Multi-agent systems and smart grid modeling

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Challenges in electricity grids

Fundamental changes in electricity grids:

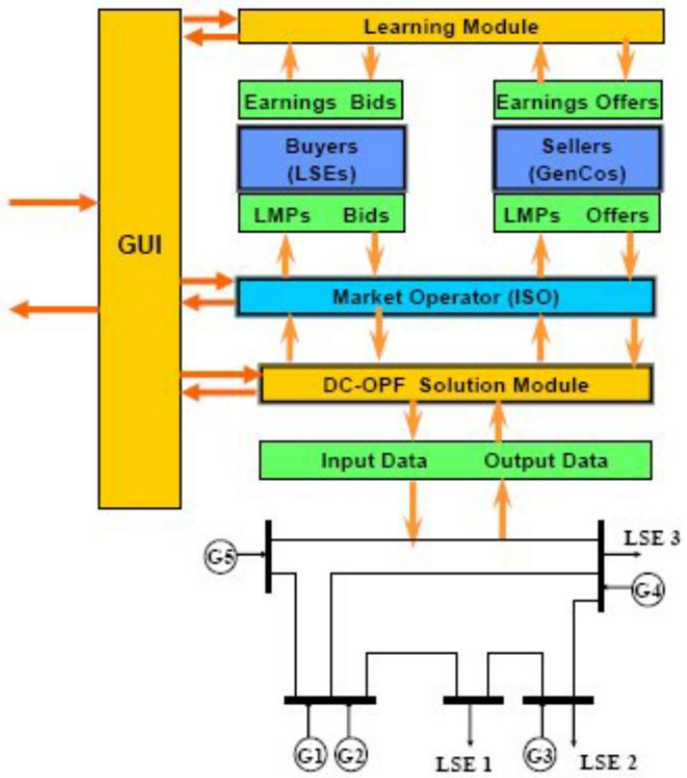
1. Increasing uncertainty (e.g intermittent renewables)
2. New demands (e.g. widespread use of electric vehicles)
3. Increasing decentralisation (many parties taking autonomous, potentially self-interested decisions)

Multi-agent systems

- Agents = software programs that are autonomous, pro-active and reactive and embedded in their environment *(c.f. Wooldridge and Jennings)*
  - Multi-agent simulation
  - Agent oriented design (coalitions, mechanism design)

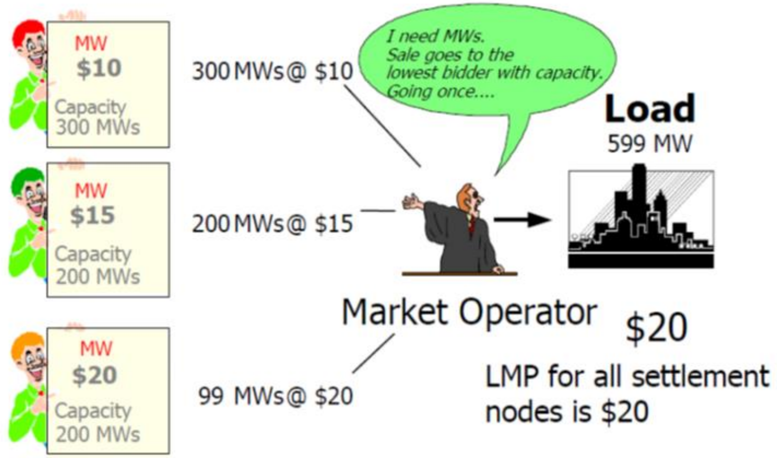
AMES Wholesale Power Market Test Bed

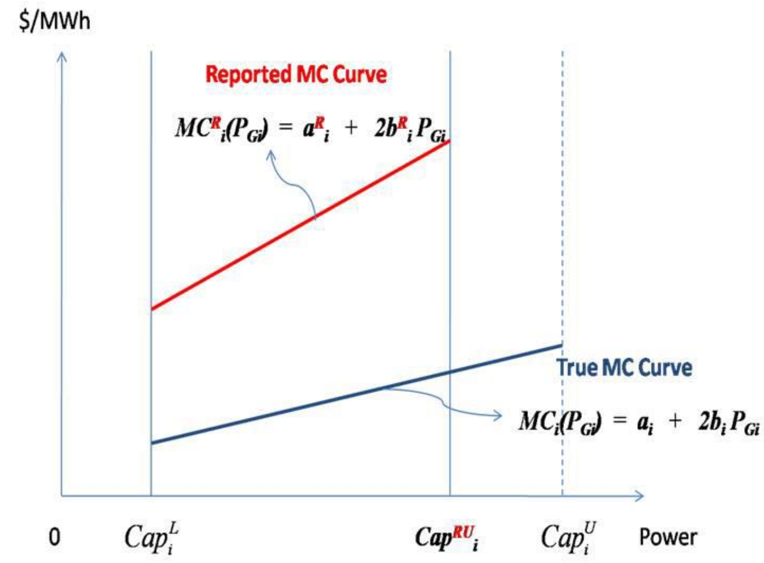
- Agent-based Modelling of Electricity Systems
- Developed by Leigh Tesfatsion (University of Iowa), open source
- Aim: Study the wholesale power market design proposed by FERC
- Management of grid congestion using **locational marginal pricing**
- Huge short-term price volatility observed in practice



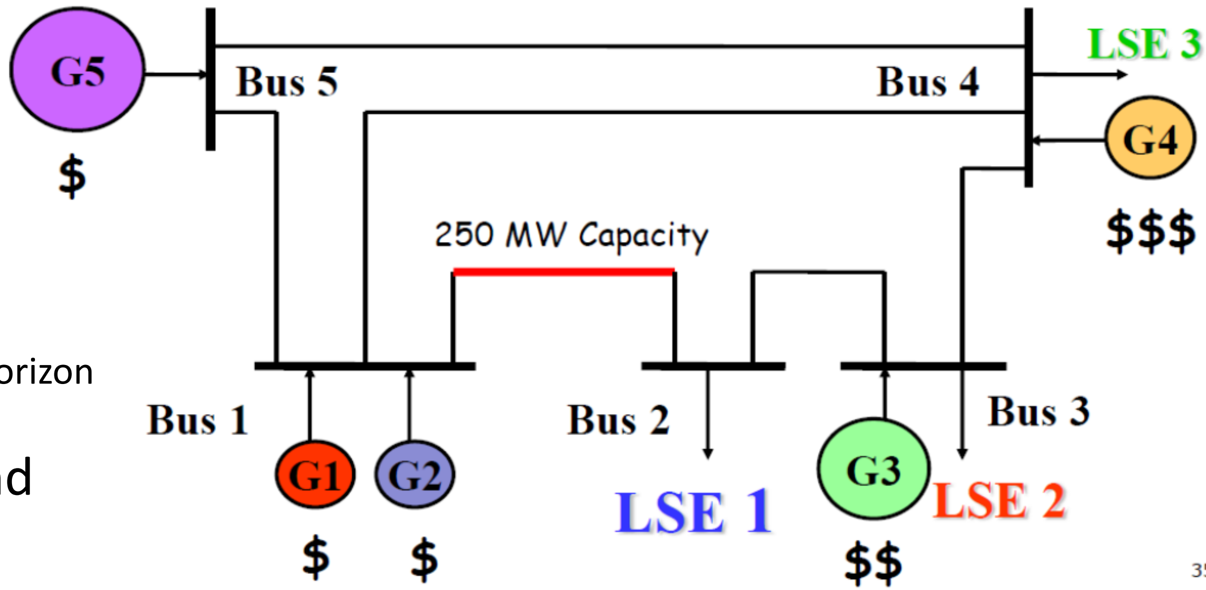
Agents in AMES package features

- **ISO**: *Independent System Operator*
- **LSE**: *Load Serving Entity*
  Buy power for retail customers using demand bids
- **GenCo**: *Generation Company ->* Maximise net profit earnings
  - Supply offers based on linear marginal cost function
  - Potentially untruthful supply offers
  - Learning agents (*stochastic reinforcement*)





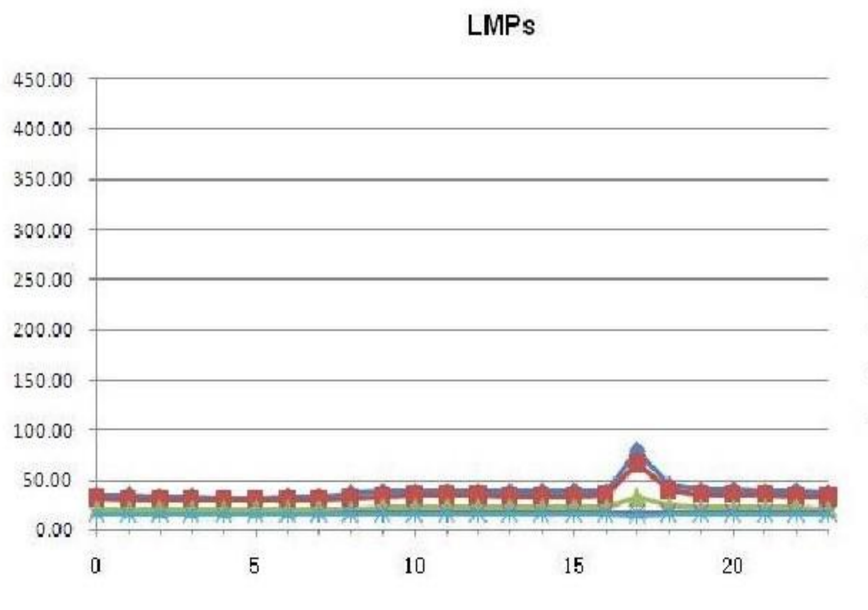
AMES simulation features



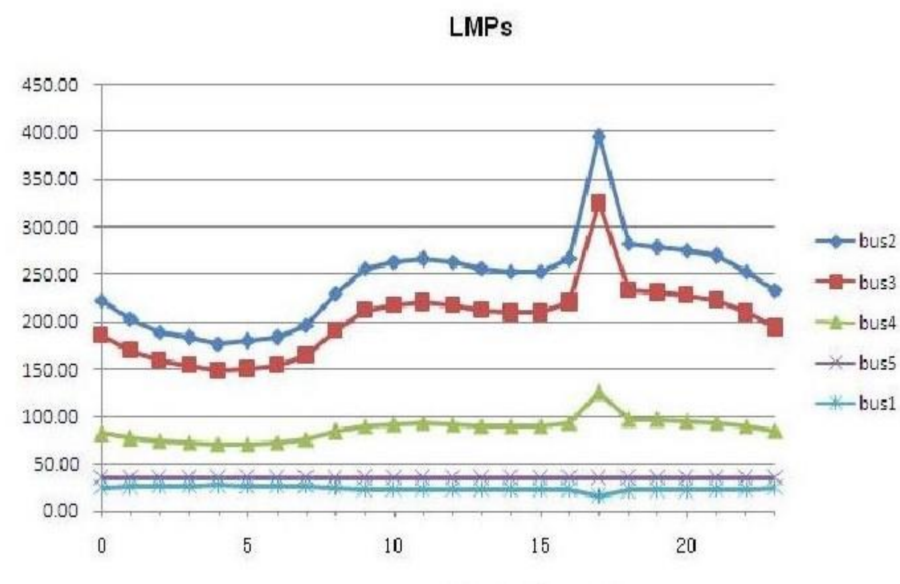
- Forward market
  - User-specified time horizon
  - Hourly simulations
- ISO determines and publicly reports
  - Hourly power supply commitments
  - LMPs based on demand bids/supply offers and Optimal Power Flow (OPF)

5-bus Test Case LMP results

Without learning(truthful GenCos)



Joint reinforcement learning on capacity bids, after convergence



Challenges addressed in my work

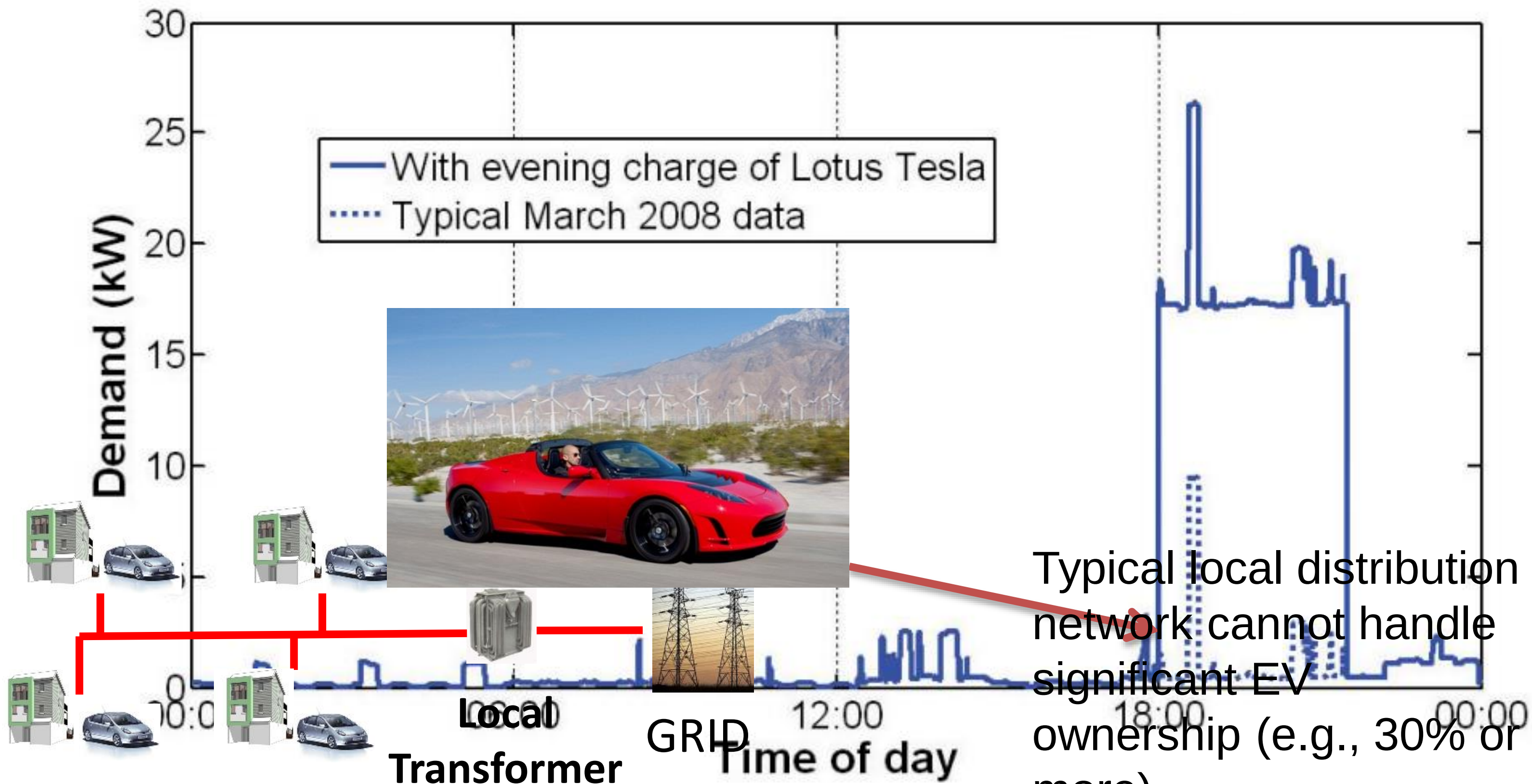
Electric Vehicles

Virtual Power Plants

Demand-side management

Group Buying Coalitions

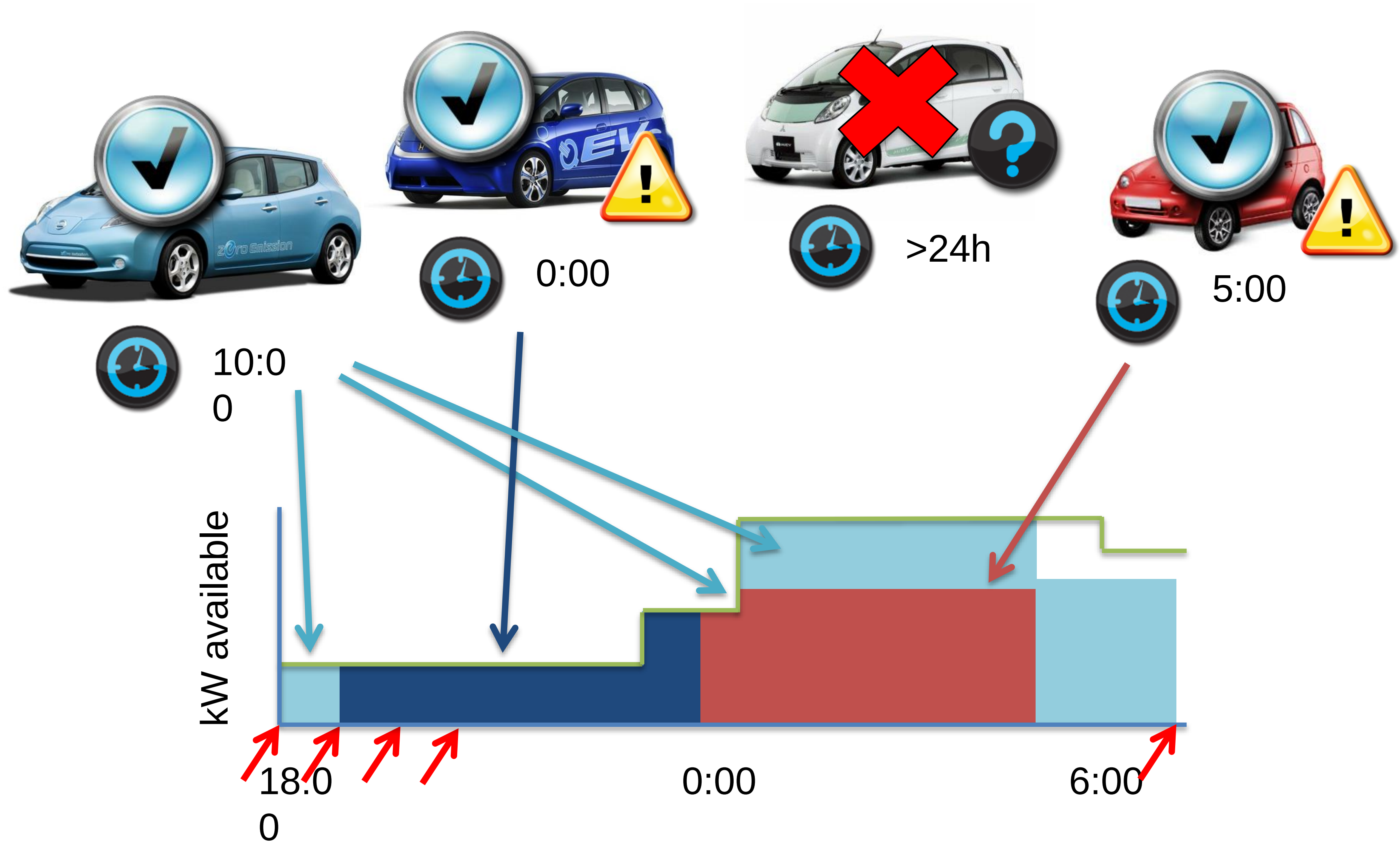
But proliferation of EVs will place unprecedented strains on distribution networks.



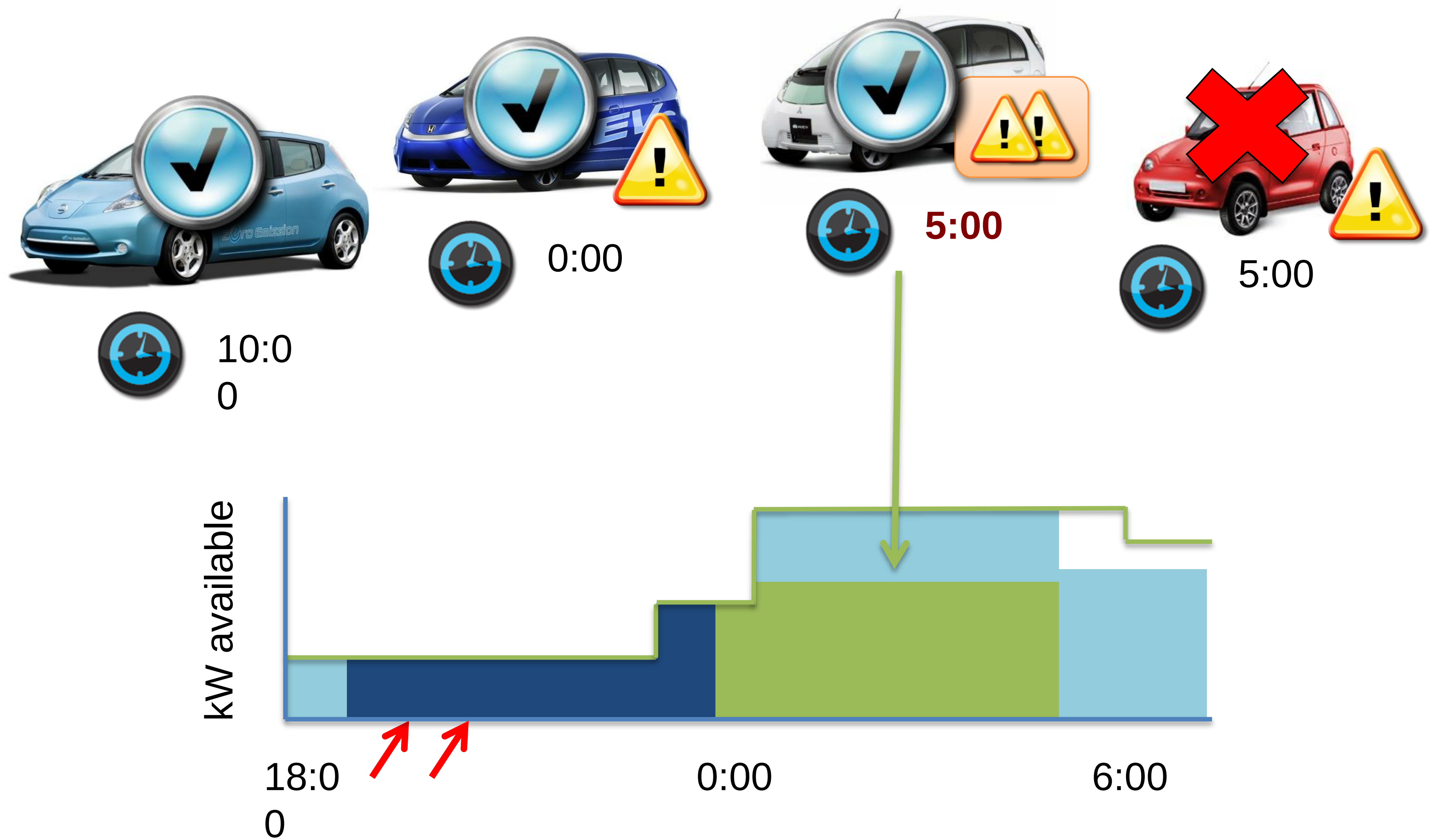
Typical local distribution network cannot handle significant EV ownership (e.g., 30% or more)

Sources: The Royal Academy of Engineering (2010) ***Electric Vehicles: Charged with potential***
ElementEnergy (2010) ***Electric vehicles in the UK and Republic of Ireland: Greenhouse gas emission reductions & infrastructure needs.***

Solution: Stochastic scheduling based on their reported values and deadline

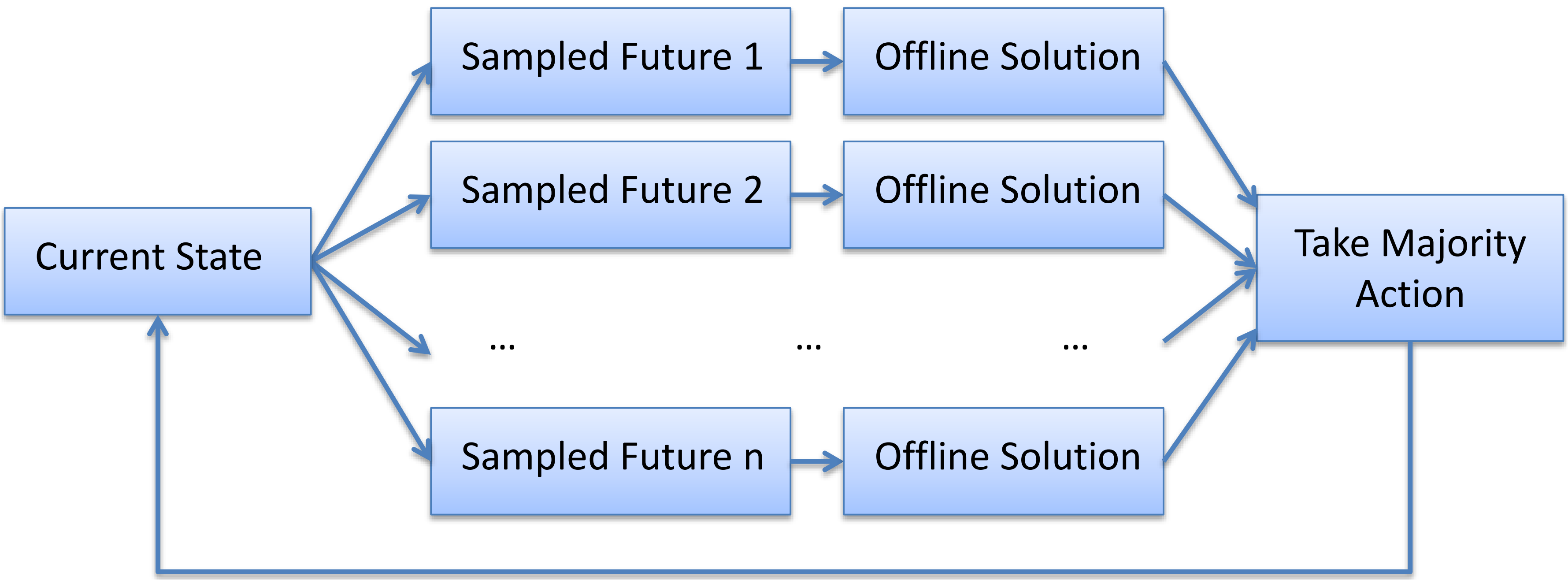


But how about **manipulation**?



We use the Consensus algorithm in our setting.

Consensus: Fast model-based optimisation algorithm based on sampling future scenarios (Bent & van Hentenryck)

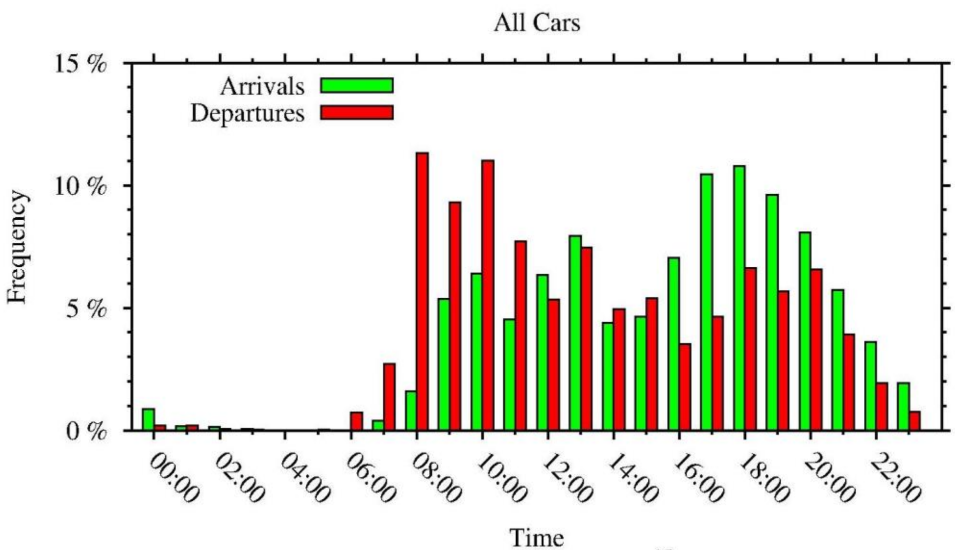


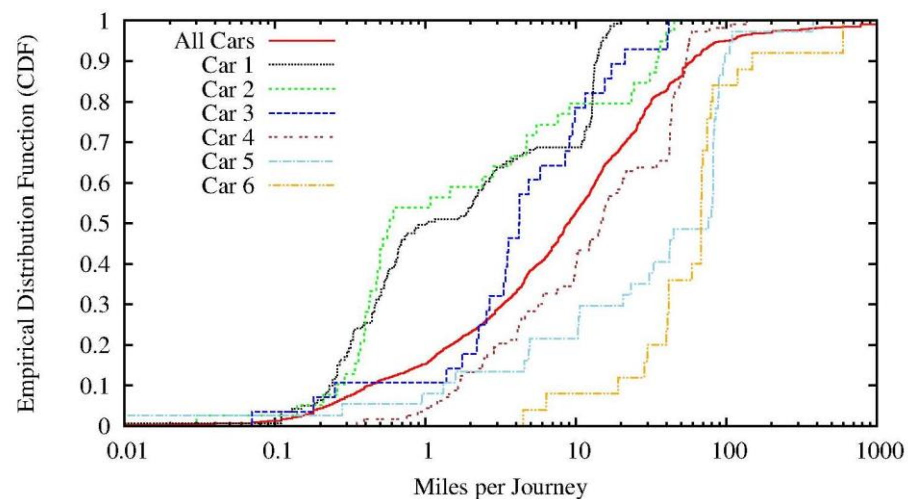
Experimental Evaluation

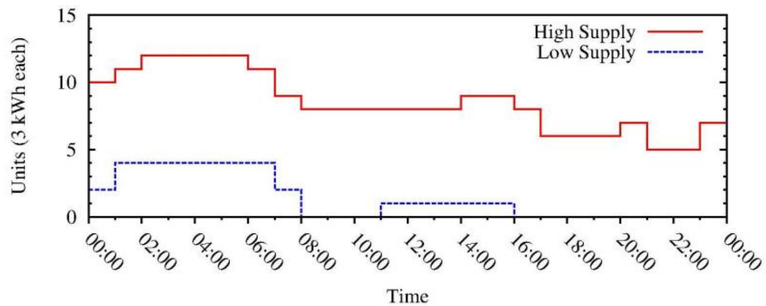
- Based on data from the largest field trial of EVs in the UK (CABLED project).
- Sample from real arrivals, departures and per-trip battery consumption.
- Supply based on typical household electricity consumption.

Using online mechanism design to address strategic manipulation

- Agents have to be truthful about their value, amount of electricity required, but also about their arrival time in the market and deadlines
- Experiments using data from **CABLED**: large-scale trial in the UK (***110 vehicles over 6 months)***

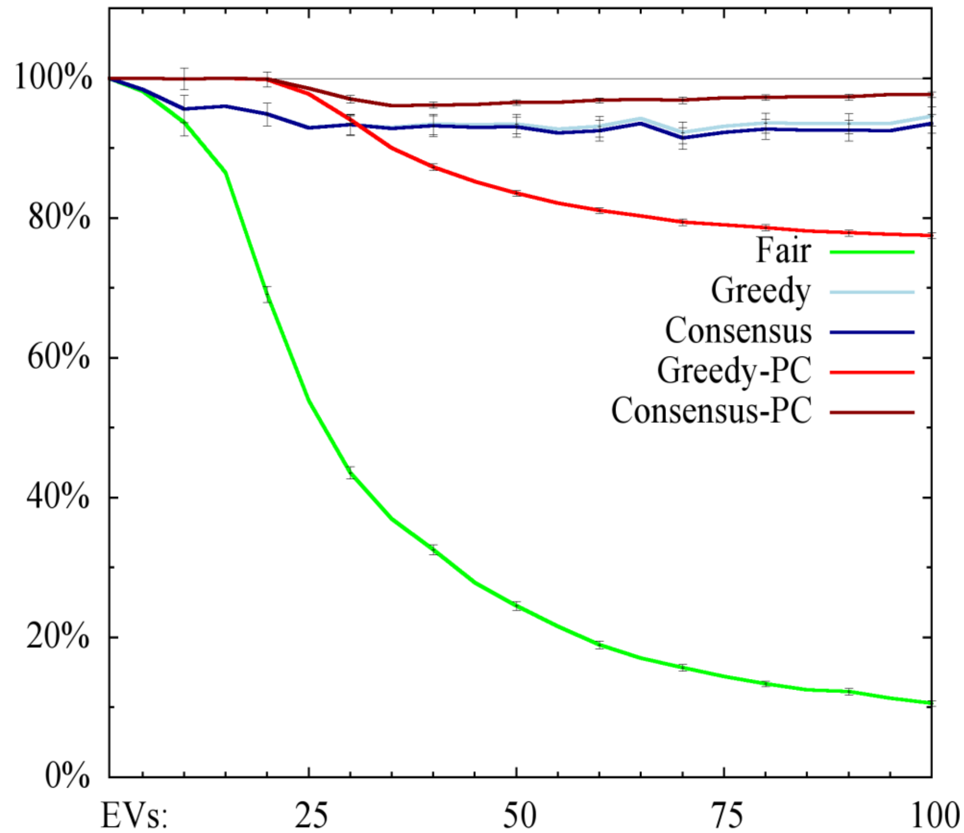






Experimental Results for Consensus

We extend a well known stochastic scheduling heuristic under uncertainty (CONSENSUS), making it work with non-truthful agents)



Average Social Welfare (% of Offline Optimal) for increasing numbers of EVs

Cooperative Virtual Power Plants

- Small renewable resources have appeared in large numbers on the grid
  - Encouraged by generous feed-in tariffs

- Joining forces can improve predictability

- Design payment scheme with dual goal:
  - **Encourage coalitions to form**
  - **Encourage accurate and truthful estimates**

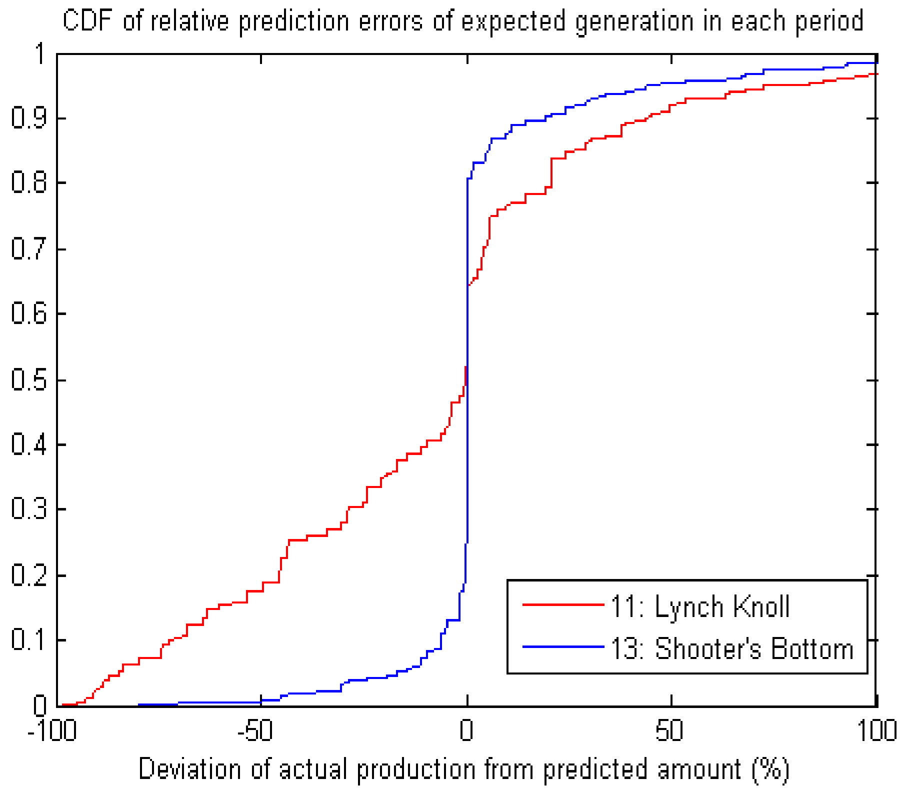
Eliciting truthful predictions through scoring rules

Data used:

- 2 months of half-hourly data from 16 Ecotricity sites
- Wind predictions obtained for 1 to 24 hours in advance

Techniques employed:

- Scoring rule-based payments = way of eliciting probabilistic estimates
- Cooperative game theoretic techniques to divide rewards (e.g. Shapley values)



Micro-trading platforms and blockchains

- Idea: micro-generators, storage owners and consumers in the same "virtual community" can trade energy with each other
  - Piclo, SonnenEnergy (DE) etc.
- In such a distributed system how can we ensure **traceability** or transactions, and non-repudiability?
- How can we make sure we are buying carbon-neutral energy?
  - **Distributed ledger technology**
- Issue of monitoring distribution network constraints

Cooperatives for Demand Side Management

- Large consumers can often shift their consumption paterns
- Sell back "negative watts" of electricity, by shifting their consumption away from peak times

- Goal: allow consumers to contribute to demand management to the grid on an ongoing basis
- Companies already exist that provide demand response services (e.g. Enernoc in the US, **Upside Energy**, Kiwi Power (UK))
- Cloud-based control vs. real time control of Demand Response

Local Renewable Energy Integration

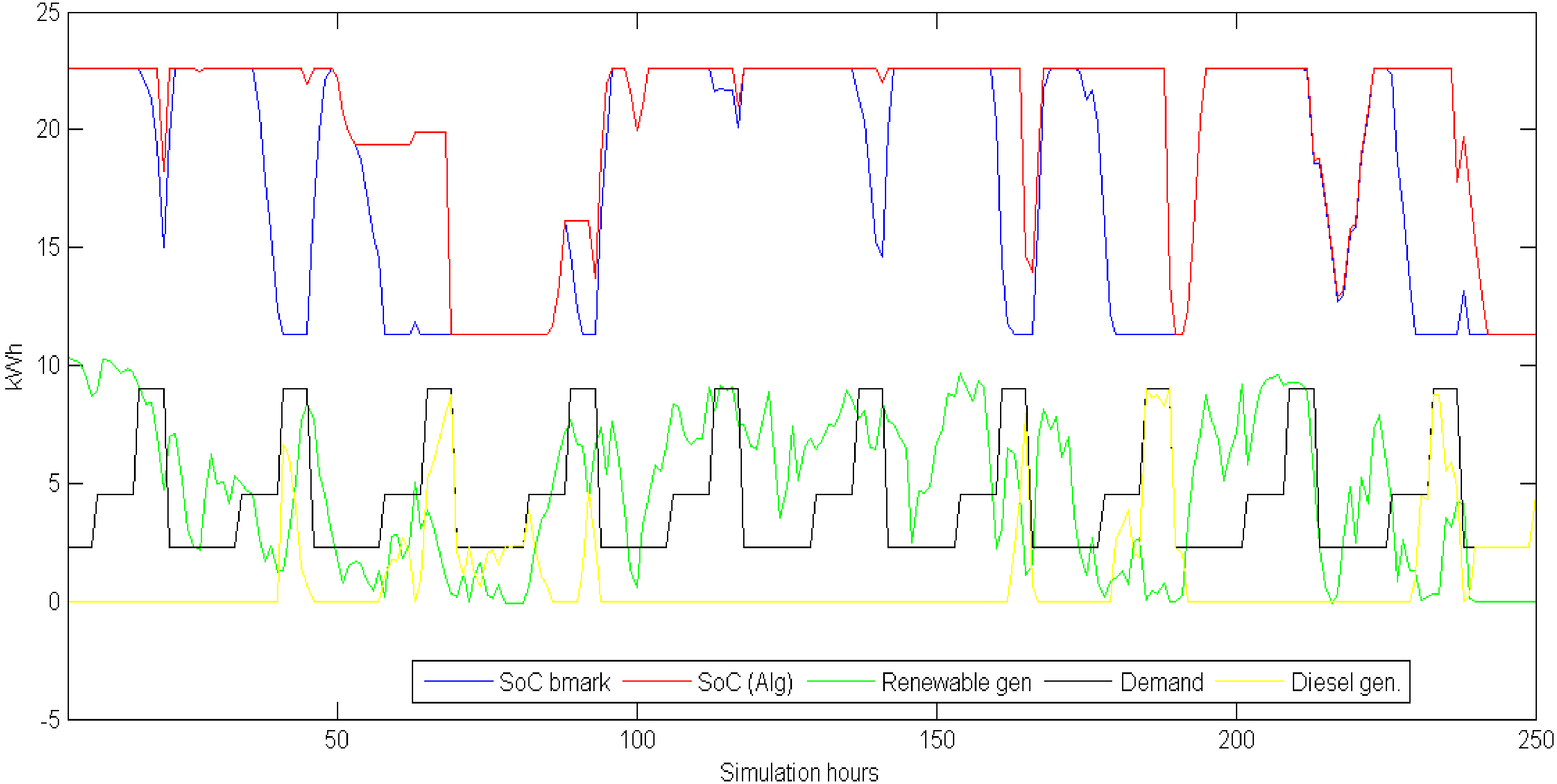
- **Goal:** Design an algorithm for controlling the smart battery charging/ discharging for **weak grid** or **off grid** environments
- Maximal use of intermittent renewable generation (**11 kW wind turbine**)
- Alternative sources:
  - **Battery storage system** (Li-Ion or Lead-Acid)
  - Back-up generation source (**Diesel generator**, partial grid connection)
  - Maximising RUL of the assets
- **Which should be used when?**

Local Renewable Energy Integration

- **Scientific Challenges:**
- Predict how much wind is available, with a certain look-ahead window & residual demand
  - Singular System Analysis, PCA, spatial evolutionary algorithms etc.
- Schedule the use of resources (battery charging and discharging, use of renewable generation, diesel back-up generator)
  - Stochastic optimisation, CONSENSUS-type algorithms

- **Goal:** provide a probabilistic guarantee of continuous supply
  - Different for different users of the system (farm vs. remote hotel in the west islands of Scotland)

SIMULATION Snapshot (~10 days)



Summary

- Multi-agent systems can be a powerful tool to design smart grid systems, both for operational and long-term decisions
- Combination of theoretical concepts (some of which have only recently began to be adopted in practice) with simulations
- Machine learning and “Big Data” aspects increasingly important in building and validating models