Requirements Driven Design and Implementation of Smart Grid Applications and Technology

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Features of a 'smart grid' - 1

According to Modern Grid Strategy project of the National Energy Technology Laboratory (NETL) in the US:

- Self-healing from power disturbance events
- Enabling active participation by consumers in demand response
- Operating resiliently against physical and cyber attack
- Providing power quality for 21st century needs
- Accommodating all generation and storage options
- Enabling new products, services, and markets
- Optimizing assets and operating efficiently

- According to Siemens: "an intelligent and flexible grid infrastructure, smart generation, and smart buildings"

Features of a ‘smart grid’ - 2

- According to the International Energy Agen [illegible]
  - uses digital and other advanced tec [illegible] gies to monitor and manage the transport of ele [illegible] from all generation sources to meet the varying [illegible] icity demands of end-users.
  - co-ordinate the need [illegible] capabilities of all generators, grid operators, e [illegible] ers and electricity market stakeholders
  - operate [illegible] s of the system as efficiently as possible, minir [illegible] costs and environmental impacts while m [illegible] sing system reliability, resilience and stability.

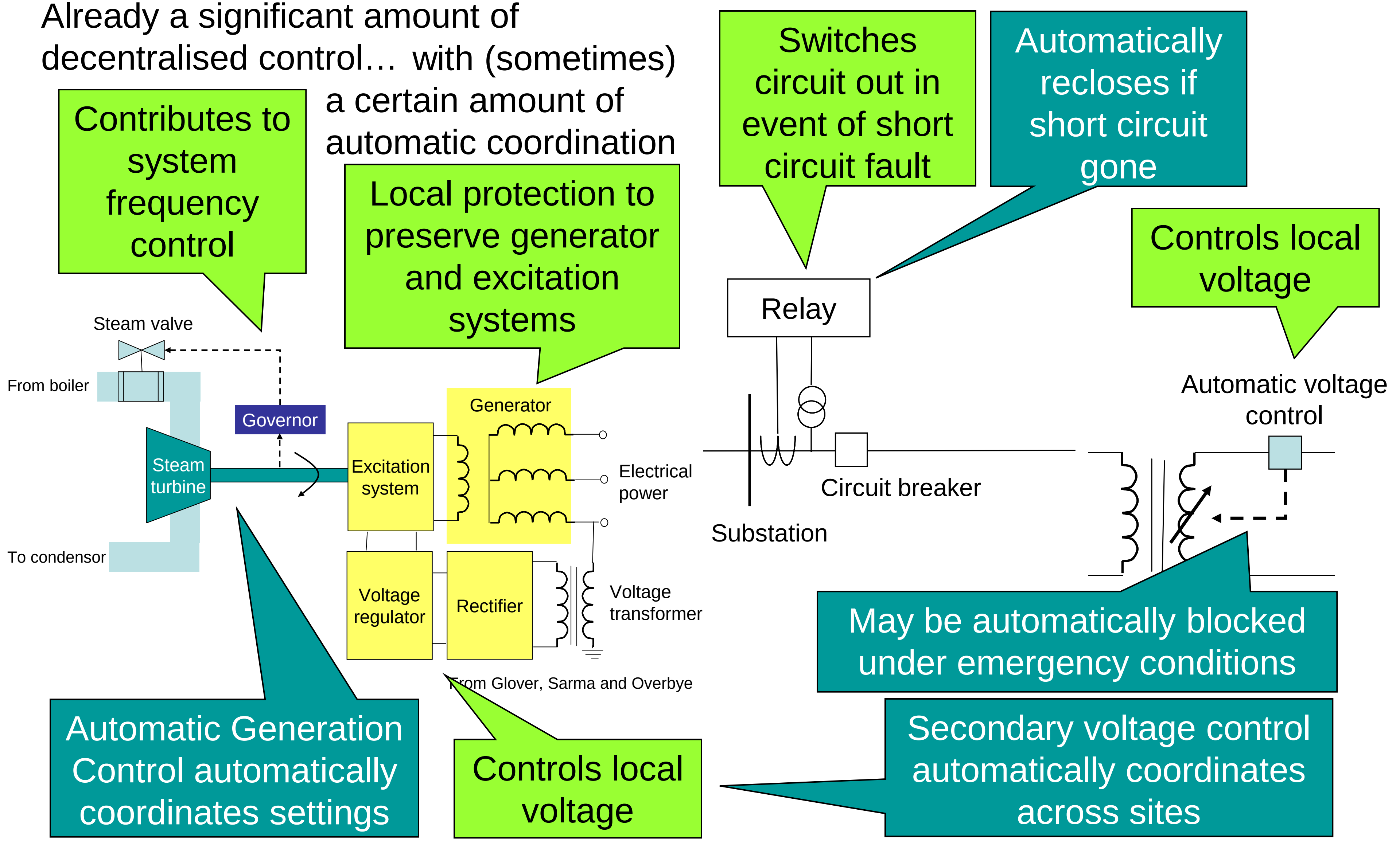
In what way does a modern power system not do this now?

What's really the challenge?

- The power system is a large, highly complex, non-linear system that experiences continuous small disturbances and not infrequent large disturbances
- Power systems already use
  - Real-time monitoring
  - Automation
  - Decentralised control
  - 'Self-healing'…
- Not so much of the above on distribution systems at present
  - Current state of development of both transmission and distribution different in different places
  - Often considerable scope for development of 'active distribution' to accommodate new loads, e.g. electric vehicles, and small generation

An already quite smart grid

Already a significant amount of decentralised control… with (sometimes) a certain amount of automatic coordination



What's new?

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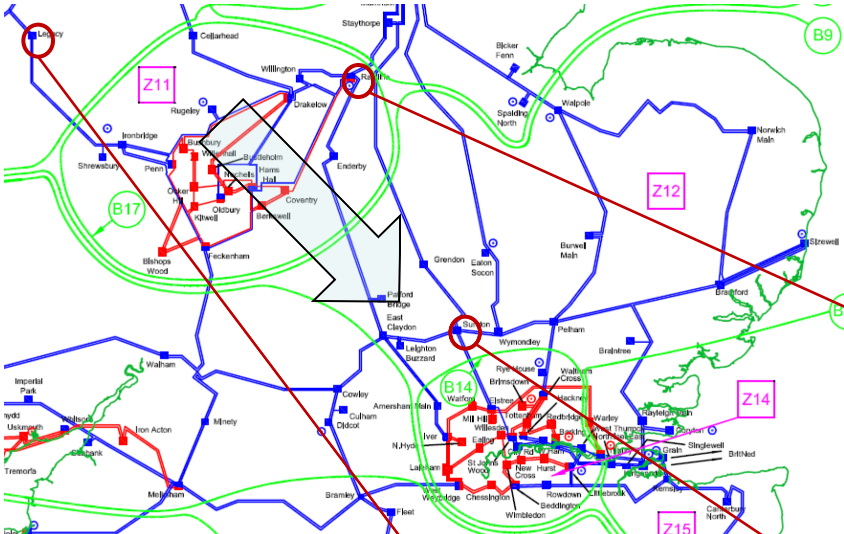
- Not all future generation is flexible and controllable
  - Attempt to meet all demand using only wind and nuclear?
- It is difficult to add to fundamental network capacity
  - NIMBY (Not in My Back Yard)
  - BANANA (Build Absolutely Nothing Anywhere Near Anyone)
- There is an intention to optimise across larger areas
  - Single, integrated European energy market?
- Growth in electric vehicle and space heating demand

Source: Trans-European Energy Networks, 2007

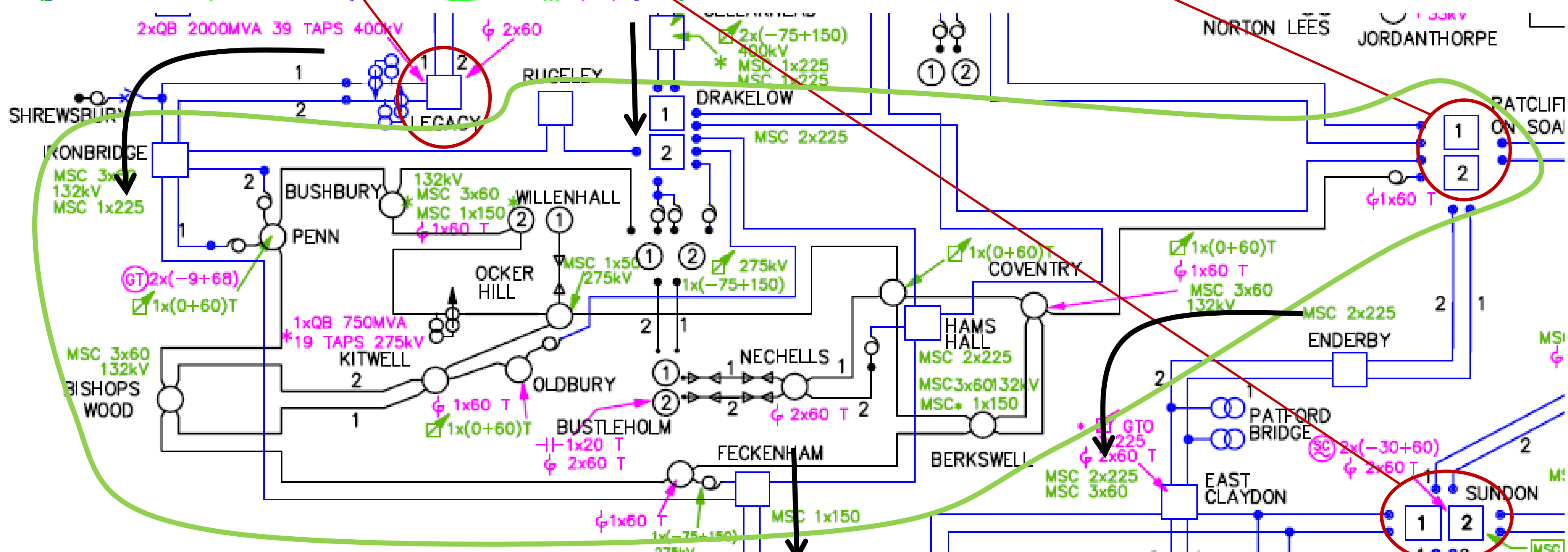
What’s not new?

- Decentralised controls need to be coordinated
  - Governor droop settings
  - Main and backup protection systems
  - Scheduling of reserve
  - Dispatch of power
- Coordination gets more difficult when there are more things to coordinate, e.g. demand side participation
  - We need ‘intelligence’!!
    - ‘Intelligence’ in a substation computer?
    - ‘Intelligence’ in a control room?
    - ‘Intelligence’ at design time?
- Take voltage control as an example…

System voltage control

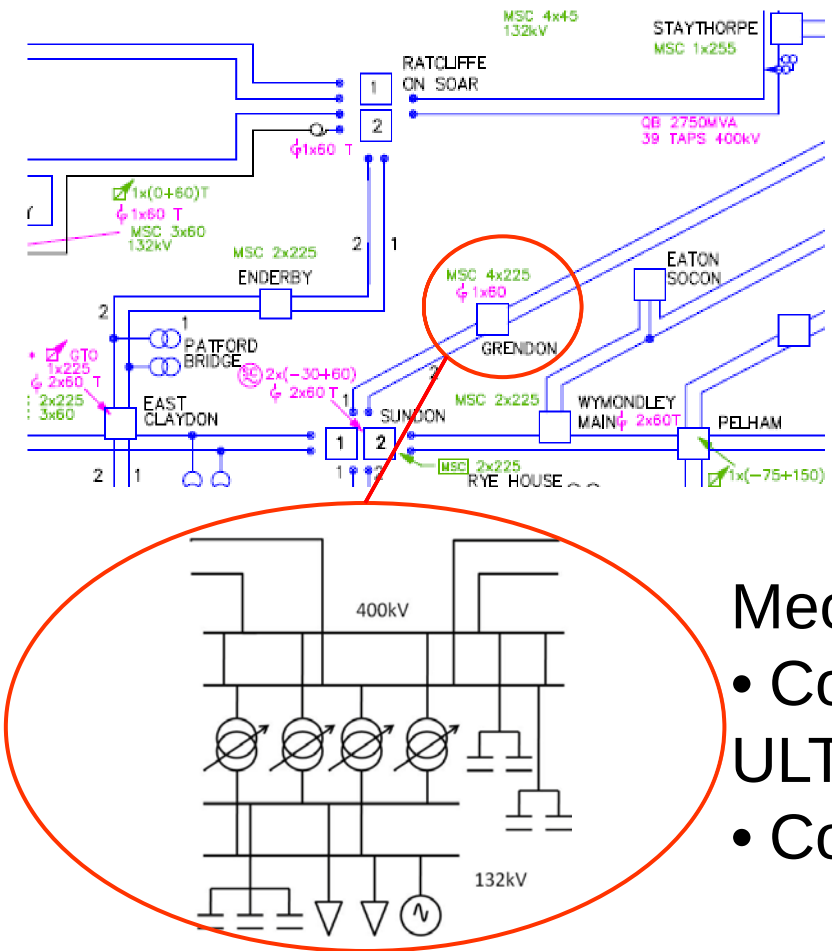


- Large load in West Midlands
- High through flows of power
- Weak 275kV network
- Few generators
  - They don't always operate!
- Lots of reactive compensation
- Need to coordinate voltage targets to
  - ensure adequate reserves for post-fault
  - get the most out of capacitances



Voltage control requirements

- “Requirements Driven Design and Implementation of Smart Grid Applications and Technology”



Set voltage targets to

- fully utilise reactive power resources
- Provide margin against ‘secured events’ (contingencies)

System level ‘intelligence’ needed

Mechanically switched capacitors (MSC)

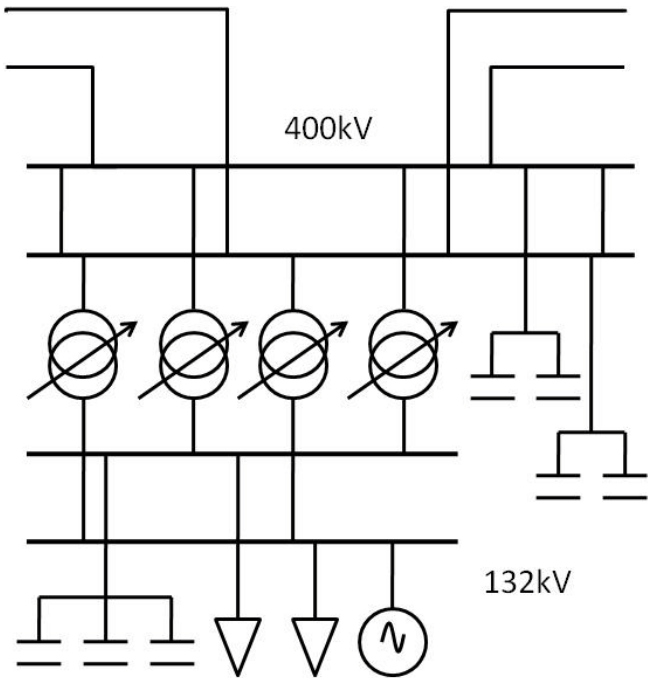
- Control voltage at HV side

ULTC, MSCs and generator (if running)

- Control voltage at HV side

Coordination of local voltage controls

- "Requirements Driven Design and Implementation of Smart Grid Applications and Technology"
  - How to ensure that controls act together at the LV side?
- Generator:
  - Continuous regulation of terminal voltage
  - Reactive power generated has a cost to system operator: minimise it
- MSC:
  - Fast response, but wait for DAR
  - Deadband ensures response made only to large voltage error, e.g. after fault outage of a transformer or OHL
  - Automatic reactive switching (ARS) cycles the circuit breakers that operate
- ULTC automatic voltage control (AVC):
  - Slower response, respect tap limits
  - Fine grain control of voltage



Using ‘intelligence’ to make better operational decisions

- What does ‘better’ mean?
  - More reliable supply to consumers?
    - In Europe, already very reliable
  - Lower cost of electrical energy
    - Access to cheaper sources
    - Cheaper integration of low carbon sources
      - Better utilisation of network capacity
      - More cost-effective balancing
    - Lower network cost
      - Deferment of asset replacement
      - Better utilisation of network capacity

The requirements should drive the technology

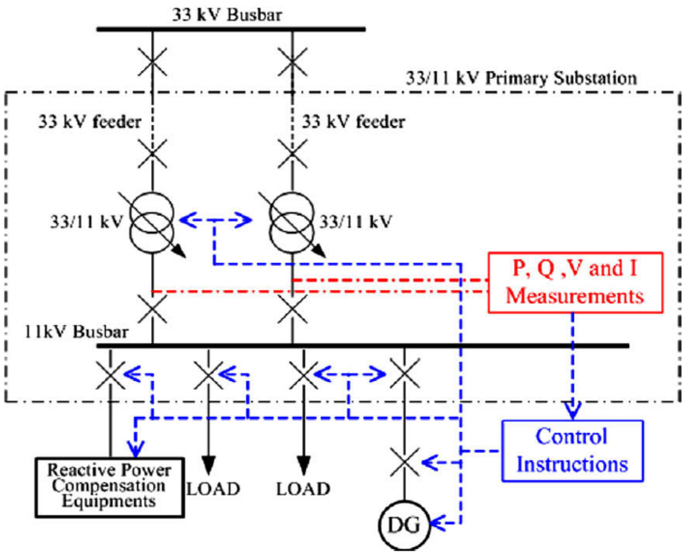


Figure: R.A.F. Currie, G.W. Ault, C.E.T. Foote, G.M. Burt, J.R. McDonald

Requirements should drive the technology

- Lower cost of electrical energy
  - Access to cheaper sources of electrical energy
    - More network capacity
  - Cheaper integration of low carbon sources
    - Better utilisation of network capacity
    - More cost-effective balancing
  - Lower network cost
    - Deferment of asset replacement
    - Better utilisation of network capacity

Make better use of existing capacity
- Get more accurate picture of what *is* the existing capacity

Better monitoring and decision making

Squeeze the margins with fast (automatic) corrective actions

- Better understanding of risk & uncertainty
- Utilisation of demand side

- Minimise wear on equipment
- Understand plant condition
- Make better use of information

(How to integrate new systems with legacy equipment?)

A new approach to coordination of voltage controls

- Objectives
  - Keep voltages at customer connections within acceptable limits
  - Avoid hunting of controls
  - Reduce number of voltage step changes
  - Minimise wear-and-tear on equipment

  (Reduce number of voltage step changes; Minimise wear-and-tear on equipment: Betterment)
- How to coordinate the following to achieve the objectives?
  - Under-load tap-changing transformers
  - Mechanically switched capacitor banks
  - Reactive power from generation

Prototype application

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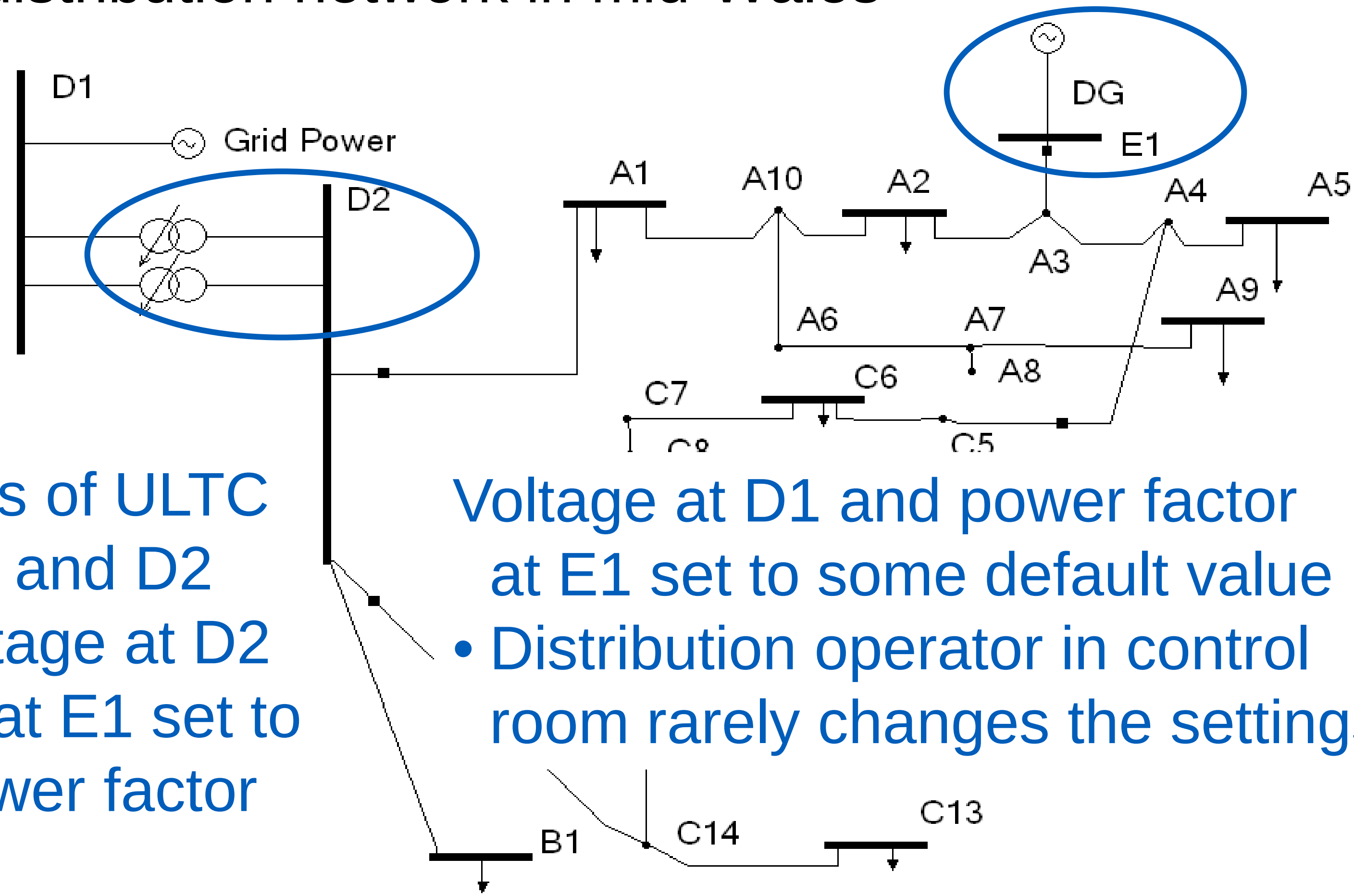
- Portion of distribution network in mid-Wales



Normally,
- Tap positions of ULTC between D1 and D2 regulate voltage at D2
- Generation at E1 set to constant power factor

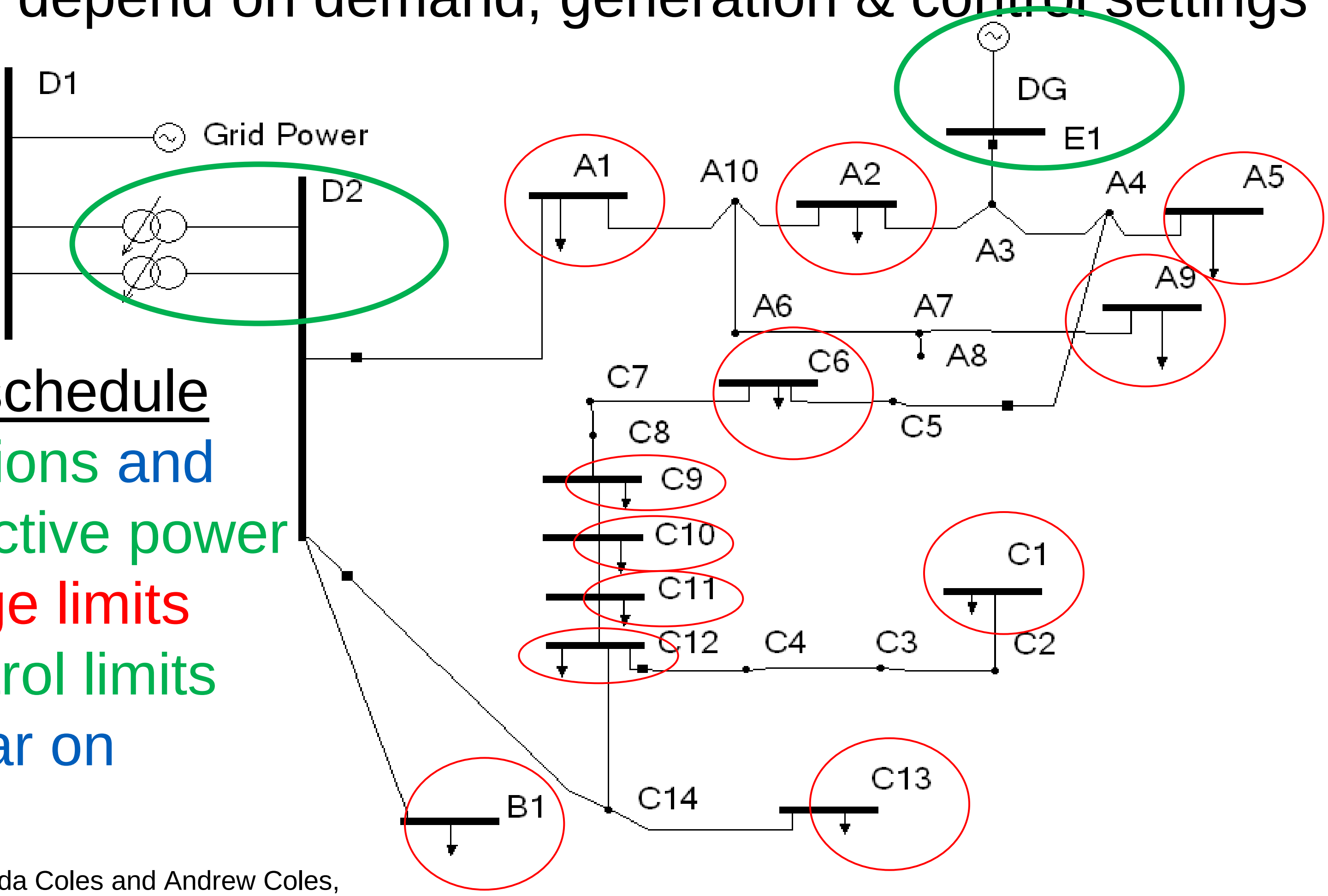
Voltage at D1 and power factor at E1 set to some default value
- Distribution operator in control room rarely changes the settings

Jianing Cao, Keith Bell, Amanda Coles and Andrew Coles,
“Voltage control of distribution network using an artificial intelligence planning method”,
CIRED 2011, Frankfurt, July 2011.

Figure: AuRA-NMS project

Prototype application

- Use a forecast of demand and generation in the group
  - Voltages depend on demand, generation & control settings



Determine a <u>schedule</u> of ULTC positions and generator reactive power

- Satisfy voltage limits
- Respect control limits
- Minimise wear on tap changer

Jianing Cao, Keith Bell, Amanda Coles and Andrew Coles,
"Voltage control of distribution network using an artificial intelligence planning method",
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Figure: AuRA-NMS project

Example simulation results

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PF1, PFC and VC:

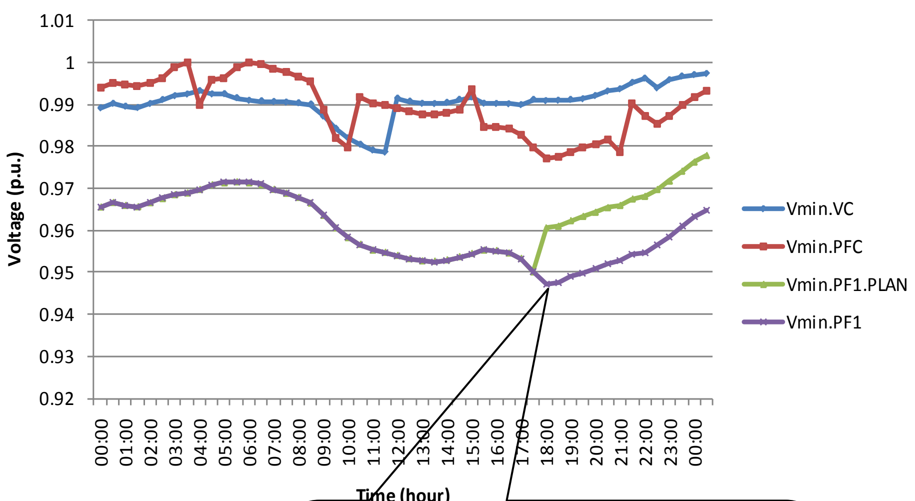
- transformer tap position changes in online mode to keep V_{D2} at 1.0 pu

PF1: generator power factor control (power factor = 1.0)

PFC: generator power factor control (power factor = 0.8)

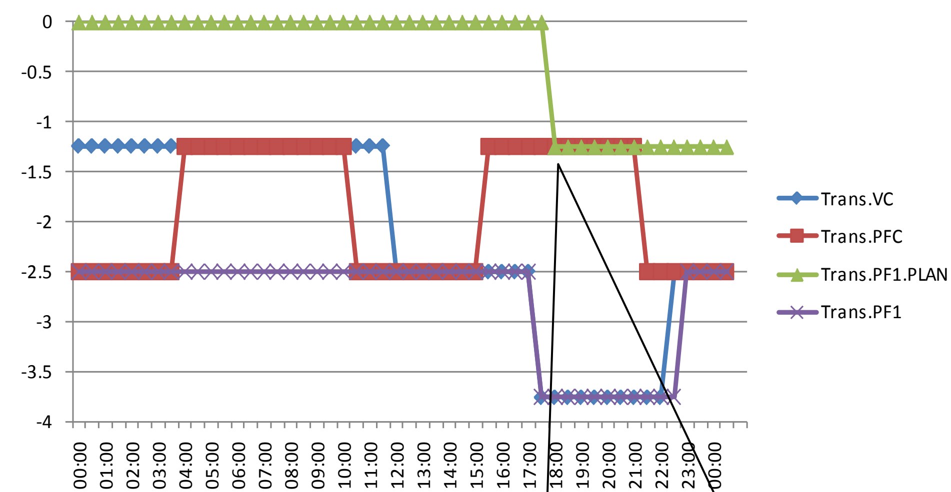
VC: generator voltage control (V = 1.0)

Minimum voltages in network



With generator reactive power regulated to power factor=1.0, voltage dips outside limit at 18:00

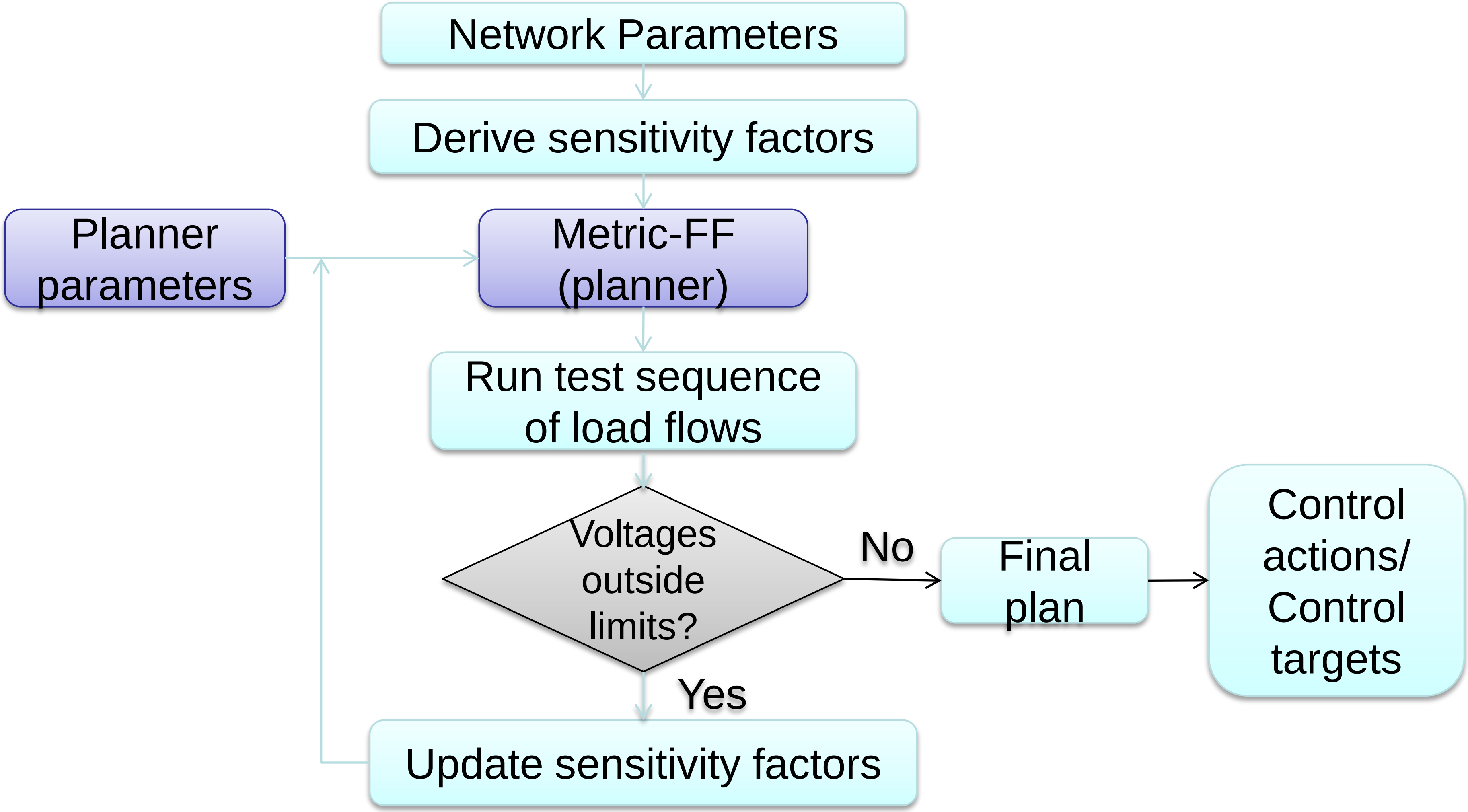
Tap changes from nominal



Voltage planner recognises that few tap changes are necessary

- Make the minimum change at 18:00

Software integration



Voltage planner issues

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An important feature of any ‘smart grid’ application

- Fail gracefully
  - With loss of comms to remote regulated sites, revert to regulation of local voltage
- Work in progress…
  - The planner is based on a generic ‘artificial intelligence planner’
    - how many variables can the planner handle?
  - Predictions of the effects
    - Sensitivity factors are linear, system is non-linear
  - Effect of uncertainty or error
    - When to re-plan?
    - Robustness against loss of measurements?

Future grids: the ‘grand challenges’

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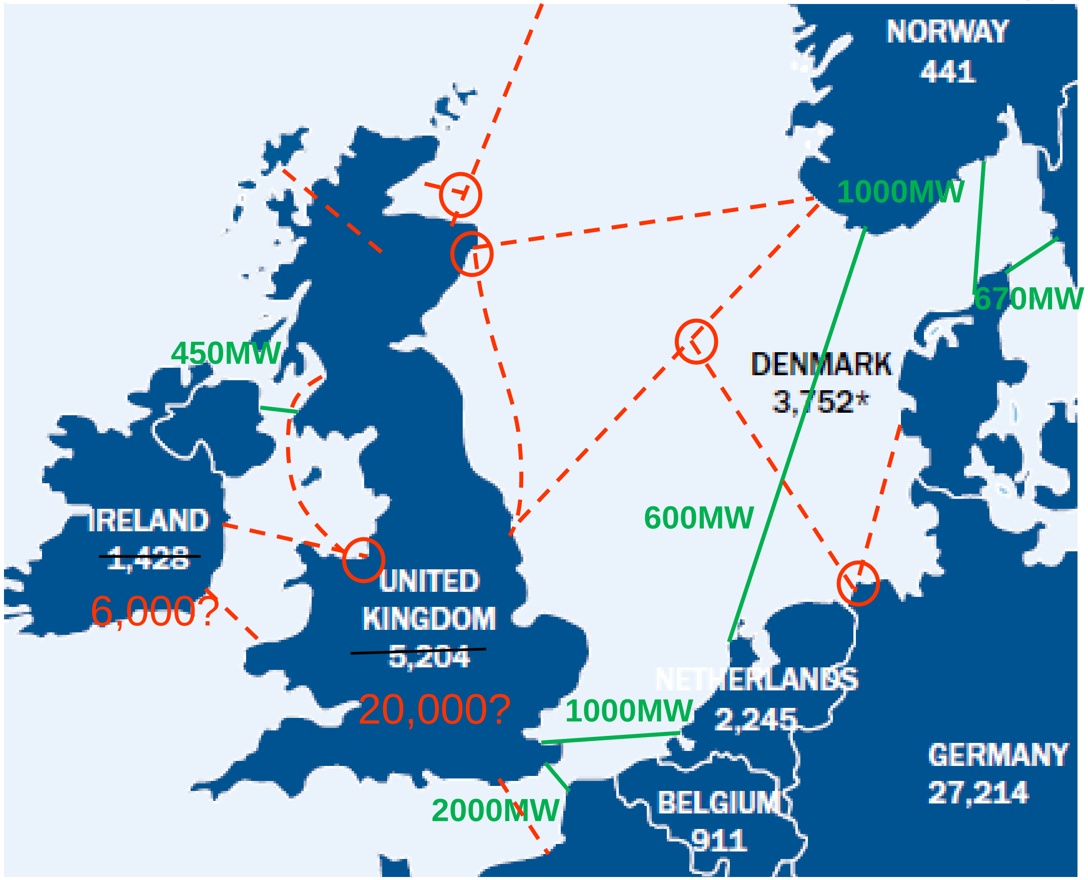
DC networks to facilitate wind energy across Europe



- Meet deficit of power in low wind conditions
- Sell surplus of power in high wind conditions
- Manage variability of power available for transfer
- Control link interaction
- Manage fault conditions
- Manage interactions with AC grid
- Facilitate investment
- Achieve market integration

What will be the key electrical energy hubs?
What does their development depend on?

2020 Twenties Transmitting wind

Installed wind generation capacity at end of 2010; source: EWEA

Future grids: the 'grand challenges'

The Autonomic Power System

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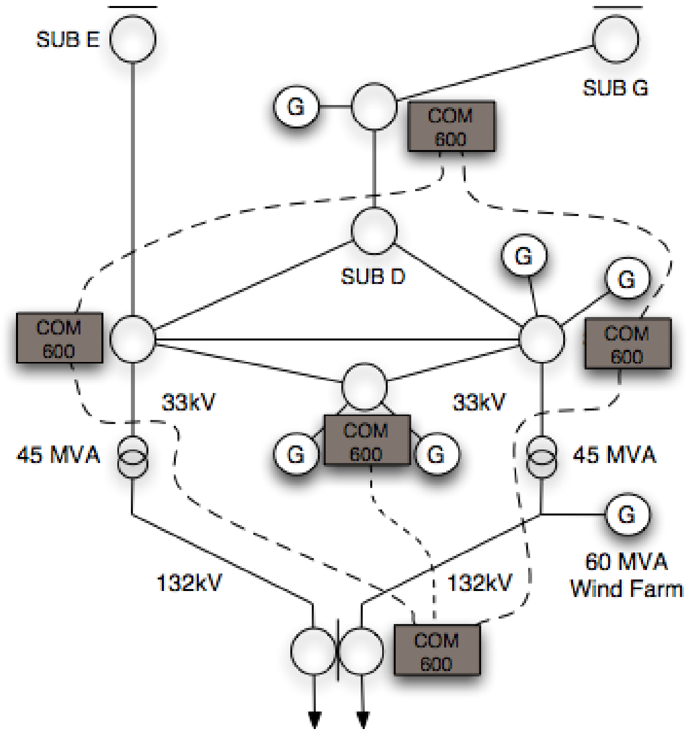
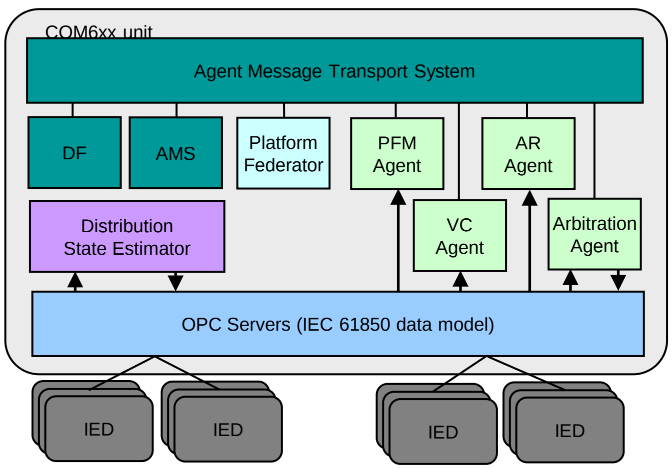
- Can a **fully distributed intelligence and control philosophy** deliver the future flexible grids required tc facilitate the low carbon transition, allow for the adoption of emerging game changing network technologies and cope with the accompanying increase in uncertainty and complexity?

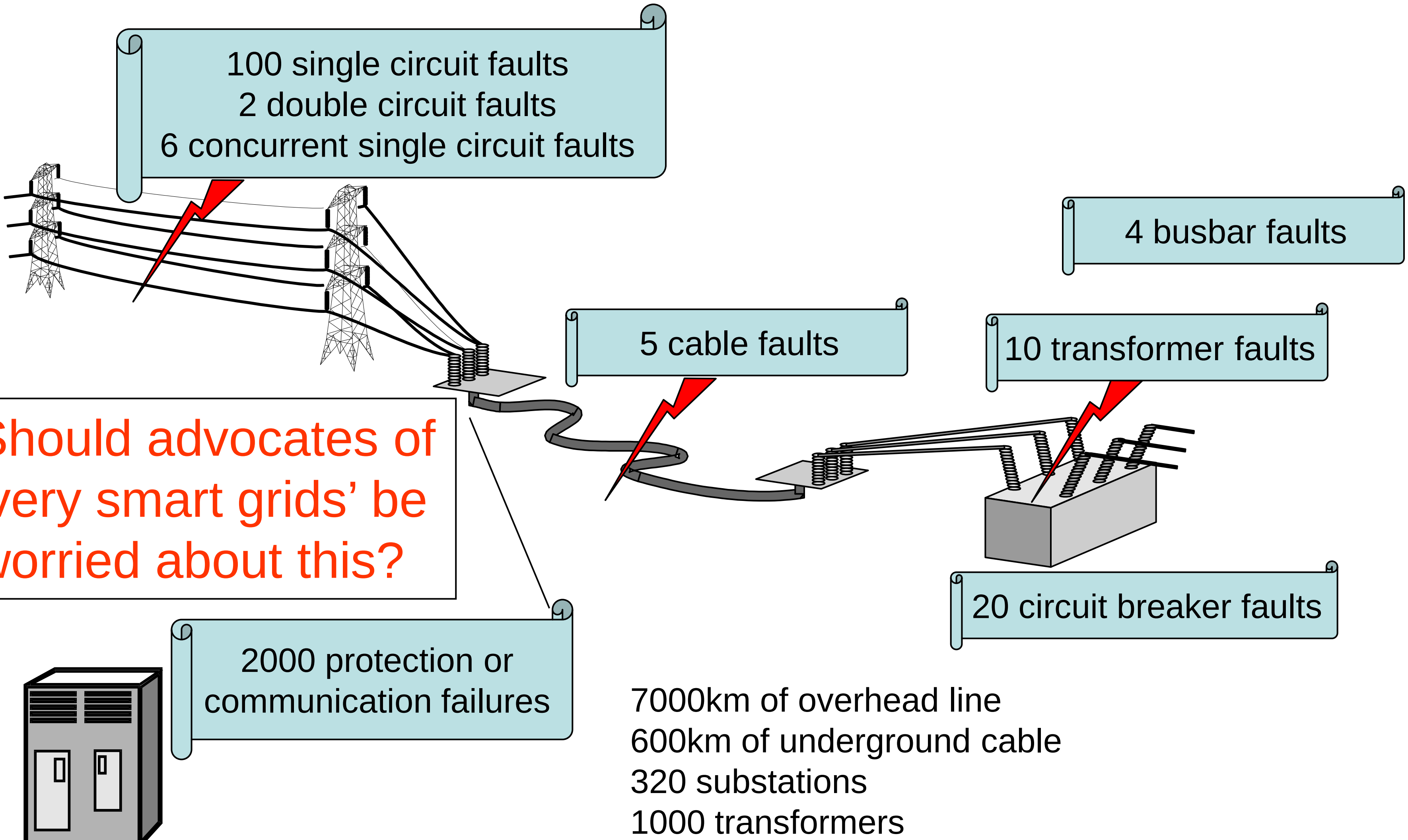
- Draws upon the computer science community's visior of autonomic computing and extends it into the electricity network.
- Research of approaches and technologies that make the network self-configuring, self-healing, self-optimising and self-protecting: collectively known as **self*** - moving beyond Smart Grid applications
- University Partners: Cambridge, Durham, Imperial College, Manchester, Strathclyde, Sussex
- Industrial Partners: Accenture, Agilent, E.On, IBM, KEMA, Mott MacDonald, PB Power, National Grid, SSE





System security/reliability

What the England and Wales transmission system may experience each year



Should advocates of ‘very smart grids’ be worried about this?

7000km of overhead line
600km of underground cable
320 substations
1000 transformers

Figure: National Grid

Summing up

- In many parts of the world, grids are already quite ‘smart’
  - ‘Smart’ features mainly exist at transmission level
    - Significant scope for development on distribution networks to accommodate embedded generation and new loads
- New computation and communications facilities offer the possibility of ‘smarter grids’
  - The costs will not be negligible, especially in respect of communications
  - We need to clear about what improvements to grid planning and operation we want to achieve
  - The desired improvements should drive the implementation of smarter grids
    - Essential to have a thorough understanding of the engineering context and objectives, and solid design
  - New facilities should
    - Be compatible with legacy systems where early asset write off costs are high
    - Fail gracefully