Offshore Wind Explainer

Government of JERSEY

Wind Turbine Efficiency

Overview:

At its simplest, a wind turbine works by the wind turning the blades, which in turn, through a gearing mechanism, spins a generator, which produces electricity.

The overall efficiency of a wind turbine, be it onshore or offshore, is based on numerous factors, including factors relating to the wind turbine itself- its height, blade radius (the "swept" area), and what model/age it is. It also includes factors not directly relating to the structure, including its location (for example wind speeds are higher and more constant offshore), the air density at any given moment (effected by temperature, air pressure, and altitude) and wind characteristics.

Wind is caused by a combination of factors. These include the earth being heated by the sun unevenly, irregularities in the shape of the earth, and the earth's rotation. These differences, as well as differences in landscape, vegetation, and bodies of water, create the wind patterns and flows experienced.

Intermittency:

To understand intermittency, which is the intermittent power of the wind at any given moment, it is necessary to understand the operation of a modern power grid. This is based on meeting energy demand, when it is required, based on time of day, seasons, and local temperatures. Patterns emerge as a population will generally all follow similar behaviours, such as putting on the heating or air conditioning, using more hot water first thing in the morning, or powering business premises during office hours. Additionally, unpredictable demands can be caused by sudden changes in weather or other factors such as emergencies or grid disruption.

Traditionally, gas fired power plants were brought online rapidly to meet sudden demand, but with renewables, this is dependent on the environmental conditions at any given moment. Until recently, this led to the understanding that renewables could only meet a certain proportion of energy demand, with the need for a reliable backup and a core supply maintained from traditional sources.

However, renewable technology is progressing and there are a number of factors specific to the development of wind power that are able to, at least partially, mitigate this problem:

- Distributed wind farms mean that if the wind is not blowing strongly in one area, there is a greater ability to call on the wind elsewhere. This also relies on an interconnected grid and even international energy trading to maximise its benefits.
- Increasingly accurate wind forecasting enables energy trading and other preparedness to be more effective.
- Hydroelectric power can also be used to help mitigate wind shortages, such as the interconnector between the UK and Norway's hydroelectric sources.
- Battery or other storage when surplus wind is generated. This can be stored in batteries or used to pump water uphill for future hydroelectric power.[1]

What proportion of renewable energy can be maintained in a resilient network?

The proportion of a grid could rely on renewable energy sources will depend significantly on the specific local circumstances. A study by Energy Innovation, a non-partisan think tank, analysed 11 independent studies which examined the feasibility of achieving an 80% clean energy grid (based on US parameters). They found that all 11 studies showed a 70-90% clean electricity system *"would be dependable (e.g., able to match supply and demand), including five studies that provide rigorous reliability checks of the grid under stressful weather and demand conditions."*.[9] Whilst these studies, prove the feasibility of the high percentage of renewables achievable, they also highlight the necessity of governmental investments in energy storage and grid connections.

The maximum percentage of renewable energy that Jersey could use whilst maintaining resilience will be based on its investments into energy storage and grid connections with other jurisdictions.

Curtailment:

Curtailment is when a source of energy production is shut off or the amount of power that it is producing is reduced. This may be because there is more supply than demand, such as strong wind or sunshine in a period of low demand. It can also be to reduce gird congestion, when an excess of energy would be fed into the grid, greater than its transmission capacity.

Energy companies are responsible for balancing grid capacity. This balance can be met through energy trading, or in the case of excess generation, through curtailment. Typically, the most expensive electricity is most likely to be curtailed.

Curtailment can lead to lost revenue for wind farm operators, however it can benefit them by avoiding low or even negative pricing when there's an excess of energy production, or if they have agreed a capacity limiting contract. This is a contract where they can be paid for reducing their output every time such a contract is enacted by the grid operator. It may also benefit a producer through the way the energy markets work, on day ahead or similar pricing and by influencing the market prices by reducing oversupply affecting prices.[2]

The need for curtailment can be somewhat mitigated by increased accuracy in wind forecasting, improving the capacity of the grid in the long-term, and increasing the capabilities for energy trading and battery or hydroelectric storage.

Balancing and Congestion:

Grid balancing refers to the efforts to maintain the power (or frequency) flowing through the grid at its optimum capacity by balancing power supply and power demand. Maintaining grid stability in real time is essential to prevent blackouts or other problems. It requires a high level of co-ordination between generators and the grid operator.

Balancing has assumed greater importance with the widespread generation by renewables.

Congestion in the grid is where there is a flow of electricity greater than the grid can handle, which can lead to blackouts and increased operational costs. Improving the capacity of the grid is a long-term solution but in the short-term "limitation contracts" and "redispatch" can be required. Congestion is generally a localised issue, where imbalance is more likely to be national one.

Limitation contracts are where the producer is paid a fee in return for lowering the amount of energy they are producing. These contracts can be triggered from several days to the morning of the expected period of congestion.

Redispatch is where producers are asked to send their energy production to a different part of the grid, or to other grids, where a congestion issue isn't predicted to occur.[3]

Wake Effects:

The wake effect on a wind farm is the distortion of the airflow by a wind turbine and the distortion between neighbouring turbines and its impact on each other. This affects the performance of the windfarm. This is managed by optimising the spacing and layout of a windfarm to maximise the number of turbines/wind farm output, for the minimum wake effect. This balances the impact of the wake affect and turbulence between turbines, whilst keeping to a minimum the cost of interconnection of the wind farm through cabling and its internal grid.

The layout of the windfarm normally follows a similar pattern of spacing and layout, as shown below, where "D" is the diameter of the turbine blades.[4]

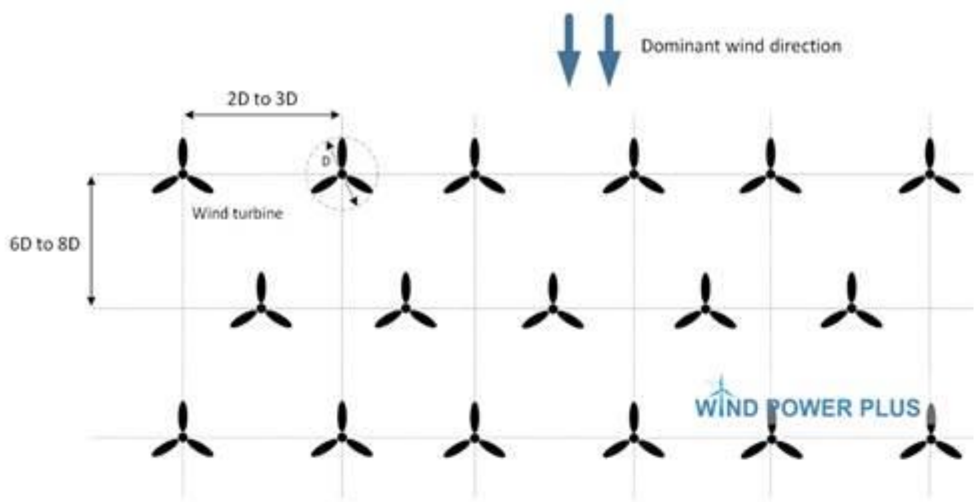

Figure 2: Recommended distribution criterion of wind turbines in a wind farm. [5]

Shadowing:

The "wind shadow" is where one windfarm is situated behind/downwind of another windfarm. This occurs due to the limited number of optimal sites for wind farm placement, and which may become a greater issue in the future with wind expansion.

"Wind theft" is the reduction or disruption of the wind by a newly built windfarm, upwind of an existing one. The scale of the impact is still being studied, but it can stretch for several times the size of the physical windfarm site and reduce wind speeds by up to 25%.[6]

A recent article in a Belgian newspaper, stated that Dutch windfarms were experiencing a 3% energy loss from the wind shadow of Belgian windfarms.[7]

Overall efficiency:

The theoretical maximum efficiency of energy extractable from the wind passing over the blades is around 59.3%, and is known as the Betz limit, after the physicist who calculated the figure. The real-world figure is around 35-45% in the best design turbines, and if other factors are included, such as the loss due to transmission and the gearing mechanism in the turbine, this figure decreases further.[11] This is about the average for both traditional and renewable energy sources:

- Coal-fired power stations: 32%-42% depending on age and technologies used.
- Natural gas-fired power stations: Average of 32-38% (The "H-class" gas turbine power station can run at up to 60% efficiency).
- Hydro-electric turbines: 85-90% (high due to the proximity of the water to the turbine and encountering limited losses mainly from the mechanics of the machinery).
- Solar- Around 20% daily efficiency but can drop to 12% over the course of a year's average, due to the change in the angle of the sun.
- Geothermal: Around 35% depending on the technology used to convert the energy.
- Nuclear: Around 38% depending on age and technologies used.
- Diesel: Large capacity diesel engines run at around a 35-42% efficiency.[12]

[1] Energy BC "The Intermittency Problem"
[2] With The Grid "What is Curtailment?"
[3] With the Grid "Understanding grid balancing & congestion management"
[4] Wind Power Plus "The Wake Effect in Wind Energy: A Key Influence of Wind Farm Performance"
[5] Ibid.
[6] Pryor, Sara C. "Wind shadows impact planning of large offshore wind farms" (15 June 2024)
[7] Brussels Times "Belgians accused of 'stealing wind' from the Dutch" (26 May 2025)
[8] US Department of Energy "Energy Reliability and Resilience"
[9] Energy Innovation "Studies Agree 80 Percent Clean Electricity by 2030 Would Save Lives and Create Jobs at Minimal Cost" (September 2021) p1
[10] House of Commons "The Resilience of the Electricity System" (12 March 2015)
[11] REUK "Betz Limit"
[12] Bright Hub Engineering "The Efficiency of Power Plants of Different Types"