Challenges in Delivering the Smart Grid

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All countries have a vision…

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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

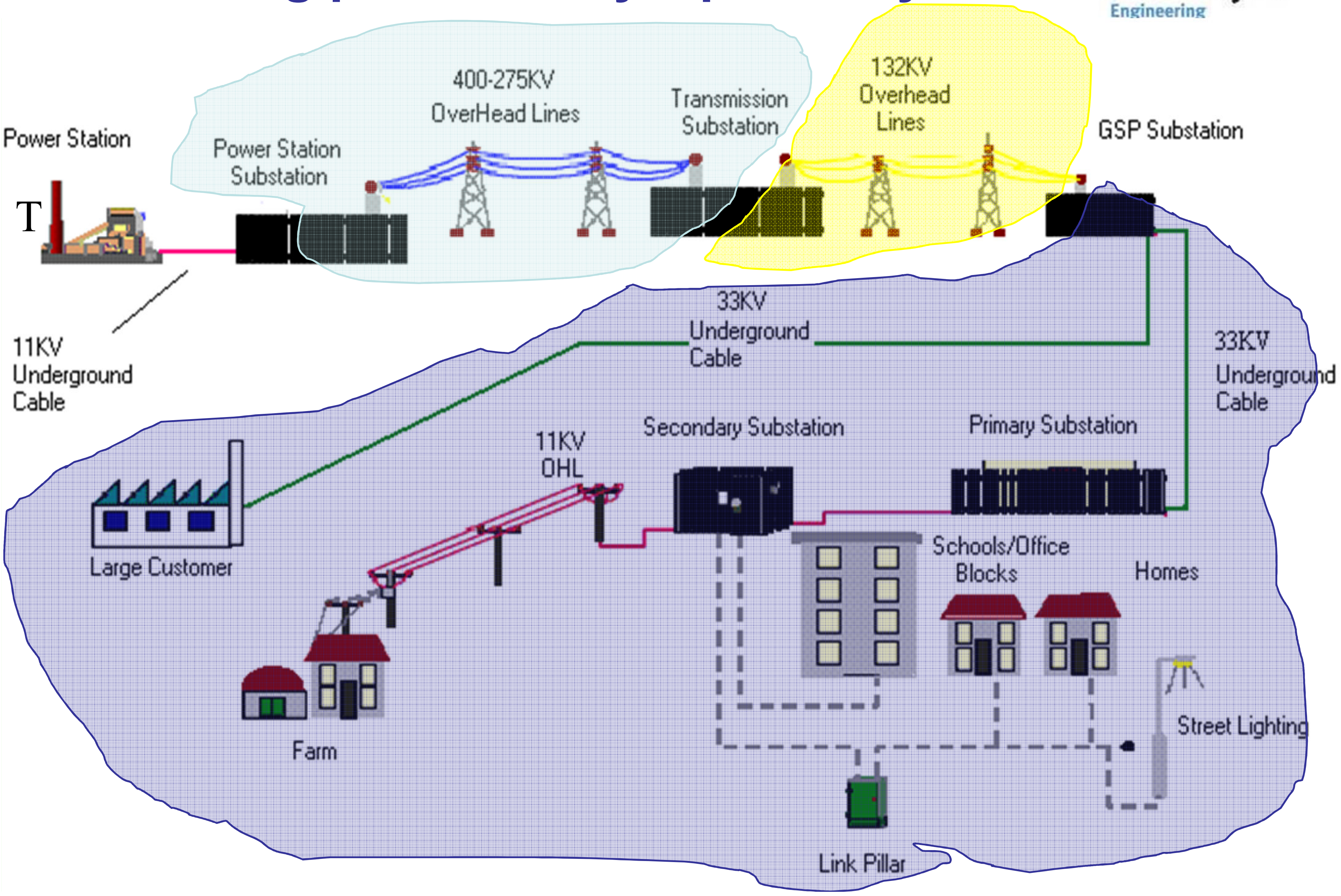
- Reduce the cost of transitioning to a low-carbon energy system, increasing affordability
- E.g. reduce need for grid reinforcement to handle new loads

"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 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 ⟷ ensg

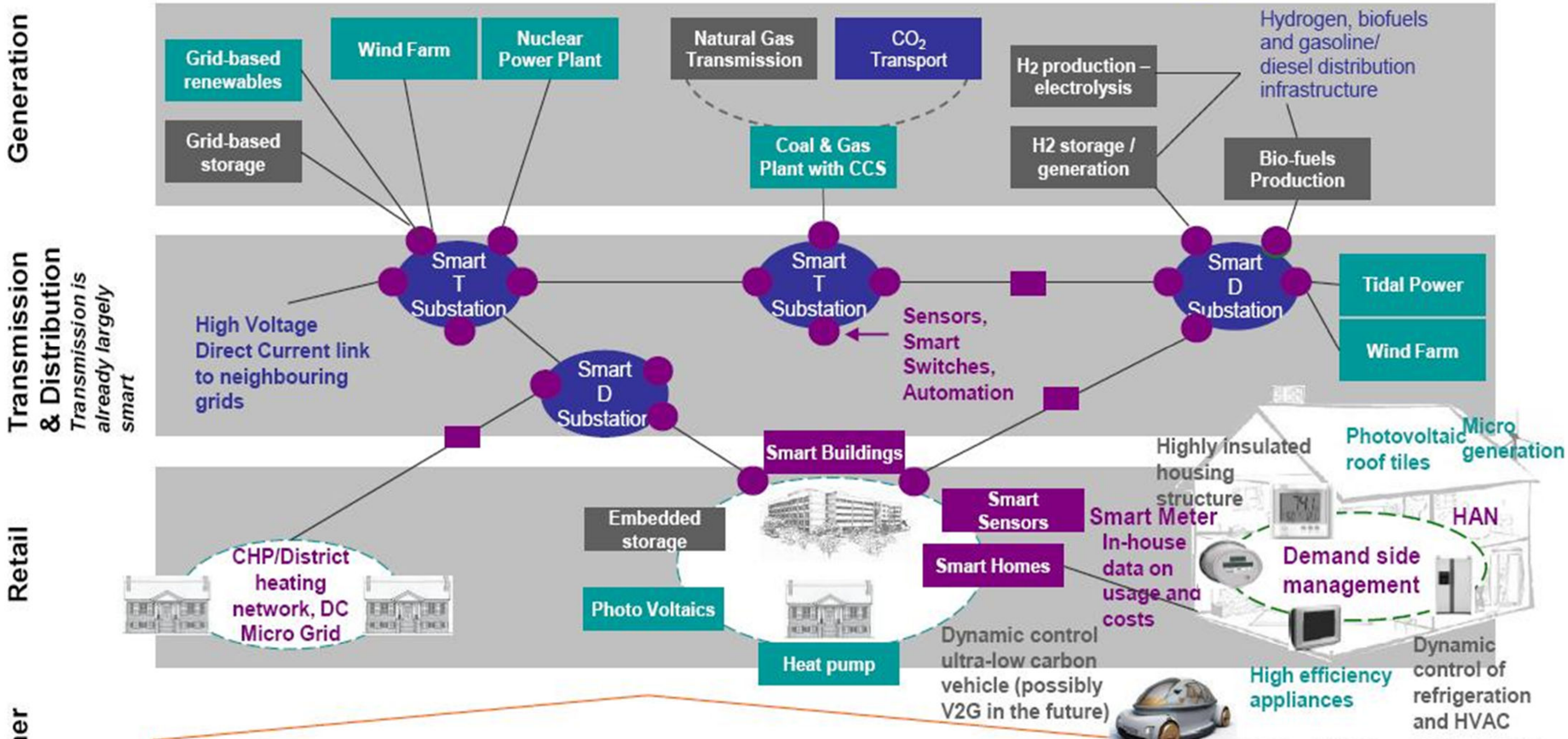
The starting point - today's power system



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

Storage and demand shifting
Electricity / heat generation
Sensing, control and integration
Other infrastructure



The customer

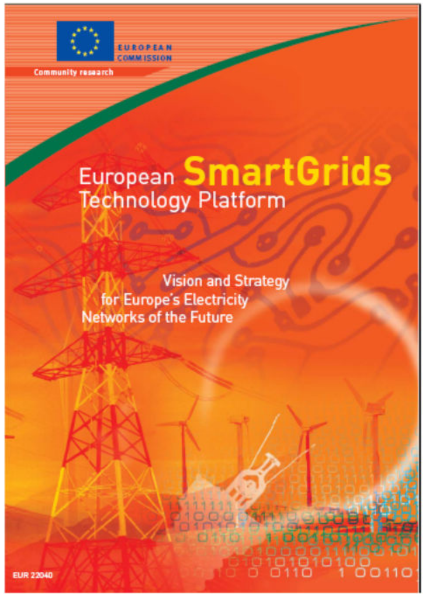
- This type of energy system could require significant changes to the role and activities of the customer within the wider energy system allowing them to participate in the market (potential for automation of customer response)
- In transitioning to a new 'role', customers will need to be supported by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

ensg

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.



Strategic Deployment Document (2008)

EU wide vision, plus research and deployment agenda, for moves towards smarter grids

What needs to be “Smart” in the Smart Grid?

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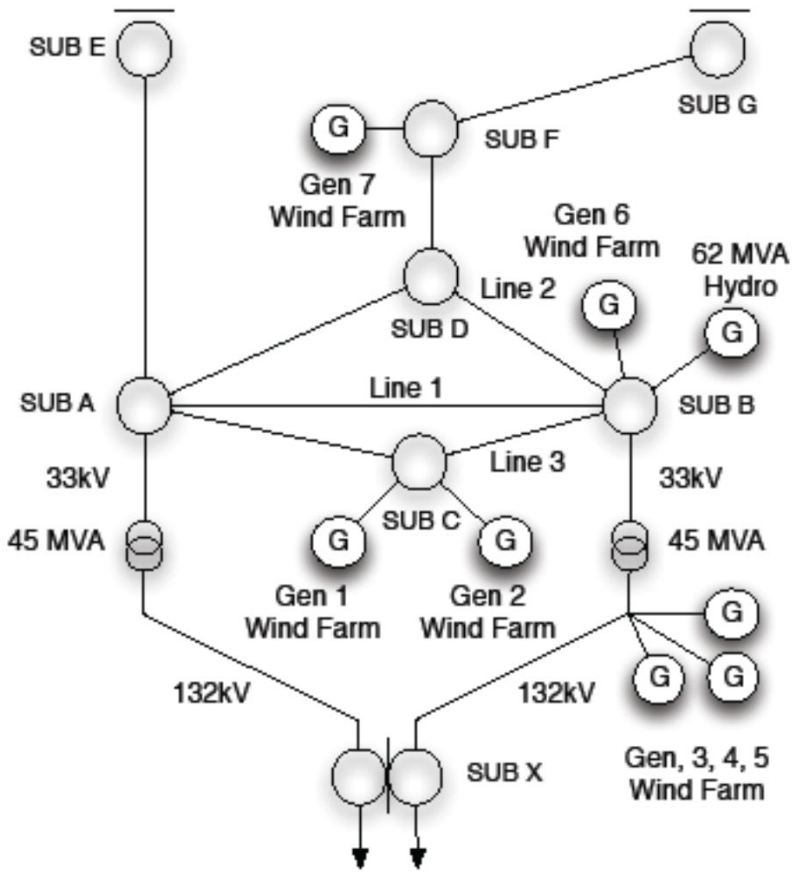
- Future energy networks must have increased flexibility and controllability through real time decision-making techniques.

- 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

EUROPEAN TECHNOLOGY PLATFORM SMARTGRIDS

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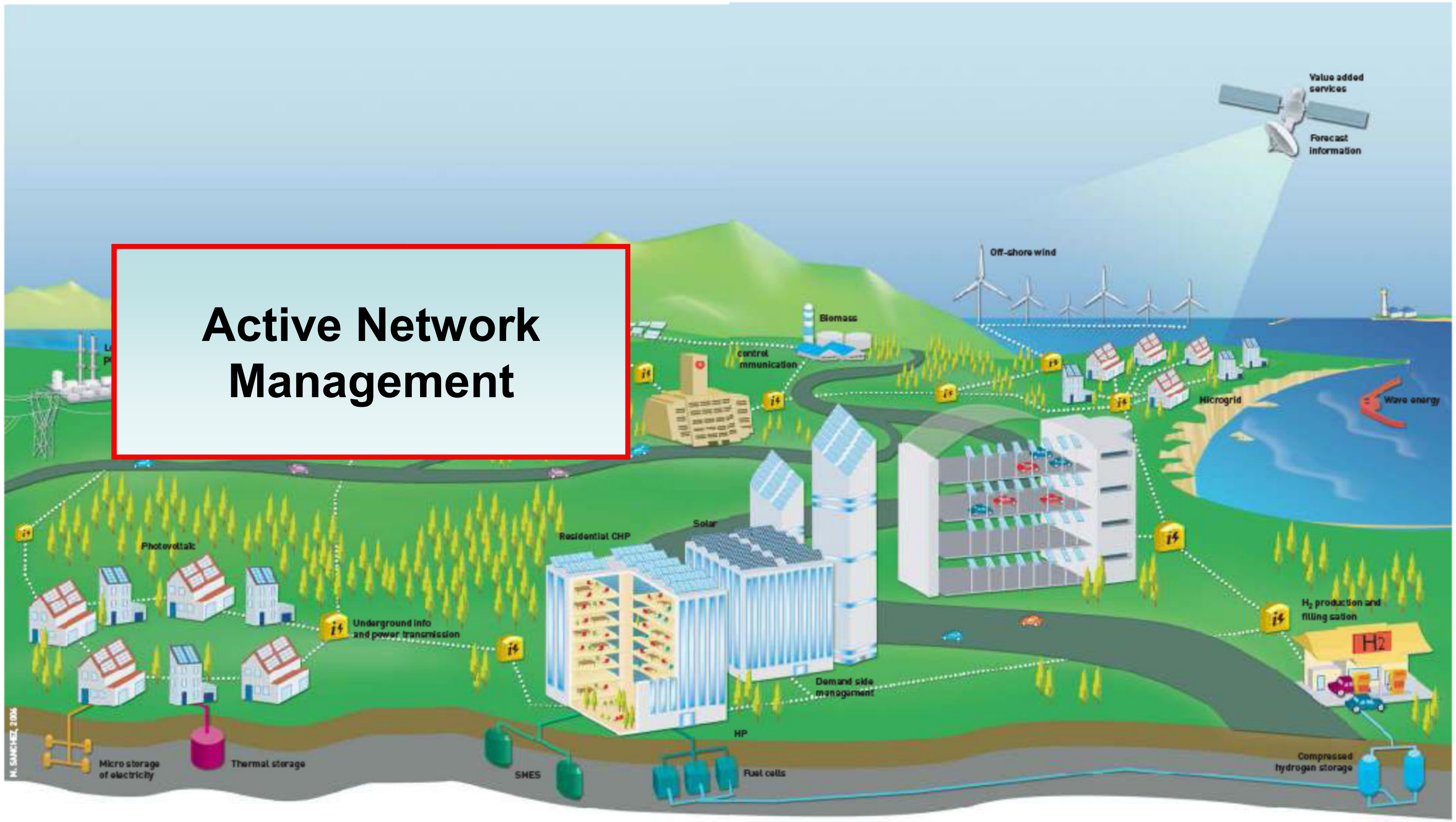
Future Network Vision

Future Network Vision



AuRA-NMS

Autonomous **R**egional **A**ctive **N**etwork **M**anagement **S**ystem

A fully integrated network management system

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

- EDF Energy
- ScottishPower
- ABB

AuRA-NMS

Autonomous **R**egional **A**ctive **N**etwork **M**anagement **S**ystem

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.

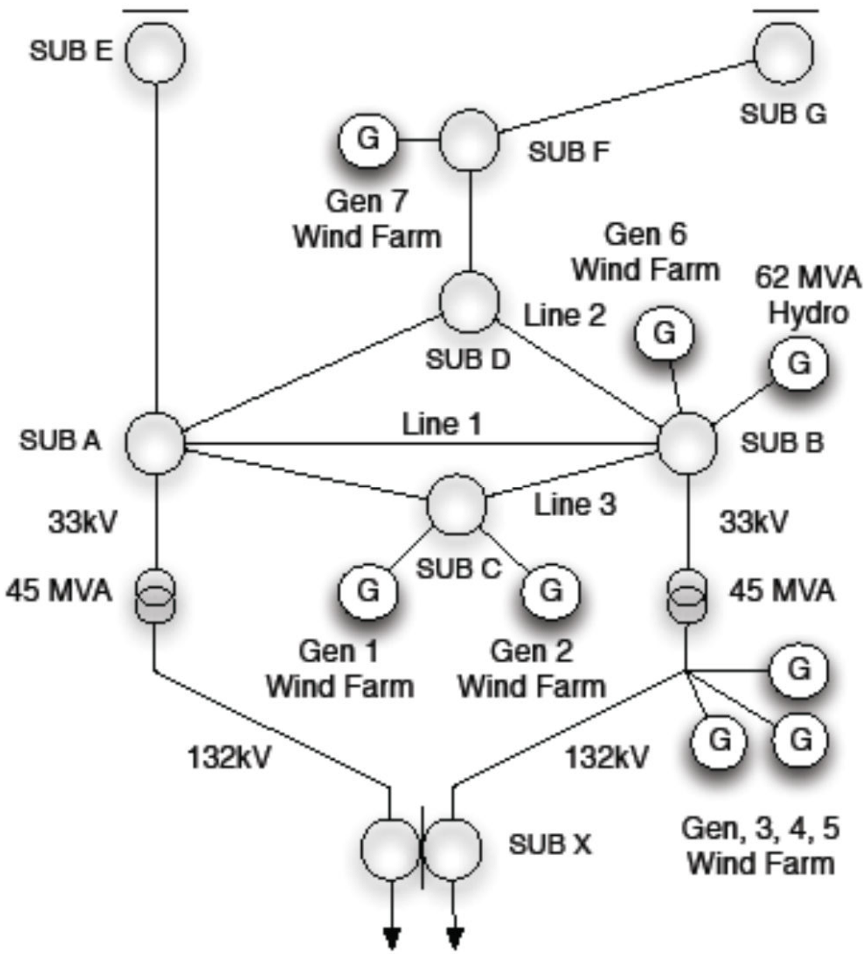
Properties of **AuRA**:

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

ABB's COM6xx series substation computer

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:

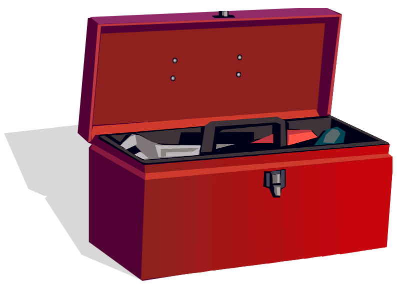
- ***Network Agnostic, Flexible and Extensible***
- ***Distributed or centralised***

Power Flow Management (PFM):

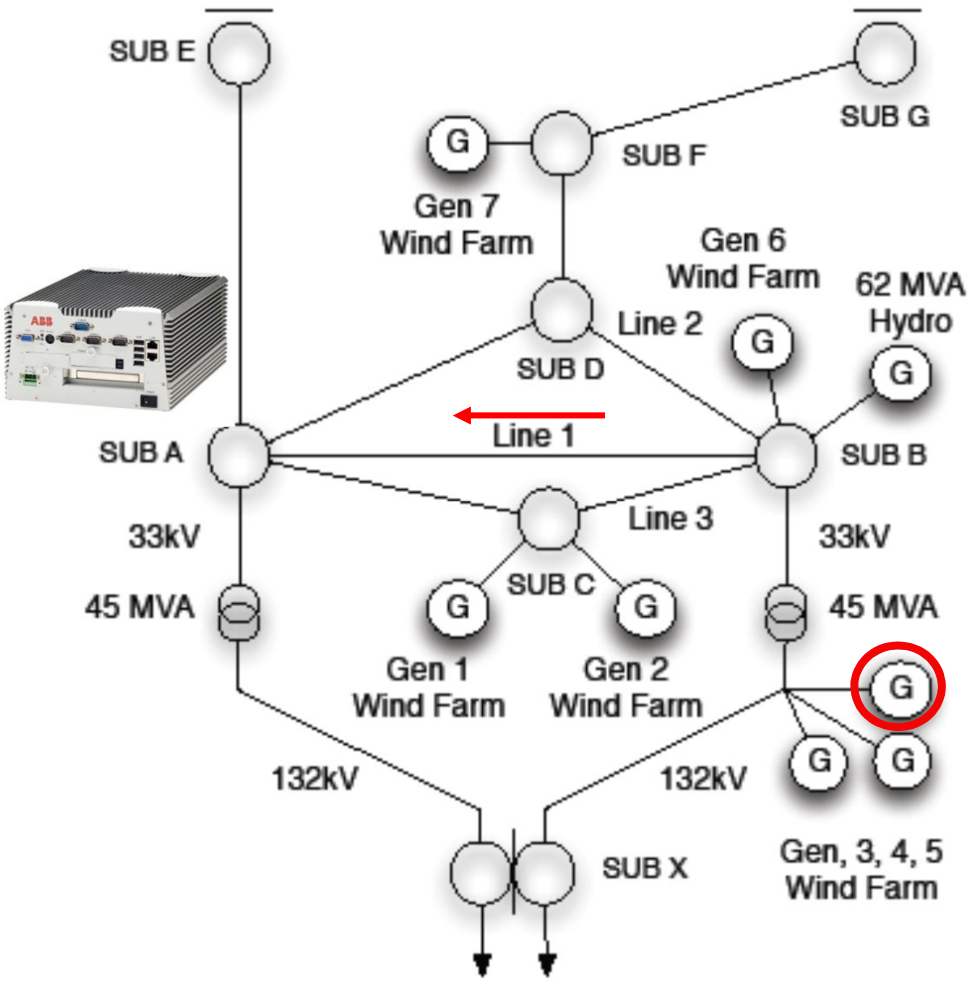
- A constraint programming based approach
- A current-tracing approach
- An Optimal Power Flow-based approach

Voltage Control (VC):

- A constraint programming based approach
- A case based reasoning approach



A Constraint Programming Approach to Power Flow Management - Example



<u>33kV interconnected distribution network</u>

- Power flow management control functionality embedded within substation hardware

<u>Load and Generation Profiles</u>

•Force a thermal constraint (Line 1)

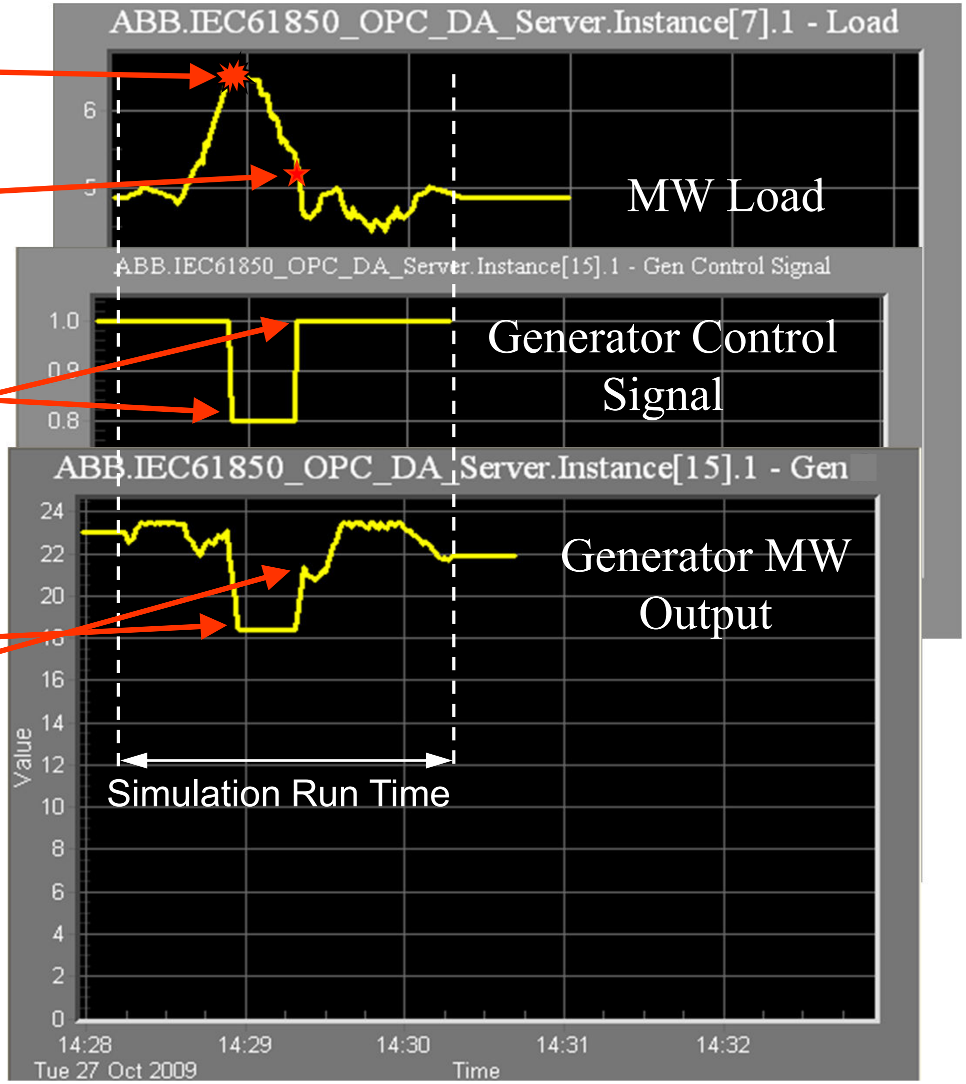
An Example…

Closed Loop Testing

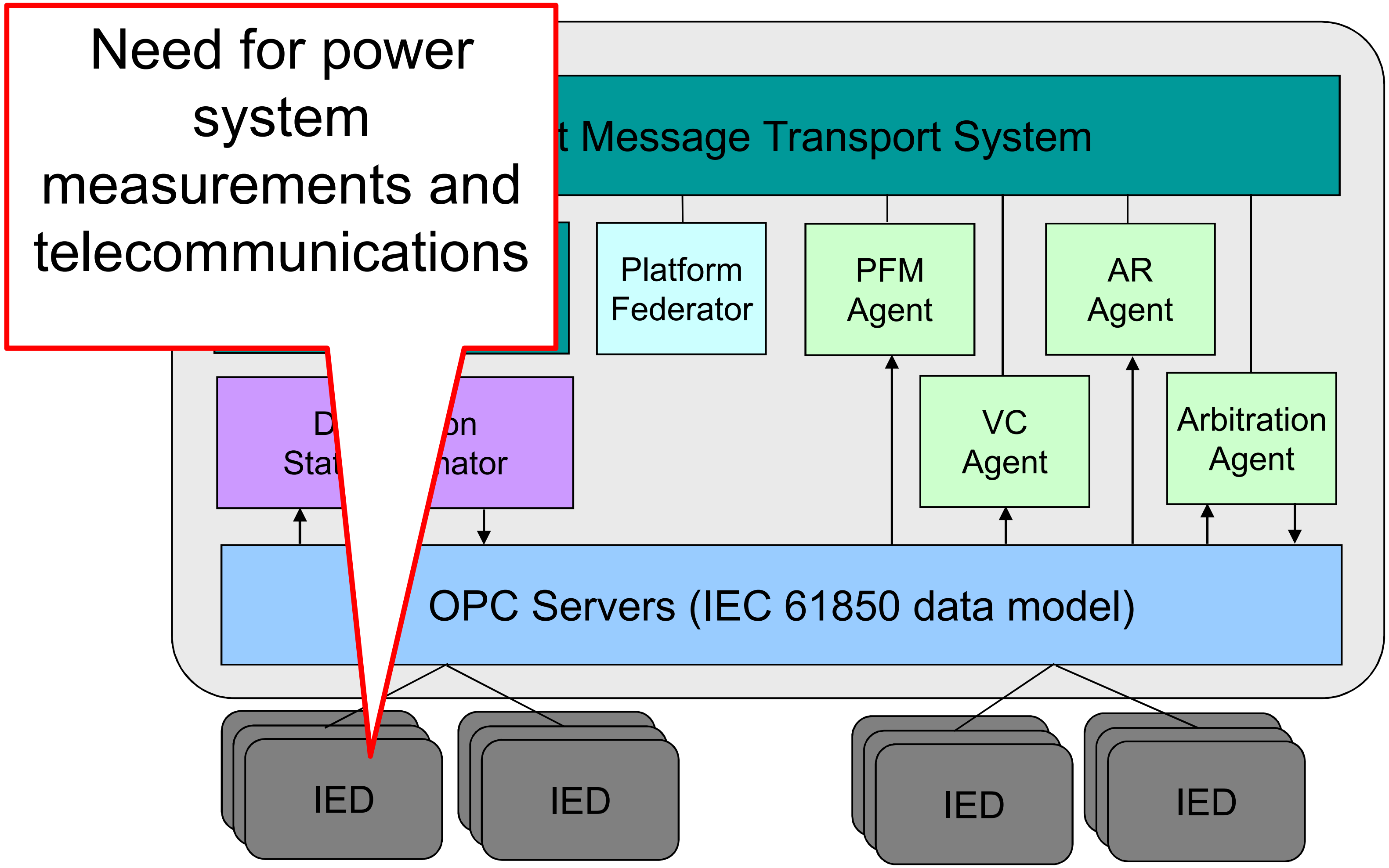
1. Line Overloaded
   a) Loading such that Curtailment can Change

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

3. Generator Output
   80% Curtailment
   c) Curtailment Lifted



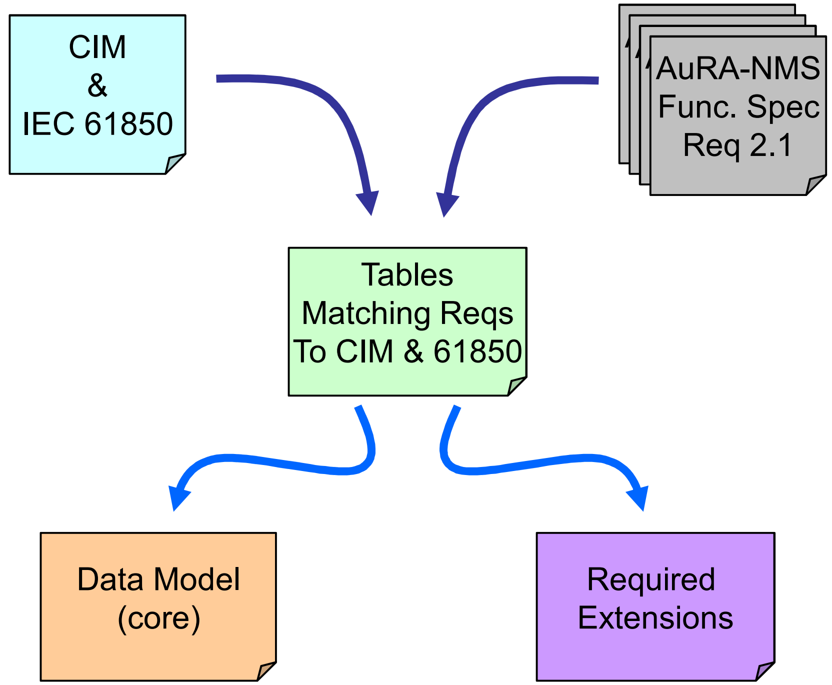
Software Architecture



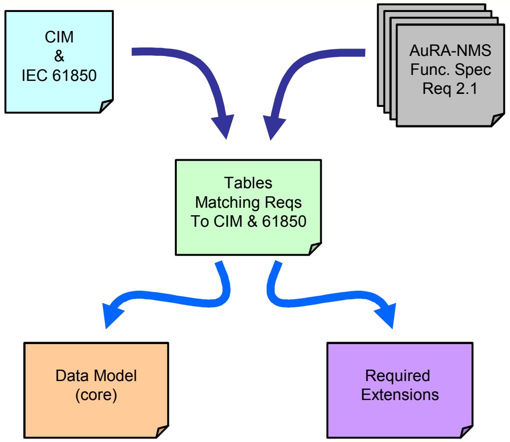
Data Model & Agent Communication Language (ACL):

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

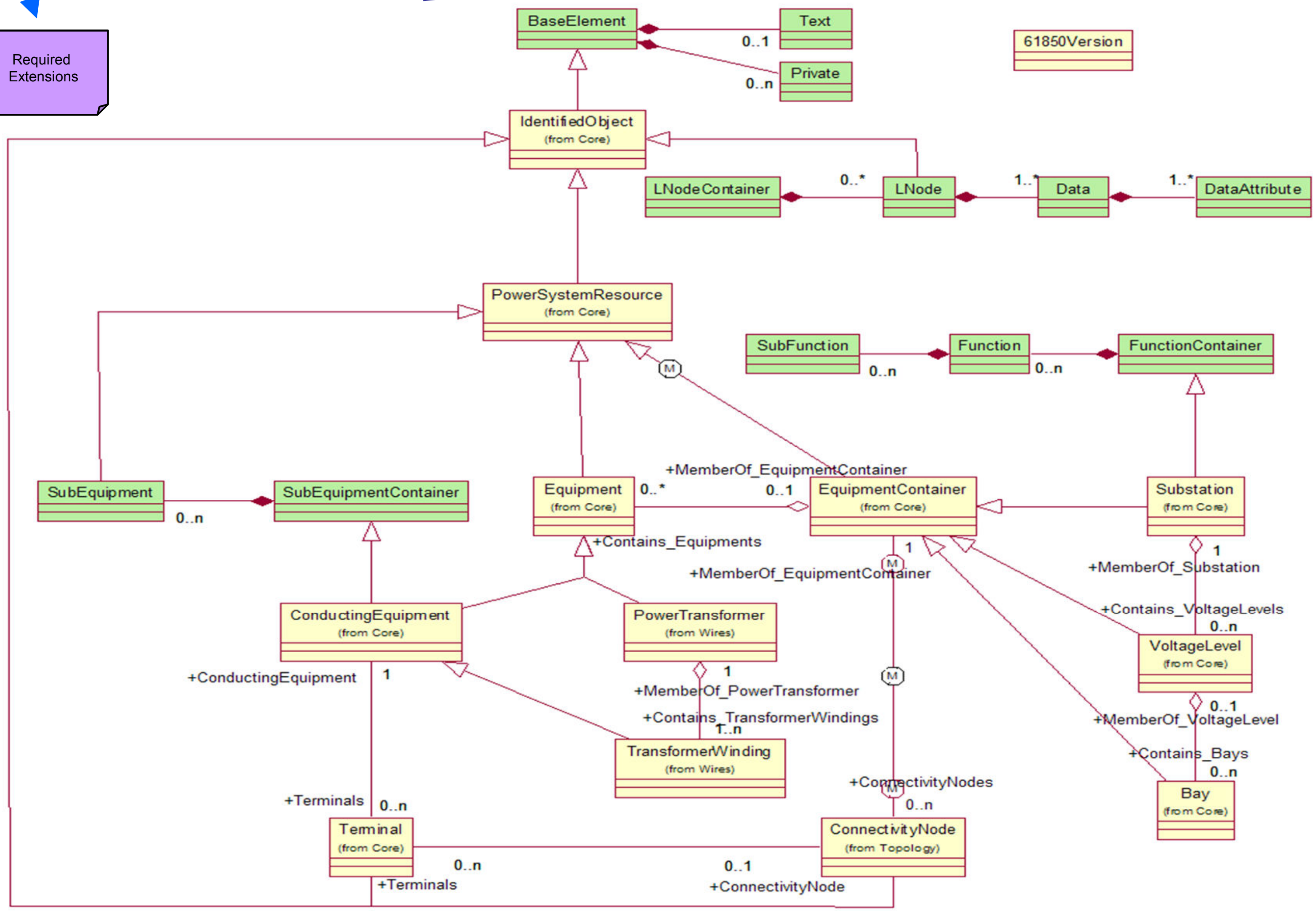
- Common Information Model (CIM)
- IEC 61850 - part 7
- FIPA Standards – FIPA SL



The Approach



Harmonised IEC 61850 and CIM



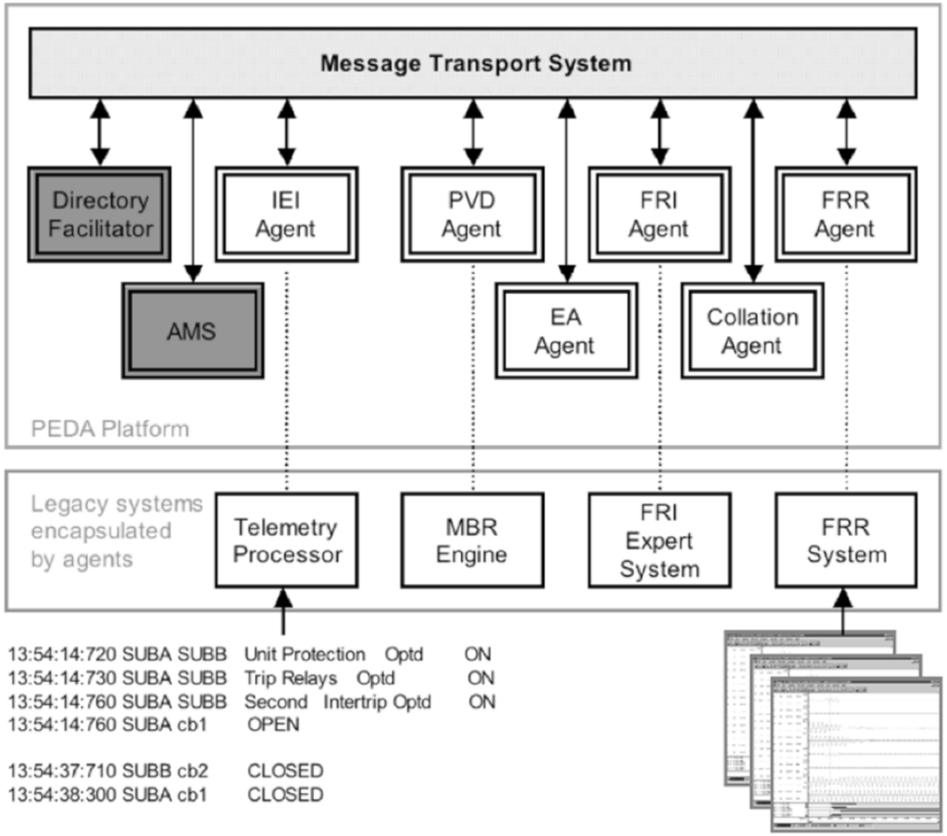
Industrial deployment of Smart Grid control

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



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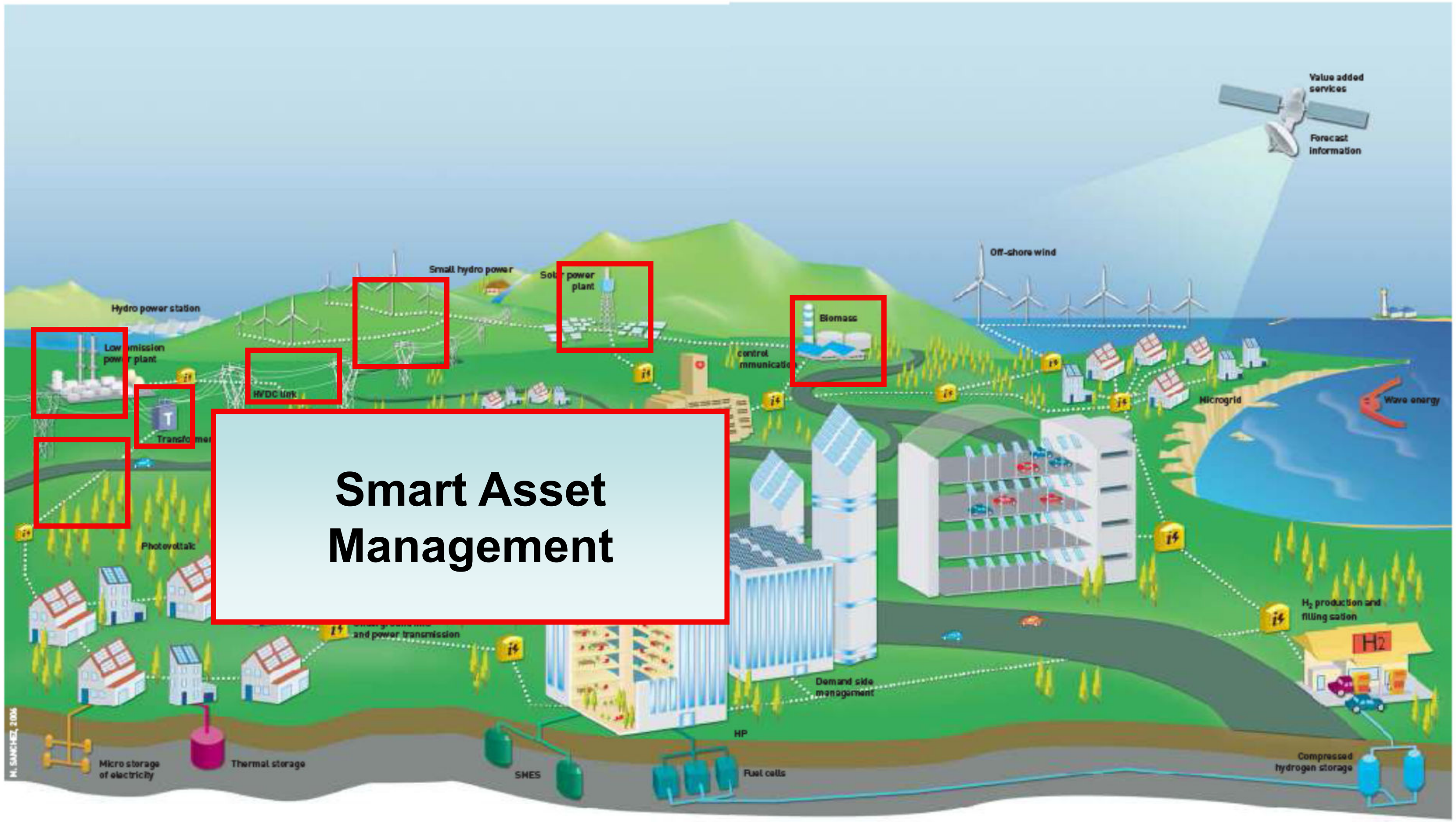
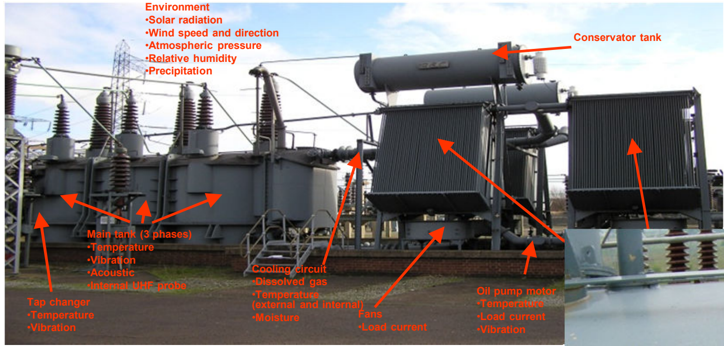
Smart Asset Management

Future Network Vision

Future Network Vision



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

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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 D

- **Local intelligence**
- **Local data management**

Substation A

- **Local intelligence**
- **Local data management**

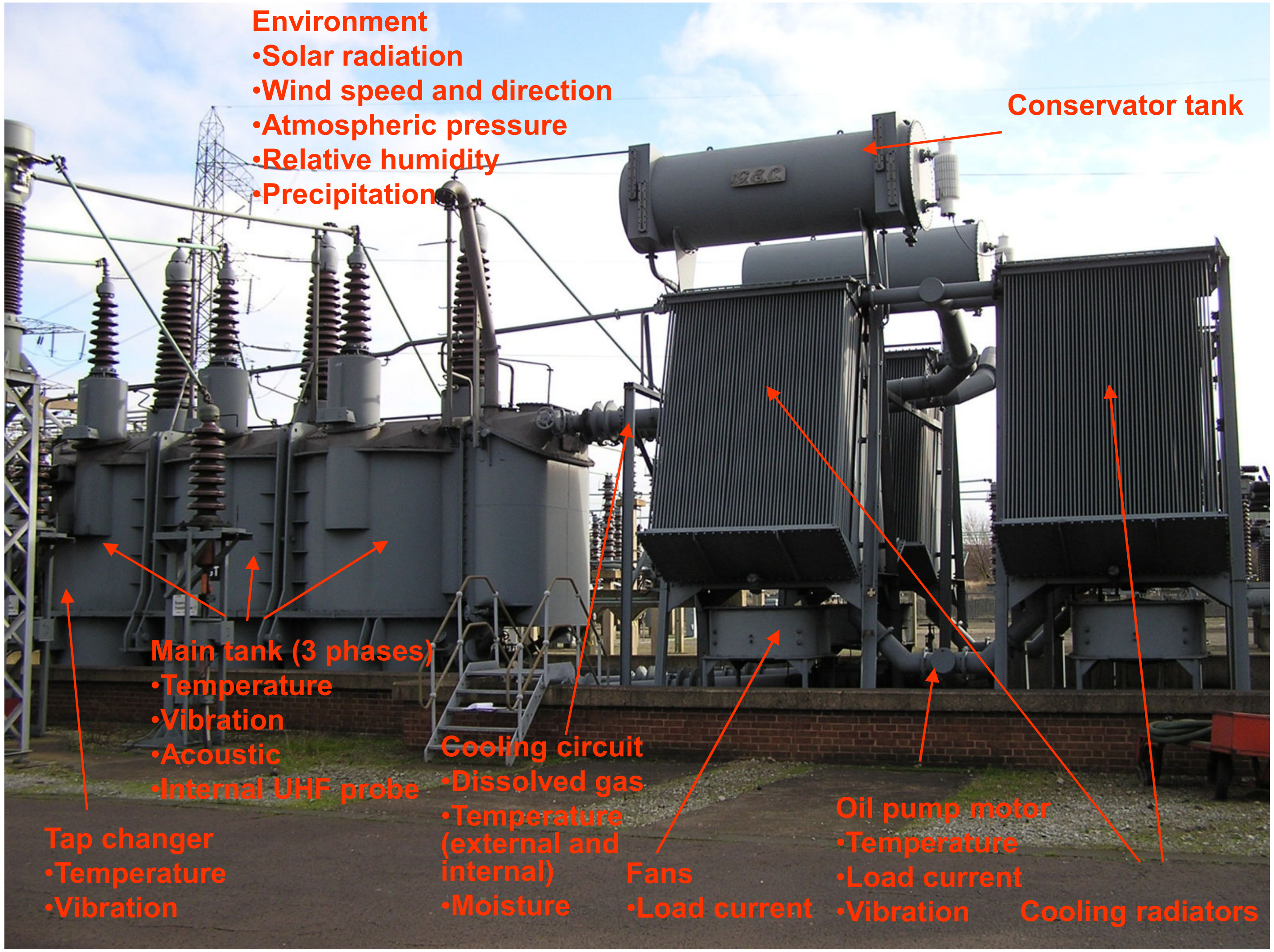
Substation B

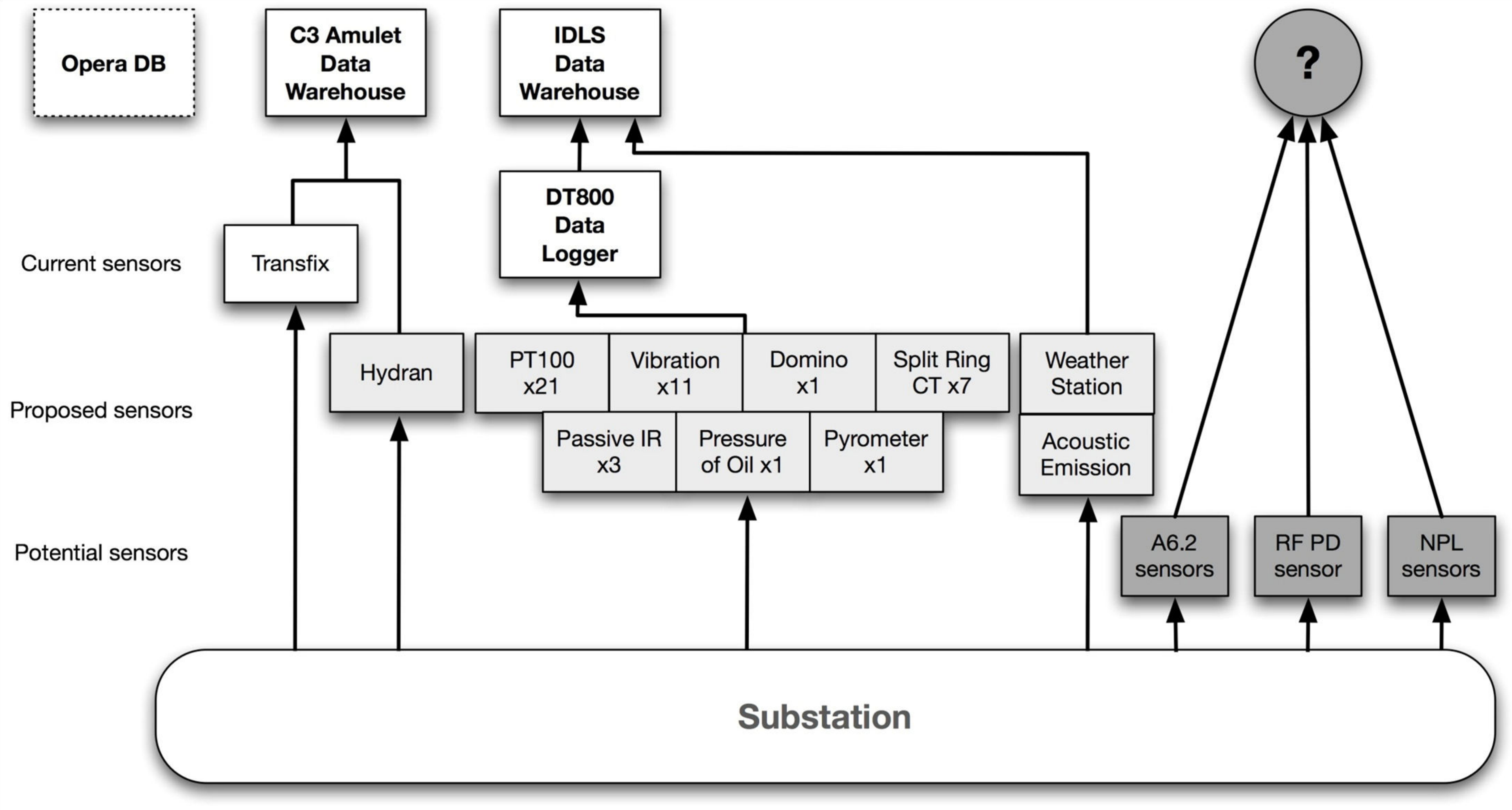
- **Local intelligence**
- **Local data management**

Substation C

EPSRC AMPerES – National Grid Demonstrator

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




Opera DB
C3 Amulet Data Warehouse
IDLS Data Warehouse
?
DT800 Data Logger
Current sensors
Transfix
Proposed sensors
Hydran
PT100 x21
Vibration x11
Domino x1
Split Ring CT x7
Weather Station
Passive IR x3
Pressure of Oil x1
Pyrometer x1
Acoustic Emission
Potential sensors
A6.2 sensors
RF PD sensor
NPL sensors
Substation

Agent Based Distributed Diagnosis

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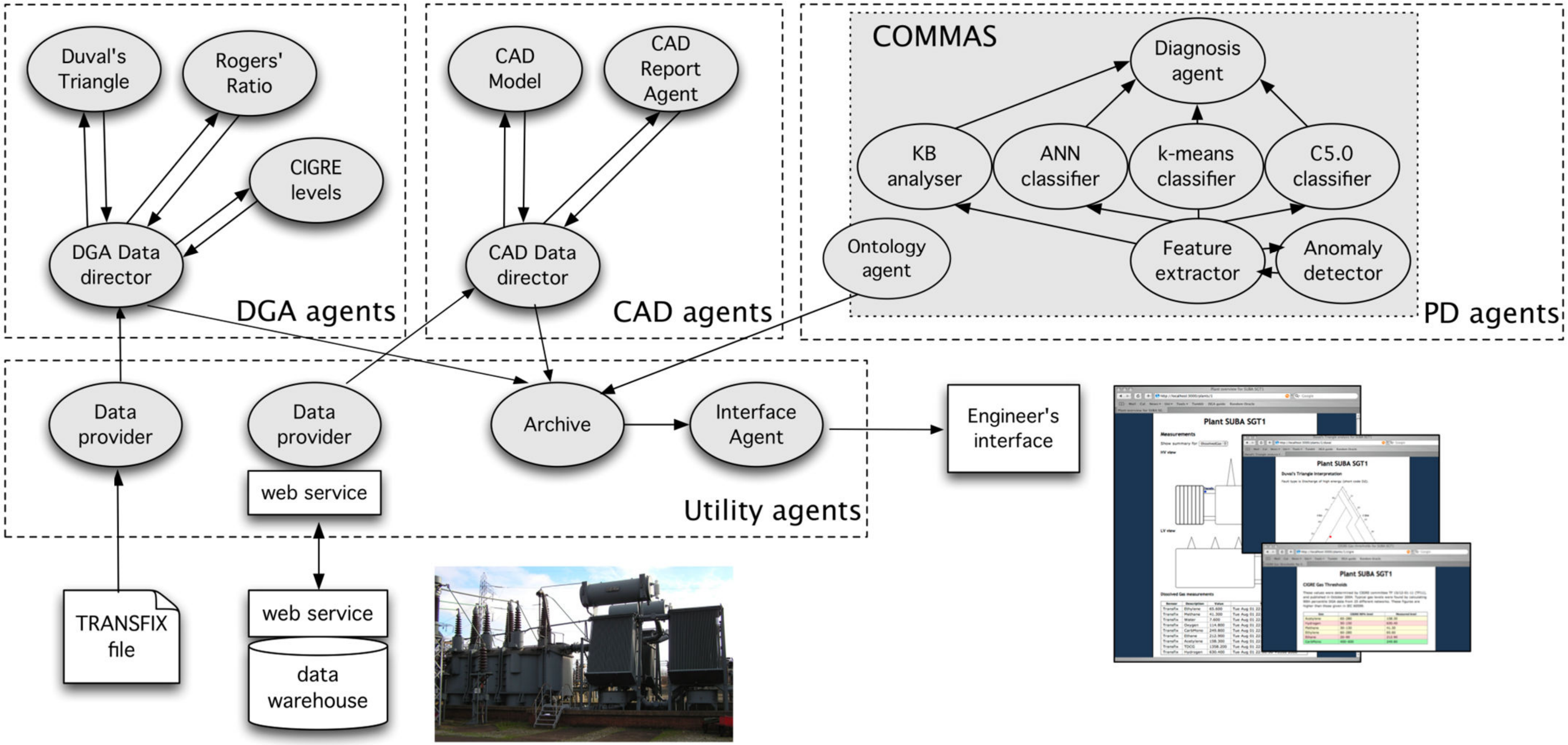
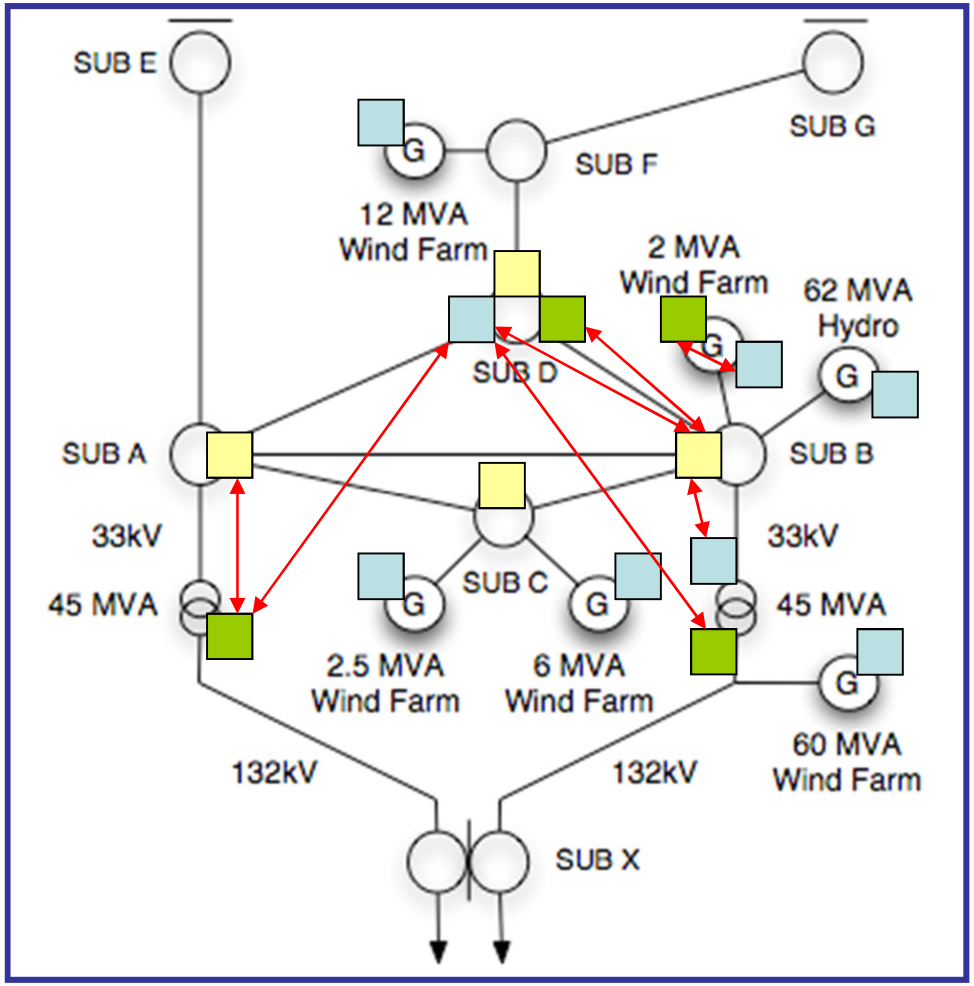
Engineering





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

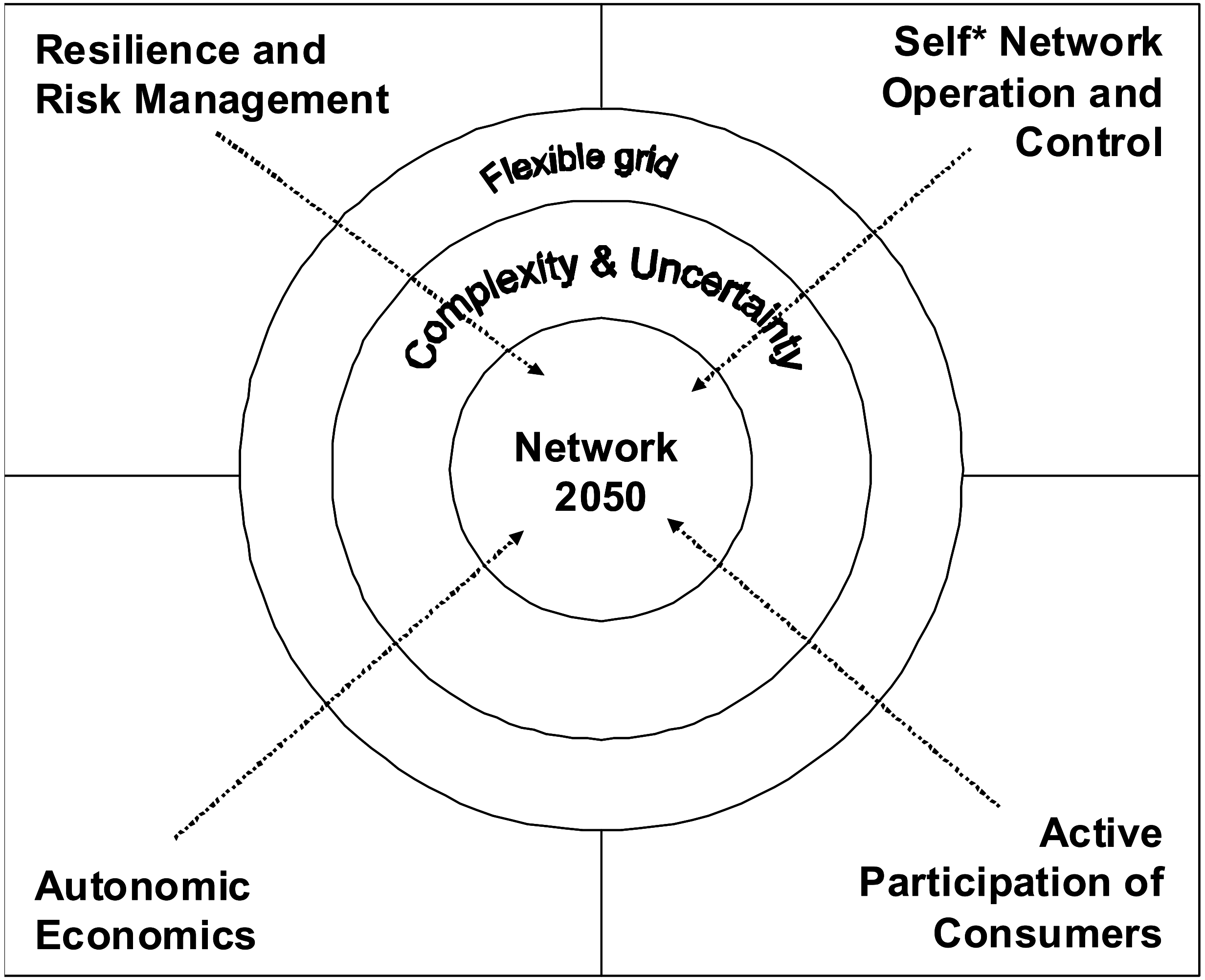
Industrial partners: IBM, Accenture, KEMA, Mott Macdonald, Agilent, …

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



Industial 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:

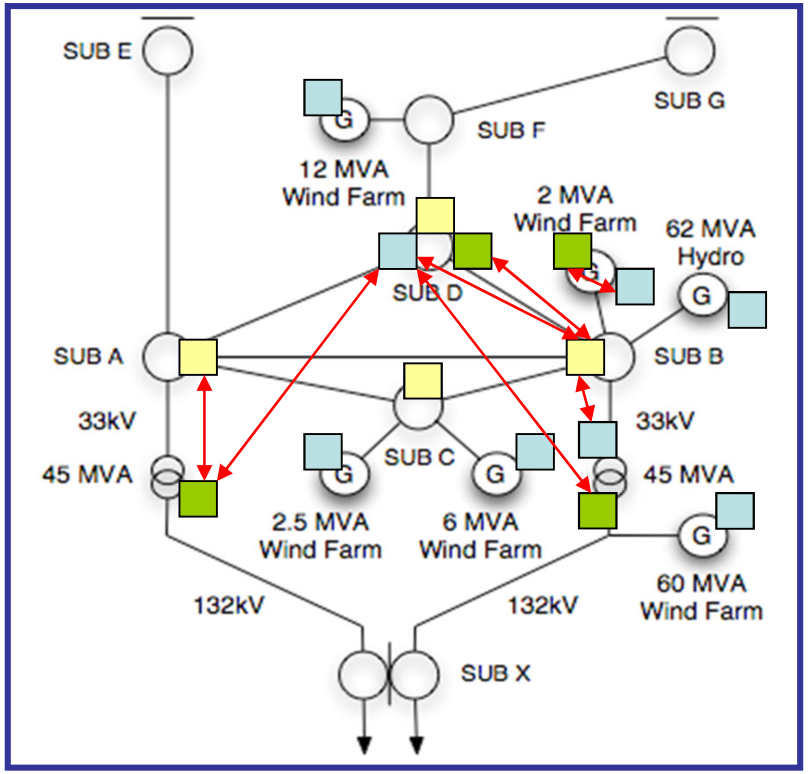
- Architectures for **distributable** control and monitoring

- "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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