EXECUTIVE SUMMARY

Inertia, Grid Stability, and Bulk Energy Storage: Impacts of Low Inertia, Synchronous Energy Storage Stability Service Capabilities, and Other Potential Solutions

PRIMARY AUDIENCE

System operators, system planners, protection engineers, and other electric utility personnel

SECONDARY AUDIENCE

Researchers, technology developers, policymakers, and other stakeholders concerned about the impact of high renewable penetration on system stability

KEY RESEARCH QUESTION

Synchronous generation is increasingly being replaced by non-synchronous inverter-based resources (IBRs). IBRs do not provide the instantaneous synchronous inertial response (SIR) that has historically been relied upon to slow the rate of change of frequency (RoCoF) after a disturbance. What impact does the decline in SIR have on system stability and what solutions are available to mitigate these effects?

RESEARCH OVERVIEW

A review was conducted of the impacts of reduced synchronous inertia on power system stability and case studies of recent grid events related to declining inertia were examined. This included an investigation of technical solutions for low-inertia systems, including system-wide inertia requirements and RoCoF limits, low-carbon sources of SIR such as synchronous energy storage (ES) and synchronous condensers (SynCons), and fast frequency response (FFR) or grid-forming (GFM) controls provided by IBRs. Economic solutions, including inertia markets, tariffs, and contracts, were also considered. The research findings are summarized and presented in this report.

KEY FINDINGS

- The initial RoCoF after a disturbance depends upon the level of synchronous inertia, the size of the contingency, and the action of other frequency response. As renewable resources replace synchronous generation, RoCoF tends to increase, and other frequency response measures may be required to prevent customer outages due to activation of under frequency load shedding (UFLS).
- Declining synchronous inertia and high RoCoFs are currently a concern for islanded systems such as Hawaii, Texas, Great Britain, Ireland, and Australia. Many systems like these have established minimum inertia requirements to maintain RoCoF within required limits. Great Britain, Ireland, and Australia are also implementing economic solutions to incentivize procurement of SIR and other stability services through tariffs, markets, and long-term contracts. The solutions that have been tested in islanded systems can serve as a guide for other grids as they begin to encounter similar issues at higher levels of IBR penetration.

- There are low-carbon technologies that provide instantaneous SIR to increase frequency stability, as well as reactive power and short-circuit current to improve voltage stability. These include SynCons and thermal and mechanical ES systems that use synchronous motors and generators in the charge and discharge cycles. In contrast to SynCons that do not offer additional benefit beyond delivery of stability services, synchronous ES systems provide storage to support grids with increasing levels of variable renewable generation.
- Flywheels can be added to both synchronous ES and SynCons to increase inertia. ES systems may also use clutches to enable operation of the generator as a SynCon during standby mode. Data provided to EPRI by ES technology developers indicates the level of inertia delivered by ES systems and SynCons is comparable, with typical inertia constants ranging from approximately 2 to 16 seconds.
- IBRs can also provide stability services. Conventional inverters may improve frequency stability through provision of FFR; however, this response is delayed (typically between 50 to over 500 ms) because the change in frequency must be detected before activation. GFM inverters have shown promise in providing frequency response within the same timeframe as SIR (i.e., response may begin within 5 ms of the disturbance). GFM controls are an area of ongoing research and are not yet widely used in the grid. Optimum placement and overall impact of these IBR technologies should be evaluated through detailed system studies.
- Synchronous ES and SynCons provide high levels of short-circuit current, which helps maintain voltage stability during a fault. IBRs can also provide short-circuit level (SCL) but the current is limited by the ratings of the inverter hardware. Therefore, as IBR penetration increases, total system SCL tends to decrease. This can present challenges for existing grid protection systems that use high SCLs to detect faults and reevaluation of protection settings may be required to prevent increased fault clearing times or operation failures.

WHY THIS MATTERS

As the electric power industry rapidly decarbonizes, the grid will increasingly be required to operate with reduced levels of synchronous inertia. This report reviews available solutions for maintaining reliable and stable grid operation in low inertia conditions.

HOW TO APPLY RESULTS

System operators, planners, and protection engineers can learn from the experiences of the islanded systems discussed in this report. The technical and economic solutions presented in this document may be used to address the challenges associated with the transition to grid operation at high levels of IBR penetration.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI Report, *Inertia, Grid Stability, and Bulk Energy Storage: Impacts of Low Inertia, Synchronous Energy Storage Stability Service Capabilities, and Other Potential Solutions* (3002028011).
- For more information about inertia, see the *Declining Inertia in the Grid: Importance, Impacts, and Solutions* webcast available on the P221, P173, P94, P40, and P39 event websites, as well as the accompanying slides (3002028344).
- A technical report (3002014970), white paper (3002015131), and slide deck (3002015132) discussing prior research conducted by EPRI's Bulk System Integration of Renewables and Distributed Energy Resources program (P173) is also available.
- The impact of increasing IBR penetration on system stability is a topic of ongoing research at EPRI. Interested parties may engage with programs such as Bulk System Integration of Renewables and Distributed Energy Resources (P173) and Transmission Planning (P40) regarding detailed stability studies of specific systems.
- More details about the synchronous AC-to-AC ES systems discussed in this report can be obtained from the EPRI Energy Storage Technology Database or by contacting EPRI's Bulk Energy Storage team (P221).

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