Technical Conference: Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software

Agenda

AD10-12-008
June 26 – 28, 2017

Monday, June 26, 2017

8:45 AM	Introduction (Meeting Room 3M-2) **Richard O'Neill**, Federal Energy Regulatory Commission (*Washington, DC*)
9:00 AM	Session M1 (Meeting Room 3M-2) **Software and Model Enhancements in CAISO Market** Petar Ristanovic, California ISO (*Folsom, CA*) Khaled Abdul-Rahman, California ISO (*Folsom, CA*) George Angelidis, California ISO (*Folsom, CA*) **Experience and Future R&D on Improving MISO Day-Ahead Market Clearing Software Performance** Yonghong Chen, Midcontinent ISO (*Carmel, IN*) David Savageau, Midcontinent ISO (*Carmel, IN*) Fengyu Wang, Midcontinent ISO (*Carmel, IN*) Robert Marring, Midcontinent ISO (*Carmel, IN*) Juan Li, Midcontinent ISO (*Carmel, IN*) **Flexibility Procurement and Reimbursement - a Multi-period Pricing Approach** Dane Schiro, ISO New England (*Holyoke, MA*) Eugene Litvinov, ISO New England (*Holyoke, MA*) Tongxin Zheng, ISO New England (*Holyoke, MA*) Feng Zhao, ISO New England (*Holyoke, MA*)
10:30 AM	Break
10:45 AM	Session M2 (Meeting Room 3M-2) **SPP Market Clearing Engine Enhancements and Performance Improvement** James Gonzalez, Southwest Power Pool (*Little Rock, AR*) **Energy Storage Integration** Hong Chen, PJM Interconnection (*Audubon, PA*) **Infra-marginal Gas Turbine Logic** Guangyuan Zhang, New York ISO (*Rensselaer, NY*)
12:15 PM	Lunch
1:30 PM	Session M3 (Meeting Room 3M-2) **Uncertainty Management in MISO Real-time Systems: Needs, Opportunities and Challenges** Long Zhao, Midcontinent ISO (*Carmel, IN*) Jessica Harrison, Midcontinent ISO (*Carmel, IN*) Yonghong Chen, Midcontinent ISO (*Carmel, IN*) **Price Formation with Evolving Resource Mix** Congcong Wang, Midcontinent ISO (*Carmel, IN*) Dhiman Chatterjee, Midcontinent ISO (*Carmel, IN*) **Factors Impacting Large-scale Security Constrained Unit Commitment Performance and Day-Ahead Market Software Design** Boris Gisin, PowerGEM (*Clifton Park, NY*) Qun Gu, PowerGEM (*Clifton Park, NY*) James David, PowerGEM (*Clifton Park, NY*) **Improving Power System Reliability and Resiliency through Enhanced Modeling and Advanced Software Tools** Marianna Vaiman, V&R Energy (*Los Angeles, CA*)
3:30 PM	Break

Monday, June 26, 2017

3:45 PM	Session M4 (Meeting Room 3M-2) **Forecasting of Dynamic Line Ratings for Market Systems** Kwok Cheung, GE (*Redmond, WA*) Prashanth Duvoor, Ampacimon (*Grâce-Hollogne, Belgium*) **Economic Optimization of Intra-Day Transient Gas Pipeline Flow, Locational Values of Natural Gas and Their Use for Gas-Electric Coordination** Aleksandr Rudkevich, Newton Energy Group (*Boston, MA*) Anatoly Zlotnik, Los Alamos National Laboratory (*Los Alamos, NM*) John Goldis, Newton Energy Group (*Boston, MA*) Pablo A. Ruiz, Boston University (*Boston, MA*) Richard D. Tabors, Tabors Caramanis Rudkevich (*Boston, MA*) Scott Backhaus, Los Alamos National Laboratory (*Los Alamos, NM*) Michael Caramanis, Boston University (*Boston, MA*) Richard Hornby, Tabors Caramanis Rudkevich (*Boston, MA*) **New Software Stack for Power Systems Modeling, Optimization, and Analysis** Adam Wigington, Electric Power Research Institute (*Palo Alto, CA*) Tomas Tinoco de Rubira, Swiss Federal Institute of Technology (*Zurich, Switzerland*) Robert Entriken, Electric Power Research Institute (*Palo Alto, CA*) **Addressing Price Indeterminacy Across Periods in Multi-Period Transmission Congestion Credit Auctions** Joseph Bright, Nexant, Inc. (*Chandler, AZ*) Mauro Prais, Nexant, Inc. (*Chandler, AZ*) Nicole Bouchez, New York ISO (*Rensselaer, NY*)
5:45 PM	Adjourn

Tuesday, June 27, 2017

8:45 AM	Arrive and welcome (Meeting Room 3M-2)
9:00 AM	Session T1-A (Meeting Room 3M-2) **Scenario-Based Decomposition for Parallel Solution of the Contingency-Constrained Alternating Current Optimal Power Flow (ACOPF)** Jean-Paul Watson, Sandia National Laboratories (*Albuquerque, NM*) Carl Laird, Sandia National Laboratories (*Albuquerque, NM*) Anya Castillo, Sandia National Laboratories (*Albuquerque, NM*) **Error Bounds on Power Flow Linearizations: A Convex Relaxation Approach** Daniel Molzahn, Argonne National Laboratory (*Lemont, IL*) Krishnamurthy Dvijotham, Pacific Northwest National Laboratory (*Richland, WA*) **Solving the Mixed Integer Non-Linear Programming Problem of Unit Commitment on AC Power Systems** Anya Castillo, Sandia National Laboratories (*Albuquerque, NM*) Carl Laird, Sandia National Laboratories (*Albuquerque, NM*) Jean Paul Watson, Sandia National Laboratories (*Albuquerque, NM*) Jianfeng Liu, Purdue University (*West Lafayette, IN*)
	Session T1-B (Meeting Room 3M-4) **An Asynchronous Distributed Algorithm for Solving Stochastic Unit Commitment at an Industrial Scale** Ignacio Andres Aravena Solis, CORE at UC Louvain (*Louvain-la-Neuve, Belgium*) Anthony Papavasiliou, CORE at UC Louvain (*Louvain-la-Neuve, Belgium*) **The Unit Commitment Problem: Convex Hulls and Strong Valid Inequalities** Yongpei Guan, University of Florida (*Gainesville, FL*) Kai Pan, Hong Kong Polytech University (*Hong Kong, China*) **Robust Unit Commitment Using the Parametric Cost Function Approximation** Raymond Perkins, Princeton University (*Lawrenceville, NJ*) Warren Powell, Princeton University (*Princeton, NJ*) Juliana Martins Do Nascimento, Princeton University (*Princeton, NJ*) **Optimization Driven Scenario Grouping for Stochastic Unit Commitment** Deepak Rajan, Lawrence Livermore National Laboratory (*Livermore, CA*)
11:00 AM	Break
11:15 AM	Session T2-A (Meeting Room 3M-2) **A Multi-period Optimal Power Flow Approach to Improve Power System Voltage Stability using Demand Response** Daniel K. Molzahn, Argonne National Laboratory (*Lemont, IL*) Johanna Mathieu, University of Michigan (*Ann Arbor, MI*) Mengqi Yao, University of Michigan (*Ann Arbor, MI*) **Advanced Voltage/VAr Management** Herminio Pinto, Nexant Inc. (*Chandler, AZ*) Joseph Bright, Nexant Inc. (*Chandler, AZ*) Brian Stott, Stott Inc. (*Scottsdale, AZ*) Mauro Prais, Nexant Inc. (*Chandler, AZ*) Ongun Alsaç, Smart Grid Applications (*Chandler, AZ*) Fernando Magnago, Nexant Inc. (*Rio Cuarto, Cordoba*) **Linearized Reactive Power and Voltage Constraints for DC OPF and Unit Commitment** Brent Eldridge, Johns Hopkins University/Federal Energy Regulatory Commission (*Washington, DC*) Richard O'Neill, Federal Energy Regulatory Commission (*Washington, DC*)
	Session T2-B (Meeting Room 3M-4) **Assessment of Wind Power Ramp Events in Scenario Generation for Stochastic Unit Commitment** Andrea Staid, Sandia National Laboratories (*Albuquerque, NM*) Jean-Paul Watson, Sandia National Laboratories (*Albuquerque, NM*) David L. Woodruff, University of California Davis (*Davis, CA*) **Unlocking Flexibility of Distributed Energy Resources for Grid Support Services** Yury Dvorkin, New York University (*Brooklyn, NY*) **Uncertainty in Ramping** Randell Johnson, Alevo Analytics (*Concord, NC*)

Tuesday, June 27, 2017

12:45 PM	Lunch
2:00 PM	Session T3-A (Meeting Room 3M-2) **Geographic Decomposition of Production Cost Models** Clayton Barrows, National Renewable Energy Laboratory (*Golden, CO*) Josh Novacheck, National Renewable Energy Laboratory (*Golden, CO*) Aaron Bloom, National Renewable Energy Laboratory (*Golden, CO*) **Temporal Decomposition of the Production Cost Modeling in Power Systems** Kibaek Kim, Argonne National Laboratory (*Lemont, IL*) Audun Botterud, Argonne National Laboratory (*Lemont, IL*) **Modeling Nuclear Power as a Flexible Resource for the Power Grid** Zhi Zhou, Argonne National Laboratory (*Lemont, IL*) Jesse Jenkins, Massachusetts Instiute of Technology (*Cambridge, MA*) Audun Botterud, Argonne National Laboratory (*Lemont, IL*) Roberto Ponciroli, Argonne National Laboratory (*Lemont, IL*) Francesco Ganda, Argonne National Laboratory (*Lemont, IL*) Richard Vilim, Argonne National Laboratory (*Lemont, IL*)
	Session T3-B (Meeting Room 3M-4) **Efficient and Incentive-compatible Solutions for Operating Energy Storage in ISO/RTO Markets** Erik Ela, Electric Power Research Institute (*Palo Alto, CA*) **Economic Opportunities for Energy Storage Systems in Electricity Markets: Combining Models, Data, and Large-scale Optimization** Alexander Dowling, University of Wisconsin-Madison (*Madison, WI*) Victor Zavala, University of Wisconsin-Madison (*Madison, WI*) **Modeling of Storage Technologies in Capacity Expansion Models** Brady Stoll, National Renewable Energy Laboratory (*Golden, CO*) Elaine Hale, National Renewable Energy Laboratory (*Golden, CO*) Clayton Barrows, National Renewable Energy Laboratory (*Golden, CO*) Trieu Mai, National Renewable Energy Laboratory (*Golden, CO*)
3:30 PM	Break
3:45 PM	Session T4-A (Meeting Room 3M-2) **Convex Formulation of the Optimal Transmission Switching Problem** Javad Lavaei, University of California, Berkeley (*Berkeley, CA*) Salar Fattahi, University of California, Berkeley (*Berkeley, CA*) Alper Atamturk, University of California, Berkeley (*Berkeley, CA)* **Danger of Using Local Search Algorithms in Statistical Learning for Power Systems: A General Theory With Case Studies on State Estimation and Bad Data Rejection** Javad Lavaei, University of California, Berkeley (*Berkeley, CA*) Richard Zhang, University of California, Berkeley (*Berkeley, CA*) **Multi-Period Dual Pricing Algorithm for Cost Allocation in Non-Convex Electricity Markets** Robin Broder Hytowitz, Johns Hopkins University/Federal Energy Regulatory Commission (*Washington, DC*) Richard O'Neill, Federal Energy Regulatory Commission (*Washington, DC*) Brent Eldridge, Johns Hopkins University/Federal Energy Regulatory Commission (*Washington, DC*)

Tuesday, June 27, 2017

	Session T4-B (Meeting Room 3M-4) **Energy Storage Optimization Using Distributionally Accurate Stochastic Wind and Price Models** Joseph Durante, Princeton University (*Princeton, NJ*) Harvey Cheng, Princeton University (*Princeton, NJ*) Juliana Nascimento, Princeton University (*Princeton, NJ*) Warren B. Powell, Princeton University (*Princeton, NJ*) **A Multi-period Optimal Power Flow Approach to Improve Optimizing Sensor Type and Location for Rapid Restoration of Power Grids** Lina Al-Kanj, Princeton University (*Princeton, NJ*) Warren Powell, Princeton University (*Princeton, NJ*) **A Massively Scalable Approach to Power System Scheduling** Ramtin Madani, The University of Texas at Arlington (*Arlington, TX*) Alper Atamturk, University of California, Berkeley (*Berkeley, CA*) Ali Davoudi, The University of Texas at Arlington (*Arlington, TX*)
5:15 PM	Adjourn

Wednesday, June 28, 2017

8:15 AM	Arrive and welcome (Meeting Room 3M-2)
8:30 AM	Session W1 (Meeting Room 3M-2) **A Methodology for the Creation of Geographically Realistic, Synthetic Optimal Power Flow Models** Thomas Overbye, Texas A&M University (*College Station, TX*) **Multiport Element Models and Sparse Tableau Network Representation for Security Constrained Optimal Power Flow** Chistopher DeMarco, University of Wisconsin-Madison (*Madison, WI*) **Grid Research for Good: High-Fidelity Power Systems Data Sets, Format, and Software Tools for Optimal Power Flow** Pascal Van Hentenryck, University of Michigan (*Ann Arbor, MI*)
10:00 AM	Break
10:15 AM	Session W2 (Meeting Room 3M-2) **Smart-DS: Synthetic Models for Advanced, Realistic Testing- Distribution Systems and Scenarios** Venkat Krishnan, National Renewable Energy Laboratory (*Golden, CO*) Claudio Vergara, Massachusetts Institute of Technology (*Cambridge, MA*) **Sustainable Data Evolution Technology (SDET) for Power Grid Optimization** Ruishing Diao, Pacific Northwest National Laboratory (*Redland, WA*) **The ARPA-E Generating Realistic Information for the Development of Distribution and Transmission Algorithms (GRID DATA) Repository** Dariush Shirmohammadi, GridBright (*Alamo, CA*) **DR POWER: a Data Repository for Power system Open models With Evolving Resources** Stephen Elbert, Pacific Northwest National Laboratory (*Richland, WA*)
12:15 PM	Adjourn

Staff Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software

Abstracts

Monday, June 26

Opening (Monday, June 26, 8:45 AM, Meeting Room 3M-2)

INTRODUCTION

Dr. Richard O'Neill, Chief Economic Advisor, Federal Energy Regulatory Commission (*Washington, District of Columbia*)

Session M1 (Monday, June 26, 9:00 AM, Meeting Room 3M-2)

SOFTWARE AND MODEL ENHANCEMENTS IN CAISO MARKET

Petar Ristanovic, California ISO (*Folsom, CA*)
Khaled Abdul-Rahman, California ISO (*Folsom, CA*)
George Angelidis, California ISO (*Folsom, CA*)

Many enhancements in the market software optimization algorithm, timelines and resource modeling capabilities have been introduced recently in the California ISO market. This presentation will give overview of these enhancement and additional ones planned in the near future to cope with the increased levels of transmission connected non-conventional generation resources, aggregation of demand response, as well as distributed generation resources. In addition, software developments related to Western Energy Imbalance Market and accounting of greenhouse reduction will also be discussed.

EXPERIENCE AND FUTURE R&D ON IMPROVING MISO DAY-AHEAD MARKET CLEARING SOFTWARE PERFORMANCE

Yonghong Chen, Midcontinent ISO (*Carmel, IN*)
David Savageau, Midcontinent ISO (*Carmel, IN*)
Fengyu Wang, Midcontinent ISO (*Carmel, IN*)
Robert Marring, Midcontinent ISO (*Carmel, IN*)
Juan Li, Midcontinent ISO (*Carmel, IN*)

This presentation first discusses the software enhancements that lead to the successful reduction of MISO DA market clearing window from 4 hours to 3 hours. The enhancement includes SCUC formulation enhancement, efficient iteration between SCUC/SCED and network analysis software, and developed module for solution polishing and post analysis. The formulation improvement also brings the possibility of improving other market design areas such as ELMP and configuration based combined cycle modeling.

MISO is collaborating with vendors and research entities on further improvement on solution algorithms and solver performance. Results with concurrent MIP, lazy constraint, variable hint and multiple MIP starts will be discussed. Meanwhile, PNNL, MISO, GE and Gurobi are developing high performance computing based next generation optimization engine under an ARPA-E project. In addition, MISO is also performing a market system evaluation to identify limiting components and potential enhancements for potential future market scenarios.

FLEXIBILITY PROCUREMENT AND REIMBURSEMENT - A MULTI-PERIOD PRICING APPROACH

Dane Schiro, ISO New England (*Holyoke, MA*)
Eugene Litvinov, ISO New England (*Holyoke, MA*)
Tongxin Zheng, ISO New England (*Holyoke, MA*)
Feng Zhao, ISO New England (*Holyoke, MA*)

The procurement and pricing of flexibility in electricity markets has become increasingly important due to the grid's continued evolution (e.g., more renewables, different generation technologies). Current solutions implemented by different ISOs, namely ramp products and multi-period dispatch, may not provide proper dispatch-following incentives and may result in compensation problems. The general design, practical shortcomings, and theoretical inconsistencies of each approach will be discussed in this presentation. A new multi-period pricing scheme for flexibility procurement and reimbursement will also be presented and compared with the existing methods.

Session M2 (Monday, June 26, 10:45 AM, Meeting Room 3M-2)

SPP MARKET CLEARING ENGINE EHANCEMENTS AND PERFORMANCE IMPROVEMENT

James Gonzalez, Southwest Power Pool (*Little Rock, AR*)

With the greater renewable energy penetration, the falling cost, and many customer benefits, the growth of energy storage (in MWhs) has been doubling last year in US. Energy storage integration is becoming a more important topic than ever before . This presentation will introduce the energy storage technologies currently operating within PJM, their participation in PJM's wholesale electricity markets, and their role in renewable integration. The challenges will also be discussed, such as modeling, economic valuation etc.

ENERGY STORAGE INTEGRATION

Hong Chen, PJM Interconnection (*Audubon, PA*)

With the greater renewable energy penetration, the falling cost, and many customer benefits, the growth of energy storage (in MWhs) has been doubling last year in US.

Energy storage integration is becoming a more important topic than ever before . This presentation will introduce the energy storage technologies currently operating within PJM, their participation in PJM's wholesale electricity markets, and their role in renewable integration. The challenges will also be discussed, such as modeling, economic valuation etc.

INFRA-MARGINAL GAS TURBINE LOGIC

Guangyuan Zhang, New York ISO (*Rensselaer, NY*)

The New York Independent System Operator (NYISO) began using Mixed Integer Programming (MIP) to develop its Day-Ahead Market solution in 2014. A MIP solution utilizes a termination criterion on the solution tolerance, or "MIP gap", to facilitate a timely convergence of the algorithms. The MIP solver uses the branch-and-bound method to search for the optimal solution until the MIP gap is reached. To achieve a balance between solution optimality and solution time, NYISO uses a two-stage MIP solver in which the first MIP stage evaluates all resources with the MIP gap set at $4000. The NYISO then performs a second MIP run that only evaluates uncommitted fast start Gas Turbines (GTs), employing a smaller MIP gap of $200. The two-stage MIP run provides a more optimal commitment schedule for small resources whose production cost may fall within the $4000 MIP gap, while keeping the unit commitment solution period within the required time limit.

<u>Session M3 (Monday, June 26, 1:30 PM, Meeting Room 3M-2)</u>

UNCERTAINTY MANAGEMENT IN MISO REAL-TIME SYSTEMS: NEEDS, OPPORTUNITIES AND CHALLENGES

Long Zhao, Midcontinent ISO (*Carmel, IN*)
Jessica Harrison, Midcontinent ISO (*Carmel, IN*)
Yonghong Chen, Midcontinent ISO (*Carmel, IN*)

The power sector is facing increased dynamics posed by various trends (e.g., larger penetration of intermittent supply, faster-than-expected investments on Energy / Transmission/ IT technologies, and etc.), in addition to traditional components (e.g., load forecast). The uncertainties and their potential scales are pushing the system complexity to a whole new level and are challenging the well-adopted deterministic approaches / practices at MISO. In this talk, we will review the opportunities and challenges to build and apply stochastic capabilities / techniques in MISO business (e.g., operations, markets, processes), and will present some preliminary experiences and thoughts.

PRICE FORMATION WITH EVOLVING RESOURCE MIX

Congcong Wang, Midcontinent ISO (*Carmel, IN*)
Dhiman Chatterjee, Midcontinent ISO (*Carmel, IN*)

With an evolving resource mix including increasing renewable penetration and demand-side participation, pricing needs have changed and will continue to change as resources are needed to balance variations and uncertainties in non-controllable generation and load over the day instead of simply meeting a system peak. This presentation tries to provide a holistic view of the price formation challenges and how MISO is preparing for the low-carbon future by connecting the dots of its recent price enhancements such as Extended LMP, Emergency Energy and Demand Response Pricing and the Ramp Capability product. Numerical examples will be presented to illustrate the potential pricing challenges, including but not limited to sustainability of traditional resources facing prices driven down by low-marginal costs renewables and flexibility of resources that must be maintained for reliability needs.

FACTORS IMPACTING LARGE SCALE SECURITY CONSTRAINED UNIT COMMITMENT PERFORMANCE AND DAY-AHEAD MARKET SOFTWARE DESIGN

Boris Gisin, PowerGEM (*Clifton Park, NY*)
Qun Gu, PowerGEM (*Clifton Park, NY*)
James David, PowerGEM (*Clifton Park, NY*)

The performance of Day-Ahead (DA) Market clearing software has become a more critical factor since the issuance of FERC Order 809. This presentation is focused on large scale DA SCUC performance based on PowerGEM experience working with PJM, MISO and other US ISOs. We will address factors that have the most impact on DA market and forward RAC software solution time including excessive virtual bidding, handling of the non-linearity of the grid model, pump storage optimization, ancillary services modeling and multi-day solutions. This presentation will provide performance benchmarks showing incremental impacts of various factors on the overall SCUC solution time. We will also discuss some conception design ideas and solutions that help to improve SCUC performance and usage.

IMPROVING POWER SYSTEM RELIABILITY AND RESILIENCY THROUGH ENHANCED MODELING AND ADVANCED SOFTWARE TOOLS

Marianna Vaiman, V&R Energy (*Los Angeles, CA*)

The presentation will focus on how advances in power system modeling, including implementation of the node-breaker model and modeling of DERs; use of cutting-edge technologies, like synchrophasor technology; and enhancements in computing technology, such multi-core and distributed programming, improve power system analysis in both real-time and planning environments. It will also cover software applications that allow system operators and planners to enhance health of the power system network.

The presentation will describe the role of IEEE PES in facilitating adoption on these enhanced modeling capabilities and training on advanced technologies.

Session M4 (Monday, June 26, 3:45 PM, Meeting Room 3M-2)

FORECASTING OF DYNAMIC LINE RATINGS FOR MARKET SYSTEMS

Kwok Cheung, GE (*Redmond, WA*)
Prashanth Duvoor, Ampacimon (*Grâce-Hollogne, Belgium*)

In North America, RTOs are fundamentally reliant on security-constrained optimization techniques to commit and dispatch generation resources and serve the native load in large geographical regions. Network security is typically limited by thermal line ratings. Traditionally, static line rating (SLR) of a line is conservatively calculated under the "worst-case" operating conditions and are updated infrequently. These conservative assumptions may restrict the line capacity whenever the real weather condition is less stressful. More accurate assessment of transmission flow limits will directly impact the efficiency of system and market operations. This presentation discusses the forecasting of dynamic line rating (DLR) which has the potential to increase the line rating, reduce transmission congestion and enhance market efficiency from the time frame of day-ahead to near real-time. Based on the real-time historical data measured by sag monitoring and wind speed sensors, the weather forecast is statistically adapted to locally observed conditions of each line span. Using a statistical degradation of the weather forecast, a safe DLR forecast for a given confidence level and a given forecasting horizon can then be computed. This presentation also discusses our approach to integrating DLR forecast into the market systems of RTOs.

ECONOMIC OPTIMIZATION OF INTRA-DAY TRANSIENT GAS PIPELINE FLOW, LOCATIONAL VALUES OF NATURAL GAS AND THEIR USE FOR GAS-ELECTRIC COORDINATION

Aleksandr Rudkevich, Newton Energy Group (*Boston, MA*)
Anatoly Zlotnik, Los Alamos National Laboratory (*Los Alamos, NM*)
John Goldis, Newton Energy Group (*Boston, MA*)
Pablo A. Ruiz, Boston University (*Boston, MA*)
Richard D. Tabors, Tabors Caramanis Rudkevich (*Boston, MA*)
Scott Backhaus, Los Alamos National Laboratory (*Los Alamos, NM*)
Michael Caramanis, Boston University (*Boston, MA*)
Richard Hornby, Tabors Caramanis Rudkevich (*Boston, MA*)

Electricity energy prices are consistent with the physical flow of electric energy in the power grid because of the economic optimization of power system operation in organized electricity markets administered by Regional Transmission Organizations (RTOs). We introduce a similar optimization approach that accounts for physical and engineering factors of pipeline hydraulics and compressor station operations would lead to location- and time-dependent intra-day prices of natural gas consistent with the physics of gas flow. We combine locational gas values and nodal electricity prices to develop an economically efficient gas-electric coordination based on the timely exchange of both physical and pricing data between participants in each market, with price formation in both markets being fully consistent with the physics of energy flow.

Physical data would be intra-day (e.g., hourly) gas schedules (burn and delivery) and pricing data would be bids and offers reflecting willingness to pay and to accept. We will present the economic concepts related to this exchange, and discuss the regulatory and institutional issues that must be addressed. We then formulate a pipeline market clearing problem whose solution provides a flow schedule and hourly pricing, while ensuring that pipeline hydraulic limitations, compressor station constraints, operational factors, and pre-existing shipping contracts are satisfied.

NEW SOFTWARE STACK FOR POWER SYSTEMS MODELING, OPTIMIZATION, AND ANALYSIS

Adam Wigington, Electric Power Research Institute *(Palo Alto, CA)*
Tomas Tinoco de Rubira, Swiss Federal Institute of Technology *(Zurich, Switzerland)*
Robert Entriken, Electric Power Research Institute *(Palo Alto, CA)*

Many critical processes in power systems depend heavily on software. Hence, improvements in software can lead to improvements in system reliability and efficiency. On one end of the spectrum, there are power system application-specific software that are useful for performing specific analyses and tasks such as contingency studies, stability analyses, market clearings, etc. On the other end, there are core numerical software such as linear and optimizations solvers that are flexible, i.e., can be used for a wide range of applications, and efficient, but are difficult to use directly in power system applications. Existing software are scattered between these two ends of the spectrum and do not easily interact with one another, and do not readily leverage new advances or features of others. We present a new software stack for power systems that covers the spectrum, ranging from core numerical solvers to applications that perform high-level analyses. These software are modular, extensible, and designed to interact with one another. They are composed of open source packages that provide optimization solvers and interfaces, model power systems optimization problems, and perform core numerical tasks in power systems, and of (nonopen source) packages developed by EPRI that perform contingency analysis, determine critical operating boundaries, and more. We also present the included Augmented Lagrangian-based optimization solver that has been shown to be robust for solving power flows.

ADDRESSING PRICE INDETERMINACY ACROSS PERIODS IN MULTI-PERIOD TRANSMISSION CONGESTION CREDIT AUCTIONS

Joseph Bright, Nexant, Inc. (*Chandler, AZ*)
Mauro Prais, Nexant, Inc. (*Chandler, AZ*)
Nicole Bouchez, New York ISO (*Rensselaer, NY*)

Multi-period TCC auctions were defined by the NYISO and its consultants in 2001. A multi-period auction is the optimization process that allows market participants to obtain the same MW value across pre-defined time periods for a single TCC bid. The individual time periods are general and may correspond to individual months as envisioned by the NYISO or can correspond to different times of use (TOUs) as presently defined in the ERCOT CRR and PJM FTR monthly auctions.
Perhaps the easiest conceptual implementation of a multi-period auction is to only allow bids and offers across all periods. But this is rarely done. However if the models for each period are identical (including network, constraints and points of injection and withdrawal (POI/POW)), binding constraints appear in only the first period. Constraints in other periods directly corresponding to those binding in the first would be fully-loaded, but their shadow prices and consequently the bus prices would be zero in those periods. Thus only the first period would have any assigned worth.

A new method has been developed to determine the best set of constraint shadow prices to improve the bus, POI/POW or TCC average clearing prices across all periods without impacting the optimality of the original solution. The method is general for any configuration of bids and offers specified in one or more or all periods and for any differences in models across the individual periods.

Tuesday, June 27

Session T1-A (Tuesday, June 27, 9:00 AM, Meeting Room 3M-2)

SCENARIO-BASED DECOMPOSITION FOR PARALLEL SOLUTION OF THE CONTINGENCY-CONSTRAINED ALTERNATING CURRENT OPTIMAL POWER FLOW (ACOPF)

Jean-Paul Watson, Sandia National Laboratories (*Albuquerque, NM*)
Carl Laird, Sandia National Laboratories (*Albuquerque, NM*)
Anya Castillo, Sandia National Laboratories (*Albuquerque, NM*)

We present a nonlinear stochastic programming formulation for a large-scale contingency-constrained optimal power flow problem. Using a rectangular IV formulation to model AC power flow in the transmission network, we construct a nonlinear, multi scenario optimization formulation where each scenario considers nominal operation followed by a failure an individual transmission element. Given the number of potential failures in the network, these problems are very large; yet need to be solved rapidly. In this talk, we demonstrate that this multi-scenario problem can be solved quickly using a parallel decomposition approach based on progressive hedging and nonlinear interior-point methods. Parallel and serial timing results are shown using test cases from Matpower, a MATLAB-based framework for power flow analysis.

ERROR BOUNDS ON POWER FLOW LINEARIZATIONS: A CONVEX RELAXATION APPROACH

Daniel Molzahn, Argonne National Laboratory (*Lemont, IL*)
Krishnamurthy Dvijotham, Pacific Northwest National Laboratory (*Richland, WA*)

The power flow equations model the relationship between the voltages phasors and power flows in an electric power system. The nonlinearity of the power flow equations results in algorithmic and theoretical challenges, including non-convex feasible spaces for optimization problems constrained by these equations. Accordingly, many practical approaches for solving power system optimization and control problems employ linearizations of the power flow equations. By leveraging developments in convex relaxation techniques, this presentation describes recent progress regarding a method for bounding the worst-case errors resulting from power flow linearizations. Specifically, with a focus on the DC power flow approximation, this presentation characterizes the worst-case error in the line flows over a specified range of operational conditions.

SOLVING THE MIXED INTERGER NON-LINEAR PROGRAMMING PROBLEM OF UNIT COMMITMENT ON AC POWER SYSTEMS

Anya Castillo, Sandia National Laboratories (*Albuquerque, NM*)
Carl Laird, Sandia National Laboratories (*Albuquerque, NM*)
Jean Paul Watson, Sandia National Laboratories (*Albuquerque, NM*)
Jianfeng Liu, Purdue University (*West Lafayette, IN*)

The ACOPF is currently not solved in practice due to the nonconvex structure of the problem, which makes the problem challenging to solve to global optimality for operations and market settlements. These challenges are even greater when considering unit commitment. Efficient and accurate solution strategies for this MINLP problem that include both UC and ACOPF is a very challenging, active area of research. In this talk we present both local and global solution techniques, and discuss the tradeoffs of these approaches.

<u>Session T1-B (Tuesday, June 27, 9:00 AM, Meeting Room 3M-4)</u>

AN ASYNCHRONOUS DISTRIBUTED ALGORITHM FOR SOLVING STOCHASTIC UNIT COMMITMENT AT AN INDUSTRIAL SCALE

Ignacio Andres Aravena Solis, CORE, UC Louvain (*Louvain-la-Neuve, Brabant Wallon, Belgium*)
Anthony Papavasiliou, CORE, UC Louvain (*Louvain-la-Neuve, Brabant Wallon, Belgium*)

We present an asynchronous algorithm for solving the stochastic unit commitment (SUC) problem using scenario decomposition. The algorithm is motivated by the scale of problem and significant differences in run times observed among scenario subproblems. The proposed algorithm performs dual iterations asynchronously using a block-coordinate subgradient descent method which allows making updates using delayed information. At the same time, the algorithm recovers candidate primal solutions from the solutions of scenario subproblems using recombination heuristics. The asynchronous algorithm is implemented in a high performance computing cluster and we conduct numerical experiments for two-stage SUC instances of the Western Electricity Coordinating Council system (WECC, 130 thermal generators, 182 nodes, 319 lines, hourly resolution and up to 1000 scenarios) and of the Central Western European system (CWE, 656 thermal generators, 679 nodes, 1073 lines, quarterly resolution and up to 120 scenarios). Using up tp 10 nodes of the cluster per instance, the algorithm provides solutions that are within 2% of optimality to all problems within 47 minutes for WECC and 3 hours, 54 minutes for CWE. Moreover, we find that an equivalent synchronous parallel subgradient algorithm would leave processors idle up to 84% of the time, an observation which underscores the need for designing asynchronous optimization schemes in order to fully exploit distributed computing on real world applications.

THE UNIT COMMITMENT PROBLEM: CONVEX HULLS AND STRONG VALID INEQUALITIES

Yongpei Guan, University of Florida (*Gainesville, FL*)
Kai Pan, Hong Kong Polytech University (*Hong Kong, China*)

In this talk, we represent our recent research progress on the polyhedral study of the fundamental unit commitment polytope. The polytope we studied includes minimum-up/-down time, generation ramp-up/-down rate, logical, and generation upper/lower bound constraints. By exploring its specialized structures, we derive strong valid inequalities and explore a new proof technique to prove that these inequalities are sufficient to provide convex hull descriptions for variant unit commitment problems under certain conditions for two, three and even general T time periods. We also discover efficient polynomial-time separation algorithms for these inequalities to improve the computational efficiency. Finally, extensive computational experiments are conducted to verify the effectiveness of our proposed strong valid inequalities by testing the applications of these inequalities to solve both self-scheduling and network-constrained unit commitment problems, for which our derived approach outperforms the default CPLEX significantly.

ROBUST UNIT COMMITMENT USING THE PARAMETRIC COST FUNCTION APPROXIMATION

Raymond Perkins, Princeton University (*Lawrenceville, NJ*)
Warren Powell, Princeton University (*Princeton, NJ*)
Juliana Martins Do Nascimento, Princeton University (*Princeton, NJ*)

As we put higher demands on the grid with electric vehicles, supplied by less reliable sources such as wind and solar, there is going to be an increasing need for strategies that allow ISOs to operate the grid robustly in the presence of increasing levels of variability and uncertainty. Considerable attention has been directed toward the use of stochastic programming, which replaces the current deterministic lookahead models used by ISOs with an approximate stochastic lookahead. In this talk, we highlight the weaknesses of this approach aside from the dramatic increase in computational complexity. Instead, we propose the use of a parametric cost function approximation, which formalizes the industry-standard practice of achieving robustness by imposing constraints on reserves. We demonstrate why this is a particularly powerful strategy for solving this class of stochastic optimization problem. We show how industry practice, which applies this strategy in an ad-hoc way, is likely to be much more effective than methods based on stochastic programming. We demonstrate the effectiveness of the idea using an aggregate energy planning problem.

OPTIMIZATION DRIVEN SCENARIO GROUPING FOR STOCHASTIC UNIT COMMITMENT

Deepak Rajan, Lawrence Livermore National Laboratory (*Livermore, CA*)

Scenario decomposition algorithms have been shown to be very promising for solving stochastic integer problems. We develop an approach that improves upon these algorithms by re-enforcing a carefully chosen subset of nonanticipativity constraints, effectively placing scenarios into "groups". We use the proposed grouping scheme as a preprocessing step for a particular scenario decomposition algorithm and demonstrate its effectiveness for solving large stochastic Unit Commitment instances.

Session T2-A (Tuesday, June 27, 11:15 AM, Meeting Room 3M-2)

A MULTI-PERIOD OPTIMAL POWER FLOW APPROACH TO IMPROVE POWER SYSTEM VOLTAGE STABILITY USING DEMAND RESPONSE

Daniel K. Molzahn, Argonne National Laboratory (*Lemont, IL*)
Johanna Mathieu, University of Michigan (*Ann Arbor, MI*)
Mengqi Yao, University of Michigan (*Ann Arbor, MI*)

The increasing penetration of renewables has driven power systems to operate closer to their stability boundaries, increasing the risk of voltage instability. We propose a new demand response strategy using flexible loads to improve voltage stability margins. Voltage stability is measured by the smallest singular value (SSV) of the power flow Jacobian matrix, and the load is shifted between different buses while keeping the total load constant so as not to affect system frequency. An energy payback period maintains the average energy consumption at its nominal value. We formulate the problem as a multi-period optimization problem; its cost function balances SSV improvements against generation costs in the energy payback period. The problem is solved to obtain an AC-feasible solution via an iterative linear programming approach that uses eigenvalue sensitivities and linearized AC power flow equations. A test case derived from the IEEE 118-bus system is used to numerically illustrate the performance of the algorithm.

ADVANCED VOLTAGE/VAR MANAGEMENT

Herminio Pinto, Nexant Inc. (*Chandler, AZ*)
Joseph Bright, Nexant Inc. (*Chandler*, *AZ*)
Brian Stott, Stott Inc. (*Scottsdale*, *AZ*)
Mauro Prais, Nexant Inc. (*Chandler*, *AZ*)
Ongun Alsac, Smart Grid Applications (*Chandler*, *AZ*)
Fernando Magnago, Nexant Inc. (*Rio Cuarto, Cordoba*, *Spain*)

The security-economy operation of a power system is normally dominated by its MW market. Voltage-VAr management occupies a secondary supporting role.
As the penetration of renewable generation increases, especially from wind sources, Voltage-VAr management becomes more critical. The associated uncertainties give rise to multiple and diverse operational scenarios that can require special deployments of voltage-support resources.

Operational voltage-VAr coordination spans a time horizon that can range from an hour to a couple of days ahead. It is a multi-stage look-ahead problem whose solution involves a sequence of security-constrained optimal power flow (SCOPF) calculations with full AC network models. Appropriate inter-temporal constraints ensure, as far as possible, a smooth operational trajectory over time. This is a complex optimization problem, requiring sophisticated solution techniques.

In this presentation, the authors demonstrate the use of mixed-integer programming (MIP) together with Benders Decomposition to cope with this problem. The algorithm iterates between optimal solutions at sub-problem and master levels. At the master level, MIP couples all time intervals by imposing constraints that limit control movements between them. The sub-problem level optimizes voltage and VAr controls for each interval in order to enforce its quasi-static operational constraints. This methodology is illustrated using realistic operational data from different ISOs and RTOs.

LINEARIZED REACTIVE POWER AND VOLTAGE CONSTRAINTS FOR DC OPF AND UNIT COMMITMENT

Brent Eldridge, Johns Hopkins University/Federal Energy Regulatory Commission (*Washington, DC*)
Richard O’Neill, Federal Energy Regulatory Commission (*Washington, DC*)

ISOs handle voltage and reactive power constraints during unit commitment by adding constraints, called “nomograms” or “closed loop interfaces” (CLIs), that limit real power flow across a set of transmission lines. The limits are determined conservatively, and there may in fact be cheaper solutions available during real time operation. Within the unit commitment problem, these constraints have the effect of cutting off solutions that do not have sufficient reactive power capability in areas that need additional voltage support. A better approach may be to introduce reactive power and voltage constraints that can also cut AC-infeasible solutions from a DC OPF-based unit commitment model. Not only would this approach help ensure that voltage constraints are satisfied, but it also allows co-optimization of real and reactive power.

Unfortunately, the linear models used to clear electricity markets ignore reactive power and voltage support, so potentially efficient changes to reactive power dispatch are ignored. This paper expands the standard linearized DC OPF to improve physical accuracy of voltage and reactive power constraints without the computational difficulty of solving the full AC OPF. In particular, alternatives to the nomogram and CLI constraints are investigated and compared in terms of the resulting operational costs, number of voltage violations, and solution speed.

Session T2-B (Tuesday, June 27, 11:15 AM, Meeting Room 3M-4)

ASSESSMENT OF WIND POWER RAMP EVENTS IN SCENARIO GENERATION FOR STOCHASTIC UNIT COMMITMENT

Andrea Staid, Sandia National Laboratories (*Albuquerque, NM*)
Jean-Paul Watson, Sandia National Laboratories (*Albuquerque, NM*)
David L. Woodruff, University of California Davis (*Davis, CA*)

Stochastic optimization models for power system operations (e.g., unit commitment and economic dispatch) rely on high-quality scenarios of uncertain quantities, such as wind and solar power production. Methods for generating scenarios often rely on historical error distributions and targeted sampling. In many cases, these result in accurate representations of the uncertainty that will be realized. However, in the case of wind power, accurate ramp events are often not captured using standard scenario generation processes. If not anticipated, ramp events stress the system and result in high costs to system operators, as they must call on expensive, fast-ramping generation to counteract the rapid change in wind production. We present a new method for generating scenarios while explicitly incorporating ramp events. The ramps are based on the historical behavior of wind power in the case study area, and we build scenarios that represent possible wind power ramps, capturing both upward and downward trends with varying magnitude and duration. We then assess the performance of these new scenarios in the context of stochastic unit commitment and compare the system costs to those when using standard scenarios that do not explicitly incorporate ramp events.

UNLOCKING FLEXIBILITY OF DISTRIBUTED ENERGY RESOURCES FOR GRID SUPPORT SERVICES

Yury Dvorkin, New York University (*Brooklyn, New York, New York*)

Recent studies have manifestly demonstrated the ability of customer- and utility-owned distributed energy resources (DERs), e.g. controllable loads, electrical vehicles, and energy storage, to provide grid support services in distribution electrical grids. This presentation will describe a modeling and simulation framework to optimally allocate available DER flexibility between distribution and transmission grid support services. This allocation will be discussed in the context of existing wholesale and prospective retail electricity markets using numerical results obtained using the proposed framework.

UNCERTAINTY IN RAMPING

Randell Johnson, Alevo Analytics (*Concord, NC*)

Dr. Johnson has conducted many modeling studies of stochastic optimizations of grids subject to uncertainty and the interconnection between day ahead market scheduling and real-time dispatch. The uncertainties studied have been renewables, fuel prices, outages, demand and others with impact to ancillary services prices and how technologies interact across the DA and RT markets to impact regulation, reserves and energy prices and scheduling.

Dr. Johnson has also been engaged in analysis of smart transmission controls, transmission switching, as well as energy storage and other technologies for addressing ramping requirements and price signals for ramping as well as price impacts to ancillary services and energy.

Session T3-A (Tuesday, June 27, 2:00 PM, Meeting Room 3M-2)

GEOGRAPHIC DECOMPOSITION OF PRODUCTION COST MODELS

Clayton Barrows, National Renewable Energy Laboratory (*Golden, CO*)
Josh Novacheck, National Renewable Energy Laboratory (*Golden, CO*)
Aaron Bloom, National Renewable Energy Laboratory (*Golden, CO*)

The computational burdens associated with modeling the unit commitment and economic dispatch (UC&ED) of power systems has resulted in simplifications designed to increase tractability. Furthermore, UC&ED models fail to represent the multitude of decision makers acting within the same physical power system. While modern computing has enabled power system planners and operators to dramatically increase the complexity of power systems studies, UC&ED problems have been unable to fully exploit the value of multi-core processing because of the serial nature of the optimization.

In this work we introduce a new modeling framework for improving the computational performance and simulation accuracy of a commercial production cost model (PCM). Our approach involves an interchange forecast step, a geographically decomposed regional commitment step, and a coordinated redispatch step; where the regional commitment step is executed in parallel on network subsets.
The Geographic Decomposition approach is applied to two use cases: 1) a new reliability test system developed as part of the DOE Grid Modernization Laboratory Consortium; and 2) a combined model of the eastern and western interconnections in the Interconnections Seam Study. Results are presented to describe solution accuracy and simulation time improvements.

TEMPORAL DECOMPOSITION OF THE PRODUCTION COST MODELING IN POWER SYSTEMS

Kibaek Kim, Argonne National Laboratory (*Lemont, IL*)
Audun Botterud, Argonne National Laboratory (*Lemont, IL*)

Production Cost Models (PCMs) simulate power system operations over a multi-year time horizon with an hourly interval of time periods. A PCM is formulated as a large-scale mixed-integer linear programming problem that computes unit commitment and dispatch schedules for a power system, and each problem can have billions of variables and constraints. We present a solution method based on Dantzig-Wolfe decomposition, which decouples a time horizon into several sub-horizons. The method has been implemented in an open-source software package, DSP capable of running on high-performance computing cluster. We provide computational results for test problems.

MODELING NUCLEAR POWER AS A FLEXIBLE RESOURCE FOR THE POWER GRID

Zhi Zhou, Argonne National Laboratory (*Lemont, IL*)
Jesse Jenkins, Massachusetts Institute of Technology (*Cambridge, MA*)
Audun Botterud, Argonne National Laboratory (*Lemont, IL*)
Roberto Ponciroli, Argonne National Laboratory (*Lemont, IL*)
Francesco Ganda, Argonne National Laboratory (*Lemont, IL*)
Richard Vilim, Argonne National Laboratory (*Lemont, IL*)

The economic viability of nuclear energy is increasingly challenged in the U.S. deregulated electricity markets due to large availability of cheap natural gas and increased penetration of renewables. It is critical to improve the competitiveness of nuclear energy to maintain energy supply diversity. In current U.S. markets, nuclear power plants are commonly operated in a “baseload” mode at maximum rated capacity whenever online. However, nuclear power plants are technically capable of flexible operation, including changing power output over time and providing regulation and operating reserves. Flexible operation can help integrate variable energy resources, meet system reliability requirements, and improve power system resilience. In this study, we present a novel model to accurately represent the technical operating constraints and flexibility of nuclear power plants, including impacts of xenon transients in the reactor core and how it changes over the fuel cycle. We integrate the improved nuclear power plant model into a unit commitment and economic dispatch model for the power system. In a case study, we investigate the economic impact of flexible nuclear operations on plant profitability and system cost in a market with high shares of renewable energy. The results show that operational flexibility can not only increase a nuclear plant's profit, but also have benefit to the system in terms of reduced operating costs and lower curtailment of renewable energy.

Session T3-B (Tuesday, June 27, 2:00 PM, Meeting Room 3M-4)

EFFICIENT AND INCENTIVE COMPATIBLE SOLUTIONS FOR OPERATING ENERGY STORAGE IN ISO/RTO MARKETS

Erik Ela, Electric Power Research Institute (*Palo Alto, CA*)

This presentation will describe potential new alternatives to solving for the operation of energy storage technologies in energy and ancillary service markets, both large reservoir storage resources, and limited energy storage resources, and the differences between these technologies. Different alternative scheduling procedures assuming ISO state-of-charge management are compared to self-managed state-of-charge, and the impacts that may be seen to reliability, efficiency, and price formation. In addition, different pricing implementations that set clearing prices based on the marginal cost of energy storage for the different methods will be shown as well, both for energy and ancillary services. Potential discussion will include practical considerations, settlements and make-whole payments, sizing of storage and impact on MIP gaps, as well as use of storage and state-of-charge management in the AGC application.

ECONOMIC OPPORTUNITIES FOR ENERGY STORAGE SYSTEMS IN ELECTRICITY MARKETS: COMBINING MODELS, DATA, AND LARGE-SCALE OPTIMIZATION

Alexander Dowling, University of Wisconsin-Madison (*Madison, WI*)
Victor Zavala, University of Wisconsin-Madison (*Madison, WI*)

We present a computational framework to analyze the economic opportunities for energy storage systems in electricity markets. Our framework combines detailed physical models for battery systems that capture performance and long-term degradation effects. We conduct the analysis by using extensive price data for CAISO that captures spatial variability and multiple market products (energy and ancillary services) at multiple timescales (day-ahead and real-time) as well as market variability. Our results reveal that economic opportunities provided by energy markets outmatch degradation effects, indicating that mitigating degradation effects are not as critical as one might intuitively think. Moreover, our analysis reveals that the majority of economic potential are provided by real-time markets and that there exist strong spatial variability in economic potential.

MODELING OF STORAGE TECHNOLOGIES IN CAPACITY EXPANSION MODELS

Brady Stoll, National Renewable Energy Laboratory (*Golden, CO*)
Elaine Hale, National Renewable Energy Laboratory (*Golden, CO*)
Clayton Barrows, National Renewable Energy Laboratory (*Golden, CO*)
Trieu Mai, National Renewable Energy Laboratory (*Golden, CO*)

The Resource Planning Model (RPM) is a capacity expansion model designed to simulate power system evolution with a regional focus. A particular concern for future power systems is the need for more flexible generators to help mitigate the variability of generation and load. While storage technologies present a high degree of flexibility, they historically have been too expensive for most applications. As storage costs decline, storage is increasingly of interest to grid planners due to its ability to help integrate variable renewable generation. Storage technologies are more complex to represent in capacity expansion models than traditional generators due to multiple value streams available to these technologies. RPM captures these value streams by estimating per-unit capacity value and curtailment reduction potential; energy value, including arbitrage and curtailment reduction; and participation in three types of operating reserves. We present the modeling techniques used to represent these value streams, as well as the impacts of storage technology on the overall capacity mix and dispatch results for several storage cost trajectories.

Session T4-A (Tuesday, June 27, 3:45 PM, Meeting Room 3M-2)

CONVEX FORMULATION OF THE OPTIMAL TRANSMISSION SWITCHING PROBLEM

Javad Lavaei, University of California, Berkeley (*Berkeley, California*)
Salar Fattahi, University of California, Berkeley (*Berkeley, CA*)
Alper Atamturk, University of California, Berkeley (*Berkeley, CA*)

Transmission lines have traditionally been considered uncontrollable devices in the infrastructure, except in the case of an outage or maintenance. However, due to the pressing needs to boost the sustainability, reliability and efficiency of power systems, there is a tendency to leverage the flexibility in the topology of the grid and co-optimize the topology to improve the dispatch. In this talk, we study the optimal transmission switching (OTS) problem. The goal is to identify a topology of the power grid that optimizes the performance while satisfying the physical and operational constraints, possibly combined with the unit commitment problem. Most of the existing methods are based on converting the OTS problem into a mixed-integer linear program (MILP), and then iteratively solving a series of convex problems. The performance of these methods depends heavily on the strength of the MILP formulation. In this talk, we propose a single convex conic relaxation of the big-M MILP formulation of the OTS problem. Strong valid inequalities designed

based on the reformulation-linearization technique are incorporated in the conic relaxation. We extensively evaluate the performance of the proposed method on various benchmarks systems and show that this technique almost always finds a globally optimal topology by solving a single convex problem of a manageable size.

DANGER OF USING LOCAL SEARCH ALGORITHMS IN STATISTICAL LEARNING FOR POWER SYSTEMS: A GENERAL THEORY WITH CASE STUDIES ON STATE ESTIMATION AND BAD DATA REJECTION

Javad Lavaei, University of California, Berkeley (*Berkeley, CA*)
Richard Zhang, University of California, Berkeley (*Berkeley, CA*)

The operation of power systems heavily relies on the mechanisms used to go from data to action. For example, state estimation plays a major role in the operation, where the goal is to estimate the underlying state of the system from unreliable data subject to noise and possible manipulations. In statistics, it is often argued that the higher the volume of data is, the better the information extraction would be. In the context of state estimation, this implies that there are statistical learning methods whose performance for the state estimation problem improves as the amount of collected data increases. Given the recent advances in the PMU deployment, a question arises as to how the large amount of PMU data could be used to improve the operation. To study this problem, we show that since the area of statistical learning often assumes that we have access to global optimization techniques but local search algorithms are used for power systems in practice, this would have adverse effects. In particular, we show that as the amount of data increases, the estimation error might unexpectedly go up even in the absence of noise due to the nonlinearity of power flow equations. To resolve this issue, we discuss how to combine convex relaxation techniques with statistical learning methods so that we can improve the operation of power systems as the amount of sensory data increases.

MULTI-PERIOD DUAL PRICING ALGORITHM FOR COST ALLOCATION IN NON-CONVEX ELECTRICITY MARKETS

Javad Lavaei, University of California, Berkeley (*Berkeley, CA*)
Richard Zhang, University of California, Berkeley (*Berkeley, CA*)

Generation costs in electricity markets are non-convex functions of output; as a result, prices are not monotonically non-decreasing with demand. Consequently, it is difficult to define a single price at each node and time period that results in a balance of supply and demand, while covering all generator-operating costs. Therefore, most markets currently pay a two-part price, consisting of a public marginal price and a private make-whole payment tailored to each generator who would otherwise incur variable costs that exceed their revenue. The expense of these make-whole payments, also called uplift payments, is usually allocated evenly across all customers. This allocation method does not take into consideration who benefits from the additional costs. We propose an alternative algorithm for prices in a non-convex market and a means to allocate those prices to market participants called the Dual Pricing Algorithm. This presentation will outline the algorithm?s extension to multiple time periods, examples on different sized test cases, and further comparisons to other pricing methods.

Session T4-B (Tuesday, June 27, 3:45 PM, Meeting Room 3M-4)

ENERGY STORAGE OPTIMIZATION USING DISTRIBUTIONALLY ACCURATE STOCHASTIC WIND AND PRICE MODELS

Joseph Durante, Princeton University (*Princeton, NJ*)
Harvey Cheng, Princeton University (*Princeton, NJ*)
Juliana Nascimento, Princeton University (*Princeton, NJ*)
Warren B. Powell, Princeton University (*Princeton, NJ*)

We consider a simple energy storage problem involving a wind farm with a forecasted power output, a stochastic load, an energy storage device, and a connection to the larger power grid with stochastic prices. Electricity prices and wind power forecast errors are modeled using a novel hidden semi-Markov model that accurately replicates not just the distribution of the error, but also crossing times, which captures the amount of time each process stays above or below some benchmark such as the forecast. This is an important property of stochastic processes involved in storage problems. The new model requires capturing a post-decision information state that is partially hidden. We derive a near-optimal time-dependent policy using a novel technique we call backward approximate dynamic programming, which overcomes the computational hurdles of classical (exact) backward dynamic programming, with higher quality solutions than the more familiar forward approximate dynamic programming methods. The method can be applied to very fine time-scaled problems, allowing it to be used for settings such as optimizing across multiple revenue streams such as frequency regulation and energy shifting.

A MULTI-PERIOD OPTIMAL POWER FLOW APPROACH TO IMPROVE OPTIMIZING SENSOR TYPE AND LOCATION FOR RAPID RESTORATION OF POWER GRIDS

Lina Al-Kanj, Princeton University (*Princeton, NJ*)
Warren Powell, Princeton University (*Princeton, NJ*)

Utilities have to manage imperfect information about the location of outages during and after storms. Lights-out calls can be used to develop probabilities of the location of outages, but considerable uncertainty remains. Sensors provide much more precise information, but they are expensive. We estimate the value of putting different types of sensors at each location in the network by optimizing the dispatch of utility trucks using a method that accurately accounts for the probability of outages across the network. We use Bayesian updating as new information arrives, either in the form of new phone calls, or as the utility truck collects information by moving around the network, performing repairs as needed. This is the first model that makes maximum

use of probabilistic information. We can then test the value of a sensor by simulating dispatch decisions with and without a sensor at different locations in the network.

A MASSIVELY SCALABLE APPROACH TO POWER SYSTEM SCHEDULING

Ramtin Madani, The University of Texas at Arlington (*Arlington, TX*)
Alper Atamturk, University of California, Berkeley (*Berkeley, CA*)
Ali Davoudi, The University of Texas at Arlington (*Arlington, TX*)

Determination of the most economic strategies for supply and transmission of electricity is a daunting challenge, in terms of computational complexity. In this talk, a computational method is developed, which is capable of approaching power system scheduling problems with a considerably large number of binary variables, while handling nonlinear equations that govern the flow of electricity. We design a family of linear and conic inequalities to form a polynomial-time solvable surrogate, with the aim of finding a near globally optimal point for the original NP-hard problem. The proposed method is demonstrated on large-scale problems based on real-world European grid data, for which feasible decisions are obtained within provably small gaps from global optimality.

Wednesday, June 28

Session W1 (Wednesday, June 28, 8:30 AM, Meeting Room 3M-2)

A METHODOLOGY FOR THE CREATION OF GEOGRAPHICALLY REALISTIC, SYNTHETIC OPTIMAL POWER FLOW MODELS

Thomas Overbye, Texas A&M University (*College Station, TX*)

The presentation will cover a methodology being developed by an ARPA-E Grid Data project for the creation of synthetic power system test models that can be used optimal power flow studies. The gist of the approach is the synthesized grid models are built to match statistical characteristics found in actual power grids, but they do not correspond to any real grid. Thus they are free from any CEII and can be publicly shared. The approach consists of five steps. First, substations are geographically placed on a selected geographic footprint, synthesized from public information about the underlying population and generation plants. Second, buses and transformers are added to the substations. Third, a network of high voltage transmission lines are added to connect the substations. The presentation covers important statistics that should be used to match actual grids including connectivity, Delaunay triangulation overlap, dc power flow analysis, and line intersection rate. Fourth, the models are augmented with actual parameters including reactive power control devices and generator cost information in order to create large, realistic cases for OPF analysis. Last, the models are validated to insure their OPF results are statistically similar to actual grids. The techniques will be demonstrated on systems with up to 10,000 buses.

MULTIPORT ELEMENT MODELS AND SPARSE TABLEAU NETWORK REPRESENTATION FOR SECURITY CONSTRAINED OPTIMAL POWER FLOW

Christopher DeMarco, University of Wisconsin-Madison (*Madison, WI*)
Michael Ferris, University of Wisconsin-Madison (*Madison, WI*)
Bernard, University of Wisconsin-Madison (*Madison, WI*)
Byungkwon Park, University of Wisconsin-Madison (*Madison, WI*)
Jayanth Netha, University of Wisconsin-Madison (*Madison, WI*)

Realistic representation of contingencies in full AC optimal power flow often challenges traditional bus-branch power system network models, based on the "Ybus" admittance matrix. Similarly, treatment of network elements as assemblies of two-terminal admittances (e.g., the pi-equivalent for transmission lines) limits the class of technologies that can be modeled, or necessitates cumbersome work-arounds that introduce non-physical component values (consider the "star equivalent" for a three winding transformer, that often yields a negative equivalent impedance for Z_s). In this work, a more general set of grid element models and network representations are developed; these provide improved fidelity in capturing physical behavior and engineering limits, and allow added flexibility in optimization solution algorithms. First, the underlying network element models are allowed to be general, implicit multi-ports: two-port elements for transmission lines, three-ports for three winding transformers, etc. The network constraints are assembled as a complete, highly sparse set of four equation types: (i) individual element constraints, based on each elements port currents and port voltages; (ii) KVL equations relating element port voltages to node/bus voltages; (iii) KCL equations relating port currents to currents externally injected at nodes/buses; (iv) nodal power relations relating externally injected node/bus complex powers to node/bus currents.

GRID RESEARCH FOR GOOD: HIGH-FIDELITY POWER SYSTEMS DATA SETS, FORMAT, AND SOFTWARE TOOLS FOR OPTIMAL POWER FLOW

Pascal Van Hentenryck, University of Michigan (*Ann Arbor, MI*)
Daniel Beinstock, Columbia University (*New York, NY*)
Russell Bent, Los Alamos National Laboratory (*Los Alamos, NM*)
Ian Hiskens, University of Michigan (*Ann Arbor, MI*)
Steven Low, Caltech (*Los Angeles, CA*)
Carleton Coffrin, Los Alamos National Laboratory (*Los Alamos, NM*)
Patrick Panciatici, RTE (*Versailles, France*)
Ferdinando Fioretto, University of Michigan (*Ann Arbor, MI*)

This talk describes the progress made by the GRG team to produce high-fidelity realistic power system data for optimal power flows. The project works closely with RTE, the French transmission operator, to deliver test cases modeling a real transmission networks in all its complexity. The project is also organized around a new JSON format to capture the required fidelity and a set of software tools to parse,

transform, and manipulate the format. In particular, the software suite makes it possible to transform the network data from a node breaker configuration to a bus-breaker or a bus-branch configuration, to perform per-unit transformation, and to validate the parameters of the networks. In addition, the project is investigating techniques to generate synthetic test cases from the real test cases through various graph-theoretic transformations, and disaggregation techniques to preserve the privacy of the data.

Session W2 (Wednesday, June 28, 10:15 AM, Meeting Room 3M-2)

SMART-DS: SYNTHETIC MODELS FOR ADVANCED, REALISTIC TESTING- DISTRIBUTION SYSTEMS AND SCENARIOS

Venkat Krishnan, National Renewable Energy Laboratory (*Golden, CO*)
Claudio Vergara, Massachusetts Institute of Technology (*Cambridge, MA*)

The National Renewable Energy Laboratory (NREL) in collaboration with Massachusetts Institute of Technology (MIT), Universidad Pontificia Comillas (Comillas-IIT, Spain) and GE Grid Solutions, is working on an ARPA-E GRID DATA project, titled Smart-DS, to create:

1. High-quality, realistic, synthetic distribution network models, and
2. Advanced tools for automated scenario generation based on high-resolution weather data and generation growth projections.

Through these advancements, the Smart-DS project is envisioned to accelerate the development, testing, and adoption of advanced algorithms, approaches, and technologies for sustainable and resilient electric power systems, especially in the realm of U.S. distribution systems.

This talk will present the goals and overall approach of the Smart-DS project, including the process of creating the synthetic distribution datasets using reference network model (RNM) and the comprehensive validation process to ensure network realism, feasibility, and applicability to advanced use cases. The talk will provide demonstrations of early versions of synthetic models, along with the lessons learnt from expert engagements to enhance future iterations. Finally, the scenario generation framework, its development plans, and co-ordination with GRID DATA repository teams to house these datasets for public access will also be discussed.

SUSTAINABLE DATA EVOLUTION TECHNOLOGY (SDET) FOR POWER GRID OPTIMIZATION

Ruisheng Diao, Pacific Northwest National Laboratory (*Richland, WA*)

Pacific Northwest National Laboratory and its industry partners propose to develop an innovative sustainable data evolution technology (SDET) to create open-access power grid datasets and facilitate updates to these datasets by the community. The lack of open-access, realistic large-scale datasets significantly limits the ability of researchers, developers and ultimately end users to develop, benchmark and compare new methods and tools for optimizing the operation and planning of the grid, which leads to slow adoption by end users. The SDET approach will uniquely 1) derive features and metrics from many private datasets provided by our industry partners NRECA, PJM, CAISO, and Avista, 2) develop data creation tools and use these tools to generate large-scale open-access realistic datasets complying with the metrics, and 3) validate the created datasets using industry tools provided by our vendor partner Alstom Grid. The data creation tools, as well as the created datasets, will be offered for integration in the data repository this GRID DATA program would fund in Category 2, so users can use the datasets and access these data creation tools to create and update datasets, thus datasets can evolve per user requirements and power grid advancements. The SDET is a novel and disruptive technology compared to current ad-hoc and static dataset generation,which will significantly enhance the development, and adoption of new methods and tools for grid optimization.

THE ARPA-E GENERATING REALISTIC INFORMATION FOR THE DEVELOPMENT OF DISTRIBUTION AND TRANSMISSION ALGORITHMS (GRID DATA) REPOSITORY

Dariush Shirmohammadi, GridBright (*Alamo, CA*)

The GRID DATA Repository is a free electronic library of publicly available test data instigated by the US Department of Energy (DOE) Advanced Research Projects Agency-Energy (ARPA-E) to support research in grid optimization and modernization.

The Repository will contain some of the existing disparate grid data existing in the utility industry, future grid data developed by the grid research community, as well as the grid models that are being created under the ARPA-E GRID DATA program focused on Generating Realistic Information for the Development of Distribution and Transmission Algorithms.

The Repository is being built by GridBright, Inc. as open source software as part of the ARPA-E GRID DATA program. The first version is being tested and is expected to be released for public use in May 2017.

The BetterGrids Foundation, a nonprofit organization, will provide support for the Repository in a self-funding and self-governing manner through volunteers.

More information can be found on www.BetterGrids.org.

DR POWER: A DATA REPOSITORY FOR POWER SYSTEM OPEN MODELS WITH EVOLVING RESOURCES

Stephen Elbert, Pacific Northwest National Laboratory (*Richland, WA*)

DR POWER is making available open-access power grid datasets with the capability to review, annotate and search submitted datasets. APIs for contributor supplied tools extend abilities to manipulate the data. The National Rural Electric Cooperative Associations (NRECA) Open Modeling Framework (OMF) is being extended to include transmission modeling. We are targeting thousands of models/data sets with millions of scenarios, all with Digital Object Identifiers (DOIs) to facilitate citation. We are committed to building a dynamic community resource based on the Digital Curation Center Lifecycle Model. We will be demonstrating the initial functionality with the web portal.