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Evaluation of NERC Requirements for Inverter-Based Resources (IBRs)

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SUMMARY

The Elkhorn battery energy storage system (BESS) plant is a 182.5 MW, 730 MWh system owned and operated by Pacific Gas and Electric (PG&E) that achieved commercial operation in April 2022. The BESS plant is on the decommissioned Moss Landing power plant site near Monterey, California. This paper will discuss the design and compliance evaluation of the BESS at the point of interconnection (POI). It will also discuss the various North American Electric Reliability Corporation (NERC) compliance standards and requirements against which the Elkhorn BESS plant was evaluated, including the evaluation's outcome.

With the proliferation of solar resources in California, BESS plants like Elkhorn have become increasingly important dispatchable resources for the California Independent System Operator (CAISO) to manage daily system ramps and provide other grid ancillary services. First, this paper provides an overview of the POI location within the CAISO system and describes the topology of the plant's main circuit. Second, the paper summarizes interconnection studies performed for different operating modes. These studies ensure compliance with NERC MOD 32 and other NERC modeling requirements. Third, the design of the plant's voltage and frequency protection trip settings is discussed in this paper to ensure compliance with NERC PRC-024 and PRC-019 requirements, including design adjustments made based on field contingency events. Finally, the plant's voltage ride-through performance compliance is verified based on evaluation with CAISO Appendix H requirements.

In addition, during project implementation, NERC published two documents in response to bulk power reliability incidents from the Electric Reliability Council of Texas (ERCOT) and CAISO (which pre-dated the Elkhorn BESS). These incidents related to unexpected voltage ride-through and reactive/active power response performance of inverter-based resources (IBRs), including BESS and photovoltaic (PV) plants. The paper discusses the design and study process to validate plant performance following the findings of these NERC publications, including specific design study aspects related to plant voltage and frequency ride-through capability and active and reactive power (P-Q) operating capability.

KEYWORDS

BESS, NERC Compliance, IBR, Protection

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I. Elkhorn Plant in the CAISO System

The Elkhorn battery energy storage system (BESS) project is part of California public policy initiatives designed to support overall system reliability and increase renewable generation. The plant is interconnected at 115 kV and is dispatched by the California Independent System Operator (CAISO). As a CAISO resource interconnected to the bulk power system (BPS), the plant is subject to CAISO and North American Electric Reliability Corporation (NERC) standards for reliability performance.

The BESS location is part of the former Moss Landing generation complex. This site previously operated with more than 2,500 MW of thermal generation and is a major transmission node in the Pacific Gas and Electric (PG&E) system. The Moss Landing site has been redeveloped with the Elkhorn BESS, other BESS facilities, and thermal generation. The Elkhorn BESS point of interconnection (POI) is interconnected to an adjacent 230 kV substation, and the 230 kV substation is connected to PG&E's 500 kV system.

PG&E achieved commercial operation of the Elkhorn BESS in April 2022. During the early stages of project implementation in 2019, NERC released two documents [1], [2] in response to bulk power reliability incidents from the Electric Reliability Council of Texas (ERCOT) and CAISO. These incidents related to unexpected voltage ride-through and reactive/active power response performance of inverter-based resources (IBRs), including BESS and photovoltaic (PV) plants. In addition to providing an overview of the overall plant design, related system studies, and compliance evaluation with the relevant NERC standards, this paper discusses the study process to validate plant performance and subsequent design revisions in response to these NERC publications.

The overall organization of the paper is described as follows. Section II discusses the main Elkhorn BESS plant description, including the BESS inverter configuration, its controls, and the balance of plant equipment. Section III discusses the plant's compliance with NERC MOD 32 and BESS modeling requirements of March 2021. Section IV discusses the plant's ride-through performance and compliance with NERC and CAISO requirements. Section V discusses the plant's active-reactive power (P-Q) operation and interconnection requirements. Section VI concludes the paper.

II. Main Circuit Description

At the inverter level, the Elkhorn BESS plant comprises 256 individual BESS units, each rated at approximately 900 kVA with a nominal terminal voltage of 505 V. From the POI, the Elkhorn BESS plant is arranged as three main branches, each with a 115 kV/21.6 kV, 75 MVA generator step-up (GSU) transformer, which interfaces with a 21.6 kV collector system. The GSU transformer configuration enables partial plant availability if one of the GSU transformers is out of service. Figure 1 shows the Elkhorn BESS plant's simplified single-line diagram.

The MV collector system comprises underground cables tied to pad-mounted distribution transformers, rated 21.6 kV/0.505 kV, 3.696 MVA each. Up to four individual BESS units are interconnected with a single pad-mounted transformer that couples the inverter-group output to the 21.6 kV collector system.

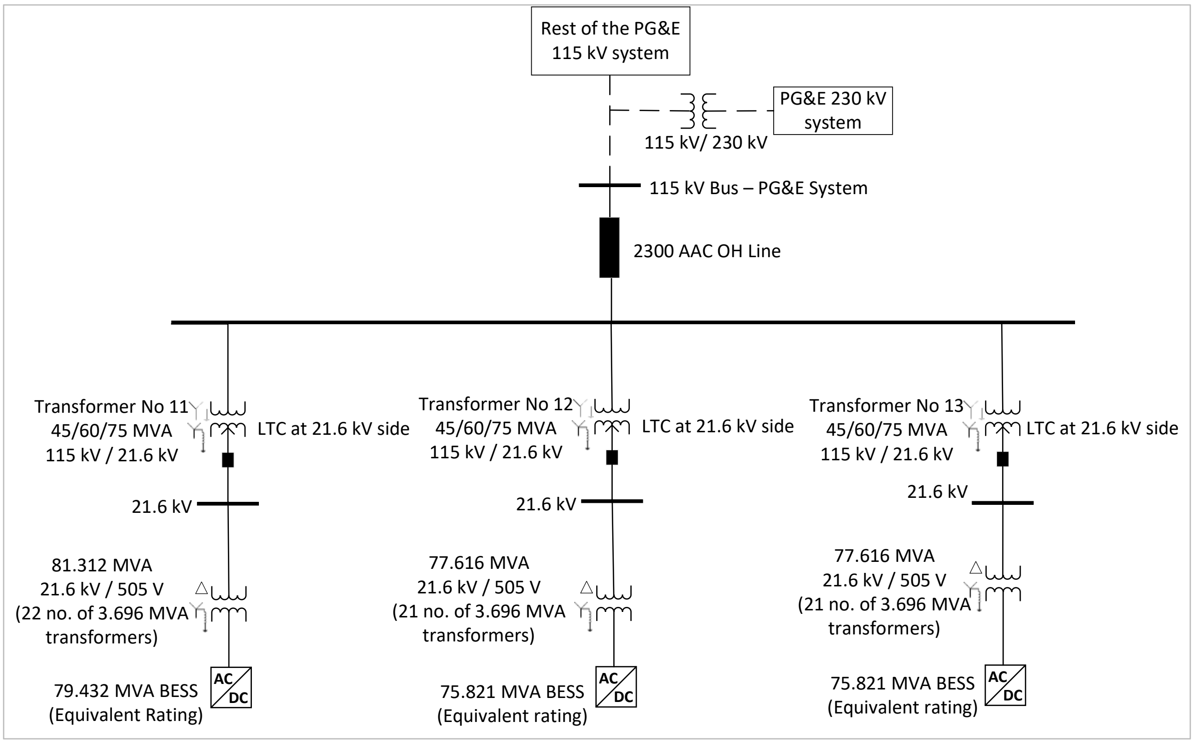

Figure 1. Simplified System Single-Line Diagram

A site controller controls the power output of the Elkhorn BESS plant at the POI. This site controller responds to CAISO-given orders and acts to optimize inverter output based on battery state of charge (SOC), inverter availability, and inverter capabilities. Each inverter pack is a containerized assembly of batteries, inverters, cooling equipment, and local control and protection. BESS control and protection includes battery monitoring systems (BMS), DC bus voltage supervision, under-voltage, over-voltage, under-frequency, and over-frequency.

The 182.5 MW Elkhorn BESS plant is interconnected to a 115 kV PG&E substation and is equipped with 256 BESS units consisting of three blocks. Table 1 shows the units in each block interconnected to the BPS via GSU transformers.

Table 1. Plant Information

Block	BESS Units	Capacity (MW)	GSU Transformer
1	88	79.432	TX-11
2	84	75.821	TX-12
3	84	75.821	TX-13

For NERC compliance, protection coordination studies include protection settings calculation beginning at the POI and continuing through the GSU transformers, collector system, and BESS protection functions. The Elkhorn BESS plant's interconnection agreement with CAISO as a large generating facility includes compliance with FERC Order 827. To comply with FERC Order 827, the Elkhorn plant is designed to achieve a ±0.95 power factor range for all output levels (charge or discharge) above 0 MW.

III. Plant Compliance Analysis for NERC MOD 32 and NERC BESS Modeling Requirements

A. *Compliance Analysis for NERC MOD 32*

This section verifies the plant's compliance with NERC MOD 32 [1] requirements, which deal with compiling and verifying power system modeling data. The power plant controller or site controller of this plant operates in the following control modes:

- Active power control
- Voltage control
- Active power-frequency (P-f) droop control

For the studies and analysis, the plant was modeled in General Electric's (GE) Positive Sequence Load Flow (PSLF) software tool [3] using the generic inverter/controller model based on the facility data and the Power Systems Computer-Aided Design (PSCAD) [4] inverter model provided by the BESS vendor. The remaining system model was developed in PSCAD. PSLF studies aimed to address dynamic system stability, while PSCAD studies helped with time-domain system analysis, including ride-through and temporary overvoltage cases.

The following case studies were performed using PSLF and PSCAD models when the plant is producing full real power (i.e., 182.5 MW) to validate and compare model performance:

- Flat run (V = 1.0 pu, P = +182.5 MW, and PF = 0.95 lagging)
- Voltage step testing (Vstep change from 1.044 pu to 1.02 pu, P = +182.5 MW, and PF = unity)
- High voltage ride-through (HVRT), where the voltage was changed based on the HVRT portion of the NERC PRC-024 [5] ride-through curve
- Low voltage ride-through (LVRT), where the voltage was changed based on the LVRT portion of the NERC PRC-024 ride-through curve
- High-frequency ride-through (HFRT), where the frequency was changed based on the HFRT portion of the NERC PRC-024 ride-through curve
- Low-frequency ride-through (LFRT), where the frequency was changed based on the LFRT portion of the NERC PRC-024 ride-through curve
- Fault (three-phase fault at 115 kV persisting for six power frequency cycles)

The PSLF model of the plant was verified against the vendor's electromagnetic transient model in PSCAD. Therefore, the PSLF model accurately represents the PSCAD model and the plant. In both models, the protection system does not trip during contingencies and/or faults that cause voltage and frequency deviation within the no-trip zone of the PRC-024. Figure 2 compares the PSLF and PSCAD models for a voltage step test. Both performances are close, indicating that the models are accurate. Thus, these studies confirm that the plant models were developed according to MOD-32 requirements. The plant's verified modeling data was submitted to the transmission planner. This satisfied compliance with the rest of the MOD-32 requirements.

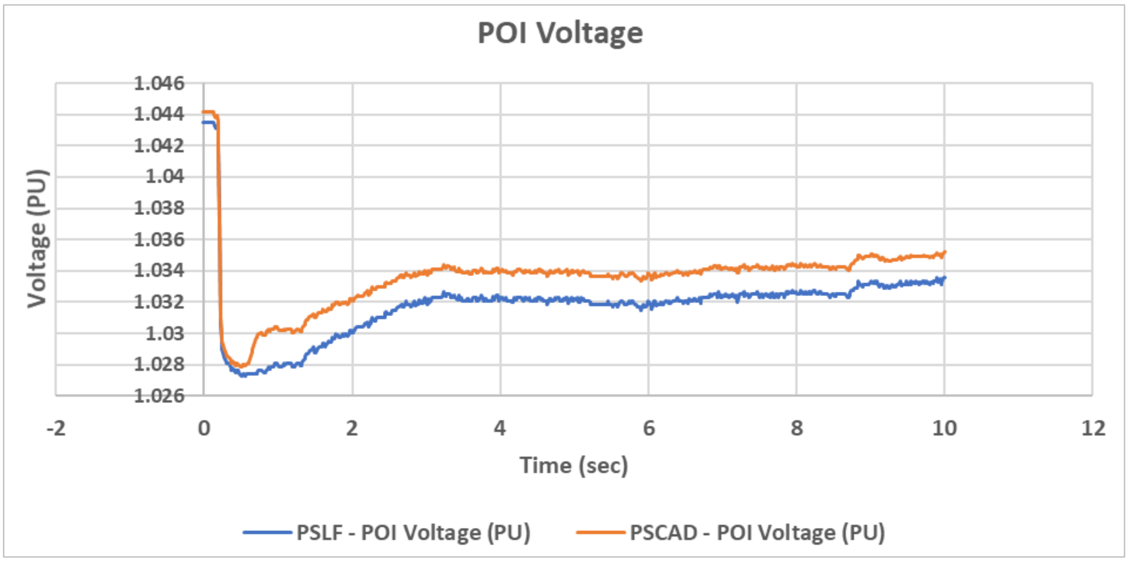

Figure 2. PSLF and PSCAD Model Comparison for a Voltage Step Test

B. Compliance Analysis for NERC BESS 2021 Modeling Requirements

This section describes how the team complied with NERC's "Reliability Guideline: Performance, Modeling, and Simulations of BPS-Connected Battery Energy Storage Systems and Hybrid Power Plants" from March 2021 [1].

These guidelines deal with modeling requirements for BESS and hybrid plants, including their performance under different conditions, such as power flow, dynamic, and short-circuit modeling conditions. These guidelines also identify the interconnection studies that need to be performed for BESS and hybrid plants. NERC has called out these conditions for modeling and studies to ensure that the models have the necessary details and accuracy for use in real-world studies.

The models used for the Elkhorn BESS plant's studies were evaluated against these requirements. The team found that the power flow, dynamic, and short-circuit modeling approach followed complied with this guideline's requirements.

The review of this NERC guideline also revealed that additional studies are needed for this BESS plant, including studies for active power ramp-up and down under different system short-circuit strengths. Based on performing these studies for the Elkhorn BESS plant, it was found that the plant successfully ramped up and ramped down active power at a low short-circuit system strength without any stability or power quality issues, which aligned with the NERC document's guidelines. These studies showed that the plant performed satisfactorily without any performance issues.

IV. BESS Plant Ride-Through Performance and Compliance Evaluation with NERC and CAISO Requirements

NERC PRC-024 deals with voltage and frequency protection requirements of generation resources connected to a bulk electric system (BES). The standard's main requirement ensures that the resource stays connected during defined frequency and voltage excursions while supporting the BES.

The Elkhorn BESS plant's voltage and frequency protection settings were evaluated for compliance with NERC PRC-024 requirements. The plant was designed with two voltage and frequency protection relays, with one relay at the low-voltage (LV) bus of the inverter and the other relay at the 115 kV POI.

The relay at the 115 kV POI provides backup protection, operating slower than the LV relay. Both relays provided under-voltage, over-voltage, and frequency protections.

A. Voltage and Frequency Protection Setting Design

The settings of these relays were designed using appropriate studies and PG&E requirements. For the design of voltage protection settings, voltage drop studies were carried out using the plant's model in PSCAD software for various BESS operating conditions. The worst-case operating condition was found to be when the plant supplied full active power at +0.95 power factor with the dynamic reactive current injection function enabled. The two relays' under-voltage and over-voltage pickup settings were determined by analyzing the voltage drop profile for this worst-case operating condition. The trip time delay determination and coordination were performed based on the minimum trip time requirements of PRC-024 and relevant PG&E requirements.

For the design of frequency protection settings, both relays' under-frequency and over-frequency pickup settings were chosen to be the same as the PRC-024 requirements. The trip time delay determination and coordination were performed based on the minimum trip time requirements of PRC-024 and relevant PG&E requirements.

B. Voltage and Frequency Protection Compliance Evaluation with PRC-024

The designed voltage and frequency protection settings of the plant were evaluated for compliance with PRC-024 using the following simulation studies with PSCAD software:

- High-voltage and low-voltage ride-through studies were performed for voltage protection compliance evaluation by applying high-voltage and low-voltage profiles as per PRC-024 at the 115 kV POI. Upon application of the profiles, neither voltage protection relay tripped in the no-trip zone of PRC-024. Thus, the plant complies with PRC-024's voltage protection requirements. Figure 3 shows the voltage protection graph demonstrating compliance with PRC-024. As shown in this figure, to comply with PRC-024, the inverter has to stay connected for more than 100 seconds if the inverter terminal voltage reaches 1.11 pu. This requirement will be further discussed in the following subsection.

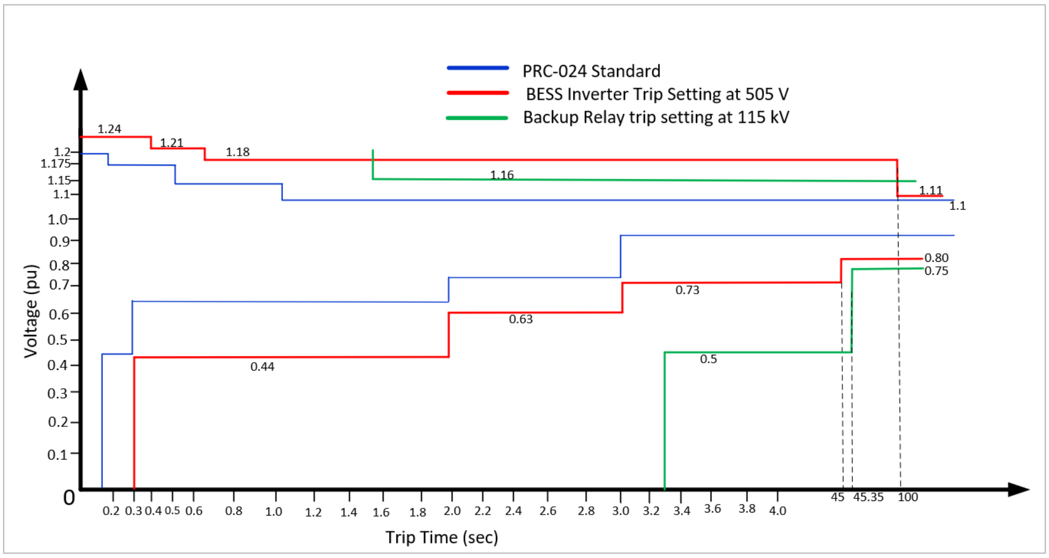

Figure 3. Voltage Protection Compliance Evaluation with PRC-024

- High-frequency and low-frequency ride-through studies were performed for frequency protection compliance evaluation by applying high-frequency and low-frequency profiles per PRC-024 at the 115 kV POI. Upon application of the profiles, neither frequency protection relay of the plant tripped in the no-trip zone of PRC-024. Thus, the plant complies with PRC-024's frequency protection requirements. Figure 4 shows the frequency protection graph demonstrating compliance with PRC-024.

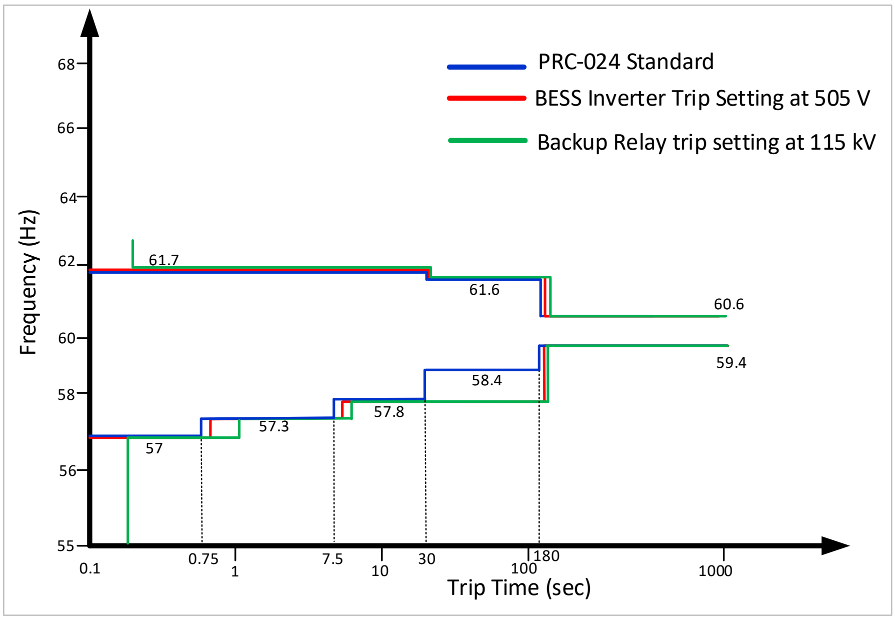

Figure 4. Frequency Protection Compliance Evaluation with PRC-024

C. Trip Setting Adjustments Based on Field Events to Ensure NERC PRC-024 and PRC-019 Compliance

The Elkhorn BESS plant experienced some events in the field during the commissioning phase, which caused a few feeders to trip due to overvoltage at the inverter level. The trip was caused by excessive reactive power injection in the healthy feeders by the site controller due to the loss of a few feeders. This excessive reactive power injection led to overvoltage at the inverter level, which caused the overvoltage trip of inverters in the healthy feeders.

Based on this field event, the overvoltage trip settings of the BESS inverter were adjusted from 1.1 pu to 1.11 pu with a trip time of 100 seconds. This provides sufficient time for the load tap changer of the GSU transformers to regulate the voltage to prevent overvoltage conditions and, thereby, prevent the inverters from tripping. To ensure compliance with PRC-024, the team ensured the updated trip settings do not cause any trip within the no-trip zone of PRC-024. Figure 3 shows this compliance evaluation. The vendor was also informed about this change to ensure this overvoltage is within the inverter's withstand capability.

Compliance with NERC PRC-019 [6] was also carried out to ensure that the adjusted trip settings do not cause equipment capability violations. The main requirements of NERC PRC-019 are to ensure coordination of the generating unit or plant capabilities, voltage regulating controls, and protection. In particular, through coordination with the BESS inverter vendor, it was confirmed that the inverter can withstand overvoltage of more than 1.11 pu for at least 100 seconds.

D. Evaluation of Voltage and Frequency Ride-Through Performance of the Plant with Other NERC and CAISO Requirements

The plant's voltage and frequency ride-through performance were also evaluated for compliance with the following NERC requirements:

- "Reliability Guideline: BPS-Connected Inverter-Based Resource Performance," NERC, September 2018 [7].
- "Appendix H: Interconnection Requirements for an Asynchronous Generating Facility," Part of Large Generator Interconnection Agreement between Pacific Gas & Electric Company and California Independent System Operator Corporation (Service Agreement No. 379 under PG&E FERC Electric Tariff Volume No. 5) [8].

To ensure compliance with the above standards' voltage and frequency ride-through requirements, an evaluation was done against these standards' requirements. The team found that the plant's design complied with most requirements. This compliance evaluation yielded the following outcomes:

- The plant's dynamic voltage support function was designed and evaluated to meet the CAISO Appendix H requirements. The design ensured that the reactive current injection k-factor of the BESS inverter was set as per CAISO Appendix H requirements. Also, the negative sequence injection k-factor was designed to support the system during unbalanced fault conditions.
- The plant-level active power frequency support function was designed to comply with the CAISO interconnection requirements and the main requirements of the above NERC standard of September 2018.

V. P-Q Operation and Interconnection Requirements

NERC issued a Level 2 alert on March 14, 2023 [2]. This alert is specific to solar PV resources. However, the recommendations may apply to the BPS-connected BESS.

Currently, the dynamic reactive power capability of the plant at the POI for regular operations and BPS disturbances is limited to a ±0.95 power factor across the full range of active power capability as per CAISO interconnection requirements. However, per Recommendation 6 of the Level 2 alert issued by NERC, inverter manufacturers and power plant controllers should not limit the dynamic reactive power that the plant at the POI can supply.

The available dynamic reactive power capability should be used during the BPS disturbances. Therefore, a ±0.95 power factor limit on the power plant controller of this plant is proposed to be disabled in the future. The plant performance has been studied using EMTP software (PSCAD) and control hardware-in-loop (CHIL) testing for performance issues. Various studies—such as the loss of one, two, and three GSU transformers—have been performed for the different transmission voltage levels, showing that the power factor limits can be disabled. Additionally, NERC PRC-024 compliance is currently being studied to see if there is any impact of disabling the power factor limits on the transient and temporary overvoltage across the plant that can violate the PRC-024 compliance requirements.

VI. Conclusion

This paper discussed the compliance evaluation of the Elkhorn BESS plant based on NERC requirements. It modified the plant design to ensure up-to-date compliance with recent NERC requirements. The following briefly summarizes the findings of this paper:

- The MOD-32 compliance evaluation revealed that the models used for studying the plant's performance complied with appropriate NERC and CAISO requirements. Further, the electromagnetic transient model of the inverter was used to adjust and validate the dynamic performance of the plant's PSLF model.
- In response to NERC BESS modeling requirements of March 2021, transient studies were performed, which involved active power ramp-up and ramp-down under different system short-circuit strengths. These studies showed that the plant performed satisfactorily without any performance issues.
- The design of the plant's voltage and frequency protection trip settings were evaluated, including the trip settings adjustment based on the field contingency events. This discussion showed that the designed trip settings complied with NERC PRC-024 and PRC-019 requirements. Specifically, adjustments were made to the inverter ride-through settings to ensure compliance.
- Evaluation with CAISO Appendix H requirements ensured the configuration of the plant's dynamic reactive current injection function to have a suitable k-factor. This ensured that the voltage ride-through performance complied with this standard's requirements. The negative sequence injection k-factor was also designed to support the system during unbalanced fault conditions.
- The plant-level active power frequency support function was designed to comply with the CAISO interconnection requirements and the main requirements of the above NERC standard of September 2018.
- Compliance evaluation with the NERC Level 2 alert of March 2023 revealed that the plant's site power factor limits should be disabled, and initial studies performed so far reveal that the limits can be disabled. Additional studies are currently being performed to ensure compliance with all requirements.

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