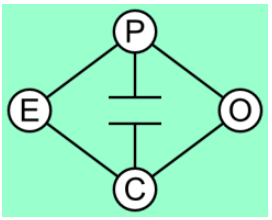

Distributed Energy Resources Workshop

We gratefully acknowledge the support of SfTI National Science Challenge on Agile and Resilient Manufacturing in making this workshop possible.

Thursday January 11th

17:00 - 18:30 **Registration and informal get together**

Friday January 12th
Location: Owen G. Glenn Building, case room 1. This is located at 12 Grafton Rd, ground floor. The university numbering for this location is building 260, room 005.

9:00 - 9:30 **Registration and opening**

9:30 - 10:15 **The Hidden Cost of Feed-in Tariffs for Wind Generation**

Georgios Patsakis and **Shmuel Oren**

Wind power generation is treated in many electricity systems as must take resources subject to a feed-in tariff. Such treatment is motivated by environmental policies aimed at promoting renewable generation and often justified by the arguments that wind power is free and the output of wind turbines is not dispatchable except for total curtailment. However, current technology does allow continuous control of wind turbine output and although the wind energy is free, the must take policy may lead to the suboptimal dispatch of conventional resources which imputes an indirect cost on the system. We demonstrate such hidden costs through simple examples and in the context of a stochastic unit commitment formulation where wind power resources are dispatched flexibly. We show that in a two-stage stochastic unit commitment, we can improve the dispatch efficiency of conventional slow resources committed in the first stage, by allowing strategic curtailment of uncertain wind power output in the second stage.

10:15 - 11:00 **Using Distributed Energy Resources for Multiple Applications Via Capacity Rights**

Ramteen Sioshansi

Distributed energy resources offer a great deal of flexibility in being able to provide services at the local distribution level and to the bulk power system. This talk will outline some of the practical and regulatory challenges in using distributed energy resources for multiple applications. We will then propose some form of capacity rights as a potential solution to these challenges.

11:00 - 11:30 **Coffee break**

11:30 - 12:15 **Using stochastic programming to analyze demand response in European electricity markets**

Asgeir Tomasgard

Due to technological developments and political goals related to renewable energy and energy efficiency, the electricity system is undergoing significant changes. One of the main consequences, is an active demand side where consumers take a more active role. We model several classes of shiftable and curtailable loads in residential, commercial and industrial sectors. The benefits of demand response consist of a reduction in peak load consumption, which leads to reduction in capacity investments, production and consumption savings, reduced congestion phases, reliable integration of intermittent renewable resources and supply and demand flexibility.

We first present a model for the scheduling of energy flexibility in buildings. Next, we propose short-term decision-support models for aggregators that sell electricity to prosumers and buy back surplus electricity. The key element is that the aggregator can control flexible energy units at the prosumers. We demonstrate the approach in a generalized market design that is flexible enough to capture todays market structure and still relevant in the next generation market design, both at wholesale and local level: an options market where flexibility is reserved for later use, a spot market for energy day-ahead or shorter, and a flexibility market where flexibility units are dispatched near real-time.

Finally, we look at the European level and analyze to what extent the demand response potential can facilitate an optimal transition to a European low emission power system. The results show that demand response decreases system operational costs and increases the capacity factors of IRES (Intermittent Renewable Sources). Results show that demand response capacity reduces investments in peak load plants and their capacity factors, from which follows lower CO2 emissions.

12:15 - 13:00 **Whats the Matter with Residential Electricity Prices?**

Severin Borenstein and **James Bushnell**

Residential energy tariffs are one of the major drivers of investments in energy efficiency and distributed energy technologies such as rooftop PV. However these investments are inefficient when the marginal energy prices do not reflect the marginal cost of supply, We study the relationship between residential electricity prices and social marginal cost, both on average and over time. We find that

while the difference between the standard residential electricity rate and the utilitys average (over hours) social marginal cost is approximately zero on average in the US, there is large regional variation, with price well above average SMC in some areas and well below average SMC in other areas. When we study the hourly variation in SMC, we find that for most utilities the largest source of difference between price and SMC is the failure of price to reflect variation in SMC over time. In a standard demand framework, total deadweight loss is proportional to the sum of squared differences between price and SMC, which can be decomposed into the component due to price deviating from average SMC and the component due to the variation in SMC. Our estimates imply that if demand elasticity were the same in response to hourly price variation as to changes in average price, then the average share of deadweight loss attributable to the failure to adopt time-varying pricing is 59%. These deadweight loss shares, however, vary dramatically across regions.

13:00 - 14:00 **Lunch break**

14:00 - 14:45 **The Economic Impact of Inefficient Distribution Network Pricing: Evidence from California and a Framework for a Proposed Solution**

Frank Wolak
(This presentation is via video conferencing)

Historically distribution network costs has been recovered through a cents per kilowatt-hour charge. Distributed solar provides consumer with ability to avoid purchases from the grid. This in turn leads to distribution network price increases and the well known problem of utility death spiral. We investigate these concepts, and the inefficiencies of distribution network pricing. We will discuss a framework for a proposed solution.

14:45 - 15:30 **Robust Energy Technology Policy: Finding common ground**

Erin Baker

We address the problem of decision making under deep uncertainty, introducing an approach we call Robust Portfolio Decision Analysis. We introduce the idea of Belief Dominance as a prescriptive operationalization of a concept that has appeared in the literature under a number of names. We use this concept to derive a set of non-dominated portfolios; and then identify robust individual alternatives from the non-dominated portfolios. The Belief Dominance concept allows us to synthesize multiple conflicting sources of information by uncovering the range of alternatives that are intelligent responses to the range of beliefs. This goes beyond solutions that are optimal for any specific set of beliefs to uncover defensible solutions that may not otherwise be revealed. We apply this approach to a problem in the climate change and energy policy context: choosing among clean energy technology R&D portfolios. We uncover portfolios that would otherwise remain

hidden and identify robust individual investments.

15:30 - 16:00 **Coffee break**

16:00 - 16:45 **Risk and efficiency in hydro-dominated electricity markets**

Andy Philpott and Ziming Guan

We present some results from an experimental study of the New Zealand wholesale electricity market over the period 2005-2016. The experiment creates optimal water release policies for a social planning model, assuming different levels of risk aversion, and simulates these in the market dispatch software vSPD. A detailed study of 2012 shows that wholesale prices generally increase in the social planning model as more uncertainty is added while remaining less than market wholesale prices, while gains in productive efficiency in comparison with market dispatch do not decrease markedly. Some preliminary tests on other years from 2005-2016 will be presented.

16:45 - 17:30 **Managing energy storage systems for flexible and efficient power systems**

Dennice Gayme

Demand growth, new demand-side technologies and the desire to integrate more renewable energy sources are driving rapid changes to the power grid, which pose new challenges. This talk demonstrates algorithms for optimizing storage dispatch and allocation throughout the network as a means of providing greater system flexibility in order to meet some of these challenges. The analysis focuses on optimal power flow (OPF) based tools, exploiting convex relaxations and model reduction techniques to understand the factors that drive optimal storage integration strategies. Two models are presented, a full AC network model that allows the investigation of the trade-offs which arise when storage is used both for conventional transmission system services and to provide reactive power (VAr) support. The second model is a computationally tractable approximation of the full AC OPF+storage problem that allows the investigation of the role of real power losses in optimizing grid-scale storage integration.

Saturday January 13th

9:30 - 10:15 **Industrial demand response in a co-optimized energy and reserve electricity market**

Golbon Zakeri

We will start by briefly reviewing the coupling of energy and reserve prices in a co-optimized energy and reserve electricity market. We will then describe our models and solution methods for co-optimized demand response and reserve offers for a large consumer of electricity in a single trade period. We will conclude with outlining our current efforts to devise optimal demand response and reserve offer strategies over a time horizon (e.g. 4 to 6 weeks). These strategies are intended for large consumers of electricity who are manufacturers and must complete a contract within a time frame. This presentation is based on a number of papers co-authored with G. Pritchard, A. Downward, M. Ferris, M. Anjos, N. Cleland, M. Habibian and K. Abbaszadeh.

10:15 - 11:00 **Flexibility in the local grid: distributed generation, storage and demand response**

Endre Bjorndal and **Mette Bjorndal**

In the European electricity market, wholesale power prices are uniform across large price areas. Even in intraday markets, congestion management is based on price areas and the aggregated transfer capacities between them. However, in the Norwegian power system there is presently considerable interest in using price differentiation and other mechanisms in the local distribution networks in order to save cost. In this talk, we discuss some pilot studies from Norwegian distribution companies, highlighting some principal issues and discussing the implications for regulation.

11:00 - 11:30 **Coffee break**

11:30 - 12:15 **Risk trading in capacity equilibrium models**

D. Ralph, G. de Maere dAertrycke, A. Ehrenmann, Y. Smeers

We present a set of power investment models, the class of "risky capacity equilibrium problems", reflecting different assumptions of perfect and imperfect markets. The models are structured in a unified stochastic Nash game framework. Each model is the concatenation of a model of the short-term market operations (perfect competition or Cournot), with a long-term model of investment behaviour (risk neutral and risk averse behaviour under different assumptions of risk trading). The models can all be formulated as complementarity problems, some of them having an optimization equivalent. We prove existence of solutions and report numerical results to illustrate the relevance of market imperfections on welfare investment

behaviour. The models are constructed and discussed as two stage problems but, time permitting, we show that the extension to multistage is achieved by a change of notation and a standard assumption on multistage risk functions. This approach is viable for industrial scale multistage models.

12:15 - 13:00 **Dynamic Risked Equilibria**

Michael Ferris and Andy Philpott

Electricity markets have evolved over the past three decades to facilitate the optimal allocation and scheduling of resources in the power grid. The recent explosion of use of renewable supply such as wind, solar and hydro has led to increased volatility in this system. We investigate models of competition and risk within the context of power system markets in a dynamic setting. We demonstrate when social optima exist, what properties on risk measures and contracts are needed, and how to solve these problems in large scale practical settings. We look at specific settings that give rise to problem insights and new computational methods.

13:00 - 14:00 **Lunch break**

14:00 - 14:45 **Sustainable Electricity Generation Portfolios**

Destenie Nock

We present a methodology for evaluating the sustainability of a regions electric generation portfolio, using New England as a case study. We focus on long term capacity planning for resource adequacy and sustainability. We first require all portfolios to satisfy resource adequacy, using a simple hourly dispatch model that abstracts from transmission. We then evaluate sustainability of generation portfolios using a set of seven criteria, including economic, environmental, and societal factors. We present the results of a multi-criteria decision analysis using ten illustrative decision-maker preference scenarios, considering a series of generation portfolios with varying levels of offshore wind, natural gas, hydro, and nuclear. We find that in the scenarios with no storage and low nuclear, restrictions on an expanded natural gas pipeline in New England may lead to a less sustainable generation portfolio, even when putting a high weight on greenhouse gas emissions.

14:45 - 15:30 **Flow-Based Market Coupling in the European Electricity Market**

Endre Bjorndal, Mette Bjorndal and Hong Cai

In May 2015, the Flow-Based Market Coupling (FBMC) model replaced the Available Transfer Capacity (ATC) model in Central Western Europe to determine the power transfer among countries (price areas). The FBMC model aims to enhance market integration and to better monitor the physical power flow. The FBMC model is expected to lead to increased social welfare in the day-ahead market and

more frequent price convergence between different market zones. This paper gives a discussion of the mathematical formulation of the FBMC model and the procedures of market clearing. We examine the FBMC model in two test systems and show the difficulties in implementing the model in practice. We find that a higher social surplus can come at the cost of more re-dispatching. We also find that the FBMC model might fail to relieve network congestion and does not better utilize the resources even when compared to the ATC model.

15:30 - 16:00 Coffee and discussion