

Report on the FERC-NERC-Regional Entity Joint Review of Restoration and Recovery Plans

Recommended Study: Blackstart Resources Availability (BRAv)



Prepared by the Staffs of the
Federal Energy Regulatory Commission
and the
North American Electric Reliability
Corporation and its Regional Entities
May 2018



NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

This report was prepared by the staff of the
Federal Energy Regulatory Commission in consultation with staff from the
North American Electric Reliability Corporation and its Regional Entities.
This report does not necessarily reflect the views of the Commission.

Table of Contents

I.	Executive Summary	1
II.	Introduction.....	6
III.	Study Process and Data.....	7
A.	Step 1: Review of Relevant Literature.....	7
B.	Step 2: Identify Candidate Registered Entities.....	7
C.	Step 3: Assess Registered Entities’ Blackstart Resource Availability, Replacement Strategies, and Testing Practices.....	9
D.	Step 4: Develop Recommendations.....	10
IV.	Assessment.....	10
A.	Overview	10
B.	Availability of Blackstart Resources	11
1.	Introduction	11
2.	Observations	12
3.	Conclusion	15
4.	Observed Practices for Consideration	16
C.	Blackstart Resource Procurement and Replacement	16
1.	Introduction	16
2.	Observations	17
a.	Assessment of Need for Replacement Blackstart Resources	17
3.	Conclusion	25
4.	Recommendations	25
5.	Observed Practices for Consideration	26
D.	Blackstart Resource Validation – Simulations and Results.....	27
1.	Introduction	27
2.	Observations	27
3.	Conclusion	35

4.	Recommendation	36
5.	Observed Practices for Consideration	36
E.	Blackstart Resource Validation - Expanded Testing	37
1.	Introduction	37
2.	Observations	37
3.	Conclusion	43
4.	Recommendations	44
5.	Observed Practices for Consideration	45
V.	Appendix 1 - Joint Study Team	46
VI.	Appendix 2 – Request Letter for Participation	47
VII.	Appendix 3 – Summary of Literature Review	50
VIII.	Appendix 4 - Expanded Testing Example	52
IX.	Appendix 5 – Glossary of Terms and Acronyms Used in Report	55

I. Executive Summary

In September 2014, the Federal Energy Regulatory Commission (Commission) initiated a joint staff review, in partnership with the North American Electric Reliability Corporation (NERC) and its eight Regional Entities, to assess registered entities’¹ plans for restoration and recovery of the bulk-power system following a widespread outage or blackout. In January 2016, this joint staff review culminated in the issuance of a joint Report on Restoration and Recovery Plans.² The Restoration and Recovery Report was designed to provide a comprehensive understanding of the electric utility industry’s bulk-power system recovery and restoration planning.

However, the Restoration and Recovery Report identified certain issues that went beyond the scope of the review and recommended further study of those issues. Two of these areas identified for further study dealt with blackstart resources: (1) the availability of blackstart resources,³ including the identification of strategies for replacing these resources going forward and the factors to be considered for such replacement resources;⁴ and (2) options for expanding system restoration plan testing beyond the currently required blackstart resource testing, to ensure that a blackstart resource can energize equipment necessary to restore the system as intended in the restoration plan.⁵ This study of the adequacy and testing of blackstart resources is important because blackstart

¹ A “registered entity” is any user, owner, or operator of the bulk-power system that is generally required to register with NERC.

² Report on the FERC-NERC-Regional Entity Joint Review of Restoration and Recovery Plans (January 2016) (Restoration and Recovery Report), <https://www.ferc.gov/legal/staff-reports/2016/01-29-16-FERC-NERC-Report.pdf>.

³ NERC defines a blackstart resource as a “generating unit(s) and its associated set of equipment which has the ability to be started without support from the System or is designed to remain energized without connection to the remainder of the System, with the ability to energize a bus, meeting the Transmission Operator’s restoration plan needs for Real and Reactive Power capability, frequency and voltage control, and that has been included in the Transmission Operator’s restoration plan.” See NERC Glossary of Terms, https://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf.

⁴ Restoration and Recovery Report at iv.

⁵ *Id.* at v.

resources are critical to maintaining the reliability and resilience of the bulk power system.

In the spring of 2017, the Commission, NERC, and the Regional Entities (joint study team) initiated a joint study based on recommendations in the Restoration and Recovery Report. The joint study focused on the availability of registered entities' blackstart resources, the potential impact of recent changes to registered entities' blackstart resources, and the manner in which any such impact could be mitigated. The joint study also included an assessment of registered entities' blackstart resource testing under anticipated blackstart conditions to ensure that these resources can effectively restore the bulk-power system following a widespread outage.

The joint study team gathered information from a representative sample of nine volunteer registered entities (the participants). The joint study team considered several factors when identifying potential participants for the study, targeting registered entities: (1) with significant bulk-power system responsibilities; (2) that are located in different regions; (3) that have experienced or are experiencing changes to the availability of their blackstart resources; (4) that have performed expanded testing;⁶ and (5) that have gained experience in restoration from extreme conditions or events, e.g., involvement in prior blackout events, hurricanes, or severe winter weather conditions.

Although some participants have experienced a decrease in the availability of blackstart resources due to retirement of blackstart-capable units over the past decade,⁷ the joint study team found that the participants have verified they currently have sufficient blackstart resources in their system restoration plans, as well as comprehensive strategies for mitigating against loss of any additional blackstart resources going forward. The joint study team also found that participants that have performed expanded testing of blackstart capability, including testing energization of the next-start generating unit,⁸ gained valuable knowledge that was used to modify, update and improve their system restoration

⁶ Expanded testing involves testing beyond the currently required blackstart testing (up to energizing a dead bus), including energizing the transmission line and the next-start generating unit, to ensure that the blackstart generating unit can energize equipment needed to restore the system as intended.

⁷ The joint study team focused on changes in blackstart resources over the past decade, as participants indicated that certain environmental and other regulations potentially affecting blackstart resources went into effect at about that time.

⁸ A next-start generating unit is the first generating unit in the cranking path to be energized using power from the blackstart generating unit.

plans. Participants also used the knowledge gained to update and improve their existing steady state and dynamic models of those plans, as well as their system restoration drills.

This report provides details of the joint study team's assessment and makes recommendations for industry-wide consideration regarding practices, procedures and methodologies aimed at improving system restoration overall, and blackstart capability planning and testing in particular. These recommendations include approaches to addressing single fuel use constraints, validation of system models, and expanded testing of system restoration plans. These recommendations are for voluntary consideration, and entities are not subject to mandatory compliance with the recommendations, separate and apart from any obligations of mandatory reliability standards.

The joint study team considers the recommendations in this report appropriate for all registered entities responsible for system restoration unless otherwise noted. Additionally, the joint study team observed numerous beneficial practices employed by individual participants that may not be universally appropriate or possible. The joint study team recommends that registered entities consider incorporating these practices, or variations thereof, as appropriate.

Recommendations

1. **Mitigating risks associated with the reliance on a single fuel.** The joint study team concludes that the reliance on a single fuel blackstart resource without fuel storage capacity or firm fuel arrangements may cause issues during a restoration event. Therefore, the joint study team recommends that single fuel dependent blackstart generator owners develop alternative fuel capability or coordinate with their fuel providers to mitigate this risk. This could include firm contracts with specifications to ensure that fuel supplies to the blackstart generating units are unimpeded during a restoration event. Furthermore, the joint study team recommends that these blackstart resource owners work with their regulators as necessary, to develop alternative solutions to address potential fuel constraints. [Section IV.C.]
2. **Consider further study of the adequacy of compensation for blackstart and other resources supporting system restoration.** The joint study team recommends that Regional Transmission Organizations (RTO),⁹ Independent

⁹ A Regional Transmission Organization is an electric power transmission system operator which coordinates, controls and monitors a multi-state electric grid.

System Operators (ISO),¹⁰ or other appropriate entities consider an examination of the adequacy of compensation for services and benefits provided by blackstart resources, including any potential threat or impact on blackstart resource procurement and retention under current compensation mechanisms. The joint study team also recommends examining appropriate compensation for next-start generating units used in system restoration, including compensation for costs associated with participating in blackstart related services such as expanded testing.¹¹ [Section IV.C.].

3. **Verification of model data to ensure accuracy of blackstart simulations through coordination between transmission and generation registered entities.** The joint study team recommends that registered entities performing simulations of their system restoration plans, especially those with cranking path auxiliary loads at a next-start generating unit that are large relative to the blackstart unit, closely coordinate with generator owner(s) to ensure that the associated modeling data used to perform restoration plan simulations is accurate. For instance, the dynamic simulations should include energizing the cranking path and next-start generating unit startup, using generator and load models that have been verified against electrical data captured during various normal system operations or disturbances. Verification of data inputs should be considered for the following models:
 - Blackstart generating unit model;
 - Blackstart generating unit excitation control system model; and
 - Next-start generating unit auxiliary motor loads. [Section IV.D.]
4. **Expanded testing, where feasible, to confirm viability of blackstart capability through coordination between transmission and generation registered entities.** The joint study team recommends that, where feasible, transmission operators, in coordination with blackstart and next-start generation operators, perform expanded testing of blackstart cranking paths. Entities could use the

¹⁰ An Independent System Operator is an electric power transmission system operator which coordinates, controls and monitors the operation of the electrical power system, usually within a single US State, but sometimes encompassing multiple states.

¹¹ Blackstart service is the capability of generating units to start without an outside electrical supply or the demonstrated ability of a generating unit to automatically remain operating at reduced levels when disconnected from the grid.

results of expanded testing to confirm the viability of system restoration plans and to update system models and system restoration training programs. Conditions that could facilitate successful testing include:

- Testing during planned maintenance outages of certain sections of the transmission system comprising a blackstart cranking path;
- System configurations in which energizing the cranking path from blackstart generating unit to the next-start generating unit involves limited or no interruptions to customers, including conditions in which the blackstart and next-start generating units are in close proximity or where transmission system redundancies allow for isolation of applicable cranking paths without customer interruption. [Section IV.E.]

5. **Obtaining insight from registered entities that have experience with expanded testing.** The joint study team recommends that applicable registered entities that have not engaged in or performed expanded testing of their blackstart capability reach out to those who have performed such testing. Registered entities could also benefit from the sharing of experiences across different regions of the country. [Section IV.E.]

Observed Practices for Consideration

The joint study team found that the participants have many practices and procedures pertaining to blackstart capability planning and testing that serve to enhance their preparations for system restoration and recovery. The joint study team acknowledges that these practices may not be applicable to all registered entities in all situations, but believes that incorporation of these practices where appropriate could add significant value to the registered entities who adopt them and to the utility industry as a whole. Examples of these beneficial practices include:

- Coordinating the use of blackstart facilities across multiple transmission service footprints, which can allow a blackstart generating unit to contribute in supplying an adjacent area's critical load.
- Development and use of additional procedures for staffing during expanded testing, including providing for additional personnel to augment system operators and substation personnel during expanded testing. The additional substation personnel would staff substations and perform safety watches at certain points along transmission lines. At control centers, additional operators would manage and coordinate expanded testing so that system operators can focus on essential system operations with minimal distractions.

- Having generation registered entities offering blackstart service enter into agreements with next-start generating unit owners in order to facilitate expanded testing of blackstart capability.

The beneficial practices observed by the joint study team are discussed further in the relevant sections of the report.

II. Introduction

In September 2014, the Commission initiated a joint staff review, in partnership with NERC and the eight Regional Entities, to assess registered entities' plans for restoration and recovery of the bulk-power system following a widespread outage or blackout. This review culminated in the issuance of a joint Report on Restoration and Recovery Plans in January 2016.¹² The Restoration and Recovery Report provided a comprehensive understanding of the electric utility industry's bulk-power system recovery and restoration planning, but identified certain issues that went beyond the scope of the review, and recommended further study of those issues. Two of the areas recommended for further study were: (1) the availability of blackstart resources, including the identification of strategies for replacing these resources going forward, and the factors to be considered for such replacement resources; and (2) options for expanding system restoration plan testing beyond the currently required blackstart resource testing, to ensure that a blackstart resource can energize equipment needed to restore the system as intended in the restoration plan.¹³

The objective of this study is to: (1) assess the current state of blackstart resource availability and registered entities' strategies for replacement of blackstart resources going forward; and (2) verify whether and how registered entities conduct testing of blackstart resources under anticipated blackstart conditions, including identifying methods and practices that could be used to improve other registered entities' system restoration plans and training.

¹² *Supra* n.2.

¹³ Events such as the September 28, 2016, South Australia blackout, in which a blackstart generating unit failed to energize the next-start generating unit, have demonstrated the potential for widespread adverse effects if registered entities' system restoration plans and blackstart resources do not perform as intended to effectively restore the bulk-power system, and highlight the need for this study.

III. Study Process and Data

The joint study team adopted a collaborative model for conducting the review. Subject matter experts from the Commission, NERC, and the Regional Entities collectively provided the necessary planning and operations expertise to conduct the study.¹⁴

In order to facilitate a full and open discussion of each participant's approach, the joint review team agreed not to disclose registered entity-specific information outside each review group. This report accordingly provides the results of the reviews without attribution to individual registered entities.

During its assessment, the joint study team reviewed relevant reports and documentation provided by each participant, and engaged in discussions with the participants to gain additional information and insights.

The process used to perform this study included four steps:

Step 1: Review relevant literature;

Step 2: Identify candidate registered entities;¹⁵

Step 3: Assess registered entities' blackstart resource availability, strategies for replacing these resources, and blackstart resource testing practices; and

Step 4: Develop recommendations (viable resources, methods, beneficial practices and training).

A. Step 1: Review of Relevant Literature

As a first step in the review process, the joint study team identified, reviewed, and summarized relevant studies, reports, manuals and references to provide the joint study team background to aid in effectively structuring and performing the study.¹⁶

B. Step 2: Identify Candidate Registered Entities

Next, the joint study team developed participant identification criteria designed to best achieve the overall study goals of assessing registered entities' blackstart resource

¹⁴ Appendix 1 lists the joint study team members.

¹⁵ As in the preceding studies on System Restoration and Recovery, the identities of participants is non-public.

¹⁶ Appendix 3 contains a summary of the literature reviewed, except for specific literature pertaining to the participants in order to protect the participants' identities.

availability and strategies for replacement of resources no longer available due to retirement of the resources or other factors. The criteria also verified whether and how registered entities conduct testing of blackstart capability under anticipated blackstart conditions, including identifying methods and practices that could be used to improve other registered entities' system restoration plans and training. The joint study team used the following criteria to identify candidate entities:

- Registered entities subject to Reliability Standards EOP-005-2 (System Restoration from Blackstart Resources) and/or EOP-006-2 (System Restoration Coordination) that have system restoration plan or coordination steps, and/or have documented procedures for starting blackstart resources;
- Registered entities located in various areas or regions, where different types of blackstart generating units (e.g., hydro, natural gas, coal) may exist;
- Registered entities with significant bulk-power system responsibilities, viewed as competent in the study's focus areas, to help maximize potential learning and improvement;
- Registered entities that have experienced or are experiencing changes in their blackstart resource availability;
- Registered entities that have performed blackstart resource testing under actual or anticipated conditions (i.e., expanded testing beyond the currently required blackstart testing); and
- Registered entities that have gained experience in restoration from encountering extreme conditions or events (e.g., involvement in prior blackout events, hurricanes, and severe winter weather conditions).

The joint study team identified nine registered entities as prospective participants that met the participant identification criteria and contacted each to request its participation.¹⁷ The study participants were, without exception, exemplary in their cooperation with the joint study team. The participants shared relevant details about the availability of their blackstart resources, replacement strategies for blackstart resources, recent changes to blackstart resources, costs and compensation related to blackstart, rationale for selection of blackstart resources, simulation and testing of blackstart resource plans, obstacles preventing expanded testing of blackstart resources, and lessons learned from expanded testing. The joint study team commends the participants for their contributions.

¹⁷ Participants in this study are located in five of the eight NERC regions.

The joint study team sent a study request letter to each participant, outlining the information needed for the study.¹⁸ The letter asked the participants to provide or make available for review and discussion documentation pertaining to:

- Criteria for selection of current and future blackstart generating units and facilities (e.g., size, fuel type, location, limitations);
- Current and future cranking paths due to changes in blackstart resources;
- Procedures addressing issues if blackstart resource is unavailable;
- Provisions for additional cranking paths if main path is unavailable;
- Operating issues associated with blackstart resources pertaining to voltage level, fuel type, and other factors;
- Any additional documents or information identified by the Commission, NERC, or the Regional Entities;
- Results of testing of current cranking paths, and lessons learned from such testing; and
- Any public or private reports or other documents that have already been produced in these areas that may be beneficial for the team to review (e.g., Severe Impact Resilience Task Force Report).¹⁹

Where possible, the joint study team reviewed these documents prior to the start of participant reviews to aid in identifying specific areas of interest for each participant and for the study as a whole.

C. Step 3: Assess Registered Entities' Blackstart Resource Availability, Replacement Strategies, and Testing Practices

The joint study team identified specific areas of focus to aid in identifying recent changes to blackstart resources, understanding participants' strategies for replacing blackstart resources, and options for expanded testing beyond the currently required blackstart resource testing. The areas of focus included, but were not limited to:

- Determination of blackstart resource replacement strategy(s) and factors considered;

¹⁸ A copy of the request letter is attached as Appendix 2.

¹⁹ NERC Severe Impact Resilience Task Force, Severe Impact Resilience: Considerations and Recommendations, May 9, 2012, http://www.nerc.com/docs/oc/sirtf/SIRTF_Final_May_9_2012-Board_Accepted.pdf.

- Assessing blackstart resource restoration plan simulations and results;
- Monitoring and control of system conditions during testing;
- Managing protection schemes during expanded testing; and
- Communication and coordination during expanded testing.

The joint study team shared with participants these areas of focus prior to the assessment. This enabled the joint study team to perform an efficient, thorough, and consistent assessment of all participants and within the scope of review.

D. Step 4: Develop Recommendations

Upon completion of the participant assessments (including site visits and teleconferences with participants), the joint study team compiled its findings and recommendations in this report. The joint study team developed this report to help registered entities address replacement of blackstart resources when existing blackstart resources may become unavailable, and to promote optimal methods for testing and validating the viability of blackstart resource restoration plans. This report also shares practices that may help registered entities improve their blackstart resource replacement strategies, validate system models, and encourage engagement in expanded testing of blackstart capability in order to optimize system restoration planning.

IV. Assessment

A. Overview

During the review process, the joint study team observed a comprehensive range of experiences and approaches regarding the availability of blackstart resources, replacement strategies where needed, and testing and validation approaches to verify their system restoration plans. The team found that some participants have experienced fairly significant changes in the availability of blackstart resources in their areas, while others have experienced few if any changes necessitating replacement of blackstart resources. Despite the decrease in the total number of available blackstart-capable resources experienced by some participants, the joint study team found that all participants have verified they have sufficient blackstart resources to support their system restoration plans. Most participants have identified multiple blackstart resources in their system restoration plans, and some also indicated that they have access to other blackstart-capable units beyond those specifically identified in their current restoration plans.

The participants consider a number of factors in selecting blackstart resources, and when procuring replacement blackstart resources. The factors, include capacity, type of units, and location (e.g., proximity to cranking path, and physical location diversity with respect

to other blackstart resources), which can impact the overall restoration plan. The team found that participants have adequate procurement strategies, arrangements and procedures in place to secure blackstart resources, including replacing existing resources that may no longer be available for blackstart service.

The team found that participants responsible for procuring blackstart generating units have detailed blackstart procurement and retention strategies. Participants indicated however, that the degree to which those strategies succeed in obtaining optimal blackstart resources may depend on several factors, including providing adequate compensation for blackstart service and for other resources supporting system restoration. While determining an appropriate level of compensation for blackstart services may be somewhat complex, the team found that it is important to ensure resource owners have adequate incentive to offer blackstart services and to otherwise participate in system restoration support roles, including expanded testing.

All participants perform steady state and dynamic studies to verify the capabilities of blackstart resources, with varying levels of detail in the studies. In addition, all participants use periodic drills to validate their steady state studies. While some participants perform expanded testing of their blackstart capability beyond the testing that is currently required (i.e., by testing energization of the next-start generating unit), such testing was only performed by participants with a system configuration that made such testing feasible with few or no customer outages. Those participants who have performed expanded testing gained valuable knowledge that they used to update and enhance their system restoration plans and system operator training programs, and to verify that their restoration plan accomplishes its intended function. Notably, however, other participants indicated that they cannot perform such testing without undue adverse impacts to customers. The joint study team assessed the merits of recommending the inclusion of an expanded testing requirement in the Reliability Standards, and concluded that it would not be appropriate at this time.

B. Availability of Blackstart Resources

1. Introduction

The joint study team examined the participants' deployment of blackstart resources under their current system restoration plans, including the types and characteristics of blackstart resources included, to assess the sufficiency of the identified resources and to better understand recent trends potentially affecting the availability of blackstart resources.

Although several of the participants indicated that they have seen a decrease in the total number of available blackstart-capable units over time in their respective footprints, the joint study team found that participants have sufficient blackstart resources in their current system restoration plans. In addition, the joint study team found that most

participants have access to other blackstart-capable units in their footprint beyond the blackstart resources identified in their current restoration plans.

2. Observations

a. Participants' Current Blackstart Resources

Participants typically identify blackstart generating units to meet priority load²⁰ requirements in alignment with their overall system restoration strategies, and most of the participants have identified multiple blackstart resources as part of their system restoration plans. Most participants include at least two blackstart generating units per island in their system restoration plan, while one of the participants includes a single blackstart generating unit for each island. The total number of blackstart units identified in the participants' system restoration plans varied, as would be expected, due to inherent differences between transmission operators' systems and the absence of specific requirements in the Reliability Standards.

The blackstart generating units included in participants' plans range in size from small (e.g., 50 MVA) to larger units (e.g., 100-200 MVA), to banks of generating units exceeding 1,000 MVA in capacity. Participants' blackstart resources include a mix of coal and gas-fired steam units, gas combustion turbines, and hydroelectric units. The joint study team found that none of the participants currently employ wind or solar resources for blackstart services due to the variability or intermittent nature of these resources. However, some participants are in discussions with vendors to assess the feasibility of procuring battery storage systems for use as a blackstart resource among other services.

The participants have taken a number of precautions to ensure that blackstart units have reliable and consistent access to fuel during a system disturbance or other extreme conditions, including the following:

²⁰ System restoration plans typically identify "priority loads," whose prolonged interruption may have an undesirable impact on health, safety, and the environment, and are therefore targeted for restoration as early as possible in the system restoration process. For the study participants, priority load includes off-site power for nuclear generating stations (to maintain safe shutdowns), cranking power to certain generating units, power to natural gas infrastructure (such as electric compressors), power to pumping stations for oil pipelines, military installations and flood water control installations, and power to hospitals and other emergency operations.

- To ensure that gas supply to next-start generators is available during restoration, some participants include gas compressors as priority loads.
- Most participants' system restoration plans have blackstart generating units with dual fuel capabilities (using both oil and gas). One participant reported that about fifty percent of its blackstart generation capacity has dual fuel capability and that it is currently considering requiring all future blackstart generating units to be dual fuel capable units.
- Some participants with dual fuel blackstart capability have procured onsite oil or gas supplies sufficient to run generators for a limited period (e.g., 48 to 72 hours), to mitigate the loss of either fuel during a blackout. Other participants secure firm contracts with fuel suppliers to escalate priority and assure fuel availability.
- Most participants with gas-fired blackstart have firm transportation contracts.

b. Sufficiency of Blackstart Resources and Response to Recent Changes

Several participants indicated that the total number of available blackstart-capable units in their respective footprints has decreased over time. Some participants indicated that they have seen a reduction in the availability of blackstart generating units, next-start generating units, or automatic load rejection units²¹ due to the impact of regulations and due to the retirement of non-economic aging assets. Other participants have seen little turnover in their fleet of blackstart resources, but have experienced changes in their next-start generating units and automatic load rejection generating units due to similar factors. Nevertheless, all participants have verified that they have sufficient blackstart resources to support their current restoration plans. In addition, most participants indicated that they have access to other blackstart-capable units beyond those specifically identified in their current restoration plans. Participants generally maintain a list of these generating units, consider them in their restoration strategies, and can potentially rely on these resources for replacement blackstart service if current blackstart resources become unavailable. As discussed in the first joint Report on Restoration and Recovery Plans, the potential for increasing cyber threats accentuates the need for viable blackstart capability. Maintaining a list of these replacement blackstart-capable units could prove valuable if a

²¹ Automatic load rejection units are generating units that provide blackstart service by automatically disconnecting from the electrical grid during a disturbance, while remaining operational, with the ability to quickly reconnect to aid in faster restoration.

cyber event prevents the use of those blackstart units identified in entities' system restoration plans.

While many participants have had to respond to the loss of individual blackstart units, they have developed mechanisms to identify alternatives that not only address the potential need for replacement blackstart services, but that also optimize their overall system restoration plans. Some participants indicated they addressed the loss of a blackstart resource or resources through the re-identification of priority loads or through re-engineering of their system restoration plans. In addition, one participant transmission operator instituted a change in its regional restoration approach, to allow generating units in one transmission owner area to provide blackstart service to another area. Another participant transmission operator is currently redefining islands to optimize load recovery, rather than defining islands purely by geographical location. This participant is also planning to use a computerized blackstart capability tool to select the optimal set of blackstart generating units for each island in its service area.

Another participant explained that it has integrated some flexibility and redundancy in its system restoration plan to mitigate the loss of key blackstart generating units. Its system restoration plan has two independent paths to its next-start generators such that if the main blackstart generating units for each cranking path are not available, other units at either blackstart generating unit location can energize any of the two cranking paths within the specified time. In addition, one participant developed a cross zonal approach within its transmission footprint to address the reduction in the number of blackstart generating units. In that case, the transmission operator has agreements with entities within its footprint that allow it to identify areas where the efficiency and speed of restoration could be increased by using blackstart resources in one transmission ownership zone to meet priority load requirements in another.

Participants indicated that they routinely re-examine their system restoration plans to identify any impact on the restoration of service to priority loads due to changes in blackstart resource availability and/or increased development and population growth in certain regions. In one case, in response to changes in its blackstart resources, a participant redefined what constitutes priority load, in an effort to prioritize restoration to certain loads during system restoration. The participant's redefinition allowed priority load to be re-energized by units with start times of four hours or less, thereby increasing the number of priority load units in the participant's service area. Another participant, whose system restoration plan was previously based on geography, revised its plan in response to blackstart resource changes to focus on restoration of priority load centers by

redefining islands in a way that leads to faster load recovery rather than on unit selection based on proximity.²²

In addition, participants are re-evaluating and modifying their system restoration strategies as necessary, including where smaller, more distributed resources are replacing more traditional large-scale blackstart and next-start generating units. In many instances, these smaller resources can be started more quickly, which can result in improved system restoration times. Some participants believe there may be similar benefits through use of renewable resources for blackstart service, but recognize that significant challenges exist. For example, while none of the participants currently employ solar or wind resources in their restoration plans or replacement strategies, some are starting to explore the feasibility of using such resources. If these types of resources are employed in restoring the system, the variability of wind and solar resources would need to be factored in, and would necessitate revisions to current plans.²³

More general strategies and processes for procuring replacement blackstart resources are discussed in greater detail in Section IV.C., below.

3. Conclusion

The joint study team found that participants have sufficient blackstart resources to support their current system restoration plans. The joint study team found that some participants have experienced a decrease in the total number of available blackstart-capable units over time. However, participants have made adjustments as needed in response to these decreases, by, for example, re-engineering their system restoration

²² One participant has been working to improve its restoration plan and process through, *inter alia*, the acquisition of additional blackstart resources. The participant's current restoration plan is limited due to the topology of its system and limited availability of blackstart resources. The topology includes the unfavorable location (from the restoration perspective) of priority loads, such as nuclear facilities. As a result of these limitations, the participant has restoration plans that bypass major load pockets, which delays the establishment of more robust islands and defers restoration of major load centers. This participant is currently working to acquire new blackstart resources and to establish additional restoration path(s) to improve restoration time to a major metropolitan area in its service territory.

²³ The joint study team is aware of one registered entity that has installed a battery storage system with blackstart capability. Such a system could be used in areas that are heavily reliant on renewables, where traditional fossil fuel blackstart units may be in short supply. Information on this battery storage system is included in Appendix 3.

plans, redefining priority loads, or identifying other blackstart-capable generating units not previously included in their system restoration plans.

4. Observed Practices for Consideration

- Coordinating the use of blackstart resources across multiple transmission service footprints, which can allow a blackstart generating unit to contribute in supplying an adjacent area's priority load.
- Maintaining a list of blackstart-capable units not identified in system restoration plans that could be used during an emergency, if other blackstart resources are unavailable.

C. Blackstart Resource Procurement and Replacement

1. Introduction

This section provides an assessment of the participants' strategies for ensuring they have sufficient blackstart service to support system restoration, including strategies for procurement of new or replacement resources, and examines the specific challenges they face in retaining and replacing blackstart resources going forward.²⁴ In assessing the need for additional or replacement blackstart resources, participants take into account the impact of federal, state, and local regulations on future resource availability, and consider the operating condition, location, and types of available blackstart resources, as well as critical load requirements, among other things, when selecting optimal resources for providing blackstart services. Overall, the joint study team found that participants' procurement strategies adequately address the changes in blackstart resource availability as described in Section IV.B.2.b above.

²⁴ Background on strategies for assessing the need for and procurement of blackstart resources, along with examples, can also be found in the original restoration and recovery assessment. *See* "Report on the FERC-NERC-Regional Entity Joint Review of Restoration and Recovery Plans" (January 2016), available at <http://www.ferc.gov/legal/staff-reports/2016/01-29-16-FERC-NERC-Report.pdf>, at pages 20-23.

2. Observations

a. Assessment of Need for Replacement Blackstart Resources

Participants responsible for identifying blackstart services perform periodic reviews to verify their restoration plans,²⁵ and have procurement strategies and procedures in place if additional or replacement blackstart resources are needed. Some transmission participants issue requests for proposals to generator owners if additional blackstart resources are needed, while some transmission owner or operator participants have been required by state regulators to acquire the blackstart generating units needed to support their restoration plans. Other participant transmission operators defer to the organized markets in their service areas to procure blackstart resources that complement their own and adjacent transmission entities' system restoration plans.

Participants undertake periodic reviews of their restoration plans to assess blackstart capability, among other things, and will generally perform a comprehensive assessment of the amount of load to be restored, priority load requirements, and identification of the areas that may need additional or replacement blackstart resources. Participants perform studies and simulations and then assess results to determine if any additional blackstart resources are required.

These participants typically issue requests for proposals to provide blackstart service to mitigate the removal from their blackstart plan or retirement of existing blackstart generating units from service, or to strengthen restoration reliability in less robust areas. One participant, who issues a regular, bi-annual request for proposals for blackstart services, uses a software optimization tool to assess its system restoration needs. The tool uses mathematical algorithms to select the optimal set (number and types) of lowest cost blackstart generating units that can meet the needs of the participant's service area. The tool simulates restoration of peak load and determines the facilities necessary to accomplish restoration. Some of the factors used in this tool include simulated restoration of peak load, proximity to load centers, priority loads and gas pipelines, availability of a strong transmission network, and restoration of off-site power to nuclear generating units, usually within four hours.

²⁵ Under Reliability Standard EOP-005-2, Requirement R6, an applicable entity must verify that its system restoration plan accomplishes its intended function through analysis of actual events, steady state and dynamic simulations, or other testing.

b. Requests for Blackstart Resource Proposals

If the participants find that a need for additional or replacement blackstart resources exists, they undertake some or all of the following steps:

- **Development of technical requirements** – Participants develop and list the technical requirements of the blackstart generating units needed for their service areas. Participants may coordinate with other registered entities in this step.
- **Issuance of requests for proposals to prospective generating unit owners to provide blackstart service** – The requests for proposals typically include guidelines for participation and information on compensation for providing blackstart service.
- **Assessment of proposals submitted by prospective generating unit owners** – Participants review the responses to ensure that the blackstart generating units can meet the objectives set by the participant, which may include requirements for maintaining voltages along the cranking path within established voltage limits, and electrical proximity to critical loads.
- **Validation of proposed units and assessment of blackstart costs and compensation** – Participants perform simulations or actual tests (e.g., unit start up tests) to assess the feasibility of the proposed units by identifying issues on cranking paths that could prevent a potential blackstart generating unit from energizing the cranking path. Participants also evaluate the costs incurred by generating unit owners in the provision of blackstart service and the appropriate compensation for their service.
- **Notification to generating units** – Blackstart generating unit owners are notified whether or not they are selected to provide blackstart service, at which time the selected generation owners will begin any upgrades needed to enable provision of blackstart service. Any current blackstart units that are not selected are provided a notice of termination. Also, participants incorporate the selected blackstart generating units and cranking paths in their restoration plans.

The procurement process for replacement blackstart service generally starts with the issuance of requests for proposals to generating unit owners by the procuring transmission owner, transmission operator, or organized market administrator. In determining the most efficient arrangement or allocation of blackstart resources, some participants may deal with multiple providers simultaneously. One participant transmission operator has an incremental process for requesting blackstart service to address any blackstart resource shortages driven by retirements, termination of service, or to address priority loads. As part of this process, if a transmission owner cannot procure

adequate blackstart service after two requests for proposals, and no regional transmission expansion plan²⁶ is available, the participant works with the other transmission owners in its service area to issue a third request for proposals to prospective blackstart resources.

Many participants specify minimum requirements and contractual terms when procuring blackstart service, including the following:

- Participants negotiate a commitment period for providing blackstart service with the blackstart service providers ranging from one to twenty years. Blackstart service providers can opt out of these contracts, but must provide timely notification to the procurer. This requirement allows for timely procurement of replacement blackstart resources in the affected areas.
- Some participants may agree to provide a contribution towards a feasibility study to assess the installation, technical capabilities, and cost of installing blackstart capability at the site.
- One participant, whose dual fuel (e.g., oil and gas) blackstart generating units currently make up about forty percent of the total blackstart resources in its service area, is considering specifying that all replacement blackstart resources have dual fuel capability (to mitigate the possible future decrease in existing dual fuel blackstart generating units).
- One participant transmission operator requires that blackstart generating unit owners enter into agreements with owners of next-start generating units, to foster better coordination and cooperation between the parties on blackstart related activities (e.g., during expanded testing of cranking paths).
- Some participant transmission operators require that the capability of the identified replacement blackstart generating units be large enough to provide sufficient power (MW) to restore priority loads and have sufficient reactive capability (MVar) for voltage control. Others require that the total generating capacity of blackstart generating units combined exceed the total priority load by a certain factor.²⁷

²⁶ The participant's regional transmission expansion plan identifies transmission system additions and improvements needed to supply power throughout its footprint.

²⁷ For instance, one participant requires that the total capacity of blackstart units be 110 percent of the total priority load.

- Some participants prioritize the procurement of fast-starting blackstart generating units physically close to priority loads, such as nuclear power plants, to ensure that power can be quickly restored to these units during an emergency.
- Some participants allow blackstart generating units to be physically located outside their footprint, provided that the blackstart resource and cranking path(s) receiving the blackstart power are appropriately identified in the relevant transmission owner or operator's blackstart capability plan and system restoration plan.
- Some participants require the provider of new blackstart services to verify that its blackstart generating unit is capable of providing the contracted service through an assessment at commissioning.

Participants may employ some or all of these strategies to secure optimal blackstart resources, based on the needs of their specific service areas, the number and types of blackstart resources available, system topology, and state and local regulations.

c. Evaluating Blackstart Resource Proposals

Participants indicated that they consider various factors when evaluating proposals from entities to provide blackstart services. In addition to certain fuel considerations discussed further below in subsection d, these factors include:

- the ability to meet priority load requirements;
- electrical proximity;
- interconnection voltage;
- age and historical forced outage rates of blackstart resources;
- the capacity or size of the units;
- reactive capability and response rate;
- start-up time;²⁸
- proximity to priority load and high-density load centers; and
- results from computer simulations of cranking paths to determine viable blackstart solutions.

Locational factors. All participants factor in the proximity of generator fuel supplies and electric transmission facilities in their assessment of replacement blackstart generating units. Some participant transmission operators also identify areas within their footprint where it would be beneficial to locate blackstart resources. These transmission operators

²⁸ The start-up time for blackstart generating units in the reviewed plans ranges from five minutes to several hours. Although not a requirement, a shorter start-up time is desirable to aid in the timely restoration of the system.

identify cranking paths for supplying blackstart service from multiple areas to meet priority load requirements (such as supplying offsite power to a nuclear power plant).²⁹

Some participants consider the blackstart generating units' proximity to high density load centers, such as major metropolitan areas, as a factor for selecting blackstart units. Blackstart generating units closest to these metropolitan areas are selected because they provide the fastest recovery time. Participants also evaluate priority loads when selecting blackstart resources, including assessment of whether the blackstart unit is capable of powering the next-start generating unit's largest motor load. For those participants, the replacement of older, larger next-start generating units with multiple smaller units could potentially increase the number of blackstart generating units capable of satisfying the next-start unit's critical load requirement. Thus, for those participants, the changing resource mix may improve blackstart resource availability and restoration plan options.

Finally, some participants take into account the value of diversifying the location of their blackstart resources to mitigate the risk of multiple blackstart generating units being unavailable due to a single-point loss or failure. The joint study team believes other industry participants should consider this practice in appropriate circumstances.

Ranking criteria. One participant considers multiple factors to formally rank each blackstart generating unit being considered, including the start-up time of each unit, the number of independent cranking paths to multiple target generating facilities, and the number of transmission transformers in the path. The participant generates an overall score based on these factors to produce a formal ranking, and finds that this ranking process allows it to select the best blackstart options for each of its service areas.

Results of Blackstart Resource Testing. Participants indicated that they also consider whether or not the blackstart generating unit owners can perform successful tests of their blackstart capability. Some transmission owner and operator participants require that the blackstart generating unit owners perform a physical test of their units by starting their

²⁹ As a result of a state mandate, one participant's affiliate acquired and now owns and manages the blackstart resources necessary to support the participant's system restoration plan. The participant explained that at the time those units were chosen for acquisition as blackstart resources, its main considerations were geography and the size of the units. The selected blackstart generating units were those large enough to support the cranking paths containing the next-start generating units. In addition, the selected blackstart generating units were located strategically throughout the participant's service area and within a few busses (i.e., close electrical proximity) of the generating stations needed to ensure a fast recovery during a restoration event.

units and energizing a dead bus. Other participants require a physical or simulated demonstration that the blackstart resource is capable of starting the next-start generating unit's largest motor. One of these participants requires blackstart generating units to perform physical tests by successfully starting up their units, energizing sections of transmission lines in the relevant cranking path, picking up load for thirty minutes, and starting the largest motor at the next-start generating unit.

Fuel Considerations. All participants consider fuel supply sources when making their selection of blackstart resources. For instance, one participant considers factors such as a secure fuel source and proximity to cranking path load in its selection of replacement blackstart generating units. This participant gives priority to blackstart generating units closer to load with secure fuel supplies over other units. In addition to proximity to cranking path, another participant considers whether the blackstart service provider has firm fuel supply contracts for its blackstart generating units, plans for fuel transportation, and/or on-site fuel storage capacity in its selection of blackstart generating units. The specific challenges participants have experienced in securing adequate blackstart resources are discussed further below, in subsection d.

Cost and Compensation. Participants also consider the costs and compensation for blackstart resources in their selection of replacement blackstart generating units. The specific challenges and concerns expressed by the participants on compensation for blackstart service are set out in subsection e below.

d. Challenges in Securing Blackstart Services - Fuel Considerations

Participants consider the firmness of fuel supplies, plans for fuel transportation, as well as on-site fuel storage capacity in their evaluation of proposals for blackstart resources. However, other factors may limit the kinds of blackstart resources available and preclude entities from securing an optimal fleet of blackstart resources. One participant indicated that the majority of its available blackstart resources rely on a single fuel (natural gas) for operation, without any storage capacity. That participant indicated that it has limited options for blackstart resource fuel type due to local regulations, and that it has secured a contract with a gas supplier for its blackstart generating units to help ensure that fuel supplies are available for those critical resources.

As was the case for the entities participating in the original restoration and recovery assessment, most participants' restoration plans identify some blackstart generating units with dual fuel capabilities (using both oil and gas). In addition, some participants with dual fuel blackstart capability have procured onsite oil or gas supplies sufficient to run generators for a limited period (e.g., 48 to 72 hours), to mitigate the risk of loss of either fuel during a blackout. One participant expressly takes into account whether or not a generating unit has dual fuel capability when evaluating a replacement blackstart

resource. This participant is currently considering a future requirement that all blackstart generating units in its service area have dual fuel capability. Another participant, whose dual fuel blackstart generating units currently make up about forty percent of the total blackstart resources in its service area is also considering requiring all replacement blackstart resources to have dual fuel capability, to mitigate the possible loss or retirement of existing dual fuel blackstart generating units.

As was found in the Restoration and Recovery Report, the joint study team finds that maximizing the use of dual fuel blackstart generating units helps to minimize the risk that the blackstart resource will not be available if one fuel is in short supply or otherwise unavailable at the blackstart site. For example, natural gas supply to blackstart generating units may become limited or unavailable due to curtailments of gas during an extreme weather event or other disturbance on the natural gas system. In addition, while the joint study team recognizes that the types of blackstart resources may be limited in certain areas, the joint study team believes that system restoration plans can be improved by including some degree of diversity or fuel assurance in fuel sources for the blackstart fleet as a whole.

e. Challenges in Securing Blackstart Services - Compensation

While the joint study team found that all transmission participants have sound processes for procuring adequate blackstart services, including for replacing blackstart generating units that may no longer be available due to retirements or other factors, participants expressed a number of concerns about the difficulty of obtaining sufficient blackstart resources if blackstart service providers are not adequately compensated for the cost of providing that service, and noted that compensation generally needs to be addressed as part of the request for proposal process.

Costs of Providing Blackstart Service. Participants explained that blackstart service involves various costs, including costs associated with the engineering, planning, and testing needed for qualification as a blackstart unit. These include costs associated with:

- The transmission system, including engineering and planning, training, capital (including start-up costs), synchronization capability, and emergency power for circuit breakers;
- The blackstart generating units, including testing, training, equipment, and labor and fuel costs during an actual event;
- The next-start generating units, including testing, training, equipment, labor and fuel costs during an actual event; and
- System operations, including operating costs for planning, testing and training, and capital costs for operations hardware and software.

While certain costs associated with generating units providing blackstart service are hypothetically easier to identify and directly associate with blackstart service, many of the costs are more indirect (e.g., transmission system or system operator costs), and are more difficult to allocate to the provision of blackstart service only. The joint study team did not attempt to resolve these issues due to the complexities involved, and finds that the issue may warrant further study or consideration by appropriate entities.

Cost Recovery/Compensation. For participants operating in an organized market, compensation for blackstart services are outlined in the ISO or RTO tariffs, which typically factor in the blackstart service provider's fixed, variable, training, and fuel storage costs plus an incentive for participation. In addition, some markets provide some degree of compensation for blackstart resource feasibility studies for the installation of equipment needed to support blackstart capability.³⁰ Other participants are compensated through bundled retail rates.

Some of the participant generator owners indicated that they are satisfied with the current compensation offered for blackstart service by their respective transmission operators or RTOs/ISOs. However, other participants raised concerns about the level of compensation currently offered:

- One participant operating an organized market indicated that some generating unit owners have expressed dissatisfaction with their current compensation for providing blackstart service.
- Another participant operating an organized market is concerned about the adequacy of its current compensation to blackstart providers, to the point that it is planning to issue a survey soliciting feedback from blackstart generating unit owners on the issue of compensation.
- One participant generator owner explained that generation owners have little incentive to provide blackstart service from fully depreciated units, because the payment for service is limited to operations and maintenance reimbursement (e.g., one percent of actual operations and maintenance costs, plus some funds for training).
- Other participants noted that the filing process required to obtain a Commission-approved rate for blackstart service can be prohibitively cumbersome and expensive.

³⁰ See, e.g., ISO New England, OATT Schedule 16 - Blackstart Service; New York ISO, 15.5 Market Services Tariff Rate Schedule 5 - Payments and Charges for Black Start and System Restoration Services.

- Some participants expressed a concern that next-start generating units generally receive no additional compensation for their role in supporting system restoration.

Participants operating in an organized market generally indicated that there are sufficient blackstart generating units available to allow for a competitive market, suggesting that compensation levels for blackstart services are adequate in the markets studied. However, a few participants expressed dissatisfaction and concerns about the adequacy of compensation for blackstart service.

The joint study team acknowledges the complexities surrounding the issue of compensation for blackstart service, including how to accurately identify and estimate which costs are blackstart-only and what proportion of indirect costs should be assigned to blackstart service. The joint study team concludes that this issue is beyond the scope of this study, and that the adequacy of current compensation practices for blackstart service and the related generating units can be examined elsewhere.

3. Conclusion

The joint study team found that all participants responsible for procuring blackstart generating units have adequate strategies and processes in place for replacing these resources when necessary (e.g., when existing blackstart resources become unavailable as units are retired, or when those resources are no longer considered to be optimal for providing such services). In addition, the joint study team observed that blackstart generating unit replacement strategies vary slightly among participants, based on the number and types of blackstart resources available, system topology, and state and local regulations. Furthermore, the team found that the adequacy of compensation for services and benefits provided by blackstart resources needs to be examined, to ensure compensation levels are adequate to secure and retain necessary blackstart resources.

Participants consider several factors in the selection of replacement blackstart resources, including the capacity of the unit, proximity to cranking path, fuel supply and location diversity, and the ability to prove through testing or simulation that the generating unit is capable of providing blackstart service. While the joint study team recognizes that blackstart resource options may be limited in certain areas, the team believes that the reliance on a single fuel source for all blackstart resources within a given region, without fuel storage capacity or firm fuel arrangements, could cause significant issues during a restoration event and that steps should be taken to mitigate this risk.

4. Recommendations

- **Mitigating risks associated with the reliance on a single fuel.** The joint study team concludes that the reliance on a single fuel blackstart resource without fuel storage capacity or firm fuel arrangements could cause issues during a system restoration event. Therefore, the joint study team recommends that single fuel

dependent blackstart generator owners develop alternative fuel capability or coordinate with their fuel providers to mitigate this risk. This could include firm contracts with specifications to ensure that fuel supplies to the blackstart generating units are unimpeded during a system restoration event. Furthermore, the joint study team recommends these blackstart resource owners work with their regulators as necessary to develop alternative solutions to address fuel constraints.

- **Consider further study of the adequacy of compensation for blackstart and other resources supporting system restoration.** The joint study team recommends RTOs, ISOs, or other appropriate entities consider an examination of the adequacy of compensation for services and benefits provided by blackstart resources, including any potential threat or impact on blackstart resource procurement and retention under current compensation mechanisms. The joint study team also recommends examining appropriate compensation for next-start generating units used in system restoration, including compensation for costs associated with participating in blackstart related services such as expanded testing.

5. Observed Practices for Consideration

- Incorporating a condition in requests for proposals for blackstart service that all replacement blackstart resources have dual fuel capability.
- Maximizing the use of dual fuel blackstart generating units, in order to minimize the risk that a blackstart generating unit will not be available if one fuel is in short supply or otherwise unavailable at the blackstart generating unit site.
- Diversifying the location of blackstart resources to mitigate the risk of multiple blackstart generating units being unavailable due to a single-point loss or failure.
- Coordination between local transmission owners in an organized market and the RTO/ISO, to develop requests for proposals for blackstart service when initial efforts by an individual transmission owner to procure blackstart services produce insufficient results.
- Using an optimization tool during the blackstart service procurement process to determine optimum sets of blackstart resources for the service areas.
- Considering blackstart generating units' proximity to high density load centers as a factor in selecting units for blackstart service.
- Selecting blackstart and next-start generating units in close electrical proximity, to facilitate coordination and improve restoration time.

- Integrating flexibility and redundancy in system restoration plans to mitigate the loss of key units in key locations.

D. Blackstart Resource Validation – Simulations and Results

1. Introduction

Participants' system restoration plans include a description of the steps needed to restore the isolated bulk-power system from the blackstart generating units. Typically, participants perform computer simulations of their system restoration plans, including verifying the capability of their identified blackstart resources, to examine whether the plan can accomplish its intended function. As discussed below, participants employ both steady state and dynamic modeling for analyzing blackstart cranking paths with varying levels of detail.³¹

Participants' models are designed to analyze the effects of the planned switching steps to be undertaken to sequentially energize transmission facilities or segments. The models analyze adding the expected increments of load, switching other devices in service (e.g., shunt reactors), and making adjustments as necessary for island stability and operation within steady state limits.

2. Observations

a. Validation of Restoration Plan: Steady State Simulations

All of the applicable participants perform steady state simulations and analyses to test the blackstart capability aspects of their system restoration plans. These steady state simulations allow the participants to accomplish the following as part of their assessment of their blackstart capability:

- Determine whether reactive power resources will be sufficient to maintain voltage within established limits while performing system restoration tasks, including:

³¹ The steady state modeling of system restoration plans typically includes a step-by-step simulation of the plan to verify operational limits for voltage control and power flows. Dynamic modeling of restoration plans starts from a steady state operating point representing a step in the plan, and includes simulation of the start-up of the largest induction motor at the next start generating unit. This verifies that the voltage supply is sufficient to start the motor.

- Energizing cranking paths, which may include large transformers (which typically requires blackstart generating unit to absorb reactive power due to charging capacitance);
 - Starting auxiliary motor loads at next-start generating units; and
 - Energizing facilities beyond the next-start generating units (i.e., building the islands).
- Determine whether load pickup will be necessary during various stages of system restoration. Load pickup may be needed for voltage control or to meet minimum-load requirements of blackstart generating units or other generating units.
 - Verify the feasibility of the system restoration plan by performing a sequential simulation to ensure compliance with operational voltage and thermal limits.
 - Study the flexibility of the system restoration plan to adapt to the unavailability of key components (such as transmission lines) identified in the plan.
 - Address Reliability Standard EOP-005-2 requirements.³²

All participants engage in periodic system restoration drills, which facilitate the review of their system restoration plan and provide coordinated training for operators through simulation exercises. Most participants use dispatcher training simulators (DTS), which permit operators to use the same simulation tools (e.g., Supervisory Control and Data Acquisition (SCADA)³³/Energy Management System (EMS)³⁴) used in normal operations. In addition to providing operators a more realistic experience for operator-execution of system restoration plan steps,³⁵ many of these DTS tools have the ability to accommodate the modeling of the elements described above, including transformer,

³² Reliability Standard EOP-005-2, requirement R6 requires each transmission operator to verify, through analysis of actual events, steady state and dynamic simulations, or other testing, that its system restoration plan accomplishes its intended function. Transmission operators verify their plans every five years at a minimum.

³³ Supervisory Control and Data Acquisition is a system of remote control and telemetry used to monitor and control the transmission system

³⁴ Energy Management System is a system of computer-aided tools used by bulk-power system operators to monitor, control and optimize system performance

³⁵ See “Report on the FERC-NERC-Regional Entity Joint Review of Restoration and Recovery Plans” (January 2016), available at <http://www.ferc.gov/legal/staff-reports/2016/01-29-16-FERC-NERC-Report.pdf>, at page 53.

generator, and relay modeling. For those participants who use a DTS with incorporation of modeling elements, it can aid in validation of their restoration plan simulations.

As found in the Restoration and Recovery Report, the blackstart joint study team also finds that all participants engage in periodic system restoration drills designed to mimic responses to actual events and to facilitate the development of the requisite skills, experience, and tools to effectively manage the system restoration process, including blackstart cranking path energization. One participant creates drill scenarios based on actual system conditions, including outages occurring on the day of the drill. Other participants introduce specific unexpected constraints in drills to mimic possible failures of blackstart related equipment, or the unavailability of a particular blackstart generating unit, in order to provide more realistic scenarios for operators. Overall, the joint study team found that these drills provide a secondary, and sufficient, validation of the participants' own steady state studies confirming the viability of the blackstart components of their system restoration plans.

b. Validation of Restoration Plan: Dynamic Simulations

Participant transmission operators also rely on dynamic analyses to evaluate their system restoration plans, including blackstart capability. These dynamic analyses allow the participants to accomplish the following:

- Determine limitations of blackstart capability, particularly in the following areas:
 - Energizing lines and transformers, and the associated charging capacitance and/or inrush current issues,
 - Evaluating capability and dynamic characteristics of blackstart generating units, including the ability to energize next-start generating units while maintaining frequency and voltage stability;
- Study behavior of islands as they are built and connected, to demonstrate viability of system restoration methods;
- Study viability of proposed/replacement blackstart resources; and
- Address Reliability Standard EOP-005-2 requirements.³⁶

Participants consider a number of elements in designing appropriate dynamic study simulations, and take a variety of approaches depending on specific areas of concern given their system configuration:

- **Cranking path energization** – Some participants simulate energizing the entire blackstart cranking path at once, while others simulate sequential energizing of

³⁶ See *supra* n.30.

multiple segments of the cranking path. In addition, one participant simulates energizing large transformers that are part of the cranking path. The method chosen by each participant generally reflects the switching capabilities and other attributes of the system being studied. These dynamic simulations can detect potential transient overvoltage conditions that may arise when cranking paths are energized.³⁷

- **Faults** – A few participants simulate faults on cranking paths to assess the ability of the blackstart resource to remain online without damaging equipment during fault conditions. Other participants do not simulate faults. Instead, they assume that a fault occurring during an actual restoration event would result in the tripping of the blackstart resource, which would restart the restoration process.
- **Relay modeling** – Some participants include relay models in their dynamic simulations and consider relay characteristics from a high level, to provide some assurance that protection systems will not operate prematurely or fail to operate to clear faults during system restoration. One participant that does not include relays in its dynamic simulations has taken that approach because it plans to disable all transmission protection systems during blackstart scenarios, and has mitigating measures for safety in place.

One of the participants that includes relay models in its dynamic simulations has time-domain simulation tools that can perform real-time dynamic simulations while connected to protective relays, allowing for extensive study of relay performance during system restoration.³⁸ The time-domain simulation tools synthesize instrument transformer signals to fully test the response of the relay to various disturbances while the simulated system is configured for blackstart scenarios. These tools also have the capability to simulate relays based on imported relay settings. Time-domain tools with detailed relay modeling are capable of providing a high level of assurance of protection system dependability and security when such performance is deemed essential for system restoration.

- **Generator modeling** –During early stages of system restoration, the blackstart generating unit controls voltage and frequency on the system as it is re-

³⁷ Transient overvoltage is a short duration, high magnitude surge in voltage resulting from electrical switching or lightning.

³⁸ Time-domain simulation tools capture the transient response and timing of control actions.

energized.³⁹ Participants indicated, therefore, that it is critical to model the speed governor and generator excitation systems of blackstart generating units. Most participants' blackstart generating unit models are based on the dynamic models found in their planning or operating dynamic base cases, with appropriate modifications to reflect the expected blackstart scenario, such as changing the governor model to represent isochronous mode for blackstart generating units.⁴⁰

- **Transformer modeling** – Most participants do not include large transformers, other than the blackstart generating unit's step-up transformer, when developing their cranking path models for dynamic simulation of their system restoration plan. However, one participant with a large transformer in its cranking path has invested significant effort into modeling the transformer to understand the potential effects of transformer inrush current during energizing. Because transformer inrush current is inherently unpredictable,⁴¹ this participant performs worst-case simulations to ensure the validity of the study.
- **Auxiliary load modeling** – The modeling of auxiliary loads at next-start generating units is of particular interest in blackstart studies, because these loads need to be energized by the blackstart unit for the restoration process to move forward. All of the participants that perform dynamic simulations perform some preliminary auxiliary load model enhancements to their typical planning model in

³⁹ Under normal operations, the effect of the controls of individual generating units is not significant because several generating units share control of system voltage and frequency.

⁴⁰ An isochronous (or zero droop) governor maintains the same speed regardless of the load, and ensures that the frequency of the electricity generated is constant or flat. Isochronous control mode is used to control frequency in an island during system restoration.

⁴¹ Inrush current is the maximum, instantaneous input current drawn by electrical equipment, such as a transformer, when it is energized. When a transformer is taken off-line, a certain amount of residual flux remains in the core due to the properties of the magnetic core material. The residual flux can be as much as 50 to 90 percent of the maximum operating flux, depending on the type of core steel. When voltage is reapplied to the transformer, the flux introduced builds upon that already existing in the core. In order to maintain this level of flux in the core, which can be well into the saturation range of the core steel, the transformer can draw current well in excess of its rated full-load current. Depending on the transformer design, the magnitude of this inrush current can be multiple times the rated full-load current.

order to account for the dynamic characteristics of the large motor loads that comprise the majority of auxiliary load. Participants are particularly interested in three auxiliary motor load characteristics: starting or locked-rotor current, inertia, and power factor. Some participants use a formulaic approximation of auxiliary load for their next-start generating units,⁴² while others use collected field data specific to each motor load to create the most accurate model possible.⁴³ The joint study team observed that participants with large auxiliary loads on their next-start generating units relative to the associated blackstart generating units put considerable effort into auxiliary load modeling, to ensure that their simulations mirror the actual performance of the loads and can accurately demonstrate that the blackstart generating units are capable of energizing the auxiliary loads.

- **Load pickup** – During dynamic simulation of the cranking paths, some participants do not simulate load pickup other than the auxiliary loads at the next-start generating unit, because of the design of the cranking paths in their system restoration plans. Other participants simulate load pickup if needed for voltage control, minimum load requirements, or to balance generation. The load pickup models are typically based on planning model assumptions, although some participants have done further work toward more accurate representation of cold load pickup characteristics, such as accurately representing the amount of inrush current.
- **Simulation tools** – Most of the participants use a dynamic simulation tool similar to that used for planning and operating studies. Some of the participants also use an electromagnetic transient program to study the more detailed aspects of the blackstart process.⁴⁴ Participants observed certain differences between electromagnetic transient program and normal dynamic simulations:
 - Time step is much finer in an electromagnetic transient program, allowing better transient analysis,
 - Three-phase simulation provides far better analysis of actual relay settings, and

⁴² For instance, one participant assumes auxiliary load to be 15 percent of total cranking MVA and motor loads to be 85 percent of total cranking MVA.

⁴³ Some participants further enhance the accuracy of their models by collecting real time data at the next-start generating units during normal start-up of those units, which provides some validation of model parameters.

⁴⁴ An electromagnetic transient program is a software tool for simulation and analysis of transients in power systems.

- Electromagnetic transient program simulations are limited by the quality of model data, but model quality can be improved and/or validated through the use of Phasor Measurement Unit (PMU) data.

Although the dynamic simulations of the participants' system restoration plans appear to be adequate to test their validity and feasibility, the team found that the simulation design and level of detail varies based on a number of factors (including the design of cranking paths). The joint study team further found that enhanced modeling of auxiliary loads is particularly critical for those participants with smaller blackstart generating units relative to their next-start generating units, as it helps ensure that their models can demonstrate that the blackstart generating units are capable of energizing the auxiliary loads under blackstart conditions and that the system restoration plan is feasible.

c. Use of Field Data for Validation of Simulation Inputs

Some participants do not perform any additional field tests to specifically validate their system restoration simulation inputs. However, all entities with applicable facilities are now required to comply with certain modeling validation requirements in Reliability Standards MOD-026-1, MOD-027-1, and MOD-033-1, which should help to ensure that blackstart simulations reflect accurate input assumptions.⁴⁵

⁴⁵ Notably, the requirements of Reliability Standard MOD-033-1 (Steady-State and Dynamic System Model Validation) went into effect after the joint study team conducted this review. These Reliability Standards include requirements that ensure verification of certain data used in participants' models as follows:

- Reliability Standard MOD-026-1 requires verification that the generator excitation control system or plant volt/var control function model (including the power system stabilizer model and the impedance compensator model) and the model parameters used in dynamic simulations accurately represent the generator excitation control system or plant volt/var control function behavior when assessing bulk electric system reliability.
- Reliability Standard MOD-027-1 requires verification that the turbine/governor and load control or active power/frequency control model and the model parameters, used in dynamic simulations that assess bulk electric system reliability, accurately represent generator unit real power response to system frequency variations.
- Reliability Standard MOD-033-1 establishes consistent validation requirements for planning authorities and planning coordinators to facilitate the collection of accurate

Most participants take steps to validate the accuracy of their models and simulations in a number of ways, both by using field data and other tools to validate the accuracy of model inputs, and by testing or comparing the results of their simulations with other studies or other parameters.

Participants use field data to validate inputs used to model or simulate their system restoration plans in several ways:

- Some participants incorporate real time data from the next-start generating units, taken during normal start-up of those units, to provide some validation of model parameters. The real time data may include locked rotor current of motors, transformer inrush current, and cranking MVA of bulk-power system equipment.
- Some participants simulate system conditions that mimic operating conditions by using actual system operations data in their dynamic models, and benchmark dynamic model simulations against results from field tests.
- Some participants use PMUs at substations across their systems, including at the distribution level, to capture real time system data for use in verification of dynamic models. The PMUs provide a useful level of granularity and a high degree of precision.⁴⁶
- As discussed further in Section IV.E, some participants use the results from expanded testing of blackstart capability to validate their studies, including their model inputs. Most of the participants who have performed expanded testing explained that they gained valuable knowledge about the restoration process from that testing, which was used to modify and improve their existing dynamic models.

To validate restoration plan simulations in one organized market, the transmission/market operator performs its own dynamic studies of blackstart cranking paths, independent of the transmission-owning entities within its footprint. The market operator then compares its results with the transmission entities' simulations, and resolves any discrepancies to ensure a more accurate representation of blackstart capabilities, using the more conservative assumption where any discrepancy exists. For instance, if the market

data and building of planning models used to analyze the reliability of the interconnected transmission system.

⁴⁶ Some participants that do not currently use PMUs as part of their blackstart simulation validation recognize the potential value in the use of PMU data, and plan to install PMUs at substations within their systems in the near future.

operator's models include more limiting voltage restrictions than a transmission entity's default values, the market operator would use its own (narrower) voltage limits.

One participant uses generation, excitation and auxiliary load data supplied by the generator owner in the participant's models. The participant discusses any abnormal results from the simulations with the data-supplying generator owner. The team found that this coordination between transmission entities and generator owner(s) is important to ensure that the associated modeling data for the generators in system restoration plans are accurate, so that the steady state and dynamic simulations can accurately verify that the system restoration plans accomplish their intended function.⁴⁷

Other participants use the results from expanded testing of blackstart capability to validate their studies and their overall system restoration plan (as discussed in the Section IV.E).

Overall, the joint study team found that validation of models varies across participants in detail and accuracy, and that participants who have incorporated real-time system data or results from actual tests into their models appear to have more accurate models.

3. Conclusion

The joint study team found that the participants perform steady state and dynamic simulations of their system restoration plans to test the validity and feasibility of their blackstart capability, with varying levels of detail modeled based on a number of factors. Among other things, the joint study team found that participants' periodic system restoration drills using DTS can aid in validation of their restoration plan simulations.

Some participants use captured field data, such as real-time operations data, to improve the accuracy of their models, while other participants use assumptions in developing certain aspects of their models. Some participants with smaller blackstart generating units relative to their next-start generating units have worked to improve the accuracy of auxiliary load modeling, to ensure that their models can accurately demonstrate that the blackstart generating units are capable of energizing the auxiliary loads of the next-start generating unit. The joint study team found that other participants in this category, with relatively large auxiliary loads at their next-start generating units, could benefit from similar improvements in the accuracy of their auxiliary load models. Finally, the joint study team found that participants who have performed expanded testing of their

⁴⁷ Reliability Standard MOD-032-1 establishes consistent modeling data requirements and reporting procedures for development of planning horizon cases necessary to support analysis of the reliability of the interconnected transmission system.

blackstart capability have been able to review and refine their steady state and dynamic models using lessons learned from these tests.

4. Recommendation

- **Verification of model data to ensure accuracy of blackstart simulations through coordination between transmission and generation registered entities.** The joint study team recommends that registered entities performing simulations of system restoration plans, especially those with cranking path auxiliary loads at a next-start generating unit that are large relative to the blackstart generating unit, closely coordinate with generator owner(s) to ensure that the associated modeling data used to perform restoration plan simulations is accurate. For instance, the dynamic simulations should include energizing the cranking path and next-start generating unit startup, using generator and load models that have been verified against electrical data captured during various normal system operations or disturbances. Verification of data inputs should be considered for the following:
 - Blackstart generating unit model,
 - Blackstart generating unit excitation control system model,⁴⁸ and
 - Next-start generating unit auxiliary motor loads.⁴⁹

5. Observed Practices for Consideration

- Comparing the results of individual dynamic studies by transmission owners or operators with a region-wide study performed by the market operator or other appropriate planning or operating entity, including resolution of discrepancies using conservative assumptions to ensure a more accurate representation of blackstart capabilities.
- Incorporating captured real time data (e.g., from motor tests, transformer inrush current, and cranking MVA of bulk-power system equipment) into models for

⁴⁸ Reliability Standard MOD-026-1 addresses this issue, but only applies to generating units above the facility ratings specified in the Applicability Section 4.2. An approach to model verification similar to that provided in MOD-026-1 could be beneficial for blackstart units not already subject to the Reliability Standard.

⁴⁹ These motor loads are generally represented by motor models in blackstart dynamic simulations. Verification of these models can be accomplished using data recorded during normal startup of the next-start generating unit.

system studies, so that restoration plan simulations better mimic actual system conditions.

- Incorporating lessons learned from past restoration events into restoration drills, to provide operators experience with actual events.
- Using PMUs to capture system data for use in verification/validation of dynamic models.
- Using tools that enable performance of real-time dynamic simulations while connected to protective relays.
- Including blackstart-capable generating units (in addition to those formally designated as blackstart resources in restoration plans) in simulations used to test system restoration planning and blackstart capability.
- Using real time simulations (steady state) of the system during system restoration drills rather than generic simulation systems or paper drills.

E. Blackstart Resource Validation - Expanded Testing

1. Introduction

All of the participants responsible for procuring or identifying blackstart resources as part of their system restoration plan require periodic testing of the units to verify their capability, with the requirements for such testing set out in their system restoration plans. Some blackstart generating unit owners test their units once every three years, consistent with Reliability Standard EOP-005-2. Other owners test their units annually. All of the participants require, at a minimum, demonstration that the blackstart generating unit is able to start when isolated from the bulk-power system and that the unit can energize a bus (consistent with Reliability Standard EOP-005-2). In addition, some of the participants perform expanded blackstart testing that exceeds the testing requirements in the Reliability Standards. While the joint study team found that expanded blackstart testing can provide significant additional insight into and validation of an entity's system restoration plan, the team also found it imposes additional costs and burdens, and may not be feasible or advisable in certain situations due to the potential impact on customer load during testing. Accordingly, the joint study team recommends that registered entities should consider expanded testing where feasible.

2. Observations

Those participants that perform expanded testing incorporate various criteria as part of their blackstart resource testing procedures, including the following:

- Blackstart generating unit must be available to serve load within three hours;

- Blackstart generating unit must remain stable and control voltage and frequency while operating isolated from the grid for a period of 10-30 minutes; or
- Blackstart generating unit must energize the entire cranking path up to the next-start generating unit.

This last type of “expanded testing” (i.e., testing the blackstart resource’s ability to supply cranking power to the next-start generating unit) requires de-energizing parts of the transmission system so they can be re-connected to the blackstart generating unit. Accordingly, this kind of expanded testing cannot always be performed without an adverse impact on customer load. Further, the participants who engage in this kind of testing generally perform it in locations where the cranking paths can be isolated with limited interruption⁵⁰ or no outages to customers, or in locations where the blackstart generating units and next-start generating units are in close proximity.

a. Staffing and Deployment of Personnel

Participants who have successfully performed expanded testing of their blackstart resources explained that such testing requires deployment of field personnel to substations. The personnel include substation or distribution personnel responsible for switching, and system protection and control technicians responsible for monitoring voltage and other system parameters during testing. One participant deploys field personnel with radios to substations and along transmission lines for safety reasons (e.g., possible sagging of transmission lines due to potential issues with line voltages and accidentally synchronizing out of phase). That participant also deploys protection and control technicians to install data recording equipment that capture voltage, current and other readings during testing. Participants employ additional control center operators to manage and coordinate testing so that system operators can focus on essential system operations with minimal distractions. One participant also involves its planning engineers during expanded testing in case adjustments to test plans are needed. Finally, one participant involves its engineers at the blackstart generating unit during testing to assist generating unit operators with the additional complexities involved in energizing the cranking path.

⁵⁰ Limited interruption to customers includes momentary outages associated with switching operations, and specific, agreed-upon interruptions associated with expanded testing execution (e.g. industrial or commercial customers) captured in procedures for such interruptions.

b. Communications and Coordination

Most participants mentioned that communications and coordination during expanded testing are more involved than during the more limited testing currently required by the Reliability Standards. For instance, prior to performing expanded testing, the transmission operator typically notifies the reliability coordinator about the date and time of the test and seeks approval for the test. In some regions, the reliability coordinator monitors the entire test. If customer outages are necessary for completing the test, the affected customers are notified prior to testing by the testing registered entity. In some regions, registered entities may also have to be mindful of the emissions restrictions imposed on the blackstart unit,⁵¹ and, if necessary, may have to secure the appropriate permits from regulators prior to the test. During testing, transmission operators communicate with substation personnel via radios and maintain constant communications with the generator operator at the blackstart generating unit.⁵² Field personnel deployed at substations and along transmission lines periodically communicate with each other and with control center operators. One participant who has successfully performed expanded testing requires constant communication between the control center operators and field personnel performing the tests during each stage of the test. For instance, during the energizing of transmission lines, control center dispatchers provide specific instructions to substation field personnel who perform functions such as opening and closing breakers, and report back to the dispatcher.⁵³

c. Managing Protection Systems

Some participants indicated that they do not make any adjustments to protection systems during expanded testing. One of these participants recognizes that its transmission line protection systems would not operate during testing, and therefore relies on protection systems installed on the blackstart generator during expanded testing.⁵⁴ Another

⁵¹ In some cases, participants are limited to a certain number of hours for testing due to environmental restrictions on fuel use at the blackstart unit. These limitations are more likely to be exceeded during expanded testing.

⁵² Communications elements and alternate communications are addressed in Reliability Standard COM-001-3 – Communications.

⁵³ This degree of monitoring and communication is not necessary during more limited testing of blackstart units.

⁵⁴ Requirements for meeting transmission system performance through operation, maintenance and testing of protection systems are found in Reliability Standards:

participant recognizes that its protection systems may potentially be less effective during expanded testing, so it dispatches field crews to monitor transmission lines and other bulk-power system equipment and to report any issues to control center operators.

Other participants do adjust their protection system settings during expanded testing. One participant makes adjustments to its synch check relays to ensure proper synchronization to the grid, but the rest of its protection system remains the same. Other participants disable some protection systems so that testing is not impeded.

d. Monitoring and Control of System Conditions

Participants use various methods to monitor and control voltage, current, and frequency during expanded testing. Blackstart generator operators monitor voltage at the generating unit, while transmission operators monitor and control voltage at control centers via EMS/SCADA.⁵⁵ Some participants also monitor voltage and voltage limit exceedances at substations. One participant dispatches field personnel to substations with recording equipment to monitor voltage and to ensure that voltage limits are not exceeded.

Participants explained that they monitor voltage to ensure that it is kept within a tight band around nominal values, which guards against exceedances and subsequent damage to equipment. Some participants also use system protection personnel to access certain substation digital devices, typically protective relays, to remotely monitor voltages and other system conditions for limit exceedances. The system protection personnel communicate with the transmission system operators for situational awareness.

Participants rely on the generator operator to control and monitor frequency during expanded testing. Some of these participants also rely on system operators to monitor frequency at control centers. Most of the participants do not pick up customer load during expanded testing other than picking up auxiliary load associated with the next-start generating unit. However, one participant does pick up customer load as part of the expanded testing process. The participant explained that monitoring of load pick up

-
- TPL-001-4 – Transmission System Planning Performance Requirements, and
 - PRC-005-1.1b – Transmission and Generation Protection System Maintenance and Testing.

⁵⁵ Requirements for operator monitoring of facilities are found in Reliability Standards:

- TOP-001-3 – Transmission Operations,
- IRO-002-5 – Reliability Coordination – Monitoring and Analysis, and
- IRO-009-2 – Reliability Coordinator Actions to Operate Within IROLs.

during expanded testing is coordinated between the blackstart generator operator and transmission operator.

e. Additional Support Tools, Resources, and Lessons Learned

In addition to the generator operators' monitoring and control of frequency and voltage, participants use the EMS/SCADA system to monitor voltage, frequency, other system parameters, and the overall progress of the expanded blackstart testing. Field personnel deployed to substations and along transmission lines during expanded testing use radios for communicating with control center operators and generating unit owners. Other participants have installed data recording equipment to capture pertinent data during expanded testing, or use data captured by microprocessor based relays.

All participants who perform expanded testing incorporate lessons learned during expanded testing into training programs for operators. One participant mentioned that its system operators use lessons learned from expanded testing to modify procedures. Another participant requires its engineers to compile all lessons learned from expanded testing into a report, which is reviewed prior to incorporating into training for operators.

f. Use of Expanded Testing Results for Model Validation

Most participants compare the results of their expanded blackstart tests with data used in their models, to review and refine model assumptions. Participants incorporate lessons learned from tests in periodic drills and update data used in dynamic models such as transformer inrush current and MVA of transmission equipment. One participant benchmarks results of its recent tests with those of prior tests to assess success. Participants also analyze the differences in test results for significance, and use the knowledge gained in subsequent tests.

g. Obstacles to Performing Expanded Testing

In discussions with participants, the joint study team found that expanded blackstart resource testing is more burdensome and costly to perform in many respects, and may not be feasible in some situations. Most participants identified the need to de-energize or interrupt certain parts of their system as the primary obstacle in performing expanded testing. Participants not only noted the difficulty of finding a suitable time for scheduling expanded testing-related outages, but also had concerns that affected commercial or industrial customers might request compensation for lost revenue during any scheduled interruption in their electric services.

Participants also noted that expanded testing requires the cooperation and involvement of the next-start generating unit owner. In some cases, next-start generating unit owners hesitate to blackstart their generating units because of the risk of damage to their units and the lack of mechanism (market or otherwise) to provide compensation for any such

damage. One participant, who was unable to obtain the consent of the next-start generating unit owner due to concerns with damage to the unit, indicated that it had to limit its expanded testing to energizing the entire cranking path while stopping short of energizing the next-start generating unit. According to participants, some owners of next-start generating units are convinced that expanded testing carries risks that outweigh the benefits of such a test, and some have expressed the need for a compensation mechanism for participating in the test.

As noted above, the joint study team found that successful expanded testing also requires extensive coordination between parties. To perform these tests without loss of load, registered entities must coordinate with all affected parties, including the blackstart and next-start generator operators, the transmission owner, the transmission operator, and in some cases the reliability coordinator. This coordination includes how to alleviate next-start generating unit's risks through accurate generator load modeling and simulations for ensuring test feasibility (as described in section D above). This coordination also includes arranging a schedule for testing to minimize any associated cost and reliability impact (e.g., by running the test when the blackstart generating unit is offline, the next-start generating unit is offline, and system loads are at a lower level).

Participants in some regions noted that they have to abide by strict state and local emissions regulations for some of their blackstart units (whether during normal operations or during any operations required for blackstart testing), and that these operating limits are more likely to be reached during expanded blackstart testing. These emissions restrictions effectively limit allowable run hours during a 12-month period, and may be so restrictive as to preclude additional or expanded blackstart testing without additional permitting or waivers. One participant explained that it is allowed only about 2 hours per test each year for its gas units, and failure of the test would require the participant to petition its regulators for special permission to re-test.

To overcome scheduling difficulties and facilitate expanded testing, one participant RTO requires that all blackstart generating unit owners seeking to provide blackstart service in its area enter into agreements with owners of next-start generators to allow performance of and cooperate in expanded testing. Although this agreement facilitates coordination between the blackstart and next-start generating unit owners in this participant's service area, a similar requirement by other registered entities in other parts of the country could be a deterrent to blackstart resource participation.

The joint study team sought feedback from participants about the impact on participants of an expanded testing requirement for all blackstart units, possibly in the Reliability Standards. One participant indicated that such a requirement could create a need to contract for or install additional blackstart generating units that are electrically closer to critical loads, which could impose a financial burden on registered entities. Other participants noted the significant burden such a requirement would impose given the need

to plan for and schedule customer outages, especially for cranking paths located in densely populated or industrial areas, and could potentially include compensating some or all of the affected customers for lost revenues resulting from the outages. Another participant mentioned that issues related to compensation of next-start generating unit owners for their participation in expanded testing would also need to be resolved. Most participants believed that such a requirement would not only be financially burdensome, but could also have unintended consequences, including a reduction in the number of blackstart generating units available for inclusion in participants' system restoration plans.

h. Benefits of Expanded Testing

Participants who have performed expanded testing, without exception, found that they gained valuable knowledge about their system restoration plans and processes which may not have been achieved otherwise. Participants use this knowledge to resolve outstanding issues, and incorporate it into annual system restoration drills, reliability studies, and other system operator training.

For instance, one participant with a 13 kV blackstart generating unit recognized during its initial expanded testing that it could not energize a 230/69 kV transformer in its cranking path. In subsequent tests, the participant successfully energized the local and remote ends of the 230/69 kV transformer at reduced generator voltage (approximately 4 kV), which limited the transformer inrush currents to acceptable levels within the capability of the blackstart generating unit.⁵⁶ Upon successful completion of the test, this participant reviewed and refined its testing procedures and training for its operators. Another participant performs expanded testing on its cranking paths periodically, and indicated that it gained knowledge from the tests which was used to improve training for its system operators.⁵⁷

3. Conclusion

The joint study team found that participants that have successfully performed expanded blackstart testing have gained valuable knowledge used to update and enhance their system restoration plans, blackstart capability plans, training programs for system operators, and system studies. Notably, the team found that all participants that perform expanded testing have system configurations that generally allow for such testing without

⁵⁶ Appendix 4 contains additional details and technical specifications about this test.

⁵⁷ The majority of that participant's blackstart and next-start generating units are located close to each other; accordingly, expanded testing requires no customer outages.

customer interruption, or that they otherwise perform the tests in locations where the cranking paths can be isolated with limited or no outages to customers.

The joint study team concludes that registered entities could gain valuable experience and insight from voluntary expanded testing, which can be used to update and refine their system restoration plans. The joint study team accordingly recommends that registered entities consider performing expanded testing, where feasible.

The joint study team weighed the benefits and costs of recommending a new expanded testing requirement in the Reliability Standards. The joint study team concluded that such a requirement would impose operational and financial burdens on registered entities for which they may not receive compensation, and that these costs and burdens currently outweigh the benefits of expanded testing. The burden would likely be acute for registered entities with existing system configurations that cannot support expanded testing, including those in situations that would require extensive customer outages to carry out the tests. Furthermore, the joint study team is concerned that an expanded testing requirement could discourage generating units from blackstart participation and potentially reduce the number of blackstart generating units available for inclusion in registered entities' system restoration plans.

4. Recommendations

- **Expanded testing, where feasible, to confirm viability of blackstart capability through coordination between transmission and generation registered entities.** The joint study team recommends that, where feasible, transmission operators, in coordination with blackstart and next-start generation operators perform expanded testing of blackstart cranking paths. Entities could use the results of expanded testing to confirm the viability of system restoration plans and to update system models and system restoration training programs. Conditions that could facilitate successful expanded testing include the following:
 - Testing during planned maintenance outages of sections of the transmission system that comprise a blackstart cranking path;
 - System configurations in which energizing the cranking path from a blackstart generating unit to the next-start generating unit involves limited or no interruptions to customers, including conditions in which the blackstart and next-start generating units are in close proximity or where transmission system redundancies allow for isolation of applicable cranking paths without customer interruption.

- **Obtaining insight from registered entities that have experience with expanded testing.** The joint study team recommends that applicable entities that have not

engaged in or performed expanded testing of their blackstart capability reach out to those who have performed such testing. Registered entities could also benefit from the sharing of experiences across different regions of the country.

5. Observed Practices for Consideration

- Development and use of additional procedures for staffing during expanded blackstart testing, including requiring additional personnel to augment system operators and substation personnel.
- Having system protection personnel access certain digital devices at substations to remotely monitor voltages and other system conditions for limit exceedances during expanded blackstart testing.
- Using data recording equipment to capture pertinent system data during expanded blackstart testing, to be reviewed and used to enhance system studies and system operator training (including for periodic drills).
- Having generation registered entities offering blackstart service enter into agreements with next-start generating unit owners in order to facilitate expanded testing of blackstart capability.

V. Appendix 1 - Joint Study Team

Federal Energy Regulatory Commission:

Robert Clark	Mary Agnes Nimis
John Denis	Louise Nutter
Kenneth Githens	Ray Orocco-John
Julie Greenisen	Alan Rukin
Oscar Guzman	Judith Sciallo
Andres Lopez	

Florida Reliability Coordination Council, Inc.:

Hassan Hamdar

Midwest Reliability Organization:

Adam Flink
William Kunkel
Daniel Schoenecker

North American Electric Reliability Corporation:

Robert Kenyon
Katherine Street
Jim Stuart

Northeast Power Coordinating Council, Inc.:

Andrey Oks
Ralph Rufrano

Reliability First Corporation:

John Idzior
Brian Thiry
Ray Sefchik

SERC Reliability Corporation:

Joe Spencer

Texas Reliability Entity, Inc.:

Jagan Mandavilli

Western Electricity Coordinating Council:

Evan Paull

VI. Appendix 2 – Request Letter for Participation

On January 29, 2016, the Commission posted to its web site the Report on the FERC-NERC-Regional Entity Joint Review of Restoration and Recovery Plans.⁵⁸ The report describes how the joint staff review team examined restoration, response, and recovery plans of a representative sample of nine registered entities and, from that review, identified beneficial practices that could be more widely deployed, recommendations for changes, and five areas for further study. Two of the areas for further study are: (1) the availability of blackstart resources, including the identification of strategies for replacing blackstart resources going forward, and the factors to be considered for such replacement resources, and (2) blackstart resource testing under anticipated blackstart conditions or other means of ensuring that the blackstart resource can function as specified in the blackstart plan to confirm the viability of entities' blackstart plans.

Commission staff, in collaboration with NERC and Regional Entity staff, is initiating the studies mentioned above:

1. To examine the availability of blackstart resources, including the identification of strategies for replacing blackstart resources and factors to be considered for such replacement resources (e.g., locational diversity, dual fuel capability, etc.)
2. To learn whether entities can perform expanded testing of blackstart resources or other means of ensuring that the blackstart resource can function as specified in the blackstart plan, and develop lessons learned that could be shared with industry.

As an entity with bulk-power system significance and representative operating characteristics that may be beneficial to this analysis, we are requesting [entity's] participation in this review. Other registered entities are also being asked to participate in order to achieve a comprehensive review.

The joint staff review will:

- Review existing literature on changes in blackstart capabilities as a result of changes to power system, technical opportunities for other resources to play a role in blackstart, and comparisons of approaches (e.g., across interconnections);
- Review pertinent literature regarding blackstart resource testing, and conduct a technical assessment of related challenges and gaps;
- Gather information via outreach with a select sample of bulk-power system entities (i.e., NERC-registered entities);

⁵⁸ “Report on the FERC-NERC-Regional Entity Joint Review of Restoration and Recovery Plans” (January 2016), <http://www.ferc.gov/legal/staff-reports/2016/01-29-16-FERC-NERC-Report.pdf> (Joint Report).

- Analyze the difficulties caused by the replacement of lost blackstart generating units in key locations by other units that may not be in an ideal location or have the same capabilities;
- Assess the procurement processes including strategies considered and factors for replacement used by the sampled entities, and identify methods or practices that may be helpful for other entities to incorporate into their processes;
- Identify any issues due to entities' introduction of renewables into the generating resource mix;
- Analyze whether entities can isolate and test the viability of their plans; whether entities can perform expanded testing, or other means of ensuring that the blackstart resource can function as specified in the blackstart capability plan.
- Identify lessons learned and good practices that may be shared across the industry.

Documents and information to be requested during the entity outreach, depending on applicable functions, pertain to:

- Criteria for selection of current and future blackstart generating units and facilities including:
 - size, type, location, MW and MVA_r capabilities
 - fuel (dual fuel capable, fuel location, etc.)
 - special controls (if applicable)
 - purpose (supplying cranking path to next generator, provide offsite power to nuclear plant, etc.)
 - limitations (e.g., documented changes in blackstart resources over the past 10-20 years);
- Current and future cranking paths due to changes in blackstart resources;
- Procedures addressing issues if blackstart resource is unavailable;
- Provisions for additional cranking paths if main path is unavailable;
- Operating issues associated with blackstart resources pertaining to voltage level, fuel type, and other factors;
- Any additional documents or information identified by NERC, FERC or the Regional Entities;
- Results of testing of current cranking paths, and lessons learned from such testing;
- Any public or private reports or other documents that have already been produced in these areas that may be beneficial for the team to review (e.g., Severe Impact Resilience Task Force Report).

In addition to the information specified above, entities are encouraged to provide any information or documents that they feel may be helpful to the study.

This collaborative assessment by the Commission, NERC and the Regional Entities is an important step in protecting reliability by gauging the electric utility industry's level of

preparation for a major event and the ability to restore the bulk-power system quickly and efficiently. In anticipation of [entity's] participation, we thank you and will work closely with you to ensure this project is conducted as a partnership with minimal disruption to your organization. My staff will contact you at your earliest convenience regarding any questions or concerns that you may have about this joint staff review.

VII. Appendix 3 – Summary of Literature Review

i. Maintaining System Blackstart in Competitive Bulk Power Markets - Brendan Kirby and Eric Hirst

This article explains that while system blackstart is conceptually well understood and universally acknowledged to be important, its detailed requirements are difficult to pin down because it is difficult to quantify expected results from blackstart service without prior knowledge of what will go wrong. Competitive markets could develop for blackstart capability, but reliability requirements restrict the locations and capability requirements for individual blackstart generators. However, if there are enough generators located so that they can provide blackstart service, the competition among them, may be enough to allow markets to determine the prices of this service. The control-area operator is the only buyer because it is responsible for determining how much of the resources to acquire and how to deploy them. The system-control and transmission portions of system blackstart cannot be provided competitively. These services, by definition, can be provided only by the monopoly entities that manage and operate control areas.

ii. September 28, 2016 - South Australia Event

Investigation of this event found that a blackstart generating was started during a blackout, but failed to energize the next start generating unit because a circuit breaker connecting the two units tripped, and subsequent attempts to close this breaker were unsuccessful. An investigation of the failure concluded that the cause was related to the switching sequence used by personnel to connect the blackstart generating unit to the next start unit which resulted in large inrush currents on the step up transformer and auxiliary load transformer.

According to the report, this problem had not been encountered during prior tests because a different switching sequence was used in the prior tests than on the day of the blackout. The switching sequence used in prior tests had the three circuit breakers connecting two busses already closed before the blackstart generating unit was started. In this configuration, the blackstart generating unit was directly connected to the next start generating unit prior to the blackstart generating unit starting. When operating in this manner, the next start unit's transformers were 'soft-started', meaning the in-rush current is gradual (as opposed to an instantaneous surge).

The switching sequence used during the blackout connected the two generating units after the blackstart generating unit was operating at nominal voltage. This essentially resulted in a large in-rush current on the next start generating unit's transformers.

iii. Simulation and Field Tests of the BlackStart of a Large Coal-Fired Generating Station Utilizing Small Remote Hydro Generation

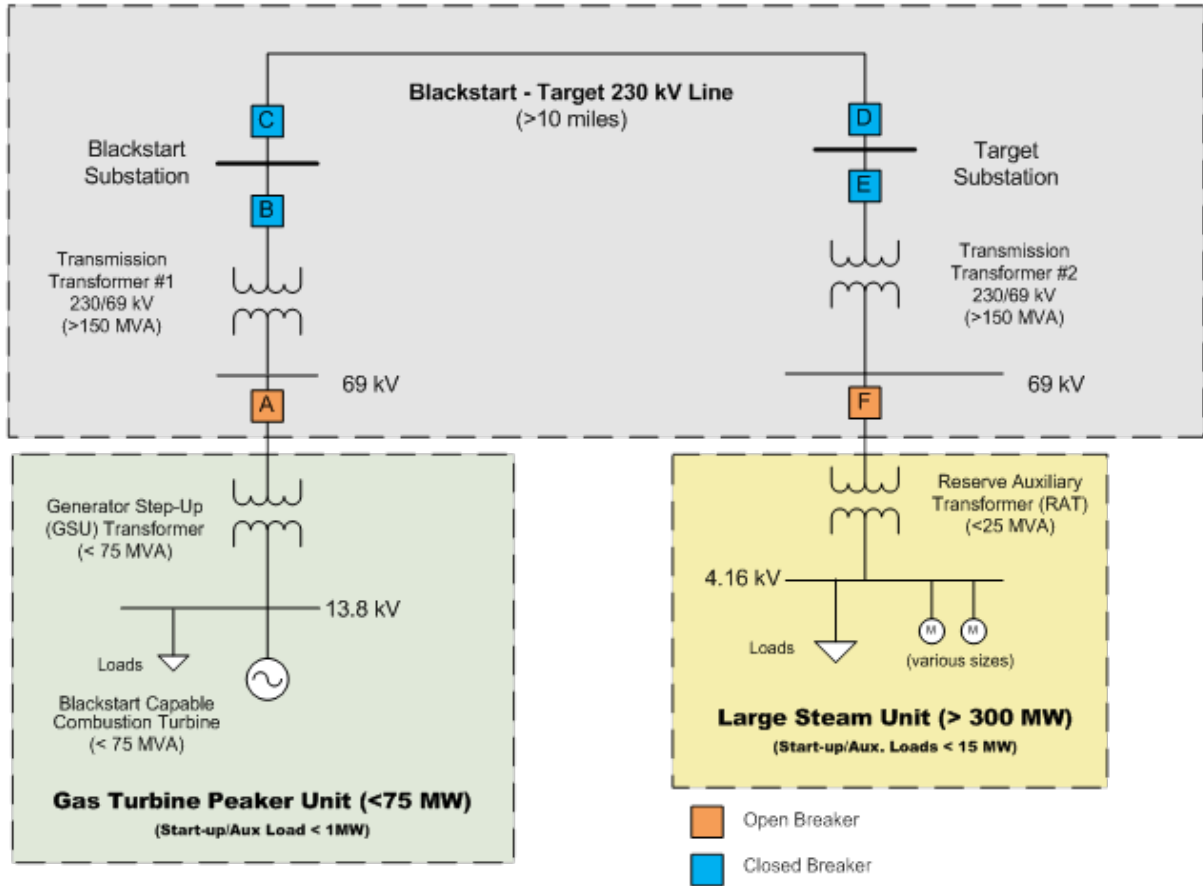
Report describes a method in which a remote hydro generation is used to restart a major coal-fired generating station. It includes considerations for a blackstart project, details of an analytical study, identification of critical factors, development and implementation of an actual blackstart test, comparison of field tests with simulation results and the required system modifications identified during the project. The report concludes that using remote hydro generation to restart a major coal fired generating station is realistic and can be achieved. With some minor system modifications and procedural changes, any problems which might occur can be avoided.

iv. Imperial Irrigation District Brings 33-MW Battery Storage System Online – November 21, 2016 by Kevon Storie

The article describes a battery energy storage system installation commissioned by Imperial Irrigation District (IID) in California. The system is a 33-megawatt (MW), 20-megawatt-hour (MWh) system. IID installed the lithium-ion based energy storage system to increase reliability while integrating renewable energy resources into the local grid. The storage system allows the utility to balance power, arrest frequency decay, provide spinning reserves, mitigate large fluctuations of energy, increase voltage stability and deliver blackstart power restoration capabilities for the nearby El Centro gas generation plant. The \$38 million installation includes the lithium-ion battery with inverters, plant controls, transformers and medium-voltage switchgear in a single enclosure.

VIII. Appendix 4 - Expanded Testing Example

Generic Example of 13.8/69/230 kV Cranking Path and Associated Loads and Resources



This example illustrates a situation where the blackstart generating unit (Gas Turbine Peaker Unit), cranking path and next start unit (Large Steam Unit) are owned and/or operated by different entities. As a result, significant coordination and cooperation is necessary to plan for, and perform the test. These activities are managed by the transmission operator, which has direct control over the cranking path.

Prior to the test, the entities performing the test isolated the cranking path components from the rest of the system and configured the system as shown in the diagram above⁵⁹. The entities were able to perform the test due to the design of the surrounding transmission system and system conditions at the time of the test, which assured the system was secure against the relevant contingencies in the operating horizon.

Using the entities' blackstart procedures, the blackstart generating unit was started without off-site power in isochronous mode, and the Generator Step-Up (GSU) transformer was energized as part of the blackstart process.

The first step to energize the cranking path is to use the Automatic Voltage Regulator (AVR) set-point adjustment at the blackstart generating unit to reduce the generator terminal voltage from a nominal of 13.8 kV to approximately 4 kV (about 30 percent of nominal). Energizing cranking path components at a reduced voltage minimized in-rush currents due to components such as large transmission transformers, given the size (MVA) of the transformers relative to the blackstart generating unit. This is a fundamental consideration for the entities due to the possibility that excessive in-rush currents could cause damage to critical equipment.

Breaker A is then closed, energizing the local 69 kV bus at 30 percent of nominal voltage, in addition to energizing the remainder of the cranking path up to breaker F. Upon closing breaker A, the entire path is energized at reduced voltage, thus all components are at 30 percent of nominal voltage. After a few minutes of stable operation, the voltage on the blackstart generating unit and the transmission system is returned to normal by adjusting the blackstart generating unit's AVR back to nominal voltage (13.8 kV).

Energizing the local and remote 230/69 kV transformers at reduced voltage limited the transformer inrush (and sympathetic inrush) currents to acceptable levels that are within the capability of the blackstart generating unit. This test has been conducted multiple times by the entities.

The testing has not progressed beyond breaker F, because the next step would be to energize the next start unit's start-up and auxiliary loads. The owners of the next start unit could not consent to energizing their unit loads due to a variety of concerns, including possible damage resulting from test and generation related financial compensation.

⁵⁹ Both the blackstart and next start generating units are located near large transmission substations. Thus, any short lines or jumpers are negligible and not represented in the diagram. The blackstart generating unit is a gas turbine peaking unit, and was built to provide blackstart service.

The entities intend to conduct future tests to energize the next start unit's auxiliary bus and start the auxiliary loads which are comprised of large motors and other equipment used to operate the plant.

The entities are only allowed a 2 hour window to conduct the tests each year. The entities must meet environmental limits during the test and for the balance of the day. The testing is not permitted to be conducted as part of normal operations. The value of these tests for the entities is that it provides confidence to the organizations involved about the viability of their plan, familiarizing operators with operations in abnormal conditions, and helping to verify engineering analyses of the emergency operating procedures.

IX. Appendix 5 – Glossary of Terms and Acronyms Used in Report

Automatic Load Rejection Generating Units: Generating units that provide blackstart service by automatically disconnecting from the electrical grid during a disturbance, while remaining operational, with the ability to quickly reconnect to aid in faster restoration.

Auxiliary Load: The load at a power generating station, which includes ancillary equipment such as pumps, fans, and soot blowers used with the main boiler, turbine, engine, waterwheel, or generator.

Blackstart Capability Plan: A documented procedure for a generating unit or station to go from a shutdown condition to an operating condition delivering electric power without assistance from the electric system. This procedure is only a portion of an overall system restoration plan.

Blackstart Resource: A generating unit(s) and its associated set of equipment which has the ability to be started without support from the System or is designed to remain energized without connection to the remainder of the System, with the ability to energize a bus, meeting the Transmission Operator's restoration plan needs for Real and Reactive Power capability, frequency and voltage control, and that has been included in the Transmission Operator's restoration plan.

Blackstart Service: The capability of generating units to start without an outside electrical supply or the demonstrated ability of a generating unit to automatically remain operating at reduced levels when disconnected from the grid.

Cranking Path: A portion of the electric system that can be isolated and then energized to deliver electric power from a generation source to enable the startup of one or more other generating units.

Dispatcher Training Simulator (DTS): An application which allows operators in-training to use the same tools and computer applications used in normal operations for the many steps executed during system restoration. The DTS also tracks the status of generation and dynamically updates and displays the latest simulated system conditions.

Energy Management System (EMS): A system of computer-aided tools used by bulk-power system operators to monitor, control and optimize system performance.

Expanded Testing: Involves testing beyond the currently required blackstart testing (up to energizing a dead bus), including energizing the transmission line and the next start generating unit, to ensure that the blackstart generating unit can energize equipment needed to restore the system as intended.

Generator Operator: The entity that operates generating unit(s) and performs the functions of supplying energy and interconnected operations services. The generator operator is responsible to have procedures for starting each blackstart resource, in accordance with Reliability Standard EOP-005-2.

Independent System Operator: An independent system operator is an electric power transmission system operator which coordinates, controls and monitors the operation of the electrical power system, usually within a single US State, but sometimes encompassing multiple states.

Inrush Current: This is the maximum, instantaneous input current drawn by an electrical equipment such as a transformer when it is energized.

Island, Electrical: An electrically isolated portion of an Interconnection. The frequency in an electrical island must be maintained by balancing generation and load in order to sustain operation. Islands are frequently formed after major disturbances wherein multiple transmission lines trip, or during restoration following a major disturbance.

Isochronous Generator Governor Control: An isochronous (or zero droop) governor maintains the same speed regardless of the load, and ensures that the frequency of the electricity generated is constant or flat. Isochronous control mode is used to control frequency in an island during system restoration.

Next Start Generating Unit: The first generating unit in the cranking path to be energized using power from the blackstart generating unit.

Organized Market: The entity that coordinates, controls and monitors the operation of the electrical power system, either within a single state or multistate.

Phasor Measurement Unit (PMU): Device that measures the electrical waves on an electricity grid, using a common time source for synchronization.

Priority Load: Specific load identified in a system restoration plan, whose prolonged interruption may have an undesirable impact on health, safety, and the environment, and are therefore targeted for early restoration. Priority load may include off-site power for nuclear generating stations (to maintain safe shutdowns), cranking power to certain generating units, power to natural gas infrastructure (such as electric compressors), power to pumping stations for oil pipelines, military installations and flood water control installations, and power to hospitals and other emergency operations.

Reactive Power, Volt-Amperes reactive (VAR): The portion of electricity that establishes and sustains the electric and magnetic fields of alternating current equipment. Reactive power must be supplied to most types of magnetic equipment, such as motors and transformers. It is also needed to make up for the reactive losses incurred when power flows through transmission facilities.

Regional Entity: An independent, regional entity with delegated authority from NERC to propose and enforce Reliability Standards and to otherwise promote the effective and efficient administration of bulk-power system reliability.

Regional Transmission Organization: A regional transmission organization is an electric power transmission system operator which coordinates, controls and monitors a multi-state electric grid.

Registered Entity: An entity that is a user, owner, or operator of the bulk-power system that is generally required to register with NERC.

Reliability Coordinator: The entity that is the highest level of authority who is responsible for the reliable operation of the bulk electric system, has the wide area view of the bulk electric system, and has the operating tools, processes and procedures, including the authority to prevent or mitigate emergency operating situations in both next-day analysis and real time operations. The reliability coordinator has the purview that is broad enough to enable the calculation of interconnection reliability operating limits, which may be based on the operating parameters of transmission systems beyond any transmission operator's vision.

Restoration: The process of returning generators and transmission system elements and restoring load following an outage on the Bulk-Power System.

Supervisory Control and Data Acquisition (SCADA): A system of remote control and telemetry used to monitor and control the transmission system.

Synchronize: The process of bringing two electrical systems together by closing a circuit breaker at an interface point when the voltages and frequencies are properly aligned. Also, when generators are brought on-line, they are said to be synchronized to the Bulk-Power System.

System Operator: An individual at a control center of a balancing authority, transmission operator, or reliability coordinator who operates or directs the operation of the bulk electric system in real-time.

System Restoration Plan: Plan required to allow for restoring the transmission operator's system following a disturbance in which one or more areas of the bulk electric system shuts down and the use of blackstart resources is required to restore the shut-down area to a state whereby the choice of the next load to be restored is not driven by the need to control frequency or voltage regardless of whether the blackstart resource is located within the transmission operator's system.

Transmission Operator: The entity responsible for the reliability of its "local" transmission system and that operates or directs the operations of the transmission

facilities. The transmission operator is required to have a restoration plan, in accordance with Reliability Standard EOP-005-2.