Our Energy Informatics Agenda: Putting Bits in Energy

Hans-Arno Jacobsen, Professor
Alexander von Humboldt Professor

Technische Universität München (TUM)
Department of Computer Science
Application and Middleware Systems Research Group
Agenda

- Where we are coming from
- What is energy informatics
- Energy informatics teaching
- Selected research projects
Our Research Scope

Application & Middleware Systems Research Group

Energy Informatics
- Energy efficiency
- Smart Grids
- PEVs

Agile Computing
- FPGAs
- GPUs
- APU

Middleware Systems
- BPM
- Event Processing
- Pub/Sub

Application Systems
- Big Data
- Machine Learning
- Analytics
- Complex Events
- Big Events
- Business Processes
- Enterprise Computing
Energy Informatics (EI)

• Emerging **interdisciplinary** area
  – Interdisciplinary research involving among others electrical, mechanical, civil & computer engineering
  – Acquisition of new competences (energy conversion, power systems, etc.)

• Two perspectives
  – Develop systems that **manage energy more sustainably**
  – Develop more **sustainable computer systems**

• Evaluate systems based on **realistic models and data**
Dagstuhl Seminar & Community Building

Energy Informatics – Current and Future Research Directions.
BISE 2013.
Our Energy Informatics Teaching

• Lecture (IN2280, 5 ECTS)
  – Big Data and data analysis in the energy domain
  – High performance computing for power systems
  – Electricity market design
  – Modeling and simulation of renewable energy resources and energy storage
  – Information age demand-response
  – Smart buildings and smart grids

• Seminar (IN4725, 4 ECTS)
  – Supervise students in research on EI topics
  – Literature review, empirical studies, and prototyping
Energy Informatics Lab

- Household demand forecasting (machine learning using WEKA)
- Wind power forecasting (machine learning using Python libraries)
- Distribution grid simulations (using GridLab-D)
- Optimal power flow and unit commitment optimization (using Matlab)
EI Database

- **Problem:** Data supporting EI research hard to come by
- **Solution:** EI database in usable format
  - Available data sets to date:
    - Household electricity consumption traces
    - EEX Day Ahead
    - EEX Generation (actual/expected conventional/solar/wind)
    - EPEX Spot Market (intra-day and auction)
    - Ancillary services (demand and tenders)
    - ECMWF (wind 10 meter, temp 2 meter, solar radiation, …)
  - Continuously updated and extended
Research Partnerships

Academia

Industry

Technische Universität München
Smart Grid Middleware Vision

- **Smart Grid Applications**
  - Power system operator apps
  - Aggregator apps
  - End user apps

- **Smart Grid Middleware**
  - Distributed computation
  - Distributed storage

- **Physical Communication Network**
  - Wide area network
  - Local network access points

- **Power Grid**
Projects Overview

Big Data & Machine Learning
- Household Electricity Demand Forecasting
- Wind Power Forecasting
- Energy Informatics Database

Modeling & Simulation
- Efficient Distributed Discrete Event Simulation
- Open Grid Map
- Bringing Distributed Energy Storage to Market
- DOPS - Distributed Optimization over Pub/Sub
- VOS-Based Real-Time EV Charging Control
- Budget-based EV Charging Control

Prototyping
- Transmission Grid Monitoring with PMUs
- Smart Energy-Saving Systems

Energy Informatics
- Database

Wind Power Forecasting

Household Electricity Demand Forecasting

Efficient Distributed Discrete Event Simulation

Open Grid Map

DOPS - Distributed Optimization over Pub/Sub

VOS-Based Real-Time EV Charging Control

Budget-based EV Charging Control

Smart Energy-Saving Systems

Transmission Grid Monitoring with PMUs
Real-Time EV Charging Control

• **Problem:** Find fast and scalable method for near-optimal real-time control of EV (dis)charging

• **Challenges:**
  – Complex optimization problem
  – Real-time requirement
  – Dynamic influences: Variable non-EV load, renewable power, and EV (dis)charging availability

• **State-of-the-art:**
  Centralized optimization based on full state information

VOS-Based Real-Time EV Charging Control

• Solution: VOS
  – Vehicle-Originating-Signals (VOS): Encode EV state as need-for-charge & willingness-to-supply signals
  – Computation of real-time controls by aggregator

• Advantages:
  – Real-time availability of controls
  – Increased privacy
  – Low dependency on predictions
  – Decoupled EV complexity
  – Faster than optimizing with comparable results

10K EVs, guarantee errors < 1% for 80% of cases

EV Charging Control

- **Problem:** Control EV charging to avoid grid overload and make optimal use of the available infrastructure

- **State-of-the-art:**
  - Direct control: Not scalable & no data privacy
  - Incentive-based control: Not fast enough

- **Challenge:**
  Define a distributed optimization algorithm that can cope with real-time requirements

[IEEE CDC’13 & CDC’2014]
Budget-based EV Charging Control

- **Solution:**
  - Budget-based control
  - Protection IEDs define a maximal charging rate for EVs based on the grid state

- **Advantages:**
  - Optimal use of the infrastructure
  - Anytime algorithm allows real-time response

[IEEE CDC’13 & CDC’2014]
Bringing Distributed Energy Storage to Market

- **Problem:** How to control a large number of stationary batteries for flexible and concurrent participation in energy and reserve markets

- **Challenges:**
  - Enabling multi-market participation
  - Develop efficient data structures for market & storage schedules
  - Design of services that translate aggregator requests/controls into individual storage requests/controls
  - Design fast planning and optimization algorithms that scale

- **Approach:**
  - Effective schedule representation
  - Flexible and scalable resource control according to market rules
  - Several techniques for solving dispatch problem
Household Electricity Demand Forecasting with Complex Event Processing

- **Problem:** Identify effective solutions for disaggregated electricity demand forecasting (smart meter & device level)

- **Challenges:**
  - Highly individual, uncertain and variable demand on household level
  - Many existing forecasting techniques
  - High computational cost of applying existing techniques

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[IEEE SmartGrid Comm’2013]
[ACM Middleware’2013; ACM E-Energy’2014]
At least someone got excited

The Forecasting Challenge for Power Networks of the Future

The energy-efficient power networks of the future will require entirely new ways of forecasting demand on the scale of individual households. That won’t be easy.
Open Grid Map

- **Problem:** Distribution grid information is often not available (even to DSO)

- **Solution:** Infer grid’s structure from available and geo-tagged information collected via crowd-sourcing
Our Energy Informatics Team

Dr. Christoph Goebel
Principal Researcher
Experienced IS researcher (KIT, EPFL, CMU, Humboldt, UC Berkeley, TUM)

Christoph Doblander, Mag.
Doctoral Student
Experienced software engineer (5+ years of industry experience), studied at FH Kufstein, previously worked in gas trading

José Rivera, Dipl.-Ing.
Doctoral Student
Electrical engineer, studied at TUM, Master’s thesis (with Siemens) on electric mobility, visiting student at MIT

Victor del Razo, MSc.
Doctoral Student
Experienced telecommunications engineer (5+ years of industry experience), studied at University of Helsinki

Mathias Kahl, MSc.
Doctoral Student
Electrical engineer, manages our Non-invasive Load Monitoring project; computer science background

Anwar Ul HAQ, MSc.
Doctoral Student
Electrical Engineer, studied at Hanyang University, Korea, Master’s thesis on Game Theory applied to Smart Grids
Conclusions

• Energy Informatics is an emerging area

• Recommendations to funding agencies
  – Establish **open data set archives**
    • The Internet trace archive of energy systems
  – Establish **smart grid test beds**
    • The PlanetLab of power grids
  – Establish **smart building test beds**
    • The EmuLab of smart buildings
Energy Informatics Papers I


Energy Informatics Papers II


