Decarbonization Readiness Assessment Mapping: Description of Stages

globalpst.org/what-we-do/system-operator-technical-support/decarbonization-readiness-assessment-mapping-framework

Background

This document details three of the four stages that comprise the **Decarbonization Readiness Assessment Mapping (DREAM)**. The purpose of this document is to offer a complete overview of each stage to ensure a thorough comprehension of their individual characteristics. This is useful when using the Decarbonization Readiness framework, as detailed in the "How To Use the Material" section in the "Overview and Guide" factsheet (globalpst.org/what-we-do/system-operator-technical-support/decarbonization-readiness-assessment-mapping-framework).

These descriptions have been compiled from system operators worldwide, incorporating the best available knowledge of power system operations and other relevant domains. While this document represents a comprehensive synthesis of industry and academic knowledge on this topic, it remains subject to continuous refinement and improvement.

Acronyms

DSO	distribution system operator
EMT	electromagnetic transients
GFM	grid-forming
IBR	inverter-based resource
MAE	mean absolute error
RMS	root mean square
TSO	transmission system operator
VRE	variable renewable energy

Introduction

The framework evaluates the readiness of an electric power system to reliably operate in the future with high levels of variable renewable energy (VRE) integration and clean energy. It employs a comprehensive approach, considering key system attributes:

- **Transmission capacity:** Refers to the ability to transport energy across the entire system while maintaining reliability, safety, and economy.
- **Power flexibility:** Refers to the ability of the system to maintain the generation-demand balance under different scenarios and timescales, guaranteeing frequency stability and reliable operation.
- **System security:** Refers to the ability of the system to provide active and reactive power in different timescales and provide damping capabilities to avoid local or systemic instabilities or violations of statutory levels of voltage, frequency, and power quality. More generally, system security is a well-known concept referring to the ability of an interconnected power system to withstand disturbances and maintain a continuous supply of electricity.
- **Energy sufficiency (ES):** Refers to the ability of the system to ensure the future supply of electricity in the medium and long term.

Stage descriptions continued on the following pages.

For More Information

Get involved with the Global Power System Transformation Consortium (G-PST): globalpst.org/get-involved.

G-PST is the world's only consortium of power system operators focused on advancing the technical solutions necessary to manage the grid's shift from largely synchronous machines to much higher contributions from inverter-based resources. G-PST supports the energy transition via the development and implementation of: grid operator tools and methods to improve situational awareness, control, and decision-making within the control room; interconnection codes and standards for inverter-based resources; and targeted support for broadening and deepening the workforce.

Stage A: Ready for VRE

Transmission

1. Few or no localized VRE curtailment cases are caused by avoiding thermal violations of existing transmission lines in the system's current state, but some cases are noted in planning scenarios. No transmission expansions are planned to mitigate.

2. Not all electrical areas are well interconnected (well interconnected generally means that no planned maintenance causes limitations in power exchange between areas).

3. The system does not have cross-border interconnections with neighboring systems, or existing interconnections are insufficient to provide support either as ancillary services (power balancing) or bulk energy imports/exports.

Power Flexibility

1. The system does not have fast-ramping capabilities as a service, but increasing demand in early evening hours and fast VRE variability do not represent a risk for normal and secure operation due to the low VRE share (particularly solar photovoltaics). Future planning scenarios reveal that operating costs can increase to securely operate through these hours.

2. The system does not have storage technologies deployed that can support reducing supply-side curtailment or unserved demand.

3. The system operator does not have formalized intra-day or near-real-time dispatch mechanisms (<24 hours).

4. The system operator does not have robust real-time forecast ensembles for solar and wind production or calculated residual-demand ramps mean absolute error [MAE] below 5%).

5. The grid code and/or market rules do not have clear specifications or incentives for the provision of dynamic containment services for all potential providers (e.g., generators, synchronous condensers, energy storage, flywheels, or others), but current installed capacity can provide sufficient reserves for secure operation. Nevertheless, there are efforts in progress to develop and incorporate such rules.

6. The grid code and/or market rules do not have clear specifications and/or incentives for demand response.

7. Distribution entities do not act as active distribution system operators (DSOs), performing monitoring and control actions under their distribution systems to aid in balancing generation and demand. Further, DSOs do not share significant telemetry with the transmission system operator (TSO).

8. The system operator (TSO) and distribution entities (DSOs) do not have ongoing efforts to establish or formalize DSO-TSO cooperation.

Security

1. The grid code has strong electrical modeling requirements for power flow, short-circuit, contingency, and root mean square (RMS) performance characteristics but none for electromagnetic transient (EMT) analyses.

2. Highly trained personnel perform demanding technical electrical engineering and market modeling tasks but lack experience in EMT-type analyses.

3. The system operator has advanced monitoring techniques for 100% of the bulk power system in the form of supervisory control and data acquisition (SCADA).

4. The system operator does not have the methods or tools to locate or prevent oscillation sources.

5. The grid code does not have clear rules that define or incentivize ancillary services related to system stability like inertia (or equivalent inertial responses) short-circuit current, or dispatching of active/reactive power in appropriate time frames. However, due to the low VRE share, they are not widely needed.

6. Transmission connected VRE sources can provide ancillary services for frequency containment and voltage stability in a wide range of time stamps, but those connected to sub-transmission or distribution level networks cannot or have not been tested nor are they required to do so.

7. The system operator has robust methods to assess the adequate participation of each resource in the transmission system to meet ancillary services requirements.

8. The system does not have grid-forming (GFM) inverter-based resources (IBRs) located in strategic parts of the grid to operate under low system strength conditions or to potentially help with black start.

9. Distribution entities do not act as active system operators (DSOs) and do not have (nor are there plans to have) validated electrical models of their networks to perform reliability simulations.

10. Distribution entities do not have visibility into the performance of distributed energy resources and are not able to determine whether they can respond to dynamic events (e.g., voltage and frequency ride-through or responses, amongst others).

11. Distribution entities do not perform monitoring and control actions for their distribution systems to leverage available control of loads or generation that could support power quality and reliability.

Energy Sufficiency

1. The system operator accurately forecasts conventional fuel availability (water, solar, wind, and thermal fuels) in the medium to long term (ranging from days to years).

2. The system operator team successfully forecasts wind and solar generation in the short term (<24 hours) with MAE <5%.

3. The system operator successfully forecasts residual demand in the short term (<24 hours) with MAE <5% and in the medium term (<10 days) with MAE <10%. Long-term demand forecasts (>10 days) have a confidence interval of +/- 10% around predicted peak demand (well-known demand sectors enable this, no novel demand types, e.g., transportation electrification, data centers, others).

4. The most predominant form of conventional generation in the system (non-VRE) has high expected supply capabilities in moments of low VRE.

5. VRE resources are concentrated in specific geographic areas of the system, which makes them collectively vulnerable to the same weather events. As a result, periods of low solar irradiance or low wind conditions can lead to simultaneous drops in generation across the entire VRE fleet, reducing overall system resilience.

6. The lack of complementary behavior between wind and solar generation poses challenges for power system reliability and flexibility, as their simultaneous variability can exacerbate net load fluctuations across different operational timescales.

Stage B: Integrating VRE

Transmission

1. A significant number of localized VRE curtailment events occur during a limited number of hours each year. These are caused by efforts to avoid violations of existing transmission lines (thermal, voltage, stability) under current grid conditions and medium-term planning scenarios. However, specific mitigation measures (primarily transmission expansions) are already planned to address these issues.

2. Almost all electrical areas are well interconnected (well interconnected generally means that planned maintenance does not cause limitations in power exchange between areas).

3. The system does not have cross-border interconnections with neighboring systems, or existing interconnections are insufficient to provide support either as ancillary services (power balancing) or bulk energy imports/exports. However, there are plans to interconnect or to reinforce existing interconnections.

Power Flexibility

1. The system does not exhibit fast ramping capabilities inherent in the resource mix or on the demand-side, nor does it define this as a system need (an ancillary service), resulting in the potential for VRE variability to represent a risk for normal and secure operations. However, due to low relative VRE share, it is possible to safely handle VRE production changes (solar photovoltaics and/or wind) during low-demand periods by dispatching existing resources. Work is ongoing to develop ramping as a flexibility ancillary service.

2. The system operator does not have formal close to real-time dispatch mechanisms (<24 hours) but there is ongoing work to consider these further.

3. The existing grid code does not have clear rules to incentivize dynamic containment services from all potential providers (e.g., generators, synchronous condensers, energy storage, flywheels, or others), but existing installed capacity can provide sufficient reserves for secure operations. Nevertheless, there are efforts in progress to develop such rules.

4. No storage technologies are deployed on the grid that can support reducing supply-side curtailments or unserved demand.

5. The system operator does not have robust real-time forecast ensembles for solar and wind generation, calculated residual-demand ramps, and demand (MAE<5%).

6. The grid code does not have clear rules and incentives for demand response programs.

7. The system operator does not have ongoing projects to formalize DSO-TSO cooperation.

8. Distribution entities do not act as active distribution system operators (DSOs), performing monitoring and control actions under their distribution systems to aid in balancing generation and demand. Further, DSOs do not share significant telemetry with the transmission system operator (TSO).

Security

1. The grid code has strong electrical model requirements for steady-state (power flow and fault simulations) and phasor domain simulations (i.e., RMS simulation) but not for EMT simulations. However, plans exist to include in new regulations/procedures the need for these types of models and related assessments of system security.

2. The system operator has highly trained personnel to perform demanding electrical and market modeling tasks, but staff lacks experience in further detailed time-domain simulations (EMT-type simulations or equivalent).

3. The system operator has advanced monitoring techniques for 100% of the bulk power system in the form of supervisory control and data acquisition.

4. The system operator does not have the tools nor the methodologies to prevent oscillations or locate oscillation sources.

5. The grid code does not have strict requirements for obtaining and dispatching ancillary services like inertia, short-circuit current dynamic active/reactive power support, or other services to support system stability in different time ranges. Due to the relatively low VRE share, these are not urgently needed; however, some system conditions now and anticipated near-future show that they will be needed to solve potential localized low system strength conditions to avoid instability.

6. VRE sources connected to transmission networks can provide ancillary services for frequency containment (P-F response) and dynamic voltage support (Q-V response), but those connected to sub-transmission and distribution networks cannot be or have not been tested, nor are they required to provide these services.

7. The system operator has strong methods to assess the adequate participation and capability of each resource in the transmission system to provide required ancillary services.

8. The transmission system does not have GFM IBRs deployed to potentially operate under low system strength conditions or to help with black start.

9. Distribution utilities do not act as active system operators (i.e., as DSOs) and do not have (nor are there plans to have) validated electrical models of their distribution networks to perform reliability and stability simulations.

10. Distribution utilities do not check that distributed energy resources comply with regulations related to voltage and frequency support and ride-through capabilities.

11. Distribution utilities do not perform monitoring and/or control actions in their distribution systems to leverage available potential controllable loads and distributed energy resources to solve reliability or power quality grid violations.

Energy Sufficiency

1. The system operator accurately f1. The system operator accurately forecasts conventional fuel (water, solar, wind, and thermal fuels) availability in long-term periods (ranging from days to years).

2. The system operator successfully forecasts wind and solar generation in short-term periods (<24 hours) with MAE<5%.

3.The system operator does not forecast residual demand in the short term (<24 hours) with MAE <5% nor in the medium term (<10 days) with MAE <10%. Similar applies to long-term demand forecasts (>10 days) with a confidence interval of +/- 10% around predicted peak demand, (particularly for electrification of transportation and/or buildings). However, projects are in place to improve forecast methodologies.

4. The dominant form of conventional generation (non-VRE) has high expected supply expectations during periods of potentially low VRE.

5.VRE resources are concentrated in specific geographic areas of the system, which makes them collectively vulnerable to the same weather events. As a result, periods of low solar irradiance or low wind conditions can lead to simultaneous drops in generation across the entire VRE fleet, reducing overall system resilience.

6. The lack of complementary behavior between wind and solar generation poses challenges for power system reliability and flexibility, because their simultaneous variability can exacerbate net load fluctuations across different operational timescales.

Stage C: Ambitious VRE

Transmission

1. A significant number of localized VRE curtailment events occur during a limited number of hours each year. These are caused by efforts to avoid violations of existing transmission lines (thermal, voltage, stability) under both current grid conditions and medium-term planning scenarios. However, specific mitigation measures (primarily transmission expansions) are already planned to address these issues.

2. All electrical areas are strongly interconnected (strongly interconnected generally means that planned maintenance does not cause limitations in power exchange between areas).

3. The transmission system has cross-border interconnections with neighboring systems, and they are sufficient to provide support in the form of ancillary services (power balancing) or bulk energy imports/exports.

Power Flexibility

1. The transmission system does not have resources with fast ramping capabilities inherent in the resource mix, nor does the system operator define this as a system need (an ancillary service), resulting in VRE variability potentially representing a risk for normal and secure operations. However, due to day-ahead and intra-day workflows, it is possible to safely handle sudden production decreases (from solar photovoltaics) as well as large wind production during challenging low-demand periods by dispatching existing generation resources as needed. There is ongoing work at the system operator to develop ramping as an ancillary service providing flexibility.

2. The system operator has formal close to real-time dispatch mechanisms (<24 hours), but there is ongoing work to propose <1 hour dispatch mechanisms.

3. The existing transmission system has storage technologies deployed to avoid curtailments or unserved demand in short time frames (<10 hours).

4. The system operator has robust real-time forecasts for solar and wind generation as well as residual demand forecasts (MAE <5%).

5. The grid code has clear rules to require or incentivize dynamic response services from all potential providers (generators, batteries, flywheels, synchronous condensers and demand response, amongst others).

6. The grid code has strong and clear rules or incentives defined for demand response. At minimum, there are programs to implement demand response in adjusting electricity consumption in response to grid conditions.

7. Work is ongoing to formalize DSO-TSO cooperation.

8. Some distribution entities act as active distribution system operators (DSOs), performing monitoring and control actions under their distribution systems to aid in balancing generation and demand. Further, all DSOs share significant telemetry with the transmission system operator (TSO).

Security

1. The grid code has strong electrical model requirements for steady-state (powerflow), phasor domain simulations (also known as root mean square), and EMT simulations.

2. The system operator has highly trained personnel to perform demanding electrical and market modeling work required for integration between system and market operations, including EMT-type simulations.

3. The system operator has advanced monitoring techniques for 100% of the bulk power system in the form of supervisory control and data acquisition and a wide area management system.

4. The system operator has tools and methodologies to find and isolate the causes of oscillations but not to prevent their occurrence in real-time operations.

5. The grid code does not have strong rules to obtain and dispatch ancillary services like inertia, short-circuit current, active/reactive power in different time ranges, and other services related to system stability. However, equipment is installed in the grid to help ensure these needs are met (sync. condensers, flywheels, GFM batteries, etc.).

6. VRE sources connected to transmission networks can provide ancillary services for frequency containment (P-F response) and dynamic voltage support (Q-V response) but those connected to sub-transmission and distribution networks cannot or have not been tested, nor are they required to provide these services.

7. The system operator has strong methods to assess adequate participation of each resource in the system to provide required or incentivized ancillary services.

8. No GFM IBRs deployed in strategic parts of the transmission network (to operate under low system strength or help with black start). However, there are active investigations into how GFM IBRs can best help system stability and resilience.

9. Distribution utilities act as DSOs (active system operators) and have (or are planning to have) electrical models of their low-voltage grid to perform reliability and stability simulations.

10. DSOs check that distributed energy resources comply with regulations related to voltage and frequency support and ride-through capabilities.

11. Distribution utilities do not perform monitoring and control actions on their distribution system to leverage available load and generation resource control to support reliability and power quality violations.

12. The system operator and responsible regulatory agency employ a systematic approach to technological innovation surveillance to continuously learn from evolving power system developments (e.g., GFM IBRs, flexible AC transmission systems, grid-enhancing technology), and to adapt strategies to enable pilot and commercial application in production environments to ensure long-term system stability.

Energy Sufficiency

1. The system operator accurately forecasts conventional fuel (water, solar, wind, and thermal fuels) availability in long-term periods.

2. The system operator successfully forecasts VRE generation in short-term periods (<24 hours) with MAE <5%.

3. The system operator successfully forecasts residual demand in the short term (<24 hours) with MAE <5% and in the medium term (<10 days) with MAE <10%. Long-term demand forecasts (>10 days) have a confidence interval of +/- 10% around predicted peak demand. This includes the electrification of transportation and buildings in the system.

4. There is no expected shortage of conventional fuel for dispatchable generation in long-term forecasts, ensuring a reliable supply during periods of low VRE.

5. VRE resources are concentrated in specific geographic areas of the system, which makes them collectively vulnerable to the same weather events. As a result, periods of low solar irradiance or low wind conditions can lead to simultaneous drops in generation across the entire VRE fleet, reducing overall system resilience.

6. The lack of complementary behavior between wind and solar generation poses challenges for power system reliability and flexibility, as their simultaneous variability can exacerbate net load fluctuations across different operational timescales.