Workshop: Optimization Tools for Renewable Energy Systems

Universidad Adolfo Ibáñez *

January 18 – 19, 2016

Researchers and practitioners get together to present the challenges that the energy sector will face in the next few years, and the tools that might be able to address them. The objective of this workshop is for industry and academia to come together and exchange ideas on how to tackle the challenges that are appearing due to the introduction of renewable energy into the grid.

Organized by UAI Systems Center and UAI+D, under the project *Centralized vs. Decentralized Energy Management in a Stochastic Setting* from professors Bernardo K. Pagnoncelli, Rodrigo A. Carrasco, and Tito Homem-de-Mello.

Detailed Program

Monday 18

- 8:30 – 9:00 **Registration**
- 9:00 – 9:30 **Workshop Opening**

  Introduction by Rodrigo A. Carrasco, UAI Systems Center Director and Assistant Professor.

  Welcome Speech by Alejandro Jadresic, Dean of the Faculty of Engineering and Sciences.

  Workshop Introduction by Bernardo K. Pagnoncelli, Associate Professor and Principal Investigator of the project *Centralized vs. Decentralized Energy Management in a Stochastic Setting*.

- 9:30 – 10:30

  Integrating transmission planning, generation investment, and market operation decisions in a joint optimization model
  Enzo Sauma *Associate Professor, Pontificia Universidad Católica de Chile*

  Based on a previous paper by Sauma and Oren, we formulate a variant of the proactive network planning model, which uses the marginal theory to clear a perfectly competitive electricity market. The equilibrium model characterizes the competitive interaction among generation firms whose decisions in generation capacity investments and production are affected by both the transmission investments and the market operation. Moreover, we also consider production costs that are inversely proportional to the installed capacity. We illustrate our results using the Chilean SIC network.

*Edited by Rodrigo A. Carrasco, rax@uai.cl, Faculty of Engineering and Sciences, Universidad Adolfo Ibáñez.

Microgrid Energy Management with Renewables and Storage
Bernardo K. Pagnoncelli *Associate Professor, Universidad Adolfo Ibáñez*

We present a microgrid model consisting of a small community, or city, comprised of a photovoltaic panel (PV) and two types of storages: batteries and pumping. Demand will be deterministic, for example via contracts, but energy generated from the PV is stochastic. We frame the problem as a multistage stochastic programming problem in which the goal is to produce the schedule that minimizes average costs, while satisfying demand at every time period. We illustrate our methodology with an example of a one-week operation of such system.

Joint work with Tito Homem-de-Mello, Rodrigo Carrasco, and Valentin Foucher

- 11:00 – 12:30

Chilean Transmission Grid & NCRE development: challenges and possible solutions
José Ignacio Escobar *CEO, Acciona*

Fast growing expansion of NCRE technologies (wind and solar PV) in northern zone of Chilean Central Interconnected System (SIC) has caused congestion in transmission lines capacity that transport energy to SIC's central zone, forcing to the System Operator to reduce the energy generation of several NCRE plants, due mainly to security restrictions. This presentation will introduce the assistants to understand the electricity market, and a solution that is in implementation phase to automate the coordination between generators and the System Operator in order to optimize the grid and increase NCRE in the SIC.

Hybrid Microgrids, the evolution of energy distribution for the arising prosumers
Micah Ortuzar *Especialista Senior Innovación, Chilectra*

Three Experiments for Centralized/Decentralized Management of Energy
Riadh Zorgati *Researcher, Electricité de France R&D*

The traditional (centralized) management of power system is based on the optimization of the global production cost while satisfying the supply-demand balance and respecting all the technical constraints of production units on a global scale and network balance management. The recent emergence of smart grids and regulatory developments will deeply impact the traditional centralized optimization on global electricity markets. In this context, we report three early experiments.

The first one consists in developing a joint optimization on production and demand in view to evaluate the effect of managing a set of production units (nuclear, coal, fuel, gas, hydro, wind and PV) together with some flexibilities on the demand such as controls on the hot water heating systems, charge of electrical vehicles and load shedding.

The second one consists in managing peak/off-peak hours, a perspective opened by smart meters which will make possible to control a part of the demand (which was

before considered as non flexible). This experiment can be seen as a special demand response problem.

The third one deals with the interaction between a big producer of electricity and a local actor, who is both consumer and producer. His production consists of photovoltaic panels, and wind turbines associated to a battery, in order to store energy and use it efficiently. Local actor interacts with the global actor by buying energy or by selling his production. We propose a bilevel optimization problem for dealing with this issue.

Joint work with C. Masquelier, and J.Y. Lucas

- 14:00 – 15:30

Coordination and uncertainty in strategic transmission network investment
Rodrigo Moreno *Assistant Professor, Universidad de Chile*

One important aspect that has so far received limited attention in network panning is that its benefits will largely depend on the eventual deployment pattern of generation infrastructure which is currently characterized by severe locational, sizing and timing uncertainty. In this context, there is a real risk for over-investment or a premature lock-in to options that exhibit limited adaptability. In this presentation we identify the optimal network investment (including topology) under several deployment scenarios and distinct policy choices differing in the level of coordination and international market integration in Europe. Furthermore, we showcase a novel min-max regret optimization model and identify minimum regret first-stage commitments which could be deployed in the near future in order to enhance strategic optionality and hence adaptability to different future conditions.

Mechanism design and allocation algorithms for energy-network markets with piece-wise linear costs and quadratic externalities
Alejandro Jofre *Professor, Universidad de Chile*

Motivated by electricity markets we introduce in this paper a general network market model, in which agents are located on the nodes of a graph, a traded good can travel from one place to another through edges considering quadratic losses. An independent operator has to match locally production and demand at the lowest expense. As argued in our previous paper "Cost-minimizing regulations for a wholesale electricity market" this setting is relevant to describe some real electricity markets, pricing behavior and market power coming from the fact that generators can bid above their true value. In a general setting of many distributed generator agents connected by a transmission network, bidding piece-wise linear cost functions, we propose a pricing optimal mechanism model to reduce market power. Our main results are the expression of the optimal mechanism design, two algorithms for the allocation problem and market power estimations. To deduce these nice properties, we intensively use convex analysis and some monotone behaviors of the set-valued maps involved. Furthermore, these algorithms make it possible to numerically compute a Nash equilibrium for the procurement auction, which is important to compare the optimal mechanism and the standard auction setting. Finally, we also show some interesting examples.

Joint work with Benjamin Heymann, Ecole Polytechnique, France

Scenario generation methods for a multi-stage stochastic program for energy planning

Tito Homem-de-Mello *Professor, Universidad Adolfo Ibáñez*

We study a multi-stage stochastic programming model for hydrothermal energy planning in Brazil, where uncertainty is due to water inflows. Solution methods for multi-stage stochastic programming require the representation of uncertainty as a scenario tree. We discuss some methods for generation of scenario trees that can be used by an optimization algorithm to solve the problem. The approaches we discuss exploit the structure of the original input process used to model the water inflows, which is a periodic auto-regressive model. One of the methods is based on Quasi-Monte Carlo techniques, which requires special care especially due to the high dimensionality of some of the random quantities involved. The second method is based on a transformation that reduces the input process to one that is stage-wise independent. Such a transformation, in turn, allows us to to proceed with generating scenarios stage-by-stage. The algorithm we propose hinges on the latter property and consists of two phases: first, we generate a scenario tree where each the distribution in each stage is approximated by a discrete distribution with large number of points; then, we apply a reduction method to find a distribution with smaller support that minimizes the distance to that discrete distribution. We show how this minimization problem can be solved with a structured binary linear program. Some numerical results are presented to illustrate the ideas.

Joint work with Vitor Luis de Matos (Plan4, Brazil) and Erlon Cristian Finardi (Universidade Federal da Santa Catarina, Brazil)

- 16:00 – 17:00

Fuzzy Prediction Interval Models for Forecasting Renewable Resources and Loads in Microgrids

Doris Saez *Associate Professor, Universidad de Chile*

An energy management system (EMS) determines the dispatching of generation units based on an optimizer that requires the forecasting of both renewable resources and loads. The forecasting system discussed in this paper includes a representation of the uncertainties associated with renewable resources and loads. The proposed modelling generates fuzzy prediction interval models that incorporates an uncertainty representation of future predictions. The model is demonstrated using solar and wind generation and local load data from a real microgrid in Huatacondo, Chile for one-day ahead forecasts to obtain the expected values together with fuzzy prediction intervals to represent future measurement bounds with a certain coverage probability. The proposed prediction interval models would help to enable the development of robust microgrid EMS.

Optimal Control of a Microgrid with Combined Heat and Power Generator

François Pacaud *Researcher, Efficacity – Cermics-Ecole des Ponts ParisTech*

Most of european countries must produce more than 20 % of their electrical energy with renewable energies by 2020, and smart and micro-grids are more and more put forward

to achieve this goal. These new technologies allow utility managers to control in real time the consumption of consumers and the production of different power plants.

Deterministic controls, such as Model Predictive Control (MPC), are the most used methods to manage a micro-grid. But consumptions and renewable energy productions are hardly foreseeable, and it is often difficult to satisfy the adequation between demand and production in deterministic framework. That is why we focus on stochastic optimal management to control a micro-grid.

We consider here a domestic micro-grid, composed of a smart home equipped with smart devices (thermostat, controller) and whose energy is produced by renewable sources (micro-cogeneration, solar panels). This system is modelled with two state variables, and we will consider thermal and electrical demands as stochastic variables. Stochastic optimal control will be used to manage the energy in this system. We will put emphasis on the algorithms used (stochastic dynamic programming) and the numerical results obtained. A benchmark with other methods, such as MPC and heurisitics, will be presented.

Tuesday 19

- 9:00 – 10:30

  The Solar Energy Challenge in Chile
  Rodrigo Palma-Behnke *Associate Professor, Universidad de Chile*

  Based on the current energy situation in Chile, a long term vision for solar energy development is presented and analyzed. The unique condition of the Atacama Desert and its solar energy potential is shown. Finally, selected challenges in the field of modeling, optimization, and economic issues are described based on specific applications.

  Ancillary Services to accommodate variable generation: more products or larger formulations?
  Héctor Chávez *Assistant Professor, Universidad de Santiago de Chile*

  The contribution of Variable Generation (VG) to the total intra-dispatch power imbalances in power systems have increase the amount or reserved capacity to maintain frequency control adequacy. On the other hand, several technologies (flywheels, batteries, compressed air, pumped hydro, synthetic inertia) have arisen as Ancillary Service (AS) providers to cope with the increasing variability, due to their superior frequency responsive ramping capability. In general, the technological diversification of frequency control providers have also led to different AS products that are quantified and paid differently, while the service provided is qualitatively the same. This talk proposes a homogenization of AS markets by focusing market definitions on the service provided rather than the providing technology. Such a definitions is based in a clear separation between the physical meaning of, and the performance standards associated with frequency control, so products definitions and payments are associated to physical functioning and compliance with performance standards. This reduces the number of products needed to include new technologies but increases the size and complexity of the market formulations.

Participation of Demand Response Aggregators in Day-Ahead and Real-Time Markets: Optimal Portfolio Management

Daniel Olivares *Assistant Professor, Pontificia Universidad Católica de Chile*

A salient feature of the Smart Grid is the new role of consumers, transitioning from being unresponsive and highly inelastic agents towards more active and responsive participants in the system. This active role of demand can be enabled by the implementation of appropriate demand response (DR) mechanisms that provide consumers with suitable incentives and control signals to adjust their consumption patterns according to the system requirements. Thus, demand response can contribute to reduce direct costs from fuel savings, improve system reliability, and facilitate the integration on intermittent energy resources (e.g., wind and solar power) by introducing more flexibility into the grid. In particular, this work studies the optimal operation of a DR Aggregation Entity, or DR Aggregator, that manages a large number of DR contracts with multiple consumers and participates in day-ahead and real-time energy markets.

The proposed model considers the DR Aggregator as a price-taker entity in the day-ahead market, where it buys the energy at an uncertain exogenous price, while it can exercise market power as a price-maker entity in the much smaller real-time (balancing) market. The aggregator has a portfolio of contracts of load curtailment and energy loads (dispatchable loads) with multiple consumers, which can be executed (dispatched) to re-shape the base load profile. Uncertainty associated with day-ahead market clearing prices and the demand in the real-time market (balancing power requirement) is represented through a set of scenarios obtained from historical data. The proposed model yields a stochastic bilevel mathematical program formulation, which is re-formulated as a mixed-integer linear program that can be solved using off-the-shelf optimization packages.

The model is tested in a medium-size system, with scenarios built using historical data from the California ISO (CAISO). Numerical results are obtained for a number of study cases with different compositions of the DR portfolio, and different scenarios of day-ahead and real-time market conditions. The results offer interesting insights into the value of demand response mechanisms in electricity markets for different levels of variability, characterized through the scenarios of balancing requirements.

Joint work with R. Henríquez, G. Wenzel, and M. Negrete-Pincetic

- 11:00 – 13:00

AMEBA: herramienta de apoyo a la toma de decisiones en mercados energéticos

Carlos Suazo *Ministerio de Energia, Centro de Energía U. de Chile y SPEC*

Las energías renovables cambiaron el paradigma de operación de los sistemas eléctricos a nivel mundial. Entre otros, sus impactos abarcan desde aspectos operacionales (procesos de despacho y predespacho en el corto y mediano plazo), planificación de la operación (mantenimiento de unidades, ciclaje de unidades térmicas, coordinación hidrotérmica), hasta ámbitos de política energética (planificación de la matriz energética). La presentación abarca diversos aspectos técnicos para abordar problemas de gran escala en este nuevo paradigma, mostrando el funcionamiento y potencialidad de AMEBA

para el análisis de sistemas eléctricos con alta penetración de energías renovables.

Solar Network SERC-Chile and new Thermal & Storage Materials for CSP plants

Gustavo Cáceres *Assistant Professor, Universidad Adolfo Ibáñez*

Chile is currently trying to solve some energy problems which affecting our competitiveness, sustainability, security and efficiency of our energy matrix towards foreign market. The high costs of energy and continuity of projects entered into the system have generated controversy and doubts regarding how to address this issue, respecting the environmental and energy policies that the current Chilean government proposes this year for the next 10 years. An example of this politics, is the current ERNC (Renewable Non-Conventional Energy) law 20/25 (20% of electricity generation at year 2025). As consequence, one of the priority and key solution proposed by the Chilean government, is develop Solar Industry: innovative technologies, high level (world class) R&D Centers like SERC-Chile and also stablish competitive industry & market conditions for solar power plants through his Strategic Program for Solar Industry Development (PES, CIFES-CORFO).

The reason for that solution is easy to understand and demonstrate, Solar energy is abundant in Chile, our country have the best worldwide solar direct radiation, more than 7 kWh/m2/day average, and presents a tremendous opportunity to achieve, for example, sustainable mining industry and green markets attributes making it more competitive. Solar power depends directly on the incident solar radiation on earth. The development of this energy for electricity and thermal generation, at low cost, run into several technology, market and policy matters. In Chile some applications are at pilot level, while others have a more finished commercial development.

Regarding R&D solar development, Chile has a large collaborative researcher solar network named Solar Energy Research Center (SERC), with 6 universities associated (U. of Chile, U. Adolfo Ibáñez, U. de Concepción, U. de Antofagasta, U. de Tarapacá and U. Federico Santa María) and one foundation (Fundación Chile). This R&D network works in Photvoltaics and Solar Thermal technologies for solar power plants, industry process and residential (buildings) applications. One of the specific and relevant development, managed by SERC, PES and UAI, is the conception of new Thermal (HTF and TES) materials. Besides of the well-known solar salts for CSP-TES and batteries Li-ion for PV, where Chile is the largest producer, there are other important new materials with high prospective to be used, such as LiNO3, LiOH, Cu, etc., that are already being studied in Chile to improve energy storage systems. The study of new materials for energy storage and transport, applied to solar power plants, can help significantly to reduce the cost of installation, operation and price of thermal and electrical energy sale from this renewable source.

This work is supported by the Chilean projects CONICYT/FONDAP/15110019 (SERC-CHILE), CONICYT/FONDECYT/ 1151061 and by UAI-EARTH.

Impact of High Penetration of Renewable Energy Technologies (RETs) in the Generation Sector: The Case of Chile

Carlos Silva *Assistant Professor, Universidad Adolfo Ibáñez*

In recent years, electricity generation from intermittent and variable RETs such as wind and solar has increased substantially, even in emerging countries. These technologies have some unique characteristics compared to the traditional technologies that create challenges in planning and operating power systems. Furthermore, they can influence the performance and outcomes of traditional electricity markets. Among the potential impacts, the emergence of high penetration rates of intermittent energy sources in the energy mix of power systems can substantially increase the need for faster-ramping the resources participating in ancillary services, such as frequency regulation service, which is procured via market mechanisms by system operators. As an example, in the traditional view of an energy market the mismatch between offer and demand, that results in the need of frequency regulation, is primarily results of variation of consumption, and therefore, its payment can be attributed to the demand. However, in a system with a high penetration of renewable, the mismatch is also due to the variation of the energy contribution from such sources, and therefore, the payment should be share between the consumption and the renewable generators.

Considering the case of Chile, the rapid grow of renewable sources has resulted in some unintended consequences leading to significant distortions in the electricity market. Chile was a pioneer in Latin America with respect to electricity market reforms. In 1982 a new electricity law functionally separated generation, transmission and distribution, introduced mandatory marginal cost dispatch, opened access to transmission lines, created a contract-based generation market and formalized price cap regulation of distribution. The two-product market (energy and capacity) has worked quite well, but this may now change with the fast and massive irruption of zero-operating-cost technologies, such as renewable energies. Over the past decade, the promotion of renewable energy in Chile, especially solar energy projects, has become increasingly important. As of the first quarter of 2015, electricity generation from RES (excluding large hydro) reached 12% of the total power capacity in the system and Chile has set a goal of lifting non-conventional renewables' share of the country's energy matrix to 70 percent of renewables (non-conventional plus large hydro) by 2050. At this time, the country has about 14.500MW of renewable energy projects with environmental approval, equal to peak demand of the country, and projects for additional 7.000 MW are under evaluation. These numbers show that, the entrance of large variable generation capacity from renewable sources to the grid is going to become a reality in the near future. In a market like this, with a high penetration of renewables with zero variable cost and no or limited capabilities to provide ancillary services, generates a downward slope in the average spot price and a significant stress on conventional generators that need to ancillary services to the system without the help of their renewable counterparts. Before 2012, ancillary services, such as frequency regulation, were calculated using equal shares, meaning each generator needed to equally contribute to the system. In 2012, the Chilean market operator introduced a cost-based ancillary services with the purpose of explicitly considering the cost of such services in the system. These amendments set a compensation mechanism to the generators in the where they need

additional maintenance, fuel consumption and the investment to provide the services. However, given the changes the Chilean system has undergone, this mechanism is quickly becoming obsolete, and therefore, it is necessary to strengthen market-based mechanisms for assignment and pricing of this important and necessary service. The paper examines the long-term economic incentives for different generation technologies in the system with high penetration of renewable generation under the criteria of an equal contribution, cost-based payment and a market-based mechanism for ancillary services, under scenarios of low and high penetration of renewable energy. The paper is organized as follows: After the introduction the second section gives a brief overview about the regulatory settings in the international market that are necessary to provide market-based ancillary services. The third section addresses the regulatory mechanisms for ancillary services in the case of Chile and discusses the market-based tools that have to be introduced to match well with the entrance of variable generations. In section four we describe the conducted power system simulation and the results. In the final section policy implications are derived.

The present work analyses the financial incentives for different generating technologies in three different scenarios of compensation for ancillary services (equal share, cost-based & market based mechanisms). The results show that as more renewable capacity enters the average marginal cost of energy decreases because of the introduction of large number of zero variable cost plants. However, this causes mixed results in combined-cycle plants. If such plant sells their energy in the spot market, then their yield decreases, however, if the plant has a high level of contracted energy, its profitability increases in the short term. A similar effect can be observed for coal-firing plants. On the other hand, renewable plants are in general highly exposed to the increase of solar and wind plants in the energy matrix due their well-documented barrier of contracting their energy with final customers.

Joint work with Claudio Agostini, Shahriyar Nasirov, and Franco Armijo.

Real-Time Strategies for an EV Fleet Aggregator to Provide Ancillary Services

Matías Negrete *Assistant Professor, Pontificia Universidad Católica de Chile*

A large share of variable generation will be a common characteristic among power grids worldwide, due to efforts of reducing greenhouse gas emissions and exploiting renewable resources such as wind and sun. In this context, sources of flexibility will be key assets to compensate the inherent volatility and uncertainty of these sources and achieving the required balance between generation and demand at every time.

This work is part of a project that aims to demonstrate the concept of Vehicle-to-Grid (V2G) with an operational fleet. The objective is to allow the fleet to participate on Ancillary Services (AS) markets by using the energy storage capacity the fleet has during the Electric Vehicles (EVs) idle time. In California, performance-based payments are being introduced for AS. In the case of frequency regulation, a fast and accurate response is compensated alongside capacity payments.

In this talk, we discuss real-time controllers for operating the fleet. First, we present a real-time controller based on following optimal pre-specified trajectories for the EVs'

state of charge, as well as an Automatic Generation Control (AGC) signal,. A sequential convex optimization problem is solved to distribute the regulation commands among the vehicles. The individual trajectories were computed by a higher level model called Distributed Energy Resources Customer Adaption Model (DER-CAM), that takes into account economical and environmental objectives. It is shown that accuracy results using that controller are better than the ones achieved using common real-time scheduling heuristics as Earliest Deadline First (EDF) and Least Laxity First (LLF).

We also present an extension of the controller that considers in a more realistic way the efficiency of the batteries and studies the effect of looking ahead when implementing a Model Predictive Control (MPC) scheme. Simulations show that improved accuracy results can be achieved by the new controller, as well as better regulation capacities while requiring less energy from the fleet, thus confirming the additional value the look-ahead characteristic adds.

Joint work with G. Wenzel, M. Negrete-Pincetic, D. Olivares, J. MacDonald, and D. Callaway

- 14:30 – 15:30 **Round Table**
  Opportunities for collaboration between industry and universities to further develop renewable energy in Chile

  Moderates: Professor Tito Homem-de-Mello

  The area of energy planning has been undergoing considerable transformation in the past few years, thanks to the increasingly prominent role played by renewable energy in the energy matrix of many countries. In Chile, in particular, such phenomenon has been observed through the use of hydro power, wind, and solar energy. Renewable sources, however, create enormous challenges for energy planning due to the inherent uncertainty associated with the generation of power from such intermittent sources. These challenges require that traditional models be revisited and modified. In this roundtable we will discuss some of these challenges and the opportunities they create for interaction between industry and academia. Participants will comment on their experiences and on possible ways to strengthen such interaction in order to meet the challenges.