Mathematical modelling for a Net-Zero grid

How to de-carbonise the grid without destabilising it

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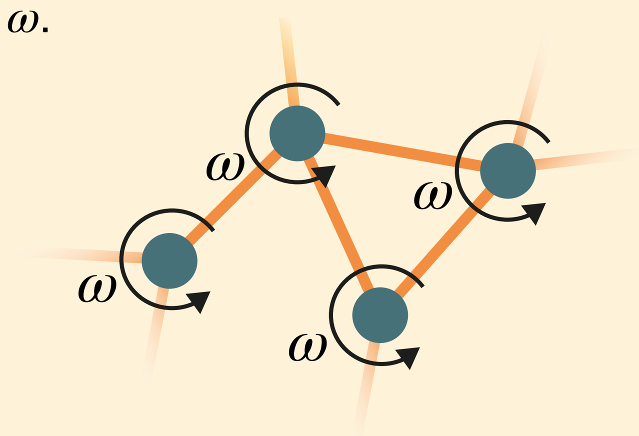
Grid stability
Why is it important?

Conventionally, the power grid is a network of generators with a **spinning** core; e.g. coal and gas power stations. These **rotating machines** spin at the grid frequency ω.



These rotating machines must supply the UK grid with AC power at a uniform grid frequency ω of **50Hz** and a **constant voltage of 240V**. The grid's **stability** is its ability to maintain these values.

If the grid is unstable, then it will drift from these values. This can cause physical damage to power infrastructure and is the main cause of **blackouts**.

Renewable power sources
Why do they reduce grid stability?

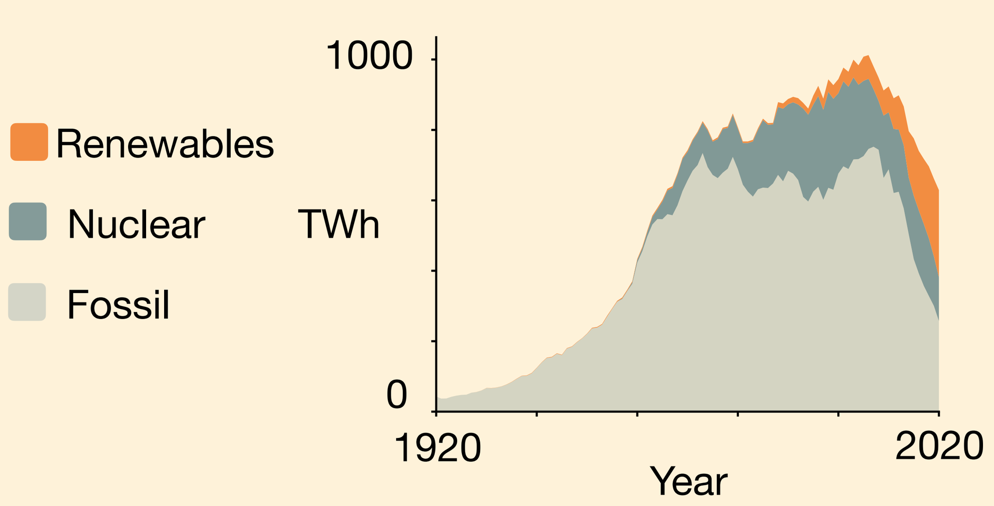
Renewable sources of power are not rotating machines. Instead, they are DC sources which must be converted to AC. Even wind turbines are DC sources.

The replacement of conventional rotating sources of power with non-rotating renewable sources is **causing a loss of spinning inertia** across the grid. **Inertia is vital for grid stability**.

The uptake of renewable sources is therefore causing a decrease in grid stability. It has been calculated that **no more than approximately 63% of power can come from renewable without causing a total loss of stability**[2].

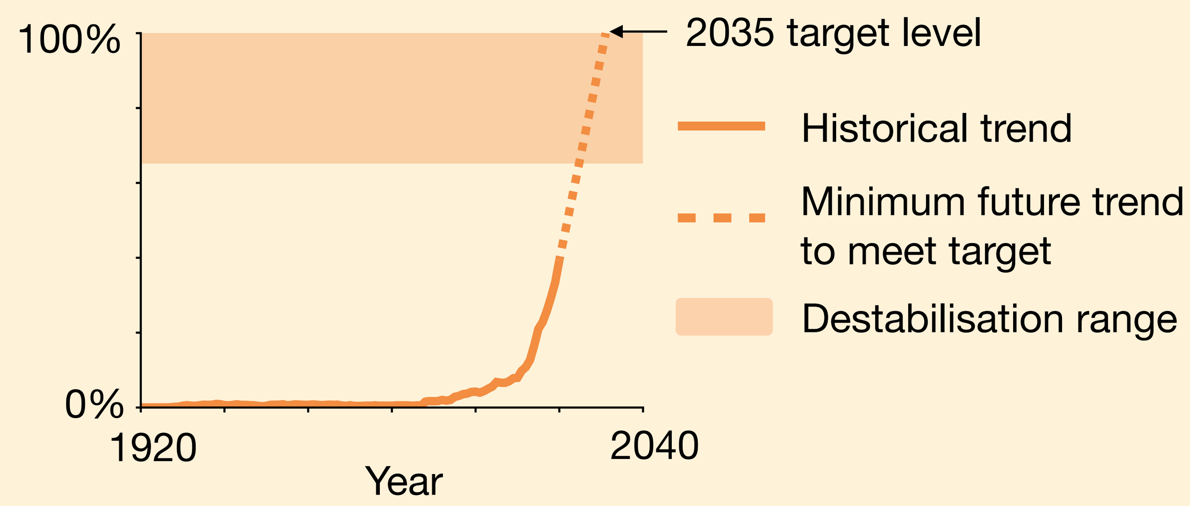
This upper limit means that renewable generation targets cannot be met with present technologies.

Fuels used for electricity production [1]



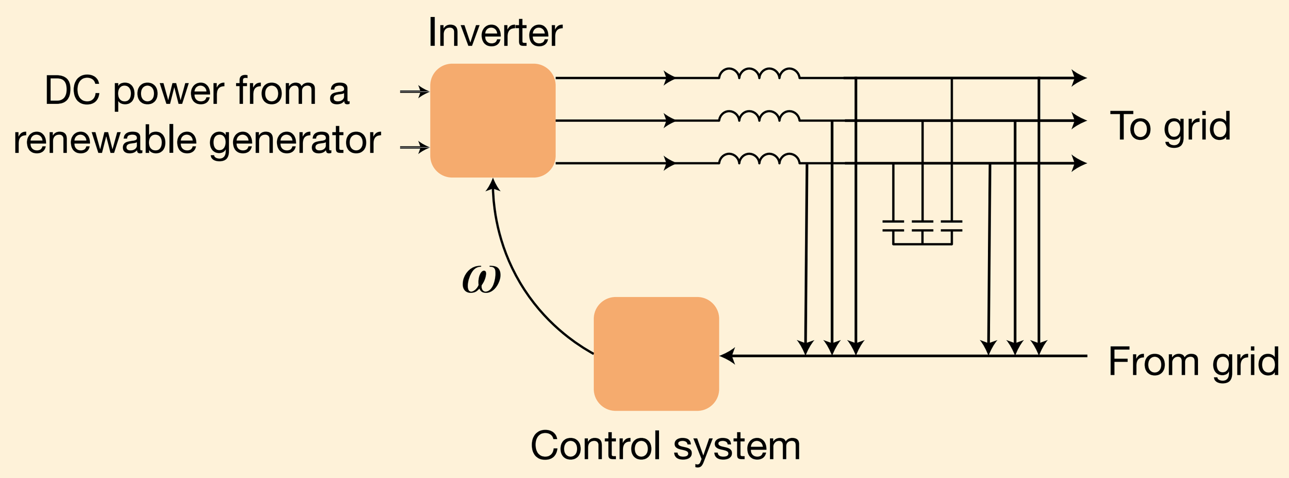
The percentage of power from renewable sources has increased rapidly in the UK and now stands at around 40%. At approximately 63%, the grid will destabilise. This threshold will need to be crossed to meet the government's 2035 100% renewable target announced at COP26.

Percentage of energy from renewable sources [1]



Control systems to boost stability
A new mathematical framework

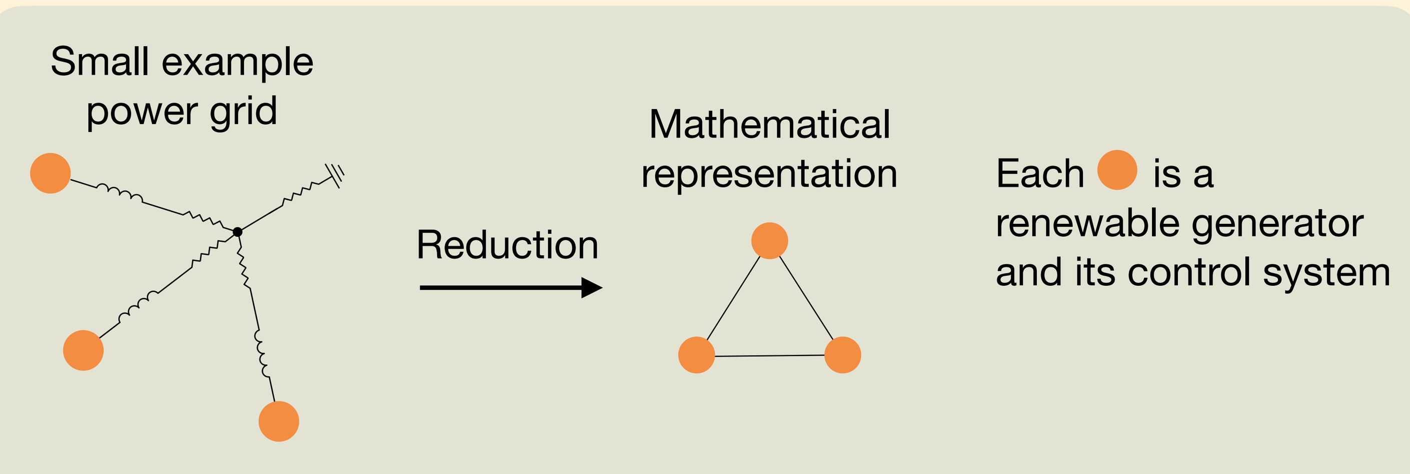
A host of novel control systems have been proposed in recent years to allow each renewable generator to simulate a rotating machine spinning at a frequency ω. Each renewable source would then provide **"synthetic inertia"** to stabilise the grid.



But each of these control systems, one of which is illustrated above, can be highly complex and their impact on the grid unpredictable.

We have developed a new mathematical framework capable of gauging the impact of any type of control system on any power grid's stability. This allows for rapid prototyping and benchmarking of control systems for low-carbon grids.

In the first step, we transform the power grid structure into a simpler mathematical representation using a **graph-reduction process:**

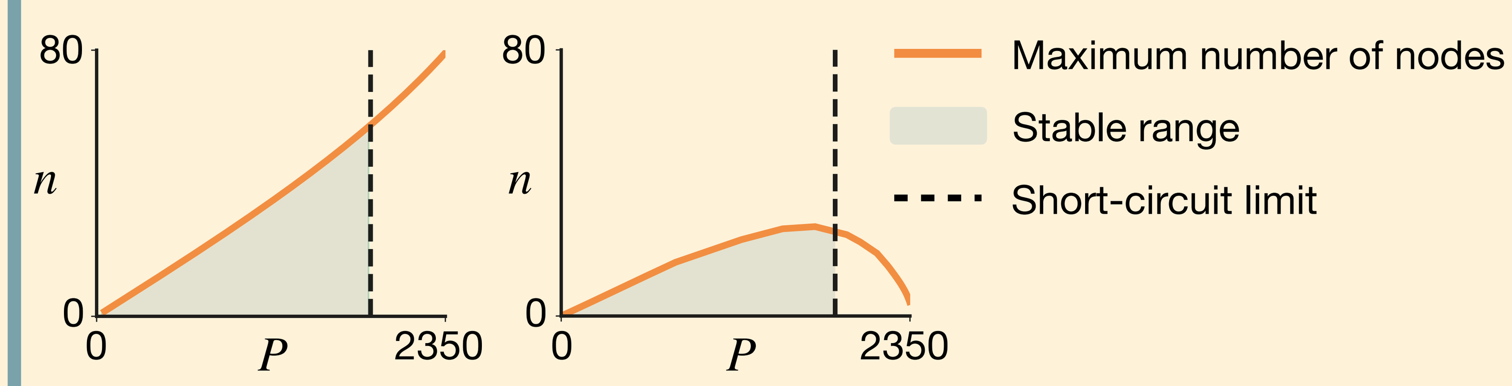


This way, large complex power grids can be represented as simpler structures. The stability of this reduced network is then assessed by formulating the system's Master Stability Function[3].

How do control systems perform?
Analysing their behaviour using the new framework

This new framework tells us how many renewable generators with a given control system can operate on a grid before instability occurs. This calculation is highly computationally efficient.

For example, we can use it to calculate the number of stable renewable generators n that can be supported as a function of power demand P for **two different proposed control system designs**:



The control system on the left has a large stable regime and would be **capable of providing a power grid with nearly 100% renewables**, whereas the control scheme on the right has a small stable regime and would fail.

This new approach will allow the performance and safety of renewable control systems to be quickly tested before they are deployed to the grid, helping us reach Net-Zero targets safely without destabilisation.

References

[1] Department for Business, Energy & Industrial Strategy, *Historical electricity data*, gov.uk/government/statistical-data-sets/historical-electricity-data

[2] M Azmy et al., (2005),"Impact of distributed generation on the stability of electrical power system," IEEE Power Engineering Society General Meeting, pp. 1056-1063 Vol. 2

[1] L.M. Pecora, T.L. Carroll, (1998), "Master stability functions for synchronized coupled systems", Physical Review Letters, **80** (10): 2109–2112