It’s got to work: the engineering detail in modelling electric power systems

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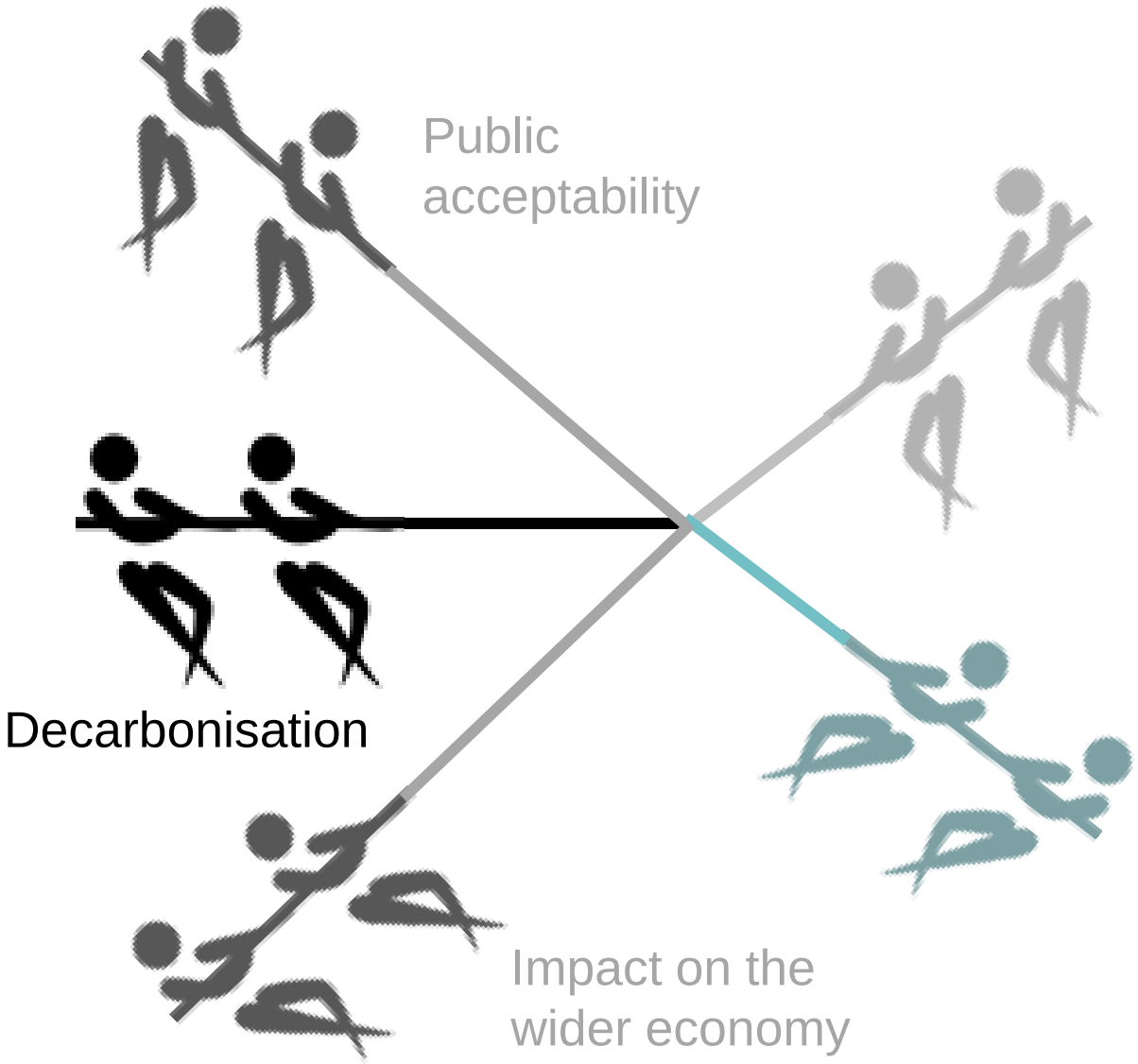
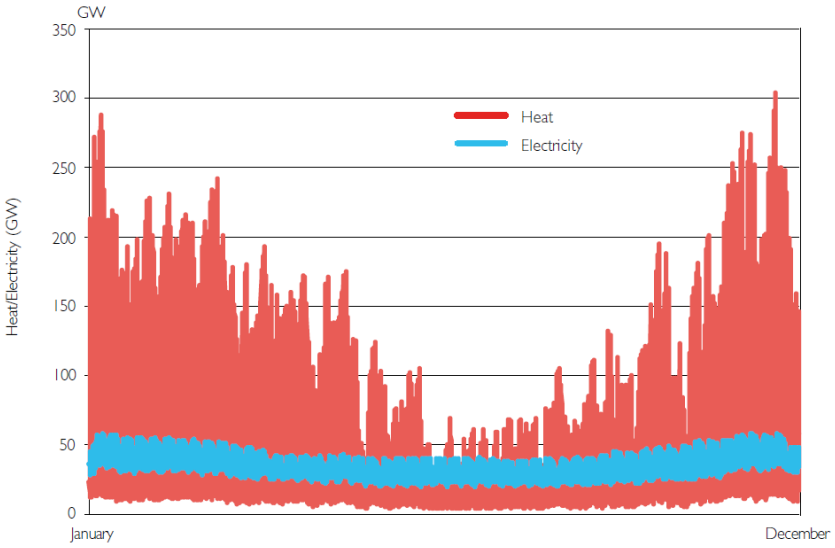
The trilemma (and extensions)



What are the options?
What will they cost?
Will they *work*?!

Energy system transition

We know what to do and how to do it, right?

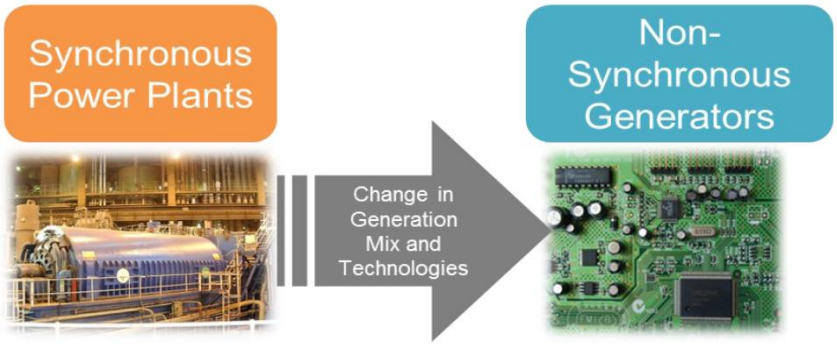


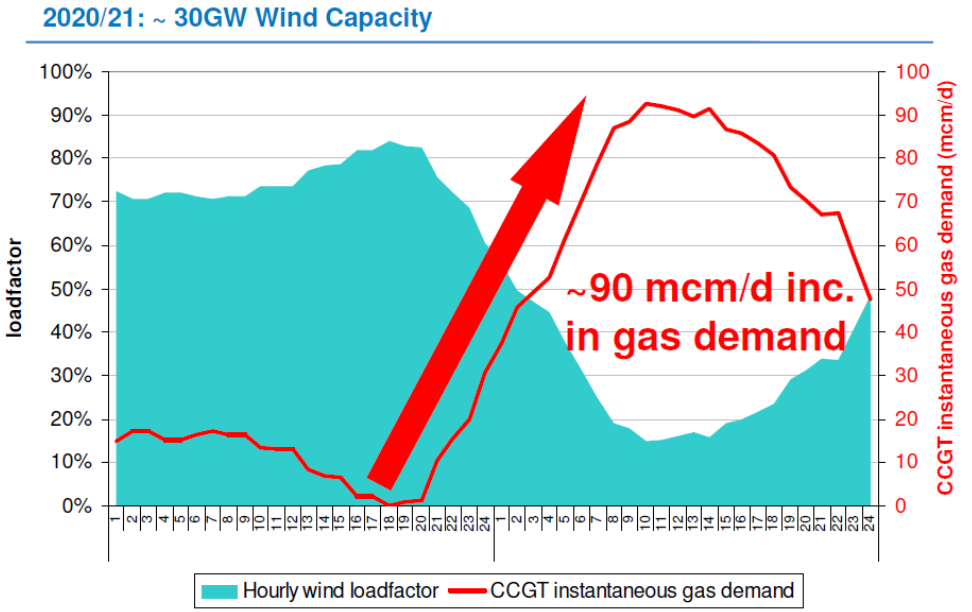
The Future of Heating: A strategic framework for low carbon heat in the UK, DECC, March 2012

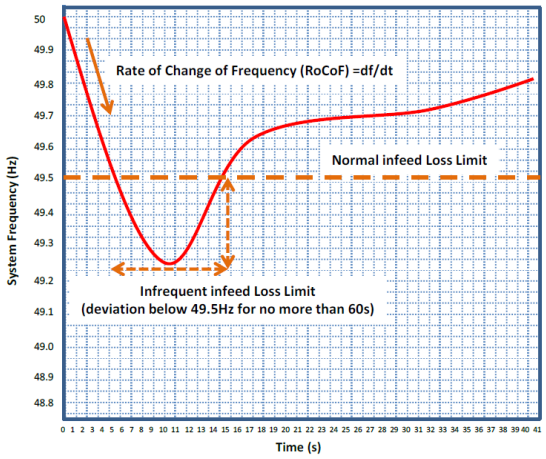
Wrong! (Sadly)

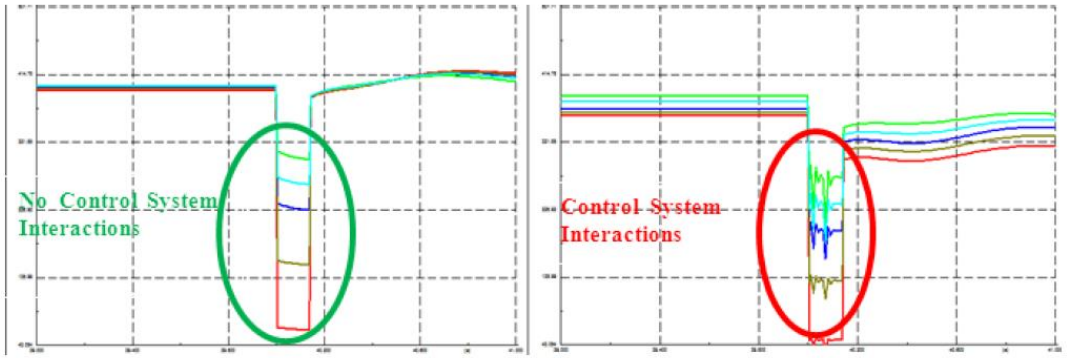
- There is still a lot of uncertainty
  - Which options are going to be cheapest?
  - Which options are technically feasible?
    - How to make them feasible?
  - How do the options interact?
  - How and when should we implement them?
    - Who pays for them?
    - Role of the state and the market?
    - Safeguarding national interests?

Electricity system challenges



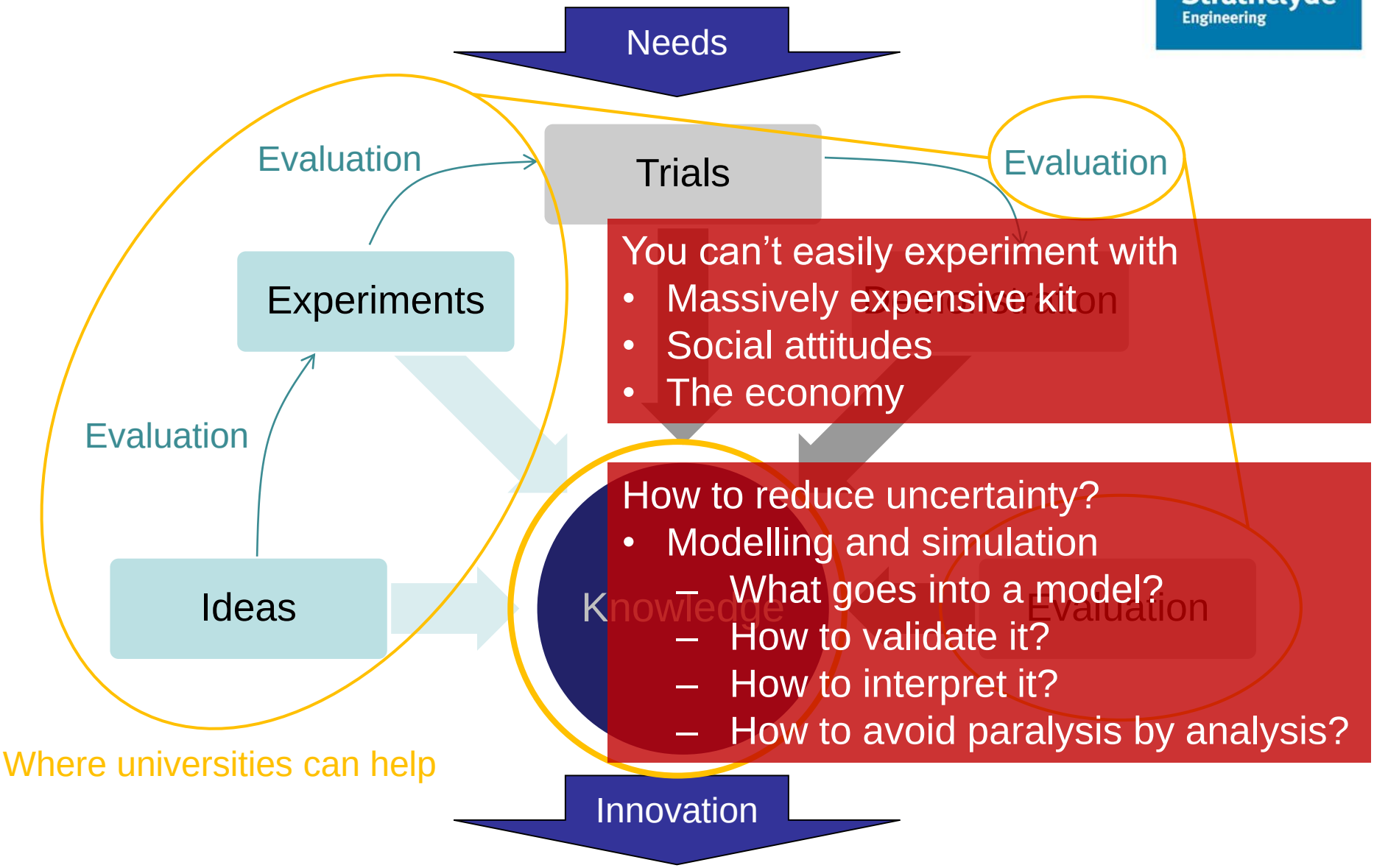






National Grid, 'System Operability Framework'

Informing innovation



The need for modelling

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- Policy needs to be informed
  - How to get evidence on future performance and outcomes except via modelling and simulation?
- Safe system operation must be ensured
  - Accurate simulation of relevant system conditions is essential to building confidence ahead of
    - on the day system operation
    - significant investment of capital
    - any changes to system or industry rules
    - installation and use of new technologies
- What sorts of models are adequate?
  - Are credible data available for them?
  - How easy are the models to use?
  - Can the results be interpreted easily and unambiguously?

What is a model?

- A representation of how a system behaves
  - Set of parameters (data)
  - Set of equations that relate system dependent states to independent states and parameters

$$H(x,u,y) \leq 0$$

$$F(x,u,p) = \dot{x}$$

where (for electricity)

y is the vector of system parameters

branch impedances, line ratings, generator characteristics, …

u is the vector of independent variables/controls

active power generation, voltage targets, demand

x is the vector of dependent variables/states

voltage magnitude and angle at all nodes, line currents, …

the equalities link variables and parameters across the system

the inequalities represent limits to system operation, e.g. no overloads

Do power system engineers solve all the equations?

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No!

- Often assume that the system is in electro-magnetic equilibrium
  - Neglect some of the differential equations
- Often assume that the system is in electro-mechanical equilibrium
  - Neglect all the differential equations
- Sometimes simplify even the algebraic equations
  - e.g. assume voltage magnitudes are 1.0 per unit, that resistances are small and that angle differences are small → linear algebraic equations
- As a result, most models are approximate
  - Some epistemic uncertainty is always present…

Do power system engineers build new models with special names?

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Not usually, no!

- As a community, we
  - have been working on modelling at least since the early 1960s
  - have had to get things right in order to
    - keep the lights on
    - manage the total cost of keeping the lights on
- Standard sets of equations* have been developed
- Standard tools to solve the equations have been developed
- A ‘model’ is simply a particular set of parameters, e.g. for a particular country’s transmission system at a particular time
  - The user chooses appropriate sets of independent variables for the modelling of different conditions
- ‘Models’ are generally transferable and readily understood by others
  - Any competent power system engineer could study power flows on the GB system

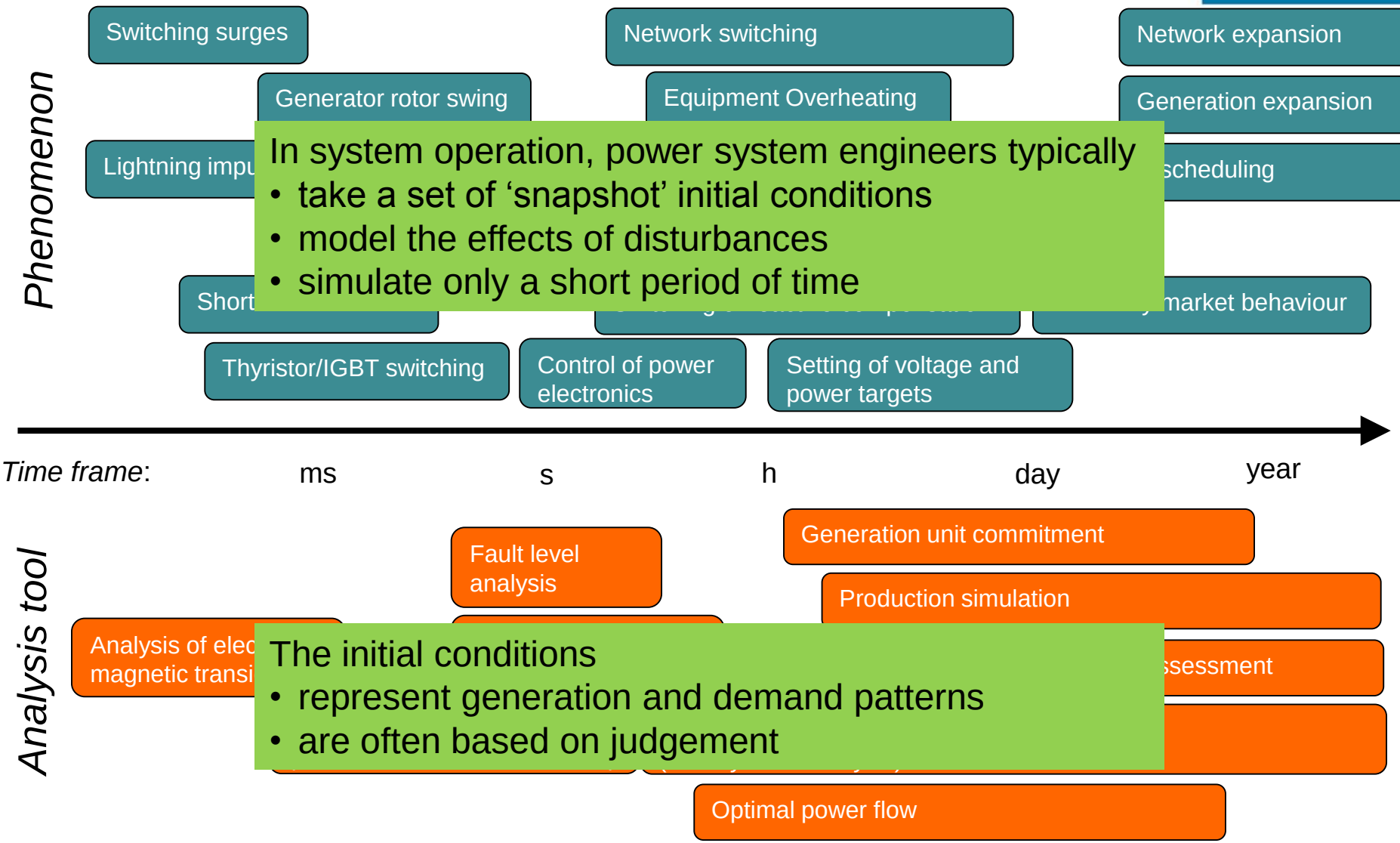
* OK, even ‘load flow’ tools do differ in detail…

What does a power system modeller do, then?

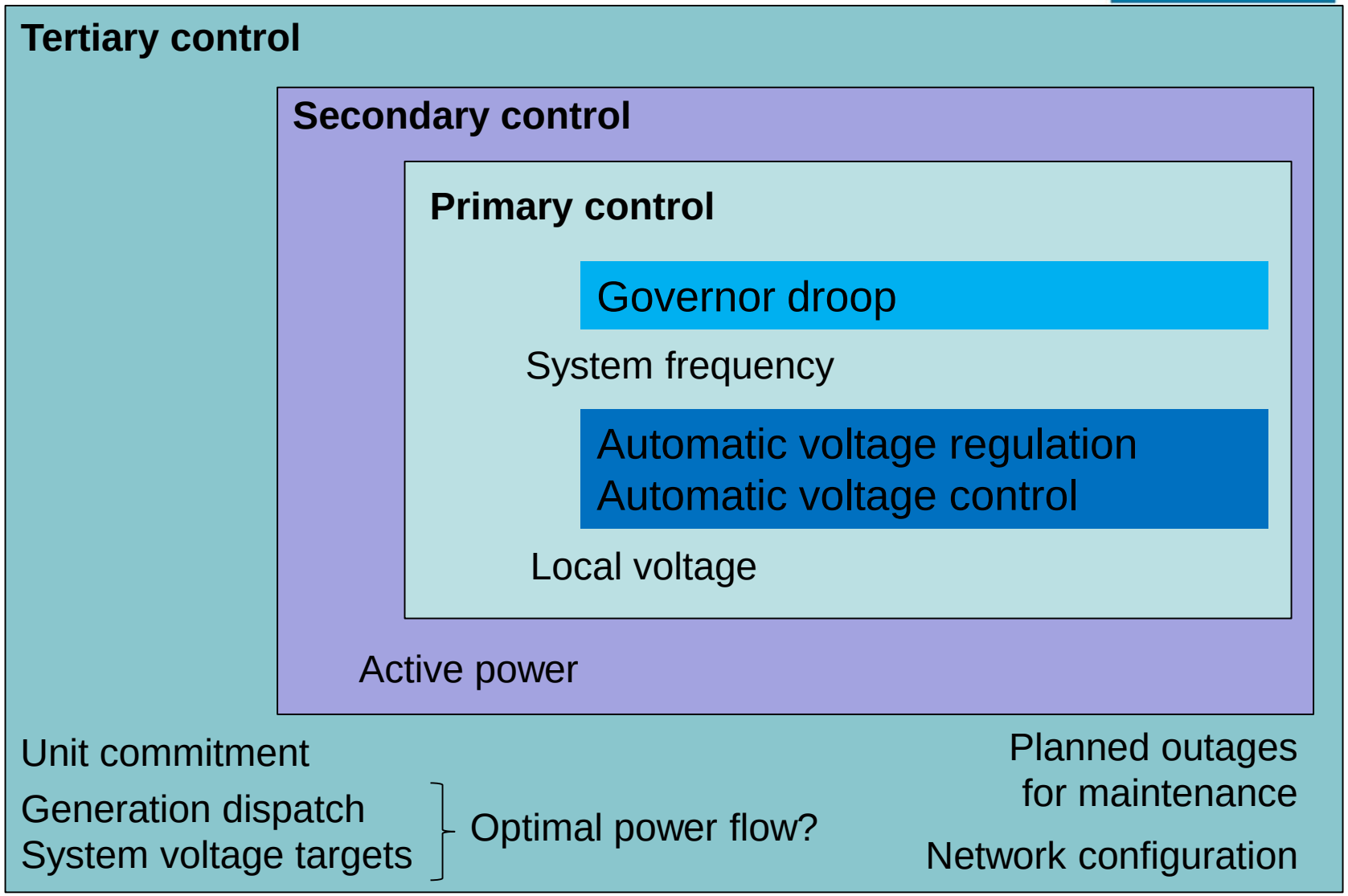
- Sets of equations/tools are still under development and discussed
  - See, for example, IEEE Transactions on Power Systems, Power System Computation Conference, …
- Still need to choose the right tool, use a ‘correct’ set of parameters and choose a ‘sensible’ control vector
  - Systems change over time
    - Equations might not change but the system parameters do
  - Some tools give scope for user defined models
    - Choice of standard relations and user-defined parameters
  - Many of the independent variables (the control vector) are uncertain
    - Choices of other independent variables dependent on expertise or tools
- Not all newer technologies have validated models
  - Some models are too heavy to always be practical
  - Some parameters are not known

Horses for courses…

How much temporal detail is needed?



How to model operation & control?

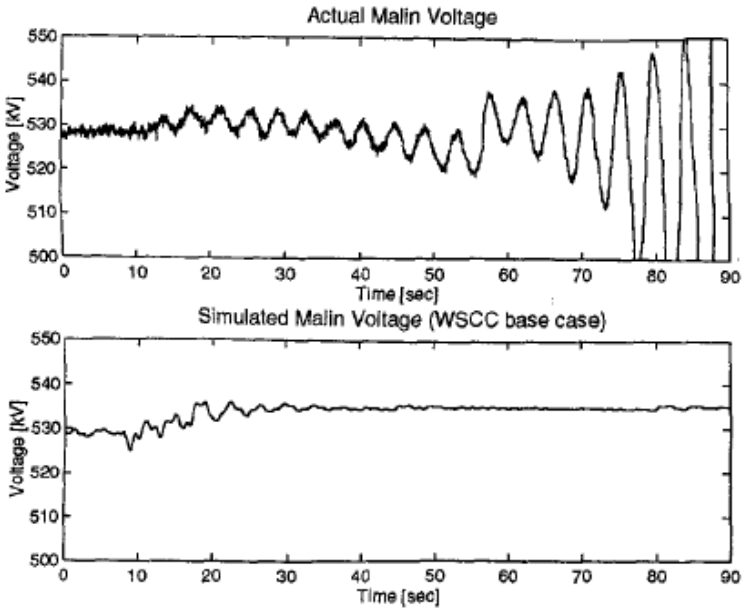


Complicated, non-linear systems

Western US, August 10, 1996

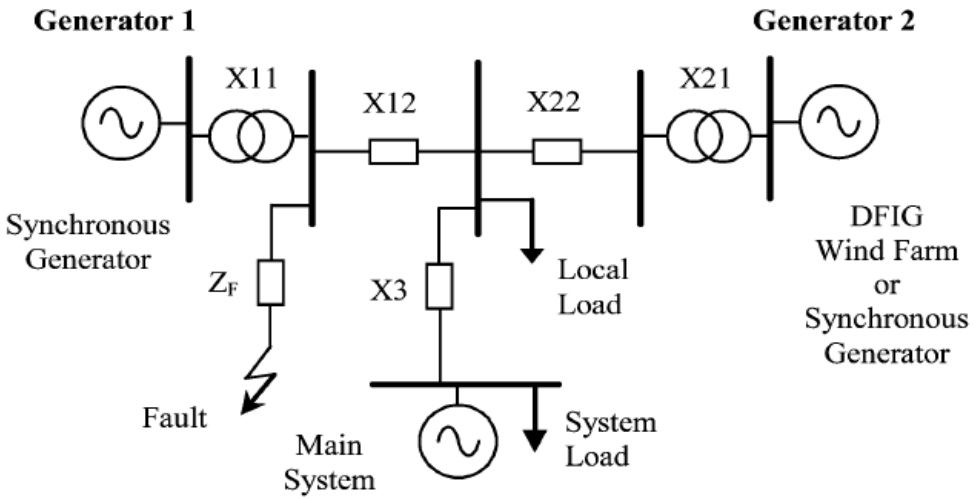
- 28,000 MW lost, 7.5 million people affected, up to 9 hours to restore
- High temperatures and lack of “vegetation management” caused an overhead line to trip and another due to configuration of the network
  - Operators failed to assess the new system state
- Subsequent cascade exacerbated by incorrect trips of some generators
  - Power and voltage oscillations started
  - AGC responses exacerbated voltage depressions
  - HVDC control responses increased the AC system oscillations
- Standard system model failed to reproduce the event
  - Improve modelling of HVDC control, AGC, governor action, voltage control and loads

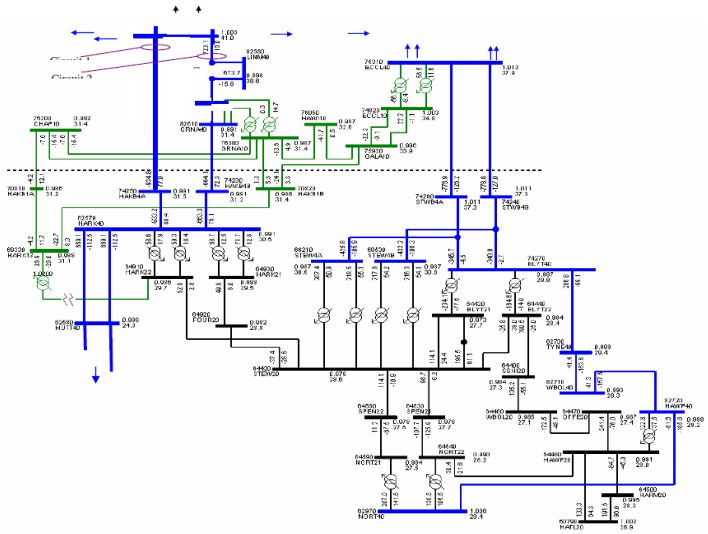
Figure: Kosterev, Taylor and Mittelstadt, ”Model Validation for the August 10,1996 WSCC System Outage”, IEEE, 1999

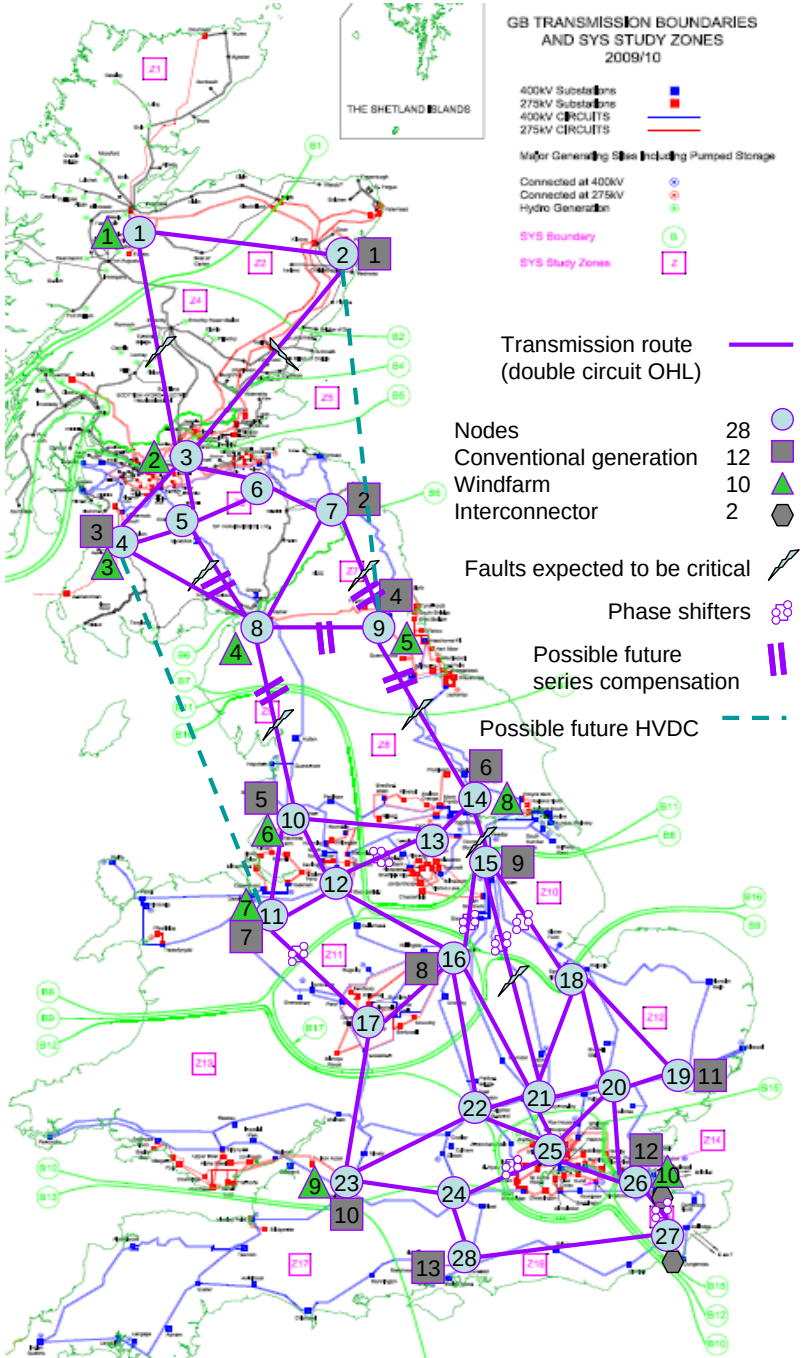


Development of understanding

- Do new technologies introduce new behaviours?
  - To manage them requires understanding of causes
- Understanding of new phenomena is effectively impossible on large system models
  - Small test systems are required for qualitative exploration
- Systems that are too small do not reveal interactions between equipment and their controls







A 'representative' GB system

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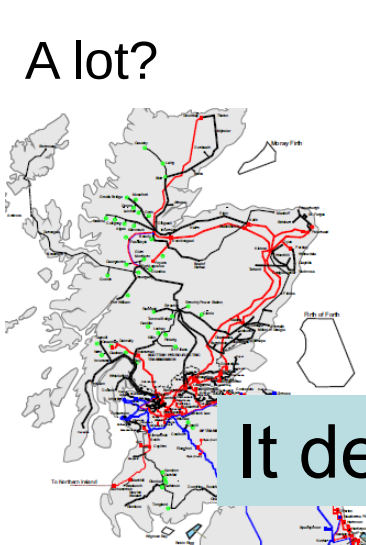
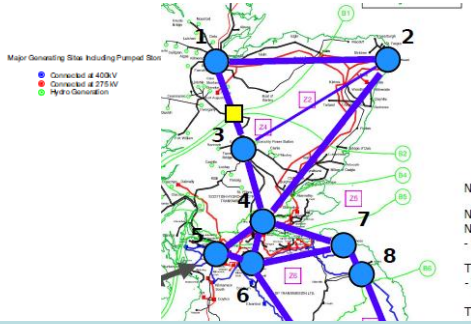
- Build network from numerical reduction or from expert knowledge?
  - Numerical reductions are correct (for given conditions) but 'unreal'
- How to validate the similarity?
  - Depends on access to some full system reference cases
  - Judgement required on closeness of representation

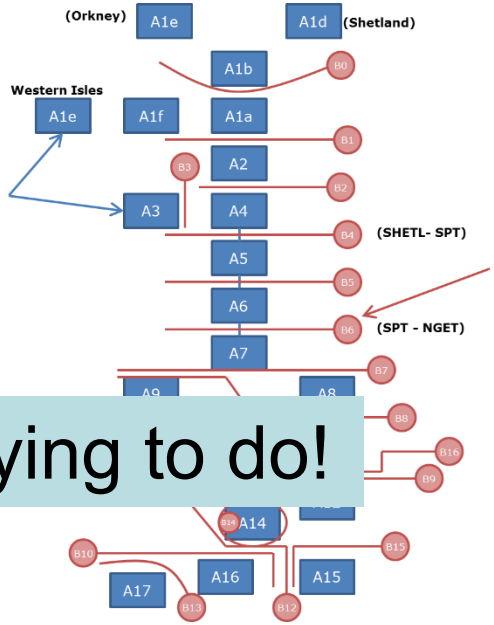
System representation choices

How much spatial and network detail is needed?

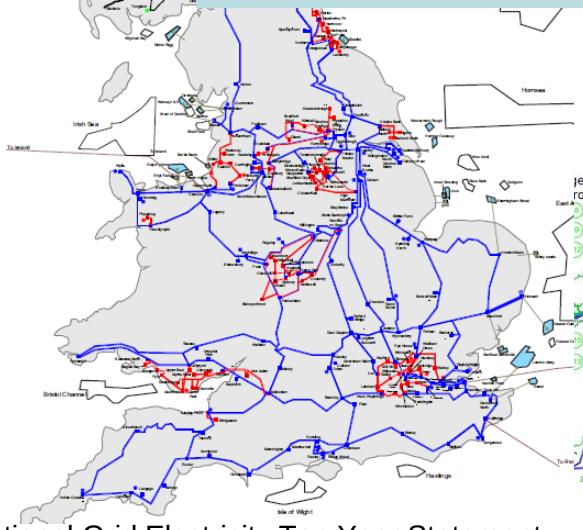
A lot?

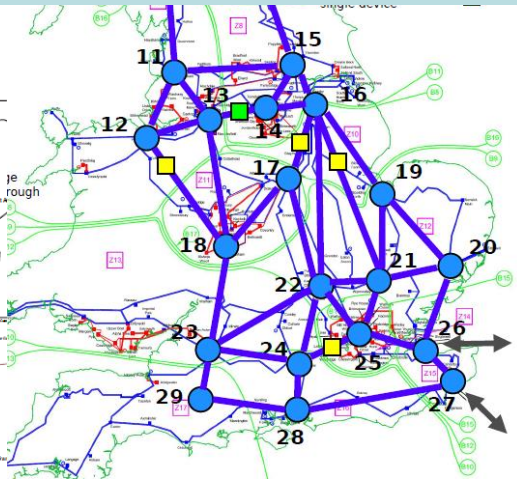


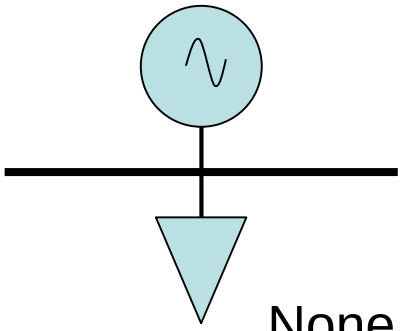




It depends on what you're trying to do!







None at all?

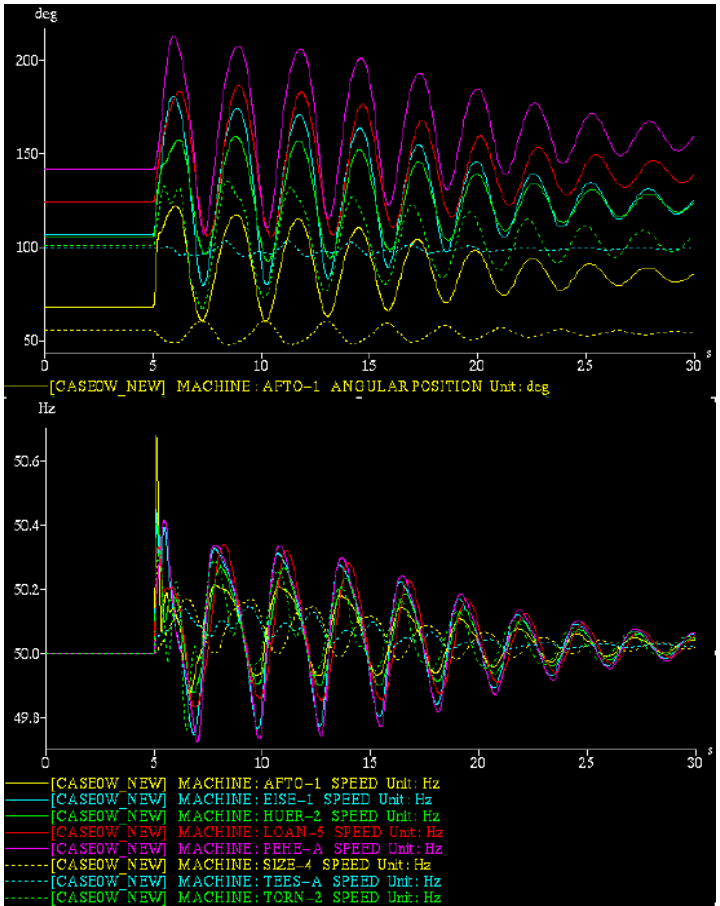
National Grid Electricity Ten Year Statement

Interpretation of results

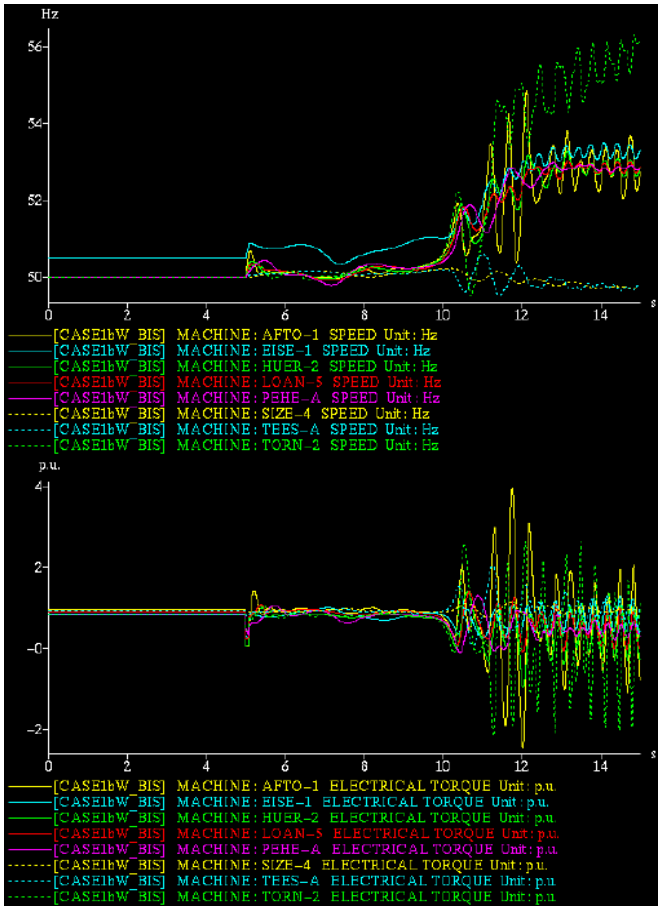
Unrealistic models, data and initial conditions could

- prevent understanding of real phenomena
- lead to misunderstanding of materiality of uncertainties

Reference case (all synch machines)



FSIGs in Scotland



Figures: National Grid for BERR, 2008

Realism of data – 1/2

Does it matter that data are ‘realistic’?

- Academic studies often more concerned with methods than ‘results’
  - Results often just a demonstration that methods can be applied
  - Their meaning is otherwise often regarded as unimportant
- Is this good enough from academics?
  - For training and development of PhD students, it often is
  - What is the final objective?
- Do utilities or governments have their own research departments any more?
  - Are some utilities relying on academics?
    - What do they expect from academics?
  - Great opportunities for academics to have ‘impact’!

Realism of data – 2/2

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Does it matter that data are ‘realistic’?

- Are modellers always open enough about their assumptions or sources of data?
- Use of unreal data can lead to
  - wrong conclusions in academic studies
  - work being ignored by industrialists
- Younger engineers and analysts need to develop
  - a ‘nose’ for right results (‘DBI filter’, giggle test)
  - an ability to make good guesstimates in absence of reliable data
  - respect for data and their maintenance

Be careful of: “it must be right; my model says so!”

Access to academic ‘models’

A ‘model’ as a particular combination of data (inputs) *and* tool (set of equations and solution method)…

- Targeted at specific questions
- Bespoke
- Complex
- Difficult to use and maintain
- Encapsulates significant time, effort and intellectual property
- “If it’s not got a name, it’s not worth anything”

- Complex
- Obscure
- Difficult to interpret results
- Not portable
- Places power in the hands of the ‘expert’

What does it mean if the UK research councils oblige open access to models funded by them?

Commercially sensitive power system data

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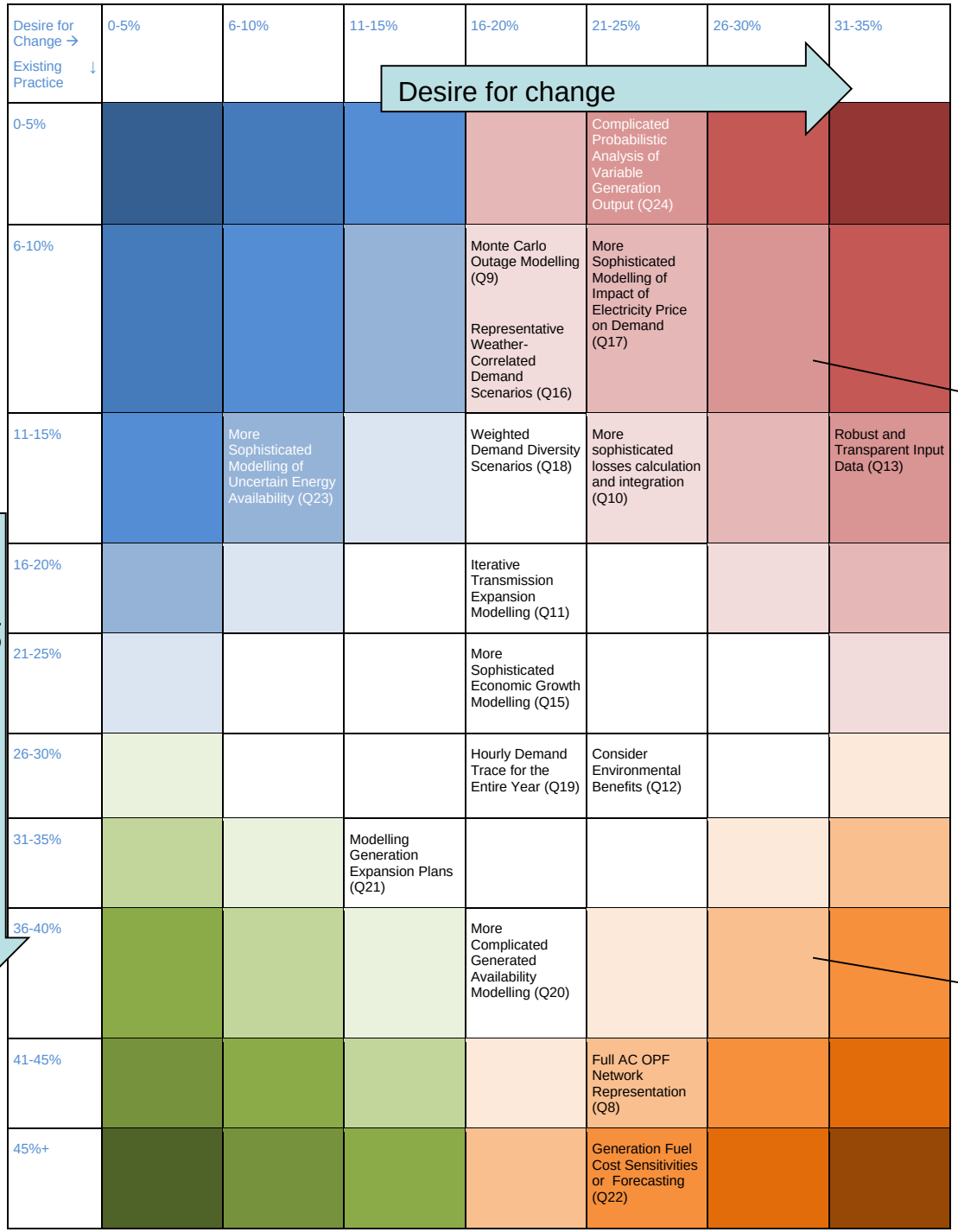
Standard power system tools depend on appropriate data

- Restriction of access
  - Many stakeholders have a legitimate interest in the costs and performance of new power system solutions
    - Many want to see ‘independent’ assessments of issues
    - The impact of such assessments is limited without access to data
- Concerns about access
  - Commercially sensitive?
    - Most significant data either already published or not addressed by the GB Grid Code
  - Utilities responsible for system performance sensitive to challenges to their judgment?
    - Their expertise ought to be unmatched
    - Greater openness should encourage greater trust

Tools & data in power system planning (CIGRE WG C1.24)



Top right: gaps in current practice

Bottom right: best practice

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Last word

The Institution of Engineering and Technology

A forthcoming set of papers…

…and a forthcoming conference, PSCC (Power Systems Computation Conference)

Methods and tools for planning the future power system: issues and priorities

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Paper 5 of 15 of Part 3: IET Special Interest Publication for the Council for Science and Technology on "Modelling Requirements of the GB Power System Resilience during the transition to Low Carbon Energy"

www.pscc2016.net/call-for-papers/ — pscc 2016

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CALENDAR

June 2015

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15	16	17	18	19	20	21
22	23	24	25	26	27	28
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CALL FOR PAPERS

IMPORTANT DATES

JULY 5, 2015
Deadline for one-page abstract submission. Authors will be notified regarding full papers within three weeks.

SEPTEMBER 15, 2015
Deadline for full paper submission.

FEBRUARY 15, 2016
Authors notied about acceptance and required modications.

MARCH 15, 2016
Final manuscript submission.

JUNE 20-24, 2016
19th Power Systems Computation Conference, Genoa