IMPACTS OF WIND AND SOLAR POWER ON POWER SYSTEM STABILITY

As power systems integrate higher shares of wind and solar, assessing their impact on system dynamics becomes increasingly important. If not properly managed, system dynamics can lead to stability problems and potential costly blackouts. Operational experience demonstrates that wind and solar power plants can help maintain stability, if the latest technology is adopted, suitable planning procedures have been implemented, and appropriate incentives are in place.

How are power system disturbances and blackouts traditionally managed?

System operators must continuously monitor the stability of their system (Figure 1) and maintain its robustness against disturbances. Strategies must be devised to minimise the effect of potential unforeseen events, e.g. sudden power plant failure or disconnection of an overhead line.

During fault conditions the system response needs to be assessed on the timescale of fractions of a second. A number of stability issues need to be considered ahead of time, depending on whether the demand is high or low, which generators are on-line, as well as the network configuration.

How can wind and solar power affect and support power system stability?

Wind and solar power are not a likely cause of system disturbances, but their hardware and control software can complicate situations caused by faults. Disturbances can be mitigated by adapting operational practices, with the support of responses from wind and solar plants. Such responses can be enforced through grid connection rules or incentivised through system services.

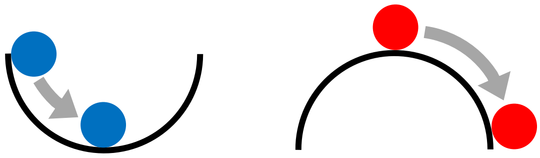

Figure 1. *Stable vs. unstable system.*

The nature of wind and solar grid support, for the main stability issues, is listed:

- *Voltage stability*: Modern wind turbines and solar PV panels can support their local voltage through a suitable control mode that adjusts their reactive power output.
- *Transient (large-disturbance rotor angle) stability*: A network fault, such as a tree branch short circuiting an overhead line, can cause damaging currents. Large, modern wind and solar plants must 'ride through' most such conditions and can enhance stability by adjusting the injected reactive current and supporting their local voltage during and after disturbances.
- *Small-signal (small-disturbance rotor angle) stability*: Generators may oscillate against each other for a period of seconds to minutes after a small disturbance. Wind and solar power plants are unlikely to initiate or contribute to such oscillations, but their presence can alter the number and location of online conventional generators, and, hence, the ability to dampen such oscillations. Wind and solar plants can support oscillation damping through control loops.
- *Frequency stability*: If a generator suddenly trips off, the system frequency falls quickly and must be restored within seconds. This can be challenging for smaller systems, especially when the instantaneous wind and solar share is more than 50% of the system demand and inertia levels are consequently low. Modern wind turbines with large blades store substantial rotational energy, which can be temporarily released for fast frequency response. Wind and solar plants can also provide other frequency support services if curtailed beforehand.

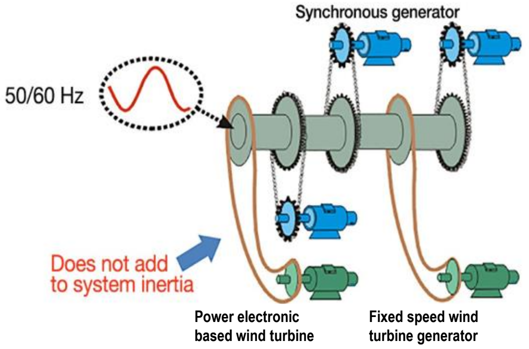

Figure 2. *Synchronous power system operates at close to a constant frequency (50 or 60 Hz). Conventional generators, due to their rotating masses, provide inertial support and tend to keep the frequency constant. Most modern wind turbines, and also solar power plants and battery storage, are connected through power electronics and will not naturally provide an inertial response. (Source: UCD).*

- *Resonance stability*: If connected radially with series compensated lines, wind and solar plants may result in sub-synchronous resonance issues. Proper tuning of control parameters of these plants is needed to mitigate the issues.
- *Converter-driven stability*: Control-driven instability is primarily caused by wind, solar or storage connected in close proximity to each other, especially in weak grid areas. Instability issues can be mitigated through coordinating controls of all involved resources and strengthening the grid.

If the worst does indeed happen and a disturbance results in the blackout of an entire power system, generators with blackstart capability are required to restart the system. Wind and solar plants are beginning to be considered for this role, with a number of demonstration projects ongoing.

What open issues exist for wind and solar power contributing to system stability?

Wind and solar power plants have been demonstrated in simulation studies, practical tests and real-world implementations to improve the stability of a well-designed system. They can provide a fast power response to aid frequency stability, a reactive power response to support the voltage during steady-state and fault conditions, and inject active and/or reactive power to dampen system oscillations, etc.

Such capabilities are increasingly applied. For example, in Quebec (Canada), Texas (USA) and Ireland, wind and solar plants actively participate in the provision of frequency and voltage support services.

As some systems transition towards net zero carbon emissions, operation with renewables only is of increasing interest. Existing wind and solar plants are designed to “follow” the grid, which has traditionally been “formed” by conventional generators. Hence, a 100% renewables system likely requires that some wind and solar plants possess “grid forming” capability. It also necessitates that some generation sources possess blackstart capability. These are areas of active study.

The Irish power system has been studied in detail for current and (potential) future stability issues. Ireland is a small-sized island system where there are fewer large rotating masses to provide inertia to resist changes to the system frequency. Hence, all changes occur more quickly, even without wind power being present (Figure 2). In 2023, Ireland experienced up to 103% contribution from wind generation at certain times, with an annual average wind energy share of ≈34%. A 80% renewables share is targeted for 2030, implying extended time periods with very high wind (and also solar) power shares. To reach these higher shares in the future, additional measures are being undertaken, including new system support services, strengthening of the existing transmission network (including increased HVDC interconnection with neighbouring systems), advanced system operator support tools, and enhanced performance monitoring of all generation plants.

Associated publications

- ESIG Guide on Grid Reliability Under High Levels of Renewables https://www.esig.energy/reports-briefs/
- Hatziargyriou, N. et al. (2021). **Definition and classification of power system stability – revisited & extended**. IEEE Trans. Power Systems, 36(4), 3271-3281. https://doi.org/10.1109/TPWRS.2020.3041774
- Holttinen, H. et al. (2021). **Design and operation of energy systems with large amounts of variable generation**. Final summary report, IEA WIND TCP Task 25. https://doi.org/10.32040/2242-122X.2021.T396
- O’Malley, M. et al. (2024). **Grand challenges of wind energy science – meeting the needs and services of the power system**. Wind Energ. Sci., 9(11), 2087-2112. https://doi.org/10.5194/wes-9-2087-2024
- Hodge, B.M., et al. (2020). **Addressing technical challenges in 100% variable inverter-based renewable energy power systems**. Wiley Interdisciplinary Reviews: Energy & Environment, 9(5), e376. https://doi.org/10.1002/wene.376

More information

This Fact Sheet draws from the work of IEA Wind TCP Task 25, a research collaboration among 17 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 TCP 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://iea-wind.org/task25/

See also other fact sheets

Impact of Wind and Solar on Transmission Upgrade Needs
Balancing Power Systems with Large Shares of Wind and Solar Energy
Wind and Solar Integration Issues