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Recent and Future Contributions of Delft University of Technology to Smart Grids

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Introduction

In this report, the recent and future contributions of experts and groups of Delft University of Technology (DUT) on the topic of smart grids (SG) are presented. This may provide guidelines on how DUT can contribute in current and future SG projects, such as the current TKI project on "Smart Grid Evolution (SGE): Developing a service platform for the Internet of Energy".

The SGE project is meant to prepare for the realization of a large-scale demonstration case in Netherlands, starting in June 2016. In this demonstration case, a smart grid with at least 100.000 connections will be constructed.[1] The 3TU.Federation is involved to contribute to the development of a collaborative design and decision support environment based on state-of-the-art knowledge of smart grid concepts with appropriate tool support. The representatives of DUT are Jok Tang, Cees Witteveen and Kees Vuik.

In the groups headed by Cees Witteveen and Kees Vuik, the topic of smart grids is under investigation. Some of the members of these groups are interviewed, and their input is the basis of this document. Also several experts from other groups and faculties of DUT are interviewed. The list of interviewed people is not exhaustive, but it can be interpreted as an overview of the total SG expertise that DUT possesses.

Delft University of Technology initiatives

DUT invests a lot in research of sustainable energy technology. Developing reliable and sustainable smart grids from a technological point of view is a part of this research. There are several initiatives related to it, such as the PowerWeb initiative ("Towards the smart energy grid of the future")[2] initiated by DUT, in which a number of PhD students, scientists and professors from different faculties of DUT is involved. Some of the people in the PowerWeb initiative were also interviewed.

In the PowerWeb consortium, the real-time power-engineering issues as well as the socio-technological problems and the multilevel control issues that constitute the core of any smart grid system are addressed.

[1] More details about the project can be found here: http://tki-switch2smartgrids.nl/projecten/smart-grid-evolution-developing-a-service-platform-for-the-internet-energy-sge-ioe/.

[2] Link of the PowerWeb initiative: http://powerweb.tudelft.nl/.

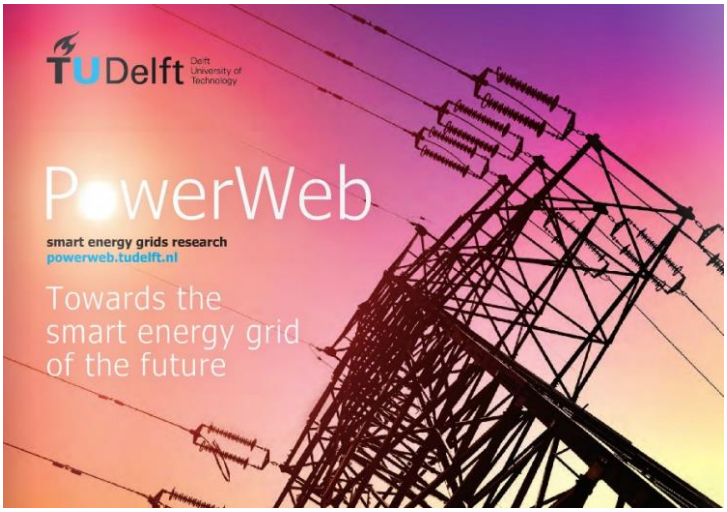

Figure 1: PowerWeb is one of DUT's initiatives to invest in the research of sustainable energy technology.

Taxonomy of SG layers

The short reports of the conducted interviews can be found in the next chapters. After analysing the interviews, three different layers of SG knowledge that are available at DUT can be distinguished. Each of these layers has different focus, problems and challenges. These layers are presented in the following figure.

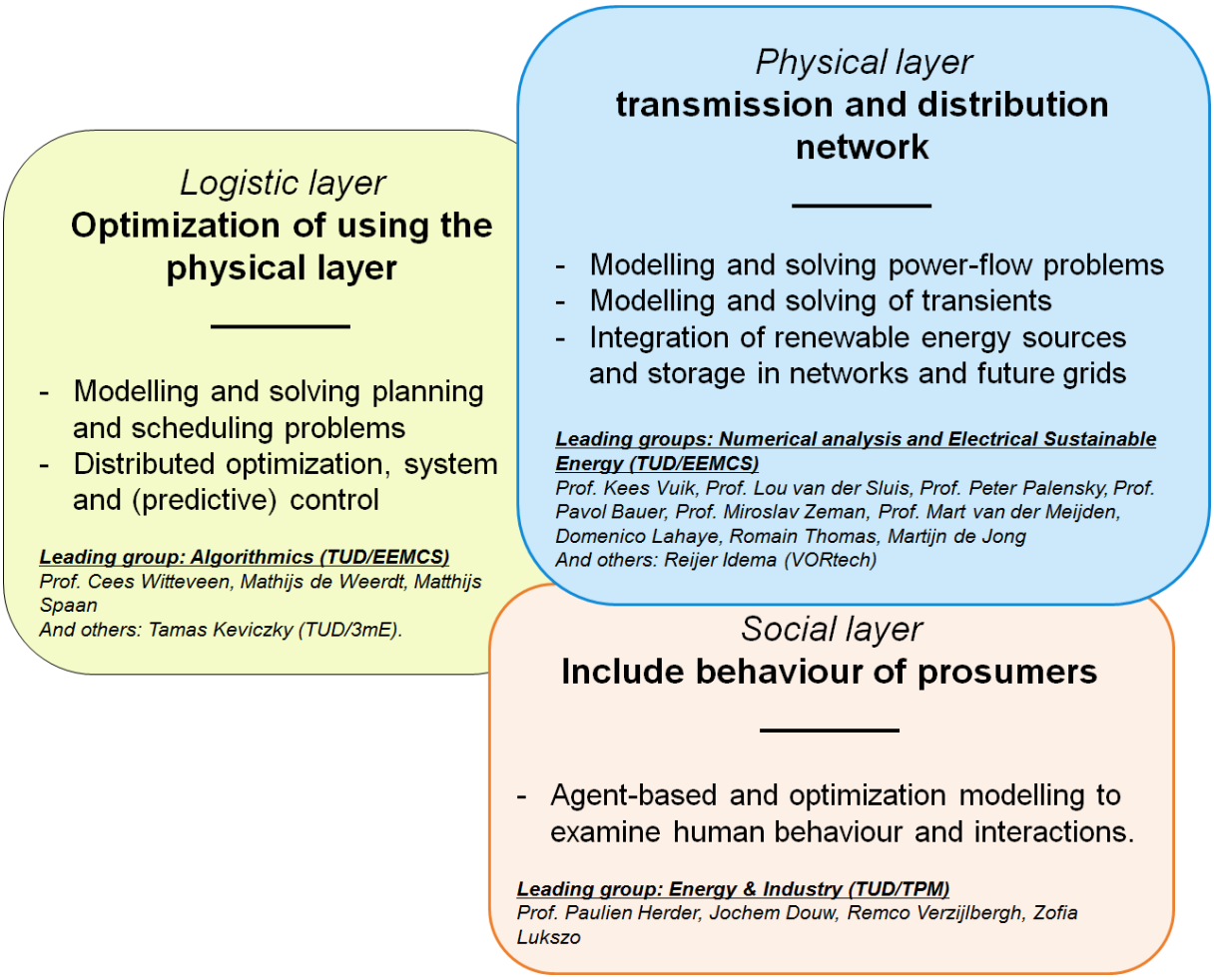

Figure 2: The three major research layers on smart grids at DUT.

DUT has specialists in all three layers, and they are all parts of the PowerWeb initiative. In the following chapters, these layers are further explored by presenting a summary of the reports of the interviews. The full reports can be found in Appendix A.

Physical layer: Transmission and distribution network

Interviewees:

- Domenico Lahaye;
- Reijer Idema;
- Romain Thomas;
- Martijn de Jong,
- Pavol Bauer.

Specific field:

- Mathematical modelling in the physical layer.
- Integration of renewable energy sources and storage in networks and future grids.

Specific contribution:

- For large networks, numerical analysis of large-scale models is required, since the bottleneck is in computing time.
- Solve the power-flow problem for large networks in a fast manner.
- Challenge here is to see where the critical elements are in the network and how to solve.
- Study the stability of a power system in a time window of a few seconds to several tenths of seconds.
- Study 'standard' deterministic models but also stochastic models.
- Make the smart grid components bidirectional and improve converters so that they are suitable for smart grids.

Connection to SGE:

- Improve and accelerate the load-flow calculations.
- Improve the design and layout of the demonstration case, including the enhancements on the technical components and their connections.

Optimization layer: Optimization of using the physical layer

Interviewees:

- Tamas Keviczky;
- Mathijs de Weerdt.

Specific field:

- Planning and scheduling in the optimization layer.

Specific contribution:

- Make smart grids more efficient by constructing a better planning.

Connection to SGE:

- Models for planning and scheduling demand response.

Social layer: Include behaviour of prosumers

Interviewees:

- Paulien Herder;
- Remco Verzijlbergh;
- Zofia Lukszo;
- Jochem Douw.

Specific field:

- Engineering Systems Design in Energy & Industry in the social layer.

Specific contribution:

- Examine which incentives should be used in SG.
- Challenges in smart grids: demand response, shifts of electricity, integration of renewables.
- Study the combination of privacy and sustainability in SG. Examine how to measure sustainability, control energy generation plants and how to use sustainable energy in a proper way.

Connection to SGE:

- Including human interaction and aspects in the models.

Connection of the layers

The research done in the three layers (physical, optimization and social layers) is all relevant to smart grids and can be seen as independent groups. There is, however, also a clear connection between those layers:

- **Physical / Optimization layer:** Load-flow calculations that are made as efficient as possible in the physical layer can be employed as constraints in the optimization models of the optimization layer.
- **Optimization / Social layer:** Optimization models are also used in the social layers in the research of incentives. Besides agent-based models, optimization models are the main models that are used in the social layer.
- **Physical / Social layer:** This connection is not yet established well. But in the future we can think of including aspects from incentives and human interaction into the physical models of load flows.

The contribution of DUT to SGE is in all three layers. Models and simulations from the SGE partners can be validated and verified based on the knowledge and expertise from these layers. On top of that, the three layers can contribute to develop new models and simulations that are required in the SGE project and other future SG projects.

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APPENDIX: Reports of the interviews

In this appendix the reports of the interview can be found. Important issues are stressed in bold-face.

Physical layer: Transmission and distribution network

Interview with Domenico Lahaye

- *Specific field:*
  - Mathematical modelling in the physical layer.
- *Specific contribution:*
  - Domenico's former PhD student Reijer Idema and his current PhD student Romain Thomas mainly work on solvers for load flows and transient modelling. **For large networks, numerical analysis of large-scale models is required, since the bottleneck is in computing time.**
  - Domenico and his team have the expertise on how to construct the describing equations and the resulting model for the load-flow networks.
  - Another PhD student of Domenico, Martijn de Jong, considers the optimization of load flows by configuring generators, loads and capacities of lines. Monte-Carlo simulations are adopted to deal with the generated power of renewable sources being distributed stochastically.
- *Connection to SGE:*
  - Improve and accelerate load-flow calculations.
- *Further ideas on smart grids:*
  - Charging electric vehicles will demand a lot of energy. What to do if a whole area is equipped with electric cars? An optimal topology of the network will then be required so that everything is functioning well in such a network.

Interview with Reijer Idema

- *Specific field:*
  - Mathematical modelling in the physical layer.
- *Specific contribution:*
  - Reijer worked on models of the electric network on a transmission level (higher voltages). He considered load-flow models, where static-state electric networks are considered. The input is the demanded amount of energy and the generated energy by the plants. The output is the voltage and resulting electric currents that go through the network.
  - The main challenge of Reijer's research was to **solve the load-flow problem of very large power systems in a fast manner**. This is beneficial for e.g. financial-decision support, where the aim is to see how to satisfy all technical requirements with the lowest cost. This is an optimization problem, where a large amount of load-flow problems need to be solved.

    - Related to it, he also worked on contingency analysis, where the problem is encountered in which elements can get defect. For this, simulations are required in which one element (usually a line or generator) does not work and it should be checked if everything would still function well. The **challenge here is to see where the critical elements are in the network and how to solve.**
- *Connection to SGE:*
    - Solve sets of load-flow problems, for example in a contingency analysis, in a fast way.
- *Further ideas on smart grids:*
    - How to deal with networks on a distribution level (lower voltages) and storage of locally generated energy? Lots of research has being conducted on these topics which could be incorporated in the load-flow simulations.
    - Biggest change/impact on the energy market: local generation and "prosumers".
    - How to deal with the market value of energy? How to make it optimal for the prosumers? Is this the cheapest or safest solution in this case? Who will support and defend these prosumers?
    - Who will manage and control the local generation?
    - Currents are important in smart grids, but also data. So up-time security is important, but cyber security too! The electric network will become more complex. What will the further implication of the new data networks in smart grids?
    - Smart grids are a huge revolution in the energy world for the next decades, and that is a relevant and interesting development. The last 100 years we only saw a small evolution in the energy world, while it is expected that the development of smart grids will cause an energy revolution.
    - Load-flow calculations are steady-state calculations, assuming perfect sinusoids in currents. But in practice we also see peaks. This is the research of other PhD students (Romain Thomas).
    - Net stability can be an issue. A small deviation in the frequency (50 Hz in most of Europe) can lead to high negative consequences.

Interview with Romain Thomas

- *Specific field:*
    - Mathematical modelling in the physical layer.
- *Specific contribution:*
    - Load-flow simulations are steady-state. Romain studies real-time simulations, where transients play an important role. He looks at the **stability of a power system in a time window of a few seconds to several tenths of seconds**.
    - Differential equations lead to time-consuming simulations (to be solved). Romain look at efficient methods for this.
- *Connection to SGE:*

- Improve the load-flow calculations and mathematical models with the inclusion of stochastics.

- *Further ideas on smart grids:*
  - None so far.

Interview with Martijn de Jong

- *Specific field:*
  - Mathematical modelling in the physical layer.
- *Specific contribution:*
  - Martijn's work is part of the PowerWeb project and also of the EU Umbrella project[3]. His research includes issues on uncertainties in the model and software. This is innovative, since **most models are deterministic, while Martijn studies stochastic elements in the model**.
  - The model that Martijn has been developing has the following combined features:
    - Forecast uncertainty,
    - Monte-Carlo sampling,
    - Risk management,
    - AC PF and AC OPF computations.
  - The model can do a risk calculation of load changes for a given current dispatch. The uncertainty arising from wind and solar in-feeds is represented by a stochastic load.
  - The model is flexible, proposes remedial actions and can also be used to study the impact of smart devices (such as FACTS, HVDC, PSTs).
  - Monte Carlo is expensive in terms of computing time, therefore, the aim of DUT is to accelerate the methods so that they can be used in intra-day and even real-time (by using Reijer's work).
- *Connection to SGE:*
  - Improve the load-flow calculations and mathematical models with the inclusion of stochastics.
- *Further ideas on smart grids:*
  - The pressure on TSOs will increase and the need for larger and better models will rise. The feasible region of the energy network should be larger in models.

Interview with Pavol Bauer

- *Specific field:*
  - Integration of renewable energy sources and storage in networks and future grids in the physical layer
- *Specific contribution:*
  - Integration of solar energy, wind energy, storage and electric vehicles in the smart grids. Think of the research on the design and layout of the components, how to convert power.
  - The challenge is e.g. to make the smart grid components in the physical layer bidirectional and how to treat converters, how to go from AC to DC, etc.

[3] Link of the Umbrella project: http://www.e-umbrella.eu.

    - On an HV level, research on HVDC is conducted. On a LV, research on microgrids is done.
- *Connection to SGE:*
    - Improve the design and layout of the demonstration case, including the enhancements on the technical components and their connections.
- *Further ideas on smart grids:*
    - Scalability is difficult to measure in smart grids. Keep local interactions and create a layer above this that connects the local grids. This second layer should be tested by simulations but also by cases. TenneT could play an essential role in this.

Optimization layer: Optimization of using the physical layer

Interview with Tamas Keviczky

- *Specific field:*
    - Predictive control and distributed optimization in the optimization layer.
- *Specific contribution:*
    - Tamas has not worked on smart grids so far. He has mainly been working on predictive control and distributed optimization. He has been looking at disturbances and constraint fulfilment, graph theory (by given topology or changing networks in time).
    - He also studies thermal energy storages and mixed storages. He solves the resulting quadratic programming problems, which are model-based, they are not static ones. In distributed optimization, results need to be obtained quickly. Linear and non-linear problems are considered in which stochastics are involved.
- *Connection to SGE:*
    - Not clear yet.
- *Further ideas on smart grids:*
    - None.

Interview with Mathijs de Weerdt

- *Specific field:*
    - Planning and scheduling in the optimization layer.
- *Specific contribution:*
    - Mathijs studies transport and balancing problems in terms of planning and scheduling. These are discrete problems where for example search trees are used. Two key specialisms:
        - **Uncertainty:** Optimize the expected value. Determine the best action for each scenario. A model for this will grow fast in complexity.
        - **Multiple parties:** Cooperative and competitive interaction, strategic behaviour, and negotiation play a role in this.

- A possible contribution of the group of Mathijs is to **make smart grids more efficient by constructing a better planning**. The need for planning grows because of the decentralized energy generation. Generation and/or consumption can sometimes be moved in time. This requires a better coordination. In addition, capacity limitations are interesting to deal with. This also holds for electric vehicles: how to load and unload them in an appropriate way?
- In the TKI project "Warmteweb B3-Hoek"[4], DUT (represented by Mathijs' group) contributes to the investigation of the mutual heat trading between horticulturists. In this, some limitations of the network exist. Economic and private conflicting interests need to be dealt with. It is a combination of an economic optimization and a technical problem. Complex models are adopted which are part of the optimization problem. For an economic purpose, Mathijs uses a complex simulation model to construct and validate a model with linear constraints which is better suited for optimization.

- *Connection to SGE:*
  - Models for planning and scheduling demand response.
- *Further ideas on smart grids:*
  - When distribution or transmission capacity is (temporarily?) insufficient, planning and coordination can ensure staying within the physical constraints (and preventing outages) in a cost efficient manner. It is not clear whether current market models are sufficient to give the main players the right incentives in such an environment.
  - We expect that in concrete settings, the different players and different goals (real-time balancing, frequency/voltage control, etc.) require different incentives and thus different pricing mechanisms. It is an interesting topic of further study to see what good combinations are.

Social layer: Include behaviour of prosumers

Interview with Paulien Herder

- *Specific field:*
  - Engineering Systems Design in Energy & Industry in the social layer.
- *Specific contribution:*
  - Agent-based modelling (ABM) is done by Jochem Douw and Zofia Lukszo, members of her team, while system optimization (including the study of technological /economic incentives) is done by Remco Verzijlbergh. The main technological challenge is: **which incentives should be used in SG?**
  - The main theoretical challenge is how to model and validate the human behaviour in the models. The so-called "choice modelling" (transport) plays a role here: model the choices prosumers can make.
  - In the PowerWeb project, ethical and philosophical aspects are considered regarding security, accessibility, privacy and affordability. On top of that, the group of Paulien also look for other incentives and price structures.

[4] Link of the project: http://tki-switch2smartgrids.nl/projecten/warmteweb-b3-hoek.

- *Connection to SGE:*
    - Including human interaction and aspects in the models.
- *Further ideas on smart grids:*
    - None.

Interview with Remco Verzijlbergh

- *Specific field:*
    - Engineering Systems Design in Energy & Industry in the social layer.
- *Specific contribution:*
    - Remco's thesis was about the power of electric vehicles. Loading the vehicles can be done in a naïve or a smart way. Think of "demand response". New optimization problem due to electric vehicles. Congestion management (respecting network constraints) including uncertainties is also important here.
    - **Challenges in smart grids: demand response, shifts of electricity, integration of renewables.** For wind energy, there is a lot of data available, doing forecasts is interesting. How to deal with stochastic elements in the network.
- *Connection to SGE:*
    - Models for charging electric vehicles.
- *Further ideas on smart grids:*
    - **Important question: how to set up the rules in SG?** Renewables are variable and uncertain, so flexibility is important. Think of flexible generators, storage, demand response, connection to a national system. Low cost, safety and reliability are important. For example, at the moment storage will not generate money. Rules may limit the development and innovation. Currently, the need is not high, but it is good to prepare ourselves for it.
    - A recent development is in system integration issues. There are calls for proposals. Relate networks to storage, couple systems to each other.

Interview with Zofia Lukszo

- *Specific field:*
    - Smart buildings and different storage possibilities on the social layer.
- *Specific contribution:*
    - Zofia does research on smart buildings and different storage possibilities, with a focus on looking at systems, distributed optimization and control algorithms. Pavol Bauer is responsible for storage and could be contacted for more information.
    - TPM has an integrated view where the involvements of stakeholders, design of an optimal strategy, and agent-based modelling are important aspects. Currently, this integrated view is not generally known or examined widely. Take for example independent EVs (i.e. electric vehicles), where human interaction is essential, how would they react in a smart grid and how to minimize constant production (or peaks)? Dynamic optimization with uncertainties plays a role here. This all can be used as an input for the further design and operation of SGs.

- *Connection to SGE:*
    - Including human interaction and related aspects in the models.
- *Further ideas on smart grids:*
    - Zofia mentioned that **design for a smart model is important**. We should think of control algorithms, technology development, and do not forget to include IT experts in the development of SG. Moreover, research on smart meters would be worthwhile, from a technological point of view, since they play a very important role in SG.

Interview with Jochem Douw

- *Specific field:*
    - Behavior and interactions of humans in smart grids in the social layer.
- *Specific contribution:*
    - The **challenge in SG is to combine privacy and sustainability.** Specific challenges are the following:
        - How do the prosumers behave and interact in SG?
        - How to use a flexible price? We distinguish different kinds of people: price-oriented, convenience-oriented and sustainability-oriented people.
        - What are the best incentives for those people to move them to certain behaviour regarding energy usage?
    - Agent-based modelling: a different approach instead of purely theoretical models. Modelling the process is sometimes more important than the results, where one looks at the problem more accurately. Agent-based modelling is vaguer, more dynamic and less exact. The agents are the consumer and producer parties. Insights from social psychology are included about how values, norms, goals etcetera guide decision processes. Interesting challenges are: how to measure sustainability, control energy generation plants and how to use sustainable energy in a proper way.
- *Connection to SGE:*
    - Including human interaction and aspects in the models.
- *Further ideas on smart grids:*
    - **Data management can be a challenge in SG.** From both a technical and a legal point of view. There should be a good reason to collect data before it is actually done, instead of the other way around. On top of that, how is security managed? How long do you want to save the data? One can think of not storing all the separate data, but aggregated data, so that hackers can do less with this information.
    - Large-scale roll-out of smart meters will be done in the Netherlands soon. How do these contribute to sustainability and how to preserve privacy? There is a need for privacy-friendly meters.