IOP | Institute of Physics
Nonlinear and Complex Physics Group

Complexity & Risk in the Energy Sector

Annual networking meeting of the IOP Nonlinear and Complex Physics Group

Wednesday 26th October 2016,
Room 3.01, RSM, Imperial College London, South Kensington Campus

Energy security plays an essential role both in alleviating poverty in developing countries and in maintaining growth and prosperity in the developed world. Yet the national and global infrastructures that deliver energy are changing rapidly in the face of new and unprecedented challenges. The biggest of these stem from the need to meet ever-increasing global demand for energy services whilst simultaneously reducing CO2 emissions caused by burning fossil fuels. Responding to these challenges will likely involve increased deployment of renewables in the energy mix, perhaps combined with a growing reliance on transported natural gas, nuclear energy and carbon capture technologies. The risks to energy security associated with this new energy landscape will need to be understood from a number of perspectives, ranging from the effects of policy and regulation on energy price and availability to the impact of weather and climate change on energy supply and demand.

Programme

1100	**Registration & Coffee**
1130	David Brayshaw, Reading: ***"Understanding climate risk in the energy sector"***
1215	Hannah Bloomfield, Reading: ***"The impact of climate variability on the GB power system"***
1240	Oluwamayowa Amusat, UCL: ***"Standalone renewable energy systems: inter-year variability in systems sizing"***
1305	**Lunch** (provided)
1415	Simon Tindeman, Imperial: ***"Managing risks in a bottom-up electricity system"***
1500	Paul Balcombe, Imperial: ***"Distribution of methane and CO_2 emissions from the natural gas supply chain"***
1525	Ellen Webborn, Warwick: ***"Exploring the risk of synchronisation of distributed demand-side response resources"***
1550	**Tea and Cakes**

1625	Steven Steer, Cambridge: ***"Power station design methods applied to commercialising novel nuclear plant"***
1650	Nick Watkins, Warwick: ***"On bunched black swans and return times in climate and other time series"***
1715	**Drinks & Discussion**
1830	**Close**

Keynote speaker: David Brayshaw, University of Reading
"*Understanding climate risk in the energy sector*"
From short term extreme weather damage to long term climate change, almost all aspects of national and global energy systems are exposed to some form of climate risk. Recent developments in weather and climate science offer new opportunities to manage these risks but also raise new challenges for how we understand, model and quantify climate impacts in complex multi-scale systems.

This talk will outline some of the key characteristics of energy-climate interaction and recent developments in this field, particularly focussing on the timescales most relevant to "climate services" (weeks to decades). Topics will include: the information content and limitations of climate data, understanding the physical processes involved with energy-climate interaction, the conversion of climate data into energy system impacts, and the need for improved decision-making using probabilistic climate data.

Keynote speaker: Simon Tindeman, Imperial College London
"*Managing risks in a bottom-up electricity system*"
This talk will discuss some of the general challenges related to the transformation of the grid from a top-down centrally managed infrastructure to an increasingly 'smart' bottom-up system. Specifically, some recent results on the decentralised control of smart refrigerators and the behaviour of active consumers, both in the context of risk management will be discussed.

Speaker: Hannah Bloomfield, University of Reading
"*The impact of climate variability on the GB power system*"
Within the power system of Great Britain (GB), there is a rapidly increasing amount of generation from renewables, such as wind and solar power. An increased proportion of weather-dependent generation will require increased understanding of the impact of climate variability on the power system.

In this project, multi-decadal records from meteorological reanalysis data are combined with a parsimonious representation of the GB power system, of which the weather-dependent components are electricity demand and wind power production. Multiple scenarios are analysed for GB power systems, including 0GW, 15GW, 30GW, and 45GW of installed wind power capacity. This study characterises the impact of inter-annual climate variability on multiple aspects of the GB power system (including coal, gas and nuclear generation). This work has shown that short records of power supply and demand variability are insufficient for providing robust power system planning guidance.

Speaker: Oluwamayowa Amusat, Paul Shearing and Eric Fraga, University College London
"*Standalone renewable energy systems: inter-year variability in systems sizing*"
Renewable energy sources such as solar and wind are variable by nature and must be integrated with suitable storage technologies in order to attain higher fractions of renewables integration into

the energy grid. This variability within and between years must be accounted for at the design stage in energy system sizing, as failure to do so has been shown to lead to signi□ficant deviations from expected performance, often at signi□cant costs to the decision-maker [1]. Deciding on the con□guration and size of renewables-dependent energy systems is therefore a balance between two contrasting objectives: cost minimisation and reliability maximisation. This work addresses the challenge of developing a methodology to account for inter-year variability in the design of standalone renewable energy systems for continuous operations.

For this, an integrated energy system consisting of three generation alternatives (photo-voltaics, solar thermal and wind turbines) integrated with three storage alternatives and modelled as a system of nonlinear di□erential algebraic equations (DAEs), is considered. The variable nature of the renewable resources is accounted for by considering multiple stochastic renewable input scenarios generated from probability distribution functions (PDFs) as inputs into the en- ergy system model. A reliability measure representing the probability of failure associated with the selection of a given design is evaluated based on the required performance level and the actual performance of the design in the input scenarios. The system cost is de□ned as a function of the capacities of the generation and storage units. The cost-reliability bi-criteria problem is implemented in MATLAB and solved with an evolutionary algorithm (NSGA-II) to obtain an approximation to the Pareto-optimal front. Two case studies of remote mines located in Chile and Canada are presented to demonstrate the approach.

The methodology presented ensures that temporal variations in renewables are accounted for in the design of renewables-based energy systems, thereby providing the decision-maker with an understanding of the performance risks associated with the selection of any given design.

[1] Oluwamayowa O. Amusat, Paul R. Shearing, and Eric S. Fraga. Optimal integrated energy systems design incorporating variable renewable energy sources. Computers & Chemical Engi-neering, 95:21□37, Dec 2016. ISSN 0098-1354. doi: 10.1016/j.compchemeng.2016.08.007. URL http://dx.doi.org/10.1016/j.compchemeng.2016.08.007.

Speaker: Paul Balcombe, Imperial College London

"*Distribution of methane and CO_2 emissions from the natural gas supply chain*"

There has been growing concern that fugitive and vented emissions from the natural gas supply chain is larger and more variable than previously thought, but there remains a lack of understanding about why we see such variation and the factors affecting these emissions. In this study, a large set of new emissions data is analysed to estimate a probabilistic distribution of methane and CO_2 emissions from each stage of the supply chain. The factors affecting emissions are defined and quantified, including reservoir type, size and supply chain route. This inventory was then used to perform a Monte Carlo simulation to determine the overall distribution of methane and CO_2 emissions for various supply chain scenarios.

Speaker: Ellen Webborn and Robert S MacKay, University of Warwick

"*Exploring the risk of synchronisation of distributed demand-side response resources*"

Ensuring electricity grid stability requires maintaining a tight balance between supply and demand. The move to a low-carbon electricity supply is causing greater need for grid balancing services due to greater generation volatility, reduced system inertia and fewer traditional providers in operation. Expanding the use of demand-side response is one option for assisting with grid stability. The use of thermostatically-controlled loads (TCLs) such as fridge-freezers, hot water tanks and air conditioners has been considered for some time although it is yet to be realised on a large, distributed scale.

Imbalance between supply and demand is reflected in deviation of the electricity grid frequency from 50Hz. We examine the potential for TCLs to adjust their temperature set-points as a function of grid frequency to provide supply-demand balancing. We consider many small units acting without a central controller and explore the stability of such a system. We find that for a population of identical TCLs the system is stable to small perturbations but that the synchronised state (all switching on and off in unison) is also attracting. Synchrony in the real system could cause huge swings in frequency with severe consequences. Our hope is that sufficient diversity in the TCL population will make the equilibrium state globally attracting.

Speaker: Steven Steer, University of Cambridge

"Power station design methods applied to commercialising novel nuclear plant"

The lengthy duration of design and construction associated with commercial nuclear power plant mean that the early design work for 'Generation IV' nuclear reactors is already an active field of work. At this stage significant decisions are made that are influential to the overall value proposition; poor choices can be complicated and expensive to correct at later design phases. Reported is an investigation contributing to the design optimisation of one particular plant proposal, the Accelerator-Driven Subcritical Reactor (ADSR), with a focus on its commercial value. Two design optimisation methods have been applied to ADSRs. One focuses on the value of preserving options within the system by paying to add flexibility into the plant design. This allows commitments to be delayed while uncertainty associated with technology is better resolved. The other method considers side-by-side recognised potential plant characteristics and attempts to identify the relationships and mutual [in/ex]clusivity between them while also attempting to rank design options. These two investigations have allowed for improved understanding of the value proposition of ADSR plant, while the study also lends some insight to the proposition for nuclear technology more widely.

Speaker: Nick Watkins (Centre for the Analysis of Time Series, LSE, University of Warwick, Open University), Sandra Chapman (University of Warwick) and David Stainforth (Centre for the Analysis of Time Series, LSE)

"*On bunched black swans and return times in climate and other time series*"

In climate science, and its applications, we frequently want to know how long on average will we have to wait until the next "large" or "severe" event. This is frequently expressed in terms of the return period of an event of a given magnitude. However, a very characteristic feature of how our climate is changing is that it varies locally. This requires quantifying the geographical patterns in changes at specific thresholds or quantiles of distributions of temperature, and their uncertainties. This talk first summarises a new approach [1,2] which maintains the flexibility to provide information at different thresholds for different downstream users, both scientists and decision makers. Our method analyses local temperature time series to assess which quantiles (and thus return times) of the local climatic distribution show the greatest and most robust changes. This involves not only determining which quantiles and geographical locations show the greatest change, but also those at which any change is highly uncertain. We demonstrate this approach using E-OBS [3] gridded data across Europe over the last 60 years. Our approach is model-independent, thus providing data of direct value to model calibration and assessment. I then discuss the problem of correlated extreme events, or "bunched black swans" [4], and show some work on progress on how correlation may affect return times.

[1] S C Chapman, D A Stainforth, N W Watkins, 2013, On Estimating Local Long Term Climate Trends, Phil. Trans. R. Soc. A, 371 20120287

[2] D. A. Stainforth, S. C. Chapman, N. W. Watkins, 2013, Mapping climate change in European temperature distributions, ERL, 8, 034031

[3] M R Haylock et al . 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. J. Geophys. Res (Atmospheres), 113, D20119

[4] N W Watkins, 2013, Bunched black (and grouped grey) swans: Dissipative and non-dissipative models of correlated extreme fluctuations in complex geosystems, Geophys. Res. Lett., 40(2), 402-410