Power systems, novel challenges

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July 31, 2017

Contents

Why now?

- Traditionally power systems have mostly been deterministic:
  - Very large population leads to highly predictable demand.
  - Conventional power station generation is deterministic.
  - Main issue was reliability, plant failure or line failure.
  - Solution is run to a $N-1$ standard.

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  - Conventional power station generation is deterministic.
  - Main issue was reliability, plant failure or line failure.
  - Solution is run to a $N-1$ standard.

- Changes from decarbonisation:
  - Renewable generation is highly variable
  - Renewable generation is highly uncertain
- Changes from technology:
  - Smart and Micro grids
  - Electric Vehicles

Power systems are the same but different

Internet

Power System

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Internet

- Servers
- Users
- Underlying transmission network
- Capacity constraints

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- Fast to react

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- No control over flows
- Slow to react

Where do the differences come from?

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  - There is no control over links used.
  - Flows obey Kirchoff's laws.
  - Only control is generation and demand amounts.

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  - Conventional generation is slow to change
  - Takes hours to change output level often
  - Takes about a day to turn on a plant
  - Can be done quicker but is more expensive

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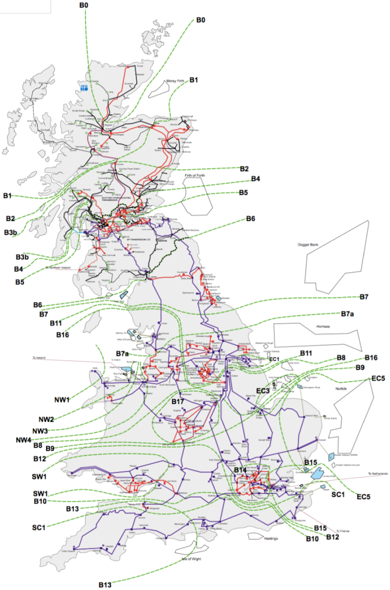
Supply must always match Demand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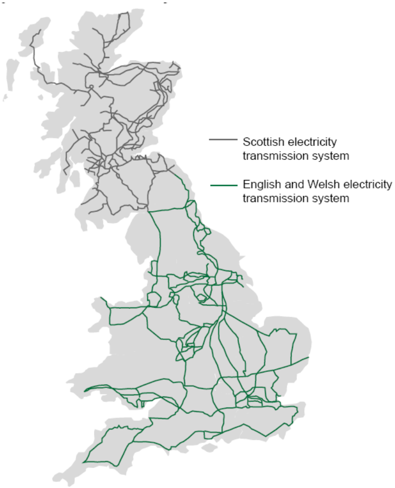
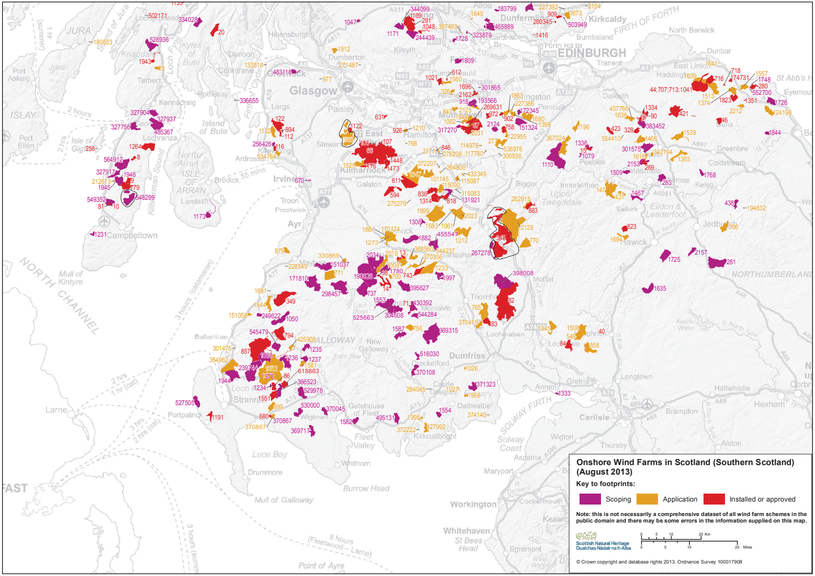

Scottish electricity transmission system
English and Welsh electricity transmission system


Onshore Wind Farms in Scotland (Southern Scotland) (August 2013)
Key to footprints:
Scoping
Application
Installed or approved
Note: this is not necessarily a comprehensive dataset of all wind farm schemes in the public domain and there may be some errors in the information supplied on this map.
Scottish Natural Heritage
Dualchas Nàdair na h-Alba
0 5 10 20 Km
0 5 10 20 Miles
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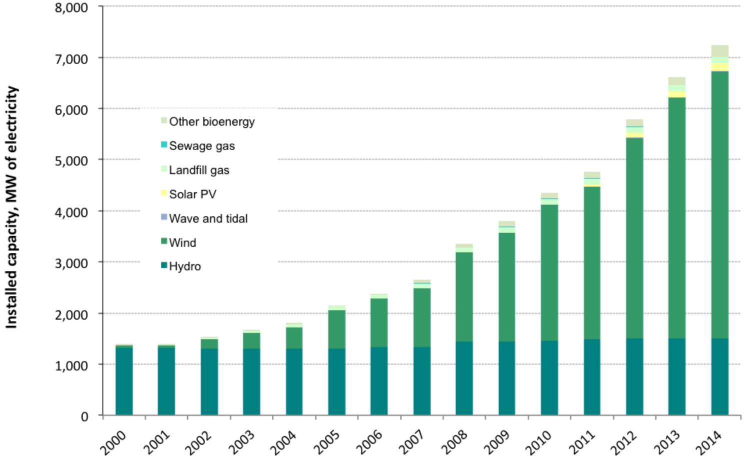
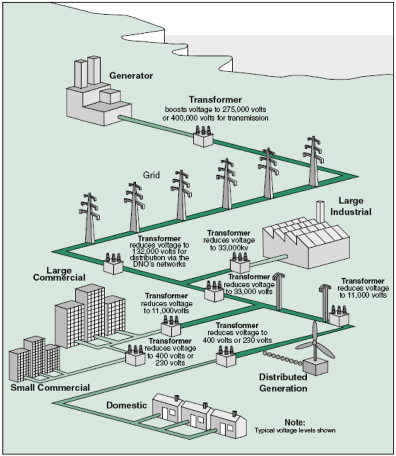


Installed capacity, MW of electricity
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Other bioenergy
Sewage gas
Landfill gas
Solar PV
Wave and tidal
Wind
Hydro
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014

There are natural multiple scales in power systems problems

Spatial Scales:

- Micro grid (small collection of house/offices)
- Distribution Network
- Transition Network



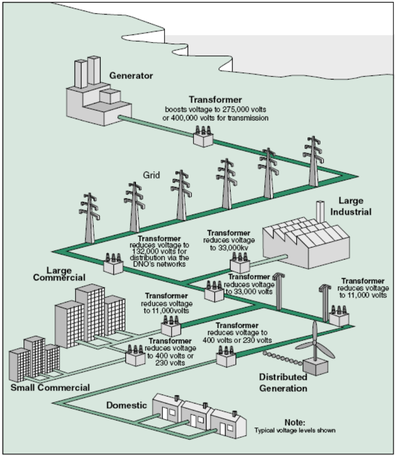
There are natural multiple scales in power systems problems

Spatial Scales:

- Micro grid (small collection of house/offices)
- Distribution Network
- Transition Network

Temporal Scales:

- Frequency (milliseconds)
- Fast responses (seconds)
- Balancing (minutes)
- Market (hours)
- Planning (years)



Why do we want electricity storage?

- Need to balance supply and demand at all times.
- Wind power can fluctuate substantially on a short timescale.
- Thermal power plants slow to react.
- Can either use expensive alternatives.
- Alternatively can use electricity storage.

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There are many other uses:

- Arbitrage
- Frequency regulation
- Reactive power support
- Voltage support
- Black start

Storage Policy

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bbc.co.uk/news/business-40699986

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Electricity shake-up could save consumers 'up to £40bn'

By Roger Harrabin
BBC environment analyst

24 July 2017 | Business | 382

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Consumers in the UK could save billions of pounds thanks to major changes in the way electricity is made, used and stored, the government has said.

New rules will make it easier for people to generate their own power with solar

Top Stories

Service marking Passchendaele centenary
The royals join thousands of relatives to remember 100 years since the 1917 battle.
3 minutes ago

Vanessa Feltz 'upset over racist column'
1 hour ago

Gun battle at Iraqi embassy in Kabul
33 minutes ago

Features

India partition: 'I saw bodies on the way to school'

Dinorwig: capacity: 9 GWh   rate: 1.8 GW   efficiency 0.75–0.80

Storage comes in many forms.

There are many types of storage with different properties:

- Pumped storage
- Battery Storage
- Compressed gas storage
- Fuel Cells
- Thermal
- Fly wheels

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- Battery Storage
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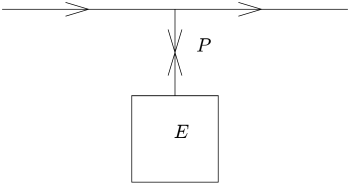
As well we can consider dynamic demand as storage:

- Control of fridges.
- Thermal inertia of buildings.
- Washing machines.
- Aluminum smelting.

A simple aggregated model



E = size of store — *capacity constraint*

P = max input/output rate — *rate constraint*

- Value of storage when used for arbitrage and ancillary services.
- How do parameters effect value?
- How do competing stores behave?

'Optimal control of storage incorporating market impact and with energy applications'

J.R.Cruise, L.Flatley, R.Gibbens, S.Zachary *arXiv:1406.3653*

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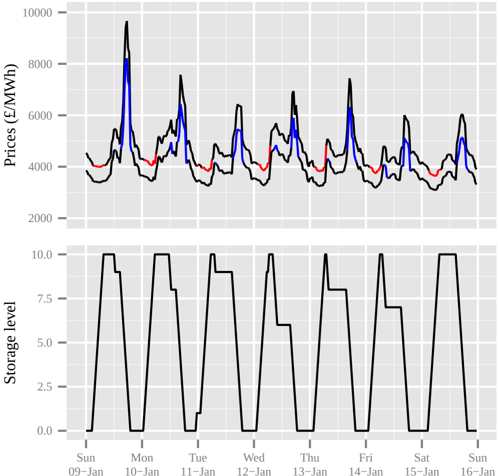
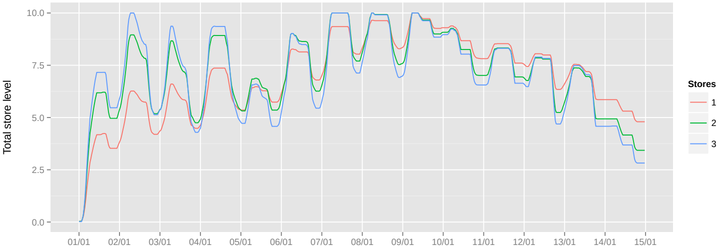
Example: Real prices with Dinorwig parameters

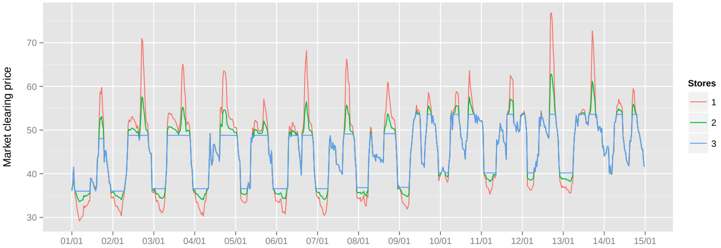
$E/P = 5$ hrs $\qquad$ *Efficiency* $= 0.85$ (ratio of sell to buy price).

Solution is *bang-bang*: red points buy, blue points sell



Example: Competition example





Open questions

- How do we optimally control multiple stores?
  - No network.
  - Connected by a single link.
  - Embedded in a larger network.

- What is the optimal position and size of store?
  - For maximum profit?
  - For social welfare?

- How do we model storage within distribution networks?
  - Storage for network reinforcement.
  - Optimal placement within distribution network.

Electric Vehicle

Electric Vehicle

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New diesel and petrol vehicles to be banned from 2040 in UK

26 July 2017 | UK

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New diesel and petrol cars and vans will be banned in the UK from 2040 in a bid to tackle air pollution, the government has announced.

Top Stories

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The royals join thousands of relatives to remember 100 years since the 1917 battle.

9 minutes ago

Vanessa Feltz 'upset over racist column'

1 hour ago

Gun battle at Iraqi embassy in Kabul

30 minutes ago

Features

Electric vehicles are a challenge for distribution networks

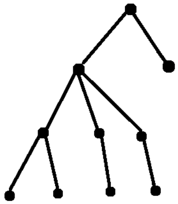
- Number of vehicles expected to increase.
- People want to charge at home and have it available on demand.
- Distribution network operators want to avoid upgrading infrastructure.
- Lack of control would lead to network failure.

This leads to a number of questions:

1. How many cars can we charge?
2. What classes of charging schemes obtain this?
3. What is a fair charging scheme?

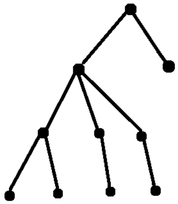
Toy model

- Consider a small part of the distribution network, for example a street.



Toy model

- Consider a small part of the distribution network, for example a street.
- Assume a tree structure to the network.
- Model as a rooted tree.
  - Root is local transformer, power constraint.
  - Cars connect at other nodes to charge.



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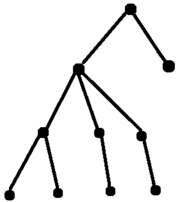
- Cars arrive as a Poisson process.
- Select charging node uniformly at random.



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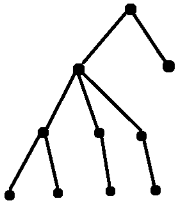
  - Cars connect at other nodes to charge.
- Cars arrive as a Poisson process.
- Select charging node uniformly at random.
- Each car has a random battery level.
- Cars leave when fully charged.



Initial computational study

Since we use a tree network a simplification of Kirchhoff's laws can be used to define feasible allocations.

- Consider two fairness criteria to allocate resources:
  - Max-flow
  - Proportional fairness
- Explored two networks, one containing 47 nodes and the other 56 nodes.
- Interested in phase transition from under-loaded to over-loaded.
- Also explored time to charge vehicles and associated fairness.

'Critical behaviour in charging of electric vehicles', R.Carvalho, L.Buzna, R.Gibbens, F.Kelly *New J. Phys.* 17(9)

Open questions

- What is the stability region?
- How does the network structure effect the stability region?
- Are there decentralized algorithms which achieve the stability region?
- What is an appropriate measure of fairness?

(Seems to have natural analogues to flow models for network traffic)

Alternative Model of Charging

Alternatively swap batteries in and out of vehicles at charging stations.

- Network of charging stations
- Arrive at a charging station:
  - Empty battery removed
  - Full battery slotted in
- Empty batteries charged ready for a different car

Modelling and Open questions

Model as a closed queueing system. Easy to analyse under Markovian assumptions.

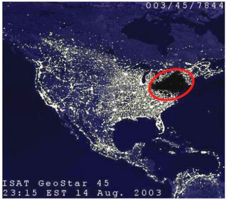
- Obtain quality of service metrics,
- Use to guide provisioning, number of batteries and rate of charging.

Open questions:

- Incorporate battery degradation.
- Integrate in an economic framework.
- Large N asymptomatics for generalised model.

What is a cascade failure?

- Number of examples:
  - Northern India 2012
  - Europe 2006
  - Italy 2003
  - London 2003
  - Northeast America 2003
- Single failure leads to cascade.
  - Line failure
  - Relay failure
  - Generator failure



Open questions for islanding and cascades

Number of open questions:

- Can we understand what makes a power network susceptible to cascade failure?
- Can we understand how reinforce a given network to minimize the probability of a cascade failure?

Related problem is 'Islanding'

- Aim to is isolate a failing resource before it causes a cascade failure.
- Minimize disruption to rest of grid.
- Need to be able to identify cut set quickly.
- Is there a randomized algorithm to do this?

'Constrained spectral clustering-based methodology for intentional controlled islanding of large-scale power systems', J.Quirós-Tortós, R.Sánchez-García, J.Brodzki, J.Bialek, V.Terzija, *IET Generation, Transmission & Distribution*, 9(1)