WILHELM UND ELSE HERAEUS-STIFTUNG

661. WE-Heraeus-Seminar

Nonlinear Dynamics, Optimization and Control of Distributed Energy Systems

January 28 – 31, 2018
Physikzentrum Bad Honnef (Germany)

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation which supports research and education in science, especially in physics. A major activity is the organization of seminars. To German physicists the foundation is recognized as the most important private funding institution in their field. Some activities of the foundation are carried out in cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft).

Aims and Scope of the 661. WE-Heraeus Seminar:

The modelling and analysis of dynamics of complex networks, such as the energy system and its future multi-modal extension, is at its core a question of Physics. Many urgent questions arising in the context of the energy transition directly relate to fundamental problems in statistical physics and nonlinear dynamics of networks. In this context, a cooperation beyond the borders of traditional scientific disciplines is inevitable to meet the challenges of the energy transition. Physicists, applied mathematicians and systems engineers must work closely together, develop a common scientific language and share methods, tools and data.

The scientific scope of the proposed 661. WE-Heraeus-Seminar is located precisely at the interface between these key enabling disciplines of the energy transition. The seminar brings together PhD students, young postdocs from all over Europe with international experts from academia and industry. Thereby creating a platform for fruitful scientific discussions and seeding future inter-academia and industry-academia collaborations. Overall ten renown scientists in the field, including four experts from industry, will give key note talks. Moreover, ten early stage researchers will present their research results.
In this way, the seminar will provide a platform to discuss and investigate important trends in nonlinear dynamics, stability theory, optimization and control of such distributed energy systems.
In order to narrow down the above mentioned challenges, the seminar focuses on two closely related core topics, which are of major interest in the energy transition:

- Topic 1 - Modelling and analysis of complex energy network dynamics
- Topic 2 - Challenges in the design and operation of future energy grids

Topic 1 will focus on the aspects of simulation, analysis and understanding the dynamics of large-scale multi-modal energy systems.
Topic 2 extends the scope from analysis and understanding of existing energy grids towards the design and operation principles of future cross-coupled networks.

Scientific Organization:

Prof. h.c. Dr.-Ing. Joachim U. Knebel	Karlsruher Institut für Technologie DE-76131 Karlsruhe, Germany e-mail: joachim.knebel@kit.edu
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Program

Program

Sunday, January 28, 2018

17:00 – 21:00	Registration
From 18:30	*BUFFET SUPPER / Informal get together*

Monday, January 29, 2018

07:30	BREAKFAST

Nonlinear Dynamics and Simulation of Large-Scale Energy Systems

08:30 – 08:40	Joachim Knebel	**Welcome and opening**
08:40 – 09:40	Albert Moser	**Power System Voltage Stability**
09:40 – 10:40	Martin Schmidt	**Mixed-Integer Formulations for Energy Systems**
10:40 – 11:10	*COFFEE BREAK*	

Program

Monday, January 29, 2018

11:10 – 12:40	**Young Scientists Presentations I (12+6)**	
	Philipp Hauser	**Modelling the German Natural Gas System – A highly temporal and spatial resolved model approach**
	Lara Welder	**Investigating Methodological Approaches to Renewable Energy Modelling in Multi-Modal Energy System Optimization**
	Thomas Schütz	**Optimal design of decentralized energy conversion systems for smart electricity grids using decomposition methods**
	Susanne Scholl	**Dynamic reformulations for the efficient optimization of hybrid energy systems**
	Benjamin Schäfer	**Non-Gaussian Power Grid Frequency Fluctuations Characterized by Lévy-stable Laws and Superstatistics**
12:40 – 14:00	*LUNCH*	

Program

Monday, January 29, 2018

14:00 – 15:30	**Young Scientists**	**Poster Session I + Boost Presentations**

Modelling and System Design

Tommaso Coletta
Ovanes Petrosian
Kristoffer Schnieders
So Kumneth Sim
Shahab Karrari
Nils Baumgärtner
Fabian Hofmann
Kai Mainzer
Alexander Kies
Michael Kyesswa
Jann Launer
Anna Golovkina
Hauke Huisinga
Lars Nolting

15:30 – 16:00	*COFFEE BREAK*	
16:00 – 17:00	Tanja Clees	**Modelling, Simulation, and Optimization of the European Gas Grid**
17:00 – 18:00	Kathrin Goldammer	**Dispatch Optimization from Electric Vehicles to Power Plants**
19:00	*HERAEUS DINNER* *(cold & warm buffet with complimentary drinks)*	

Program

Tuesday, January 30, 2018

07:30	*BREAKFAST*	

System Design, Optimization, and Control of Multi-Modal Energy Systems

08:30 – 09:30	Tobias Weissbach	**Interconnecting Regions – A TSO's Perspective on Distributed Energy Systems**
09:30 – 10:30	Sheila Samsatli	**Value Web Model: a powerful optimisation-based framework for integrated spatio-temporal multi-vector energy networks and value chains**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 12:30	**Young Scientists Presentations II (12+6)**	
	Rafael Finck	**Impacts of the uncoordinated introduction of capacity mechanisms on European power flows**
	Hauke Haehne	**Impact of Intermittent Wind Power Generation on Power Grid Frequency Measurements**
	Dominic Groß	**Global synchronization of grid-forming power converters**
	Johannes Schiffer	**Cyber-Physical Aspects of Distributed Averaging Control in Power Systems: Time Delays and Dynamic Communication Topology**
	Riccardo Appino	**Considering Forecasting Uncertainties in Scheduling of Energy Systems**
12:30 – 14:00	*LUNCH BREAK*	

Program

Tuesday, January 30, 2018

14:00 – 15:30	**Young Scientists**	**Poster Session II + Boost Presentations**
	Control and Stability Analysis	
	Alexander Murray Patrick Sauter Nico Meyer-Hübner Alexander Engelmann Martin Zimmerlin Katrin Schmietendorf Sirkka Porada Robert Scholz Uwe Bau Leonardo Rydin	
15:30 – 16:00	*COFFEE BREAK*	
16:00 – 17:00	Mathias Duckheim	**Strategies for the operation and flexibility allocation of power grids with a large share of distributed energy resources**
17:00 – 18:00	Iiro Harjunkoski	**Demand Side Management and its Applications in the Industry**
18:00 – 19:30	*DINNER*	

Program

Tuesday, January 30, 2018

20:00 – 21:30 **Young Scientists** **Poster Session III + Boost Presentations**

Scheduling and Optimization

Tillmann Mühlpfordt

Leander Kotzur

Christian Hans

Konstantin Sharafutdinov

Matthias Wolff

Jorge Velásquez

Robin Delabays

Melvyn Tyloo

Lennart Merkert

Anton Plietzsch

Max Lutz

Timo Nowak

Fritz Röben

Program

Wednesday, January 31, 2018

07:30	*BREAKFAST*	

System Design, Optimization, and Control of Multi-Modal Energy Systems *(continued)*

08:45 – 09:45	Marc Timme	**From Collective Network Dynamics to Systemtemic Risk in Power Grids**
09:45 – 10:45	Stefan Nykamp	**Challenges for DSOs in energy transitions - physics, economics, laws (and examples from the real-world)**
10:45 – 11:15	*COFFEE BREAK*	
11:15 – 12:00	Dirk Witthaut Martin Robinius Timm Faulwasser	**Best Poster Award Ceremony,** **Wrap Up** **and Feedback of Participants**
12:00	*LUNCH*	

End of the seminar *and FAREWELL COFFEE* ***/ Departure***

Please note that there will be ***no*** *dinner at the Physikzentrum on Wednesday evening for participants leaving the next morning.*

Posters

Posters

P01	Uwe Bau	**Nonlinear model-predictive-control of adsorption chillers: first implementation and experimental evaluation**
P02	Nils Julius Baumgärtner	**Relax-and-Aggregate – The RelAgg-Method for the rigorous synthesis of energy systems depending on large-scale time series**
P03	Tommaso Coletta	**Performance Measures in Electric Power Networks under Line Contingencies**
P04	Robin Delabays	**The Size of the Sync Basin Revisited**
P05	Alexander Engelmann	**Distributed Non-Convex Optimization in Power Systems**
P06	Anna Golovkina	**Optimization models for application to radioactive waste transmutation and energy grids**
P07	Christian Hans	**Optimal Operation Control of Microgrids**
P08	Fabian Hofmann	**Principal Components of a highly-renewable European Power System**
P09	Hauke Huisinga	**Order Reduction in Electric Power Systems using the Singular Perturbation Method under Application of the Extended Nodal Approach**
P10	Shahab Karrari	**High-speed flywheel energy storage systems for voltage support in low voltage networks**
P11	Alexander Kies	**Non-linear effects in the modelling of sector-coupled energy systems**

Posters

P12	Leander Kotzur	**Time series aggregation for renewable energy system design: How to link typical periods to integrate seasonal storage operation?**
P13	Michael Kyesswa	**An extendable and scalable simulation tool for the analysis of power system dynamics in large and complex networks**
P14	Jann Launer	**Energy system modeling - Challenges to linear representations and approaches to nonlinearities with the heat sector as an example**
P15	Max Lutz	**A PDE based model for improved voltage stability control in highly DG penetrated distribution grids**
P16	Kai Mainzer	**Analysis and optimization of urban energy systems**
P17	Lennart Merkert	**Integrated optimal control of heating and electric grids**
P18	Nico Meyer-Hübner	**N-1-Secure Generator Redispatch in Mixed AC/MTDC Networks with Distributed Energy Storage**
P19	Tillmann Mühlpfordt	**Stochastic Optimal Power Flow with non-Gaussian Uncertainties - Formulation and Solution**
P20	Alexander Murray	**Global solution to the Distributed Battery Scheduling problem**
P21	Lars Nolting	**Complexity Management in Energy System Models (ESMs)**

Posters

P22	Timo Nowak	**Optimization of a Decentralized State-Feedback Controller with Structural Constraints**
P23	Ovanes Petrosian	**Cooperative Non-Transferable Utility Game Model as an Approach for Automated Controlling Smart Grid Topology and Prices**
P24	Anton Plietzsch	**Asymptotic Dynamical States in Networks of Kuramoto Oscillators with Inertia**
P25	Sirkka Porada	**Impact of active distribution networks on the voltage stability of transmission systems**
P26	Fritz Röben	**Dynamic optimization of an energy-intensive industry processes to provide grid services**
P27	Leonardo Rydin	**Rigorous bounds for stability and instability in the third- and fourth-order model**
P28	Patrick Sauter	**Optimization Based Energy Management for Northern Communities' Microgrids with Electric Thermal Storage System**
P29	Katrin Schmietendorf	**On the impact of turbulent wind energy production on power grid stability and quality**
P30	Kristoffer Schnieders + So Kumneth Sim	**Modelling wind speed data from an offshore platform**
P31	Robert Scholz	**Model-based Optimal Feedback Control of Microgrids**
P32	Konstantin Sharafutdinov	**Rotor-angle versus voltage instability in the third-order model**
P33	Melvyn Tyloo	**Robustness of synchrony in electrical power grids and generalized Kirchhoff indices**

Posters

P34	Jorge Velásquez	**An approach for testing controller interaction for dynamic security assessment of distribution grids**
P35	Matthias Wolff	**The role of heterogeneities on the return time of power grids to stable operation**
P36	Martin Zimmerlin	**Sector Coupling: Optimized Scheduling of Electric Vehicle Charging and Heat Production in Home Energy Systems**

Contributed Talks

(in alphabetical order)

Contributed Talks

Riccardo Remo Appino	**Considering Forecasting Uncertainties in Scheduling of Energy Systems**
Rafael Finck	**Nonlinear model-predictive-control of adsorption chillers: first implementation and experimental evaluation**
Dominic Groß	**Relax-and-Aggregate – The RelAgg-Method for the rigorous synthesis of energy systems depending on large-scale time series**
Hauke Haehne	**Performance Measures in Electric Power Networks under Line Contingencies**
Philipp Hauser	**The Size of the Sync Basin Revisited**
Benjamin Schäfer	**Distributed Non-Convex Optimization in Power Systems**
Johannes Schiffer	**Optimization models for application to radioactive waste transmutation and energy grids**
Susanne Scholl	**Optimal Operation Control of Microgrids**
Thomas Schütz	**Principal Components of a highly-renewable European Power System**
Lara Welder	**Order Reduction in Electric Power Systems using the Singular Perturbation Method under Application of the Extended Nodal Approach**

Abstracts of Lectures

(in chronological order)

Power System Voltage Stability

Prof. Dr.-Ing. Albert Moser

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Stability issues in the power system can be classified according the system variable affected, the size of the disturbance causing instabilities and finally the time frame of the dynamics. Therefore, angle, voltage and frequency stability of power systems for small and large signal disturbances covering time frames of electromagnetic transients, electromechanical transients and network controls are typically considered. Usually, the models used for stability analysis are tailored for the respective stability issue. One stability issue often discussed in the context of the "Energiewende" is the long-term large-signal voltage stability. A lack of reactive power may cause declining voltages which will finally lead into a so called voltage collapse. There are several developments within the "Energiewende", which cause concerns about the future voltage stability of the German power system.

As a consequence of the "Energiewende", the transmission grid is heavily loaded caused by wheeling electricity from wind energy converters in northern Germany to the densely populated areas in western and southern Germany. The higher loading of the transmission grid requires more reactive power in order to keep the voltage of the transmission system on sufficiently high values. In addition, the reactive power needs of the transmission system will increase further, when AC cables will be used more in the future. On the other side, the phase-out of nuclear power plants as well as the closedown of natural gas fired power plants due to their economic inefficiencies will result in less reactive power providers for the German transmission grid. Capacitor banks are basically able to replace power plants as providers of reactive power, but they show a less favorable behavior in situations with declining voltages. Among others, one reason to choose HVDC lines for upgrading the transmission capacities within Germany is to support the reactive power balance and therefore the voltage stability in the German transmission grid.

Voltage stability is also determined by the behavior of the distribution system. The voltage dependency of loads in the distribution system is able to stabilize the system in critical situations of declining voltages. But with the integration of wind energy converters and PV plants in the distribution system, their voltage control can also influence the voltage stability of the power system. In situations of declining voltages, the voltage control of decentral generation plants let the central generation plants use more reactive power in order to keep the voltage level in the distribution system on predefined levels, thus destabilizing the system.

The presentation will focus on an overall model comprising transmission and distribution system in order to analyze the voltage stability in the future German power system. The results show, that there is a need keep an eye on this issue in the future.

Mixed-Integer Formulations for Energy Systems

JProf. Dr. Martin Schmidt

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How does the cost-minimal operation of a gas network look like? Which expansion lines should be build in order to maximize the increase of capacity of the German electricity network? What is the best market design for trading electricity or natural gas? These questions reveal that the consideration of energy systems very often leads to mathematical optimization problems.

In this talk we give examples of optimization tasks within the field of energy networks, discuss modeling techniques, classify the resulting optimization models, and discuss state-of-the-art solution methods for solving problems of real-world size.

The choice of the solution method strongly depends on the type of models that one has to deal with. When making decisions (building a certain new electricity transmission line or not; activating a power plant or not), the incorporation of discrete variables in the considered optimization models typically cannot be avoided.

Thus, we discuss the class of mixed-integer linear optimization problems (MIPs) and give an overview of modern solution methods. Moreover, meaningful models from physics, economy, or engineering often lead to nonlinearities. The resulting models thus are mixed-integer nonlinear problems (MINLPs) that are much harder to solve in general. While MIPs of reasonable size can be solved quite reliable and fast, MINLPs are extremely challenging and often render today's general-purpose software inappropriate. This leads to the need for problem-tailored solution approaches. In this talk, we study an exemplary problem from natural gas transport and from electricity market modeling and sketch powerful problem-tailored solution methods.

References

[1] S. Dempe, V. Kalashnikov, G. A. Pérez-Valdés, N. Kalashnykova: Bilevel Programming Problems. Theory, Algorithms and Applications to Energy Networks. Springer Berlin Heidelberg. 2015.

[2] P. Belotti, C. Kirches, S. Leyffer, J. Linderoth, J. Luedtke, A. Mahajan: Mixed-integer nonlinear optimization. Acta Numerica, 22, 2013.

[3] T. Koch, B. Hiller, M. E. Pfetsch, L. Schewe (Eds.). Evaluating gas network capacities. Society for Industrial and Applied Mathematics. 2015.

[4] B. Geißler, A. Morsi, L. Schewe, M. Schmidt: Solving Highly Detailed Gas Transport MINLPs: Block Separability and Penalty Alternating Direction Methods. INFORMS Journal on Computing. DOI: 10.1287/ijoc.2017.0780. 2017.

[5] V. Grimm, T. Kleinert, F. Liers, M. Schmidt, G. Zöttl: Optimal price zones of electricity markets: a mixed-integer multilevel model and global solution approaches. Optimization Methods and Software. DOI: 10.1080/10556788.2017.1401069. 2017.

Modelling the German Natural Gas System – A highly temporal and spatial resolved model approach

P. Hauser[1]

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In the ongoing discussion of coupling energy sectors, e.g. electricity and natural gas, the detailed modelling of the natural gas system is focused by researchers during the last years. While electricity models are well studied, the academic literature on techno-economic natural gas networks is limited. The reasons for a backwards development in national gas system models are diversely. (1) Since there is a slower process of liberalization in the natural gas market the transparency of infrastructure data is more limited than in electricity systems. (2) Due to technical characteristics of pipelines and storages the flexibility of gas systems to balance demand and supply is higher than in electricity systems. However, politics aim to reduce CO_2-emissions. This objective drives the question of the importance of gas in the future energy mix. A renewable based energy system may use “renewable gas”, produced by power-to-gas facilities and injected into the pipeline system. Additionally, natural gas could become more important to provide back-up capacities in gas power plants and balance fluctuating production of renewable energy sources. In order to analyze the resilience and robustness of the German natural gas system, a detailed model with high temporal and spatial resolved infrastructure elements is needed. This presentation propose a model that based on GIS-related infrastructure data. The data include the gas infrastructure of all German TSOs, the low and high caloric networks as well as storages and gas power plants. Additionally, data of indigenous gas production and biogas production is included as well as connecting pipelines to German neighboring countries. The gas demand is modelled, using a bottom-up approach on a spatial resolution. The temporal resolution bases on days. Furthermore, the demand is clustered in three components: electricity heat and industry based natural gas demand. First applications were done for the northeast German natural gas grid [1]. The deterministic model will be extended to cover stochastic methodologies.

References

Hauser, P.; Hobbie, H.; Möst, D.: Resilience in the German Natural Gas Network: Modelling Approach for a High-Resolution Natural Gas System, 14th International Conference on the European Energy Market – EEM2017, Lehrstuhl für Energiewirtschaft an der Technischen Universität Dresden,
Dresden, 6. - 9. Juni 2017

Investigating Methodological Approaches to Renewable Energy Modelling in Multi-Modal Energy System Optimization

L. Welder, S. D. Ryberg, J. Linßen, M. Robinius, D. Stolten

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A key element in greenhouse gas mitigation strategies is a strong increase of the share of renewable energies sources (RES) in the energy systems. However, the consideration of photovoltaics and on- and offshore wind power in national energy systems is a modelling challenge due to their intermittent nature and regional distribution. This applies particularly if storage options are additionally considered for shifting renewable surplus power to time periods with low renewable power production.

Since the consideration of each renewable power plant in the energy system would be computationally intractable, simplified approaches to model the RES are made in literature in order to reduce the complexity of the investigated energy system. To reduce the number of investigated components in the energy system, the generation profiles of the RES are cumulated into regional contribution potentials. The intermittent nature of the renewables is often captured by using hourly resolved time series data for one weather year, assuming repetitive yearly production and demand patterns. Rarely multiple weather years are considered. Further complexity reductions are considered in literature by considering larger time steps over several hours and applying clustering algorithms. The time series for the demand data in the energy system is modelled correspondingly.

In this study, the influence of these complexity reduction approaches on the optimal energy system design is analyzed. For the analysis, a scenario for Germany is established, in which the specified energy demands are exclusively supplied by RES, and an optimization formulation to determine the optimal design and operation of the energy system is stated. The assumption on the spatial and temporal scope and resolution in the formulation are then varied. The number of regions in the scenario is varied to demonstrate the influence of regional weather phenomena on the optimal system design. Temporal aspects are investigated by choosing different time step sizes and clustering algorithms for the selection of typical days in the optimization. Furthermore, the research question whether it is sufficient to model only one weather year is investigated.

Optimal design of decentralized energy conversion systems for smart electricity grids using decomposition methods

T. Schütz[1], X. Hu[1], M. Fuchs[1] and D. Müller[1]

[1]RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate, Aachen, Germany.
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The optimal design of decentralized energy conversion systems in smart residential electricity grids is a challenging optimization problem due to the variety of available generation and storage devices. Common measures to reduce the problem's size and complexity are to reduce modeling accuracy, aggregate multiple loads or change the temporal resolution. However, since these attempts alter the optimization problem and consequently lead to different solutions as intended, this presentation analyses a decomposition method for solving the original problem iteratively. The presented work has previously been published [1].
The decomposed method is validated by comparison with the original compact model formulation, proving that both models deviate by less than 1.8%. Both approaches furthermore lead to similar energy systems that are operated similarly, as well. The findings also show that the compact model formulation is only applicable to small- and medium-scale electricity grids due to current limitations of computing resources and optimization algorithms, whereas the distributed approach is suitable for even large-scale grids. We apply the decomposed method to a large-scale grid in order to evaluate economic and ecological benefits of interconnected buildings inside the grid. The results show that with local electricity exchange, costs can be reduced by 4.0% and emissions by even 23.7% for the investigated scenario.

References

[1] T. Schütz, X. Hu, M. Fuchs. D. Müller, *Optimal design of decentralized energy conversion systems for smart microgrids using decomposition methods.* 30th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems. July 2.-6. 2017, San Diego, California, USA.

Dynamic reformulations for the efficient optimization of hybrid energy systems

S. Scholl[1] and A. Mitsos[2,1,3]

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A major challenge of the energy transition from conventional to renewable energy resources is the adaptation of energy systems to the decentralization and volatility of energy supply. Hence, the design and operation of new and existing energy systems have to be (re-)optimized. This is a sophisticated and computationally costly task due to the high variety and number of components that can be used to fulfill different types of demands, like heating and electricity demand, and, thus, the large scale of the model.

Because of this, (quasi-)steady models are commonly used for design optimization and optimal control of energy systems [1,2] to keep the computational effort tractable in spite of the transient behavior of energy systems, particularly of its thermal components. However, the optimal operating points achieved with the help of (quasi-) steady models may differ significantly from the operating points possible in reality due to inertial effects. This can lead to suboptimality when realizing the calculated solutions.

With the aim of an efficient dynamic optimization of energy systems comparable to the (quasi-)steady approaches, we investigate dynamic reformulations that can keep the size of the component models small while still representing the transient behavior correctly. This concept is illustrated with the help of an example energy system comprising both thermal and electrical components.

References

[1] P. Voll, C. Klaffke, M. Hennen, A. Bardow, Energy **50,** 374-388 (2013).

[2] F. Verrilli, S. Srinivasan, G. Gambino, M. Canelli, M. Himanka, C. Del Vecchio, M. Sasso, L. Glielmo, IEEE Transactions on Automaton Science and Engineering **14**, 547-557 (2017)

Non-Gaussian Power Grid Frequency Fluctuations Characterized by Lévy-stable Laws and Superstatistics

B. Schäfer[1,2], C. Beck[3], K. Aihara[4], D. Witthaut[5,6], M. Timme[1,2]

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Multiple types of fluctuation impact the collective dynamics of power grids and thus challenge their robust operation. Fluctuations result from processes as different as dynamically changing demands, energy trading, and an increasing share of renewable power feed-in. Here we analyze principles underlying the dynamics and statistics of power grid frequency fluctuations. Considering frequency time series for a range of power grids, including grids in North America, Japan and Europe, we find a substantial deviation from Gaussianity.

We present a coarse framework to analytically characterize the impact of arbitrary noise distributions as well as a superstatistical approach. Both approaches systematically interpret heavy tails and skewed distributions and identify inertia and damping in the grid as essential when reducing fluctuation risks.

References

[1] B. Schäfer, et al Nature Energy, accepted (2017)

Modelling, Simulation, and Optimization of the European Gas Grid

T. Clees[1] and B. Klaaßen[1] and Igor Nikitin[1] and Lialia Nikitina[1]

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Natural gas pipeline systems are an essential part of our energy supply. Systems can have several thousands of kilometers of pipes and several thousands of network elements such as pipes, valves, regulators, compressors etc. For simulation, they can be modeled based on isothermal Euler equations. The isothermal Euler equations form a coupled system of PDEs consisting of mass and momentum balance laws together with a constitutive relation. De facto, nonlinear ODE or DAE systems are usually solved in practice. Our MYNTS software computes several fields in space (steady-state mode) or space-time (time-dependent mode), namely for pressure, mass flow (volume flow, power), temperature, and 21 main components of natural gas.

In this talk, we address several issues when solving practical applications, including modeling aspects and global convergence, graph analysis and hierarchical coarsening, acceleration by means of lookup tables, behavioural models and graphic cards, and robust optimization. We outline solution methods and present results for several novel methods.

In particular, we discuss two applications. The first considers global optimization of compressor stations in large long-distance networks with a focus on energy efficiency. The second broadens our view to cross-sectoral grids for several sectors, namely electrical power, gas, dictrict heating, cooling cycles, and mobility, and certain options for flexibilizing energy support by employing gas grids as backbones.

References

[1] T. Clees, I. Nikitin, and L. Nikitina. Making Network Solvers Globally Convergent. In: Obaidat M., Ören T., Merkuryev Y. (eds) Simulation and Modeling Methodologies, Technologies and Applications. SIMULTECH 2016. Advances in Intelligent Systems and Computing, vol 676. Springer, Cham. DOI: https://doi.org/10.1007/978-3-319-69832-8_9 (2018)

[2] T. Clees, I. Nikitin, L. Nikitina. Advanced modeling of gas compressors for globally convergent stationary network solvers. Procs. 7th Int. Conf. Advanced Communications and Computation (INFOCOMP 2017)

[3] T. Clees et al., MYNTS: Multi-phYsics NeTwork Simulator, In Proc. SIMULTECH 2016, pp. 179-186, SCITEPRESS (2016)

Dispatch Optimization from Electric Vehicles to Power Plants

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Energy system components such as power plants and flexible loads can be optimized in their daily operation. This so-called dispatch process makes use of technical parameters as well as external factors like energy prices, price forecasts, load, grid restrictions etc. This talk will give first-hand experience of real-life dispatching problems in the energy industry for components ranging from power plants to renewable energy technologies and electric vehicles.

Interconnecting Regions – A TSO's Perspective on Distributed Energy Systems

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The European Transmission Networks ensure a reliable electrical energy supply of households, businesses and industry and thus play a key role in a modern economy and society. As in other industry sectors, the advancing digitization is rapidly and fundamentally changing processes, roles, responsibilities and business models within the electrical energy system. At the same time, a large variety of new options and opportunities comes into existence. In other industry sectors, the so-called business-models 4.0 that are based on an increasing "internetting of things" have brought forth new substantial players virtually overnight: for example, Uber has grown to one of the biggest mobility service providers, and AirBnB has created one of the biggest platform for overnight stays, directly attacking the established hotel chains and accommodation service providers. Do "Distributed Energy Systems" represent a comparable "model 4.0" for the future electricity sector?

First, one can expect that the operation and marketing of so-called "Virtual Power Plants" based on business-to-business (B2B) and business-to-consumer (B2C) will further increase. Through interconnecting a large number of small plants – generators, storages, consumers – several VPPs have already reached and even outnumbered the installed power of large conventional power plants. Second, also consumer-to-consumer (C2C) networks have already left behind a pure experimental status with some front-runner implementations within local grid areas. However, the potential effects of these new business models on security and cost of the electricity supply still have to be assessed carefully with regard to overall welfare maximization and sustainability of European-wide markets within the European Interconnected network. From the point of view of Transmission System Operators (TSOs) the process of digitization is not only an option to further increase the efficiency and security of the system, but rather a must on the way to a fully realized "energy turnaround". This aspect forms another focus of the presentation: Starting from today's responsibility of a TSO and the legal framework, selected "smart" elements and tools are presented, which are already in use today or will become necessary within the coming years.

In conclusion, the assumed area of conflict between the interconnection of regions and the approach of distributed energy systems is addressed and solutions are proposed, where meaningful supported by practical examples.

Value Web Model: a powerful optimisation-based framework for integrated spatio-temporal multi-vector energy networks and value chains

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The Value Web Model (VWM) is a multi-objective spatio-temporal optimisation model, based on mixed integer linear programming, that can simultaneously determine the design and operation of any integrated multi-vector energy networks. It has been developed to answer variants of the following questions: "What is the most effective way, in terms of cost, value/profit and/or emissions, of designing and operating the integrated multi-vector energy networks that utilise a variety of primary energy sources to deliver different energy services, such as heat, electricity and mobility, given the availability of primary resources and the levels of demands and their distribution across space and time? When to invest in technologies, where to locate them; what resources should be used, where, when and how to convert them to the energy services required; how to transport the resources and manage storage inventory?"

The many different possible pathways from all possible primary energy sources to all energy services via any number of energy vectors form a complex web of interactions between all of the elements of the system, including circular pathways. As value is being added at each transformation from primary resource to energy service, the whole system can be viewed as a value web. The system needs to be robust with respect to uncertainties such as the availability of primary energy sources, levels and timings of demands, costs and prices, policy changes and other technological uncertainties (e.g. appearance of a disruptive technology). The VWM can be applied to a wide variety of systems such as integrated energy systems, water networks, chemicals and pharmaceutical supply chains. In this presentation I will focus on the application of VWM for strategic design and tactical operation of integrated energy value chains (or networks) with various energy carriers such as hydrogen, electricity, natural gas, syngas, methanol and so on.

References

[1] Samsatli, S. and Samsatli N.J., Applied Energy, 2017 (in press). DOI: 10.1016/j.apenergy.2017.09.055. Accepted version: http://opus.bath.ac.uk/57220/

[2] Prates Pereira, A. and Samsatli, S. Computer Aided Chemical Engineering, **40**, 2527–2532, 2017.

[3] Samsatli, S., Staffell, I. and Samsatli, N.J., Int. J. of Hydrogen Energy, **41**, 447–475, 2016.

[4] Samsatli, S., Samsatli, N.J. and Shah, N., Applied Energy, **147**, 131–160, 2015.

[5] Samsatli, S. and Samsatli N.J., Computers and Chemical Engineering, **80**, 155–176, 2015.

Impacts of the uncoordinated introduction of capacity mechanisms on European power flows

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The rising share of renewable energy sources and the decline of electricity wholesale market prices have led to concerns about mid-term security of supply in some European countries. To address this issue, several countries introduce capacity mechanisms or consider the implementation in the near future [1]. The national effects of such capacity mechanisms have been studied in the literature. Some works also consider the (macro-) economic impacts on neighbouring countries [2][3]. During the conception of these mechanisms, the focus is mainly on the solution of national concerns and cross-border effects are often considered only insufficiently [4]. Furthermore, the positive impact of cross-border electricity delivery is only taken into account in a generalized, simplified way in many cases [1][2][3]. The impact on an interconnected European electricity market and especially on the physical flows in the interconnected power grid are not sufficiently explored. Further research is needed.

This work presents a model to investigate the impact of the (uncoordinated) implementation of capacity mechanisms in several European countries under transmission grid constraints and flow-based market coupling to account for cross-border power flows. First results are shown for the modelling of different capacity regimes for a group of neighbouring countries to investigate the impacts on cross-border flows and power plant utilization.

References

[1] ACER, Annual report on the results of monitoring the internal electricity markets in 2016, Electricity Wholesale Markets Volume. Available: www. www.acer.europa.eu.

[2] R. Meyer & O. Gore, Energy Economics Vol. 51, pages 9-20 (2015)

[3] P. Bhagwat et al., Utilities Policy Vol. 46, pages 33-47 (2017)

[4] D. Newbery, Energy Policy Vol. 94, pages 401-410 (2016)

Impact of Intermittent Wind Power Generation on Power Grid Frequency Measurements

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Future power grids will be fed by a high share of renewable generation among which wind energy plays a key role. Short-term fluctuations of wind power generation show strongly heavy-tailed increment statistics that stem from the intermittency of atmospheric turbulence. This implies that large fluctuations on short time scales are much more likely than expected from a normal distribution. Intermittent feed-in poses new challenges for resilient grid operation as well as for power quality. From a physical perspective, the uncontrolled, self-organized response of a power grid under intermittent perturbation is of particular interest given that it can be described with simple models of phase-synchronization. We use high-resolution frequency measurements of the continental European power grid to analyze the impact of wind power injection on the transient short-term stochasticity of the grid frequency. We show that on time scales below the activation of primary control, frequency increment statistics broaden with increasing amount of wind power feed-in. Our results complement and confirm prior numerical results from theoretical physics.

References

[1] Milan, P., Wächter, M., & Peinke, J. (2013). "Turbulent character of wind energy." *Physical review letters*, *110*(13), 138701.

[2] Anvari, M., Peinke, J., *et al.* (2016). "Short term fluctuations of wind and solar power systems." *New Journal of Physics*, *18*(6), 063027.

[3] Schmietendorf, K., Peinke, J., & Kamps, O. (2017). "The impact of turbulent renewable energy production on power grid stability and quality." *The European Physical Journal B*, *90*(11), 222.

Global synchronization of grid-forming power converters

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A fundamental challenge in AC power systems is to design decentralized control algorithms for grid-forming power converters that ensure synchronization and voltage stability. In a more abstract setting, the problem of synchronizing power converters is closely linked to oscillator synchronization problems. This connection between coupled oscillators and control of power converters has been extensively studied in the literature. Most of the standard approaches consider so-called droop control and, for analysis, rely on modified versions of the Kuramoto model of coupled oscillators.

In contrast to these results, we do not work in polar coordinates and do not consider oscillations of fixed magnitude. We propose a synchronizing feedback based on relative state information and local measurements that induces consensus-like dynamics. Under a mild stability condition, the synchronizing feedback with a decentralized magnitude control law renders the oscillators' almost globally asymptotically stable with respect to set-points for the phase shift, frequency, and magnitude.

These technical results are applied to rigorously solve an open problem in control of converter-based AC power systems. In this context, the stability condition can be interpreted as a limit on maximum power transfer imposed by the connectivity of the transmission network as well as a limit on the control gains imposed by the dynamics of the transmission network. For a converter-based power system, the proposed control strategy can be implemented using purely local information, induces a grid-forming behavior, and ensures almost global asymptotic stability with respect to a pre-specified solution of the AC power-flow equations.

References

[1] M. Colombino, D. Groß, J.-S. Broullion, F. Dörfler, Global phase and magnitude synchronization of coupled oscillators with application to the control of grid-forming power inverters, arXiv:1710.00694 (2017)

Cyber-Physical Aspects of Distributed Averaging Control in Power Systems: Time Delays and Dynamic Communication Topology

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Frequency control is one of the most relevant control applications in power systems. Traditionally, this task has been carried out on the high-voltage transmission system by using large fossil-fueled power plants as actuators. Yet, the increasing penetration of distributed renewable generation interfaced to the network via power inverters renders these conventional schemes inappropriate, creating a clear need for robust and distributed solutions that actively integrate generation units on the lower voltage levels. Thus far, the literature on distributed frequency control has primarily focused on disturbance rejection, steady-state optimality and adaption to complex physical system models without considering uncertainties on the cyber and communication layer nor their effect on robustness and performance. In the present talk, sufficient delay-dependent conditions for robust stability with respect to heterogeneous delays, link failures and packet losses will be provided via the Lyapunov-Krasovskii method. The efficacy of the proposed conditions is illustrated by numerical examples.

Considering Forecasting Uncertainties in Scheduling of Energy Systems

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Generation from volatile renewable sources is generally difficult to integrate into electricity markets and power system operation. Hence storage systems are seen as a promising technology to enable dispatchability of this kind of generation. However, the computation of a dispatch schedule for this kind of aggregated systems is non-trivial due to inherent uncertainties surrounding predictions of load and generation.

In this talk, we focus on optimization-based scheduling using stochastic forecasts. Specifically, we discuss grid-connected systems where inflexible generation/demand is combined with energy storage. We present a formulation of the scheduling problem based on data-driven probabilistic forecasts of the inflexible power and energy output (i.e. uncontrollable loads, generators dependent on renewable energy sources, etc.). A key feature of or approach is that the probabilistic forecasts include both power and energy profiles of the uncertain demand/generation. We suggest using techniques from stochastic robust optimization to ensure the online feasibility of the dispatch schedule with a given security level. Simulation results will illustrate the efficacy of the method.

References

[1] Appino, R. R., Ordiano, J. Á. G., Mikut, R., Faulwasser, T., & Hagenmeyer, V. "On the use of probabilistic forecasts in scheduling of renewable energy sources coupled to storages" *Applied Energy* **in press** (2017)

Strategies for the operation and flexibility allocation of power grids with a large share of distributed energy resources

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Electric power systems accommodate a growing share of (renewable) distributed energy resources (DERs). Compared to the fleet of conventional power plants these energy resources are typically larger in number, smaller in nominal power, more volatile in generation, less well integrated in SCADA and energy management systems and connected to weaker nodes of the power grid.

In this presentation I will give an overview over the research efforts at Siemens Corporate Technology that derive from these properties. A first part of the presentation focuses on operation strategies and the coordination of flexibility calls between transmission and distribution grids. This part of the presentation will detail several approaches of integrating virtual power plants (with generators in the lower grid levels) in to the energy scheduling system and show how control conflicts between the distribution and transmission system operators can be avoided. In a second part of the talk an approach is presented how to estimate the state of low and medium voltage grids that potentially will accommodate a growing share of DERs, but are so far not equipped with a comprehensive measurement infrastructure. The last part of the talk covers projects concerned with the design of nationwide multimodal energy systems. [1]

[1] Raths, S.; Koopmann, S.; Müller, C.; Meinerzhagen, A.; Falke, T.; Cramer, M.; Kulms, T.; Beulertz, D.; Barrios, H.; Schnettler, A. Tackenberg, M.; Steinke, F.; Wolfrum, P.; Metzger, M.; Schlageter, B.; Kusian, W.; Schmidt, A., The Energy System Development Plan (ESDP), International ETG Congress 2015,

Demand Side Management and its Applications in the Industry

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The transition to more intelligent electrical grids, enabling remote and distributed generation, poses a challenge to the process industry. Due to the increasing amount of uncontrollable renewable generation, e.g. wind and solar, the volatility of the availability and price of electricity has significantly increased. At the same time, each company needs to strive for better efficiency. The smart grid provides an opportunity for traditional electricity consumers to increase their awareness of their electricity consumption, as well as, also become flexible market participants as producers (prosumers) through the concept of virtual power plants, mainly enabled by industrial demand-side management. In this presentation we will show some recent research results, existing software approaches and example solutions that are already today running in various industries. We also briefly discuss what the main conditions are that needs to be fulfilled in order to be able to participate in the volatile energy markets. The keyword to identify the best win-win-win scenarios is collaboration!

From Collective Network Dynamics to Systemic Risk in Power Grids

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Networks prevail in a wide range of infrastructure systems around us, ranging from the internet to traffic networks and power grids. Although most networks exhibit collective dynamical features that essentially underlie their proper function, collective network phenomena are far from fully understood today. In this talk, I will focus on two collective dynamical phenomena that emerge across networked systems and that have particular relevance for power grids: (i) nonlocal flow rerouting [1,2], the finding that network measures predict more accurately than local measures whether a link is systemically relevant; and ii) perturbation spreading [3,4], asking how local changes dynamically impact networks in a distributed yet often characteristic way. We discuss consequences of our findings for the design and operations of future-compliant power grids

This is work with Dirk Witthaut, Xiaozhu Zhang, Malte Schröder and others.

References

[1] D. Witthaut, M. Rohden, X. Zhang, S. Hallerberg, and M. Timme, *Phys. Rev. Lett.* **116**, 138701 (2016)

[2] C. Kirst, M. Timme, and D. Battaglia, *Nature Communications* **7**, 11061 (2016)

[3] J. Wolter, B. Lünsmann, X. Zhang, M. Schröder, and M. Timme, Quantifying Transient Spreading Dynamics on Networks, preprint http://arxiv.org/abs/1710.09687 (2017)

[4] X. Zhang, S. Hallerberg, M. Matthiae, D. Witthaut, and M. Timme, Dynamic Response Patterns of Complex Oscillator Networks, submitted

Challenges for DSOs in energy transitions - physics, economics, laws (and examples from the real-world)

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In Germany, the ongoing "Energiewende" or energy transition process has led to a rise in the installed power of Renewable Energy Sources (RES) up to 96 GW in 2015, whereby 96 % of these power plants are connected to the distribution grid.
One possibility for coping with the occurring challenges is to use storage systems for a better integration of RES. This solution as well as the curtailment of RES is particularly relevant in rural grids whereas new challenges occur due to the integration of new and large adjustable consumption devices, especially in urban grids.
I will focus in this talk on real-world examples from the grid and "smart-grid-projects".
Next to these technical solutions, the regulatory perspective and the usage of flexibility for markets, systems and grids will be discussed.
As I will show, the best technical solution and the preferred one from a welfare point of view is not always the chosen option when considering individual economical optimisation.

References

See https://scholar.google.com/citations?user=zqquhGoAAAAJ&hl=de

1. Value of storage in distribution grids—Competition or cooperation of stakeholders? S Nykamp, MGC Bosman, A Molderink, JL Hurink, GJM Smit, IEEE transactions on smart grid 4 (3), 1361-1370, 2013
2. 'Standard' incentive regulation hinders the integration of renewable energy generation S Nykamp, M Andor, JL Hurink, Energy policy 47, 222-237, 2012
3. Statistics for PV, wind and biomass generators and their impact on distribution grid planning S Nykamp, A Molderink, JL Hurink, GJM Smit, Energy 45 (1), 924-932, 2012.
4. Integration of heat pumps in distribution grids: Economic motivation for grid control, S Nykamp, A Molderink, V Bakker, HA Toersche, JL Hurink, GJM Smit, Innovative Smart Grid Technologies (ISGT Europe), 2012 3rd IEEE PES 2012
5. Storage operation for peak shaving of distributed PV and wind generation, S Nykamp, A Molderink, JL Hurink, GJM Smit, Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES, 1-6 2013
6. Controlling the heating mode of heat pumps with the TRIANA three step methodology HA Toersche, V Bakker, A Molderink, S Nykamp, JL Hurink, GJM Smit, Innovative smart grid technologies (ISGT), 2012 IEEE PES, 1-7, 2012.
7. Integrating renewables in distribution grids: storage, regulation and the interactions of different stakeholders in future grids, S Nykamp, University of Twente, 2013
8. The project" ElChe" Wettringen: storage as an alternative to grid reinforcements-experiences, benefits and challenges from a DSO point of, S Nykamp, T Rott, N Dettke, S Kueppers, International ETG Congress 2015; Die Energiewende-Blueprints for the new, 2015
9. Break-even analysis for the storage of PV in power distribution grids, S Nykamp, V Bakker, A Molderink, JL Hurink, GJM Smit, International Journal of Energy Research 38 (9), 1112-1128, 2014
10. Power-to-Gas: Electrolyzers as an alternative to network expansion–An example from a distribution system operator, M Robinius, T Raje, S Nykamp, T Rott, M Müller, T Grube, B Katzenbach, ... Applied Energy 210, 182-197, 2018