workshop

# MODELLING SMART GRIDS 2016

## A Challenge for Stochastics and Optimization

Akademie věd České republiky

Akademie věd České republiky
Strategie AV21

### workshop

September 21st, 23rd 2016
ČVUT v Praze, Karlovo nám. 13
Praha 2, Nové Město

### Energy Day

September 22nd 2016
UK v Praze, Malostranské nám. 25
Praha 1, Malá Strana

cost

### contact email

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Main goal of the workshop is to connect researchers and energy providers, traders and operators. The workshop will focus on using modern optimization, statistical and computational methods suitable for analysis of big data, creation of advanced forecast models for both deterministic and probabilistic prediction, development of new optimization methods for energy leak management, environmental quality improvement, etc.

Round table discussion with introductory talks given by leading representatives of Czech energy industry and research, and by representatives of European Network for Business and Industrial Statistics, will form part of the workshop. Language of the round table discussion will be both Czech and English, translation will be provided.

Main output of the workshop will be up-to-date knowledge transfer from the researches to the users and, conversely, opening new research targets and horizons as required by the power and gas industry.

Registration, program and other information:
**www.energy-workshop.cz**.

# Program

## Wednesday, September 21st:

**8:30 – 9:00** Registration

**9:00 – 9:15** Opening

**9:15 – 17:00** Workshop on Macroeconomic Energy Systems Modeling and Optimization

(Czech Technical University, Faculty of Mechanical Engineering, Karlovo náměstí 13, Prague 2, building A, room 312)

## Thursday, September 22nd:

**8:30 – 9:00** Registration

**9:00 – 12:00** Lectures

**13:30 – 17:00** Round Table Discussions

**18:00 – 19:00** Concert of Singers

(Charles University, Faculty of mathematics and physics, Malostranské náměstí 2/25, Prague 1; 3rd floor, room S4)

## Friday, September 23rd:

**9:00 – 12:30** Mathematical Optimization in the Decision Support Systems for Efficient and Robust Energy Networks - COST Action TD 1207

**14:00 – 16:00** Discussion about a future work (Horizon 2020 proposals)

(Czech Technical University, Faculty of Mechanical Engineering, Karlovo náměstí 13, Prague 2, building A, room 312)

# Detailed Program

## Workshop on Macroeconomic Energy Systems Modeling and Optimization

### September 21st, 2016

### 9:15 – 10:15 Introduction

**9:15** **Computational challenges for Energy System Modelling – the long and difficult road to use high performance computing**
Frieder Borggrefe, German Aerospace Agency (DLR), Stuttgart, Germany

**9:45** **Multi-model Methodologies for Integrating Energy Systems Modelling with Macroeconomic Modelling and Power Systems Modelling**
Prof. Brian Ó Gallachóir, University College Cork and Chair IEA ETSAP, Ireland

**10:15 – 10:45 Coffee break**

### 10:45 – 11:45 Improving Energy System Models

**10:45** **The Open-Source Electricity System Model DIETER - Scope, Applications, and Computational Issues**
Dr. Alexander Zerrahn, German Institute for Economic Research (DIW Berlin), Berlin, Germany

**11:15** **BEAM-ME project – lessons learned: A Practical Guide to Faster Energy System Modelling**
Hans Christian Gils, Manuel Wetzel, Kai von Kribek, Tobias Fichter, Karl-Kiên Cao, Frieder Borggrefe, German Aerospace Centre (DLR), Stuttgart, Germany

**12:00 – 13:30 Lunch**

### 13:30 – 15:00 Decomposition, Uncertainty and Parallel Computing

**13:30** **Benefits of Decomposition Methods to Speed-up Energy System Modelling and Application to Stochastic Optimization**
Manuel Wetzel, Frieder Borggrefe, German Aerospace Agency (DLR), Stuttgart, Germany

**14:00** **Zero-price Energy Offering by (Multiband) Robust Optimization**
Fabio D'Andreagiovanni, Department of Mathematical Optimization, Zuse Institute Berlin (ZIB), Germany

**14:30** **On a Strategic Multistage with Tactical Multi-period Scenario Tree Framework for Energy Network Capacity Expansion Planning and Decomposition Algorithms for Problem Solving**
L.F. Escudero, A. Alonso-Ayuso and F. Javier Martin-Campo, Universidad Rey Juan Carlos and Universidad Complutense de Madrid, Spain

**15:00 – 15:30 Coffee break**

## 15:30 – 17:00 Mathematical Optimization and High Performance Computing

**15:30 Structure Exploitation in Optimal Power Flow**
Andreas Grothey, University of Edinburgh, Scottland

**16:00 Massively Parallel Solution of Mixed-Integer Energy System Models by Distributed Branch-and-Bound**
Daniel Rehfeldt (Speaker), Ambros Gleixner, Yuji Shinano, Department of Mathematical Optimization, Zuse Institute Berlin (ZIB), Germany

**16:30 Closing discussion and summary**

## Energy day 2016 – Keynote lectures, Round Table Discussions

**September 21st, 2016**

**9:00 – 9:50** **Berit Müller:** Outreach of energy system simulations – from models to reality

**10:00 – 10:50** **Dana Drabova**: The Puzzle of Future Energy mix and possible Role of Nuclear

**11:00 – 11:50** **Filip Procházka:** Smart grid applications – from models and simulations to real solutions implemented in distribution grid

**12:00-13:30 Lunch**

**13:30 – 13:40** **Round Table Discussions Opening**

Three groups of discussants will be formed and rotated between three round tables in three sessions. Each table will be devoted to one given theme (see Theme 1 to 3). The discussions will be moderated and results will be summarized.

Each session will be 40 minutes long. Times of changes: **13:50, 14:30, 15:10**

**Theme 1: Impact of research activities to real energy systems**

**Theme 2: Nuclear versus smart grids (future energy mix)**

**Theme 3: Real applications in energy production and distribution practice**

**16:00-16:50** **Closing summary**

**18:00-19:00** **Concert of Singers**

**Mathematical Optimization in the Decision Support Systems for Efficient and Robust Energy Networks - COST Action TD 1207**

**September 23rd, 2016**

## 9:00-12:30 Workgroups meetings

**09:00-09:45** **Database development of all applications of EP&D, with extensive cross-link**
(Antonio Frangioni, WG1 leader)

**09:45-10:30** **Complements and contributes to the "wiki" of WG1 regarding the methodological advances that are relevant to make novel EP&D problems addressable**
(Jean Bernard Lasserre and Christoph Helmberg, WG2 leaders)

**10:30-11:00** **Coffee**

**11:00-11:45** **Complements and contributes to the "wiki" of WG1 on the area of the technical validity of the mathematical models currently used in EP&D applications**
(Sandrine Charousset, WG3 leader)

**11:45-12:30** **Methodological results of WG2 with actually usable software, ready to exploit data provided by WG3**
(Martin Mevissen, WG4 leader)

**12:30-14:00 Lunch**

## 14:00-16:00 Discussion about a future work (Horizon 2020 proposals).

## Local Organizing committee

Jaromír Antoch
Charles University in Prague
Gejza Dohnal
Czech Technical University in Prague
Ivan Kasanický
Czech Academy of Sciences
Emil Pelikán
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## Scientific Program committee

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Christoph Helmberg
Chemnitz University of Technology
Thorsten Koch
Zuse Institute Berlin (ZIB)
Martin Mevissen
IBM Ireland Research Dublin Technology Campus
Emil Pelikán
Czech Academy of Sciences

## Sponsors

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Strategie AV21
Špičkový výzkum ve veřejném zájmu

Akademie věd České republiky

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EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

# Book of Abstracts:

## Keynote Lectures

### Outreach of energy system simulations – from models to reality

**Berit Müller**, founding member of the Reiner Lemoine Institut (RLI, established in 2010), she focuses on the intersectoral simulation of energy systems and on the development of publicly available simulation models and basic data to improve the scientific performance of the work and the sociopolitical dialogue.

**Abstract:** As many other institutions the RLI is working with energy system simulations. We do that with different objectives. We want to learn more about the function of different energy systems or the characteristics of individual components – and we want to support the transformation of the energy system. But – Energy System Models. often fall short of expectations serving more as academic exercises than as tools for actual decision makers:. We need to close the gap between the researcher and the stakeholders.

In this keynote we will discuss chances and barriers of energy system modelling and will critically ask ourselves about the necessity of what we are modelling.

We will also touch the question if the global change in energy systems is caused by breakthroughs in engineering or if the great success of renewable energies and smart technologies primarily is a political matter

### The Puzzle of Future Energy mix and possible Role of Nuclear

**Dana Drabova,** president of the State Nuclear Safety Authority of the Czech Republik, in period 2006-2009 president of Western European Nuclear Regulators Association (WENRA),

# Smart grid applications – from models and simulations to real solutions implemented in distribution grid

**Filip Prochazka** (Masaryk University in Brno), director of MycrofitMind company (http://www.mycroftmind.cz/en/models-and-simulations/) and the leader of development team of LODIS project (control of local distribution networks) and others applications in real networks.

**Abstract**: There are various possible applications which can utilize smart metering / smart grid infrastructures like smart meters or secondary substation metering and monitoring. To design and implement such application in real distribution grid is a complex task which have to respect specific distributor needs, available communication infrastructure speed and reliability, quality of available data about distribution grid etc. We will present modelling and simulation tool GridMind developed by Mycroft Mind company in cooperation with Masaryk University, Czech Technical University in Prague and Brno Technical University which allows to create complex models of smart grid infrastructures. This tool was used in real projects for energy distributors in Czech Republic (CEZ, E.ON, PRE). We will present real smart grid application LODIS for local load control implemented in three substations of CEZ distribution grid. We will mainly focus on practical implementation issues and its consequences to application design.

# Poster session

## Nonlinear Model Predictive Control for Waste Heat Energy Recovery Systems: an Application to Heavy Duty Trucks

**Enrique Guerrero Merino**, IWR - Heidelberg University

**Abstract:** On heavy duty trucks, fuel is burnt in the engine to produce mechanical energy. As a result, warm exhaust gas is expelled to the atmosphere. Part of the gas' thermal energy might be recaptured for application on the vehicle by means of an Exhaust Heat Recovery System (EHR), consisting of an Organic Rankine Cycle in which the working fluid's pump mass flow is the control variable. It has been observed that the system performance is strongly dependent on the way it is controlled. In order to achieve an optimal performance, the authors propose the application of the Real-Time Iteration Scheme for Nonlinear Model-Predictive Control (NMPC), which pursues the maximization of the cycle's generated energy subject to the corresponding operational constraints. Results are obtained on a real-world test scenario. The algorithm reaches fast computational times and exhibits successful results.founding member of the Reiner Lemoine Institut (RLI, established in 2010), she focuses on the intersectoral simulation of energy systems and on the development of publicly available simulation models and basic data to improve the scientific perform

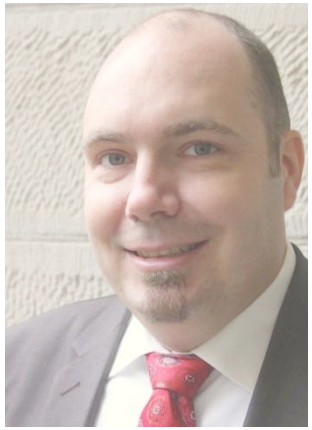
# Workshop on Macroeconomic Energy Systems Modeling and Optimization

## I. Introduction

### 1. Computational challenges for Energy System Modelling – the long and difficult road to use high performance computing

**Frieder Borggrefe, German Aerospace Agency (DLR), Stuttgart, Germany**

**Abstract:** Energy system models (ESM) are widely used in research and industry to analyze today's and future energy systems and potential pathways for the European energy transition. Current studies address future policy design, analysis of technology pathways and the analysis of future energy systems. To analyze these questions and support the transformation of today's energy systems, ESM are required to become increasingly complex in order to provide valuable quantitative insights for policy makers and industry. For research institutions and industries all over Europe applying ESM becomes more and more difficult, as boundaries with regard to computational power of today's decentralized workstations impose significant constraints to energy market modelling. The use of high performance computing might be one path to solve these constraints. This presentation provides an overview of the challenges to improve speed-up methods and apply ESM to high performance computing. Further the presentation introduces the project BEAM-ME, a three year research project funded by the German Federal Ministry for Economic Affairs and Energy. The research project aims at overcoming current constraints and at improving computational performance of energy system models.



***Frieder Borggrefe*** works since February 2014 as a researcher in the department of systems analysis and technology assessment in the institute of engineering thermodynamics at the German Aerospace Center (DLR) in Stuttgart/Germany with focus on energy systems analysis.

Frieder studied business and engineering at the Karlsruhe Institute of Technology (KIT), Germany, and received a master in industrial engineering and operation research at the University of Massachusetts, Amherst, USA. Between 2005 and end of 2010 he was a research associate at the Institute of Energy Economics (EWI) at the University of Cologne, Germany, with research focus: energy system modelling and application to long-term projections for the energy industry and politics. From 2008 until 2009 he became a visiting researcher at the Energy Policy Research Group (EPRG) and faculty of Economics in Cambridge, UK. In 2011 Frieder Borggrefe worked as a lecturer for the Centre International de Formation Européenne (CIFE) in Berlin. From beginning of

2012 until end of 2013 he worked as a consultant for grid operators with focus on asset management, business simulation and business optimization in Munich/Germany.

***DLR*** (Deutsches Zentrum für Luft- und Raumfahrt – German Aerospace Centre) is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. The Institute of Engineering Thermodynamics (**DLR-TT**) in Stuttgart, does research in the field of efficient energy storage systems that conserve natural resources, and next generation energy conversion technologies. Within the institute the department for Systems Analysis and Technology Assessment (**DLR-TT STB**) provides methods and tools which support problem solving in the field of energy related systems analysis and technology assessment. The systems analysis work of the department combines top-down analysis of the overall energy supply system at regional, national and European level with technology oriented bottom-up studies.

## 2. Multi-model Methodologies for Integrating Energy Systems Modelling with Macroeconomic Modelling and Power Systems Modelling

**Prof. Brian Ó Gallachóir, University College Cork and Chair IEA ETSAP, Ireland**

**Abstract:** Integrated energy systems models are very effective in exploring the future evolution of energy systems to meet our energy needs at least cost while also meeting policy goals (e.g. maximum levels of CO2 emissions, renewable energy targets, etc.). The insights gained from scenario analysis using these models are being used in national and international deliberations on appropriate medium and long term mitigation goals. Further questions also arise however, including those relating to the economic impacts and to power system operation. The impacts of the low carbon energy transition on the economy are multi-faceted, with increased energy costs on the one hand and economic opportunities on the other. Combining energy systems models with macro-economic models using a soft-link or hard-link approach can shed light on these interacting aspects. Separately, the impacts of increased renewable electricity generation on the operation of power systems represents a further modelling challenge as it requires techniques for incorporating short term operational issues into long term energy systems planning models. Again recent development in multi-modelling approaches are enabling this analysis to be improved. This presentation will use outline some research in a national, an EU and global context to illustrate some of these modelling techniques and to share the results.

***Brian Ó Gallachóir*** is Professor of Energy Policy and Modelling in University College Cork's Environmental Research Institute. He is also Chair of the Executive Committee for IEA's Energy Technology Systems Analysis Programme (IEA-ETSAP). Brian's research focus is on building and using integrated energy systems models to inform energy and climate change mitigation policy. He has published extensively with a h-index of 24 and an i10-index of 54. Brian is also a Co-Principal Investigator in the MaREI Centre for Marine and Renewable Energy, one of twelve national Science Foundation Ireland (SFI) centres in Ireland. He is also a member of Ireland's Gas Innovation Group and is Vice-Chair of Energy Cork, an industry-driven cluster pursuing coordinated actions to strengthen enterprise and employment within the energy sector in the Cork region.

The Energy Policy and Modelling Group in UCC (www.ucc.ie/energypolicy) has been engaged in energy policy and energy modelling research for over 17 years. The results of this research have been published in journal papers, conference proceedings and reports and have directly informed the development of national energy and climate mitigation policy. The research focus is on i) integrated energy systems modelling, ii) low carbon opportunities and iii) energy policy. The Group forms part of the MaREI Centre for Marine and Renewable Energy (www.marei.ie), which is headquartered in UCC's Environmental Research Institute (ERI) and includes 5 other Universities and Third Level Institutes, over 45 industrial partners and has research funding of approximately

€35M. An independent assessment of research quality at UCC in 2015 stated about research related activity at the ERI that 'of particular note is the level of societal impact that is evident, and thus justifies a classification of 'excellent'.

The IEA Energy Technology Systems Analysis Programme (www.iea-etsap.org) is one of the IEA's 39 Technology Collaboration Programmes. IEA ETSAP was initiated in 1976 with the aim of carrying out a joint program of energy technology systems analysis. IEA ETSAP evolved from the analysis of existing tools to evaluate R&D strategies in its first year of operation to the combination of the energy flow optimization approach with macroeconomic top-down modelling, technology learning, and stochastic modelling. Today, IEA ETSAP is a unique network of energy modelling teams from approximately 70 countries involving 177 institutions over the world, well beyond the number of its contracting parties, which are the governments of 18 countries and the European Commission.

## II. Improving Energy System Models:

### 3. The Open-Source Electricity System Model DIETER - Scope, Applications, and Computational Issues

**Dr. Alexander Zerrahn, German Institute for Economic Research (DIW Berlin), Berlin, Germany**

**Abstract:** The talk will introduce DIETER, The Dispatch and Investment Evaluation Tool with Endogenous Renewables, developed at DIW Berlin. DIETER is a lean and tractable yet reasonably comprehensive numerical optimization model for the electricity sector. Applications so far analyzed the role of different storage technologies as well as other flexibility options for the integration of variable renewables on a large-scale. DIETER is an open-source model and steadily being expanded toward new sectors and features. Specifically, its focus is on the long-term, thus demanding extensive sensitivity and scenario calculations. To this end, fast and convenient computations are essential.

**Alexander Zerrahn** is research associate at the German Institute for Economic Research (DIW Berlin) within the Department of Energy, Transportation, Environment. He studied economics in Tübingen and Copenhagen, and received his PhD from Technical University Berlin. His research focuses on analysis of the large-scale integration of renewable energy, and issues of coordination in markets, with both statistical and numerical methods. Specifically, Alexander is currently concerned with expanding and applying (one of) DIW's open-source electricity system model(s) DIETER.

## 4. Methods to Improve Computing Times in Linear Optimization Models

**Karl-Kiên Cao, Felix Cebulla, German Aerospace Agency (DLR), Stuttgart, Germany**

**Abstract:** Due to the high number of decentralized components, as well as the increasing importance of storage, grid and demand side management, energy systems based on renewable energy sources feature a very high complexity. This complexity is reflected in state-of-the-art energy system models, which typically combine a comprehensive representation of energy sectors and technologies with a high spatial and temporal resolution. The continuous increase in level of detail, however, goes hand in hand with rising model solution times. Consequently, measures to reduce model solution times are urgently needed, as well as guidelines how to find a reasonable balance between degree of detail and solution time.

The BEAM-ME project addresses the need for improved computing power and efficiency in energy systems modelling. With the DLR – German Aerospace Center being the principal investigator on the modelling side, the project gathers various partners with complementary expertise in the fields of algorithms, computing and application development. JSC and HLRS in Stuttgart engage in the task of enabling simulations to run on high performance computing infrastructures, the Zuse-Institut in Berlin (ZIB) takes on the task of developing taylor-made parallel algorithms suited for state-of-the-art many-core systems and the GAMS Software GmbH contributes with application level research and development. This talk provides an overview and evaluation of the conceptual and technical strategies identified so far to reduce the model solution time of the REMix energy system model. Furthermore, it provides insight in the implementation and assessment of selected speed-up strategies applied to the energy system model REMix so far. Finally, conclusions from the first project results are drawn, and an outlook on the subsequent works is given.

***Hans-Christian Gils*** studied physics at the Universities of Konstanz, Padua and Hamburg. He joined the Systems Analysis and Technology Assessment department of the German Aerospace Center (DLR) in 2010. In 2015, he received his PhD from the University of Stuttgart for a thesis on “Balancing of intermittent renewable power generation by demand response and thermal energy storage”. His main fields of scientific interest are the modelling of energy systems and the development of future energy supply systems. Specific research focuses are demand side management and the linkage of energy demand sectors.

***Karl-Kiên Cao*****,** graduated as Bachelor in Electrical Power Engineering at the Baden-Wuerttemberg Cooperative State University Mannheim in 2010. He received his M.Sc. in Electrical Engineering and Information Technologies at Karlsruhe Institute of Technology. Since 2013, he has worked as a PhD-student at the German Aerospace Center, Institute of Engineering Thermodynamics in Stuttgart. His research fields include the analysis of the German and European transmission system considering the power flow balance in energy systems.

# III. Decomposition, Uncertainty and Parallel Computing:

## 5. Benefits of Decomposition Methods to Speed-up Energy System Modelling and Application to Stochastic Optimization

**Manuel Wetzel, Frieder Borggrefe, DLR – German Aerospace Center, Stuttgart, Germany**

***Abstract:*** The transition of the energy system towards a sustainable supply with low carbon emissions requires the long term planning of power generation capacity expansion. Energy scenarios can give insight into the development of complex electricity systems in the coming decades. Each scenario includes a large number of external factors which influence the pathway of energy system development. However, due to the long term nature of the energy transition, these external parameters (e.g. fuel prices, technology development, weather influences etc.) contain large uncertainties. To a certain degree, cross-impact-balance analysis can evaluate the consistency and improve the holistic image of future energy scenarios, but a large degree of uncertainty remains. So far, this problem was usually tackled by deterministic optimization with subsequent sensitivity analysis.

Recent development towards parallel computing allow for stochastic optimization over a large set of scenarios. When considering flexibility options like electrical energy storage, demand side management and electric mobility, high temporal resolutions of the modelled energy system are required. Consequently, the implementation of stochastic optimization into high resolution optimizing energy system models will lead to an increased complexity, due to the additional scenario dimension. This problem can be tackled using decomposition approaches like enhanced Benders decomposition in order to guarantee achieving the global optimum while taking computational restrictions into account. Challenges arise especially regarding CPU load balancing for the aspired migration to high performance computing.

The presentation will discuss preliminary results from an extension of the energy system model REMix, developed at the German Aerospace Center (8760 h per year, developed in GAMS and solved as a LP or MIP using CPLEX). By implementing different decomposition techniques and improving convergence, computational constraints can be overcome and the number of evaluated scenarios can be increased. Aim of this analysis is to increase the complexity of the stochastic models and improve the quality and robustness of the modelling results.

***M.Sc. Manuel Wetzel:*** received a Bachelor degree in Renewable Energies and his Master in Sustainable Energy Supply from the University of Stuttgart, focusing on energy economics and energy system modeling. Since 2016 he is working as a research associate at DLR in the research group for System Analysis and Technology Assessment. His main research interests include material balances for electricity generation technologies as well as stochastic optimization and decomposition techniques for energy system models.

## 6. Zero-price Energy Offering by (Multiband) Robust Optimization

**Fabio D'Andreagiovanni, Department of Mathematical Optimization, Zuse Institute Berlin (ZIB), Germany**

***Abstract:*** We consider the problem of a price-taker generating company that wants to select energy offering strategies for its generation units, to maximize the profit while considering the uncertainty of market price. First, we review central references available in literature about the use of Robust Optimization (RO) for price-uncertain energy offering, pointing out how they can expose to the risk of suboptimal and even infeasible offering. We then propose a new RO-based offering method, which is characterized by making offers at zero price and overcomes all the limits of the benchmark methods. We show the effectiveness of the new method on realistic instances provided by our industrial partners, getting very high increases in profit. Our method is based on Multiband Robustness (MR - Büsing, D'Andreagiovanni, 2012), an RO model that refines the classical Bertsimas-Sim model, while maintaining its computational tractability and accessibility. MR is essentially based on the use of histogram-like uncertainty sets, which result particularly suitable to represent empirical distributions commonly available in uncertain real-world optimization problems.

**Fabio D'Andreagiovanni** is Head of Research Group at Zuse Institute Berlin and Lecturer at Freie Universität Berlin and Technische Universität Berlin. He received his M.Sc. in Industrial Engineering (2006) and Ph.D. in Operations Research (2010) from Sapienza Università di Roma. In 2016, he was appointed First Class Researcher at the French National Center for Scientific Research (CNRS), where he will join Sorbonne University - UTC.

His research has been focused on theory and applications of Robust Optimization and Mixed Integer Programming and has received several awards, such as the Accenture M.Sc. Prize 2006, the INFORMS Telecom Doctoral Dissertation Award 2010 and the INFORMS Telecom Best Paper Award 2014. He has worked as consultant for several major European telecommunications and electric utility companies.

## 7. On a Strategic Multistage with Tactical Multi-period Scenario Tree Framework for Energy Network Capacity Expansion Planning and Decomposition Algorithms for Problem Solving

**L.F. Escudero, A. Alonso-Ayuso and F. Javier Martin-Campo, Universidad Rey Juan Carlos and Universidad Complutense de Madrid, Spain**

***Abstract:*** One of the great and difficult problems in the energy area that European Union (EU) is facing today consists of the estimation of the timing for clean power generation technologies and electricity free transmission expansion network at a Pan-European level in a long term (e.g., 30-year time horizon). EU has established aggressive pollutant emission reduction targets for the time being. So, vast amounts of new generation plants / farms are expected to be built in the medium term future. A substantial part of this new Renewable Energy Sources (RES) generation could probably must be decided in the near future. Mathematical models and algorithms for problem solving to address the environmental challenges under high uncertainty in the main parameters along a long time horizon are essential computerized tools for helping in the decision making on the following items: feasible type and mix of power generation sources, timing for power generation plant / farm site location and dimensions, and timing for location and capacity of new lines in the transmission network. So, the solution should satisfy the electricity demand from main focal points in the European region and optimizing different types of utility criteria at Pan-European level. That solution should quantify the benefits of using cleaner, safer and efficient (cheaper) energy, accessible to all the consumption nodes from perhaps far away power generation sites in the network.

In an open energy market, the electricity generation companies (gencos) have a high freedom for organizing and timing the required energy mix to satisfy the EC and National environmental directives while pursuing their own agendas. So, the Pan-European Transmission System Operators have no choice but being pro-active and, so, anticipating the transmission network infrastructure strategic decisions on location, quality and timing of the new transmission lines, and expecting that the gencos will follow. That anticipation should also consider given gencos' potential strategic decisions on the energy mix and timing. On that way, the model may help to plan the new energy transmission network in a min cost energy production environment to satisfy the energy demand and strongly penalizing high VOLL -Volume lost load-.

In order to make manageable the gigantic stochastic multi-period multi-objective, mixed integer optimization model for risk management that results for achieving the above goals, an essential feature of the tool is the scheme for handling the information related to the main parameters of the problem. Those parameters are electricity demand at focal nodes in the energy network; operating hours per period of power generation technologies; CO2 emission and Green Certificates allowed bounds; power generation costs of different technologies; electricity loss of current and candidate power generation plants / farms; availability (and cost in case) of raw material for power generation technologies in classical sources (gas, fuel, water, etc.) as well as intermittent technologies (wind, solar, etc.); transmission lines disruptions; technical characteristics (as maximum energy flow, reactance and flow loss, among others) of cable types on new energy transmission lines; etc. That information (i.e., the

realization of the uncertain parameters) is usually structured in a finite set of scenarios along the periods (in our case, grouped in stages of different length) in the time horizon.

The accessibility of the uncertain data and the characteristics of the problem affect to the way on which the scenario tree is represented. On the other hand, its representation affects to the type of decision variables to consider as well as the related optimization model and decomposition algorithm to develop. So, the quality of the solution to offer to the decision making process is also affected by the scenario tree to generated. Undoubtedly, there are two types of data, two types of uncertainties and two types of variables, all of them are so-named strategic (i.e., related to the energy mix and timing decisions) and tactical ones (related to operation planning) of the electricity transmission system as well as its production one. So, we have the strategic type of model and the tactical one, very different and very much related.

The aim of this work is twofold. First, we present a framework for representing a multistage non-symmetric tree with strategic nodes in the stages (being related to their first periods), and tactical two-stage scenario multi-horizon subtrees along the periods (semesters, years, bi-years, ...) in the stages as rooted with the strategic nodes. The nodes in the tactical scenario trees are so-named tactical ones. So, the investment in transmission and generation is assumed to be made at the strategic nodes and the running of the joint electricity transmission + production system for each type of hour in the related period is made at the tactical nodes. The goal consists of minimizing the NPV of the expected investment (transmission + generation) costs plus operation costs (transmission + production) plus demand shortage penalization in the global model, where the strategic and tactical submodels are run interconnected by the so-named linking variables. The second aim of this work is to present a typology of decomposition algorithms for problem solving that is very amenable for dealing with the special structure of the scenario tree and problem presented above.

***Laureano F. Escudero*** received his PhD Degree in Economic Sciences from Universidad de Deusto, Bilbao, Spain, 1974, and a Ms degree in Computer Sciences from Universidad Politecnica de Madrid, Spain, 1972. He taught Mathematical Optimization courses at the Mathematical Sciences School, Universidad Complutense de Madrid, 1992-2000. He has been full professor of Operations Research at the Universidad Miguel Hernandez de Elche (Alicante), Spain, 2000-2007 and Universidad Rey Juan Carlos, Mostoles (Madrid), Spain, 2007-2013, where currently he holds an honorary position. He has supervised 12 PhD theses. In the period 2003-04 he was the President of EURO (Association of European Operational Research Societies). He has worked at IBM Research, Scientific and Development Canters in Madrid (Spain), Palo Alto (California), Sindelfingen (Germany) and Yorktown Heights (NY), 1972-1991. He has held different positions at the IBERDROLA group (the biggest electric power generation and distribution company in Spain), being in period 1997-1999 the Manager of the Dept. of Decision Support Systems Engineering at its Engineering company. He has been very active on international projects, with a contribution in 8 EC co-funded projects, being

the principal coordinator of 5 of them. He is the author of 5 books, co-author of another on. He has published 140 +scientific papers in leading journals, such as Mathematical Programming, European Journal of Operational Research, Computers and Operations Research, SIAM Journal on Optimization, Operations Research Letters, Advanced Software Engineering, Pattern Recognition, TOP, Statistics and Operations Research Transactions, Transactions, etc. He is the author of 35+ chapters of edited books. He has been Co-Editor-In-Chief of TOP, a journal of SEIO, the Spanish Statistics and Operations Research Society, 1993-2000, and member of the Editorial Board of the European Journal of Operational Research, 1977-2006. He is currently serving in the Editorial Board of the following journals: Revista de Matematicas Complutense, TOP, SORT (Statistics and Operations Research Transactions), RAIRO-Operations Research, and Computational Management Science. He has worked on different mathematical optimization fields (linear and nonlinear mixed integer optimization, and decomposition algorithms for large-scale two-stage, and multistage stochastic mixed integer optimization with risk reduction measures. His main applications fields are energy, supply chain management, production planning, revenue management, air traffic planning and conflict resolution, and energy, among other sectors.

**Universidad Rey Juan Carlos:** It started its activities in 1996 and focusing its teaching and interdisciplinary research to find solutions to current problems, and ranks among the best universities in Madrid for excellence academic programs and international scientific quality. Located in Madrid, the facilities and infrastructure of the campuses of Aranjuez, Alcorcon, Fuenlabrada, Madrid and Mostoles, Spain, encourage university life and an academic environment-oriented to research, innovation and learning. The Faculties and Schools are as follows: Faculty of Information Sciences, Faculty of Law and Social Sciences, Faculty of Health Sciences, School of Experimental Sciences and Technology, and School of Computer Sciences.

# IV. Mathematical Optimization and High Performance Computing

## 8. Structure Exploitation in Optimal Power Flow

**Andreas Grothey, University of Edinburgh, Scotland**

***Abstract:*** Security Constrained Optimal Power Flow is an increasingly important problem for power systems operation both in its own right and as a subproblem for more complex problems such as transmission switching or unit commitment.

The structure of the problem resembles stochastic programming problems in that one aims to find a cost optimal operation schedule that is feasible for all possible equipment outage scenarios (contingencies). Due to the presence of power flow constraints (in their "DC" or "AC" version), the resulting problem is a large scale linear or nonlinear programming problem. This talk reviews how the special structure of the problem can be exploited in solution algorithm with particular emphasis on interior point methods.

***Andreas Grothey:*** is a senior lecturer at the University of Edinburgh. Andreas received his MSc at the University of Dundee in Numerical Analysis in 1995. He completed his PhD at the University of Edinburgh in 2001 (supervisor Ken McKinnon) and worked in Edinburgh since. His research interests are: Large Scale Optimization, Stochastic Optimization, Interior Point methods, Applications in particular Power Systems and Telecommunications, High Performance Computing.

## 9. Massively Parallel Solution of Mixed-Integer Energy System Models by Distributed Branch-and-Bound

**Daniel Rehfeldt (Speaker), Ambros Gleixner, Yuji Shinano, Department of Mathematical Optimization, Zuse Institute Berlin (ZIB), Germany**

***Abstract:*** Mixed-integer programming has frequently proved to be a powerful tool for optimizing energy systems. Since the complexity of these problems often renders sequential solving prohibitive for realistically-sized scenarios, one natural approach is to employ parallel solution algorithms.
To this end, we performed computational experiments with the UG framework, a generic tool developed at Zuse Institute Berlin that can parallelize branch-and-bound based solvers. As the underlying solvers we used the commercial Xpress and the academic SCIP/SoPlex.
We will present preliminary results and point to possible problem-specific enhancements that could be implemented in the future.

***Daniel Rehfeldt*** is a research assistant and Ph.D. student at the Technical University of Berlin. He has been the main developer of the Steiner tree problem solver SCIP-Jack and is part of the SCIP developers team at the Zuse Institute Berlin. His main project is the development and implementation of methods to solve the large-scale (LP and MIP) optimization problems arising from the energy models of the BEAM-ME project.
The Zuse Institute Berlin (ZIB) is an interdisciplinary research institute for applied mathematics and data-intensive high-performance computing. Its research focuses on modeling, simulation and optimization with scientific cooperation partners from academia and industry.

# CONCERT OF SINGERS

## Program:

| | |
|---|---|
| **Giusseppe VERDI** | **La forza del destino – aria of Preziosilly** |
| **Gustav MAHLER** | **Songs on the Death of Children** |
| **Modest Petrovič MUSORGSKIJ** | **Songs and dances of death** |
| **Antonín DVOŘÁK** | **Stabat Mater – Inflamatus, Fac, ut ardeat cor meum, O sanctissima** |

## Performing:

**Petra Vondrová (mezzo-soprano)**
**Jan Janda (basbaryton)**
**Jaroslav Šaroun (grand piano)**
**Music Faculty of Academy of Performing Arts in Prague**

## Place

**Refectory of the House for Professed, Charles University, Faculty of Mathematics and Physics, Malostranské nám. 2/25, Prague 1 (same place where our workshop takes place on Thursday)**

# SOME NOTES ON THE HOUSE FOR PROFESSED

**Jitka Zichová, Faculty of Mathematics and Physics, Charles University Prague**

The building is situated in the center of Lesser Town, a historic quarter under the Prague Castle, the seat of the sovereigns of the Czech State for one thousand years. In 1556, the Society of Jesus came to Prague. Their college Klementinum was included in the University existing since 1348. The Jesuits built in the 17th century in the main square of Lesser Town so called House for Professed, the seat of the most important representatives of the Order. The plans of the building elaborated by Italian architects are now preserved in the National Library in Paris.

A gem of Prague baroque, St Nicholas Church, was adjoined to the House for Professed in the 18th century by father and son Dienzenhofer, the leading personalities of Czech baroque architecture. After the death of W. A. Mozart, a Requiem was performed there. Thousands of people came to say the last goodbye to the composer who felt deep love to Prague and met with understanding here. The music has always been present in the church, recently in various concerts.

Mathematics returned to Lesser Town square several times in the past. Jan Šindel, a mathematician and astronomer, who had taught at a school in this place in the 15th century, became later rector of the University of Prague. He is known as the constructor of the famous astronomical clock on the façade of the Old Town Hall, which is one of the most attractive sights of the city.

In the 18th century, a large library with thousands of books including a lot of mathematical ones created an important part of the House for Professed. Some Fathers Jesuits were professors of this branch at the University. They founded a mathematical museum in the Klementinum college, the first museum open to the public in the Czech Lands. We can say that the Jesuits were the only scientists interested in mathematics at that time.

After the suppression of the Jesuite Order in 1773, the House for Professed had become property of the Habsburg Monarchy, which located the Provincial Court there. After establishing the Czechoslovak Republic in 1918, the basement of the building was housing the golden treasure of the new state. In the years of the 2nd world war, the house was used by German army. Later on, its rooms passed on the University. The section Informatics of the Faculty of Mathematics and Physics resides here now.

After the year 2000, the building underwent a costly renovation. The Conference and Social Centre „House for Professed“ including a charming restaurant in the basement of the building was opened in 2006. The following inauguration of the reconstructed refectory adorned with splendid ceiling paintings and adapted for concerts, conferences and graduation ceremonies can be considered as the accomplishment of this restoration process which renewed the original beauty of the building.