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Transmission Connected Dynamic Reactive Resources and HVDC Equipment – Assessment of Applicability in Reliability Standards

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Background

The bulk power system (BPS) in North America continues to experience a change in generating resources, technologies, and transmission system devices used to provide essential reliability services (ERS) such as voltage control, frequency control, and ramping/balancing capability. In particular, the BPS is experiencing a rapid change in generation resource mix, with an increasing installation base of inverter-based generation resources and accompanying retirements of synchronous generation resources. Additionally, generation is increasingly being located farther from load centers than it was in the past. These factors are contributing to an increased reliance on non-generation transmission-connected dynamic reactive resources – both rotating machine (i.e. synchronous condenser) and power-electronics based – to provide ERS in the BPS. Synchronous condensers are being used to provide dynamic reactive power and transient voltage support, as well as synchronous inertia and fault current contribution in weak grid conditions. Static var compensators (SVCs) and static compensators (STATCOMs) are increasingly being used to provide dynamic reactive power and transient voltage support.

Many relevant NERC Reliability Standards are not applicable to these types of transmission-connected dynamic reactive resources. It is now clear that an increasing number of these reactive resources are being used to provide the same ERS as generation resources to ensure reliability of the BPS. In many cases, these types of dynamic reactive resources are critical to BPS reliability because they are used to increase power transfer capability, mitigate system instability, provide grid resilience for physical and cyber attacks, and provide safety nets for severe contingencies. In this respect, ensuring their electrical capability, verification of performance, and ability to ride through grid events is no less important than for traditional generators.

The NERC Planning Committee and the NERC System Analysis and Modeling Subcommittee (SAMS) expressed concerns that the existing NERC Reliability Standards may not clearly address non-generation transmission-connected dynamic reactive resources. In response to these concerns, SAMS has developed this white paper that comprises an assessment of the applicability of relevant NERC Reliability Standards to such dynamic reactive resources and provides recommendations to address any identified reliability gap. In particular, SAMS focused on the following NERC Reliability Standards:

- **MOD-025-2:** Verification and Data Reporting of Generator Real and Reactive Power Capability and Synchronous Condenser Reactive Power Capability
- **MOD-026-1:** Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions

- **MOD-027-1:** Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions
- **MOD-032-1:** Data for Power System Modeling and Analysis
- **PRC-019-2:** Coordination of Generating Unit or Plant Capabilities, Voltage Regulating Controls, and Protection
- **PRC-024-2:** Generator Frequency and Voltage Protective Relay Settings

Results from this assessment and recommendations for moving forward are provided in this white paper.

Applicability Assessment

SAMS reviewed relevant NERC Reliability Standards related to the model verification, capability testing, disturbance ride through, and protection coordination aspects of generation resources to evaluate if the transmission-connected dynamic reactive resources are included within the applicability sections of these standards. The goal was to determine the reliability need/justification for including transmission-connected dynamic reactive resources as applicable Facilities within the Applicability section of these standards.

Recommended Applicability

Table 1 shows the applicability of relevant NERC Reliability Standards to dynamic reactive resources – including both generation resources and non-generation transmission connected reactive resources. The cells with green bold font show the existing applicability and the cells with red bold italicized font show the recommended applicability based on this SAMS assessment .

For the assessed non-generation reactive resources (refer to Appendix A for their descriptions), each cell includes either a Yes or N/A as the recommendation for its inclusion as Facilities in the Applicability section of the relevant Reliability Standard. The technical basis and justification for the recommended applicability is provided in the following sub-sections.

Table 1: Applicability of Relevant NERC Reliability Standards to Dynamic Reactive Resources

	MOD-025	MOD-026	MOD-027	MOD-032	PRC-019	PRC-024
Synchronous Generator	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Inverter-Based[1] Generator	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Synchronous Condenser	**Yes**	***Yes***	***N/A***	**Yes**	**Yes**	***Yes***
SVC	***Yes***	***Yes***	***N/A***	**Yes**	***Yes***	***Yes***
STATCOM	***Yes***	***Yes***	***N/A***	**Yes**	***Yes***	***Yes***
LCC HVDC	***N/A***	***N/A***	***Yes***	**Yes**	***Yes***	***Yes***
VSC HVDC	***Yes***	***Yes***	***Yes***	**Yes**	***Yes***	***Yes***

Existing applicability
SAMS recommendation

[1] Nonsynchronous generating resource

Technical Basis for Applicability

The sub-sections below describe the technical basis and justification for applicability of the relevant NERC Reliability Standard to each type of transmission-connected dynamic reactive resource listed in Table 1.

MOD-025

The purpose of MOD-025 is to ensure that accurate information on generator gross and net Real and Reactive Power capability and synchronous condenser Reactive Power capability is available for planning models used to assess Bulk Electric System (BES) reliability. The technical justification for applicability of MOD-025 recommended in Table 1 is described below:

- **SVC:** A SVC serves many of the same purposes as a synchronous condenser, particularly the injection or absorption of dynamic reactive power to support steady-state and transient voltage conditions. Similar to a synchronous condenser, an SVC has a current injection capability that translates to a reactive power capability based on terminal voltage. For this reason, a power electronics resource like a SVC connected to the BPS should be a Facility to which MOD-025 is applicable for reactive power capability verification.
- **STATCOM:** A SVC and STATCOM are very similar in terms of being power electronic resources connected to the BPS that provide steady-state and dynamic voltage support. The STATCOM and SVC differ in their reactive capability, particularly under off-nominal voltage conditions. Their controls are also different based on the types of equipment technologies used in the different devices. Again, the power electronics have a current injection capability that translates to reactive power capability based on voltage. For this reason, STATCOM should be a Facility to which MOD-025 is applicable for reactive power capability verification.
- **LCC HVDC:** A LCC HVDC circuit is predominantly used to transfer large amounts of active power across long distances (as well as other applications such as underground cables, etc.). LCC HVDC technology inherently consumes very large quantities of reactive power at the converters. AC filters located at the converter terminals to mitigate harmonics also provide reactive power and offset its consumption from the grid. However, ac filters are comprised of static shunt reactive devices with known reactive capability ratings that do not need verification. LCC HVDC does not have independent control of active and reactive power because there is no voltage source within the converters. For these reasons, LCC HVDC should ***not*** be a Facility to which MOD-025 is applicable for reactive power capability verification.
- **VSC HVDC:** VSC HVDC is different than LCC HVDC in that it has independent control of active and reactive power because of the independent voltage source within the converters. Therefore, these elements are able to operate in automatic voltage control, controlling their terminal voltage (or some other compensated voltage) to support scheduled voltages on the BPS. Therefore, VSC HVDC should be a Facility to which MOD-025 is applicable for reactive power capability verification.

MOD-026

The purpose of MOD-026 is to verify 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

(BES) reliability. The technical justification for applicability of MOD-026 recommended in Table 1 is described below:

- **Synchronous Condenser:** A synchronous condenser is a synchronous machine without a prime mover (freely rotating shaft) and therefore delivers/absorbs reactive power to the BPS based on its excitation. In essence, a synchronous condenser exhibits the same dynamic behavior as a synchronous generator from the perspectives of MOD-026. A synchronous condenser should be required to provide verified dynamic models as described in MOD-026.
- **SVC:** SVCs provide dynamic reactive power to the BPS to support grid voltage, voltage stability, and power transfers. These devices include elements and controls that can respond very quickly to grid conditions (during and after faults, for example). There are no (or minimal) moving parts in these devices, and the majority of the response is determined based on the settings programmed into the controls. It is important that these control settings are verified, and the dynamic response of the model matches reality. For these reasons, SVCs should be required to provide verified dynamic models as per the intent of MOD-026.
- **STATCOM:** STATCOMs use different technology than SVCs, but they also provide dynamic reactive power to the BPS and their response is determined based on the settings programmed into the controls. Therefore, similar to SVCs, STATCOMs should be required to provide verified dynamic models as per the intent of MOD-026.
- **LCC HVDC:** For the same reasons listed in MOD-025, LCC HVDC should ***not*** be a Facility to which MOD-026 is applicable.
- **VSC HVDC:** Similar to SVCs and STATCOMs, VSC HVDC Facilities also provide dynamic reactive power to the BPS and their response is determined based on the settings programmed into the controls. Therefore, VSC HVDC should be required to provide verified dynamic models as per the intent of MOD-026.

MOD-027

The purpose of MOD-027 is to verify 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 (BES) reliability, accurately represent generator unit real power response to system frequency variations. The technical justification for applicability of MOD-027 recommended in Table 1 is described below:

- **Synchronous Condenser:** A synchronous conderser is a dynamic reactive power resource and does not have the capability to provide active power to the BPS. It does not include a turbine-governor or active power-frequency control system. Therefore, MOD-027 is not applicable..
- **SVC:** It does not include a turbine-governor or active power-frequency control system. Therefore, SVC should ***not*** be a Facility to which MOD-027 is applicable.
- **STATCOM:** A STATCOM is a dynamic reactive power resource and does not have the capability to provide active power to the BPS. It does not include a turbine-governor or active power-frequency control system. Therefore, STATCOM should ***not*** be a Facility to which MOD-027 is applicable.
- **LCC HVDC:** Although LCC HVDC is *not* a dynamic reactive power resource, it has the capability to provide active power/frequency control to the BPS. Since its active power/frequency control system

response is determined based on the settings programmed into the controls, it should be required to provide verified dynamic models as per the intent of MOD-027.

- **VSC HVDC:** A VSC HVDC is a dynamic reactive power resource and also has the capability to provide active power/frequency control to the BPS. Since its active power/frequency control system response is determined based on the settings programmed into the controls, it should be required to provide verified dynamic models as per the intent of MOD-027.

MOD-032

MOD-032 has sufficiently comprehensive applicability to include transmission-connected dynamic reactive resources for the purposes of obtaining their modeling data. Therefore, SAMS does not recommend any changes to the applicability of MOD-032.

PRC-019

The purpose of PRC-019 is to verify coordination of generating unit Facility or synchronous condenser voltage regulating controls, limit functions, equipment capabilities and Protection System settings. The technical justification for applicability of PRC-019 recommended in Table 1 is described below:

- **Synchronous Condenser:** A synchronous condenser is protected with a number of protective functions and limiters, similar to a synchronous generator. If not properly coordinated, the limiters and protection elements could potentially limit the output or trip the machine below its rated capability. Therefore, PRC-019 should be applicable to synchronous condensers.
- **SVC:** Analogous to the synchronous machines, SVCs have voltage regulating controls, limiters, and protection functions. If not properly coordinated, the limiters and protection elements could potentially limit the output or trip the SVC below its rated capability. Therefore, PRC-019 should be applicable to SVCs.
- **STATCOM:** Analogous to the SVCs, STATCOMs have active and reactive voltage regulating controls, limiters, and protection functions. If not properly coordinated, the limiters and protection elements could potentially limit the output or trip the STATCOM below its rated capability. Therefore, PRC-019 should be applicable to STATCOMs.
- **LCC HVDC:** LCC HVDC does not have independent control of active and reactive power because there is no voltage source within the converters. To the extent that LCC HVDC has voltage regulating controls, limiters, and protection functions, they, they could potentially limit the LCC HVDC output below its rated capability if not properly coordinated. PRC-019 should be applicable to LCC HVDC due to its control and protection equipment abilities.
- **VSC HVDC:** VSC HVDC does have independent control of active and reactive power because they use voltage source converters. Analogous to the SVCs and STATCOMs, the VSC HVDC has voltage regulating controls, limiters, and protection functions. If not properly coordinated, the limiters and protection elements could potentially limit the VSC HVDC output below its rated capability. PRC-019 should be applicable to VSC HVDC due to its control and protection equipment abilities.

PRC-024

In the “Evaluating Protective Relay Settings” section of PRC-024 --Attachement 2 Item #2 states that the GO must “Evaluate voltage protective relay settings assuming that additional installed generating plant reactive

support equipment (such as static VAR compensators, synchronous condensers, or capacitors) is available and operating normally." However,this evaluation focuses on reactive power devices within the generating plant and does not include similar reactive power devices that are transmission connected.
The purpose of PRC-024 is to ensure Generator Owners set their generator protective relays such that generating units remain connected during defined frequency and voltage excursions. The technical justification for applicability of PRC-024 recommended in Table 1 is described below:

- **Synchronous Condenser:** Synchronous condensers, like synchronous generators, have frequency and voltage protective relays whose settings should not be within the ride through characteristics of PRC-024. Undervoltage and overvoltage protection, overspeed protection, etc., are all applied to a synchronous condenser since it is inherently a rotating electric machine without a prime mover. The synchronous condenser is expected to ride through grid voltage and frequency excursion events to provide dynamic voltage support and provide system inertia for stabilizing wide-area system frequency. Therefore, PRC-024 should be applicable to synchronous condensers.
- **SVC:** SVCs provide dynamic reactive power support during and immediately after a grid disturbance during the transient timeframes. In this respect, its purpose and functionalty is very similar to that of synchronous condensers (and synchronous generators). The SVC would be expected to ride through grid voltage and frequency excursion events to provide dynamic voltage supportsupport herefore, PRC-024 should be applicable to SVCs.
- **STATCOM:** STATCOMs provide dynamic reactive power support during and immediately after a grid disturbance during the transient timeframes. In this respect, its purpose and functionalty is very similar to that of synchronous condensers and SVCs. The STATCOM would be expected to ride through grid voltage and frequency excursion events to provide dynamic voltage support. PRC-024 should be applicable to STATCOM.
- **LCC HVDC:** The LCC HVDC would be expected to ride through grid voltage and frequency excursion events to provide continuity of service (i.e. maintaining MW output). Therefore, PRC-024 should not be applicable to LCC HVDC.
- **VSC HVDC:** VSC HVDC provide dynamic reactive power support during and immediately after a grid disturbance during the transient timeframes. In this respect, its purpose and functionalty is very similar to that of SVCs and STATCOMs. The VSC HVDC would be expected to ride through grid voltage and frequency excursion events to provide dynamic voltage support. Therefore, PRC-024 should be applicable to VSC HVDC.

Other Considerations

The following additional considerations were noted during the assessment. While not necessarily directly related to the assessment of applicability of elements to relevant NERC Standards, SAMS believes these additional topics are important and should be addressed.

1. Definitions for the following terms should be reviewed for potential additions and/or revisions in the NERC Glossary of Terms include, but are not limited to, the following:
    a. Generator (or Generating Facility)
    b. Generating Unit Capability[2]
    c. Dynamic Reactive Power
    d. Synchronous Condenser
    e. Static Var Compensator (SVC)
    f. Static Synchronous Compensator (STATCOM)
    g. High Voltage DC (HVDC)
    h. Line Commutated Converter (LCC) HVDC
    i. Voltage Source Converter (VSC) HVDC
    j. Flexible AC Transmission Systems (FACTS)
2. NERC SAMS and the NERC Power Plant Modeling and Verification Task Force (PPMVTF) have both identified a significant inconsistency between the intent of MOD-025-2 to "ensure that accurate information on generator…capability[3] is available for planning models used to assess Bulk Electric System (BES) reliability" and the actual results obtained during testing. MOD-025-2 does not require the full (maximum achievable) reactive capability of the resource to be reached via test. This is warranted because the testing conditions likely will limit the resource from reaching its full (maximum achievable) reactive capability before other limits are reached such as system voltage, generator terminal voltage, or auxiliary bus voltage limits. While this is reasonable for testing, the standard does not require calculations to be performed to prove that the resource could reach its full (maximum achievable) reactive capability under more favorable operating conditions (i.e. when that full reactive capability is needed for maintaining voltage schedule). Therefore, there is a significant misconception in the industry that the testing results should be used as the same data submitted for MOD-032-1 for capability of the machine. This misconception is likely leading to incorrect data being supplied for the purposes of MOD-032-1 and is driven by the requirements in MOD-025-2.

[2] This is a defined term; however, the definition is not sufficiently reflective of the term.
[3] and synchronous condenser reactive power capability