Challenges in Delivering the Smart Grid

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All countries have a vision...

- **Carbon reduction**
  - Enable and accelerate power system carbon reduction
  - E.g. demand-side response to cost effectively integrate inflexible low-carbon generation

- **Energy security**
  - Increasing the network’s capacity to manage a potentially diverse set of new requirements
  - E.g. manage the technical risk of connecting new generation, and of changing demand patterns

- **Economic competitiveness & affordability**
  - Reduce the cost of transitioning to a low-carbon energy system, increasing affordability
  - E.g. reduce need for grid reinforcement to handle new loads

“The UK’s smart grid will develop to support and accelerate a cost-effective transition to the low-carbon economy. Smart grid will help the UK meet its 2020 carbon targets, while providing the foundations for a variety of power system options out to 2050.

The Vision sets out how smart grids may, directly or indirectly: maintain or enhance quality and security of electricity supply; facilitate the connection of new low- and zero-carbon generating plants, from industrial to domestic scale; enable innovative demand-side technologies and strategies; facilitate a new range of energy products and tariffs to empower consumers to reduce their energy consumption and carbon output; feature a holistic communications system that will allow the complete power system to operate in a coherent way, balancing power system to operate in a coherent way, balancing carbon intensity and cost, and providing a greater visibility of the grid state; allow the cost and carbon impact of using the networks themselves to be optimised.”

UK Electricity Networks Strategy Group

University of Strathclyde
Engineering
The starting point - today's power system
Ultimately the UK smart grid routemap is driving toward a smart grid end state

- There are a variety of potential end states and the UK should not be deciding now the precise nature of the UK’s 2050 energy system
- But the ENSG believes that it is important to have an end state in mind even if it changes and evolves over time
- The image below outlines a potential smart grid end state. This was presented in the ENSG smart grid vision

- Grid-based renewables
- Wind Farm
- Nuclear Power Plant
- Natural Gas Transmission
- CO₂ Transport
- Coal & Gas Plant with CCS
- H₂ production – electrolysis
- H₂ storage / generation
- Bio-fuels Production
- Hydrogen, biofuels and gasoline/diesel distribution infrastructure

**Grid-based Storage**

**Transmission & Distribution**

High Voltage Direct Current link to neighbouring grids

**Retail**

- CHP/District heating network, DC Micro Grid
- Photo voltaics
- Heat pump
- Dynamic control of ultra-low carbon vehicle (possibly V2G in the future)
- Demand side management
- Highly insulated housing structure, micro generation

**Customer**

- This type of energy system could require significant changes to the role and activities of the customer within the wider energy system allowing them to participate in the market (potential for automation of customer response)
- In transitioning to a new ‘role’, customers will need to be supported by energy retailers or other organisations with open access and standards widening the net for innovative products and services
The move towards Smart Grids

A SmartGrid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.

A SmartGrid employs innovative products and services together with intelligent monitoring, control, communication, and self healing technologies.

EU wide vision, plus research and deployment agenda, for moves towards smarter grids
What needs to be “Smart” in the Smart Grid?

- Future energy networks must have increased flexibility and controllability through real time decision-making techniques.

- Intelligent control
  - intermittent renewable and distributed generation
  - storage devices
  - demand side actions
  - electric vehicle charging regimes
  - electricity markets

- Intelligent monitoring
  - condition monitoring
  - dynamic ratings systems

- Self healing
  - network power flow management
  - fault level management
  - supply restoration
How do we deliver a SmartGrid which “employs innovative products and services together with intelligent monitoring, control, communication, and self healing technologies”?

- **Distribute intelligence:**
  - Provide localised autonomy within the power system
  - Break down the complexity
  - Manage and interpret data locally
  - Arbitrate and co-operate globally

- **Implement automated data interpretation techniques**

- **Automatically aggregate interpreted data into meaningful information**

- **Provide “plug and play” architectures – flexible and extensible**

**New control and monitoring systems are generating large volumes of data**

**Our vision for new Smart Grid applications requires further measurement, monitoring and control data**

**How can we transmit the data effectively?**
Enabling Technologies

- **Telecommunications, plus:**
  - Knowledge discovery in databases
    - Data mining to uncover useful patterns and relationships
  - Intelligent Systems – data interpretation through AI
    - Knowledge based systems
    - Model based reasoning
    - Neural networks, etc.

- **Machine Learning**
  - Continual on-line learning of behavioural patterns
  - Anomaly detection

- **Multi-Agent System Technology**
  - Autonomy
  - Co-operation
  - Automation of activities
  - Systems integration
  - Customisation of information displays
Distributed Smart Control

Combining power systems, intelligent systems and telecommunications
Active Network Management
AuRA-NMS

Autonomous Regional Active Network Management System

A fully integrated network management system

- Strathclyde
- Imperial College
- Durham
- Edinburgh
- Loughborough
- Bath
- Cardiff

- EDF Energy
- ScottishPower
- ABB
AuRA-NMS

Autonomous Regional Active Network Management System

A fully integrated network management system

Scope of Automation & Control:
- Restoration
- Voltage Control – keep voltage within limits
- Power Flow Management – keep within thermal limits for cables, lines, etc.

Properties of AuRA:
- Selectively Devolved Control
- Network Agnostic
- Flexible (control solutions)
- Extensible (architecture)
- Transparent to Control Engineers
- Robust (CIs & CMLs)

Software functionality deployed on distributed hardware platforms
AuRA-NMS – The Challenges

Challenges:

- Distributed Generation Access
  - Deferral of reinforcement
- Network Performance
  - CML/CI
- Reduce complexity of current constraint management solutions
AuRA-NMS – The Techniques

**Characteristics:**
- Network Agnostic, Flexible and Extensible
- Distributed or centralised

**Power Flow Management (PFM):**
- A constraint programming based approach
- A current-tracing approach
- An Optimal Power Flow-based approach

**Voltage Control (VC):**
- A constraint programming based approach
- A case based reasoning approach
A Constraint Programming Approach to Power Flow Management - Example

33kV interconnected distribution network
• Power flow management control functionality embedded within substation hardware

Load and Generation Profiles
• Force a thermal constraint (Line 1)
An Example...

Closed Loop Testing

1. Line Overloaded
   - a) Loading such that Curtailment can Change

2. Generator Control
   - 80% Signal Sent
   - b) Run unconstrained

3. Generator Output
   - 80% Curtailment
   - c) Curtailment Lifted
Software Architecture

Need for power system measurements and telecommunications
Data Model & Agent Communication Language (ACL):

The “data model” will become the ontology for the multi-agent system. It is based on:

- Common Information Model (CIM)
- IEC 61850 - part 7
- FIPA Standards – FIPA SL
The Approach

Harmonised IEC 61850 and CIM
Industrial deployment of Smart Grid control

Extensive demonstration projects in “piecewise” automation:

- UK - £62M already apportioned of £500M low carbon network fund
- Orkney and Shetland – Smart control of wind generation – SGS
- Smart Grid Cities in US – Boulder, Co, NYC, etc.
- SuperTapp+ and GenAVC – commercial voltage control products.
- S&C Electric, Chicago – IntelliTeam II reconfiguration product
  - Applied in the US and the UK
Distributed Intelligence and Decision Support
Post fault analysis of SCADA and digital fault records

- Decision support for system operation support team
- Implemented for ScottishPower
- Automated analysis of SCADA alarms and events
- Automated data gathering and interpretation of digital fault records
- Multi-agent system solution
Smart Asset Management
Future Network Vision
Future Network Vision

Smart Asset Management
Drivers

Key requirements:
- State and health of assets
- Real-time rating
- Prognostics

Condition monitoring is increasing:
- In terms of new sensors and sensor technology
- In terms of more condition monitoring systems
- In terms of deployment, both on-line & offline

Improved engineering support is necessary:
- In terms of managing and interpreting data
- In terms of corroborating evidence from different sensors and monitoring systems
- Provision of decision support
Unlocking the true value of CM

- Combine condition monitoring with real time network control decisions
- Link condition monitoring with utility asset management systems – combine business and technical information

- Local intelligence
- Local data management

Substation A

Substation B

Substation C

Substation D

Link condition monitoring with utility asset management systems – combine business and technical information

- Local intelligence
- Local data management
EPSRC AMPerES – National Grid Demonstrator

- Two sister transformers
- 275/132kV, 180MVA

Environment
- Solar radiation
- Wind speed and direction
- Atmospheric pressure
- Relative humidity
- Precipitation

Main tank (3 phases)
- Temperature
- Vibration
- Acoustic
- Internal UHF probe

Cooling circuit
- Dissolved gas
- Temperature (external and internal)
- Moisture

Fans
- Load current

Oil pump motor
- Temperature
- Load current
- Vibration

Conservator tank
Active Network Management

Intelligent Condition Monitoring

Network Diagnostics
EPSRC Energy Networks Grand Challenge Project
The Autonomic Power System

**Universities:** Strathclyde (lead), Cambridge, Durham, Imperial College, Manchester, Sussex

**Disciplines:** power engineers, computer scientists, AI scientists, mathematicians, complexity scientists, economists, social scientists

**Industrial partners:** IBM, Accenture, KEMA, Mott Macdonald, Agilent, …

**Grand Challenge for 2050:**

- Can a fully distributed intelligence and control philosophy deliver the future flexible grids required to facilitate:
  - the low carbon transition
  - allow for the adoption of emerging game changing network technologies and
  - cope with the accompanying increase in uncertainty and complexity
EPSRC Energy Networks Grand Challenge Project
The Autonomic Power System

**Programme:** £3.2M over 4.5 years
Industrial Challenges:
- Telecommunications infrastructure & costs

- Utility and manufacturer acceptance of new approaches
  - Including IT/IS Departments

- Legacy equipment and move to new data/automation standards

Research Challenges:
- Architectures for **distributable** control and monitoring

- “Controlled” autonomy vs. emergent behaviour?

- Platforms and toolkits for distributed intelligence

- Data standards

- Explanation – for control centres
Conclusions

To deliver the “Smart Grid” we require a blend of technical expertise:

- Power systems, protection and control
- Distributed intelligence and agents
- Telecommunications

The fundamental building blocks exist:

- Through existing research and prototypes
- In other industrial / commercial sectors

We need to co-operate as a wider community to:

- Deliver the systems
- Convince the end-users, via meaningful applications
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