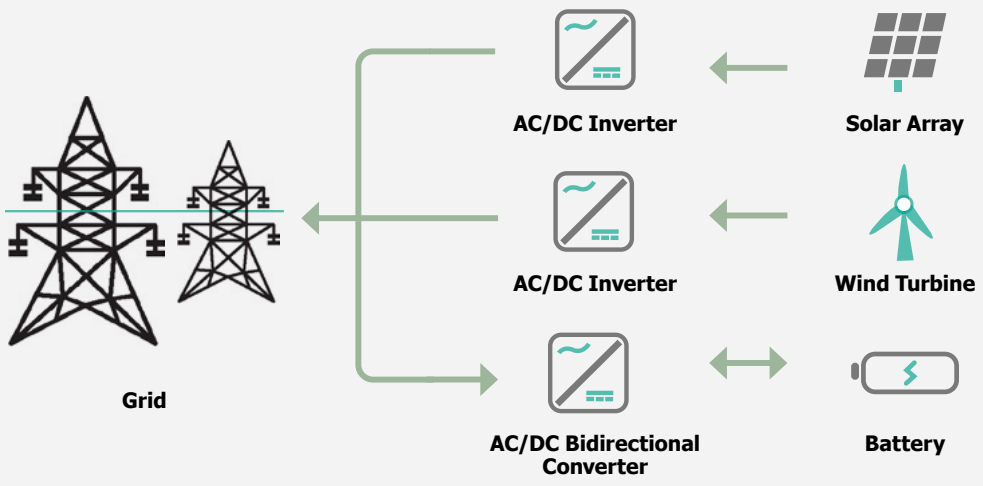
AN INTRODUCTION TO INVERTER-BASED RESOURCES ON THE BULK POWER SYSTEM

June 2023

Inverter-based resources are now found everywhere across the bulk power system (BPS) in North America and are the most significant driver of grid transformation today. This short guide is intended to help educate industry, policymakers, and other stakeholders by providing a basic understanding of inverter technology and inverter-based resources.

What is an inverter?

An inverter is a power electronic device that converts direct current (dc) electricity to alternating current (ac) electricity.



NERC uses the term "inverter-based resource" to refer generally to BPS-connected facilities that have a power electronic interface between the ac grid and the source of electricity.

What types of inverter-based resources exist?

Inverter-based resources include modern wind turbines, meaning type 3 and type 4 wind turbines, solar photovoltaic, and battery energy storage resources, as well as high voltage direct current circuits and flexible alternating current transmission system devices like static synchronous compensators and static volt-ampere reactive compensators.

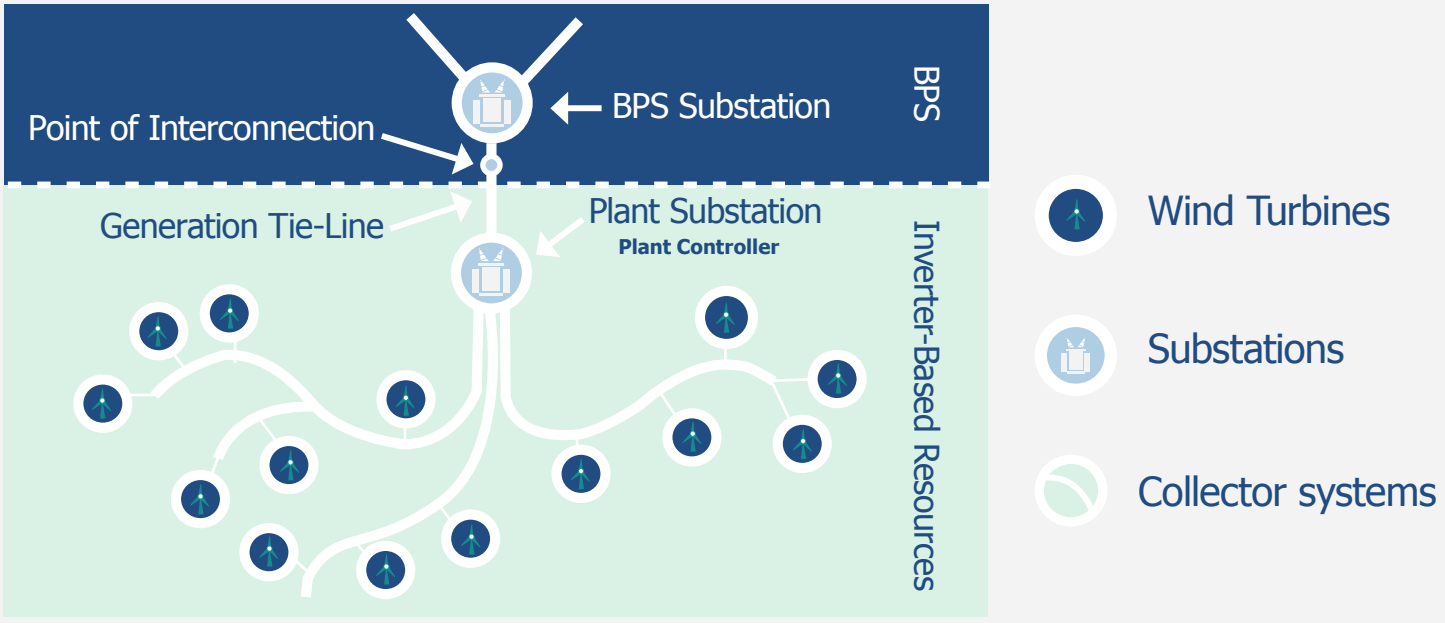
What is the difference between inverter-based resources and distributed energy resources?

Distributed energy resources are generating resources located on the distribution system. Distributed energy resources may or may not use inverter technology to interface with the ac grid; however, they are distinctly different than BPS-connected inverter-based resources (connected to transmission and sub-transmission levels).

What are the key components of inverter-based resources?

Inverter-based resources are dispersed power-producing resources that generally have the following components:

- **Energy source:** The power sources that convert one form of energy into dc electricity (e.g., solar arrays, wind turbines, batteries).
- **Inverter:** The power electronic device that converts the dc electricity into ac electricity, which involves the software controls that dictate how the resource responds to grid events.
- **Step-up transformer:** The device that steps up low voltage ac electricity to a medium voltage level.
- **Collector system:** Underground or overhead medium voltage system of feeder circuits that aggregate the power generated by the turbines/inverters to a central location within the facility.
- **Plant substation:** The location where the collector system feeder circuits aggregate and ac electricity is stepped up to a higher voltage level for transmission across the BPS.
- **Plant controller and protection:** An overarching controller and associated plant protection used to help manage individual inverter commands and plant output, and communicate with transmission entities.
- **Tie-line and point of interconnection:** The connecting line or point of demarcation where ownership changes from the Generator Owner to the Transmission Owner.

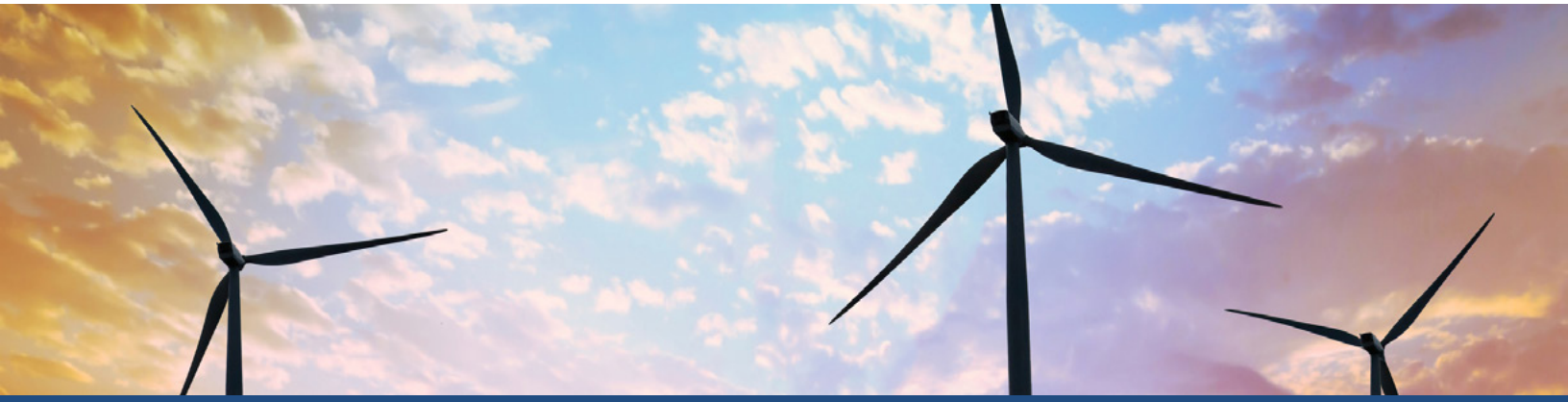


What are the differences between inverter-based resources and synchronous generation?

Both inverter-based resources and synchronous generation can provide essential reliability services to the BPS. However, the industry is facing challenges integrating significant levels of inverter-based resources because of the unique differences between technologies. BPS planning, design, protection, and operations practices will all need to evolve to ensure reliability and resilience of the BPS under this rapid pace of change.

Differences between Inverter-Based Resources and Synchronous Generation

Inverter-Based Resources	Synchronous Generation
• Driven by power electronics and software	• Driven by physical machine properties
• No (or little) inertia	• Large rotating inertia
• Very low fault current	• High fault current
• Sensitive power electronic switches	• Rugged equipment tolerant to extremes
• Very fast and flexible ramping	• Slower ramping
• Very fast frequency control	• Inherent inertial response
• Minimal plant auxiliary equipment prone to tripping	• Sensitive auxiliary plant equipment
• Dispatchable based on available power	• Fully dispatchable
• Can provide essential reliability services	• Can provide essential reliability services

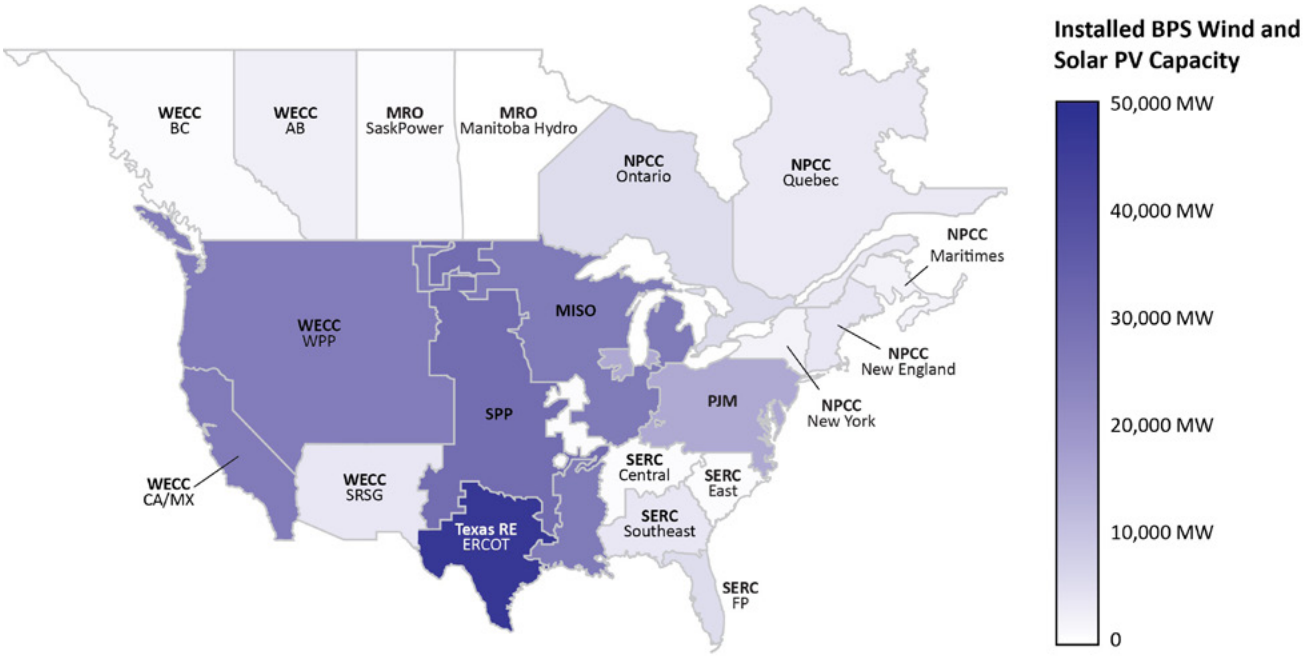


How does NERC ensure reliability under rapid grid transformation?

Consistent energy production levels from inverter-based resources (mainly renewable, variable energy resources) are still relatively low; however, even today, *instantaneous penetrations** of inverter-based resources are reaching very high levels (70+%) across multiple areas in North America.

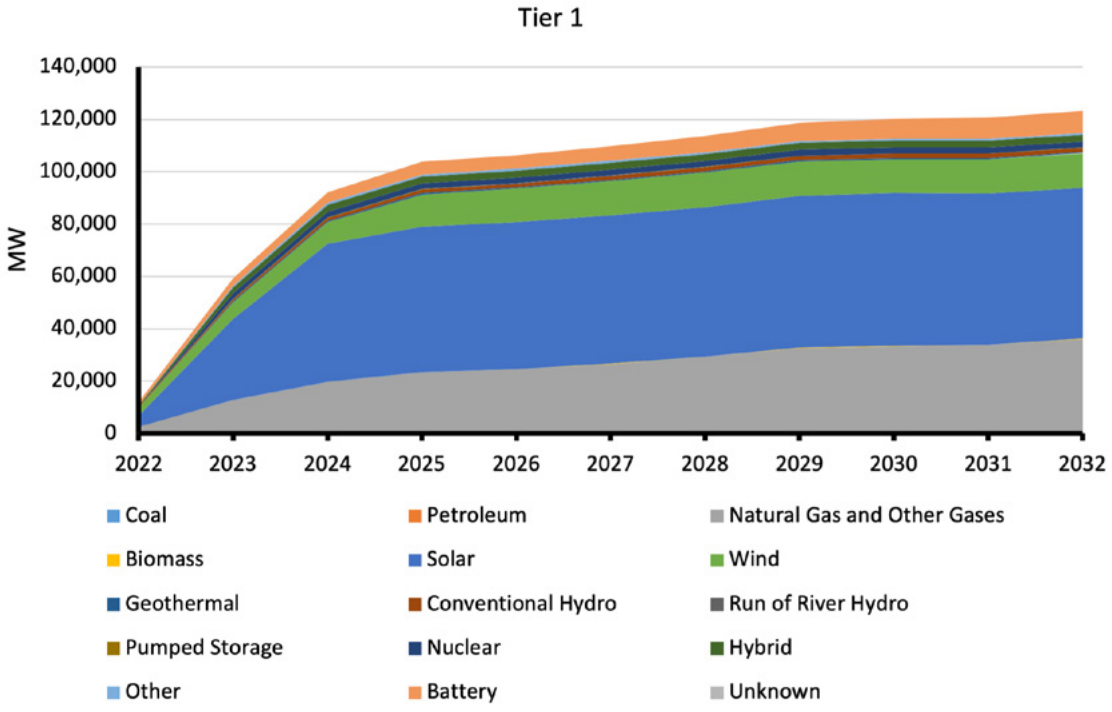
Penetration levels are growing rapidly, with most newly interconnecting generation being inverter-based. This increased penetration is coupled with significant levels of synchronous generation retirements. Maintaining grid reliability under the energy transition is of paramount importance moving forward.

**Instantaneous penetration refers to the amount of power generated by these resources at any given time. Energy production is typically measured over a longer time period (e.g., a year).*



How does NERC ensure reliability under rapid grid transformation? [continued]

NERC continues to analyze large-scale grid disturbances involving common mode failures in inverter-based resources that, if not addressed, could lead to catastrophic events in the future. It is crucial that industry recognize that the aggregate impact of these resources must be considered when developing policies, regulations, and requirements. The historical approach of examining individual generators' impact on the BPS is increasingly obsolete under this rapid grid transformation toward inverter-based resources.



Where can I learn more about NERC's inverter-based resource activities?

To learn more about the work being done surrounding these technological advancements, please refer to the Inverter-Based Resource Quick Reference Guide. NERC is committed to identifying and working toward solutions to better manage the complex reliability problems facing industry during this time of unprecedented resource change.

INVERTER-BASED RESOURCE QUICK REFERENCE GUIDE