Special Topics: Improving Power Systems' Operations to achieve deep decarbonization

Spring 2021 **ENV 718**

Nicholas School of the Environment Duke University

Time

Tuesdays 12:00 – 1:30 PM

Instructor

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Pre-requisites ENV716 and ENV717

Course Description

Increasing penetration of wind and solar power generators augments both the variability and uncertainty of the available power generation and this **increases the risk** of having instances when demand and supply do not match, or when transmission line loadings are above safe limits. Failing to preposition all the power system's components to economically respond to deviations from DA forecasts of wind and solar generation forces Power System Operators to make costly dispatch adjustments in the real time. The numerous deleterious effects of these adjustments include: higher system operation costs, more severe scarcity events, higher divergence between DA and RT prices, increased need for out-of-market revenue sufficiency guarantee payments to generators (aka uplift payments) and inequitable distribution of revenue. In this seminar, we will study different approaches by balancing authorities in the U.S. to set operational reserve targets and to dispatch their power generation fleet.

Course Objectives

At the end of this course students will have a better understanding of:

- the challenges to integrate energy from wind and solar resources in the US electricity system and how different Balancing Authorities are tackling them

- the tools to characterize the uncertainty on demand, renewable energy production, and the performance of conventional generators
- alternatives to the conventional unit commitment/economic dispatch algorithms, including stochastic unit commitment and stochastic market clearing

Course evaluation

1. Two class presentations (30%)
2. Quizzes (30%)
3. Mid-term report (15%)
4. Final report (25%)

*Mid-term and final report: flexible options as explained in class

Weeks 1-2: Review of Power System Operations

FERC Staff. *Price Formation in Organized Wholesale Electricity Markets*. 2014; Available from: https://www.ferc.gov/legal/staff-reports/2014/AD14-14-operator-actions.pdf.

CAISO Staff. *Business Practice Manual for Market Operations Approval History, California ISO*. 2017.

Foley, A.M., et al., *Current methods and advances in forecasting of wind power generation.* Renewable Energy, 2012. **37**(1): p. 1-8.

PJM Staff. *PJM Manual 11: Energy and Ancillary Services Market Operations*. 2016; Available from: http://www.pjm.com/~/media/committees-groups/committees/mrc/20160428/20160428-item-13b-draft-manual-11-revisions-dasr.ashx.

Weeks 3-4: Challenges of renewables integration and determination of reserves

Holttinen, H., et al., *Methodologies to determine operating reserves due to increased wind power.* IEEE Transactions on Sustainable Energy, 2012. **3**(4): p. 713-723.

Ela, E., et al. *Effective ancillary services market designs on high wind power penetration systems*. in *2012 IEEE Power and Energy Society General Meeting*. 2012. IEEE.

Mount, T.D., et al., *The hidden system costs of wind generation in a deregulated electricity market.* The Energy Journal, 2012. **33**(1).

Week 5-6: Characterization of Uncertainty

Pinson, P., et al., *From probabilistic forecasts to statistical scenarios of short-term wind power production.* Wind Energy, 2009. **12**(1): p. 51-62.

Denaxas, E.A., et al. *SynTiSe: A modified multi-regime MCMC approach for generation of wind power synthetic time series*. in *2015 Annual IEEE Systems Conference (SysCon) Proceedings*. 2015. IEEE.

Etingov, P., et al. *Balancing Needs Assessment Using Advanced Probabilistic Forecasts*. in *2018 IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)*. 2018. Piscataway, New Jersey: IEEE.

Etingov, P.V., et al., *Online Analysis of Wind and Solar Part I: Ramping Tool*. 2012, Pacific Northwest National Lab.(PNNL), Richland, WA (United States).

Vitart, F., et al., *The Subseasonal to Seasonal (S2S) Prediction Project Database.* Bulletin of the American Meteorological Society, 2016. **98**(1): p. 163-173.

Week 7-8 Reserves determination - Flexible reserves

Xu, L. and D. Tretheway. *Flexible Ramping Products Draft Final Proposal, California Independent System Operator (CAISO)*. 2012; Available from: https://www.caiso.com/Documents/DraftFinalProposal-FlexibleRampingProduct.pdf.

Krad, I., E. Ibanez, and E. Ela. *Quantifying the potential impacts of flexibility reserve on power system operations*. in *2015 Seventh Annual IEEE Green Technologies Conference*. 2015. New Orleans, Louisiana: IEEE.

CAISO Staff. *Flexible Ramping Product Revised Draft Final Proposal, California Independent System Operator (CAISO)*. 2015; Available from: https://www.caiso.com/Documents/RevisedDraftFinalProposal-FlexibleRampingProduct-2015.pdf.

Price, J.E. *Testing market alternatives for renewable integration using a reduced network model*. in *2014 IEEE PES General Meeting| Conference & Exposition*. 2014. IEEE.

Cornelius, A., R. Bandyopadhyay, and D. Patiño-Echeverri, *Assessing environmental, economic, and reliability impacts of flexible ramp products in MISO's electricity market.* Renewable and Sustainable Energy Reviews, 2018. **81**: p. 2291-2298.

Wang, B. and B.F. Hobbs, *A flexible ramping product: Can it help real-time dispatch markets approach the stochastic dispatch ideal?* Electric Power Systems Research, 2014. **109**: p. 128-140.

Navid, N. and G. Rosenwald. *Ramp Capability Product Design for MISO Markets, Mid-Continent System Operator*. 2013; Available from: https://www.misoenergy.org/Library/Repository/Communication Material/Key Presentations and Whitepapers/Ramp Product Conceptual Design Whitepaper.pdf.

Virguez, E.; Wang,X and Patiño-Echeverri, D., Utility-scale photovoltaics and storage: decarbonizing and reducing greenhouse gases abatement costs. Applied Energy. Volume 282, Part A, 15 January 2021, 116120:
https://doi.org/10.1016/j.apenergy.2020.116120

Week 9-10 Flexible Assets - BES

Y. Zhang, V. Gevorgian, C. Wang, X. Lei, E. Chou, R. Yang, Q. Li, and L. Jiang, *Grid-Level Application of Electrical Energy Storage: Example Use Cases in the United States and China*. 2017; IEEE Power and Energy Magazine, vol. 15, no. 5, pp. 51{58, Sep. 2017, issn: 1540-7977. doi: 10.1109/MPE.2017.2708860. http://ieeexplore.ieee.org/document/8011515/.

A. S. Siddiqui, R. Sioshansi, and A. J. Conejo, *Merchant Storage Investment in a Restructured Electricity Industry.* The Energy Journal, vol. 40, no. 4, pp. 129{164, 2019, issn: 01956574. doi: 10.5547/01956574.40.4.asid.

S. Vejdan and S. Grijalva, *The expected revenue of energy storage from energy arbitrage service based on the statistics of realistic market data.* 2018 IEEE Texas Power and Energy Conference, TPEC 2018, vol. 2018-Febru, pp. 1{6, 2018. doi: 10.1109/TPEC.2018.8312055

S. Vejdan and S. Grijalva, *Analysis of multiple revenue streams for privately owned energy storage systems*. 2018 IEEE Power and Energy Conference at Illinois, PECI 2018, vol. 2018-Janua, pp. 1{5, 2018. doi: 10.1109/PECI.2018. 8334979.

F. Braeuer, J. Rominger, R. Mckenna, and W. Fichtner, *Battery storage systems: An economic model-based analysis of parallel revenue streams and general implications for industry*. Applied Energy, vol. 239, no. August 2018, pp. 1424{1440, 2019, issn: 0306-2619. doi: 10.1016/j.apenergy.2019.01.050. [Online]. Available: https://doi.org/10.1016/j.apenergy.2019.01.050.

J. E. Contereras-Ocana, Y. Wang, M. A. Ortega-Vazquez, and B. Zhang, *Energy storage: Market power and social welfare*. IEEE Power and Energy Society General Meeting, vol. 2018-January, pp. 1{5, 2018, issn: 19449933. doi: 10.1109/ PESGM.2017.8274080.

R. Fernandez-Blanco, Y. Dvorkin, B. Xu, Y. Wang, and D. S. Kirschen, *Optimal Energy Storage Siting and Sizing: A WECC Case Study*. IEEE Transactions on Sustainable Energy, vol. 8, no. 2, pp. 733{743, 2017, issn: 19493029. doi: 10.1109/TSTE.2016.2616444.

Virguez, E.; Wang,X and Patiño-Echeverri, D., *Utility-scale photovoltaics and storage: decarbonizing and reducing greenhouse gases abatement costs*. Applied Energy. Volume 282, Part A, 15 January 2021, 116120: https://doi.org/10.1016/j.apenergy.2020.116120

Week 9-12: Stochastic Unit Commitment:

Daraeepour, A., D. Patino-Echeverri, and A.J. Conejo, *Economic and environmental implications of different approaches to hedge against wind production uncertainty in two-settlement electricity markets: A PJM case study.* Energy Economics, 2019. **80**: p. 336-354.

Cheung, K., et al., *Toward scalable stochastic unit commitment.* Energy Systems, 2015. **6**(3): p. 417-438.

Papavasiliou, A. and S.S. Oren, *Multiarea stochastic unit commitment for high wind penetration in a transmission constrained network.* Operations Research, 2013. **61**(3): p. 578-592.

Price, J.E. *Evaluation of stochastic unit commitment for renewable integration in California's energy markets*. in *2015 IEEE power & energy society general meeting*. 2015. IEEE.

Ruiz, P.A., C.R. Philbrick, and P.W. Sauer. *Wind power day-ahead uncertainty management through stochastic unit commitment policies*. in *2009 IEEE/PES Power Systems Conference and Exposition*. 2009. IEEE.

Papavasiliou, A., S.S. Oren, and R.P. O'Neill, *Reserve requirements for wind power integration: A scenario-based stochastic programming framework.* IEEE Transactions on Power Systems, 2011. **26**(4): p. 2197-2206.

Pritchard, G., G. Zakeri, and A. Philpott, *A single-settlement, energy-only electric power market for unpredictable and intermittent participants.* Operations research, 2010. **58**: p. 1210-1219.

Martín, S., Y. Smeers, and J.A. Aguado, *A stochastic two settlement equilibrium model for electricity markets with wind generation.* IEEE Transactions on Power systems, 2015. **30**(1): p. 233-245.

Zavala, V.M., M. Anitescu, and J. Birge, *A stochastic electricity market clearing formulation with consistent pricing properties.* Argonne national Lab/ Mathematics and Computer Science (MCS) Division, 2016. **ANL/MCS-P5110-0314**.

Khazaei, J., G. Zakeri, and S.S. Oren, *Single and multisettlement approaches to market clearing under demand uncertainty.* Operations Research, 2017. **65**(5): p. 1147-1164.

Morales, J.M., et al., *Pricing electricity in pools with wind producers.* IEEE Transactions on Power Systems, 2012. **27**(3): p. 1366-1376.

Week 13: Risk Management

Rockafellar;, R.T. and S. Uryasev, *Optimization of conditional value-at-risk.* J. Risk, 2000. **2**(Spring): p. 21.

Ruiz, C. and A.J. Conejo, *Pool strategy of a producer with endogenous formation of locational marginal prices.* IEEE Transactions on Power Systems, 2009. **24**(4): p. 1855-1866.