Lesson Learned
IBR Control Interactions and Oscillatory Events

Primary Interest Groups
Reliability Coordinators (RC)
Balancing Authorities (BA)
Generator Owners (GO)
Generator Operators (GOP)

Problem Statement
A company commissioned its first installations of hybrid[1] battery energy storage systems (BESS) and photovoltaic (PV) sites, but during the commissioning process, controller integration challenges caused two inverter-based resource (IBR) site batteries to create large interconnection-wide "oscillations." This happened three times across two plants and led to instances of a utility disconnecting IBRs for reliability reasons, requiring controller integration improvement evaluations for future IBR interconnections. The frequency of controller forced oscillations in all three cases was near 0.25 Hz, close to that of the North-South mode A frequency,[2] causing the modemeter[3] to trigger alerts (see **Figure 1**), indicating an NS-A mode critical damping ratio. The critical damping alert occurs when the damping ratio of a mode under forced oscillations drops below zero.

Details
First Event
The battery began in an idle state when the site controller received a +200 MW discharge setpoint from the utility. The site then began to ramp but started oscillating prior to reaching the +200 MW discharge setpoint.

The oscillations lasted 17 minutes with maximum swings from +275 MW discharging to -138 charging. When the utility contacted the site operator, the site controller was placed in local mode by the site operator with a +200 MW discharge setpoint (as requested by the utility). That mode change resulted in the oscillations being arrested.

[1] A hybrid power plant is a generating resource that is comprised of multiple generation or energy storage technologies controlled as a single entity and operated as a single resource behind a single POI. See footnote on page vi of https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_BESS_Hybrid_Performance_Modeling_Studies.pdf.
[2] See NERC Synchronized Measurement Working Group *Recommended Oscillation Analysis for Monitoring and Mitigation Reference Document* page 7, Table 1.1 (https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Oscillation_Analysis_for_Monitoring_And_Mitigation_TRD.pdf)
[3] The modemeter is an operator tool that alarms for the presence of oscillatory behavior at or near predefined frequencies. In this case, the modemeter was set to detect the NS Mode A and NS Mode B. For more on the modes, see NERC's 2019 *Interconnection Oscillation Analysis Reliability Assessment*.

Figure 1: The First of Three Oscillatory Controller Responses

Prior to the BESS+PV site commissioning, metering algorithms were developed for point of interconnection (POI) compensation to calculate for transformer losses for solar production when solar energy was passing through the transformer even when solar energy was used for charging the BESS. This algorithm was approved by the operator and the utility and was tested by the operator with passing results. The initial commissioning tests did not uncover an issue with invalid data related to a divide-by-zero condition. The oscillations were the result of implausible MW compensation values calculated by the site metering algorithms. An evaluation indicated that the compensation algorithm encountered invalid data referred to as NaN (not a number, or invalid number, resulting typically from dividing by zero). The use of this data created an error that increased the compensated MW values beyond the actual MW capacity of the site.

Second Event (Six Weeks Later)

The second event (see **Figure 2**) began with an initial state of the battery dispatched from a 0 MW setpoint to 80 MW charge at ~11:53 Eastern. The battery ramped to -80 MW (charging) and then began oscillating, with maximum indicated "output" of ~-8 MW and minimum of -160 MW. The adjacent PV site was under commissioning and was injecting power to the grid during the event. The site controllers had a control system update pushed the day prior to the event. To perform this update, the programmable logic controller (PLC) was restarted, and all inverters were taken off-line and restarted, which was NOT standard practice for a controller update. Typically, the inverters would remain on-line during the update in standby mode. After restarting, some of the inverters came back on a mode where they were not on-line unless a MW dispatch signal was being received. This resulted in a delay in the response of the inverters at the site. The oscillatory behavior was not consistent between the three-site generator step-up transformers (GSU) as GSUs 1 and 2 showed similar behavior and GSU 3 had more aggressive output swings indicating that the problem was not sourced with the site controller but with the translation of the controller commands to the three GSUs.

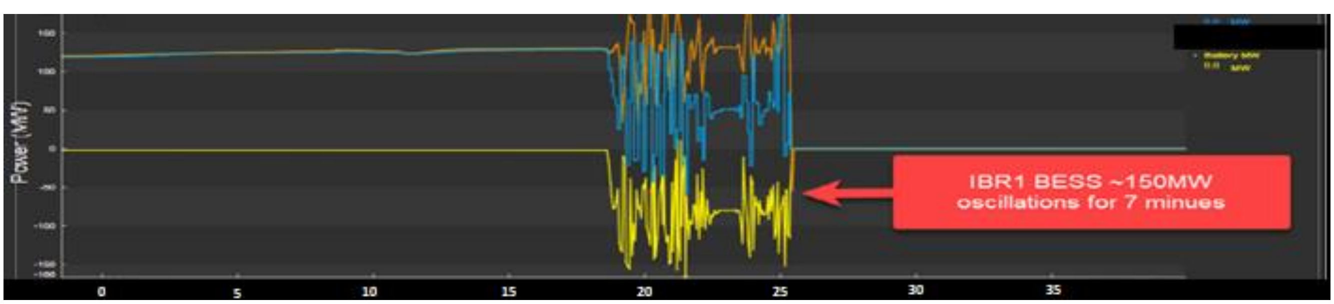

Figure 2: The Second of Three Events

Third Event (Two Days After the Second)

The third event (see **Figure 3**) began with an initial state of the battery dispatched from a 0 MW setpoint to 37 MW discharge at ~17:25 EST. Site output immediately began oscillating, with maximum output of ~85 MW and minimum output of -40 MW. The adjacent PV site was under commissioning and injecting ~50 MW at the time of event initiation.

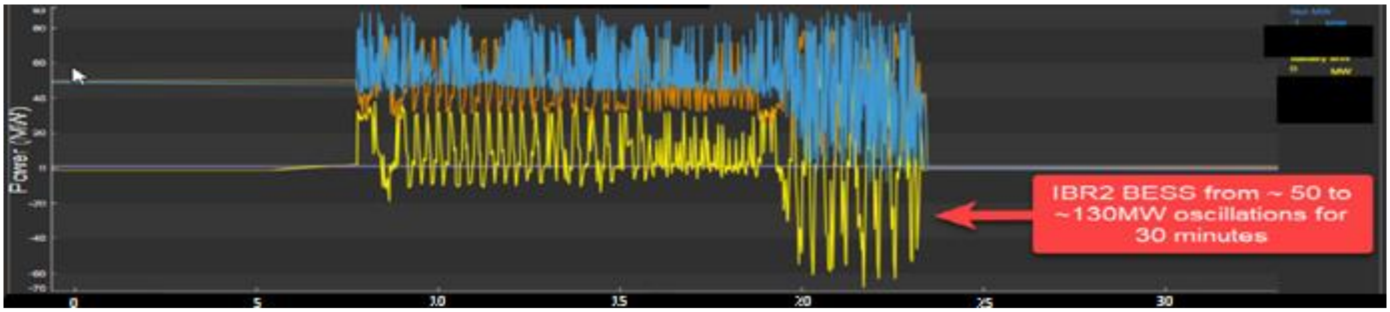

Figure 3: The Third of Three Events

The battery MW output value that is fed back to the proportional integral derivative (PID) control loop (see **Figure 4**) is dependent on the site charging or discharging status. For battery discharging, the logic must include solar power contributions to prevent interconnection limit violations. At the time of the event, an incorrect forced 0 MW solar output was fed into the metering scheme that resulted in the controller interpreting the measured solar power output as BESS output. When the BESS + solar meter source was selected, the controller incorrectly determined that the site was exceeding interconnection limits. But when the battery was commanded to discharge, the controller included the 50 MW of solar power as battery output, which went over the commanded 37 MW output. This caused the controller to reduce output, switching to the battery-only meter once the output dropped below zero. Once the battery output dropped below zero, the controller saw the output as too low based on the commanded 37 MW and swung back to the BESS + solar meter, thus triggering the oscillation.

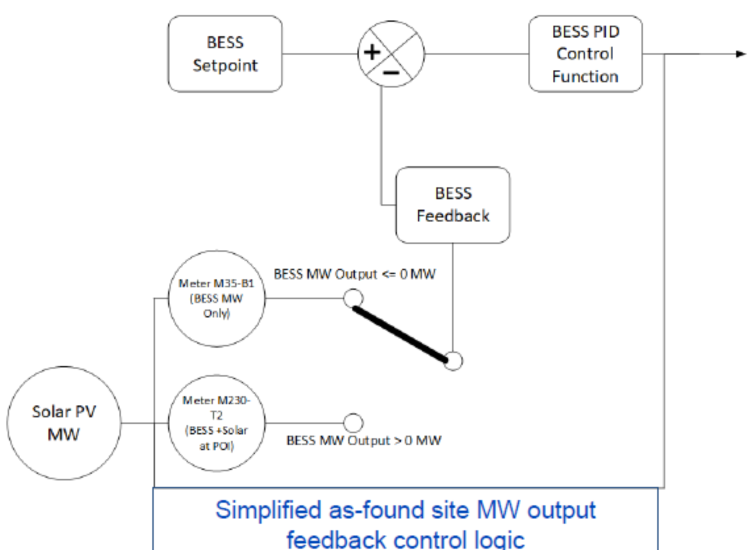

Figure 4: As-Found PID Controls Scheme

Corrective Actions

First Event

Four days after the event, the loss compensation logic was disabled in the meters for the solar charging BESS conditions and new loss compensation logic was written to eliminate the divide-by-zero scenario; this logic has been approved by the utility and implemented on the site controller.

Second Event

The GSU MVA protection logic was updated to prevent the MVA remaining value from going negative as well as the mismatch in GSU command interpretation logic across all three GSUs made consistent across GSUs. The secondary cause of the extended/unbalanced startup of inverters was repaired by ensuring that all inverters start up with a 0 MW command (instead of starting up only with non-zero commands) to avoid the potential for inverter restarts regardless of a PLC controller restart.

Third Event

The short-term solution was to force the controller feedback to only one source, the BESS-only meter, until more robust dual-meter logic could be developed. The long-term solution is to reincorporate solar into the BESS site MW feedback function, validate that these same countermeasures are applied at all co-located solar/BESS facilities under construction, and update integrator functional design specifications.

Mitigation for All Three Events

The developer assigned dedicated site operators 24/7 for monitoring and control of all the utility facilities, improved developer control center oscillation detection, and requested investigation into possible local site controller oscillation detection.

Lesson Learned

Utility Operations Improvements

Immediately following the first event, the utility sent oscillation mitigation directives to its operators to open the utility’s POI breakers within three minutes upon no response or an inability of the IBR operator to arrest oscillations. In the near term, the utility is developing an official operating procedure for its operators. In the long term, the utility is developing an internal operations engineering process and team to utilize synchrowave operations for oscillation detection and mantra for off-line oscillation analysis to catalog and notify appropriate groups within the utility of all risk levels of oscillatory behaviors, whether identified as controller-driven or caused by system issues.

Future IBR Operator Improvements

The utility has identified that more rigorous testing of IBR controllers is critical to ensure reliable commissioning and operation of IBR sites, including the following:

- Potential interconnection requirement to perform hardware in the loop (HIL) testing and either provide a report on the results (what gaps in the controller logic were found and how were they fixed) or provide an opportunity for the utility to witness the HIL testing.
- Establish requirements for commissioning test procedures and test reporting.
- Control logic should be updated to not use NaN as a number and take appropriate action whenever data is unavailable.

- The entity developed a unit manager role, where that individual became the main point of contact for a specific site. Any changes at that site are communicated with this individual.
- Requests have been communicated to IBR operators to develop apparent oscillation monitoring at their control center or directly on individual power plant controllers.
- Improvements to IBR controllers or other site changes that, whether considered to affect operation of the plant or not, need to be communicated to the BA for situational awareness.

See also NERC Lesson Learned LL20210501 Interconnection Oscillation Disturbances.

NERC's lessons learned seek to provide industry with technical and understandable information that helps them maintain the reliability of the bulk power system. NERC asks entities that have acted on this lesson learned to respond to the short survey provided in the link below.

Click here for: Lesson Learned Survey

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