Agent Based Modelling of Smart grids:
From Markets to Active demand, Grid control and Adoption of technology

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Transition to a Smart Grid...

- **A smart grid** is an electricity network that can efficiently integrate the behaviour and actions of all users connected to it — generators, consumers and generator/consumers — in order to ensure an economically efficient, sustainable power system with low losses and a high quality and security of supply and safety.” - EC Smart Grid Task Force, 2010

**Smart**

**Efficient**

**Economical**

**Reliable**

**Sustainable**
Transition to a Smart Grid...

* Source: Own Figure

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Goals of a Smart Grid...

- Optimized System Operation
- Active Participation of Demand
- Competitive Market Mechanisms
- Robust and Self Healing Grids
- Integration of Resources

* Source: Own Figure

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Smart Grid will make possible high levels of penetration of renewables by:

- Balancing intermittency with demand side resources and storage
- Better monitoring and forecasting for enhancing the predictability of impacts of intermittent generation
- Managing complicated power flows from DG
- Using advanced technologies for communication and control for managing operational issues such as system balancing, voltage control, short-circuit protection, ancillary services, etc.
Smart Grid Operational Packages

- **SCADA (Supervisory Control and Data Acquisition)**
  - System that collects data from sensors within a plant or remote locations and processes centrally to manage and control devices on the field

- **EMS (Energy Management Systems)**
  - Topology processor
  - State Estimation
  - Three phase balanced power flow
  - OPF (Optimal Power Flow)
  - Contingency analysis
  - Short circuit analysis
  - Relay protection coordination
- **DMS (Distribution Management System)**
  - Optimal Network Reconfiguration
  - Integrated volt/VAR control
  - Optimal Capacitor and VR sizing and placement
  - Optimal DG sizing and placement
  - Load Modelling and Estimation
  - State Estimation
  - Outage Management Systems
  - Fault Detection, Isolation and Restoration
  - Interface to GIS

- **DRMS (Demand Response Management Systems)**

- **AMI (Advanced Metering Infrastructure)**
PREMIO – in mainland France by EDF, 2008 – 2012

- Includes a VPP integrating approximately 50 distributed resources
- Significant load reductions up to 40 %
- Control improvements are needed for more sensitive demand response
- Differences between the types of distributed resources must be taken into account if the results are to be used as leverage to enhance performance
- Communication between distributed resource technologies is crucial for the success of the VPP

Resource types investigated:
- Hot water tank coupled to heat pump to provide load shifting in houses.
- Individual electric storage unit coupled to PV panels.
- Load shedding module dedicated to residential and small tertiary buildings.
- Dimming of LED based public lighting.
- Thermal storage for industrial and tertiary cooling applications.
- Electricity generation unit thanks to thermal storage.
- Solar heat pump along with hot water storage.
- Control of in-home wood stove for winter peak shaving.
California Automated Demand Response System Pilot

- **CPP** with high prices between 2pm - 7pm
- Customers notified during the day before a Super Peak event.
- Users able to view current electricity price on-line or via thermostat.
- Devices could be set to automatically respond to prices.
- 12 Super Peak events in 2004 and 11 in 2005.

- **Time-of-Use (TOU):** A schedule of rates for each period of the day, the simplest case being peak and off-peak periods. There is certainty over the rates and time-periods.

- **Critical Peak Pricing (CPP):** Customers pay higher peak period prices than they would during peak hours on the few days when wholesale prices are the highest. CPP effectively transfers the cost of generations especially for those few hundred hours when supply costs are very high.

- Shifting just 5% of peak demand reduces prices substantially for all users, as expensive peak power plants are not turned on and even need not be built.

- Brattle group found that TOU rates cut peak demand by 3% - 6% and CPP cut peak demand by 27% - 44%.
Projects at IESD

• **CASCADE:**
  ▫ Complex Adaptive Systems Cognitive Agents and Distributed Energy
  ▫ 3-year EPSRC sponsored project
  ▫ Partners: E.On, Ecotricity, Cranfield Univ, CSIRO (Australia), NEF
  ▫ Complexity Science based investigation into the Smart Grid concept
  ▫ Predominantly at the Distribution level

• **AMEN:**
  ▫ Agent-based Modelling of Electricity Networks
  ▫ 3-year EPSRC sponsored project
  ▫ Partners: E.On, NEF, EIFER (Karlsruhe), E.On, Western Power
  ▫ Builds on the CASCADE model
The **CASCADE** Project:

- **Aims to:** reveal, classify and explicate complex system behaviours, entities and reconfigurations that may emerge from interactions of heterogeneous *agents* at multiple scales in decentralised electricity markets.

- **Objective is to:** build an *Agent Based Modelling* (ABM) framework to support simulations of sufficient complexity under various scenarios to achieve the above aim.
**Why Use ABM?**

- Individual, decision-making entities
  - Mutual interaction (co-evolution)

- Patterns (self organisation) emerge from collective behaviour of many individuals

- Feedback and other dynamics

- Change in behaviour (learning)

- Object Oriented features
  - Composition
  - Portability

- Easily scalable
  - Aggregator
  - Generators / consumers
Agent-Based Modelling of Electricity Networks

Technical
- Smart Control of the Grid: Network Management, Voltage & Frequency Control
- Integration of Renewables, Demand Side Management

Strategic
- Strategic operative regimes for increased participation of: Renewables, CCGTs, EVs, Storage, Demand
- Operational and Economic strategies for: Virtual Power Plants, Microgrids, Demand Aggregators

Economic
- Electricity Market Reforms and Mechanisms for a Secure and Efficient Grid
- Market-based scheduling and control by TSO/DSO

Tools
- Agent-Based Modeling: evolution of features
- Optimization tools: operation & control of smart grids
Framework...

[Diagram of energy system framework with various components like Supplier(s), Wholesale Generator(s), Distribution System Operator(s), National Grid Operator, Aggregator, Interactive Gateway, Consumer (Buildings, EV), Producer (DER, EV), Prosumer, Price Signals, Communication Interface (Wi-Fi, WiMax, PLC, RF), Power, Voltage Information.]

* Source: Own Figure

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UK Electricity Market

- Bilateral, OTCs
- Spot Market, Power Exchange
- Balancing Market
Sequencing Chart of the Short Term Electricity Market

- PN = Physical Notifications are generation and demand profiles
- IMBAL = Imbalance between total supply and demand
- Power eXchange operates in multiple blocks
- MIP = Market Index Price
- SSP/SBP = System Sell and Buy Prices

* Source: Own Figure
Sample Case:

- Coal Plants = 2
- CCGT Plants = 3
- Wind Farms = 44
Framework…
• Prosumers
  ▫ Household Prosumers
  ▫ Nondomestic Prosumers
  ▫ Units of conventional centralized power stations
  ▫ Distributed Generators
  ▫ Storage Prosumers

• Aggregators:
  ▫ Aggregating units of a centralized power station
  ▫ Aggregating distributed power resources
  ▫ Aggregating Prosumers within a distribution network zone
  ▫ Aggregating Prosumers of a common supplier
  ▫ Aggregating turbines on an off shore wind farm

Commercial and/or electrical aggregation of heterogeneous/homogeneous prosumers
Aggregator

✓ Commercial aggregation of demand profiles of Prosumers
✓ Market participation: Bids and Offers based on aggregate profiles
✓ Derives and transmits smart signal to Prosumers
✓ Aggregates change in demand
✓ Learns new price signal based on earnings
✓ Satisfies physical constraints of distribution network
Response to Price Signal:

- Baseline Demand, which is an estimate of the next-day demand $D_0$

- Each demand BMU allowed to respond to a price signal $P$

- Reference price for the $i^{th}$ settlement period $=> P_0[i] = \frac{\sum_{j=1}^{N} SBP_j[i]}{N}$

- New Demand $=> D = D_0 \frac{(1 + a)}{(1 - a)}$  
  $a = e \frac{(P - P_0)}{(P + P_0)}$

- The aggregated demand at each $i^{th}$ settlement period of a given day $= D[i] = D_0[i] \frac{(1 + a_i)}{(1 - a_i)}$
• 5 LARGE_DEM, 3 SMALL_DEM sites
• COAL, CCGT, WIND Generators
• Scenario with aggregated elasticity factors of 10% and 30%
• For increase in price signal, aggregate demand reduces
• Deviation of actual price signal from reference price is substantial with less wind penetration

<table>
<thead>
<tr>
<th></th>
<th>Price Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>-0.05 to -0.12</td>
</tr>
<tr>
<td>Commercial</td>
<td>-0.01 to -0.28</td>
</tr>
<tr>
<td>Industrial</td>
<td>-0.01 to -0.38</td>
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Coal plants - 4, CCGT - 7, Wind farms - 3
Framework…

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Grid structure...

- Transmission system: 400 kV, 275 kV, 132 kV
- Sub-transmission system: 66 kV, 33 kV
- Primary Distribution system: 33 kV, 11 kV, 6.6 kV
- Secondary Distribution system: 400 V, 3-phase, 240/230 V, 1-phase

Tie-lines to other systems

* Source: Own Figure

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Snapshot of UK National Grid
IEEE 123-node test feeder
Class Diagram of the Power System Model

* Source: Own Figure

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Voltage Control by DNO:

- Substation Transformer Tap Changing (OLTC)
- Voltage regulator tap changes across the feeders
- Shunt capacitor switching
- Reactive power control at DG nodes
- Network reconfiguration
- Phase-shifting and shedding of loads
Node Voltages on all 3 phases of Feeder
Research Topics Under Investigation

- **Electricity Markets and Trading**
  - Electricity Market Reform and re-design of Balancing Mechanism
  - Optimal Generation Dispatch
  - Active participation of DERs

- **Demand Side Response (DSR)**
  - DSR for following renewable energy generation
  - Energy storage and V2G applications

- **Service delivery modes**
  - Aggregators
  - Contracts and trading models (e.g. Time of Use Tariffs)

- **Social and behavioural aspects**
  - Automatic control (smart boxes, etc)
  - Technology adoption

- **Distribution System Management**
  - Feeder Analysis
    - Voltage profile correction, Congestion Mgmt, Phase Balancing, Network Reconfiguration
  - Intelligent placement and Operation of DERs
  - Reactive power planning
  - Feasible operation of micro-grids
Thank You

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http://www.iesd.dmu.ac.uk/~cascade

http://www.iesd.dmu.ac.uk/~amen