Future Energy Grids – Challenges and Potential for ICT

Hartmut Schmeck

Mischa Ahrens, Florian Allerding, Birger Becker, Kevin Förderer, Christian Hirsch, Fabian Kern, Sebastian Kochanneck, Manuel Lösch, Ingo Mauser, Jan Müller, Fabian Rigoll, Fredy Rios, Julian Rominger, Sebastian Steuer, and many students
Starting points …

- Didn’t we have a nice, stable energy system:
  - (almost) constant voltage on several levels
  - (almost) constant frequency
  - (almost) no black-outs
  - Mainly central power generation followed by transmission, distribution, consumption
  - Intelligent system of balancing power, almost no need for communication
  - Affordable power prices
Ongoing Changes: Smart Grids

- Use of information and communication technologies (ICT) for an increasingly smarter and more efficient power generation, transmission, distribution and consumption.

→ Smart Grid Architecture Model **SGAM**

→ But still no fundamentally different structure of the grid

- New problem: **Cybersecurity**, i.e. vulnerability of the energy grid by attacks on the “ICT”

- Vulnerable due to mainly centralised structure

- So, why do we really need ICT4Energy?
Further changes: European Energy Technology Targets

Strategic Energy Technology Plan 20-20-20:
March 2007: EU targets to be met by 2020:

- 20% reduction of EU greenhouse gas emissions (relative to 1990)
- 20% share of renewables of overall EU energy consumption
- 20% increase in energy efficiency. (relative to 1990)

More ambitious targets of Germany:

Fall 2010:

30% renewables by 2020,
50% by 2030,
80% (?) by 2050

Spring 2011: “Energiewende”

Highly accelerated replacement of nuclear power with renewables (by 2022)

2010: 140 TWh (22 % of total)  →  2012: 90 TWh  →  2022: 0 TWh ??

For a sailor, “wenden” means tacking:
→ There won’t be just one tack!
Major problems to cope with:
**Fluctuations – in demand and supply**

- Variations at different time scales, only partially predictable
- How to deal with fluctuations? → demand and supply management
- How to compensate for a „dead calm“??
Power generation in Germany

February 8-17, 2018

Source: Fraunhofer ISE, www.energy-charts.de

July 22 – 31, 2017
Major Problems: Uncertainty
actual and predicted wind+solar on 14.6.2017

14.6.17, predicted: at 12 h: PV 20 GW, Wind 25.4 GW
14.6.17, actual: at 12 h: PV 25.5 GW, Wind 4.7 GW

→ Additional need of 10 GW from conventional power plants!
→ How to deal with these spontaneous deviations??
Major Problems: decentralization bottlenecks in the low voltage distribution grid

Local voltage increase due to PV power infeed

Local voltage decrease due to EV charging

These visualizations are a result of E-Energy project MeRegio.

Source: Stephan Kautsch ABB
Traditional Energy Management

Power grid needs a steady balance between demand and supply (otherwise problems from fluctuations of frequency and voltage)

- Traditional assumptions of energy management and control:
  - Demand cannot be controlled
  - Electricity cannot be stored
  - Mainly centralized supply at the high voltage grid
  - Demand located in the low voltage grid.

- Standard control using spinning reserve, balancing power (primary, secondary, minute, hour,..)
- Triggered by deviations of frequency

→ Major Principle: Supply follows demand
Future Energy Management

Implications of renewable energy sources:

- Supply only partially controllable or predictable.
- Supply becomes decentralized and moves towards demand side into the low voltage distribution grid.
- Potential reversal of power flow

→ New Challenge: Demand has to follow supply!

Consequence

- Discover and exploit degrees of freedom for decentralized “demand (and supply) management” (load shifting)
- Develop new storage technologies

⇒ Strong need for flexibility by intelligent “demand and supply management” to increase dependability of the energy system in spite of fluctuating, hardly controllable power generation from renewable sources.
Need for flexibility – a fundamental problem

In the future there will be abundant energy, but not always at the appropriate time.

How can we create flexibility in demand and supply of energy?

- **Discover** degrees of freedom with respect to time and size of power consumption or generation
  - Observe the relevant components (→ HVAC like components)
  - Ask explicitly (→ user controlled devices, appliances, EVs, …)

- **Exploit** the information about flexibility to adjust the load profile to external requirements (for balancing supply and demand)

- **Utilize** storage capacities.

→ **This has to be supported by intelligent use of ICT:**
  - Measuring
  - Modelling and simulation
  - Prediction and optimization
  - Operational control
Future Energy System + ICT

Transmission grid

Distribution grid
+collection
+exchange

Energy flow (electricity)

Information flow
(Energy information network with distributed system intelligence)
Where should “system intelligence” be located?
What do we have to communicate?

Power generators

Substation (transformer) (20kV / 0,4kV)

EEX or other markets

Power provider (utility)

PV-panels

Communication

Power flow

E-car

BGM

CHP

stove

WaMa

IM

CE

DSL
Who is communicating in the power grid?

Physical view

- Generation (coal/gas/water)
- Extra-high voltage level
- High voltage level
- Medium voltage level
- Low voltage level
- Rural (radial) network
- Urban (interconnected) network
- Urban (meshed) network
- Business Consumer
- Private Consumer
- Energy Storage (water)

System operation:
- Balancing groups
- Regulation

Source: C. Gitte
Who is communicating in the power grid?

Source: M. Ahrens (KIT-AIFB)
Who is communicating in the power grid?

Source: M. Ahrens (KIT-AIFB)
What do we have to communicate?

- **Information on the current state of relevant components**
  - Energy consumers
  - Energy producers
  - Storage („Prosumer“)
  - Grid components (Substations, cables,…)

- **Which information?**
  - Voltage (+ current? + frequency?)
  - Power
  - Phase shifts (cos $\varphi$)
  - Current degrees of freedom wrt
    - Amount of consumption / production
    - Time period for consumption / production
What is sent to whom?

- **Exchange information on the current state with those who need this information for performing their duties:**
  - Next level energy manager (distribution system operator, energy supplier (trader), demand side manager, aggregator, …)
  - Partner in the energy system who is involved in cooperation.

- **Communicate derived data:**
  - Demand/supply forecast values, price, and control signals
  - “Day-ahead”, “intra-day”,… price signals
  - Control signals for the anticipated use of components in the energy system
  - Sent between buildings, markets, aggregators, DSOs, TSOs, …
More detailed questions …

- **Which and how much information is needed?**
  - On each consumer/producer or aggregated over many?
  - On which time scale? Real-time? Every second, minute, x minutes, hours?

- **How to communicate?**
  - Using the power grid (Powerline? Digital current?)
  - Using a data grid (fibre? DSL? phone? …)
  - Wireless (WLAN, GSM, GPRS, UMTS, LTE, LoRa, …)?

- **Where is the information processed?**
  - Decentralized (within a house? an EV? a grid segment?)
  - Centralized (in a balancing group? at the power supplier? at the distribution grid operator?)

- **Which system architecture is needed?**
  - Central, decentral, hierarchical,
  - Tree-like, mesh-like, cellular?
... and even more ...

**Which are the most appropriate concepts for the control of demand and supply of electrical (and thermal) energy?**
- Market mechanisms
- Exact or approximate planning and optimisation
- Strictly local versus strictly global versus hierarchical, Trade-offs

**What are the objectives?**
- Balancing demand and supply
- Generation of system services (reactive power, balancing energy,..)
- Reduction of energy consumption
- Generation of monetary profit

**What about data protection and privacy??**
- Anonymisation / Pseudonymisation
- Traceability

**Which problems arise wrt security and safety?**
- Access protection, detecting and preventing attacks
- Resilience, dependability / manipulation of data, robustness issues
Integrated multi-modal energy grids

Power plants:
- Wind Power Plant
- Steam Power Plant
- Gas & Steam PP
- Bio-PP

Power transmission grid:
- Power transmission grid

Power distribution grid:
- Power distribution grid

Gas transmission grid:
- Gas transmission grid

Gas distribution grid:
- Gas distribution grid

Gas storage:
- Gas storage

Heat distribution grid:
- Heat distribution grid

Bio-CHP

Integrated energy management:
- Power management
- Gas management
- Heat management

Heat pump

PV

E-Mobility

H2-Mobility

CHP

boiler

G

G

Thermal storage

Hartmut Schmeck - MMB 2018
Integrated Energy Management Systems

- Balancing demand and supply within each grid
- Energy conversion in between gas, power, and heat, e.g.
  - "real conversion" of power to gas e.g. by electrolytic methods (H₂) and methanation in order to consume overflow of power supply from wind power plants
  - "virtual conversion" of power to gas in bivalent systems e.g. by switching between gas boiler and electric boiler
- Interoperability of energy management systems for power, gas, and thermal grids (→ standardized interfaces?)
- Integrated energy information grid with distributed system intelligence in order to increase the efficiency, flexibility, and stability of the integrated grids.
Looking for flexibility …

- **„Smart Homes“ and buildings**
  - Power flow
  - Communication
  - PV-panels

- **Electric vehicles**
  - G2V and V2G
  - Most of the time parked somewhere
  - Charging process offers high potential for flexibility

- **Industrial processes**
  - Exploit potential flexibility without reducing productivity
  - Utilize large consumers (HVAC), producers (CHP) or storage for energy system services

Hartmut Schmeck - MMB 2018
Some projects …

SESAM: P2P-based energy market

Kopernikus project ENSURE

MeRegio (mobile): Organic Smart Home architecture

FZI House of Living Labs: generic architecture for communication and control

Center of competence for applied security technologies
Patterns for Communication and Exploitation of Flexibility

- The pattern determines which information needs to be exchanged

- **Physical demand response**
  - Full transparency of devices

- **Direct market demand response** of abstracted flexibility
  - Communication via an abstract model

- **Indirect market demand response**
  - Incentive based flexibility exploitation

- **Decentralized market demand response**
  - Exchange of abstracted flexibilities and coordination signals without centralized entities

Source: K. Förderer et al, Proceedings ETG 2017

Hartmut Schmeck - MMB 2018
Energy Smart Home Lab on KIT Campus

- Intelligent appliances
- Electric heater
- CHP
- A/C
- Energy Management System (EMS)
- Observes and controls electric/thermal consumers & providers
- Charging station
- 4-quadrant amplifier
- Smart Meter
- Battery simulator
- Solar inverter
- PV power simulator
- Visualisation of energy usage
- Discover user preferences
- Energy Management Panel (EMP)

- PV power simulator
- 4-quadrant amplifier
- Intelligent appliances
- Electric heater
- CHP
- A/C
- Energy Management System (EMS)
- Observes and controls electric/thermal consumers & providers
- Charging station
- 4-quadrant amplifier
- Smart Meter
- Battery simulator
- Solar inverter
- PV power simulator
- Visualisation of energy usage
- Discover user preferences
- Energy Management Panel (EMP)
User interaction in the Energy Smart Home Lab
Energy Management Panel

Provide information
- Transparent information on current energy situation
- Information on load profile

Discover degrees of freedom
- Input on preferred time of operation
- Configuration of user preferences
User interaction in the Energy Smart Home Lab

Energy Management Panel

Provide information

- Transparent information on current energy situation
- Information on load profile

Discover degrees of freedom

- Input on preferred time of operation
- Configuration of user preferences
Energy Management Panel

Example Tumble Dryer

Programmed state

Forced start

Degree of freedom

Automatic start: 18:00h

Hartmut Schmeck - MMB 2018
Building Energy Management System

- **Organic Smart Home**
  - Monitoring
  - Simulation and Optimisation
  - Control

actively running at ESHL and at FZI HoLL

http://www.organicsmarthome.org
Optimization in the Organic Smart Home:

EA

Initial/current Population

Evaluation

Selection

Recombination/Mutation

Stopping criteria reached?

Transform()

PP WaMa

Transform()

PP DishWasher

Transform()

PP CHP

Evaluate()

PP WaMa

Evaluate()

PP DishWasher

Evaluate()

PP CHP

Simulation core

Signals and (user) preferences
Improving self-supply by load management

- Ratio of self-supply with power from PV and µ-CHP (typical profile of a 5-person household, without stationary batteries)

Source: F. Allerding
Load flexibility observed in MeRegio pilot region (1000 customers)

[Hillemacher et al. 2012]
How can the flexibility potential be utilized?

- "peak shaving": relevant for industry having power-based tariffs
- **Increase self-supply** with energy, reduce dependence on the grid.
- **Energy trading**: buy or sell on the spot markets
- Provide energy system services:
  - **Demand response**: adjust the load to desired profiles.
  - **Balancing power**: primary, secondary, … quite often using “aggregators”.

How to organize management of flexibility in larger facilities?

Facility Energy Management System

- Energy Demand
- Energy Supply
- Flexibility Potential
- Energy Storage

- Combined Heat and Power
- Condensing Boiler
- Space Cooling
- Space Heating
- Electric Vehicle Trips
- Electric Vehicles

- Buy/sell day-ahead
- Buy/sell intraday

- Offer possible schedule deviations (kW per time slot)

- Call of reserve offer
  (i.e. order to adjust overall facility schedule $\pm x$ kW in relevant time slot)

- Day-ahead
- Intraday in case of reserve call

- On-site needs
- Predictions
- Interaction with 3rd parties

- Device schedules
- Adjusted device schedules

- Adjusted device schedules

- Device schedules

- Energy Market
- Reserve Market

- Energy Supply
- Flexibility Potential
- Energy Demand

- Source: Manuel Lösch (FZI)
How to test and simulate? The scenario at KIT-ESHL

- Basic “Hardware in the Loop” scenario
- Uses power grid models

- Needs time synchronization
Summarizing challenges for "ICT for energy"

- Communication of essential information between the relevant "entities" in the grid
- Efficient and dependable information processing for various tasks
  - Prediction of power demand and supply
  - Modeling and simulation of the energy system
  - Planning and optimisation of grid operations
  - Support of market operations (trading agents, blockchains (??)…)
  - Demand and supply management
  - Control of batteries of various types of EVs (charging, power-feedback)
  - Virtualisation of components (virtual power plants, virtual storage, …)
  - Support of system services (reactive power, demand response,…)
  - Support of emergency actions (failures, power outages,…)
  - Authentication, roaming, accounting, billing,…
- Various services for integration of electric mobility into the grid
- Various issues wrt security and safety
Summary

Power generation from renewable sources produces a need for

- **Energy information and control networks with distributed system intelligence.**
- Dependable energy supply in spite of highly decentralized, cellular systems.
- Discovery and exploitation of load flexibility.
- Integration of storage (mobile and stationary) to allow for intelligent balancing of power demand and supply and for new power system services.
- Load management and load shifting without inflicting with personal comfort or industrial productivity.
- Coping with safety and security problems.
- Inherently multi-disciplinary challenges for
  - Power Engineering
  - Control Engineering
  - (Energy) Informatics

→ **We have to provide realistic and adequate solutions!**

Thanks for your attention!

Questions?
Contact:

KIT Campus South
Prof. Dr. Hartmut Schmeck
Institute AIFB – Geb. 05-20
Kaiserstr. 89
76133 Karlsruhe
Germany

hartmut.schmeck@kit.edu
www.aifb.kit.edu and www.fzi.de