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The Behaviour of Storage Devices in Electricity Grids

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Institute of Physics

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Contents

1. The electrical utility engineer perspective
2. Storage performance requirements
3. Where now?

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The Electricity Utility

ABB.com

- Generation – plant + fuel
- Transportation - Transmission + Distribution
- Ancillary services – energy balance + protection

Cost not just Joules

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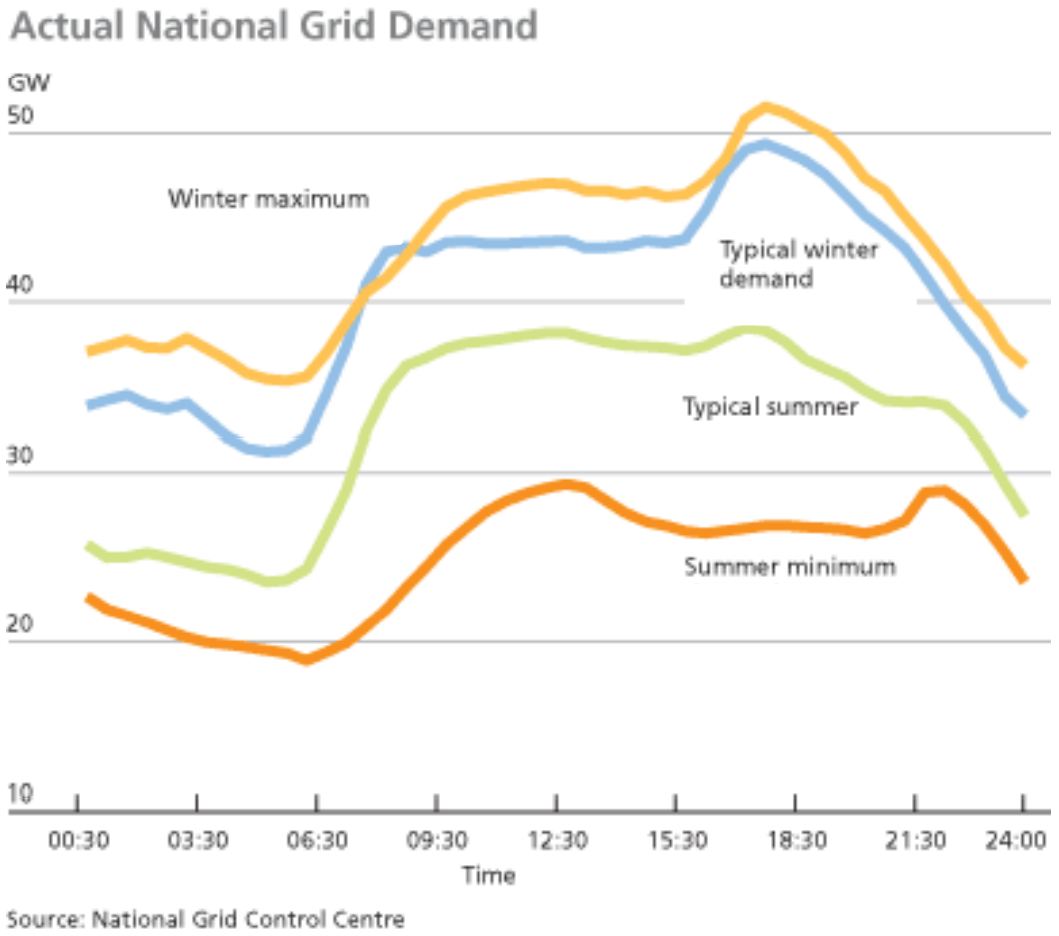
The Challenge



- 'Keep the lights on' = Meet consumer demand on a second-by-second basis **safely (conservative industry)**

How?

- Mix of Base Load-Generation and Fast Responsive Plant and operation/protection schemes designed for this plant

- Primary Response
  - Deloaded CCGT

- Secondary Response
  - Spinning Reserve

- Pumped Storage (e.g.Dinorwig)

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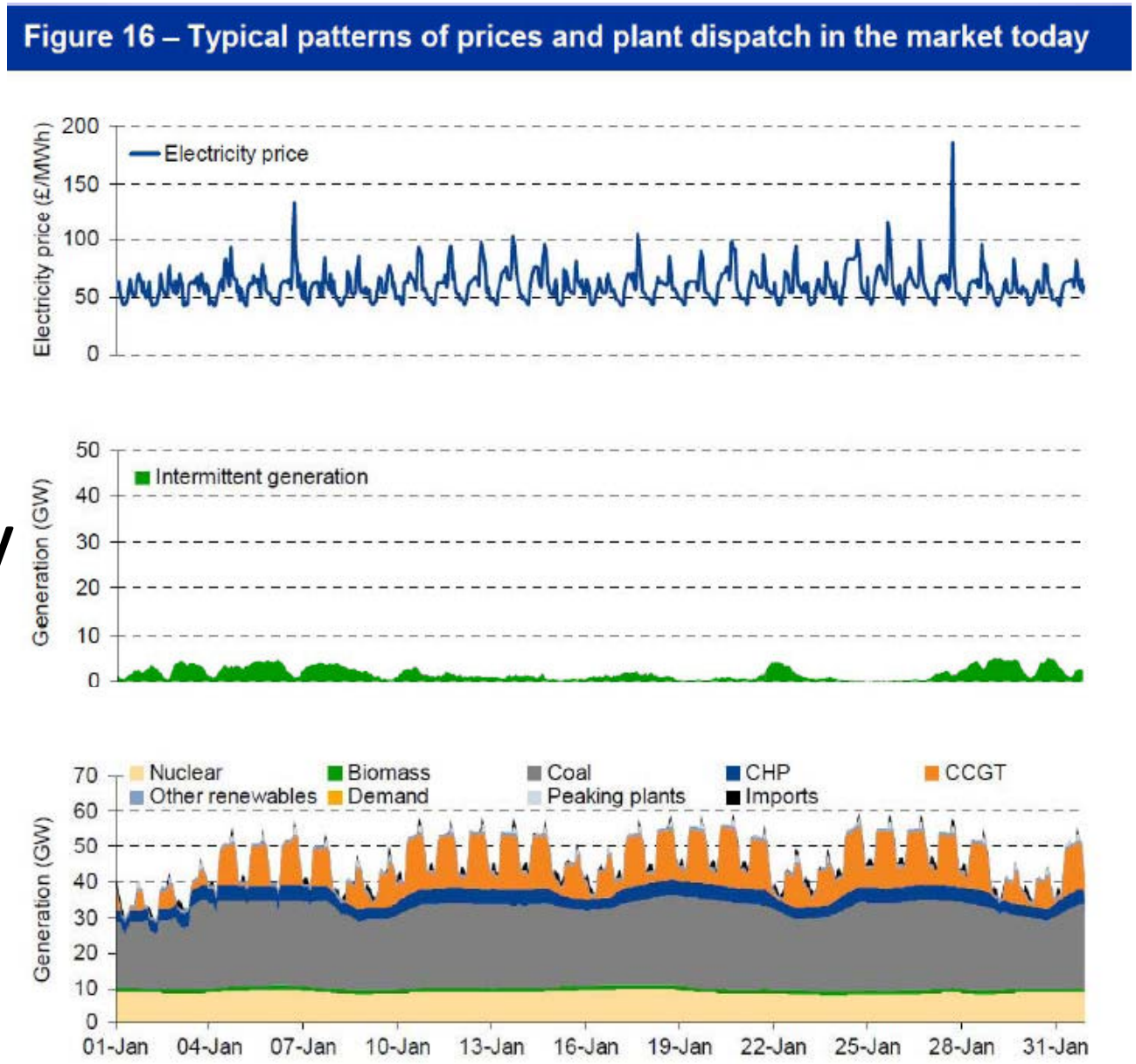
Pöyry– Impact of intermittency (2009)



http://www.poyry.com/index_cases/index_cases_12.html

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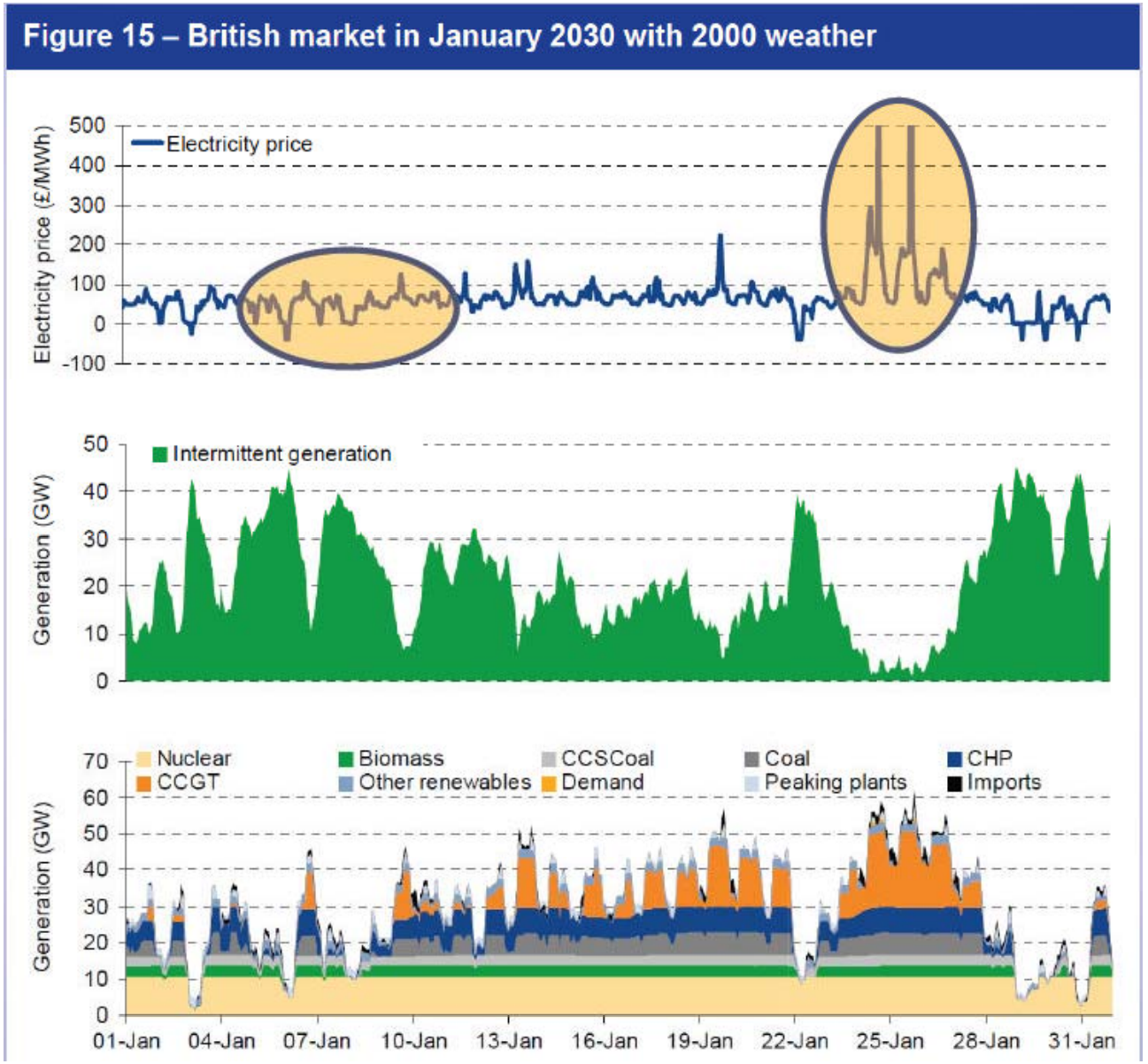
Pöyry– Impact of intermittency (2030)

Key traditional role for storage: managing intermittency (TOU)



http://www.poyry.com/index_cases/index_cases_12.html

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Drivers for New Utility Energy Storage

High Value Loads

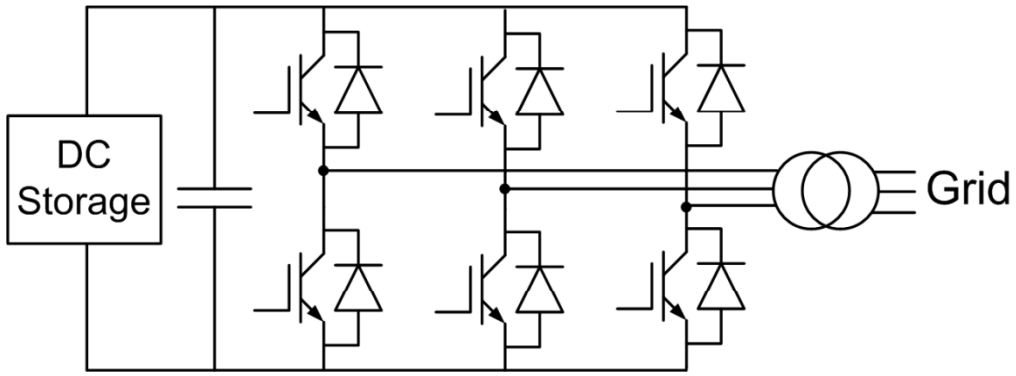
Changing (High Density) Load Patterns

New Power Generation

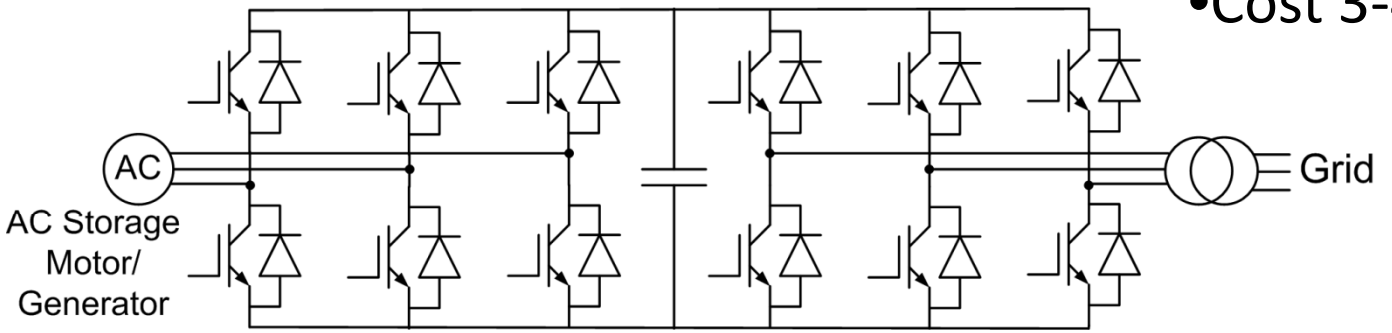
Vehicle to Grid

‘Storage’ Solutions

- **Stand-by Generation: Base case**
  - Cheap ca. £100/kW
  - Cheap to run in ‘hot-standby’ (spinning reserve)
  - Transfer time – several cycles



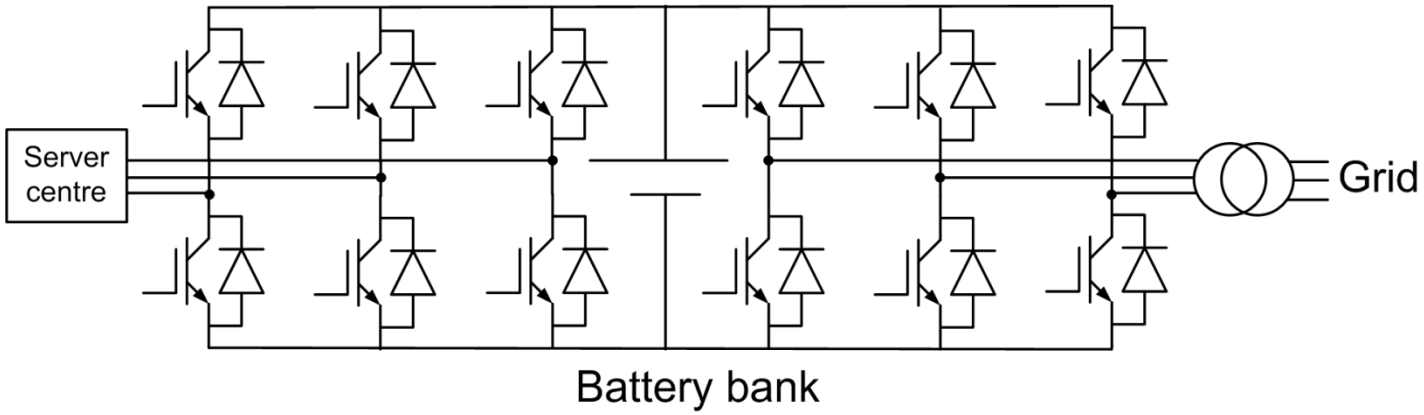
- **DC Storage**
  - Nearly instantaneous response
  - Inverter efficiency ca. 95-98% (one way)
  - Cost 3-4x generator



- **AC Storage**
- More expensive
- More losses

High Value Loads

- Banks, Data Centres
- In-line UPS. But variants:
  - in shunt with static transfer switch
  - DC ring
  - AC machine / flywheel / AC generator



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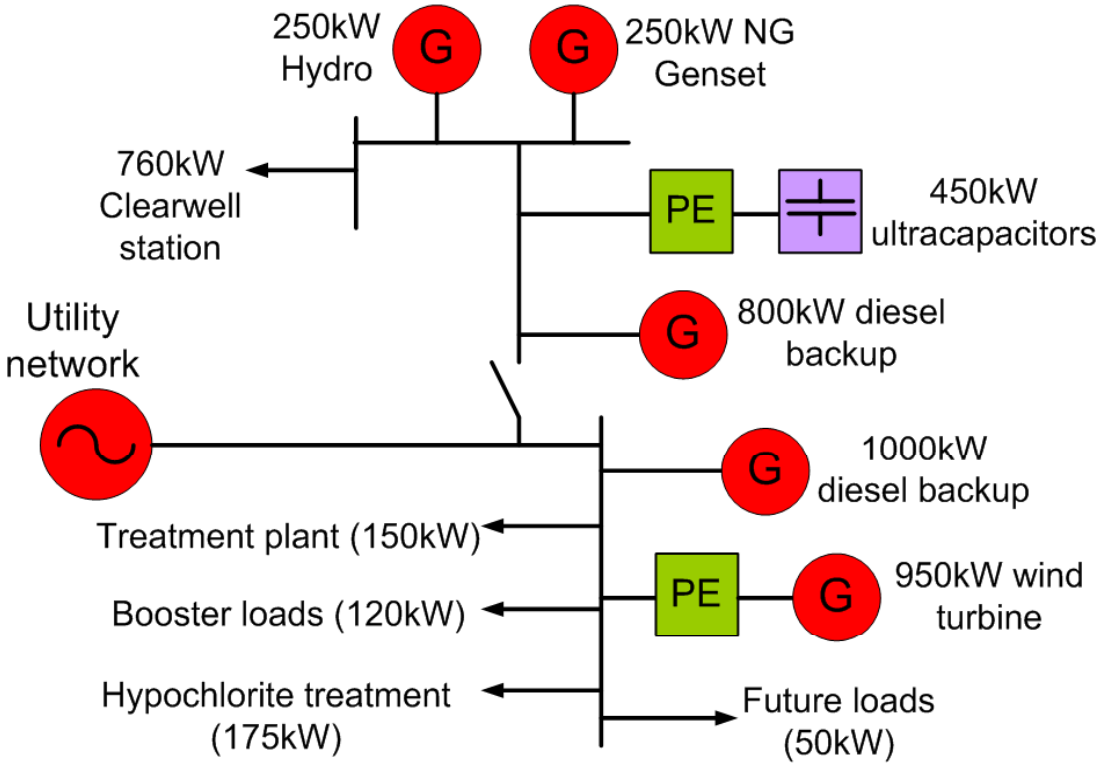
Changing (High Density Load Patterns)

E.g. Palmdale Water Treatment Plant (California)



Alternative to upgrading T & D Plant

- Cost / environmental impact (NIMBY-ism)
- Future changes to existing city centres
- Digging up the ground and extending a substation may be impossible

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New Power Generation

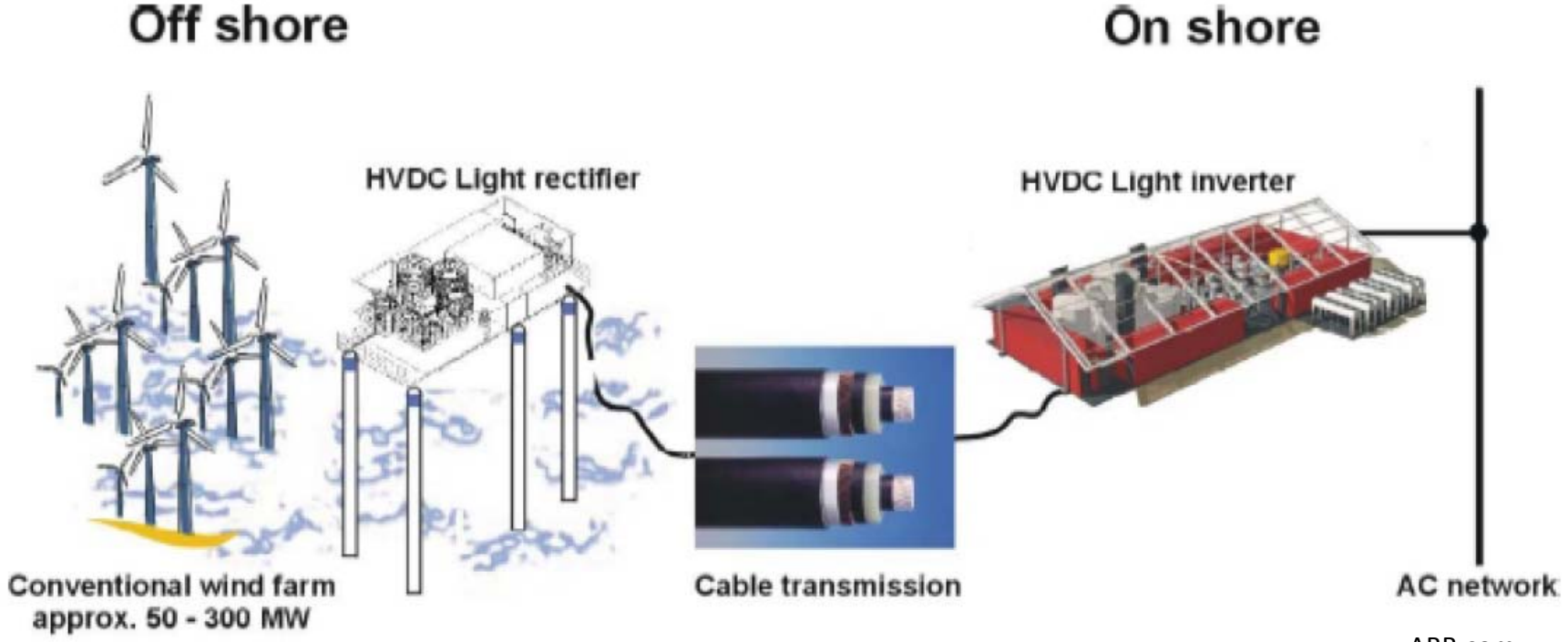

ABB.com

- Voltage source converter High-Voltage DC transmission
- Access to large offshore renewables with high capital cost (low fuel cost)

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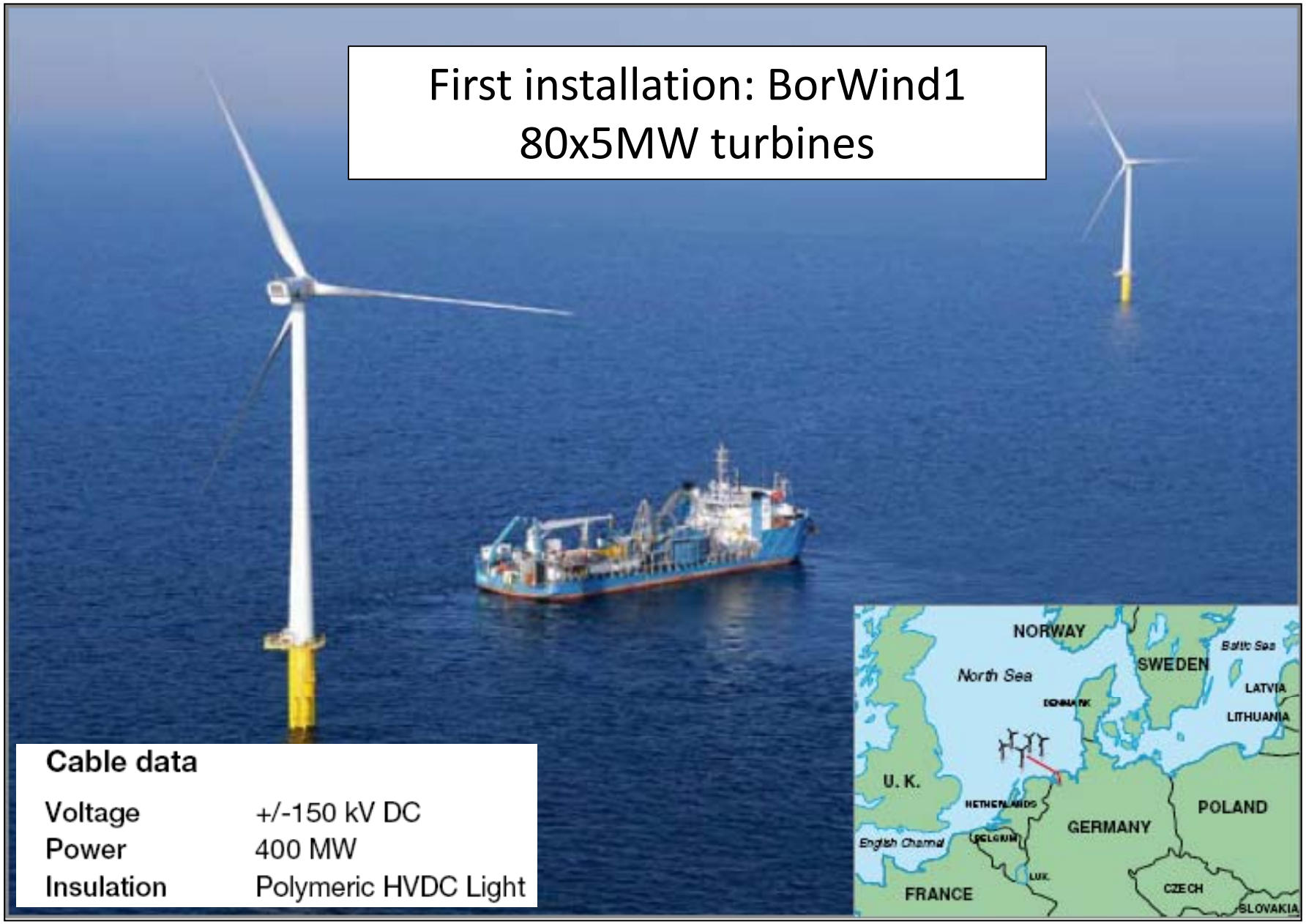
First installation: BorWind1 80x5MW turbines



Cable data

Voltage	+/-150 kV DC
Power	400 MW
Insulation	Polymeric HVDC Light

Role of Storage for Wind Farms (RAL/STFC)

- In offshore substation
  - enhance stability in steady state
  - enhance stability following external/internal disturbances & transients
- Onshore
  - enhance stability following external disturbances
  - **avoidance of curtailment**
  - 1=energy
  - 2=making network work

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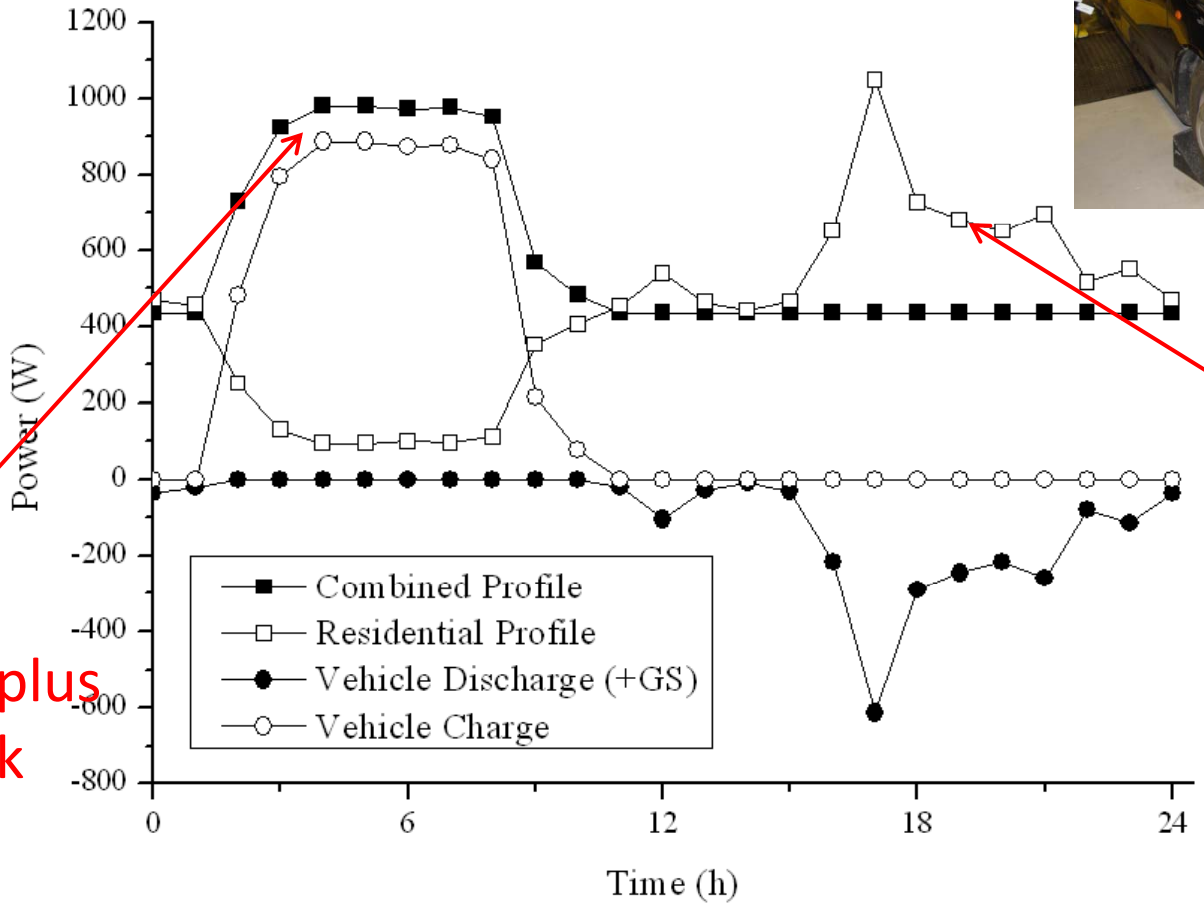
Vehicle-to-Grid (V2G)

- E.g Tuvie (www.tuvie.com)
- Use of ‘high value storage’ (Li batteries) for ‘low value’ grid support?
- Will see: optimised charging scheduling (demand side participation)
- May see: local storage to supply ‘fast charging’ of EVs

Electric Vehicle + Grid Support



Night (surplus of network capacity)

Evening (shortage of network capacity)

- Do you really want to do this though?

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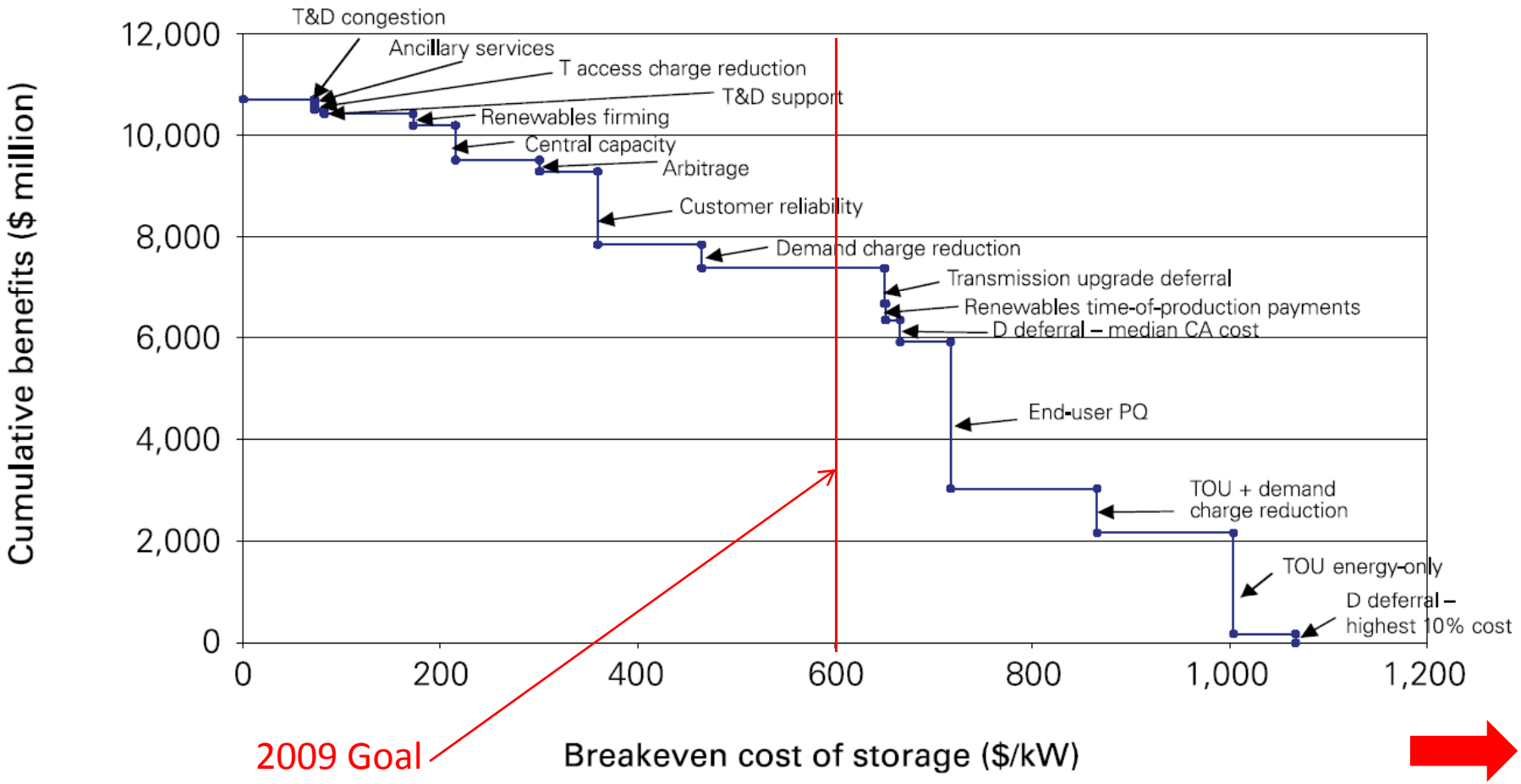
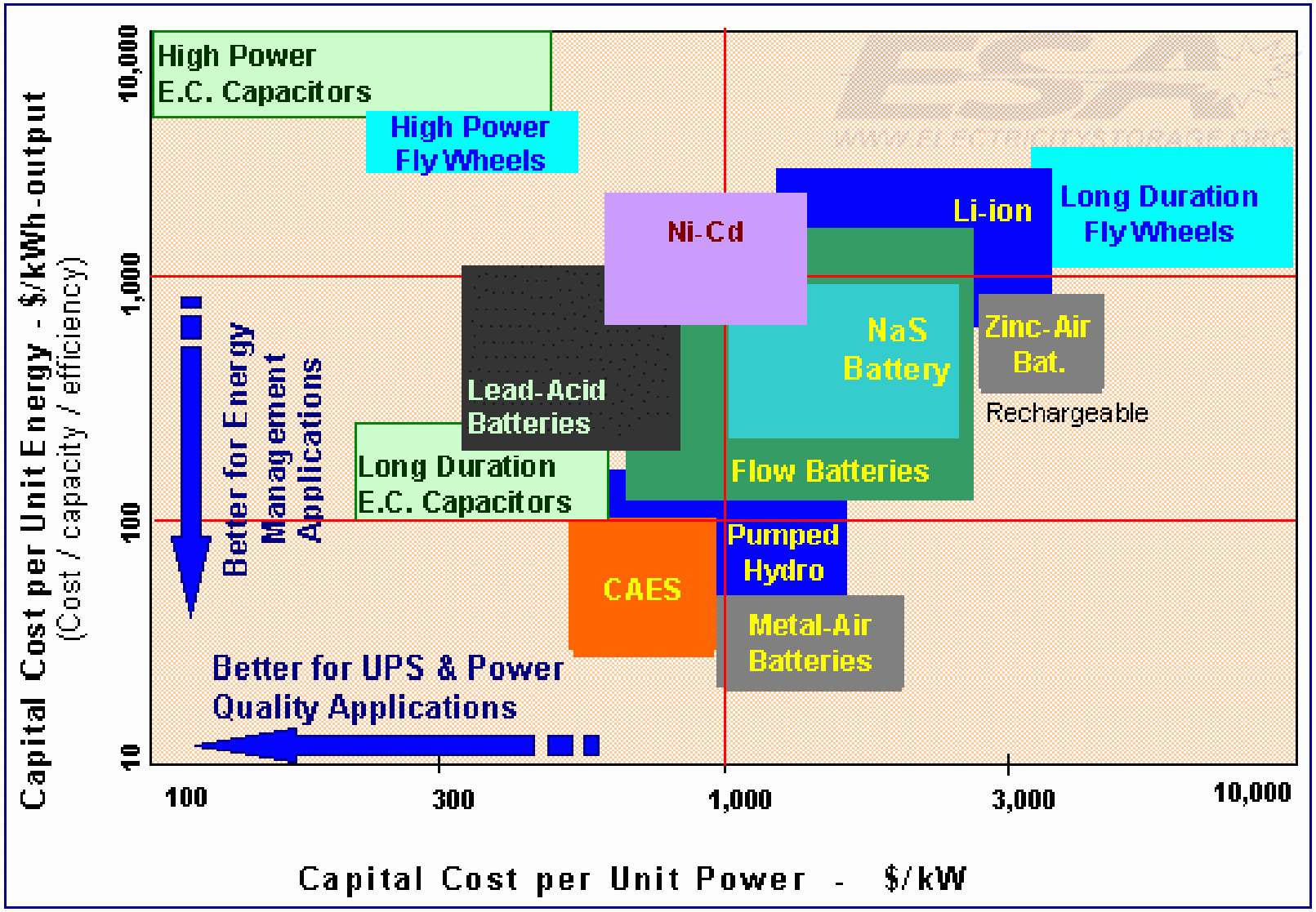
Electrical Energy Storage System – T&D Value



- Global Watch Mission Report for the DTi, December 2006.
- SNL, 2004 California projection (US=8xCA)
- Very limited application until cost <$700/ kW (waste is cheaper)

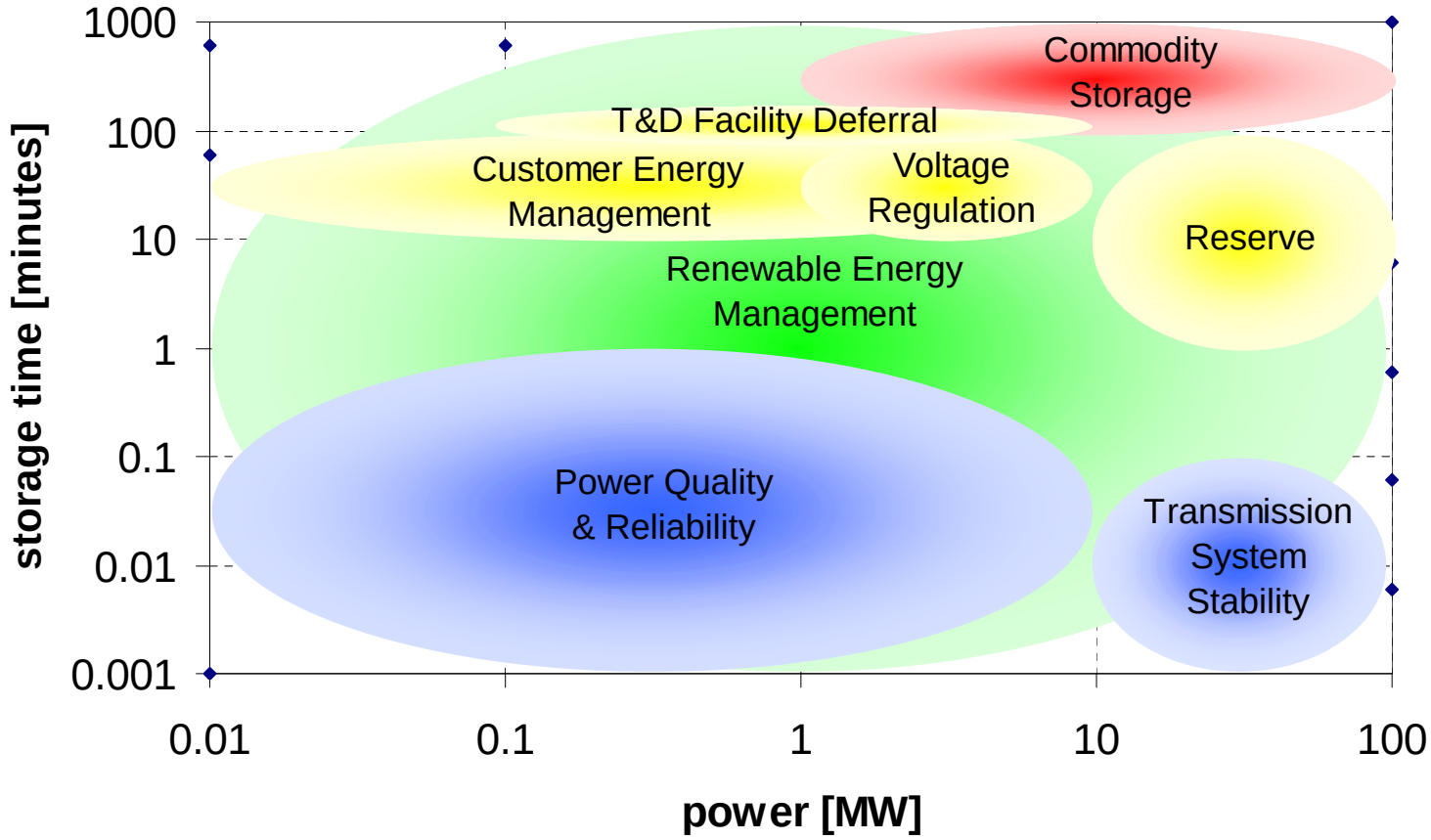
UPS Value

Costs



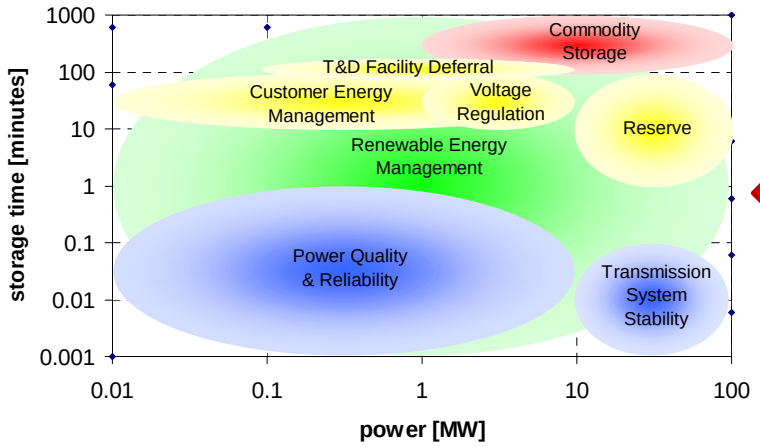
Electricity Storage Association

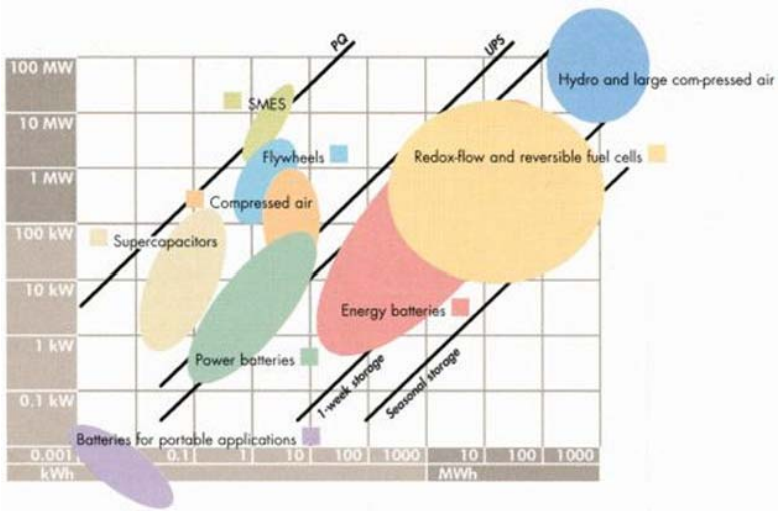
Value issues



Using data from: P. Butler et al, Sandia report SAND2002-1314

Technology-Capability Mapping

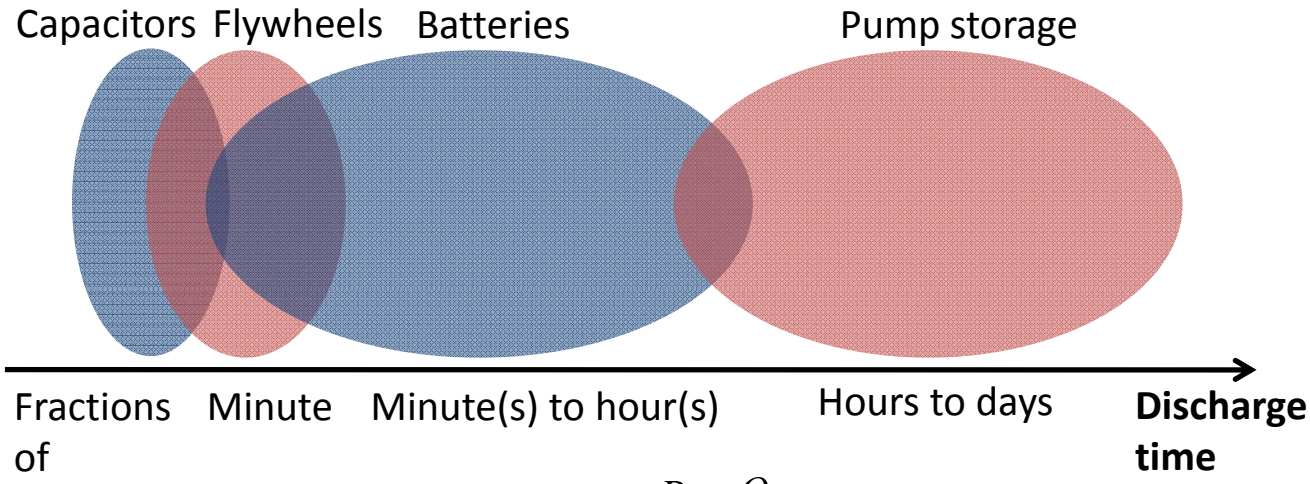


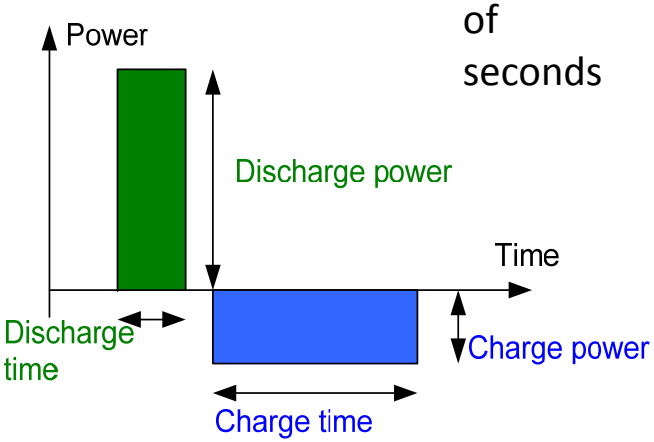


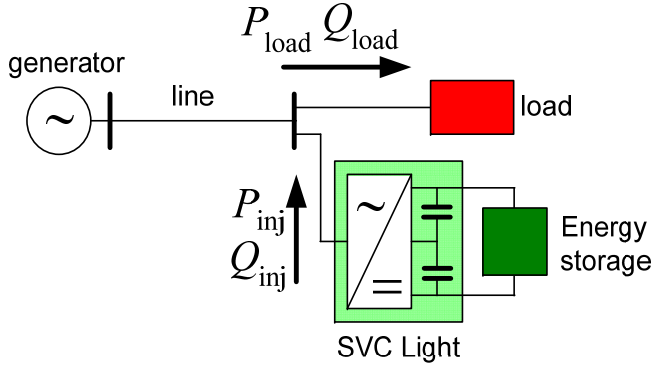
- **Add**
  - Portability/relocate-ability (stranded asset issue)
  - Reliability / availability / maintenance
  - Local environmental impact

ABB SVC Light

- ABB SVC Light (core range 5 to 60 mins, 5 to 50 MW)
- Li-ion battery
- 5 MWh

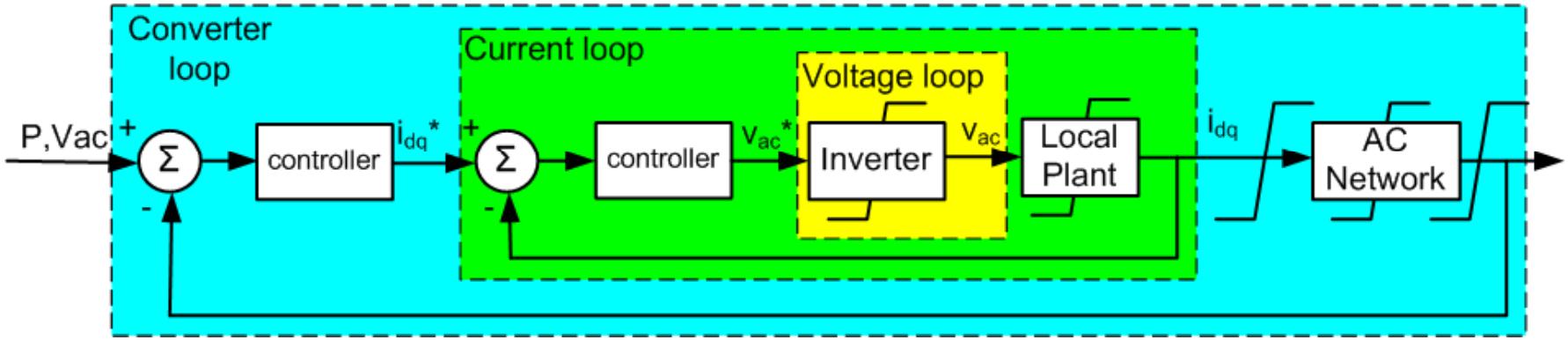




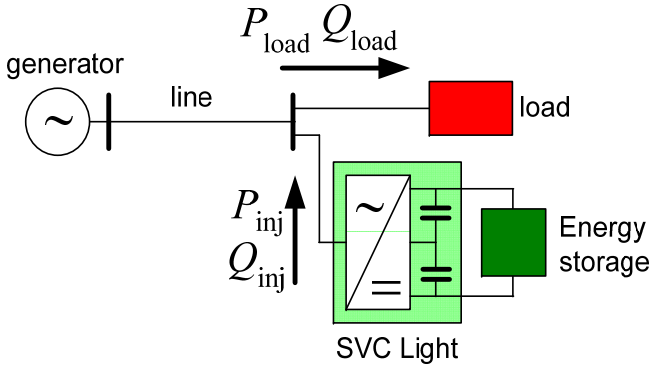


pictures from ABB SVC Light presentation

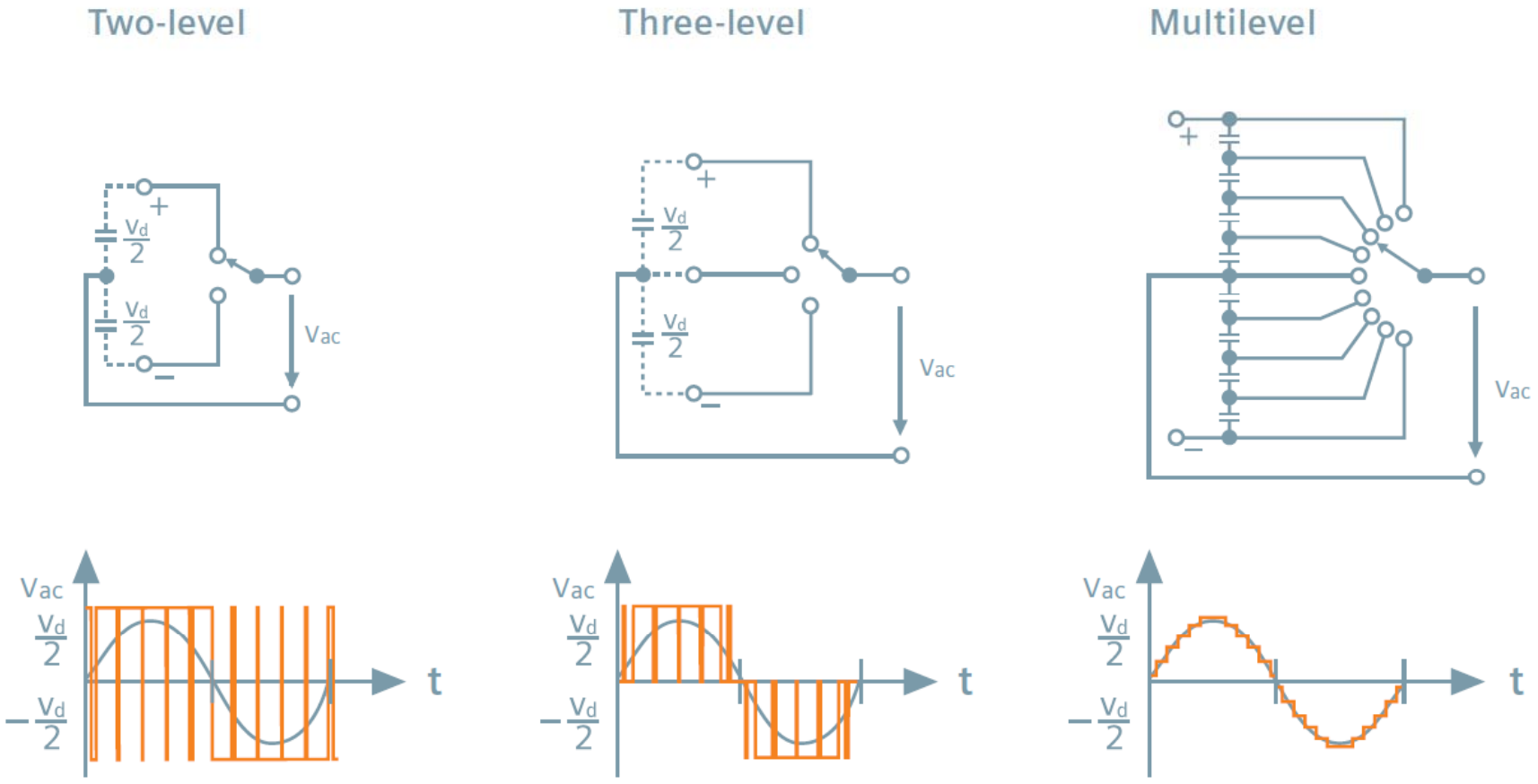
System behaviour



- Set real power absorption or injection
- Convert this to current set-points
- Synthesize a voltage output to affect this

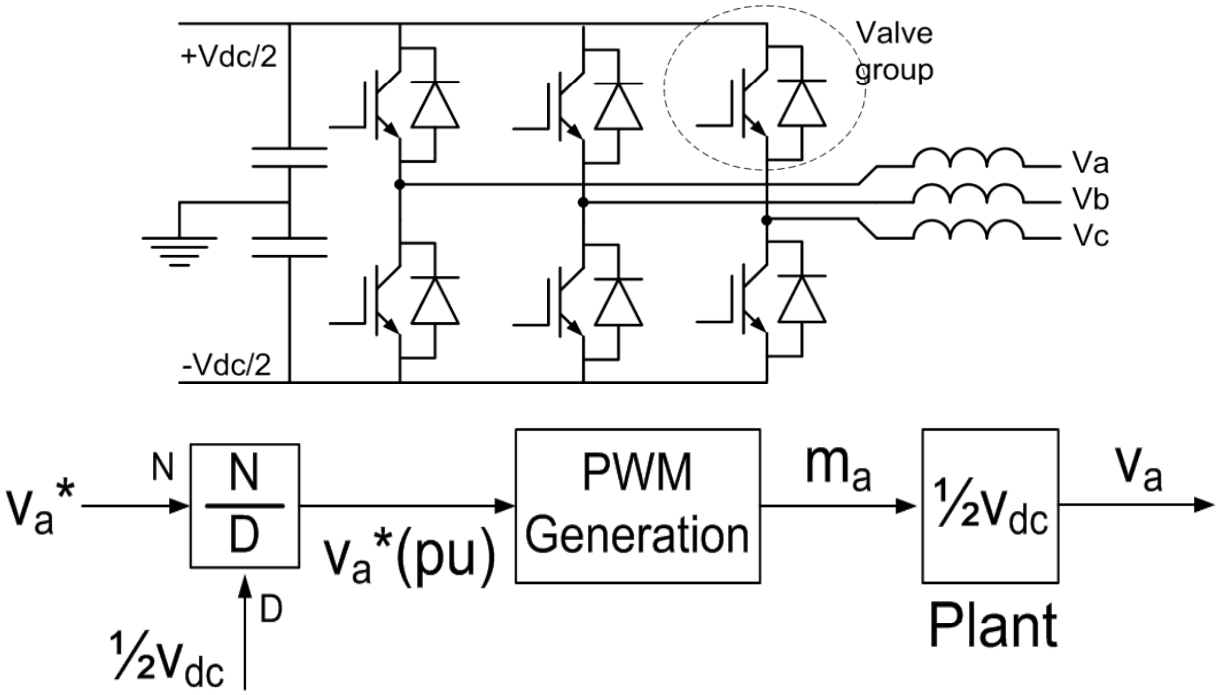


Voltage Control Loop



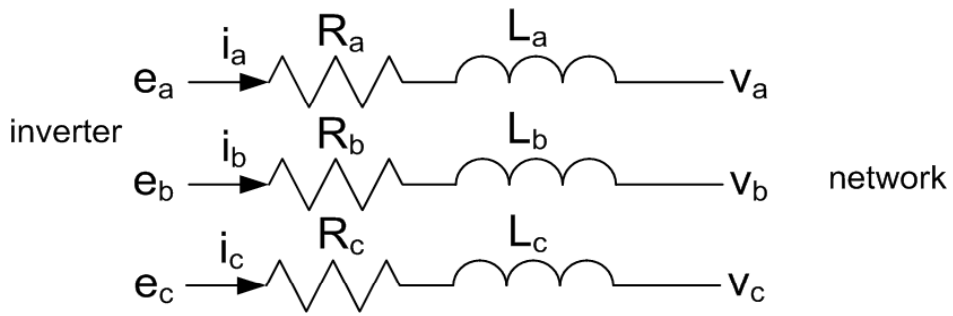
http://www.energy.siemens.com/hq/en/power-transmission/hvdc/

Voltage Control Loop (2)



- Fast feed-forward loop (limited by PWM freq=several kHz)
- How quickly does storage need to respond?
  - Vdc disturbance decoupling removes short-term storage dynamics (as long as approx. ½Vdc>Vac peak)
  - Can use other fast-response storage technology as DC buffer

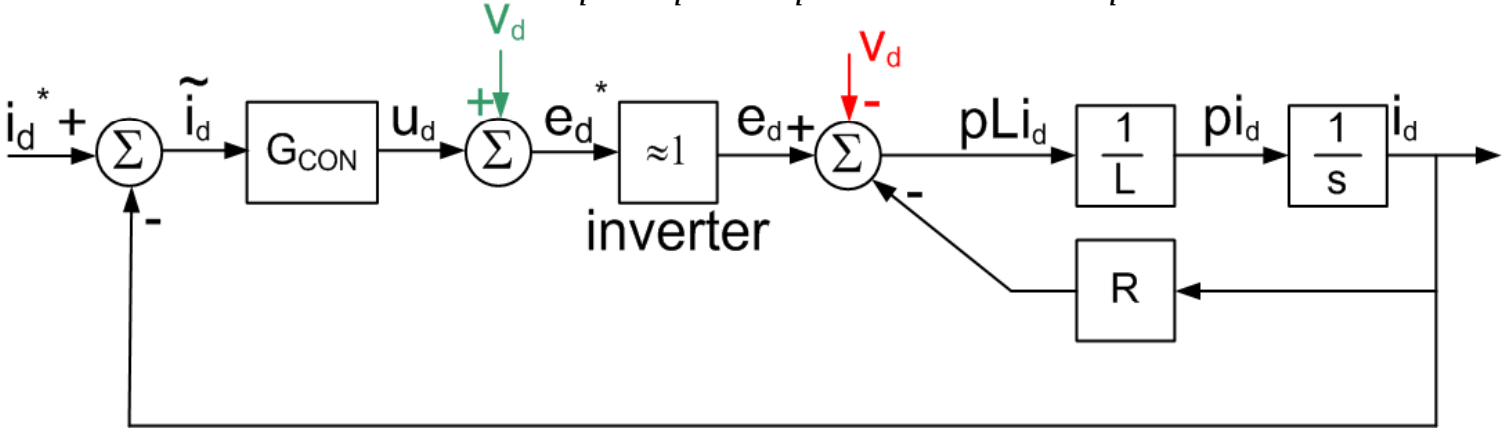
Current Loop



- Convert three-phase AC system equations to artificial rotating DC state-equations (dq0):

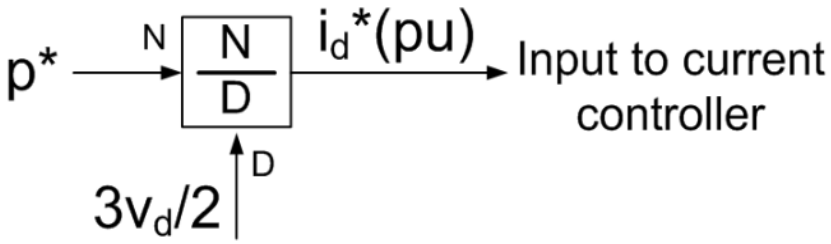
$$e_d - v_d - Ri_d + \omega Li_q = pLi_d$$

$$e_q - v_q - Ri_q - \omega Li_d = pLi_q$$

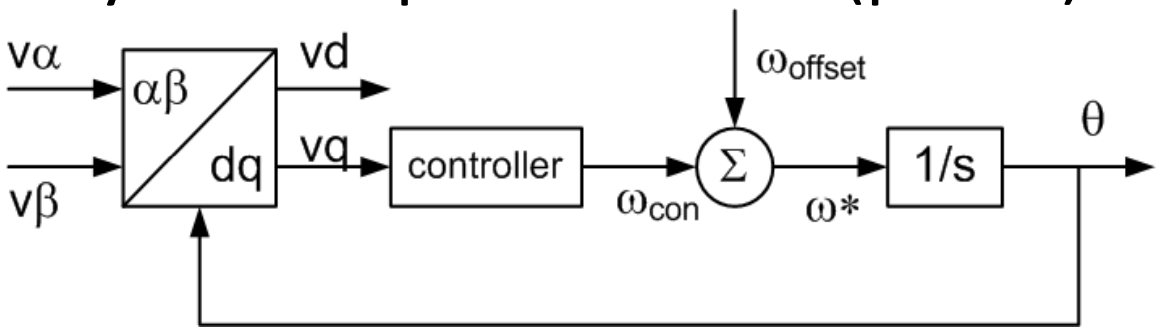


Power Loop

- Power loop (in dq0) is fast feed-forward loop



- Limited by current loop (kHz)
- Limited by abc->dq0 conversion (phase)



- Filtering out noise slows this (i.e. 10s of Hz)

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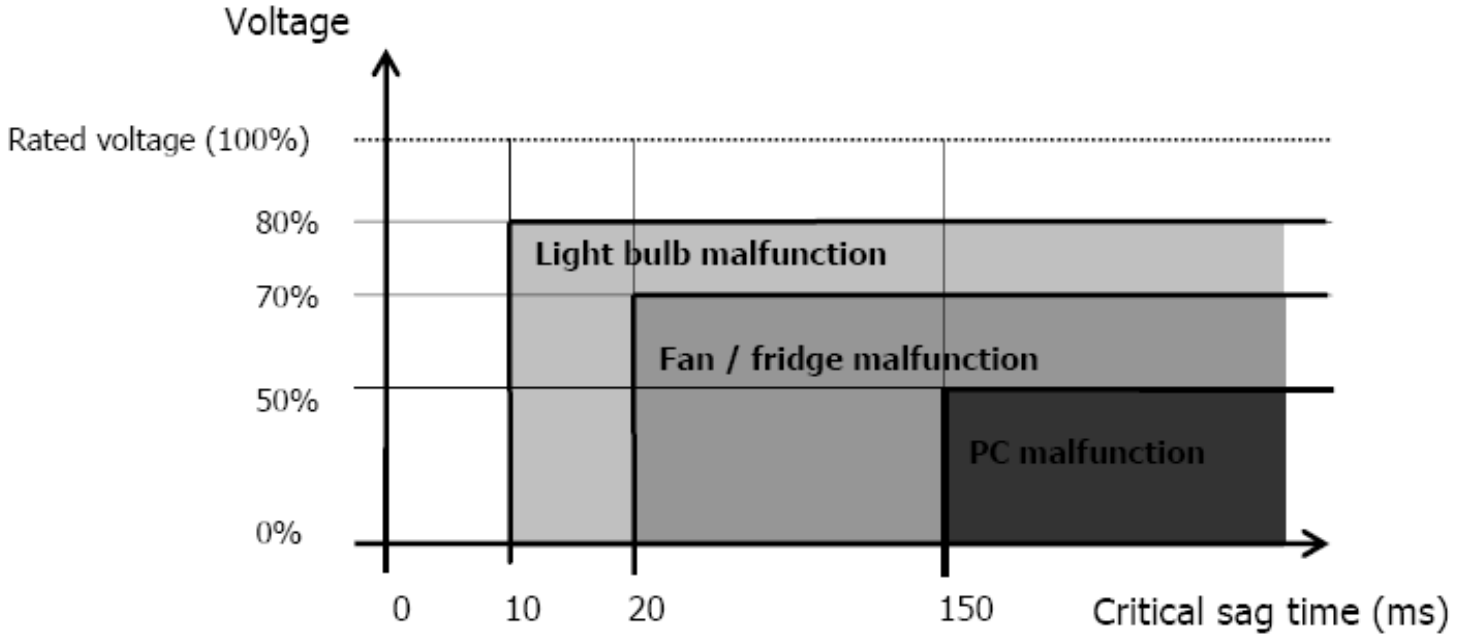
Flywheel Energy Storage

- Speed of response limited by feedback loop (needed to filter out DC link noise)

How fast do you need?



Load	Operation without Malfunction	Acceptable Interruption
Lightbulb	10ms	100ms
PC	150ms	150ms
Fridge	20ms	1 minute
Fan	20ms	250ms

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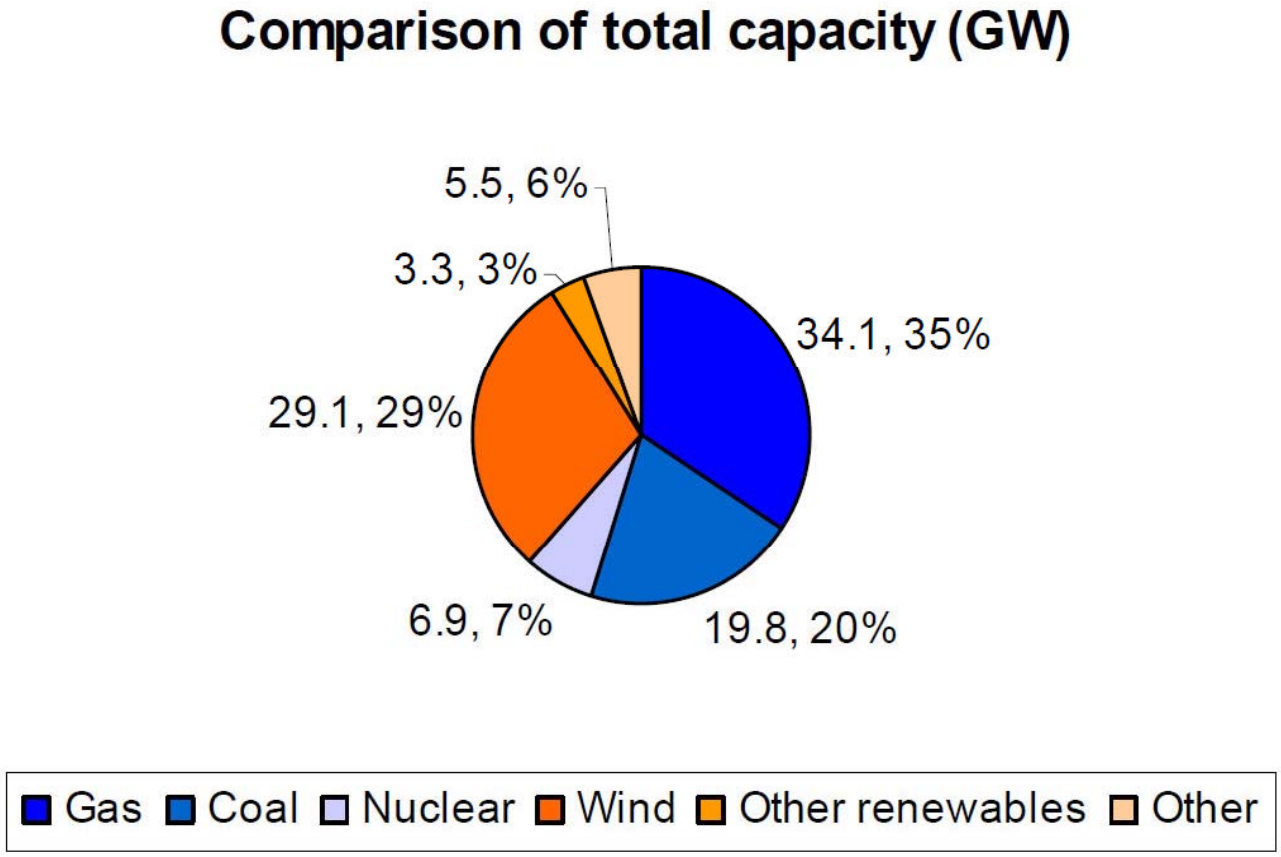
Drivers in the Future Smart(Grid)

Huge Changes Ahead

2020 Gone Green Scenario

- **Electricity Networks Strategy Group (ENSG)**
  - Cross industry study group chaired by DECC/Ofgem



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Transmission System

- HVDC Reinforcement
  - Massive investment
  - Significant technology step-change

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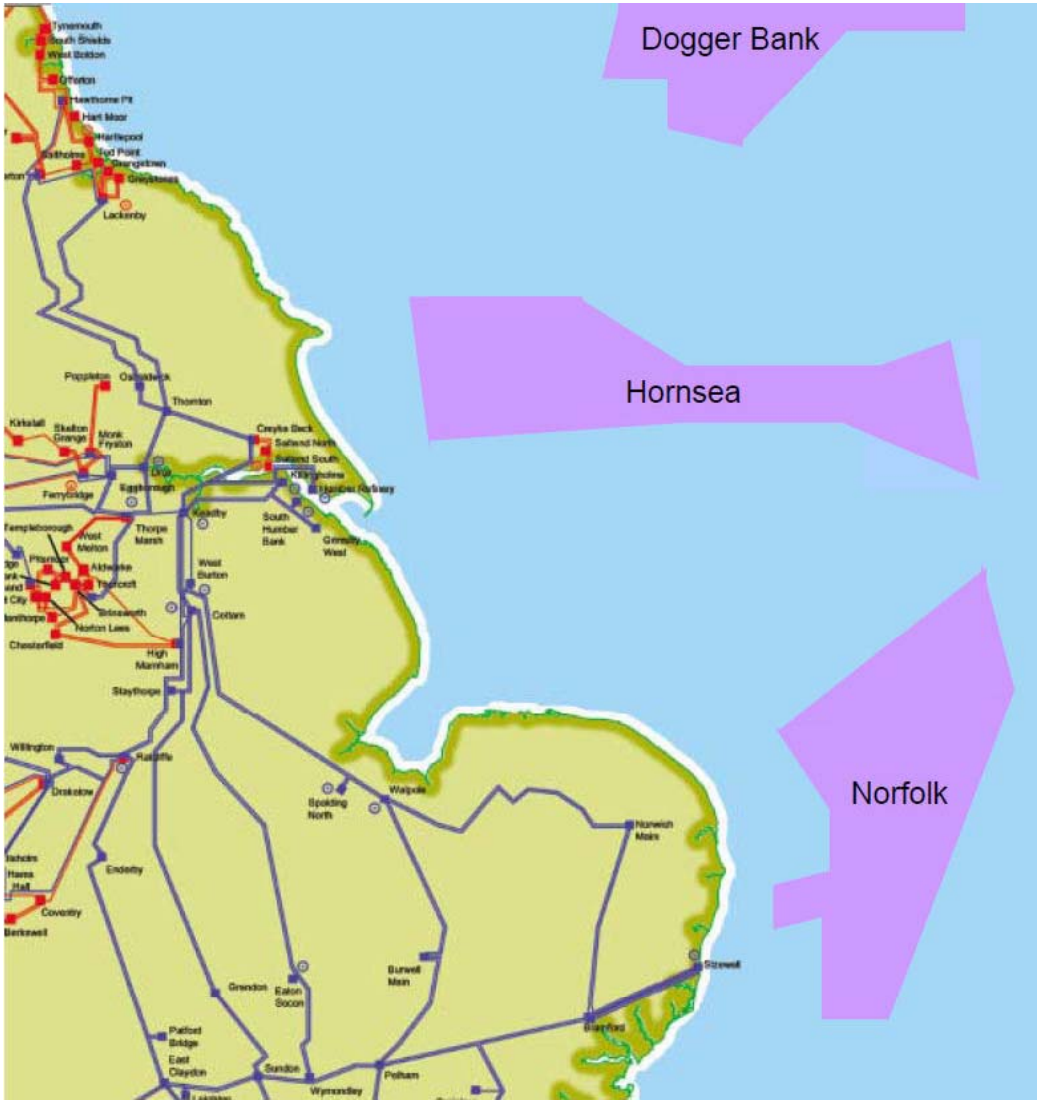
East-Coast Huge windfarms

Dogger Bank
-9GW
Hornsea
-4GW
Norfolk Bank
-7.2GW

-Summer nights Dogger Bank could supply 1/3 of England



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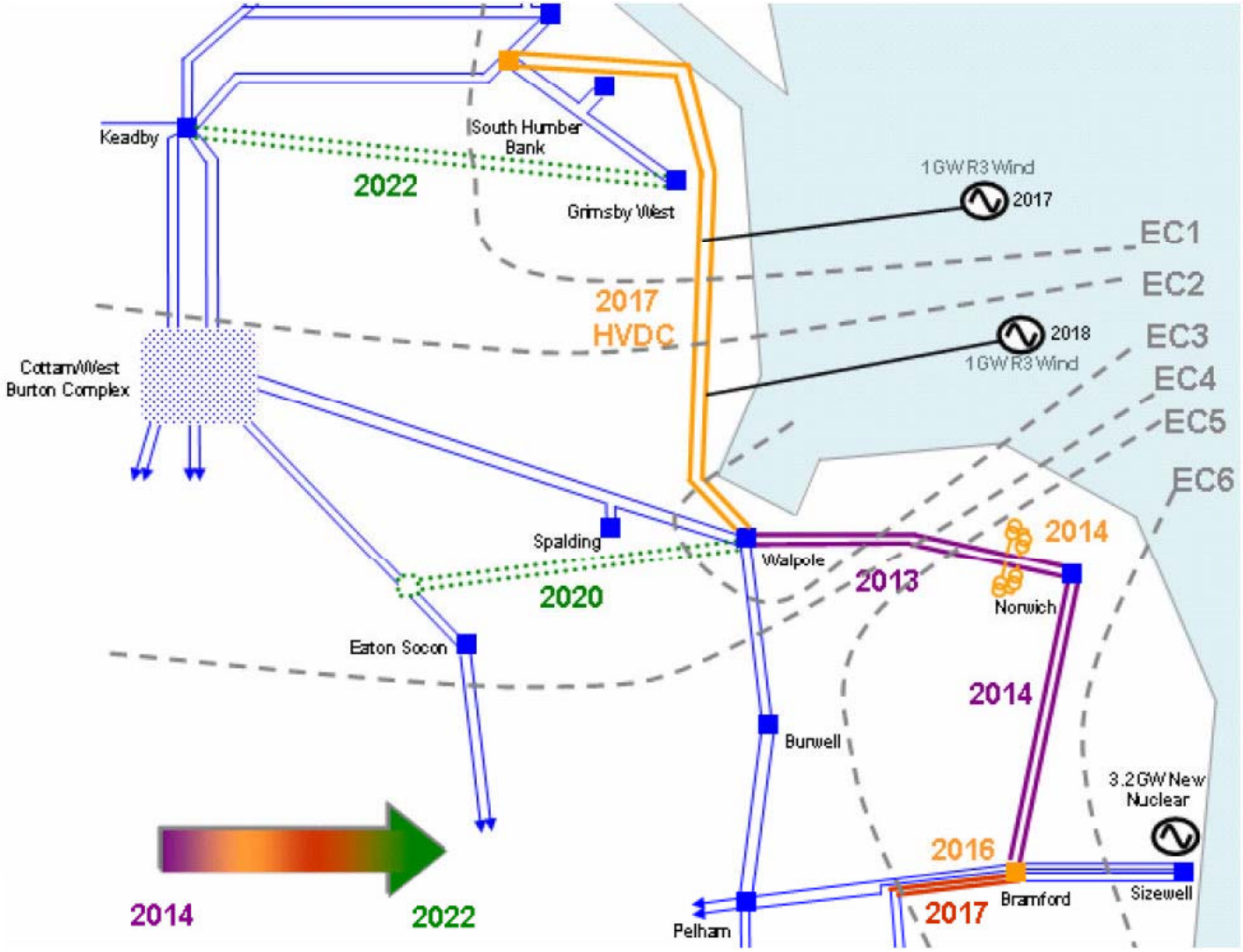
East Coast Reinforcement



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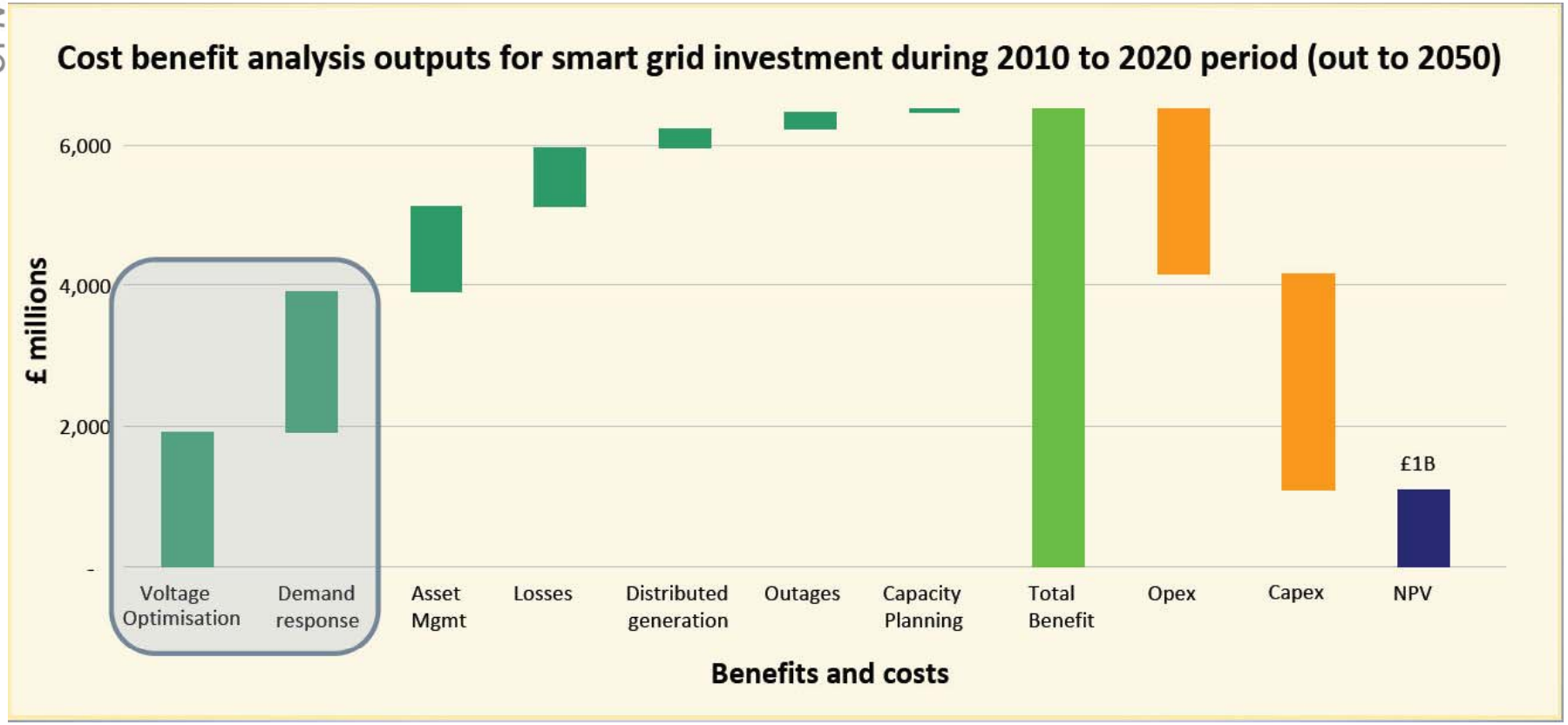
ENSG Smart Grid Vision (Nov 2009)



Source: www.ensg.gov.uk

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Key Issues

- New sets of uses require totally different hardware and software structure
- Not just time-of-use – also enhancing network function
- Role of storage depends on
  - Lifetime costs (CAPEX+OPEX)
  - Investment decision made by financiers
    - based on risk
    - upfront capital cost

– Maximise role by minimising **cost**
  - Power electronics is now cheap and high efficient
  - Storage system physics needs attention…

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Thanks to:

- Dr Alan Ruddell – Science and Technology Facilities Council – Rutherford Appleton Labaroratory
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