SOURCES OF GRID RELIABILITY SERVICES

	Inverter-Based			Synchronous				Demand Response
	Wind	Solar PV	Storage/ Battery	Hydro	Natural Gas	Coal	Nuclear	Demand Response
Disturbance ride-through	●	◔	◔	●	◑	◑	◑	◑
Reactive and Voltage Support	●	●	●	●	●	●	●	◔
Slow and arrest frequency decline (arresting period)	◔	◔	◔	◔	◑	◑	◔	◑
Stabilize frequency (rebound period)	◔	◔	◔	◔	●	◔	◔	◑
Restore frequency (recovery period)	◑	◑	◑	●	●	◔	○	◑
Frequency Regulation (AGC)	◔	◔	●	●	●	◔	○	●
Dispatchability/Flexibility	◑	◑	●	●	◔	◔	○	◑

These services also contribute to frequency restoration, but are also considered essential reliability services on their own.

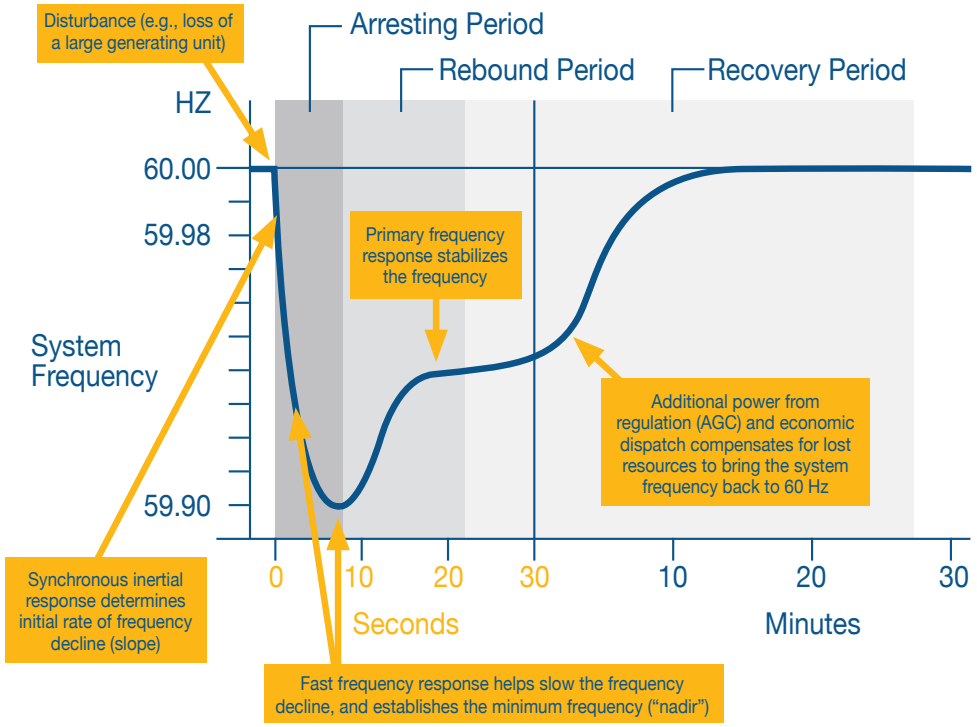
● Excellent ◔ Very Good ◑ Good ◔ Limited ○ Incapable

The electrical power system is in the midst of a digital revolution. Modern inverter-based generation and storage are electronically coupled to the power system, and using their digital controls, they can provide a wide range of grid services. This table provides a conceptual comparison of the ability of key resources to provide essential reliability services to the grid, and is derived from recent and ongoing efforts by the North American Electric Reliability Corporation (NERC), which sets the reliability rules for the power system.

Essential reliability services are required to ensure that the power system can be operated successfully—reliably and economically. These services can be divided into those that are needed for "routine" system operation, and those that are needed primarily during, or immediately after, grid disturbances. These disturbances may include outages of large generators or transmission lines.

DURING ROUTINE OPERATION: **Voltage** must not exceed prescribed limits, and can be controlled by injecting **reactive power,** if needed. Demand and supply must be balanced at all times, and therefore the **frequency regulation** service is used to ensure this balance. Computers monitor the grid frequency/balance and send signals to regulating resources to increase or decrease their output, nominally every four seconds; the process is often called automatic generation control (AGC). This frequency regulation service compensates for the constant, small variations in demand and supply. To ensure economic operation, an economic dispatch function is typically carried out every 5 minutes, which instructs resources to increase or decrease output for at least 5-minute intervals. This service is provided by resources that have sufficient **flexibility** to be **dispatched** in this manner. This service ensures that system balance is maintained and helps manage longer trends of increasing or decreasing demand.

DURING, AND RECOVERING FROM, GRID DISTURBANCES:



Although the services described above are still used during or immediately after a grid disturbance, additional services are needed to support reliability during a disturbance. Immediately after a major grid disturbance, such as the unexpected loss of a large generating unit or transmission line, frequency drops from its nominal value of 60 Hz. The combination of system inertia, primary frequency response (PFR), and fast frequency response (FFR), provided by the combination of resources that are online, acts to slow and then stop the frequency decline. If necessary, under-frequency load shedding (UFLS) responds to further frequency declines, which protects sensitive equipment. Following this **arresting period**, PFR, acting via governor response, with similar action provided by FFR and power electronics, stabilizes the frequency during the **rebound period.** During the next several minutes, and even up to about an hour, the **recovery period** occurs during which a combination of frequency regulation and economic dispatch brings the nominal frequency back to 60 Hz. In the future, additional FFR and PFR may be needed from new inverter-based resources to ensure grid stability.

During a grid disturbance, some resources may trip offline, unable to ride through either voltage excursions or frequency excursions. To help maintain grid stability, some resources can provide **disturbance ride-through,** continuing to operate during either voltage disturbances, frequency disturbances, or both.

Note: Fact sheet derived from Milligan, M. (2018). Sources of grid reliability services. *The Electricity Journal, 31*(9), pp. 1-7. doi: 10.1016/j.tej.2018.10.002

MILLIGAN GRID SOLUTIONS

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