractive multilevel converter topology for voltage-sourced converter high-voltage direct current (VSC-HVDC) transmission systems. The salient features of MMCs include: 1) modularity and scalability to meet any voltage level by stacking up additional numbers of SMs without increasing topology complexity, 2) inherent redundancy and fault-tolerance capability to improve reliability, 3) high efficiency suitable for high-power applications, and 4) high power quality and low filter and transformer cost due to filter-free and transformerless applications by realization of high-level converters. With the increasing number of MMCHVDC systems embedded into the AC grid, performance of the present power system can be dramatically improved, including stability, reliability, capacity, and efficiency. However, MMCs' applications in power systems are restricted due to the challenge to efficiently and accurately model a variety of such power electronics-based components for large-scale power system analysis, modeling, and simulation. In this project, the PI proposes to investigate and develop new generalized high-efficiency modeling techniques, with covering various submodule (SM) circuits and MMC topologies, which can be used and integrated in electromagnetic transient (EMT) power system simulation software packages and real-time hardware-in-the-loop (HIL) simulation platforms for large-scale MMCs-embedded power system analysis and simulation.
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Input-Output Properties of the Power System Swing Dynamics: Identification, Model Reduction, and Controller Designs (S-79G)

Summary	Variability in the bulk power transmission network introduced by the integration of intermittent renewables, among other reasons, is necessitating new wide-area controls for managing oscillations and transients. At the same time, new technologies including synchrophasors and power electronics are enabling implementation of fast wide-area controls. The evaluation and design of these controls requires understanding input-output processes---and specifically the presence or absence of nonminimum-phase zeros---in the power network¿s swing dynamics. In a previous PSERC project, we have demonstrated how nonminimum-phase dynamics are tied to the topology and input-output channel location, generation profile, and damping in the network, as well as the specifics of deployed controllers (e.g. HVDC modulation). Further, the project has demonstrated that appropriate modeling of nonminimum-phase behaviors is crucial for many aspects of control/analysis of fast dynamics, including model reduction, disturbance analysis, and control design. This new project will be focused on developing the methods necessary for: 1) model-based quantitative analysis of nonminimum-phase dynamics, 2) model reduction to preserve zero structure, 3) wide-area controller design, and 4) estimation of transfer function zeros from synchrophasor measurements. These design tasks will be achieved by drawing on the topology-based results developed in the first project year, as well as structural transformations and control design techniques that account for a linear system¿s zero dynamics. The investigators will also undertake application of the methods to a model of the France-Spain power network.
Academic Team	Project Leader: Sandip Roy (Washington State University, sroy@eecs.wsu.edu)
Industry Advisors	Patrick Panciatici (RTE)

Life-cycle Management of Mission-Critical Systems through Certification, Commissioning, In-Service Maintenance, Remote Testing, and Risk Assessment (T-57HI)

Summary	The life-cycle management of mission critical systems requires tools and methodologies that are not readily available. For example, no standard tools for certification, commissioning, in-service maintenance, and risk assessment are available for synchrophasors used for Wide Area Protection, Monitoring and Control; and Special Protection Schemes. This project will deliver such tools for: • Device and system testing of synchrophasor systems, substation measurement equipment, etc. • Calibration and field testing equipment for in-service maintenance • Remote testing and detection of device failures and data management architecture problems • Visualization to track the state of mission-critical systems and to help with maintenance and repair.
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Power Electronics to Improve the Performance of Modern Power Systems: Case Study on Partially Rated Solid-State Transformers (T-58)

Summary	As the power industry prepares to update distribution and transmission assets that are reaching the end of their lifetime, it is prudent to consider alternatives and likely new applications enabled by technological advances. Among these technologies are power electronics solutions, especially in the light of recent and / or potential advances in technology and material science (e.g., the advent of wide bandgap devices). We propose a two-pronged research effort: (i) an explorative study on the requirements of power electronics (e.g., ratings, basic impulse level, lifetime, and maintenance) and necessary improvements in this technology to enable its use in power systems and (ii) an application design study of partially rated power electronics-enabled transformers for truck-mounted and load tap changer applications.
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PSERC Projects Ending in 2019

Development of Expansion Planning Methods and Tools for Handling Uncertainty (M-37)

Summary	Appropriately addressing uncertainty has been recognized as a major challenge for generation and transmission planning. Most existing planning models and tools become computationally intractable when considering a large number of scenarios; however, a small set of scenarios often fail to include the low probability and high impact ones that are critical to ensure the resiliency of the transmission network. We propose to develop a new method for generating a small number of high quality scenarios to help existing expansion planning models and tools to produce more resilient solutions. The effectiveness of the new method will be validated using existing planning tools on realistic case studies
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Coordination Mechanisms for Seamless Operation of Interconnected Power Systems (M-38)

Summary	Concerted coordination among grid operators (GOs) such as ISOs/RTOs/PMAs in an interconnected power system is imperative to fully exploit the spatial and temporal diversity of renewable wind and solar resources, as well as other grid resources. An effective coordination mechanism needs to respect practical limitations on information exchange, be harmonized with existing market structures that GOs operate and/or facilitate within the areas they control, and be able to explicitly incorporate the impacts of uncertainty under deepening penetration of renewable resources. This project broadly aims to design and analyze the performance of such coordination mechanisms and to construct a unified framework to quantify their benefits. In addition, we adapt the proposed mechanisms in the bulk power systems to coordinate among neighboring microgrids in the emergent distribution network market environment.
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Synchrophasor – Data Analytics for a More Resilient Electric Power System (S-74)

Summary	The aim of this proposal is to develop wide area measurement systems (WAMS)-based tools and algorithms for monitoring, protection, and control of the electric power system. The specific topics of focus are: faster islanding detection schemes and online asset health monitoring (monitoring application); combating cyber-attacks by developing data analytics algorithms that enhance system resiliency (protection application); increasing situational awareness when system has large penetration of renewable generation (control application). Synthetically-generated simulated data will be used to test the tools while synchrophasor data obtained from the field will be used to validate the tool's performance for real-world applications.
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Reliability Evaluation of Renewable Generation Integrated Power Grid including Adequacy and Dynamic Security Assessment (S-75)

Summary	Probabilistic methodologies are needed for reliability assurance in the emerging power grids with increasing penetration of renewable resources. Most of the probabilistic methodologies have focused on the adequacy issues. Some work has also been done on the probabilistic stability including, small signal and transient stability. The objective of this proposal is to integrate reliability into a single frame work including adequacy and transient stability evaluation and develop computationally tractable methods to achieve this objective.
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Modeling, Control, and Protection of Multi-Terminal Direct-Current Transmission for Improving Power Grid's Performance (S-76)

Summary	High Voltage DC (HVDC) transmission is a long-standing technology with many installations around the world. Over the past few years, significant breakthroughs in the Voltage-Sourced Converter (VSC) technology along with their attractive features have made the HVDC technology even more promising in providing enhanced reliability, functionality, reducing cost, and power losses. Concomitantly, significant changes in generation, transmission, and loads such as (i) integration and tapping renewable energy generation in remote areas, (ii) need for relocation or bypassing older conventional and/or nuclear power plants, (iii) increasing transmission capacity, and (iv) urbanization and the need to feed the large cities have emerged. These new trends have called for Multi-Terminal DC (MTDC) systems, which when embedded inside the AC grid, can enhance stability, reliability, and efficiency of the present power grid. Amid the optimism surrounding the MTDC grids, the following fundamental research questions must be addressed. First, what control strategies are required to operate the MTDC converter stations? Secondly, how will the MTDC grid interact with its surrounding AC system and what kind of services (e.g., frequency support and power oscillation damping) can it provide? Thirdly, how would a converter station outage impact the operation/stability of the system? Lastly, how can DC faults be detected, identified, and cleared? To this end, a multi-pronged research effort is proposed: (i) to development of suitable dynamic models of the MTDC systems which can be efficiently solved together with the AC systems; (ii) design of advanced control strategies enabling the MTDC systems to support the resulting hybrid AC/DC systems; and (iii) development of strategies for DC fault detection, identification, and protection of MTDC systems.
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Oscillation Monitoring and Control of the RTE Power System Using Synchrophasors (S-81G)

Summary	Recent advances in design of fast oscillation monitoring algorithms have paved the way for real-time detection and analysis of electromechanical oscillations from wide-area synchrophasor measurements in large power interconnections. The oscillations if left unmitigated can lead to unwanted tripping of transmission lines and generators that could cascade into devastating blackouts. Oscillation monitoring algorithms developed at Washington State University have previously been implemented and tested in North American power grid and in India. In this project, we will study oscillation phenomena in the RTE portion of the European power grid by using available synchrophasor data. Suitability of ambient versus ringdown analysis algorithms for analyzing recent oscillation events in RTE will be investigated. Oscillation analysis results using transmission level PMUs will be compared with corresponding results using distribution level Phasor Measurement Units (PMUs). The effectiveness of the oscillation algorithms will be tested and improved by using simulated PMU data from dynamic models of the RTE system wherein the expected answers are known from small-signal analysis of the dynamic models. New oscillation analysis and control algorithms will be developed in the project as needed in collaboration with RTE to address the oscillation issues in RTE.
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Cyber-Physical Modeling, Visualization and Metric for Microgrid Resiliency (S-82G)

Summary	Keeping the power on especially to the critical facilities (e.g. hospitals and fire department) during extreme outages is essential. System vulnerabilities and the growing prevalence of cyber attacks present significant risks to cyber-physical power grids, especially for a military or critical microgrid. This project aims to develop cyber-physical microgrid models and simulations focused on evaluating resiliency and enabling a 3D visualization framework through following tasks: i) Cyber-Physical Microgrid Modeling for IEEE test system and Miramar Microgrid, ii) Cyber-Physical Resilience Metric and Visualization inspired by the Ukraine Attack, and iii) Cyber-Physical Defense Mechanisms and Enhanced Resilience. Increased awareness of the microgrid operational status considering cyber-physical layers will enable the operator to take cyber-physical control actions and enable resiliency.
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Framework to Analyze Interactions between Transmission and Distribution (T&D) Systems with High Distributed Energy Resource (DER) Penetrations (T-60)

Summary	This project aims at developing an integrated T&D system analysis framework to study and mitigate the impacts of high penetrations of DERs. A coupled T&D analysis framework is developed through co-simulation approach. The framework utilizes legacy software to separately solve the decoupled models. The T&D interactions are captured by exchanging network solutions at the point of common coupling (PCC). The co-simulation approach adds modularity to the analysis and helps in achieving speed and scalability. The framework is utilized to understand and mitigate the impacts of high DER penetrations. Power quality issues which are otherwise difficult to model are studied, and mitigation schemes are proposed. Finally, the utility of DERs as an active participant in system operations is explored.
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PSERC Projects Ending in 2020

Development of Expansion Planning Methods and Tools for Handling Uncertainty (M-39)

Summary	Energy markets are ever evolving due to operational complexities as well as complications due to a changing resource mix (e.g., renewables). Independent system operators are introducing new market products and reformulations in an attempt to accommodate the inherent complexity of the electricity production, transmission, and consumption. Flexible ramping products and generator contingency modeling are examples of such changes. This project will evaluate the essential structural changes to energy markets and provide a comprehensive evaluation of the impacts on settlements. This project will also result in suggested market reformulations to enhance market efficiency, pricing, and transparency.
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Coordination Mechanisms for Seamless Operation of Interconnected Power Systems (S-80)

Summary	The project uses point on wave measurements made in power systems following disturbances of different types and severity to first determine accurate three-phase load composition along distribution feeders. Based on the detailed three-phase load composition characterization obtained, more accurate load compositions for conducting positive-sequence time domain simulations will be developed. The operational and planning benefits of more detailed load compositions in making electric utilities more competitive will be quantitatively evaluated.
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Industry Advisors	Brian Keel (Salt River Project), Mahendra Patel (EPRI), Anish Gaikwad (EPRI), Bajarang Agrawal (APS), Eugene Litvinov (ISO-NE), Jianzhong Tong (PJM), Melvin Schoech (CenterPoint), Di Shi (GEIRI North America Inc.), Xing Wang (Centrica), Hung-Ming Chou (Dominion Energy)

Hybrid Simulation for Large Scale MMC-MTDC Embedded Power Systems (S-83G)

Summary	Modular multilevel converter (MMC) has become the most attractive converter topology for voltage-sourced converter high-voltage direct current (VSC-HVDC) transmission systems. The salient features of MMC include: 1) modularity and scalability to meet any voltage level by stacking up additional numbers of SMs without increasing topology complexity, 2) inherent redundancy and fault-tolerance capability to improve reliability, 3) high efficiency suitable for high-power applications, and 4) high power quality and low filter and transformer cost. MMC based multi-terminal high voltage dc (MTDC) system is a promising technology in grid integration of various renewable energy resources, interconnection of asynchronous ac grids, long-distance power transmission, and enhancement of ac networks. However, it is challenging to analyze and understand the dynamics of large-scale MMC-MTDC embedded hybrid ac and dc systems due to large amount of mixed power electronic switches, electromagnetics devices, and electromechanical components. Electromagnetic transient (EMT) simulation is not suitable for these mixed large-scale systems due to extremely low simulation speed. On the other hand, transient stability (TS) simulation is employed for studying the conventional ac systems and incapable of analyzing power electronics-based systems. In this project, a hybrid simulation strategy is proposed for modeling and simulating large-scale MMC-MTDC-based ac and dc systems. The PI will investigate and develop new hybrid simulation techniques for efficient simulation while keeping high accuracy. The developed simulation techniques will be implemented and tested on a newly developed platform in which EMT models are built on PSCAD\EMTDC and phasor TS models are realized on MATLAB\SIMULINK, along with the developed interface algorithms.
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Industry Advisors	Di Shi (GEIRINA), Xi Chen (GEIRINA), Zhiwei Wang (GEIRINA)

Data-Driven and Machine Learning Based Load Modeling (S-84G)

Summary	Load modeling is important to the planning, operation and control of power systems. Although many studies have focused on load modeling, it is still a challenging task due to complexity and time variability of loads, and the increasing integration of distributed energy resources and power electronic loads. This project will leverage data-driven techniques and a multitude of measurement data from diverse sources to develop static and dynamic load models. The expected outcomes include load identification algorithms, validation cases, and an open-source software tool for load modeling.
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Optimal Model Coordination for Integrated Transmission and Distribution Systems (T-61)

Summary	As distributed energy resources (DERs) are more widely deployed, mainly within the distribution system, traditional models for T&D networks may not be satisfactory. Historically, distribution and transmission have been loosely coupled because the majority of energy resources were interconnected at the transmission system level. The emerging changes to distribution systems are driving the industry to consider modeling greater detail of the distribution system, and potentially co-simulation between transmission and distribution models. The challenge is determining how much of the distribution system needs to be modeled and whether all three phases (with unbalance) need to be included in the models. The goal is to provide planners with sufficient data to form an accurate view of the system with increasing penetrations of DER. This project will identify the necessary details that are required to provide a reasonably accurate picture of future T&D systems. The following questions will be addressed in this work: (a) With more generation at the distribution level, do all, or only a subset, of distribution feeders need to be modeled? (b) How effective are composite load models, as increasing levels of DER are connected? (c) What is the incremental value of co-simulation? (d) To what extent can existing proprietary applications such as GE PSLF and Cyme be used to support future needs? Separate models for transmission that include critical amount of information of distribution, and for distribution that include relevant transmission characteristics, in place of a fully combined model will be investigated. Existing models will be evaluated, and new models will be developed as needed, by comparing with traditional separated T&D framework and a fully combined T&D co-simulation.
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Unified Approach to the Optimization of Transmission Lines for Maximum Power Transfer Capacity Based on their Electric Field Distribution (T-62G)

Summary	The objective of the research project is to develop an approach for overhead transmission line design that uses electric field characteristics to provide a direct link between capacity considerations and corona and flashover performance. The method would provide greater insight into transmission line characteristics and could improve industry capabilities regarding line optimization. The approach could also provide a better way to assess electrical clearances both in terms of reliability and personnel safety.
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Industry Advisors	Dr. Carol Liu, American Electric Power (AEP)