WIND AND SOLAR INTEGRATION ISSUES

Wind and solar power plants, like all new generation facilities, will need to be integrated into the electrical power system. This fact sheet addresses concerns about how power system reliability, efficiency, and the ability to balance the generation (supply) and consumption (demand) are affected by the variability and uncertainty of wind and solar power production.

How is wind and solar power different from other generation?

The main characteristics that differentiate wind and solar power from other forms of generation are their variability and uncertainty. Depending on resource, also the location may be constrained to sites remote from demand. And the technical connection to the grid is different from conventional power plants.

- Conventional power plants generate at specified levels. The operators can turn them on and off, as well as up and down as needed - they are dispatchable (except in cases of operational failure).
- Wind and solar generation varies depending on how wind fluctuates and sun radiation is available. However, the variations in output are smoothed when many wind and solar power plants are aggregated over an area in a power system (Figure 1).
- To deal with uncertainty, wind and solar power output can be forecast minutes, hours, and even days ahead. Forecasts for minutes or a few hours ahead are more accurate than for 12 to 48 hours ahead. Aggregating power plants over a wider geographic area will improve the forecast accuracy at all time frames.

See Fact Sheet: [Variability and Predictability of Large-Scale Wind Power]

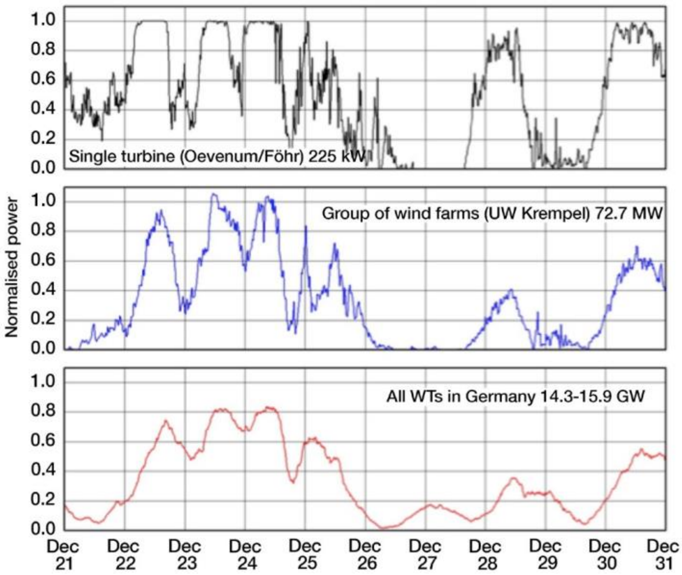

Figure 1. Short-term power output variations of a single turbine (top) are smoothed when aggregated with a group of wind power plants (middle). Aggregating the output from all turbines across Germany (bottom) smoothes the variations even more. As seen in the middle plot, the power generation from a small area can sometimes exceed the installed capacity. (Source: Task 25 summary report, 2009)*).*

How do operators balance wind and solar plant output? Do wind and solar power need a dedicated back-up?

Power systems experience varying electricity consumption (demand), as well as failures that cause power plants to go off line; all of these are balanced together with wind and solar power.

- To balance the variations in demand and supply, system operators adjust the output of some power plants. Also demand can be adjusted. In this way demand and supply are balanced.
- Variations of system demand and wind and solar output often cancel each other out. Sudden, large changes of wind and solar and demand are rare events.
- Power systems are balanced by operators at the system level, with all imbalances, between supply and demand, aggregated (net imbalances).

- Variations in solar and wind power output distributed across a large, system-wide area are combined with other uncertainties that the power system experiences. Only the net imbalance at each minute is balanced.
- Since power systems are balanced at system level, dedicated back-up or storage should not be allocated to any single source of variability. Introducing back-up or storage, only for wind or solar, would be inefficient, and an unnecessarily costly utilisation of installed resources.

See Fact Sheet: Storage and Wind Power

How do system operators manage the system during increasing and decreasing winds and solar radiation?

Operators schedule generators to meet the expected demand at each hour. Reserve capacity is held back for balancing unexpected real-time variations.

- Power plants are scheduled in advance, with individual plant outputs fine-tuned closer to real-time.
- System operators balance supply and demand real-time by using operating reserves - generation or demand responses that can be quickly increased or decreased.
- Anticipated increases and decreases of wind and solar power will change the scheduling of other power plants (Figure 2). Unexpected real-time variations will impact the use of operating reserve.
- Operating reserves are called to match the combined variability and uncertainty of demand and wind and solar output (the net demand).
- The ability to respond both in the real-time and day-ahead time scales is called flexibility. In today's power systems the available flexibility is often (much) higher than what is actually required. However, increased flexibility is important for power systems anticipating large wind & solar shares. Modified operational practices can achieve more flexibility from existing assets (Figure 3).

See Fact Sheet: Balancing Power Systems with Large Share of Wind and Solar Energy

What will operators do when there is no wind or solar radiation?

Power systems need to plan for sufficient generation during high demand situations.

- All power plants have a possibility of failure, with dire consequences during critical hours of demand.
- Wind and solar power plants are not likely to fail all at once. However, there is risk of no wind and sun during high demand, even with aggregated supply from many wind and solar power plants dispersed over a large region.
- A commonly used metric for system operators when planning for generation adequacy is capacity value, the probability of wind or solar power being available during high-demand situations.
- Capacity value for wind power is smaller than for conventional power plants - in the range of 5 to 40% of wind power plant rated capacity compared to 80-95% for conventional power plants. The wide range reflects the differences in the timing of when the wind blows in periods of high demands. For solar, the capacity value can be very high in systems where peak demand is during sunny hours.
- So far, other generation has been available during high demand periods and low wind / solar generation. However, some other generation may retire as the wind and solar share increases further. In that case, other measures will be required, during these rare periods, to ensure that generation meets demand, e.g. controlling demand, building low-capital-cost and high-operational-cost (peaking) plants, or installing storage.

See Fact Sheet: How much wind and solar contribute to system adequacy?

Do wind and solar power cause extra emissions?

The primary value of wind and solar energy is to offset fuel consumption and the resulting emissions, including carbon.

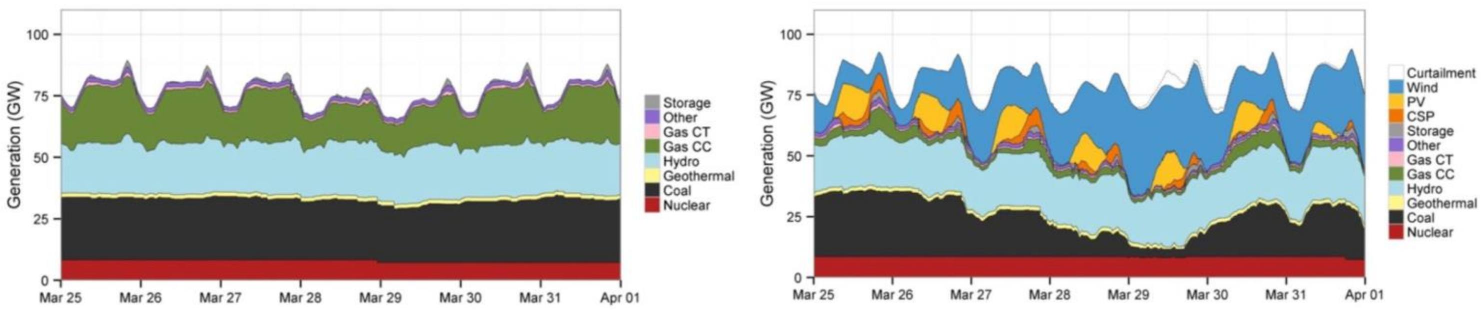

Figure 2. *High wind and solar power generation will alter the contribution of more stable generation of conventional power plants, especially coal (in black) and gas-fired generation (in green), when compared to a case of no wind and solar. The example here is for the US Western Interconnect over one week for no wind or solar (left) and for high wind and solar (right). (Source: WWSIS, NREL)*

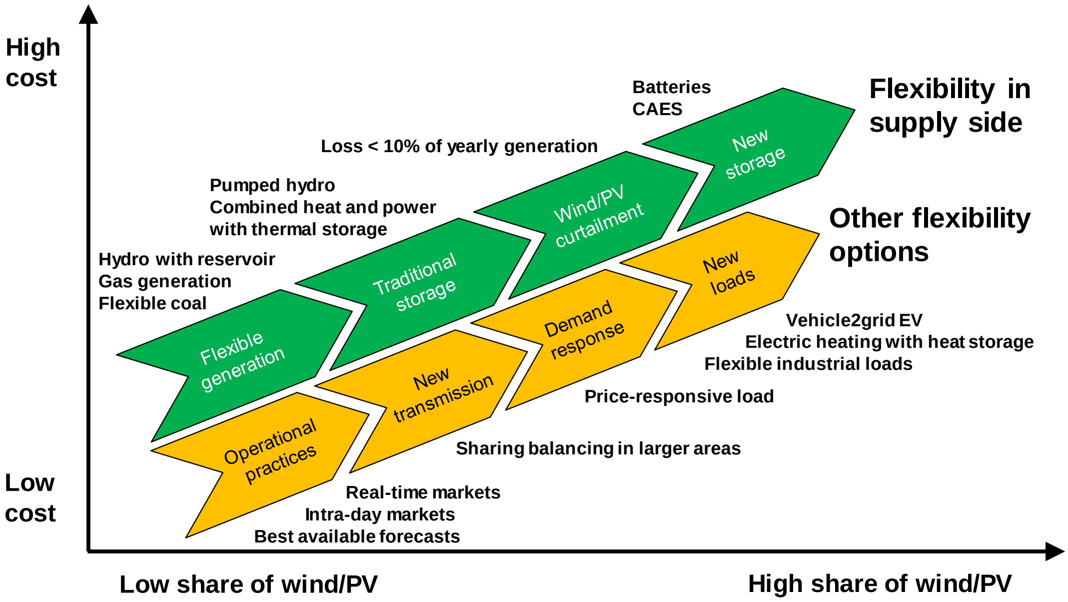

Figure 3. *Methods to increase flexibility in power systems. (The relative order of options is illustrative only).*

- Each megawatt-hour (MWh) generated by wind and solar reduces the required operation of fuel-consuming generation units; the remaining generation need only supply the demand not supplied by wind or solar.
- At high wind and solar shares, fuel-consuming generators will experience more start-ups, shut-downs, and steeper ramps to compensate for variation in wind and solar generation and demand. This may require lower efficiency operating levels. Start-ups, ramping, and lower efficiency operation of fuel-consuming generators increase emissions relative to steady-state operation. Balancing wind and solar power with these units will thus incur some extra emissions.
- Extra emissions, due to balancing wind and solar energy from fuel-consuming generation, is estimated to be less than 2%. The increased emission of some generation units is vastly outweighed by the overall reduction of emissions when wind and solar generation reduces the need to operate fuel-consuming units (Figure 4).

See Fact Sheet: **Emission Impacts of Wind Power**

How much new transmission investment is needed for wind power?

The need for new grid investment for wind depends on the location of the wind plants and the strength and characteristics of the existing grid.

- Any new power plant usually requires a new transmission (or distribution) line to connect it to the existing power grid. Upgrades to existing transmission lines may also be needed to accommodate the added power from the new plant.
- New wind power plants will alter how power flows through the existing transmission grid. The power flow direction may change resulting in increased or decreased losses in transmission and distribution. Wind power may increase or decrease bottleneck situations or congestion.
- Adding large amounts of wind power usually requires some transmission grid investment, however, the upgraded network will benefit the entire power system. Hence, transmission cost is not normally allocated to a single power plant or technology.
- Overall, transmission is only a small fraction of the total energy price for consumers. Numerous studies to allocate transmission system costs to wind energy indicate reasonable costs.

For solar power the increase in grid costs are seen more in distribution system, except for some large solar power plants.

See Fact Sheet: **Transmission Adequacy**

Compound Emitted	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260 – 300 million lbs 29%–34%	Negligible Impact
NO_x	170 – 230 million lbs 16%–22%	3–4 million lbs
SO_2	80 – 140 million lbs 14%–24%	3–4 million lbs

Figure 4. *The increase in fuel consuming plant emissions from cycling to accommodate variable renewables is very low compared to the overall reduction in CO_2, NO_x, and SO_2 due to adding renewables. (Source: WWSIS2, 2013) (1 million lbs = .45 million kg).*

Can wind or solar power cause a blackout of the power system?

The consequences of a blackout are very costly in modern society, so power systems must have a high level of reliability.

- With higher shares of wind and solar power, assessing their impacts on power system dynamics will be important.
- Power systems must stay stable in different power flow situations as well as during and after faults or sudden disconnection of generation or demand.
- Studies in Ireland show that during hours when the wind share is more than 50% of the entire demand, special measures like altering relay protection settings may be needed to maintain reliability. Ireland is a special case, since it is a small system and all events are felt more quickly with fewer large power plants are on-line (small inertia).
- In larger, interconnected power systems it is less probable that wind or solar power would cause a blackout than in small, isolated systems.
- Wind and solar power plants can help support system voltage and frequency during power system disturbances with control capabilities that are important and still evolving.

See Fact Sheet: Impacts of Wind Power on Power System Stability

Can lessons learned in countries using wind and solar power be transferred to power systems in other countries?

The short answer is "somewhat."

- Power systems worldwide are quite different in regard to the mix of generation plants, the inherent variability of system demand, the strength of the transmission grid, and the rules and strategies practiced in daily operations.
- Experience and studies conducted so far conclude that for smaller wind and solar shares, some basic measures are relevant:
    - o For power plant operational decisions, forecasting of wind and solar power output is important to incorporate.
    - o System operators should monitor the online generation of wind and solar plants at control rooms.
    - o Grid connection rules for wind and solar power plants should require sufficient system support.
- For larger shares of wind and solar, grid studies should be conducted to understand relevant technical issues. For most systems, Integrating more than a 20% share of annual demand from wind and solar will require new tools for transmission planning and operational practices.

Is there a limit to how much wind and solar capacity can be accommodated by the grid?

In 2019, six countries (DK, IE, PT, DE, UK, ES) had large (20% to 50%) wind power contributions to total electricity consumption. Ambitious targets for wind and solar are seen in many countries.

- High instantaneous wind and solar contributions to demand are considered technically and economically feasible. Investigations are ongoing in Ireland to enable a 75% contribution to demand from non-synchronous generation like wind and solar. Denmark and Portugal already experience more than 100% share of wind during one hour - and manage this with exports to neighbouring countries.
- Future decarbonisation targets will see new demand coming from electrifying transport, heating and industry. This will also bring new opportunities for energy transition towards renewable energy systems.

See Fact Sheet: Electrification

See also ESIG Guide on Grid Reliability Under High Levels of Renewables https://www.esig.energy/esig-101/

Associated publications

- Holttinen, H. et al. (2019) Design and operation of power systems with large amounts of wind power. Final summary report, IEA WIND Task 25, Phase four 2015–2017. https://community.ieawind.org/task25/ourlibrary
- Greening the Grid Fact sheets available at: https://greeningthegrid.org/Grid-Integration-Toolkit
- Milligan, M., et al. (2009) "Wind power myths debunked." IEEE Power & Energy Magazine, vol. 7, 6, ss. 89–99. DOI: 10.1109/MPE.2009.934268 https://www.researchgate.net/publication/38289316_Preface_Wind_Power_Myths_Debunked
- International Energy Agency (2017) Getting wind and sun onto the grid. IEA, Paris, https://www.iea.org/reports/getting-wind-and-solar-onto-the-grid
- WWSIS Western Wind and Solar Integration Study 1-3 https://www.nrel.gov/grid/wwsis.html

More information

This Fact Sheet draws from the work of IEA Wind Task 25, a research collaboration among 18 countries. The vision in the start of this network was to provide information to facilitate the highest economically feasible wind energy share within electricity power systems worldwide. IEA Wind Task 25 has since broadened its focus to analyze and further develop the methodology to assess the impact of wind and solar power on power and energy systems.

See our website at
https://community.ieawind.org/task25