UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

Increasing Market and Planning Efficiency through Improved Software	Docket No. AD10-12-012

SUPPLEMENTAL NOTICE OF TECHNICAL CONFERENCE ON INCREASING REAL-TIME AND DAY-AHEAD MARKET EFFICIENCY THROUGH IMPROVED SOFTWARE

(May 28, 2021)

As first announced in the Notice of Technical Conference issued in this proceeding on March 11, 2021, Commission staff will convene a technical conference on June 22, 23, and 24, 2021 to discuss opportunities for increasing real-time and day-ahead market efficiency of the bulk power system through improved software. Attached to this Supplemental Notice is an agenda for the technical conference and speakers' summaries of their presentations.

While the intent of the technical conference is not to focus on any specific matters before the Commission, some conference discussions might include topics at issue in proceedings that are currently pending before the Commission, including topics related to capacity valuation methodologies for renewable, hybrid, or storage resources. These proceedings include, but are not limited to:

PJM Interconnection, L.L.C.	Docket No. ER20-584-000
PJM Interconnection, L.L.C.	Docket No. EL19-100-000
PJM Interconnection, L.L.C.	Docket Nos. ER21-278-000 and ER21-278-001

The conference will take place virtually via WebEx, with remote participation from both presenters and attendees. Further details on remote attendance and participation will be released prior to the conference. Attendees must register through the Commission's website on or before June 11, 2021.[1] WebEx connections may not be available to those who do not register.

The Commission will accept comments following the conference, with a deadline of July 30, 2021.

There is an "eSubscription" link on the Commission's web site that enables subscribers to receive email notification when a document is added to a subscribed docket(s). For assistance

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[1] The attendee registration form is located at https://ferc.webex.com/ferc/onstage/g.php?MTID=e97c1ef8334b1f4db52394fe644edfe57 . Click "Register" to be taken to the form.

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Secretary.

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

Agenda

AD10-12-012
June 22 – 24, 2021

Tuesday, June 22, 2021

9:45 AM	Introduction **Thomas Dautel**, Federal Energy Regulatory Commission (*Washington, DC*)
10:00 AM	Session T1 **Addressing Uncertainties through Improved Pricing and Reserve Product Design** Yonghong Chen, Midcontinent ISO (Carmel, IN) **On the Formulation Dependence of Convex Hull Pricing** Feng Zhao, ISO New England (Holyoke, MA) Dane Schiro, ISO New England (Holyoke, MA) Jinye Zhao, ISO New England (Holyoke, MA) Tongxin Zheng, ISO New England (Holyoke, MA) **Modeling of Renewable Generation and Energy Storage Capacity Expansion** John Meyer, New York ISO (Rensselaer, NY) **Deploying Modernized Applications in a Secure and Compliant Manner** Jeff Price, Midcontinent ISO (Carmel, IN)
11:40 AM	Lunch
12:40 PM	Session T2 **Generator Performance Evaluation at ISO New England** Slava Maslennikov, ISO New England (Holyoke, MA) Izudin Lelic, ISO New England (Holyoke, MA) Kory Haag, ISO New England (Holyoke, MA) Xiaochuan Luo, ISO New England (Holyoke, MA) **Pumped Storage Optimization in Day-ahead and Real-time Market under Uncertainty** Bing Huang, Midcontinent ISO (Carmel, IN) Arezou Ghesmati, Midcontinent ISO (Carmel, IN) Yonghong Chen, Midcontinent ISO (Carmel, IN) Ross Baldick, University of Texas at Austin (Austin, TX) Rui Bo, Missouri University of Science and Technology (Rolla, MO) **Integration of Storage Resources in the CAISO's System** Guillermo Bautista Alderete, California ISO (Folsom, CA) Rahul Kalaskar, California ISO (Folsom, CA) **HIPPO Concurrent Optimizer – Enhanced Simultaneous Feasibility Test (SFT) and Migration to Private Cloud** Jesse Holzer, Pacific Northwest National Laboratory (Richland, WA) Joanna Wu, Midcontinent ISO (Carmel, IN) Yonghong Chen, Midcontinent ISO (Carmel, IN) Arun Veeramany, Pacific Northwest National Laboratory (Richland, WA) Feng Pan, Pacific Northwest National Laboratory (Richland, WA) Ruchi Rajasekhar, Midcontinent ISO (Carmel, IN)
2:20 PM	Break
2:30 PM	Session T3 **Co-located Hybrid Resources with Shared Limited Injection Modeling** Matthew Musto, New York ISO (Rensselaer, NY) **Market Participation Challenges and Potential Modeling Options for Hybrid Resources** Nikita Singhal, Electric Power Research Institute (Palo Alto, CA) Erik Ela, Electric Power Research Institute (Denver, CO) **From Today's Hierarchical Control to End-to-end Flexible Interactive Electricity Services** Marija Ilic, Massachusetts Institute of Technology (Cambridge, MA) Pedro Carvalho, Instituto Superior Técnico (Lisbon, Portugal)
3:45 PM	Break

Tuesday, June 22, 2021

4:00 PM	Session T4 **Pricing in Dynamic ISO Markets with Unit Commitment** Richard O'Neill, ARPA-E (Silver Spring, MD) Yonghong Chen, (Carmel, IN) **Efficient Prices under Uncertainty and Non-Convexity** Brent Eldridge, Johns Hopkins University (Baltimore, MD) Jacob Mays, Cornell University (Ithaca, NY) Bernard Knueven, National Renewable Energy Laboratory (Golden, CO) **Convex Hull Pricing Considering Practical Market Features** Yongpei Guan, University of Florida (Gainesville, FL)
5:15 PM	Adjourn

Wednesday, June 23, 2021

9:55 AM	Introduction
10:00 AM	Session W1 **Case Studies of Transmission Topology Optimization to Efficiently Mitigate Congestion and Overloads** Pablo Ruiz, NewGrid, Inc. and The Brattle Group (Cambridge, MA) Xiaoguang Li, NewGrid, Inc (Cambridge, MA) **Grid Enhancing Technologies and Renewable Integration** T. Bruce Tsuchida, The Brattle Group (Boston, MA) Jay Caspary, GridStrategies (Washington, DC) **Meso/Microscale of Wind Fields on Overhead Conductors for Enhancing Visibility into Changing System Conditions** Ricardo Marquez, WindSim Power (Idaho Falls, ID)
11:15 AM	Break
11:30 AM	Session W2 **Agent-based Storage Valuation and Market Participation Analysis** Bolun Xu, Columbia University (New York, NY) Xin Qin, Columbia University (New York, NY) Ningkun Zheng, Columbia University (New York, NY) **Modeling and Valuation of Pumped Storage Hydropower Resources** Majid Heidarifar, Electric Power Research Institute (Palo Alto, CA) Nikita Singhal, Electric Power Research Institute (Palo Alto, CA) Aidan Tuohy, Electric Power Research Institute (Palo Alto, CA) Russ Philbrick, Polaris Systems Optimization (Seattle, WA) Erik Ela, Electric Power Research Institute (Denver, CO) Pablo Ruiz, NewGrid (Cambridge, MA) **Multi-Stage Modeling with Recourse Decision for Solving Stochastic Complementarity Problems with an Application in Energy** Pattanun Chanpiwat, University of Maryland (College Park, MD) Steven A. Gabriel, University of Maryland (College Park, MD)
12:45 PM	Lunch
1:45 PM	Session W3 **Primary Frequency Response Reserve Requirements with Application to ERCOT** Manuel Garcia, Sandia National Laboratories (Albuquerque, NM) Ross Baldick, University of Texas at Austin (Austin, TX) Felipe Wilches-Bernal, Sandia National Laboratories (Albuquerque, NM) **Coordinated Ramping Product and Regulation Reserve Procurements in CAISO and MISO using Multi-Scale Probabilistic Solar Power Forecasts (Pro2R)** Venkat Krishnan, National Renewable Energy Laboratory (Golden, CO) Benjamin Hobbs, Johns Hopkins University (Baltimore, MD) Jie Zhang, University of Texas Dallas (Dallas, TX) Carlo Siebenschuh, IBM (Yorktown Heights, NY) Ibrahim Krad, National Renewable Energy Laboratory (Golden, CO) Binghui Li, University of Texas Dallas (Dallas, TX) Paul Edwards, National Renewable Energy Laboratory (Golden, CO) **Flexibility Auction: A Framework for Managing Imbalance Risk** Evangelia Spyrou, National Renewable Energy Laboratory (Golden, CO) Robin Broder Hytowitz, Electric Power Research Institute (Palo Alto, CA) Ben Hobbs, Johns Hopkins University (Baltimore, MD) Mohamed Al-Ashery, Johns Hopkins University (Baltimore, MD) Mengmeng Cai, National Renewable Energy Laboratory (Golden, CO) Erik Ela, Electric Power Research Institute (Denver, CO) Yingchen Zhang, National Renewable Energy Laboratory (Golden, CO)

3:00 PM	Break
3:15 PM	Session W4 **Stochastic Look Ahead Commitment for Managing Grid Uncertainty** Junshan Zhang, Arizona State University (Tempe, AZ) Bernard Knueven, National Renewable Energy Laboratory (Golden, CO) Trevor Werho, Arizona State University (Tempe, AZ) Mohammad Faqiry, Midcontinent ISO (Carmel, IN) Manuel Garcia, Sandia National Laboratories (Albuquerque, NM) Yonghong Chen, Midcontinent ISO (Carmel, IN) Roger Treinen, Nexant, Inc. (Sacramento, CA) Vijay Vittal, Arizona State University (Tempe, AZ) **Issues with Near Optimal Solutions and Near Identical Generators in Unit Commitment** Dominic Yang, University of California at Los Angeles (Los Angeles, CA) Jonathan Schrock, University of Tennessee (Knoxville, TN) Ben Knueven, National Renewable Energy Laboratory (Golden, CO) Jim Ostrowski, University of Tennessee (Knoxville, TN) Jean-Paul Watson, Lawrence Livermore National Laboratory (Livermore, CA) **UnitCommitment.jl: A Julia/JuMP Optimization Package for Security-Constrained Unit Commitment** Alinson Santos Xavier, Argonne National Laboratory (Lemont, IL) Feng Qiu, Argonne National Laboratory (Lemont, IL) **State-of-the-Art Techniques for Large-Scale Stochastic Unit Commitment** Bernard Knueven, National Renewable Energy Laboratory (Golden, CO) James Ostrowski, University of Tennessee (Knoxville, TN) Jean-Paul Watson, Lawrence Livermore National Laboratory (Livermore, CA) David L. Woodruff, University of California at Davis (Davis, CA)
4:55 PM	Adjourn

Thursday, June 24, 2021

9:25 AM	Introduction
9:30 AM	Session H1

ABSCoRES, A Novel Application of Banking Scoring and Rating for Electricity Systems
Alberto J. Lamadrid, Lehigh University (Bethlehem, PA)
Audun Botterud, Massachusetts Institute of Technology (Cambridge, MA)
Parv Venkitasubramaniam, Lehigh University (Bethlehem, PA)
Marija Ilic, Massachusetts Institute of Technology (Cambridge, MA)
Shalinee Kishore, Lehigh University (Bethlehem, PA)
Bo Chen, Argonne National Laboratory (Lemont, IL)
Jhi-Young Joo, Lawrence Livermore National Laboratory (Livermore, CA)
Shijia Zhao, Argonne National Laboratory (Lemont, IL)

A New Swing-Contract Design for Wholesale Power Markets
Leigh Tesfatsion, Iowa State University (Ames, IA)

Market-based Resource Adequacy Assessment Framework: The Impact of Market Design on Long-run Resource Investment and Reliability
Jonghwan Kwon, Argonne National Lab (Lemont, IL)
Todd Levin, Argonne National Lab (Lemont, IL)
Zhi Zhou, Argonne National Lab (Lemont, IL)
Audun Botterud, Argonne National Lab (Lemont, IL)

10:45 AM	Break
11:00 AM	Session H2

HELICS: Integrated Distribution and Transmission Planning
Jason Fuller, Pacific Northwest National Laboratory (Richland, WA)
Henry Huang, Pacific Northwest National Laboratory (Richland, WA)
Trevor Hardy, Pacific Northwest National Laboratory (Richland, WA)

Linear Decision Rules with Performance Guarantees for Scalable Multi-Stage Generation Planning
Vladimir Dvorkin, Massachusetts Institute of Technology (Cambridge, MA)
Dharik Mallapragada, Massachusetts Institute of Technology (Cambridge, MA)
Audun Botterud, Massachusetts Institute of Technology (Cambridge, MA)

Co-Optimized Planning of Generation and Transmission
Kai Van Horn, National Grid (Charlottesville, VA)
Russ Philbrick, Polaris Systems Optimization (Seattle, WA)
Aleksandr Rudkevich, Newton Energy Group (Cambridge, MA)

Two and Three-Stage Scenario Based Modeling and Optimization for Wind and Storage Expansion Planning
Devon Sigler, National Renewable Energy Laboratory (Golden, CO)
Michael Kratochvil, University of Iowa (Iowa City, IA)
Jonathan Maack, National Renewable Energy Laboratory (Golden, CO)
David E. Stewart, University of Iowa (Iowa City, IA)

12:40 PM	Lunch

1:40pm	Session H3
	Open Source Production Cost Modeling at Scale Jean-Paul Watson, Lawrence Livermore National Laboratory (Livermore, CA) Bernard Knueven, National Renewable Energy Laboratory (Golden, CO) Darryl Melander, Sandia National Laboratories (Albuquerque, NM)
	Creating Large Scale 8760 Solved AC Power Flow Models for Transmission Planning Studies from Production Cost Models using PROBE and TARA Brian Thomas, PowerGEM (Clifton Park, NY) Boris Gisin, PowerGEM (Clifton Park, NY)
	A High-efficiency and Numerically Robust Computing Tool for Power Flows and Dynamic Simulation Rui Yao, Argonne National Laboratory (Lemont, IL) Feng Qiu, Argonne National Laboratory (Lemont, IL) Yichen Zhang, Argonne National Laboratory (Lemont, IL)
	Absence of Spurious Local Trajectories in Time-Varying Optimal Power Flow Salar Fattahi, University of Michigan (Ann Arbor, MI) Cédric Josz, Columbia University (New York, NY) Yuhao Ding, University of California at Berkeley (Berkeley, CA) Julie Mulvaney-Kemp, University of California at Berkeley (Berkeley, CA) Reza Mohammadi, University of California at Berkeley (Berkeley, CA) Javad Lavaei, University of California at Berkeley (Berkeley, CA) Somayeh Sojoudi, University of California at Berkeley (Berkeley, CA)
3:20 PM	Break
3:30 PM	Session H4
	Verifying Global Optimality of Candidate Solutions to Polynomial Optimization Problems using a Determinant Relaxation Hierarchy Cédric Josz, Columbia University (New York, NY)
	Solving Large-scale Stochastic, Security-constrained, Multi-period Grid Optimization Problems with the Exascale Grid Optimization (ExaGO) Toolkit Shrirang Abhyankar, Pacific Northwest National Laboratory (Richland, WA) Slaven Peles, Pacific Northwest National Laboratory (Richland, WA) Asher Mancinelli, Pacific Northwest National Laboratory (Richland, WA)
	Distributed Computing and Cloud Software: Applying Lessons from the Internet Era to the Bulk Power System Cody Smith, Camus Energy (San Francisco, CA) Astrid Atkinson, Camus Energy (San Francisco, CA)
	Natural Gas Infrastructure Development in North America under Integrated Markets Charalampos Avraam, Johns Hopkins University (Baltimore, MD) Daniel Chu, Johns Hopkins University (Baltimore, MD) Sauleh Siddiqui, Johns Hopkins University (Baltimore, MD)
5:10 PM	Adjourn

Session T1 (Tuesday, June 22, 10:00 AM, WebEx)

ADDRESSING UNCERTAINTIES THROUGH IMPROVED PRICING AND RESERVE PRODUCT DESIGN

Dr. Yonghong Chen, Consulting Advisor, Midcontinent ISO (Carmel, IN)

Aligning market with reliability requirements ensures that electricity market prices reflect system operating conditions and encourages resource availability under extreme events. Out-of-market actions taken for reliability purpose, particularly during emergency and scarcity conditions, may affect price formation and lead to price suppression. This presentation discusses recent work at MISO to incorporate means to address system wide and sub-regional uncertainties through reserve product design, resulting in improved pricing.

ON THE FORMULATION DEPENDENCE OF CONVEX HULL PRICING

Dr. Feng Zhao, Principal Analyst, ISO New England Inc. (Holyoke, MA)
Dr. Dane Schiro, Lead Analyst, ISO New England Inc. (Holyoke, MA)
Dr. Jinye Zhao, Principal Analyst, ISO New England Inc. (Holyoke, MA)
Dr. Tongxin Zheng, Advanced Technology Solutions Director, ISO New England Inc. (Holyoke, MA)

Convex hull pricing provides a potential solution for reducing out-of-market payments in wholesale electricity markets. This work explores its important but underappreciated formulation-dependence property. Namely, convex hull prices may change for different formulations of the same unit commitment problem. After a conceptual exposition of the property, its practical significance is illustrated with two reformulations observed in the market clearing process. Sufficient conditions under which convex hull prices will be preserved by a reformulation are also explored. These findings contribute to a better understanding of convex hull pricing.

MODELING OF RENEWABLE GENERATION AND ENERGY STORAGE CAPACITY EXPANSION

Mr. John Meyer, Senior Energy Market Engineer, NYISO (Rensselaer, NY)

The New York Independent System Operator (NYISO) has been working on capacity expansion modeling methods to project the future generation mix and wholesale market pricing of the NY state electric system, given the constraints of clean energy policy goals like the Climate Leadership and Community Protection Act (CLCPA). These methods employ mathematical programming to optimize the total cost to carry load over the course of 10-20 years, considering key financial inputs and structure of the Energy, Capacity, and Ancillary

Service Markets. This presentation will review the approach and considerations used in the NYISO's model development.

DEPLOYING MODERNIZED APPLICATIONS IN A SECURE AND COMPLIANT MANNER

Mr. Jeff Price, Manager, Platform Engineering, Midcontinent ISO (Carmel, IN)

MISO has strived to improve reliability, security, and agility by embracing new technologies. Developing and maturing cloud capabilities has been key to the success of the market system enhancements program. With the upcoming deployment of the MUI 2.0, MISO is commissioning an on-premises critical infrastructure protection environment on which to deploy modern, containerized workloads. Work throughout the organization was conducted to develop a thorough understanding of how security and compliance controls translate into modernized IT Infrastructure. Existing controls were used wherever possible due to the maturity and widespread acceptance, and new controls were developed where required.

Session T2 (Tuesday, June 22, 12:40 PM, WebEx)

GENERATOR PERFORMANCE EVALUATION AT ISO NEW ENGLAND

Dr. Slava Maslennikov, Technical Manager, ISO New England (Holyoke, MA)
Mr. Izudin Lelic, Principal Analyst, ISO New England (Holyoke, MA)
Mr. Kory Haag, Principal Operations Analyst, ISO New England (Holyoke, MA)
Dr. Xiaochuan Luo, Power System Technology Manager, ISO New England (Holyoke, MA)

ISO New England (ISO-NE) uses Manual Response Rate (MRR) offered by Market Participants for generators in order to determine real-time dispatch instructions and account for on-line generator ten- and thirty-minute reserves. In order to verify that MRRs are consistent with generator performance, ISO-NE has developed the Generation Performance Evaluation (GPE) process. This process gives ISO-NE the capability to track the statistical variation of generator historical response to electric dispatch signals and generate probabilistic weighted average MRRs as a function of MW output. The implementation of the GPE software in 2018 allowed ISO-NE to implement an efficient generator MRR auditing process. As a result, multiple Market Participants in New England have significantly changed their offered MRR, reducing the variation between offered MRR parameters and generators' actual ramp rate performance. This has resulted in an increase in the quality of ISO's dispatch solution to meet real-time load and reduced the error in the estimation of available ten- and thirty-minute reserves. The presentation discusses the GPE process and the efficiency of the results.

PUMPED STORAGE OPTIMIZATION IN DAY-AHEAD AND REAL-TIME MARKET UNDER UNCERTAINTY

Dr. Bing Huang, Research Engineer, Midcontinent ISO (Carmel, IN)
Dr. Arezou Ghesmati, Research Engineer, Midcontinent ISO (Carmel, IN)
Dr. Yonghong Chen, Consulting Advisor, Midcontinent ISO (Carmel, IN)
Dr. Ross Baldick, Emeritus Professor, University of Texas at Austin (Austin, TX)
Dr. Rui Bo, Professor, Missouri University of Science & Technology (Rolla, MO)

This presentation first gives an overview of the DOE-sponsored research project Modeling and Optimizing Pumped Storage Hydro (PSH) in a Multi-stage Large Scale Electricity Market under Portfolio Evolution. We then focus on the tasks of developing models for the day-ahead (DA) market and real-time (RT) market to enhance the use of PSH resources for flexibility. A compact, configuration-based PSH model is proposed for the DA market. The proposed model accommodates a flexible transition between different modes in a PSH with an enhanced state of charge constraint. The proposed model has been prototyped in a benchmarked clearing engine proxy of the Mid-continent Independent System Operator DA market, the High Performance Power-grid Optimization engine (“HIPPO”) and it is tested with numerical studies using MISO system data. The configuration- based PSH model has been further developed and extended to a look-ahead commitment (LAC) problem. A probabilistic RT locational marginal price (LMP) forecast methodology is developed. The LMP forecast is used to estimate the cost of dispatching a PSH in a LAC. We have also developed formulations to reflect participants’ risk preference from the real- time volatile prices. The simulation platform of LAC rolling windows is developed and tested on the HIPPO LAC platform with the MISO system data.

INTEGRATION OF STORAGE RESOURCES IN THE CAISO'S SYSTEM

Dr. Guillermo Bautista-Alderete, Director of Market Analysis and Forecasting, California ISO (Folsom, CA)
Mr. Rahul Kalaskar, Manager of Market Validation, California ISO (Folsom, CA)

The electric grid is quickly evolving with the integration of new technologies. In recent years, integration of renewable resources has posed technical challenges to design efficient market dispatch tools. In recent years there has been a fast growth of storage resources being integrated to the electric grid. The advent of these new technologies with their fascinating capabilities pose unique challenges for its efficient utilization in the CAISO’s system. These challenges can be further compounded when storage resources are coupled with other technologies like renewables. In this presentation, we will introduce the modeling capabilities in the CAISO’s market to efficiently integrate and dispatch storage-based resources, including the original non-generation resource model, batteries, co-located resources and hybrid resources.

Operational challenges and dispatch implications based on actual market results will also be discussed.

HIPPO CONCURRENT OPTIMIZER – ENHANCED SIMULTANEOUS FEASIBILITY TEST (SFT) AND MIGRATION TO PRIVATE CLOUD

Dr. Jesse Holzer, Research Scientist, Pacific Northwest National Laboratory (Richland, WA)
Dr. Joanna Wu, Senior Research And Development Engineer, Midcontinent ISO (Carmel, IN)
Dr. Yonghong Chen, Consulting Advisor, Midcontinent ISO (Carmel, IN)
Dr. Arun Veeramany, Scientist, Pacific Northwest National Laboratory (Richland, WA)
Dr. Feng Pan, Applied Mathematician, Pacific Northwest National Laboratory (Richland, WA)
Mr. Ruchi Rajasekhar, Senior R&D Technology and Analytics Program Manager, Midcontinent ISO (Carmel, IN)

This presentation discusses recent development of a MISO-benchmarked, high-performance optimization engine, High Performance Power-grid Optimization ("HIPPO"), including further enhancement on SFT to reduce the number of required computing nodes and improve the efficiency for solving multiple-intervals and large numbers of contingencies. The research team is also moving HIPPO from high performance computers to MISO's private cloud to run security-constrained unit commitment concurrently with various formulations and solution approaches.

Session T3 (Tuesday, June 22, 2:30 PM, WebEx)

CO-LOCATED HYBRID RESOURCES WITH SHARED LIMITED INJECTION MODELING

Mr. Matthew Musto, Senior Scientist, New York ISO (Rensselaer, NY)

The NYISO has developed a prototype mixed-integer programming model for co-located resources consisting of a battery (an electric storage resource, or ESR) and intermittent resource sited behind a point of injection, which is limited to less than the maximum output of both units combined. This presentation will outline that model and analysis and how it helped to inform the market design and development of the production model.

MARKET PARTICIPATION CHALLENGES AND POTENTIAL MODELING OPTIONS FOR HYBRID RESOURCES

Dr. Nikita Singhal, Senior Scientist, Electric Power Research Institute (Palo Alto, CA)
Dr. Erik Ela, Principal Manager, Electric Power Research Institute (Denver, CO)

Electric storage resources (ESRs) and other technologies that are co-located and share a point of interconnection are increasingly being planned and integrated into bulk power systems and wholesale electricity markets through interconnection requests in the interconnection queue or modification requests for existing generators. Such hybrid storage resources are predominantly seen being combined with variable energy resources (VERs) and are either being operated as two separate independent resources or as a single resource. Market designers and system operators are presently researching approaches to effectively incorporate such hybrid storage resources into their contemporary system operations and scheduling or market operation processes given the tremendous increase in interest in regions across the U.S. as well as internationally.

This research briefly reviews the definitions and participation model design proposals for such hybrid storage resources that numerous market operators across North America have proposed to address their stakeholder regional needs. It describes the key market participation challenges for hybrid resources that relate to market clearing software, including an exploration of the implications for many different aspects of electricity market design. Hybrid storage market designs require unique consideration and innovative approaches to incorporate them in a flexible yet reliable manner. This research proposes four potential market modeling approaches or participation modeling options for hybrid resources: 1) Two Independent Resources Model, 2) Single Resource Model, Self-Management, 3) Single Resource Model, ISO-Managed Feasibility, and 4) Two Independent Resources Model, Linked. Additionally, it provides preliminary design considerations for representing such hybrid storage resources in market clearing software for each of the aforementioned participation model options. The proposed designs may continue to evolve as new information becomes available and as technology evolves.

FROM TODAY'S HIERARCHICAL CONTROL TO END-TO-END FLEXIBLE INTERACTIVE ELECTRICITY SERVICES

Dr Marija Ilic, Senior Research Scientist, MIT (Sudbury, MA)
Dr. Pedro Carvalho, Professor, Instituto Superior Técnico (Lisbon, Portugal)

In this talk, we first discuss typical algorithmic and software problems that arise when attempting to integrate smaller-scale MV/LV stakeholders in electricity markets. These comprise lack of accurate information about the grids and stakeholders' models; numerical problems when combining radial distribution systems software into software which must model their meshed system interactions (typically needed when connecting and disconnecting for economic and reliability reasons); and, the inter-temporal effects. The basic problem becomes one of establishing an interactive co-simulator which enables communications at the interfaces between models and software of different detail. We show that it is possible to characterize interfaces using common information given as a triplet of {energy, power, rate of change of reactive power}. This information can be used to have minimal number of derivatives in electricity markets which support ex ante energy provision; near-real-time power balancing, and near-optimal reactive power/voltage support in system operations. In other words, these are sufficient to align operations and markets at value. For this to be implemented, a transparent set of binding protocols which: 1) extend today's Balancing Authorities (BAs) into intelligent Balancing Authorities (iBAs); 2) require commitments made to be implementable; and, 3) utilize end-to-end SCADA. We give an illustration of this approach and show how operations and markets signals get aligned.

Session T4 (Tuesday, June 22, 4:00 PM, WebEx)

PRICING IN DYNAMIC ISO MARKETS WITH UNIT COMMITMENT

Dr. Richard O'Neill, Distinguished Senior Fellow, ARPA-E (Silver Spring, MD)
Dr. Yonghong Chen, Consulting Advisor, Midcontinent ISO (Carmel, IN)

We examine the pricing mechanisms in multi-period ISO markets with unit commitment and co-optimized energy and reserves—a non-convex market with scale economies—and present an approach to pricing called average incremental cost (AIC) pricing. The market rules include offer mitigation to incremental costs and charges for excursions from the dispatch signal at a minimum of the costs of redispatch. A generator offer includes startup and fixed-operating costs per period, and a multi-step marginal-cost function with minimum and maximum operating levels, ramp rate limits and minimum run times. Consumers bid simple step-function demand. The pricing procedure relaxes each binary variable bounded by zero and its optimal value. Cut sets are added to allocate the excess capacity costs from lumpy commitments to prices, but avoid degeneracy. The result is locational incremental prices (LIPs) that are conceptually similar to LMPs in convex markets. No dispatched generators lose money at the LIPs. No make-whole payments or uplift are needed. Incremental generators make zero profits and infra-incremental generators make positive profits. Demand pays Ramsey–Boiteux prices. Small examples are presented to illustrate the procedure. The results for actual MISO day-ahead market instances validate the procedure's theoretical properties.

Efficient Prices under Uncertainty and Non-Convexity

Dr. Brent Eldridge, Researcher, Johns Hopkins University (Baltimore, MD)
Dr. Jacob Mays, Assistant Professor, Cornell University (Ithaca, NY)
Dr. Bernard Knueven, Researcher, National Renewable Energy Laboratory (Golden, CO)

Operators of organized wholesale electricity markets attempt to form prices in such a way that the private incentives of market participants are consistent with a socially optimal commitment and dispatch schedule. In the U.S. context, several competing price formation schemes have been proposed to address the non-convex production cost functions characteristic of most generation technologies. This paper considers how the design and analysis of price formation policies for non-convex markets is affected by the uncertainty inherent in electricity demand and supply. We argue that by excluding uncertainty, the analytical framework underlying existing policies mischaracterizes the incentives of market participants, leading to inefficient price formation and poor incentives for flexibility. We establish favorable theoretical properties of a new construct, ex ante convex hull pricing, demonstrate the difference between this policy and existing methods on an ISO-scale test system, and discuss the implications for price formation in organized wholesale markets.

Convex Hull Pricing Considering Practical Market Features

Dr. Yongpei Guan, Endowed Professor, University of Florida (Gainesville, FL)

Uplift payment minimization through convex hull pricing has been studied to increase market transparency. It has been shown that the convex hull price could provide an optimal uniform price for the system. Also, recently, efficient algorithms and formulations have been developed to achieve the minimal uplift payment if all generation assets are submitted through three-part offers to wholesale markets (e.g., independent system operators) for market clearance. However, in practice, the offer submission formats and compensation amounts from the wholesale markets could be different. In this paper, we explore solution approaches for the customized electric market settings, including self-commitment offers, transmission constraint violations, and online generation compensation only payment scheme options. We derive corresponding formulations and algorithms that can help lead to the exact convex hull price. The computational experiments on large-scale Midcontinent ISO (MISO) instances show the effectiveness of the proposed approaches.

Session W1 (Wednesday, June 23, 10:00 AM, WebEx)

CASE STUDIES OF TRANSMISSION TOPOLOGY OPTIMIZATION TO EFFICIENTLY MITIGATE CONGESTION AND OVERLOADS

Dr. Pablo Ruiz, CEO and CTO (NewGrid) and Senior Consultant (The Brattle Group), NewGrid and The Brattle Group (Cambridge, MA)
Mr. Xiaoguang Li, Director, NewGrid (Boston, MA)

The transmission grid, normally operated as a static asset with flow constraints, has the potential to provide operational flexibility by adjusting its physical configuration to changing system conditions and needs. Utilizing transmission flexibility is becoming critical in light of the power system transition to integrate increasing levels of variable renewable resources, frequently located away from demand centers.

Topology optimization software is a grid-enhancing technology that finds reconfiguration options to re-route power flow around congested transmission constraints, relying on other less-utilized facilities and satisfying all specified reliability criteria. The reconfigurations are implemented by changing the open/close status of circuit breakers and can also complement any other available power flow control devices. This technology provides cost savings to power customers and increases the value of the existing transmission network, from both a reliability and a market efficiency perspective, by identifying and implementing strategies that use the existing flexibility of the grid. This presentation will illustrate the impacts of topology optimization using recent case studies of heavily congested operating conditions in MISO, SPP and National Grid Electricity System Operator (ESO).

GRID ENHANCING TECHNOLOGIES AND RENEWABLE INTEGRATION

Mr. T. Bruce Tsuchida, Principal, The Brattle Group (Boston, MA)
Mr. Jay Caspary, Vice President, GridStrategies (Little Rock, AR)

The Brattle Group performed a study for the WATT Coalition looking at how the combination of three Grid-Enhancing Technologies, which are either software solutions or operated through advanced software solutions, can help increase the amount of renewables that can be integrated by reducing transmission congestion and renewable curtailments. The study simulates the Southwest Power Pool system focusing on Kansas and Oklahoma as a showcase. Using the queue of projects with signed interconnection agreements and historical operational snapshots, this case study analysis shows that Grid-Enhancing Technologies could double the amount of renewable generating capacity that could be integrated based on approved plans by 2025.

MESO/MICROSCALE OF WIND FIELDS ON OVERHEAD CONDUCTORS FOR ENHANCING VISIBILITY INTO CHANGING SYSTEM CONDITIONS

Dr. Ricardo Marquez, Software Solution Architect, WindSim Power (Idaho Falls, ID)

The ability of the electric grid to meet demand on a second-to-second basis is highly dependent on the designed capacity of the transmission assets. The grid can become congested if power flows are such that nodes and links reach capacities and, therefore, disrupt the economic delivery of electricity. One of the major sources of transmission congestion is the thermal capacity of conductors. The thermal capacity of conductors is dynamic and varies with the electric current transmitted through conductors and the atmospheric environment conditions, such as ambient temperature, solar irradiance, and wind speed.

Because environment conditions have historically been difficult to obtain at small scales – sub-hourly and at the spatial level of a span – it has been common practice in the transmission industry to use conservative static or seasonal line ratings. These static or seasonal ratings significantly limit the capacity of overhead conductors to transmit electricity. By incorporating dynamic line ratings (DLR), system operators can take advantage of anywhere between 5% to as much as 100% additional capacity over static ratings on a regular basis.

DLRs have been a topic of interest for the last decade or so and has more recently attracted attention from several transmission owners. In particular, the dynamic line rating system based on the direct monitoring of conductor physical properties such as conductor temperature, vibration, or sag have had a number of installed pilots and economic benefit analysis performed. Most of these systems require devices (hardware) installed on or near the lines. Nevertheless, the pilot and simulation results have been favorable from an economic and operational perspective. However, the full-scale and real-time adoption of the technology systems have been sparse to nearly non-existent in the U.S. Thus, the wide- scale deployment of DLR technology needs to be simplified and designed for scalability.

To achieve system-wide scalability, some level of microscale modeling of environmental conditions is needed, especially for wind. Working with the Idaho National Laboratory over the last 8 years, WindSim has developed WindSim Power Line (WPL), which is a commercial software-based wind and DLR modeling and forecasting system tailored to monitor the changing system conditions, in particular, the thermal conditions of overhead conductors. This presentation will cover 1) how meso-/micro-scale modeling is performed and important factors affecting accuracy, 2) how WPL is currently being deployed as a pilot for the New York Power Authority, 3) how WPL can be employed over large and complex geographic areas.

Session W2 (Wednesday, June 23, 11:30 AM, WebEx)

AGENT-BASED STORAGE VALUATION AND MARKET PARTICIPATION ANALYSIS

Dr. Bolun Xu, Assistant Professor, Columbia University (New York, NY)
Ms. Xin Qin, Research Assistant, Columbia University (New York, NY)
Mr. Ningkun Zheng, Research Assistant, Columbia University (New York, NY)

In this talk, we introduce an agent-based approach to assess how increasing participation from storage resources may impact the electricity market outcomes. We estimate the capacity value of storage resources based on price forecasts, simulate their bidding into the electricity market, and demonstrate how an increasing participation capacity of storage resources may impact market outcomes. We present a novel and extremely computation-efficient stochastic dynamic programming algorithm to valuate energy storage capacity and design market bids based on future price forecasts, and demonstrate how different price predictions and storage valuation approaches could impact the market outcome.

MODELING AND VALUATION OF PUMPED STORAGE HYDROPOWER RESOURCES

Dr. Majid Heidarifar, Engineer/Scientist II, Electric Power Research Institute (Palo Alto, CA)
Dr. Nikita Singhal, Engineer/Scientist III, Electric Power Research Institute (Palo Alto, CA)
Dr. Aidan Tuohy, Program Manager, Electric Power Research Institute (Palo Alto, CA)
Dr. Russ Philbrick, CEO/CTO, Polaris Systems Optimization (Seattle, WA)
Dr. Erik Ela, Principal Manager, Electric Power Research Institute (Denver, CO)
Dr. Pablo Ruiz, CEO/CTO, NewGrid (Cambridge, MA)

Pumped Storage Hydropower (PSH) resources have fast response times and ramping capabilities that are essential to address the uncertainty and variability introduced by stochastic resources, such as wind and solar. Presently, PSH resources provide a majority of the ISO products. PSH has the ability to provide considerable flexibility and enhances system and market operations. The objective of this research is to develop a framework and outline the parameters that are needed to analyze the energy and ancillary services PSH provides to the electricity grid currently and how that value may change as the generation asset mix on the grid changes over time. Additionally, this research outlines different modeling approaches to PSH resources, including ways to potentially model hydraulics for entities that may have the need and the data to better assist with managing water quantities and appropriately capturing physical characteristics, e.g., constraints on river flows, or by using an approach that is similar to electric storage resource modeling by managing energy quantities, e.g., state-of-charge management through different scheduling processes in different timeframes. This research provides a summary of the state-of-the-art in modeling of PSH operation and aims to improve upon the contemporary modeling approaches to better capture the value of energy and ancillary services provided by PSH resources. It demonstrates the value of different PSH technologies/configurations (e.g., traditional site-specific design, variable speed) and C rate (MWh/MW ratio) to better understand which technologies and storage durations may provide the most value. The goal of the study is to illustrate how the value of PSH resources changes for a southeast utility system under different case scenarios, e.g., for different operational and technology sensitivities, under anticipated future variable energy resource penetrations and changing generation asset mix.

MULTI-STAGE MODELING WITH RECOURSE DECISION FOR SOLVING STOCHASTIC COMPLEMENTARITY PROBLEMS WITH AN APPLICATION IN ENERGY

Mr. Pattanun Chanpiwat, Graduate Student, University of Maryland (College Park, MD)
Dr. Stephen A. Gabriel, Professor, University of Maryland (College Park, MD)

The role of variable renewable energy (VRE) resources (e.g., wind and solar power) is important for the power market since there are no carbon dioxide emissions. However, the amount of wind and solar radiation is uncertain spatially and temporally. The intermittency of the variable renewable energy in power generation could be mitigated using energy storage systems. This project concerns utilizing battery storage for the implementation of renewable energy technologies in the electricity market. We developed multi-stage modeling with recourse decision for solving stochastic complementarity problems with an application in energy. The model is based on a Nash-Cournot formulation of imperfect competition among power producers. We have analyzed the value of variable renewable energy and battery storage from multiple perspectives of uncertainty. Stochastic programming allows us to capture the intermittency nature of the VRE. A recourse problem permits us to make some corrections in the future like a “wait-and-see” approach. This energy system optimization modeling, based on game theory and energy market equilibria, is expected to provide great insights for energy market planners.

<u>Session W3 (Wednesday, June 23, 1:45 PM, WebEx)</u>

PRIMARY FREQUENCY RESPONSE RESERVE REQUIREMENTS WITH APPLICATION TO ERCOT

Dr. Manuel Garcia, Senior Researcher, Sandia National Laboratories (Albuquerque, New Mexico)

Dr. Ross Baldick, Emeritus Professor, University of Texas at Austin (Austin, TX)
Dr. Felipe Wilches-Bernal, Senior Researcher, Sandia National Laboratories (Albuquerque, NM)

As inverter-based-resources (IBRs) are replacing traditional generators the system-wide inertia levels are dropping, less governor response is available, and primary frequency control is being challenged. The Texas interconnection is beginning to experience these challenges because it has relatively low inertia levels as compared to Western and Eastern interconnections, to which it is only asynchronously connected. In response, ERCOT, the Independent System Operator (ISO) in Texas, is introducing a primary frequency response reserve product into the electricity market termed Responsive Reserve Service (RRS) reserve. The Texas experience is important because it may inform other ISOs how to improve primary frequency control to accommodate low inertia levels caused by high penetrations of IBRs.

In this presentation we first explain the subtypes of ERCOT's RRS reserve including Primary Frequency Response (PFR) reserve, which accommodates droop control, and Fast Frequency Response (FFR) reserve, which is provided by IBRs that exhibit a step response to frequency deviations. We will then explain the RRS reserve requirements used by ERCOT, which use equivalency ratios that are derived empirically through dynamic simulation. A new reserve requirement is then proposed that limits the PFR reserve allocated to a single generator. This reserve requirement is derived analytically and then validated empirically through dynamic simulation. The presentation will continue by exploring computationally practical approximations of the proposed PFR reserve limits, which are non-convex by nature, and pricing structures for PFR and FFR reserve. Finally, we explain how our proposed reserve requirement can accommodate additional primary frequency response reserve products that may be introduced to the market in the future.

Coordinated Ramping Product and Regulation Reserve Procurements in CAISO and MISO using Multi-Scale Probabilistic Solar Power Forecasts (Pro2R)

Dr. Venkat Krishnan, Senior Engineer, National Renewable Energy Laboratory (Golden, CO)
Dr. Benjamin Hobbs, Professor, Johns Hopkins University (Baltimore, MD)
Dr. Jie Zhang, Assistant Professor, University of Texas Dallas (Dallas, TX)
Mr. Carlo Siebenschuh, Research Scientist, IBM (White Plains, NY)
Dr. Ibrahim Krad, Engineer, National Renewable Energy Laborator (Golden, CO)
Dr. Binghui Li, Post Doctoral Researcher, University of Texas Dallas (Dallas, TX)
Mr. Paul Edwards, Researcher, National Renewable Energy Laboratory (Chattanooga, TN)

The specification of target amounts of ancillary services to acquire is crucial to the efficient and reliable operation of ISO markets. System operators recognize that conditioning requirements for flexible ramp product, regulation, spin, and other reserves on weather conditions can simultaneously lower acquisition costs – by decreasing requirements when unconditional requirements are too conservative—and improve sufficiency during times of system stress – by increasing requirements when weather conditions make net load or ACE more uncertain. A Pareto analysis that considers both acquisition costs and requirement sufficiency compares weather-conditioned requirements for CAISO flexible ramp product and regulation with the performance of unconditional requirements based on present CAISO procedures. A variety of methods to estimate requirements are tested, considering alternative sets of independent variables including solar, wind, and gross load forecasts, and solar uncertainty and volatility from probabilistic solar forecasts. Out-of-sample analyses show, for example, that decreases of approximately 20% are likely to be possible in the case of flexible ramp requirements without affecting the average fraction of intervals in which ramp needs exceed the identified requirement. A system for visualizing projected ramps and their uncertainty will be demonstrated. Simulations of operations of the western US markets, including a detailed representation of the CAISO system and sources of its imports, indicate that the consequent reductions in production costs and the costs of managing uncertainty are of the same magnitude as the CAISO's annual expenditures on the flexible ramp product.

FLEXIBILITY AUCTION: A FRAMEWORK FOR MANAGING IMBALANCE RISK

Dr. Evangelia Spyrou, Research Engineer, National Renewable Energy Laboratory (Golden, Colorado)
Dr. Robin Broder Hytowitz, Engineer, Electric Power Research Institute (Palo Alto, CA)
Dr. Ben Hobbs, Professor of Environmental Management, Johns Hopkins University (Baltimore, MD)
Dr. Mohamed Al-Ashery, Post-doctoral Researcher, Johns Hopkins University (Baltimore, MD)
Dr. Mengmeng Cai, Post-doctoral Researcher, National Renewable Energy Laboratory (Golden, CO)
Dr. Erik Ela, Principal Manager, Electric Power Research Institute (Denver, CO)
Dr. Yingchen Zhang, Chief Scientist and Group Manager, National Renewable Energy Laboratory (Golden, CO)

As the electricity generated by variable resources grows, system operators and variable resources have to manage challenging imbalances between forward and real-time markets. The Flexibility Auction is a novel approach for managing imbalances as it will allow resources with imbalance risk to hedge their production by buying flexibility options. The flexibility options are offered by grid-connected resources that can provide physical flexibility. This presentation will focus on the design of the Flexibility Auction, its properties, and how it can complement system-level services such as CAISO's proposed imbalance reserves. The presentation will include simple examples to illustrate the impact of the Flexibility Auction on the market participants and the system's imbalance risk.

Session W4 (Wednesday, June 23, 3:15 PM, WebEx)

STOCHASTIC LOOK AHEAD COMMITMENT FOR MANAGING GRID UNCERTAINTY

Dr. Junshan Zhang, Professor, Arizona State University (Tempe, AZ)
Dr. Bernard Knueven, Research Scientist, National Renewable Energy Laboratory (Golden, CO)
Dr. Trevor Werho, Assistant Research Scientist, Arizona State University (Tempe, AZ)
Dr. Mohammad Faqiry, Senior R&D Analyst, Midcontinent ISO (Carmel, IN)
Dr. Manuel Garcia, Senior Member of Technical Staff, Sandia National Laboratories (Albuquerque, NM)
Dr. Yonghong Chen, Consulting Advisor, Market Development, Midcontinent ISO (Carmel, IN)
Dr. Roger Treinen, Principal, Nexant (Folsom, CA)
Dr. Vijay Vittal, Professor. Arizona State University (Tempe, AZ)

The electric power industry is rapidly evolving, with operational uncertainties increasing as bulk renewables, distributed energy resources (DER), and advanced demand response (DR) capability grow and generation units age. How can we improve our operational models to account for these aggregate uncertainties in the wholesale electricity markets? This presentation summarizes the findings of our ARPA-E-funded project for the development of a prototype stochastic-based advisory tool, tailored and trialed with MISO, that will assist in managing these uncertainties to enhance system reliability and efficiency in managing uncertainty.

ISSUES WITH NEAR OPTIMAL SOLUTIONS AND NEAR IDENTICAL GENERATORS IN UNIT COMMITMENT

Mr. Dominic Yang, Graduate Student, University of California Los Angeles (Los Angeles, CA)
Mr. Jonathan Schrock, Graduate Student, University of Tennessee (Knoxville, TN)
Dr. Ben Knueven, Research Scientist, National Renewable Energy Laboratory (Golden, CO)
Dr. Jim Ostrowski, Associate Professor, University of Tennessee (Knoxville, TN)
Dr. Jean-Paul Watson, Senior Research Scientist, Lawrence Livermore National Laboratory (Livermore, CA)

There are often many near-optimal solutions to the Day Ahead Unit Commitment problem that satisfy typical optimality gaps. This can result from the presence of many "under-the-margin" generators or nearly identical generators. In a sense, which of the many near-optimal solutions chosen by the solver to be reported as optimal is random. However, the market impact of these seemingly marginal effects can be significant. We investigate the market payouts of a variety of near-optimal solutions and explore a strategy that decreases this market variability while also improving overall solution times.

UNITCOMMITMENT.JL: A JULIA/JUMP OPTIMIZATION PACKAGE FOR SECURITY-CONSTRAINED UNIT COMMITMENT

Dr. Alinson Santos Xavier, Computational Scientist, Argonne National Laboratory (Lemont, IL)
Dr. Feng Qiu, Principal Computational Scientist, Argonne National Laboratory (Lemont, IL)

In this talk, we introduce a new open-source optimization package for the Security-Constrained Unit Commitment Problem (SCUC), which aims to eliminate some of the roadblocks researchers typically face when developing and evaluating new solution methods for the problem. The package provides: (i) an extensible and fully-documented JSON-based data specification format for SCUC, developed in collaboration with Independent System Operators (ISOs), which can help researchers to share data sets across institutions; (ii) a diverse collection of large-scale benchmark instances, collected from the literature and extended using data-driven methods make them more challenging and realistic; (iii) a Julia/JuMP implementation of state-of-the-art formulations and solution methods; and (iv) automated benchmark scripts to accurately evaluate the performance impact of newly proposed methods. The package is being developed as part of the IEEE Task Force on Solving Large Scale Optimization Problems in Electricity Market and Power System Application.

STATE-OF-THE-ART TECHNIQUES FOR LARGE-SCALE STOCHASTIC UNIT COMMITMENT

Dr. Bernard Knueven, Research Scientist, National Renewable Energy Laboratory (Golden, CO)
Dr. James Ostrowski, Associate Professor, University of Tennessee (Knoxville, TN)
Dr. Jean-Paul Watson, Senior Research Scientist, Lawrence Livermore National Laboratory (Livermore, CA)
Dr. David L. Woodruff, Professor, University of California Davis (Davis, CA)

The electric power industry is rapidly evolving, with operational uncertainties increasing as bulk renewables, distributed energy resources (DER), and advanced demand response (DR) capability grow and generation units age. How can we improve our operational models to account for these aggregate uncertainties in the wholesale electricity markets? This presentation summarizes the findings of our ARPA-E-funded project for the development of a prototype stochastic-based advisory tool, tailored and trialed with MISO, that will assist in managing these uncertainties to enhance system reliability and efficiency in managing uncertainty.

Session H1 (Thursday, June 24, 9:30 AM, WebEx)

ABSCORES, A NOVEL APPLICATION OF BANKING SCORING AND RATING FOR ELECTRICITY SYSTEMS

Dr. Alberto J. Lamadrid L., Associate Professor, Lehigh University (Bethlehem, PA)
Dr. Audun Botterud, Principal Research Scientist, Massachusetts Institute of Technology (Cambridge, MA)
Dr. Parv Venkitasubramaniam, Associate Professor, Lehigh University (Bethlehem, PA)
Dr. Marija Ilic, Senior Research Scientist, Massachusetts Institute of Technology (Cambridge, MA)
Dr. Shalinee Kishore, Professor, Lehigh University (Bethlehem, PA)
Dr. Bo Chen, Computational Engineer, Argonne National Laboratory (Lemont, IL)
Dr. Jhi-Young Joo, Engineer, Lawrence Livermore National Laboratory (Lemont, IL)
Dr. Shijia Zhao, Postdoctoral Appointee, Argonne National Laboratory (Lemont, IL)

In this presentation we will discuss a project funded by the Advanced Research Projects Agency -Energy, ARPA-E, under the PERFORM program. This proposed effort will develop a framework for asset and system risk management that can be incorporated into current electricity system operations to improve economic efficiency.

We plan to establish an Electric Assets Risk Bureau. ABSCoRES is a multilayered framework for asset risk management and system risk management. The novelty of our approach lays on three main areas: (1) the measurement of risk based on mathematical norms to calculate ABSCoRES ratings and scores, (2) the development of novel data-driven dispatch algorithms that integrate the ABSCoRES, and (3) the identification of missing markets and development of new products to mitigate incurred risks. We will leverage scoring and ratings from banking and financial institutions alongside current optimization methods in dispatching power systems to help system operators and electricity markets schedule resources. This approach is based on the observation that there are major discrepancies between the power scheduled by a system operator and the actual power generated/consumed.

These discrepancies—exacerbated by unplanned contingencies are caused by multiple factors. There is a compromise associated to the risk sources, which now are varied and include an active demand side, loss of inertia and distributed energy resources, inter-dependencies with other systems and cybersecurity, renewable energy generators and the associated integration schemes across the balancing area, and different financial, environmental and risk preferences of power producers, consumers, and aggregators (e.g., FERC orders 841 and 2222).

Our objective is to develop a framework that counteracts two failures in existing electricity systems: (i) frictions in knowledge of assets (imperfect or asymmetric information regarding the risk they may induce in the system) and (ii) missing mechanisms (or markets) for products to mitigate risk incurred by a system of such assets. Including all constraints reflective of the probability function support for the stochastic sources would be uneconomical for system operators. Our proposed methodologies will improve economic efficiency of assets in the electricity system while recognizing limitations in assessing the distribution of information uncertainties affecting agents participating in these systems. A particularly attractive feature of our approach is its connection to economic theory of decision making under uncertainty. The trading of contingent claims in different states of the world in an Arrow-Debreu Economy with complete markets allows for full insurance coverage leading to a competitive equilibrium output. The acknowledged need to better assess and act upon risk profiles for grid assets has not been met by industry, and our innovative approach to managing risk can also improve energy efficiency and give the U.S. a technological lead in advanced energy technologies.

A New Swing-Contract Design for Wholesale Power Markets

Dr. Leigh Tesfatsion, Research Professor of Economics and Courtesy Research Professor of Electrical & Computer Engineering, Iowa State University (Ames, IA)

This presentation will discuss a new linked swing-contract market design for centrally-managed wholesale power markets to facilitate increased reliance on renewable energy resources and demand-side participation. The proposed swing contracts are firm or option two-part pricing contracts permitting resources to offer the future availability of dispatchable power paths (reserve) with broad types of flexibility in their power attributes. The presentation will begin with a brief overview of the proposed design. Analytical examples and test cases will be used to illustrate how optimal contract clearing for a swing-contract market can be formulated as a Mixed Integer Linear Programming (MILP) problem to which standard MILP solvers can be applied. The presentation will next discuss how the proposed design addresses important recognized issues for current U.S. RTO/ISO-managed wholesale power markets. The presentation will conclude with an examination of two key questions: How might current U.S. RTO/ISO-managed wholesale power markets transition gradually to a swing-contract form? And how might independent distribution system operators, functioning as linkage entities at transmission and distribution system interfaces, make use of swing contracts to facilitate their participation in these wholesale power markets as providers of ancillary services harnessed from distribution-side resources in return for appropriate compensation, thus addressing the requirements of FERC Order 2222?

MARKET-BASED RESOURCE ADEQUACY ASSESSMENT FRAMEWORK: THE IMPACT OF MARKET DESIGN ON LONG-RUN RESOURCE INVESTMENT AND RELIABILITY

Dr. Jonghwan Kwon, Energy Systems Engineer, Argonne National Lab (Lemont, IL)
Dr. Todd Levin, Energy Systems Engineer, Argonne National Lab (Lemont, IL)
Dr. Zhi Zhou, Principal Computational Scientist, Argonne National Lab (Lemont, IL)
Dr. Audun Botterud, Energy Systems Engineer, Argonne National Lab (Lemont, IL)

Increasing penetrations of low or zero marginal cost generation may lead to declining wholesale energy prices and a corresponding decline in revenues for generators and other resources in the system. As a result, resources may increasingly rely on revenues from providing other services, such as operating reserves or capacity, to ensure revenue sufficiency. This presentation will introduce a market-based resource adequacy assessment framework that can analyze the system generation portfolio that results in a competitive market environment. The model provides improved analysis of generation expansion and revenue sufficiency in a competitive market environment by capturing the strategic capacity investment decision-making of profit-maximizing generation companies. The modeling framework is based on Stackelberg leader-follower games and is formulated as a bi-level optimization problem, which is then transformed into a mathematical program with equilibrium constraints. A case study of the ERCOT system will be discussed. Lastly, our recent enhancement of the modeling framework will be presented.

Session H2 (Thursday, June 24, 11:00 AM, WebEx)

HELICS: INTEGRATED DISTRIBUTION AND TRANSMISSION PLANNING

Mr. Jason Fuller, Research Manager, Pacific Northwest National Laboratory (Richland, WA)
Dr. Henry Huang, Lab Fellow, Pacific Northwest National Laboratory (Richland, WA)
Dr. Trevor Hardy, Senior Engineer, Pacific Northwest National Laboratory (Richland, WA)

The power system is becoming more reliant on resources outside the traditional utility footprint - Distributed Energy Resources (DERs) providing power at the edge of the grid, natural gas pipelines that serve dozens of generators, and energy intense loads that are mobile and currently unpredictable. But to operate the power system with a leaner reserve margin and reduce overall costs, these new resources need to participate in maintaining—or improving—system resiliency and reliability. Hierarchical Engine for Large-scale Infrastructure Co-simulation (HELICS), a multi-lab, open-source, co-simulation tool created by the DOE's Grid

Modernization Lab Consortium (GMLC), is designed to meet this need by enabling seamless interactions between best-in-class simulators, models, and tools from multiple domains.

LINEAR DECISION RULES WITH PERFORMANCE GUARANTEES FOR SCALABLE MULTI-STAGE GENERATION PLANNING

Dr. Vladimir Dvorkin, Postdoctoral researcher, Massachusetts Institute of Technology (Cambridge, MA)
Dr. Dharik Mallapragada, Research Scientist, Massachusetts Institute of Technology (Cambridge, MA)
Dr. Audun Botterud, Principal Research Scientist, Massachusetts Institute of Technology (Cambridge, MA)

Power system investment planning requires scalable programs to accommodate the uncertainty of engineering, economic, and policy parameters. The complexity of scenario-based stochastic programs (SSP), however, grows exponentially in the number of investment stages. To alleviate the computational burden, SSP formulations often include only a few selected scenarios or disregard the dynamic aspect of investment decisions, thus misrepresenting the inherent stochastic processes. To fully represent uncertainty, we leverage linear decision rules (LDR) that restrict the problem's recourse to linear functions of uncertain parameters and propose a scenario-free chance-constrained problem formulation, which grows linearly in the number of investment stages. The LDR formulation can scale to large markets and can efficiently model the emerging policy uncertainty around renewable targets, emission caps, and carbon taxes. However, the inherent complexity reduction comes at the expense of optimality loss with respect to the SSP solution. We thus assess the optimality loss using a duality-inspired method and a sample-based method. While the former yields a global upper bound on the optimality loss, the latter leverages historical data to tighten this bound and to establish less conservative performance guarantees for the resulting investment decision rules. We demonstrate the value of the proposed multi-stage generation planning formulation by exploring the collective impact of uncertainty in carbon policies, technology costs, and system demand on near-term investments in natural gas and renewable generation.

CO-OPTIMIZED PLANNING OF GENERATION AND TRANSMISSION

Dr. Kai Van Horn, Manager, National Grid (Charlottesville, VA)
Dr. Russ Philbrick, Founder, Polaris Systems Optimization (Seattle, WA)
Dr. Alex Rudkevich, President, Newton Energy Group (Boston, MA)

Achieving policies targeting near full decarbonization of the electric sector will necessarily draw upon wind and solar deployments far from load centers, and thus likely involve significant new transmission development. Efficiently meeting these policy aims therefore requires close coordination of generation and transmission investments. Past planning efforts, focused largely on more conventional generation resources, did not require such close coupling and were also limited by the capabilities of planning tools.

We present a new computationally-efficient approach to model co-optimized generation and transmission investments over horizons on the order of decades. This approach preserves a high level of physical fidelity, including a security-constrained economic dispatch, commitment, fuel, emissions, and a range of other constraints and costs normally reserved for production cost models. We demonstrate the approach using a model of the Eastern Interconnection with detailed representation of NYISO and ISONE that has been used to model long-term decarbonization pathways for the region.

TWO AND THREE-STAGE SCENARIO BASED MODELING AND OPTIMIZATION FOR WIND AND STORAGE EXPANSION PLANNING

Dr. Devon Sigler, Researcher, National Renewable Energy Laboratory (Golden, CO)
Mr. Michael Kratochvil, Graduate Student, University of Iowa (Iowa City, IA)
Dr. Jonathan Maack, Researcher, National Renewable Energy Laboratory (Golden, CO)
Dr. David E. Stewart, Professor, University of Iowa (Iowa City, IA)

With costs of large-scale wind and storage devices decreasing, there is an increasing interest to bring these technologies onto the power grid. The intermittent nature of renewable energy makes it a challenge to determine the optimal location and capacity of these devices. In this talk, we present wind and storage generation expansion as a multi-stage, linear optimization problem where the first stage represents build decisions and subsequent stages represent operations. We explore different operational assumptions involving load, thermal set points, and renewable outputs in a two-stage and three-stage version of the model. We compare solutions using different time resolutions and differing numbers of scenarios. Additionally, to get around these scalability issues, an implementation of the Progressive Hedging algorithm is used to obtain results when the extensive form of the model cannot be solved.

Session H3 (Thursday, June 24, 1:40 PM, WebEx)

OPEN SOURCE PRODUCTION COST MODELING AT SCALE

Dr. Jean-Paul Watson, Senior Research Scientist, Lawrence Livermore National Laboratory (Livermore, CA)
Dr. Bernard Knueven, Research Scientist, National Renewable Energy Laboratory (Golden, CO)
Mr. Darryl Melander, Technical Staff, Sandia National Laboratories (Albuquerque, NM)

Recent efforts funded by DOE/ARPA-E's Performance-based Energy Resource Feedback, Optimization, and Risk Management (PERFORM) program have yielded open source data sets describing large-scale ISO operations, including the recently released "Texas7K" synthetic representation of the ERCOT footprint (by Texas A&M) with corresponding renewables forecasts at multiple look-ahead time scales and actual time-series (by NREL). We have integrated this data with state-of-the-art commitment/dispatch optimization models and production cost model simulators, respectively embodied by the Egret and Prescient open source software libraries. The result is a realistic, large-scale, and fully open source production cost model simulation capability. We will discuss the data sets, their use in Prescient and Egret, and simulation results.

Creating Large Scale 8760 Solved AC Power Flow Models for Transmission Planning Studies from Production Cost Models using PROBE and TARA

Mr. Brian Thomas, Lead Consultant, PowerGEM (Clifton Park, NY)
Dr. Boris Gisin, President, PowerGEM (Clifton Park, NY)

Rapid growth of intermittent renewable and energy storage resources emphasizes the need to study number of different system conditions in transmission planning studies. Currently Regional working groups or ISOs develop 1 or 2 power flow cases per year for future conditions for transmission planning studies, which will not be adequate as renewable penetration increases substantially, markets evolve, and new types of resources are introduced. In addition, there are several challenges and limitations associated with the process of creating power flow cases for transmission planning studies.

Production Cost Models (PCM) simulate 8760 hourly market conditions per study year based on SCUC with ancillary services and N-1 reliability constraints, which cannot be captured adequately using a single power flow case. While some PCM products offer the capability to create power flow models (called Round Trip), the process is not efficient due to software limitations, modeling assumptions, and AC power flow solution challenges.

This presentation describes PowerGEM's experience automating and creating hourly AC solved power flow models and addresses some of the major challenges associated with creating realistic power flow cases for transmission planning studies including enforcement of voltage constraints. PowerGEM will share a practical solution to create automated hourly AC solved power flow models integrating commercial high performance products - PCM PROBE with TARA software widely used for AC analysis.

A HIGH-EFFICIENCY AND NUMERICALLY ROBUST COMPUTING TOOL FOR POWER FLOWS AND DYNAMIC SIMULATION

Dr. Rui Yao, Energy Systems Scientist, Argonne National Laboratory (Lemont, IL)
Dr. Feng Qiu, Principal Computational Scientist, Argonne National Laboratory (Lemont, IL)
Dr. Yichen Zhang, Postdoctoral Appointee, Argonne National Laboratory (Lemont, IL)

As the power systems are facing potential disturbances with a wider spectrum of timescales and increasing interdependencies, traditional computational approaches for steady-state or dynamic analysis have shown apparent limitations in many aspects, such as numerical stability, scalability, multi-time-scale simulation efficiency, etc. In this presentation, we will introduce the semi-analytical solutions (SAS) -- an emerging computational methodology for the modeling and computation of power system and other engineering systems. The SAS has desirable features such as numerical robustness, high efficiency, cross-timescale capability, modeling flexibility, as well as support for parallel computing. This presentation will first introduce the concept of SAS, and then we will discuss the key SAS-based methods for steady-state analysis, dynamic analysis and multi-timescale hybrid analysis in the power system planning and operational scenarios. Computational experiments, including benchmarking against commercial software PSS/E, will also be presented to highlight the features of the SAS methodology.

ABSENCE OF SPURIOUS LOCAL TRAJECTORIES IN TIME-VARYING OPTIMAL POWER FLOW

Dr. Salar Fattahi, Assistant Professor, University of Michigan (Ann Arbor, MI)
Dr. Cédric Josz, Assistant Professor, Columbia University (New York, NY)
Mr. Yuhao Ding, PhD Student, University of California Berkeley (Berkeley, CA)
Ms. Julie Mulvaney-Kemp, PhD Student, University of California Berkeley (Berkeley, CA)
Dr. Reza Mohammadi, Postdoctoral Scholar, University of California Berkeley (Berkeley, CA)
Dr. Javad Lavaei, Associate Professor, University of California Berkeley (Berkeley, CA)
Dr. Somayeh Sojoudi, Assistant Professor, University of California Berkeley (Berkeley, CA)

In this work, we analyze solution trajectories for optimal power flow (OPF) with time-varying load. Despite its nonlinearity, time-varying OPF is commonly solved every 5-15 minutes using local-search algorithms. Failing to obtain the globally optimal solution of power optimization problems jeopardizes the grid's reliability and causes financial and environmental issues. The objective of this work is to address this problem by understanding the optimality behavior of OPF solution trajectories. An empirical study on California data shows that, with enough variation in the data, local search methods can solve OPF to global optimality, even if the problem has many local minima. To explain this surprising phenomenon, we capture the behavior of time-varying OPF with a time-varying ordinary differential equation and analyze the behavior of its solutions. In particular, we show that the solution trajectories can be modeled as the iterations of a stochastic gradient ascent algorithm on an implicitly convexified formulation of OPF, justifying the escape of poor solutions over time.

Session H4 (Thursday, June 24, 3:30 PM, WebEx)

VERIFYING GLOBAL OPTIMALITY OF CANDIDATE SOLUTIONS TO POLYNOMIAL OPTIMIZATION PROBLEMS USING A DETERMINANT RELAXATION HIERARCHY

Dr. Cédric Josz, Assistant Professor, Columbia University (New York, NY)

We propose an approach for verifying that a given feasible point for a polynomial optimization problem is globally optimal. The approach relies on the Lasserre hierarchy and the result of Lasserre regarding the importance of the convexity of the feasible set as opposed to that of the individual constraints. By focusing solely on certifying global optimality and relaxing the Lasserre hierarchy using necessary conditions for positive semidefiniteness based on matrix determinants, the proposed method is implementable as a computationally tractable linear program. We demonstrate this method via application to several instances of polynomial optimization, including the optimal power flow problem used to operate electric power systems.

SOLVING LARGE-SCALE STOCHASTIC, SECURITY-CONSTRAINED, MULTI-PERIOD GRID OPTIMIZATION PROBLEMS WITH THE EXASCALE GRID OPTIMIZATION (EXAGO) TOOLKIT

Dr. Shrirang Abhyankar, Senior Scientist, Pacific Northwest National Laboratory (Richland, WA)
Dr. Slaven Peles, Optimization and Control Chief Scientist, Pacific Northwest National Laboratory (Richland, WA)
Mr. Asher Mancinelli, Software Engineer, Pacific Northwest National Laboratory (Richland, WA)

ExaGO is an open source package for solving large-scale nonlinear power grid optimization problems on parallel and distributed architectures, particularly targeted for heterogenous architectures (GPUs). It consists of applications to solve large-scale stochastic optimization, security-constrained optimization (SCOPF), and multi-period ACOPF problems. ExaGO is being developed with funding from DOE Office of Science Exascale Computing initiative (ECP). This talk will introduce the ExaGO package discussingits capabilities, implementation details, and usage.

DISTRIBUTED COMPUTING AND CLOUD SOFTWARE: APPLYING LESSONS FROM THE INTERNET ERA TO THE BULK POWER SYSTEM

Mr. Cody Smith, Chief Technology Officer, Camus Energy (San Francisco, CA)
Ms. Astrid Atkinson, Chief Executive Officer, Camus Energy (San Francisco, CA)

Cody Smith and Astrid Atkinson helped pioneer Google's approach to managing reliability across a system with unreliable parts through cloud computing. To better understand opportunities to increase real-time and day-ahead market efficiency of the bulk power system, Cody and Astrid can help shed light on how technology companies used software best practices to improve the efficiency and reliability of complex computing networks with billions of endpoints. Cody and Astrid will also speak to helpful (and harmful) approaches to data sharing with cloud software -- providing advice for balancing privacy with visibility and control. Overall, Cody and Astrid will help attendees better understand how the bulk energy market can best leverage the lessons learned from scaling distributed computing infrastructure at information technology companies like Google.

NATURAL GAS INFRASTRUCTURE DEVELOPMENT IN NORTH AMERICA UNDER INTEGRATED MARKETS

Mr. Charalampos Avraam, PhD Candidate, Johns Hopkins University (Baltimore, MD)
Mr. Daniel Chu, Research Assistant, Johns Hopkins University (Baltimore, MD)
Dr. Sauleh Siddiqui, Associate Professor, American University (Washington, DC)

Environmental policies and natural gas resource availability affect natural gas infrastructure decisions. Faster transition to a low-carbon economy can result in low global oil prices and stimulate technological change in the natural gas sector. We assess the resiliency of the integrated North American natural gas markets to three types of shocks: low global oil prices, technological change, and natural gas resource availability. We show that cross-border US-Mexico trade can be more resilient under all three shocks compared to US-Canada trade. We also find that increasing Mexican production could drive the growth of the domestic Mexican market instead of reducing US-Mexico trade.