Accommodating distributed energy resources: technical, commercial and regulatory challenges

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The University of Strathclyde

University of
Strathclyde
Engineering

- John Anderson founded a ‘place of useful learning’ in 1796
- Became Royal Technical College in 1912
- Became Royal College of Science and Technology in 1956
- Merged with Scottish College of Commerce and became University of Strathclyde in 1964
- Now one of Scotland’s biggest universities and one of the UK’s leaders in engineering, technology and business studies

“The Place of Useful Learning”

Innovative Learning

New Learning models and processes

Campus Regeneration

Research and Innovation

Aligned to social and economic needs

Knowledge Transfer

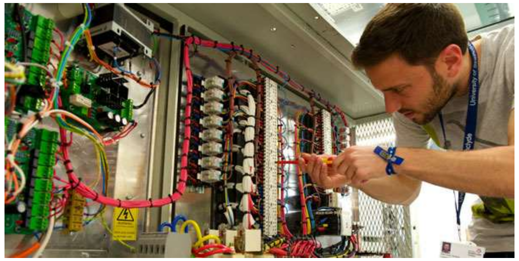
Integrated with the global economy

Institute for Energy and Environment

- Advanced Electrical Systems

- Wind Energy and Control

- Power Electronics, Drives and Energy Conversion



- High Voltage Technologies & Electrical Plant Diagnostics

Postgraduate study

University of
Strathclyde
Engineering

5G Advanced Communications
MSc

Advanced Electrical Power Engineering
MSc

Autonomous Robotic Intelligent Systems
MSc

Electrical Power Engineering with Business
MSc

Electronic & Electrical Engineering
MSc

Machine Learning & Deep Learning
MSc

Smart Grids with the Comillas Pontifical University, Madrid & Iberdrola
MSc

Wind Energy Systems
MSc

EPSRC Centre for Doctoral Training in Wind & Marine Energy Systems

- CDT in Wind and Marine Energy Systems
- Industrially linked PhDs in many other areas

Power systems activity

Examples of areas of work at Strathclyde

Commercial innovation	Data analytics	Power system analysis methods	‘Smart’ solutions	New primary technology
Non-firm access rights	Diagnostics	Reliability assessment	Active network management	HVDC
Arrangements for DSO	Prognostics	Optimisation	Phase shifter control	New protection
Charging arrangements	Demand characterisation	Monte Carlo simulation	Dynamic ratings	Fault current limiters
Network planning process	Characterisation of renewables	Stability assessment	Demand side responses	New controls for generation
	Forecasting	Replacement planning		
	Risk assessment			

Power Networks Demonstration Centre (PNDC)

University of Strathclyde Engineering

UNIVERSITY of STRATHCLYDE
POWER NETWORKS
DEMONSTRATION CENTRE

- Dedicated power systems R&D facility
- Open access model of engagement for projects
- 1 MVA capacity with independent frequency and voltage control and P-HiL
- Realism and flexibility through an 11 kV and LV network including fault throwing
- End-to-end sensors to DMS integration

Scottish Enterprise
Scottish Funding Council
Promoting further and higher education

SP ENERGY NETWORKS
Scottish & Southern Electricity Networks
UK Power Networks
vodafone
S&C
Locamation smart smart grid solutions
OMICRON

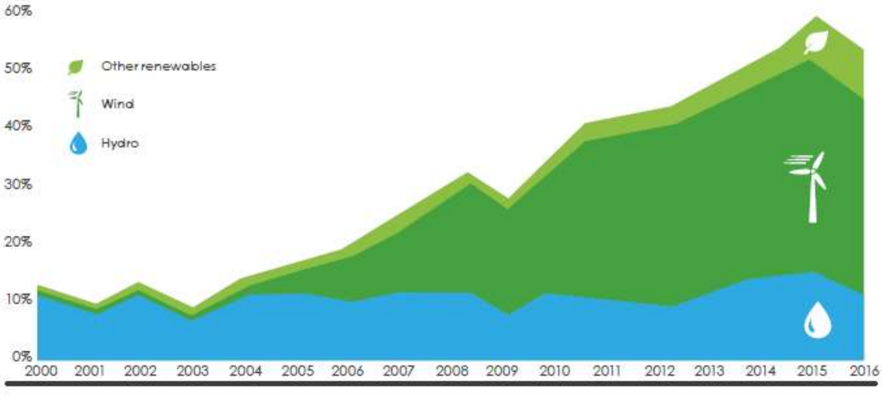
Offshore Electrical Infrastructure Research Hub

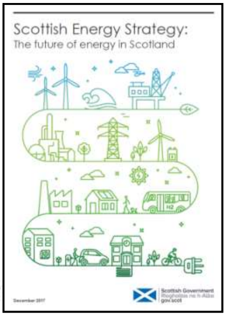
- 5-year partnership between Offshore Renewable Energy Catapult, University of Strathclyde and University of Manchester
- £3.1m programme
- Three themes of research
  - component reliability and availability;
  - system and sub-system optimisation;
  - smart energy systems of the future
- Hosting a minimum of
  - 10 PhD students
  - 3 research associates
- Scientific Directors:
  - Keith Bell (Strathclyde)
  - Ian Cotton (Manchester)

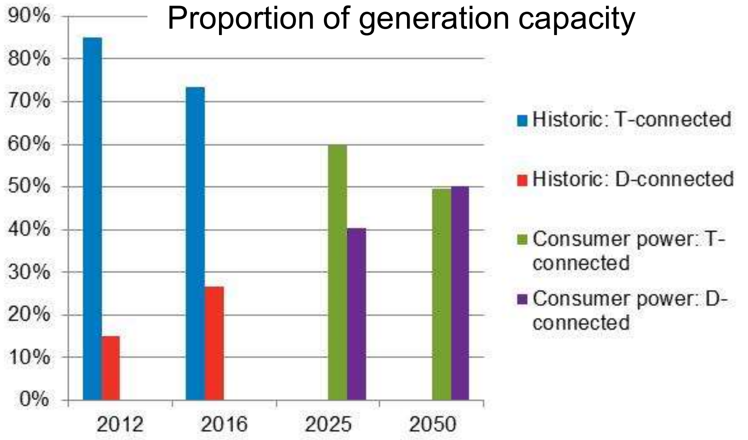
The changing nature of generation

1. An increasing contribution to energy provision from highly variable, weather dependent renewable generators
2. More generation and flexible resources connected to distribution
3. A change in the system’s dynamic characteristics

In 2016, the equivalent of 54% of total Scottish electricity consumption came from renewable sources, four times greater than the level in 2000[7].

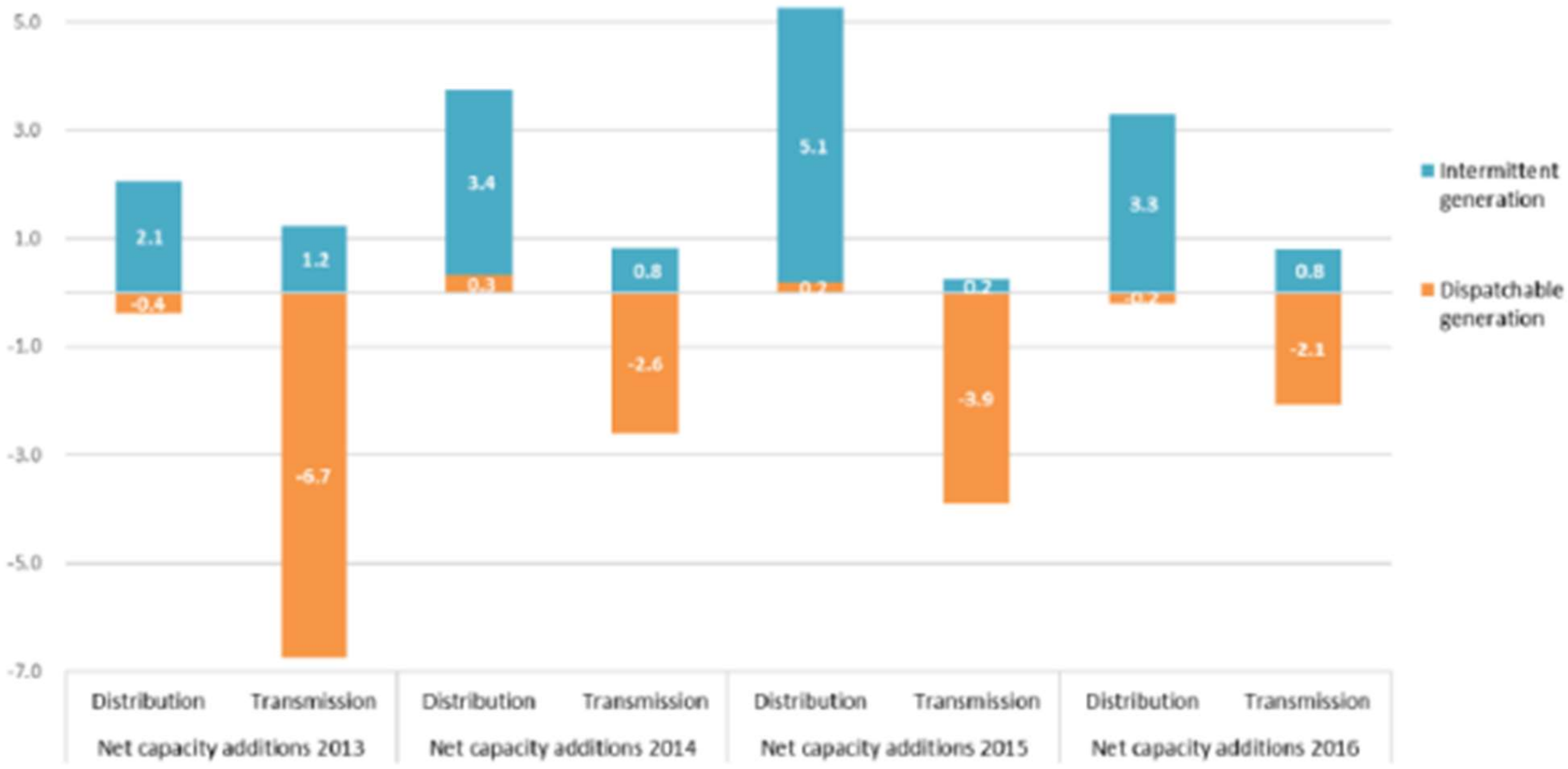



Scottish Energy Strategy:
The future of energy in Scotland


Proportion of generation capacity

Data: DUKES 2017 and National Grid FES 2017

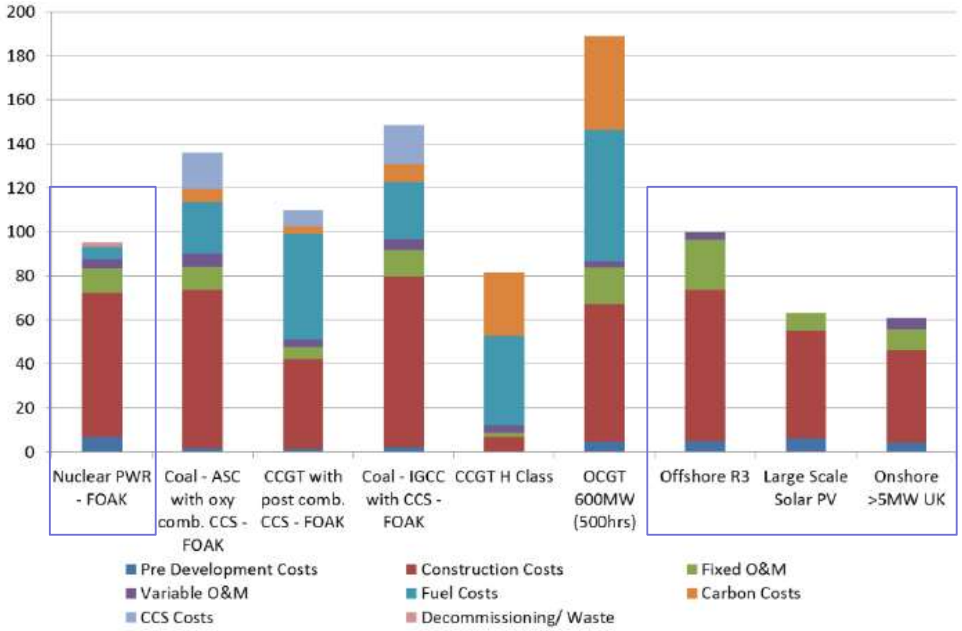
Changing generation mix in the UK



Source: Dept. of Business, Energy and Industrial Strategy, 2016

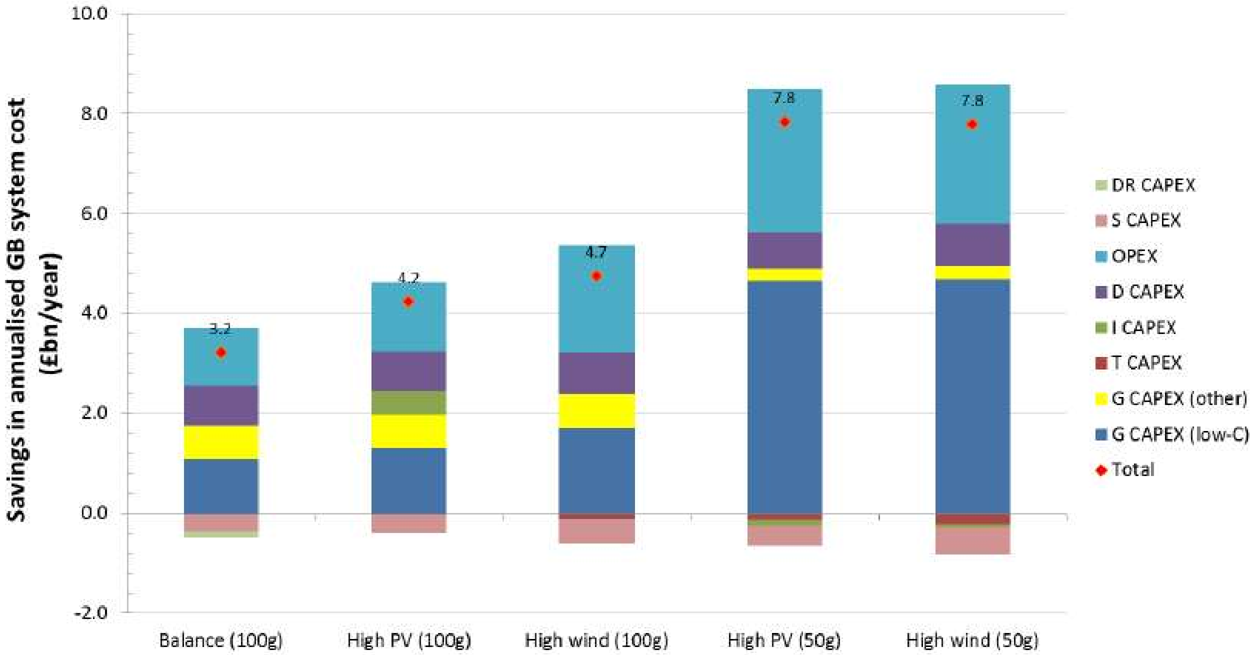
The changing nature of generation

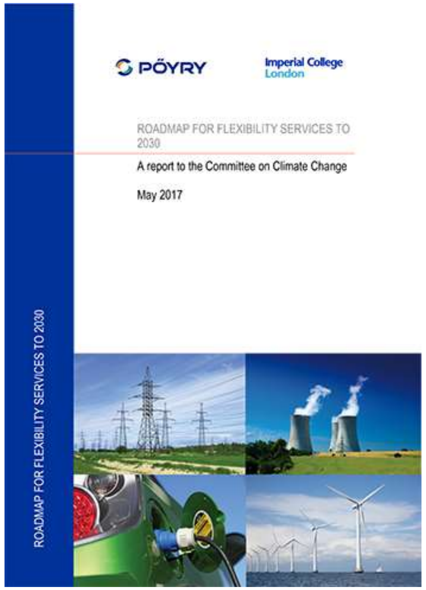
- Fossil fuelled plant
  - – Fuel a significant cost
- Low carbon generation
  - – Limited choice of location
  - – Limited ‘schedulability’
  - – More variability
  - – Higher capex, lower opex
  - – Competitive wholesale markets hinge on short-run marginal costs (SRMC)
- In general, less money based on energy, more on ‘services’



Levelised cost of energy, £/MWh
Department for Business, Energy & Industrial Strategy, Electricity Generation Costs, November 2016

Potential benefits of an ‘optimal’ mix of services




PÖYRY

Imperial College London

ROADMAP FOR FLEXIBILITY SERVICES TO 2030

A report to the Committee on Climate Change

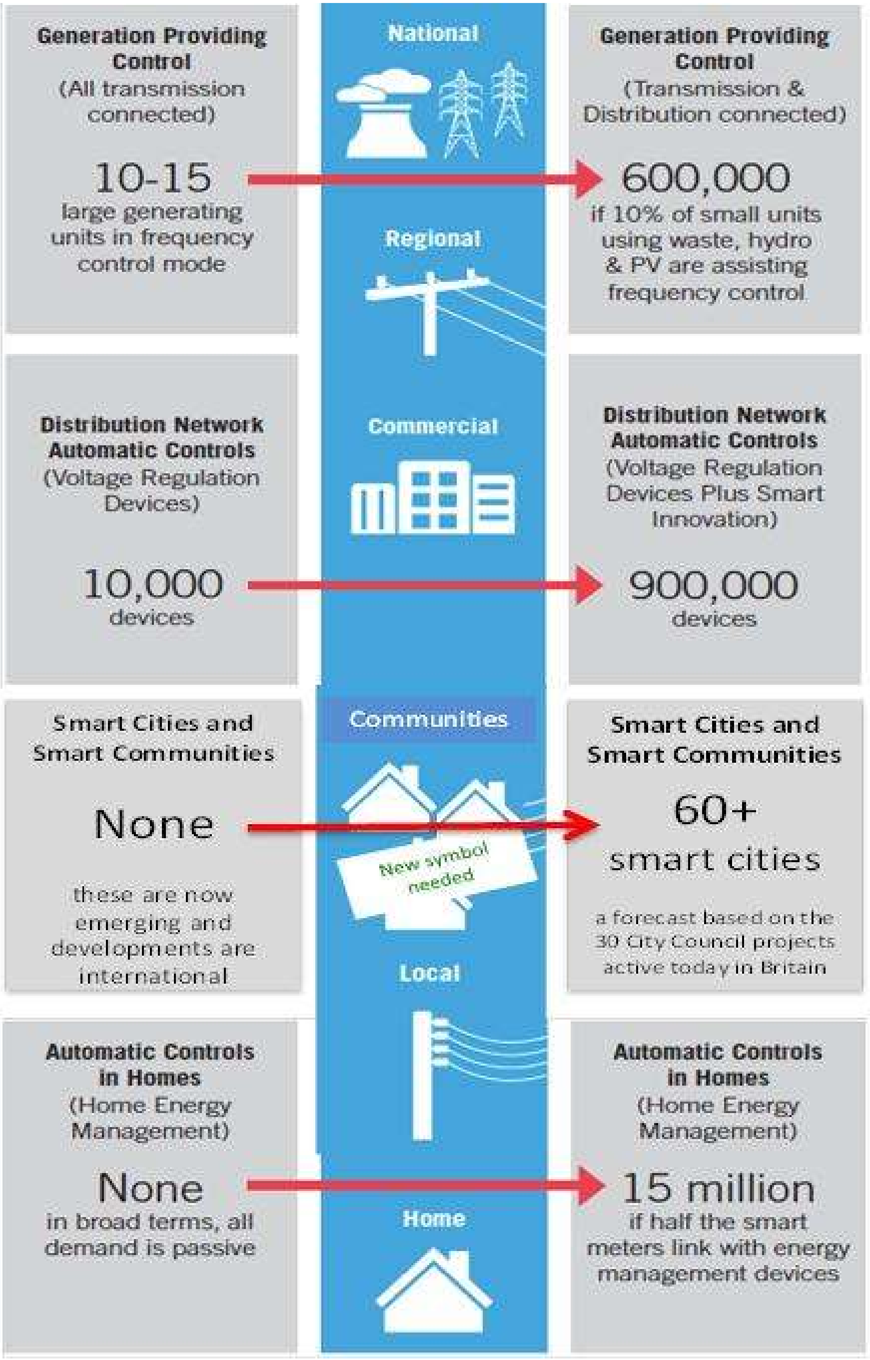
May 2017

ROADMAP FOR FLEXIBILITY SERVICES TO 2030

Modelling by Strbac et al of CCC scenarios, Imperial College

- Savings from optimality in a credible, low carbon 2030 scenario: ~£4 billion
- cf. total consumer expenditure on electricity in 2016 (all sectors): ~£40 billion

Potentially lots of value from **flexible demand**.
Which commercial and regulatory mechanisms will deliver services at least cost?



Generation Providing Control
(All transmission connected)
10-15
large generating units in frequency control mode

Generation Providing Control
(Transmission & Distribution connected)
600,000
if 10% of small units using waste, hydro & PV are assisting frequency control

Distribution Network Automatic Controls
(Voltage Regulation Devices)
10,000
devices

Distribution Network Automatic Controls
(Voltage Regulation Devices Plus Smart Innovation)
900,000
devices

Smart Cities and Smart Communities
None
these are now emerging and developments are international

Smart Cities and Smart Communities
60+
smart cities
a forecast based on the 30 City Council projects active today in Britain

Automatic Controls in Homes
(Home Energy Management)
None
in broad terms, all demand is passive

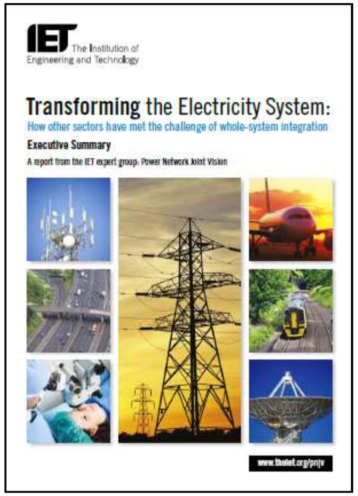
Automatic Controls in Homes
(Home Energy Management)
15 million
if half the smart meters link with energy management devices

University of Strathclyde Engineering

Parties connected to the distribution network will be increasingly important

- There are lots of them…
- …an explosion in the number of active elements…
- … and volume of data

From The IET
Power Network Joint Vision



The Institution of Engineering and Technology

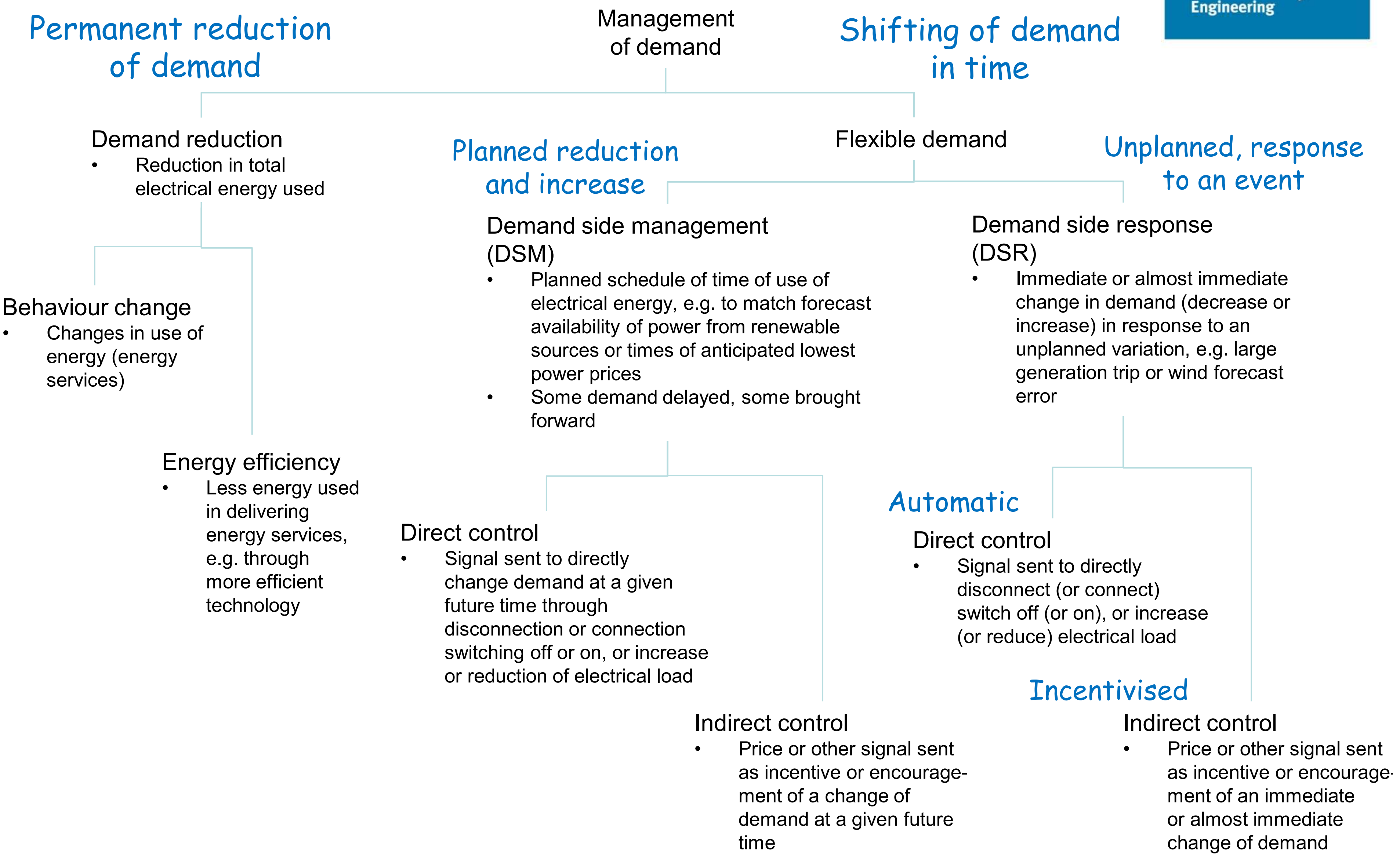
Transforming the Electricity System:
How other sectors have met the challenge of whole-system integration
Executive Summary
A report from the IET expert group: Power Network Joint Vision

www.theiet.org/pnjv

Some questions

- What are the impacts of changes in system dynamic characteristics?
  - reduction of synchronous generation
  - changes in the requirement for response/frequency containment services
- What does ‘flexible demand’ mean?
- How can DER be managed cost-effectively?
  - To minimise adverse impacts in system operation?
  - To avoid excessive network reinforcement?
  - To enable it to contribute to system services?
- Is DER observable and controllable?

A taxonomy of management of demand



Management of demand

Permanent reduction of demand

Demand reduction
- Reduction in total electrical energy used

Behaviour change
- Changes in use of energy (energy services)

Energy efficiency
- Less energy used in delivering energy services, e.g. through more efficient technology

Shifting of demand in time

Flexible demand

Planned reduction and increase

Demand side management (DSM)
- Planned schedule of time of use of electrical energy, e.g. to match forecast availability of power from renewable sources or times of anticipated lowest power prices
- Some demand delayed, some brought forward

Direct control
- Signal sent to directly change demand at a given future time through disconnection or connection switching off or on, or increase or reduction of electrical load

Indirect control
- Price or other signal sent as incentive or encouragement of a change of demand at a given future time

Unplanned, response to an event

Demand side response (DSR)
- Immediate or almost immediate change in demand (decrease or increase) in response to an unplanned variation, e.g. large generation trip or wind forecast error

Automatic

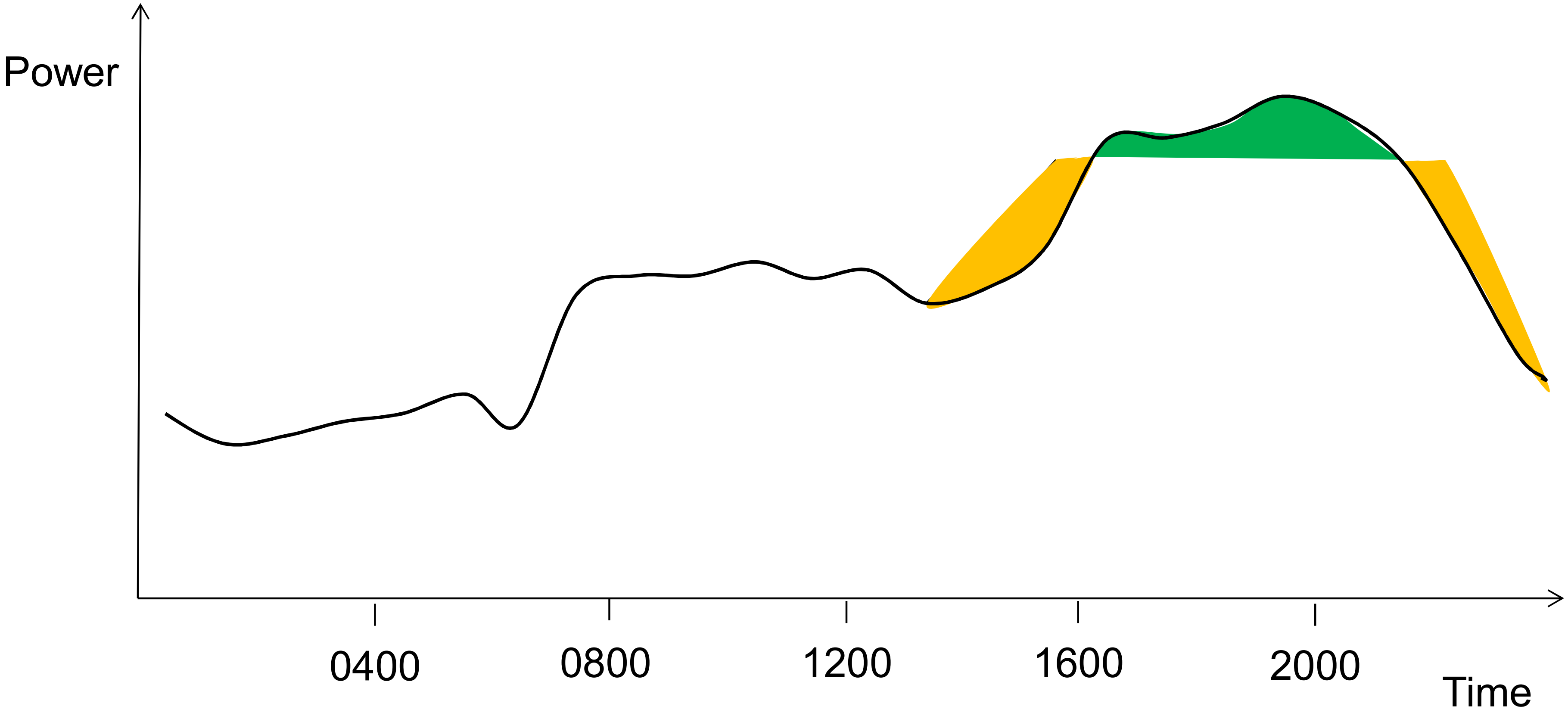
Direct control
- Signal sent to directly disconnect (or connect) switch off (or on), or increase (or reduce) electrical load

Incentivised

Indirect control
- Price or other signal sent as incentive or encouragement of an immediate or almost immediate change of demand

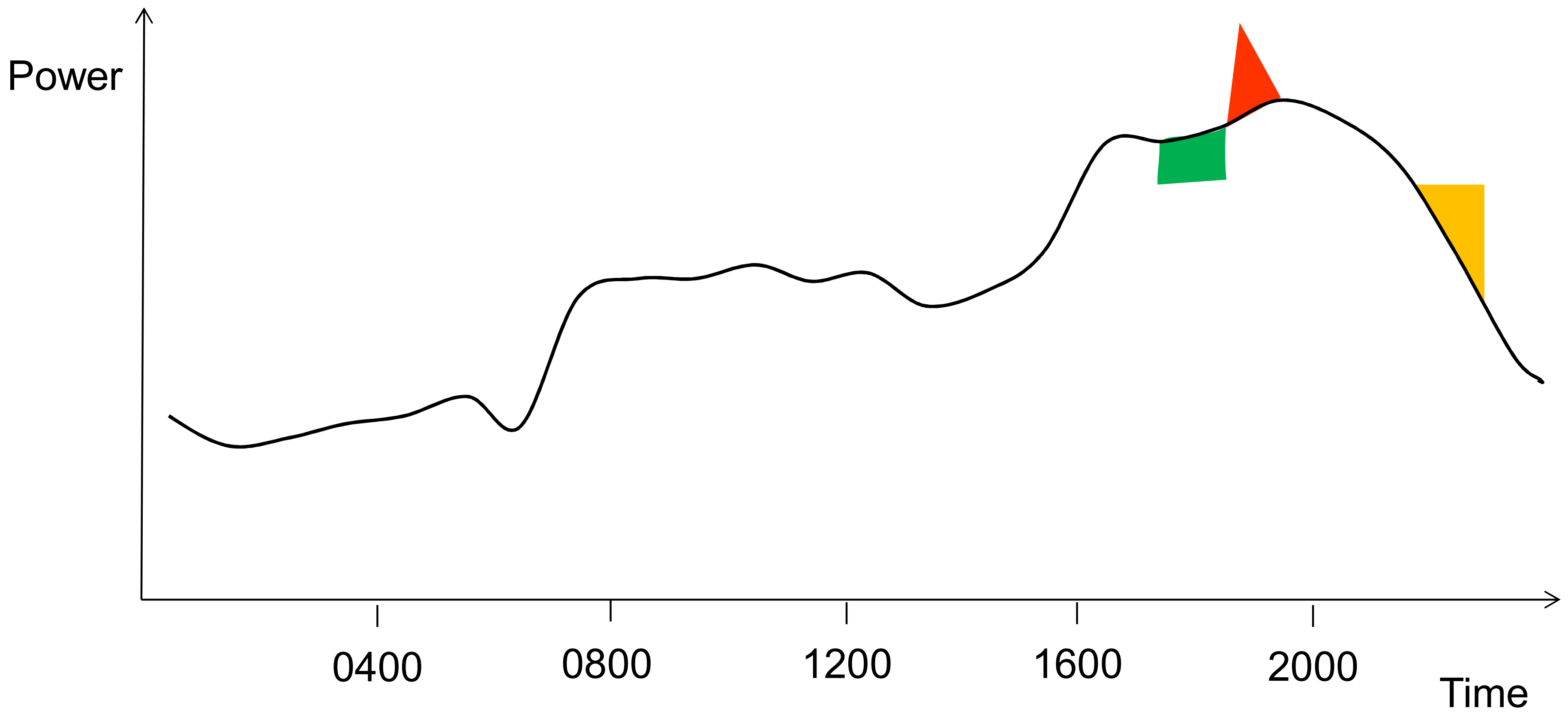
Demand side management

- Use of energy shifted from green area to orange areas
- Timing of switch on and switch off planned



Demand side response

- Demand reduced (quickly) in response to an unplanned event
- Uncertain timing of reduction
- Uncertain timing and magnitude of return of demand



Let's recall the motivation



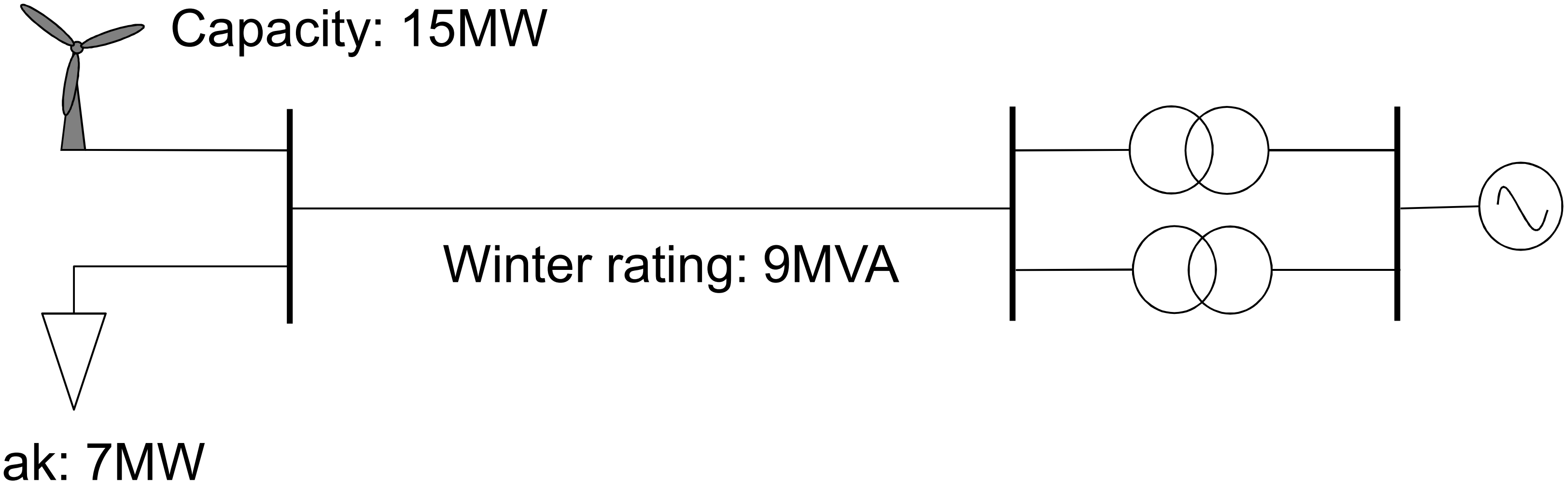


- Facilitation of distributed resources
  - Low carbon generation technologies
    - Solar PV
    - Small/medium scale wind
  - Low carbon technologies on the demand side
    - More electric heat
    - Charging of electric vehicles
- Efficient use of underlying network infrastructure
  - Respect physical network and system limits
  - Actively manage power flows, voltages and limits
  - Manage potential conflicts between needs of transmission and distribution operation
  - Encourage appropriate contributions/responses by different actors
  - Identify and deliver appropriate network reinforcements

Connecting distributed generation

- ‘Distributed generation’ is generation embedded within a distribution network
  - Much of it uses variable renewable sources, e.g. wind or solar PV, but might also be, for example, combined heat and power (CHP) or thermal generation based on biomass

e.g.



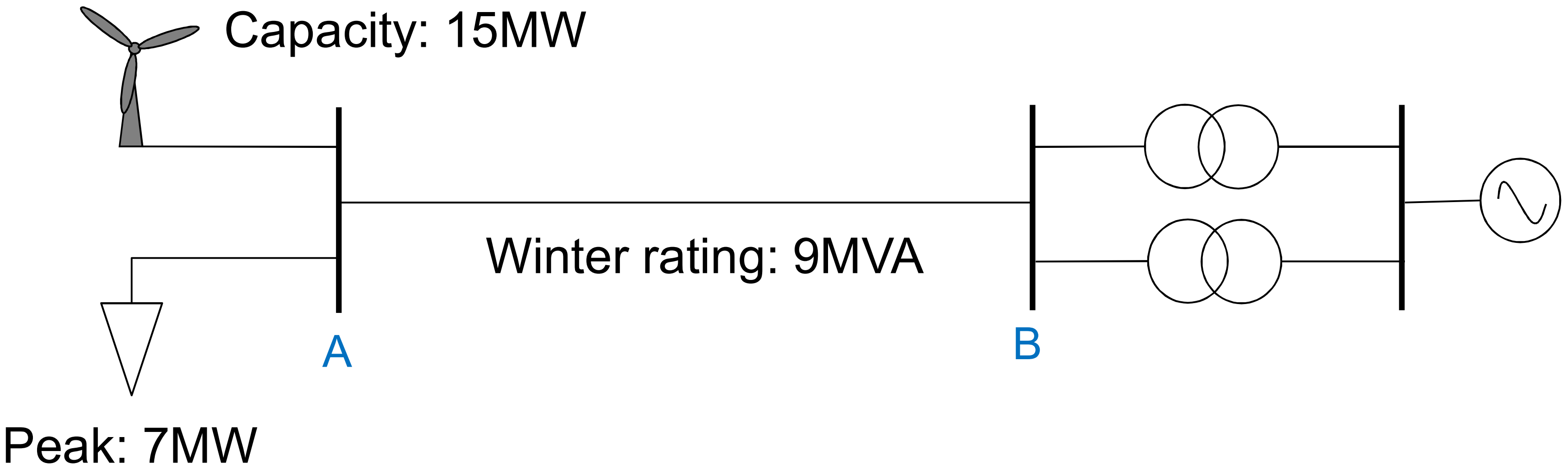
Capacity: 15MW

Winter rating: 9MVA

Peak: 7MW

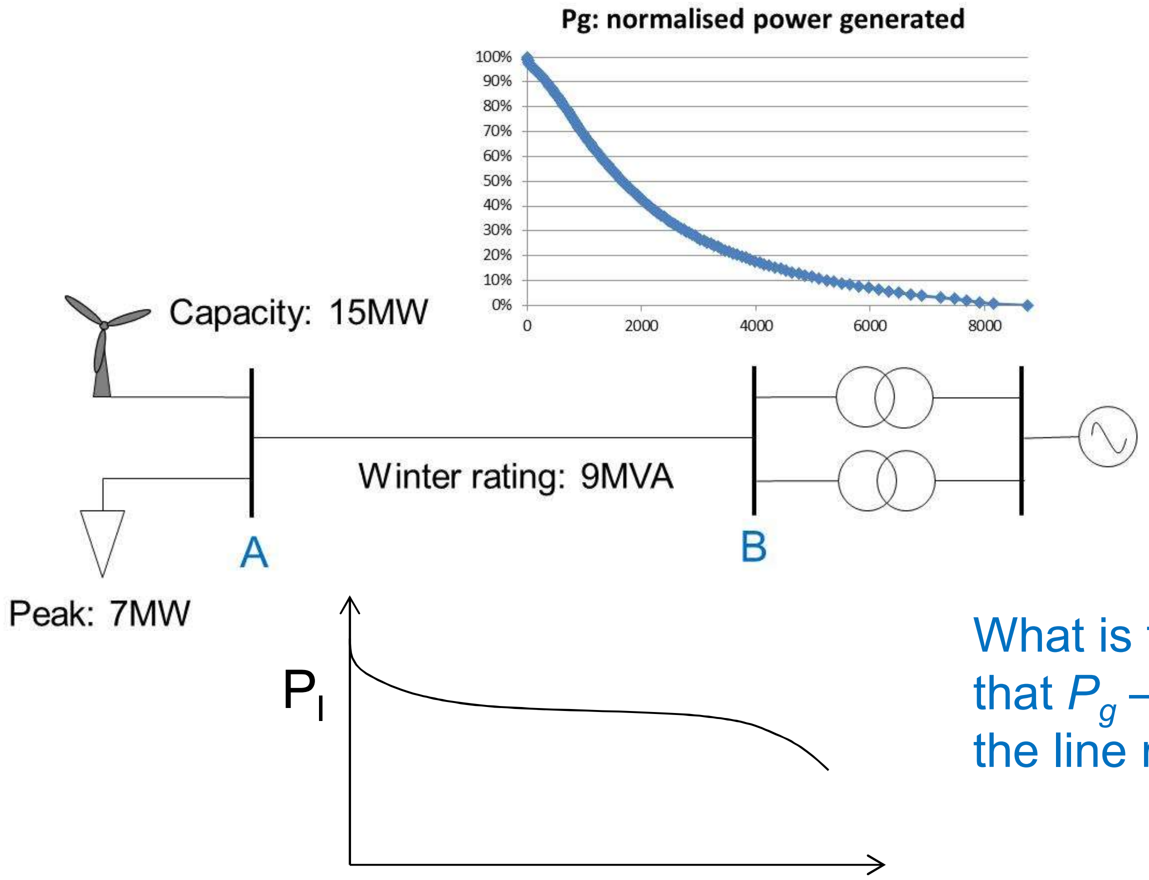
Connecting distributed generation

- Example: a 15MW wind farm applies for a connection at A
  - Is a reinforcement of the line between A and B required?
- *What if we knew that the minimum demand at A is 4MW?*
- *What account can be taken of real-time ratings?*



Connecting distributed generation

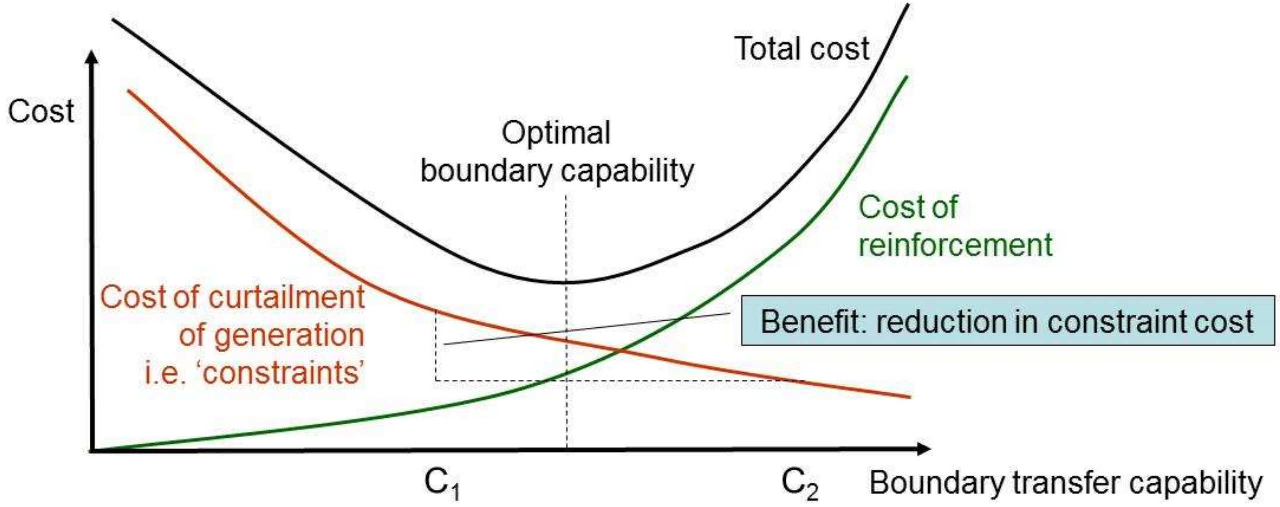
- Consider the load duration curves of demand and generation
  - Can we assume that they are independent of each other?



What is the probability that $P_g – P_l$ exceeds the line rating?

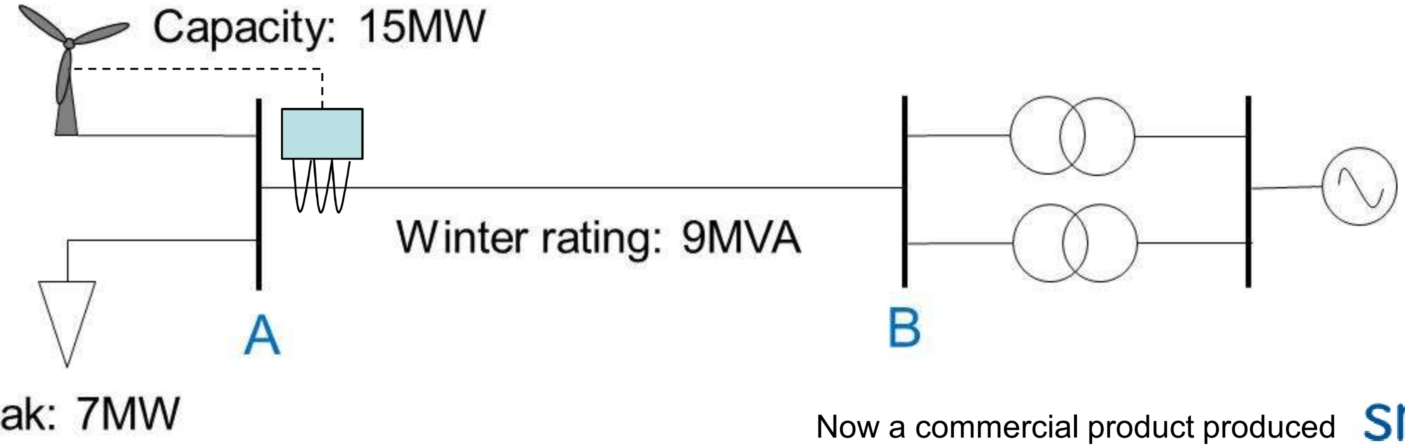
Connecting distributed generation

- Why not monitor the line loading relative to the rating and curtail wind output
  - by just enough
  - only when necessary?
- What is the ‘constraint cost’ when curtailing distributed generation?
  - Who incurs it? Does it help in valuing network capacity?



Connecting distributed generation

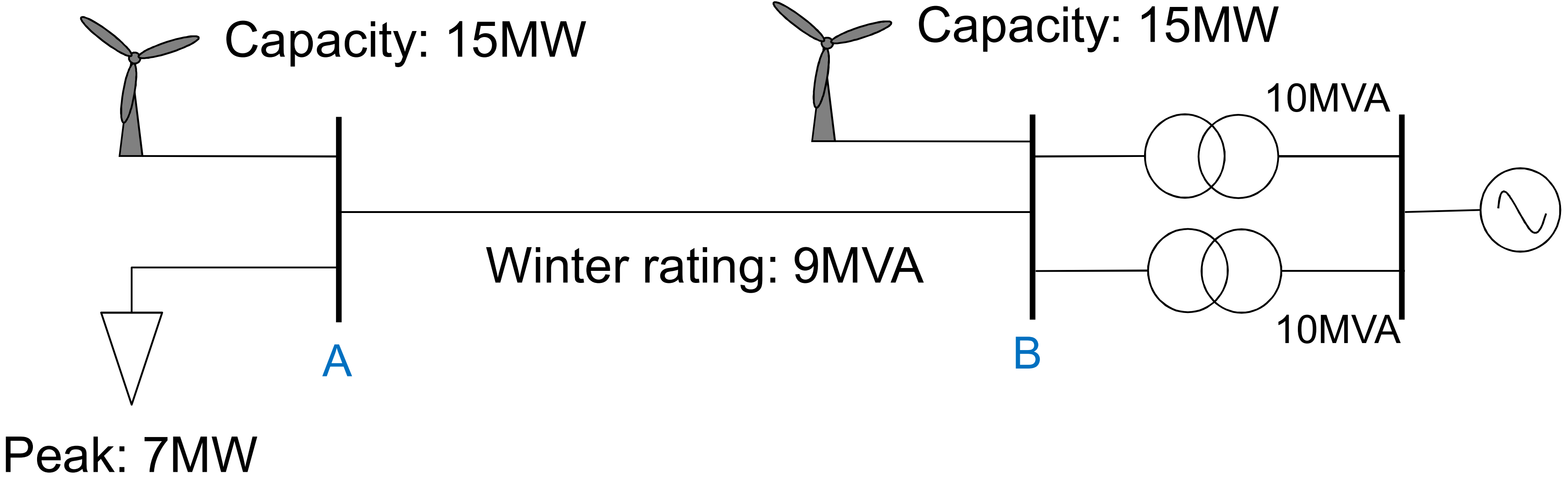
- Options:
  - The wind farm pays for an enhanced line rating
  - The wind farm installs fewer turbines
  - An ANM system is installed to manage the periods when a line would be overloaded
- How much energy would be curtailed?
  - How much income does the wind farm lose?
  - Whose responsibility is it to make an estimate?



Now a commercial product produced by a Strathclyde spin-out

Extending the example 1

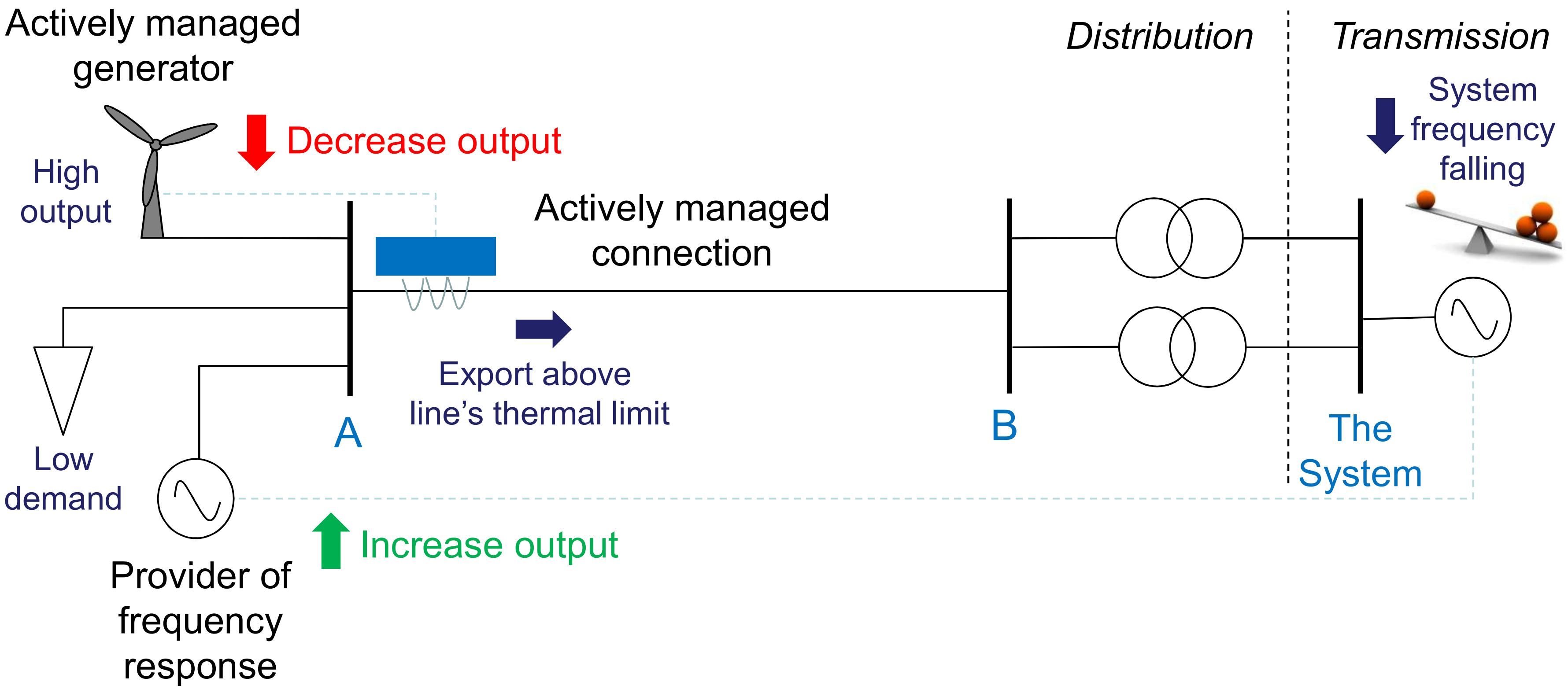
- The wind farm at A does not have a ‘firm’ connection, i.e. it is not N-1 secure
- Does the wind farm at B expect a ‘firm’ connection?
- If the line A-B is ok but the transformers at B are overloaded, which wind farm should be curtailed?
  - LIFO*? Pro-rata? Minimum losses answer? Market solution?



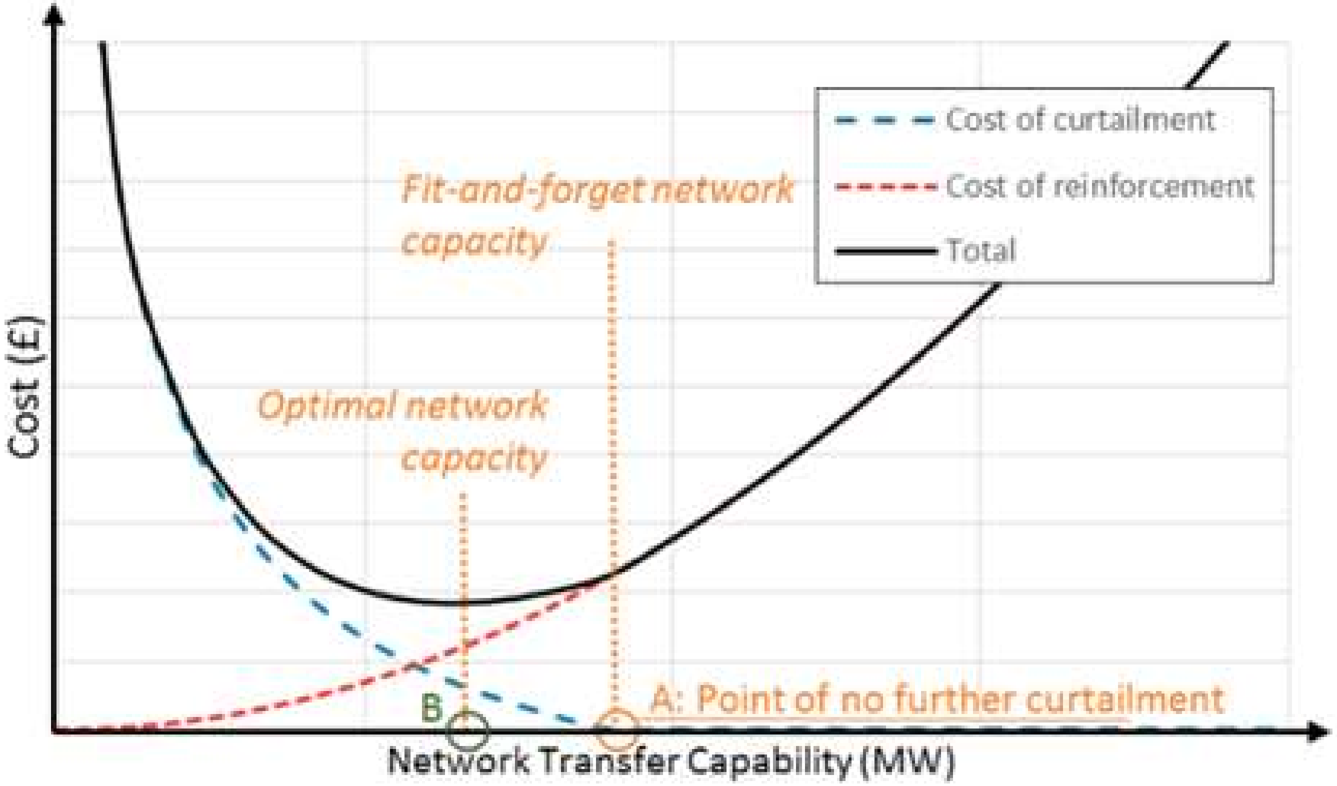
* Last in, first out

Extending the example 2: possible conflict between transmission System Operator and a DSO

- What if, at the same time,
  - the DSO wants to reduce DG output to avoid overloading the line?
  - the TSO wants to reduce demand or increase generation to balance out the whole system?

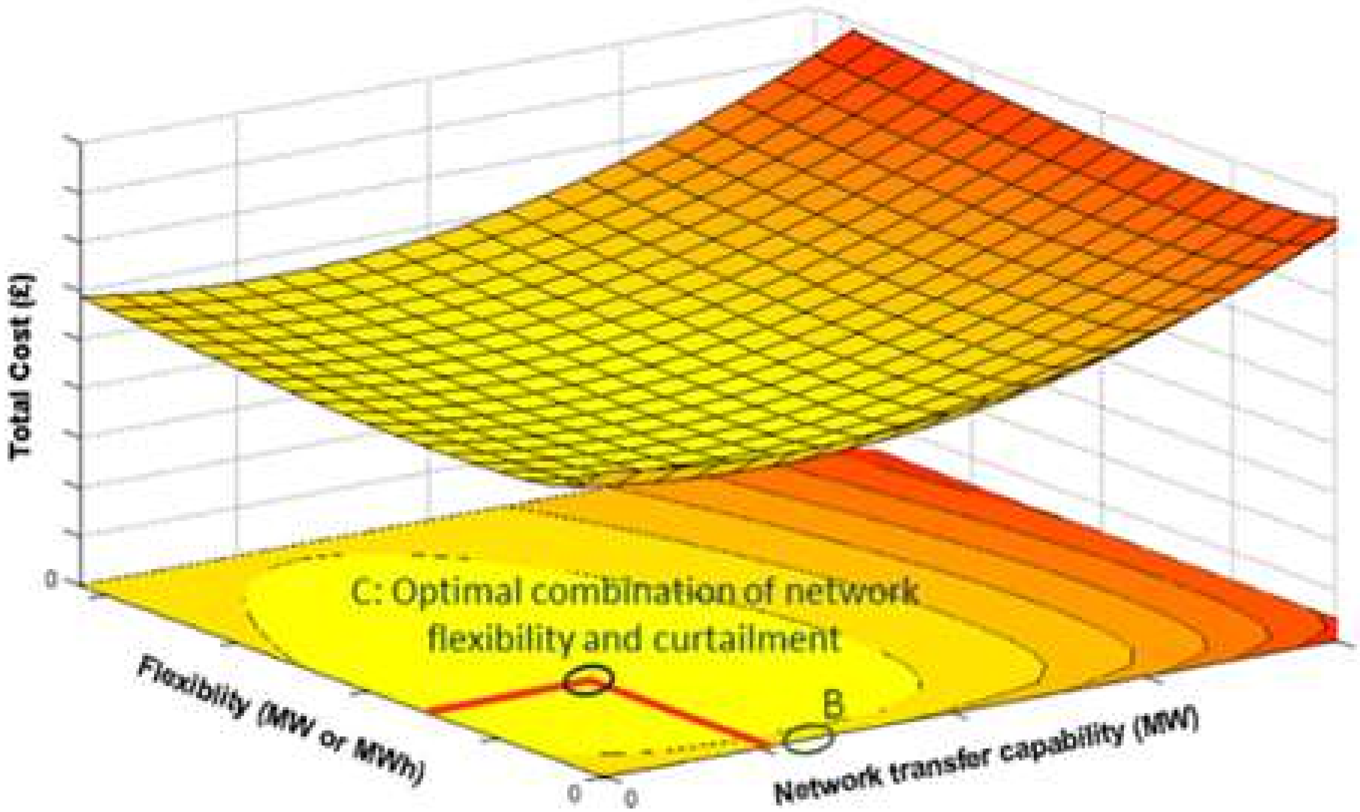


‘Fit and forget’ is sub-optimal



The optimal network capacity is not constraint-free.
Constraints need to be actively managed.
Constraint management depends on observability and controllability

Enabling flexibility



Flexibility can reduce network capacity…
However, more network capacity might be needed
in order to access flexibility

Step-by-step towards a DSO

- Who are the key actors/agents and what regulatory status?
  - What do they do now?
  - What do they not do now?
  - What might they do in future?
- What are the main functions required
  - Of a power system in general?

Some work already done on this, e.g. FPSA

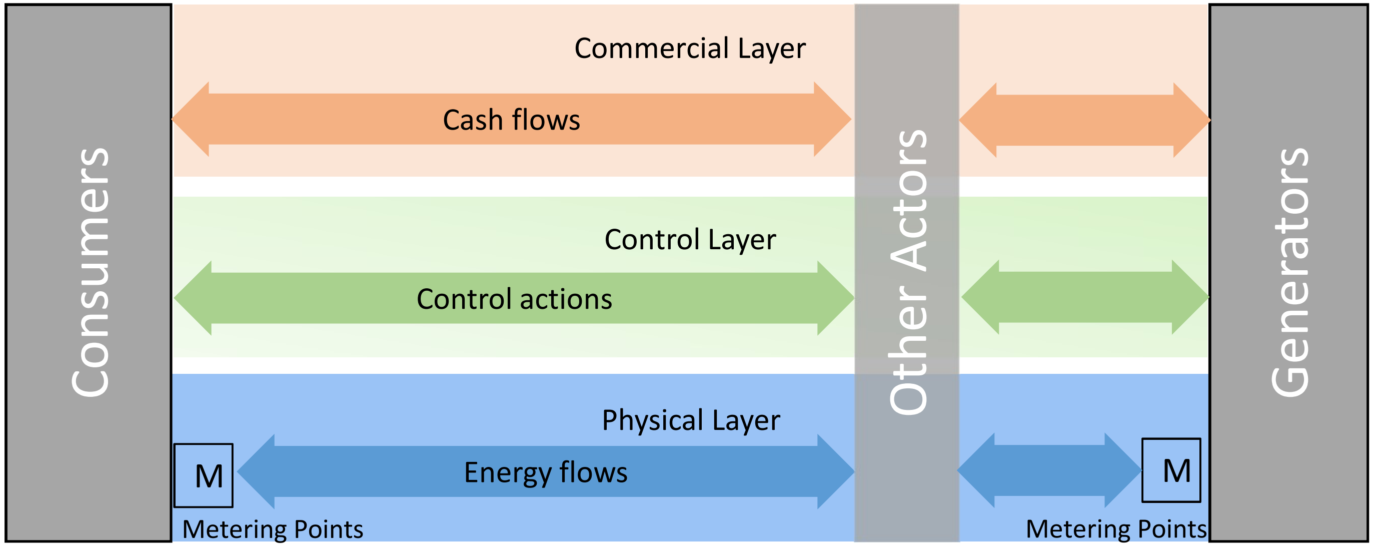
  - Of a distribution network in particular?
- Does the low carbon transition require any fundamental change in what a power system does?
  - Or might there simply be change in *how* it does it?
  - Which party is best placed to fulfil each need?
  - Which responsibilities should not be taken away from network licensees?
- How are new concepts such as peer-to-peer trading accommodated?
  - What does ‘peer-to-peer’ require?

Roles of network licensees

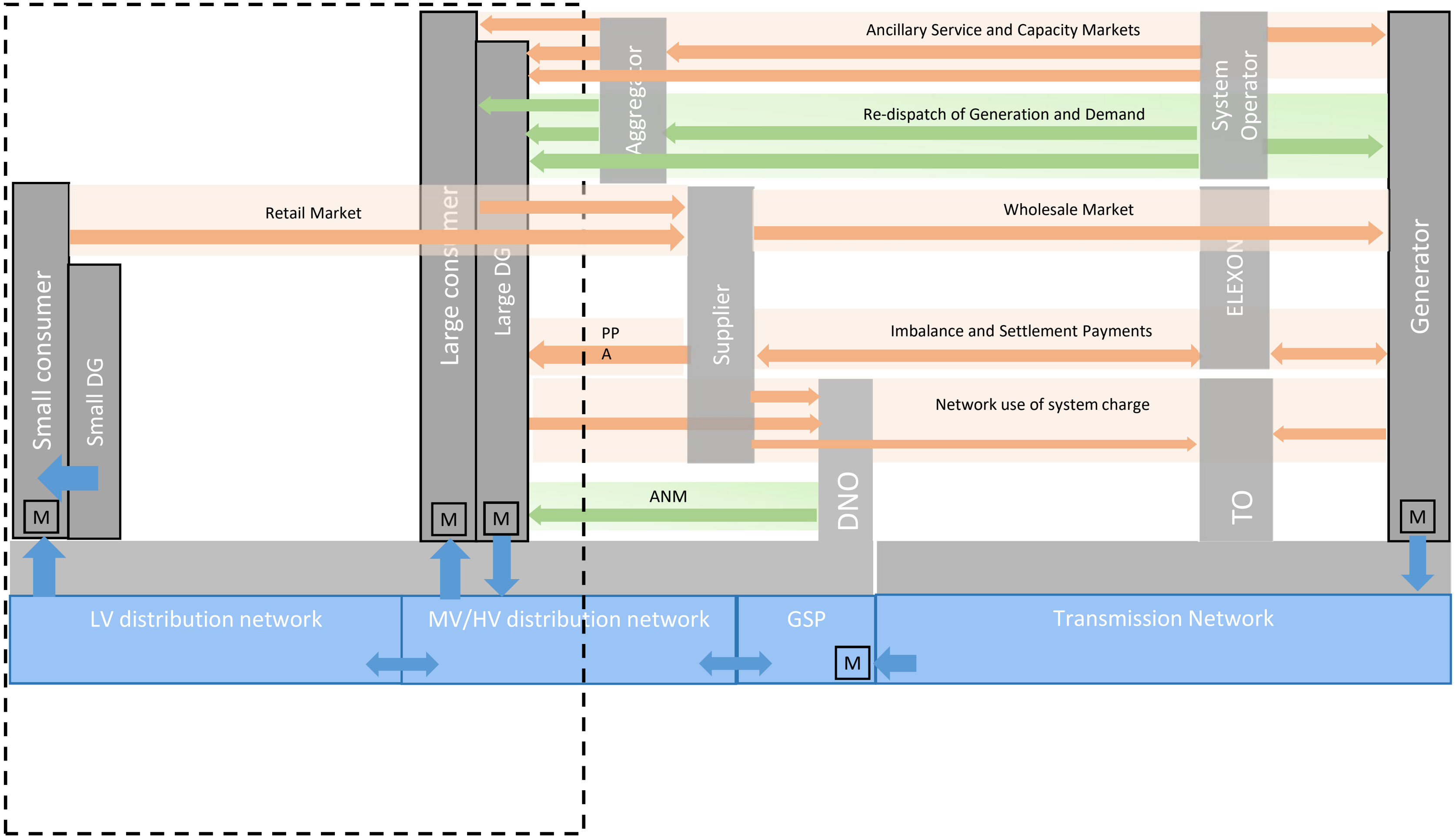
	TRANSMISSION	DISTRIBUTION	
SO	provide contracts to connectees	provide contracts to connectees	**DNO**
	specify need for new network infrastructure	specify need for new network infrastructure	
TO	build and maintain connections to connectees	build and maintain connections to connectees	
	build and maintain network infrastructure	build and maintain network infrastructure	
	carry out switching to enable safe working	carry out switching to enable safe working	
SO	decide and implement system control settings	decide and implement system control settings	

Mapping the relationships

The Basic Archetype Model



Incumbent Archetype



Questions in design of commercial and regulatory arrangements

With lots of DER, how do you structure things such that

a) there is competition and choice for energy users?
  - Does peer-to-peer trading make sense for electricity?

b) things are manageable/operable and safety is assured?
  - Network limits need to be respected
  - Contributions of DG to ancillary services?
  - Who procures services? (DSO or TSO?)

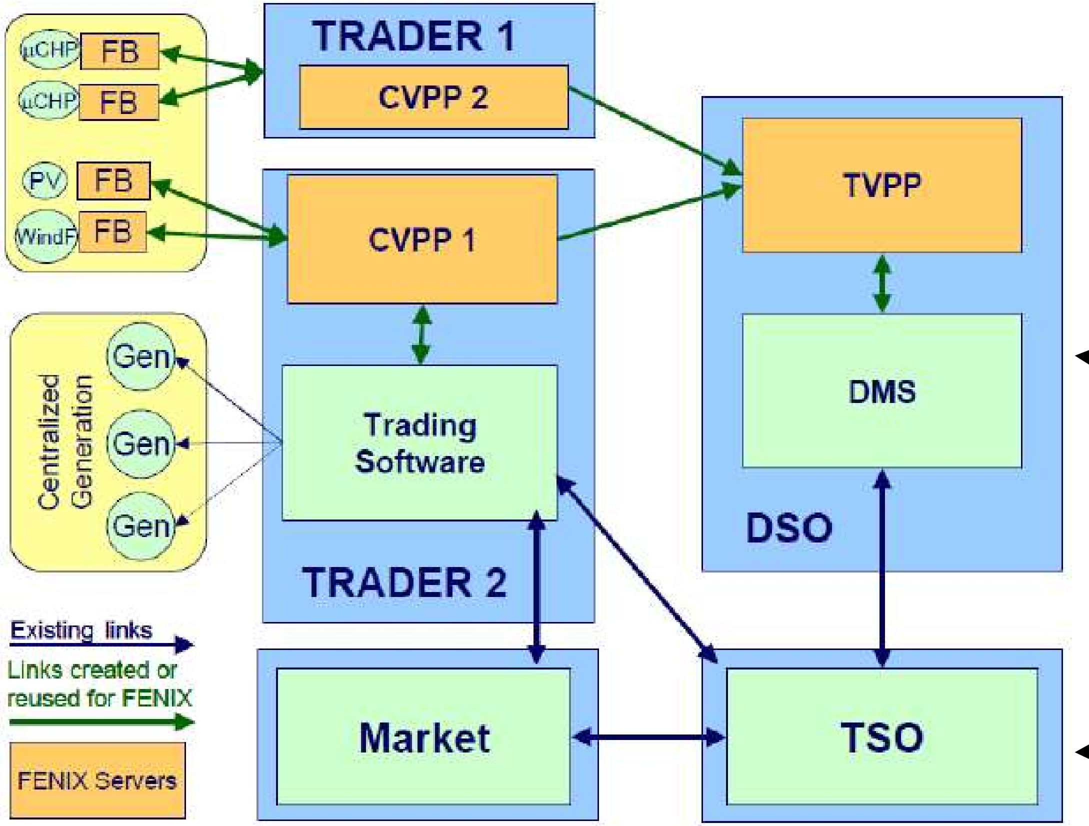
c) energy users' access is enabled?

d) the overall cost of the system is minimised (using suitable signals aimed at parties able respond to them)?
  - How to signal need for investment in new network facilities and incentivise appropriate responses to those signals?

e) there is scope for innovation?

Virtual Power Plants

- Commercial VPP (CVPP) has no regard for location or physical network limits
  - In FENIX, leads to an apparent need to define Technical VPPs (TVPPs)
- How do CVPPs and TVPPs relate to each other?
- How does a DSO remunerate CVPPs for actions on TVPPs?



How are possible conflicts between TSO and DSO requirements resolved?

A hierarchical approach

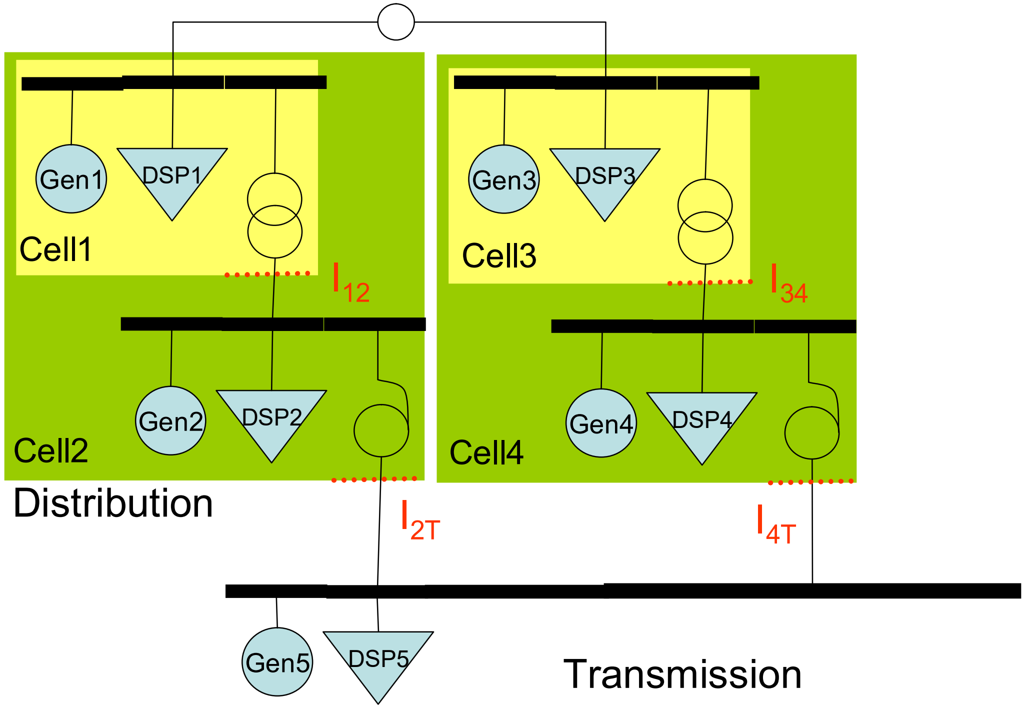
- How to frame the influences and actions of
  - Distribution System Operator (DSO)?
  - Transmission System Operator (TSO)?
  - Generators?
  - Demand Side Participants (DSPs)?
- Define clear interfaces between groups/‘cells’:
  - Because physical engineering system limits must finally be respected, define based on electrical rather than commercial groupings
  - Boundaries of electrical groups defined by
    - Voltage level
    - Open points
    - Power transfer bottleneck

Might change depending on system state

Hierarchical model

- P_{max12} = *minimum*(rating$_{12}$, Gen1$_{max}$ – DSP1$_{min}$)
- P_{min12} = *minimum*(rating$_{12}$, DSP1$_{max}$ – Gen1$_{min}$)
- P_{max2T} = *minimum*(rating$_{2T}$, Gen2$_{max}$ + P12$_{max}$ – DSP2$_{min}$)
- P_{min2T} = *minimum*(rating$_{2T}$, DSP2$_{max}$ – Gen2$_{min}$ – P_{12min})

Limits also subject to adjustment to take account of voltage and reactive power issues



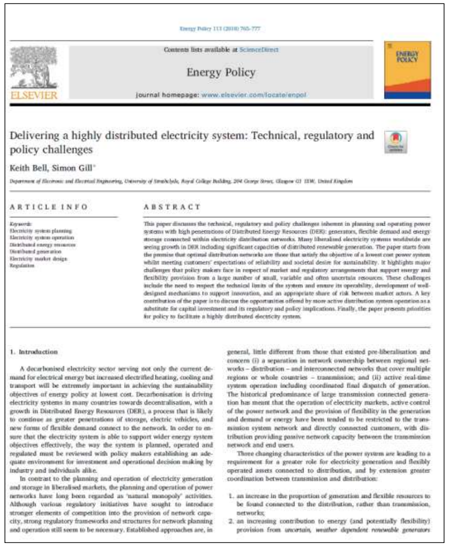
Issues in potential DSO model

- Monolith versus multiple parties/openness to innovation?
- ICT big bang?
- Culture change/expertise?
- Precision/optimality?
- Knowledge of the distribution networks and access to information (not just data)?
- DSO getting in the way and denying choice to the SO or to service providers?
- Who monitors physical limits on the distribution network?
- How are physical limits enforced?
  - Systems designed to ‘fail gracefully’
- “Make every bit of data available and the market will provide”

Policy principles

The set of arrangements for energy trading, system operation and network investment should be such that

1. The system can be safely operated in accordance with relevant physical limits.
2. The overall cost of the system is minimised within environmental, reliability and quality of supply constraints that accurately represent societal and individual preferences.
3. Access to the electricity system is fairly and efficiently facilitated for users of the system at all scales and voltage levels.
4. Risk and uncertainty is held and managed by those best able to manage it.
5. Innovation is encouraged.
6. The complexity of market arrangements and incentives is managed such that, while signals are as reflective of whole electricity system costs as possible, active participation in different markets is encouraged.



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Delivering a highly distributed electricity system: Technical, regulatory and policy challenges

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Distributed generation
Electricity market design
Regulation

ABSTRACT

This paper discusses the technical, regulatory and policy challenges inherent in planning and operating power systems with high penetrations of Distributed Energy Resources (DER): generators, flexible demand and energy storage connected within electricity distribution networks. Many liberalised electricity systems worldwide are seeing growth in DER including significant capacities of distributed renewable generation. The paper starts from the premise that optimal distribution networks are those that satisfy the objective of a lowest cost power system whilst meeting customers' expectations of reliability and societal desire for sustainability. It highlights major challenges that policy makers face in respect of market and regulatory arrangements that support energy and flexibility provision from a large number of small, variable and often uncertain resources. These challenges include the need to respect the technical limits of the system and ensure its operability, development of well-designed mechanisms to support innovation, and an appropriate share of risk between market actors. A key contribution of the paper is to discuss the opportunities offered by more active distribution system operation as a substitute for capital investment and its regulatory and policy implications. Finally, the paper presents priorities for policy to facilitate a highly distributed electricity system.

1. Introduction

A decarbonised electricity sector serving not only the current demand for electrical energy but increased electrified heating, cooling and transport will be extremely important in achieving the sustainability objectives of energy policy at lowest cost. Decarbonisation is driving electricity systems in many countries towards decentralisation, with a growth in Distributed Energy Resources (DER), a process that is likely to continue as greater penetrations of storage, electric vehicles, and new forms of flexible demand connect to the network. In order to ensure that the electricity system is able to support wider energy system objectives effectively, the way the system is planned, operated and regulated must be reviewed with policy makers establishing an adequate environment for investment and operational decision making by industry and individuals alike.

In contrast to the planning and operation of electricity generation and storage in liberalised markets, the planning and operation of power networks have long been regarded as 'natural monopoly' activities. Although various regulatory initiatives have sought to introduce stronger elements of competition into the provision of network capacity, strong regulatory frameworks and structures for network planning and operation still seem to be necessary. Established approaches are, in general, little different from those that existed pre-liberalisation and concern (i) a separation in network ownership between regional networks – distribution – and interconnected networks that cover multiple regions or whole countries – transmission; and (ii) active real-time system operation including coordinated final dispatch of generation. The historical predominance of large transmission connected generation has meant that the operation of electricity markets, active control of the power network and the provision of flexibility in the generation and demand or energy have been tended to be restricted to the transmission system network and directly connected customers, with distribution providing passive network capacity between the transmission network and end users.

Three changing characteristics of the power system are leading to a requirement for a greater role for electricity generation and flexibly operated assets connected to distribution, and by extension greater coordination between transmission and distribution:

1. an increase in the proportion of generation and flexible resources to be found connected to the distribution, rather than transmission, networks;
2. an increasing contribution to energy (and potentially flexibility) provision from *uncertain, weather dependent renewable generators*