SOE 20: Energy Systems (joint session DY/ AK Energy / SOE)

Time: Thursday 9:30–12:45 Location: BH-N 243

SOE 20.1 Thu 9:30 BH-N 243

Decentral Smart Grid Control — •Benjamin Schäfer[1], Moritz Matthiae[1], Dirk Witthaut[1,3,4], and Marc Timme[1,2] — [1]Network Dynamics, Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen — [2]Institute for Nonlinear Dynamics, Faculty of Physics, University of Göttingen, 37077 Göttingen — [3]Forschungszentrum Jülich, Institute for Energy and Climate Research (IEK-STE), 52428 Jülich — [4]Institute for Theoretical Physics, University of Cologne, 50937 Köln

Stable operation of complex flow and transportation networks requires balanced supply and demand. For the operation of electric power grids - due to their increasing fraction of renewable energy sources - a pressing challenge is to fit the fluctuations in decentralized supply to the distributed and temporally varying demands. Common smart grid concepts suggest to collect consumer demand data, centrally evaluate them and send price information back to customers. Besides restrictions regarding cyber security, privacy protection and large required investments, it remains unclear how such central smart grid options guarantee overall stability.

Here we propose a Decentral Smart Grid Control, where the price is directly linked to the local grid frequency at each customer. The grid frequency provides all necessary information about the current power balance such that it is sufficient to match supply and demand without the need for a centralized IT infrastructure. We analyze the performance and the dynamical stability of the power grid with such a control system and determine its stability conditions.

SOE 20.2 Thu 9:45 BH-N 243

Dynamical Models of Power Grids: Identifying and Curing Weak Links — •Martin Rohden and Hildegard Meyer-Ortmanns — Jacobs University Bremen, Canpus Ring 8, 28759 Bremen

The inclusion of more and more renewable energy sources into modern power grids leads inevitably to drastic changes of the topology of power grids [1]. Nevertheless it is not known to date what an optimal network topology for power transport and robustness could be. Adding simply new transmission lines can induce long-ranged alterations on the power flow [2]. Here we use the recently introduced novel criteria of redundant capacities to identify weak links in power grids. We propose new strategies to cure these critical links and show their advantages over possible alternatives. Our results may serve as a step towards optimal network topologies in real-world power grids.

[1]: M. Rohden, A. Sorge, D. Witthaut and M. Timme, Chaos **24**, 013123 (2014)

[2]: D. Labavic, R. Suciu, H. Meyer-Ortmanns and S. Kettemann, Eur. Phys. J. Special Topics (EPJ ST), **223**, pp 2517-2525 (2014)

SOE 20.3 Thu 10:00 BH-N 243

The induced feedback of Demand-Side Management in the German power market and grid — •Sabine Auer[1,2], Jobst Heitzig[1], and Jürgen Kurths[1,2,3,4] — [1]Potsdam Institute for Climate Impact Research, D-14412 Potsdam, Germany — [2]Department of Physics, Humboldt University Berlin, D-12489 Berlin, Germany — [3]Institute for Complex Systems and Mathematical Biology, University of Aberdeen, AB24 3UE Aberdeen, UK — [4]Department of Control Theory, Nizhny Novgorod State University, Gagarin Avenue 23, 606950 Nizhny Novgorod, Russia

The integration of Variable Renewable Energy (VRE) into the German power system becomes increasingly challenging with growing wind and solar power capacities. To prevent negative energy prices and to secure future energy supply, a debate about redesigning the German power market has aroused. Two competing solutions, a capacity market and an optimized spot market, are under consideration, so far [1]. Either using demand as negative capacities or real-time market pricing will increase the price elasticity of demand and therefore, create a feedback loop between physical loads and power pricing [2].

In our research, we study these feedbacks in regard to power market and grid, especially in terms of stability [3]. Will these new concepts increase system stability by smoothing price evolution or rather provoke highly non-linear dynamics?

[1] BMWi. Ein Strommarkt für die Energiewende (2014). [2] M. Roozbehani et. al. (2012), IEEE, 27(4), 1926-1940. [3] P. Menck, J. Heitzig, N. Marwan J. & Kurths (2013). Nature Physics, 9(2), 89-92.

SOE 20.4 Thu 10:15 BH-N 243

Flow tracing in renewable electricity networks — Mirko Schäfer[1], •Bo Tranberg[2], and Martin Greiner[2] — [1]Frankfurt Institute for Advanced Studies — [2]Aarhus University

Renewable electricity networks are defined as power grids with a large penetration of fluctuating renewable power generation. Flow tracing algorithms track the renewable power as it flows from the generation nodes through the network to the consumption nodes. This allows for fair pricing schemes of future transmission investments. A new analytical expression is presented and applied to the pan-European transmission grid.

SOE 20.5 Thu 10:30 BH-N 243

Large-deviation study of the maximum-disturbance stability of power grids — •Alexander K. Hartmann[1], Timo Dewenter[1], Wiebke Heins[2], and Benjamin Werther[2] — [1]Institut of Physics, University of Oldenburg — [2]Institut for Electrical Energy Technology, Technical University of Clausthal

We study numerically the distribution of “maximum-disturbance” stability of power grids. The model is based on networks of oscillators. Here, we consider different ensembles of random networks, like standard Erdös-Renyi and two dimensional spacial networks. To access the distribution down to very small probabilities, we use specific large deviation techniques [1]. The stability is given by a conservative estimation of an asymptotic stability boundary, which is well known in stability theory [2,3]. The starting point is the matrix $\mathbf{A}$ defined by $\mathbf{J}^{\mathbf{T}}\mathbf{A} + \mathbf{A}\mathbf{J} = \mathbf{E}$, $\mathbf{J}$ being the Jacobean Matrix. By calculating the maximum disturbance of $\mathbf{x}$, which results in the quadratic form $V = \mathbf{x}^{\mathbf{T}}\mathbf{A}\mathbf{x} = \epsilon(\mathbf{x})$ not being a Lyapunov-function of the system any longer, the boundaries for the stability can be found.

For comparsion, for the given networks also simple stability measures beased on shortest paths [4], on the eigenvalues of the Jacobi matrix and on a linearized power-flow model [5] are obtained.

[1] A.K. Hartmann, Eur. Phys. J. B **84**, 627-634 (2011)
[2] R. Unbehauen, Systemtheorie (Vol. 2), Oldenbourg, Munich (1998)
[3] E.J. Davison and E.M. Kurak, Automatica **7**, 627-636 (1971)
[4] A.K. Hartmann, Eur. Phys. J. B **87**, 114 (2014)
[5] T. Dewenter and A.K. Hartmann, preprint arXiv:1411.5233 (2014)

SOE 20.6 Thu 10:45 BH-N 243

Impact of network topology on decentral frequency-based smart grid control — •Carsten Grabow[1] and Jürgen Kurths[2] — [1]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [2]Potsdam Institute for Climate Impact Research, Potsdam, Germany

Replacing conventional power sources by renewables in power grids poses a big challenge nowadays. In particular, a stable operation of the power grid requires new methods and ideas in aligning the arising fluctuations in decentralised supply to the temporally varying demands. In this context, a decentral Smart Grid Control has been proposed recently in order to directly link the price information to the local grid frequency. Principally, it has been shown that this approach leads to an efficient decentralized strategy for matching supply and demand in a dynamically stable way. However, first results are restricted to simple small and regular networks. In our talk, we will extend the local and global stability analysis of the decentral Smart Grid Control to the collective dynamics of small network motifs, in particular, star-like networks and regular grid motifs. For larger networks, we numerically investigate decentralization scenarios finding additional phenomena that have to be considered to support power grids in exhibiting a stable state.

15 min. break

SOE 20.7 Thu 11:15 BH-N 243

Detours around basin stability in power networks — •Paul Schultz[1,2], Jobst Heitzig[1], and Jürgen Kurths[1,2,3,4] — [1]Potsdam Institute for Climate Impact Research, D-14412 Potsdam, Germany — [2]Department of Physics, Humboldt University Berlin, D-12489 Berlin, Germany — [3]Institute for Complex Systems and Mathematical Biology, University of Aberdeen, AB24 3UE Aberdeen, UK — [4]Department of Control Theory, Nizhny Novgorod State University, Gagarin Avenue 23, 606950 Nizhny Novgorod, Russia

To analyse the relationship between stability against (large) perturbations and topological properties of a power transmission grid, we employ a statistical analysis of a large ensemble of synthetic power grids, looking for significant statistical relationships between the single-node basin stability measure and classical as well as tailor-made weighted network characteristics. Especially, we propose a strategy to directly estimate a power grid's stability - even on short time scales - to omit the need of costly simulations. The focus lies on the identification of grid nodes that appear critical for stability, using for example a version of Newman's current flow betweenness. This method enables us to predict poor values of single-node basin stability for a large extent of the nodes, offering a node-wise stability estimation at low computational cost.

Further, we analyse the particular function of certain network motifs to promote or degrade the stability of the system. Here we uncover the impact of so-called detour motifs on the appearance of nodes with a poor stability score and discuss implications for power grid design.

SOE 20.8 Thu 11:30 BH-N 243

Network Measures for Power Grid Stability in Practice — •Frank Hellmann — Potsdam-Institut für Klimafolgenforschung, Potsdam, Deutschland

A key challenge for the emerging future grid infrastructure is the dynamical stability of the power grid in the presence of fluctuating power sources and changing topologies.

I show how tools based on novel as well as existing network topology measures can help with identifying vulnerable points in the power grid and can guide the design of the future grid in practice.

SOE 20.9 Thu 11:45 BH-N 243

Predicting critical links in complex supply networks — •Xiaozhu Zhang[1], Dirk Witthaut[1,2,3], Martin Rohden[1,4,5], Sarah Hallerberg[1], and Marc Timme[1,6] — [1]Network Dynamics, Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen, Germany — [2]Forschungszentrum Jülich, Institute for Energy and Climate Research - Systems Analysis and Technology Evaluation (IEK-STE), 52428 Jülich, Germany — [3]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany — [4]IIIrd Institute of Physics, Faculty of Physics, Georg August University, 37077 Göttingen, Germany — [5]School of Engineering and Science, Jacobs University, 28759 Bremen, Germany — [6]Institute for Nonlinear Dynamics, Faculty of Physics, Georg August University, 37077 Göttingen, Germany

It has been observed that most large-scale outages in power grids can be traced back to single transmission line failures [1]. Yet, identifying which infrastructures in power grids and other supply networks are critical remains an open challenge, with severe consequences for network planning and stability. In this work we propose that the critical links can be reliably predicted from the network structure and the normal operation state prior to edge failure. Numerical simulations of a variety of flow network models confirm that the topological edge redundancy as well as renormalized linear response theory provide general key indicators for network robustness.

[1] Pourbeik et al., Power and Energy Magazine, IEEE 4.5 (2006): 22-29.

SOE 20.10 Thu 12:00 BH-N 243

Modelling the Dynamical Formation of Coalitions of Power Grid Operators to Reduce Needs for Backup Capacity — •Jobst Heitzig[1] and Sarah Becker[2] — [1]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [2]Frankfurt Institute for Advanced Studies, Frankfurt, Germany

Power grid operators face an increasing need for backup capacity due to a raising amount of volatile renewable energy production. This need may be decreased by extending transmission capacities between several neighbouring grids and then pooling their backup capacities. Due to the physical properties of electricity transmission grids, extending a line between two grids may however also reduce the backup capacity needs of a third connected grid, and may do so even more than when the third grid's connection were extended as well. These physical effects generate complex and interesting strategic incentives for individual grid operators to join a backup capacity sharing coalition or not. In this talk, we'll use a model of dynamic coalition formation to show which grids may form coalitions in which order, using real-world example data.

SOE 20.11 Thu 12:15 BH-N 243

Short-Time Stochastic Characterization of the Offshore Wind Profile — •Christian Behnken, Pedro Lind, Matthias Wächter, and Joachim Peinke — ForWind, Institute of Physics, Carl-von-Ossietzky University, 26111 Oldenburg, Germany

Currently descriptions of vertical wind profiles are mostly performed by using standard logarithmic or power law approaches. Especially for short time scales ($1\,s \leq t \leq 10\,min$) the dynamics of the profile strongly influence the load situations and the energy conversion of wind turbines. Since these short-time dynamics are not considered when using the standard techniques, a more detailed approach is presentend in this work. Firstly, PDFs of spatial and temporal velocity increments, estimated from offshore wind speed data, are fitted by using a superposition of Gaussian distributions with a varying standard deviation. It is shown that the empirical PDFs follow a heavy-tailed distribution which matches the proposed theoretical distribution. Furthermore, drift and diffusion coefficients for two-dimensional systems of Langevin equations are estimated directly from wind speed data to investigate dynamic coupling along the profile. This approach gives a first insight into the dynamics of wind profiles on short time scales.

SOE 20.12 Thu 12:30 BH-N 243

Intermittency and Synchronization in Wind Farm — •Mehrnaz Anvari and Joachim Peinke — Institute of Physics and Forwind, Carl von Ossietzky University, 26111 Oldenburg, Germany

The renewable wind and solar sources and their share in electricity production have been increased constantly in recent years. These sources have new stochastic characteristics such as intermittency and non-Gaussian behavior, which may cause instability in power grids in very short-term time scales.

In this work, we focus on wind power that influenced by atmospheric turbulence. Hence frequent extreme fluctuations in power output of wind turbines are detectable. This intermittent behavior also, is present in cumulative power of the total wind field, even for a country-wide installation. To understand the origin of such extreme events, we consider the interactions between wind turbines and for this purpose, we evaluate the phase synchronization in wind farm. We conclude that, the existence of partial phase synchronization between turbines in specific time intervals can explain the origin of extreme events in this complex system. We found that higher synchronized wind turbines will produce higher intermittent power output.