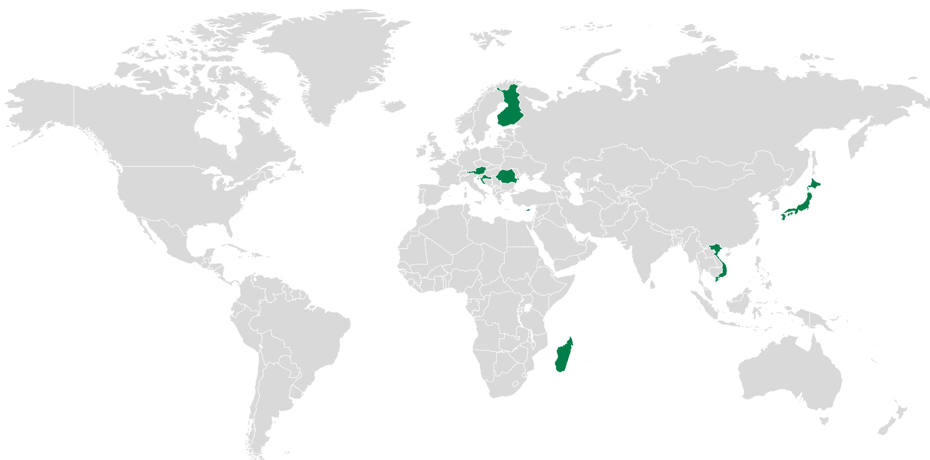
Decarbonization Readiness Assessment Mapping

Archetype: Integrator (Stage BC)

Example Integrator (Stage BC) System Operator Archetypes Based on Decarbonization Readiness Assessment Mapping:



Austria, Croatia, Cyprus, Finland, Japan, Romania, Sri Lanka, and Vietnam.

Acronyms

DER	distributed energy resource
DSO	distribution system operator
EMT	electromagnetic transient
ES	energy sufficiency
IBR	inverter-based resource
PF	power flexibility
SS	system security
SCADA	supervisory control and data acquisition
TC	transmission capacity
TSO	transmission system operator
VRE	variable renewable energy

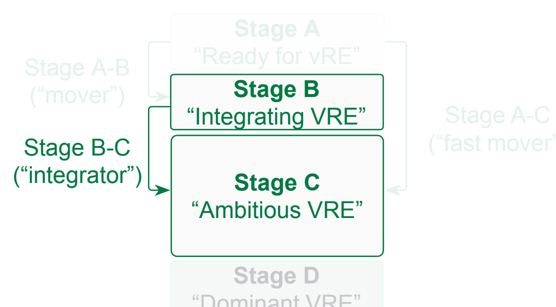


Figure 1. DREAM archetypes.

Attributes/Themes	Stability	Grid Codes and Standards	Services
Business Practices	• Goal PF1	• Goal PF2 • Goal SS10	• Goal SS2
Facilities and Equipment	• Goal SS5 • Goal SS7	• Goal PF5 • Goal PF6 • Goal PF7 • Goal SS6	• Goal TC1 • Goal TC2 • Goal TC3 • Goal PF3 • Goal SS3 • Goal ES1 • Goal ES2
Tools, Data, and Methods	• Goal SS4	• Goal SS1 • Goal PF8	• Goal PF4 • Goal SS8 • Goal SS9 • Goal ES3

Table 1. Summary of Attributes for Stage BC (Integrator) System Archetype Across Themes

Introduction

Power systems around the world vary widely in terms of their electrical characteristics, available natural resources, and ambition and time frames for decarbonization. Power systems that share similar physical characteristics also face similar technical challenges as they advance, which typically involves increasing integration of variable energy resources with power electronics interface (known as inverter-based resources) like wind, solar photovoltaics and batteries.

The **Decarbonization Readiness Assessment Mapping (DREAM)** framework seeks to inform high-impact technical activities and their prioritization based on an approach applying archetypes capturing systems with similar characteristics. These activities describe the technical actions that are fit-for-purpose for specific power system archetypes, as defined by the characteristics that most influence the operational changes that these systems will experience as they progress through increasing levels of decarbonization.

This factsheet outlines the decarbonization pathway for Stage BC ("Integrator").

The DREAM framework is based on the following concepts:

- An **intake** establishing the characteristics of the existing and future (10 years, based on goals) interconnected bulk power system.
- The intake is informed based on a range of inherent interconnected bulk power system **characteristics** (clean energy, transmission capacity, power flexibility, system security, energy sufficiency) [1],[2] as provided by a system operator (primary audience) or a sponsor, regulator, solutions provider, or practitioner (secondary audience).
- These data are used to establish the equivalent **stage** of decarbonization of the interconnected bulk power system using simple mathematical operations and logic, as detailed further in the "Overview and Guide" factsheet.
- The mapping to an **archetype** is then based on the two stages defining the power system (present and 10 years in future).
- From this, DREAM uses **themes** (stability, grid codes and standards, services, and inverter-based resource [IBR] capabilities and needs) across a set of attributes (including business practices; facilities and equipment; and tools, data, and methods).
- The **goals** of each archetype align with the end-stage descriptors outlined in the "Description of Stages" factsheet.

DREAM Overview

For further context on the DREAM framework, see the **"Overview and Guide" factsheet**, in which more information is provided on the purpose, framework, archetypes, and how to use these materials [3].

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

This factsheet is intended to serve as a reference tool for end users of this framework to guide deeper strategy development and prioritization of implementation actions. To understand how these goals relate to the broader progression of system transformation, readers should refer to the "Description of Stages" factsheet, which provides an overview of the key characteristics defining each stage of the system landscape.

What Is an Integrator Archetype (Stage BC)?

An Integrator ("Stage BC") archetype is a system that is starting from a modest level of decarbonization but is aiming to integrate ambitious levels of clean energy in the next 10 years (**Figure 1**).

Themes and Attributes

The goals and resulting technical actions across the characteristics of the power system archetype can be categorized into the themes and attributes of the DREAM framework (**Table 1**).

Transmission Capacity

This characteristic refers to the ability to transport energy across the interconnected power system while maintaining reliability, safety, and economic efficiency.

Goal TC1:

Mitigation measures, primarily transmission expansions, are already planned to address a significant number of localized VRE curtailment events that 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.

Actions:

1. Create a comprehensive set of scenarios where expected utility-scale VRE generation across the entire system varies from the full expected range of VRE (0 to maximum for a feasible dispatch), in a 1-year horizon, under different energy demand scenarios with detailed expected grid topology in 10 years.
2. Perform a complete contingency analysis of the interconnected bulk power system (single-circuit contingency, at least), and identify elements that cause thermal or voltage constraints associated with VRE sources (i.e., reducing VRE will alleviate the constraint).

Outcome:

Corroborate that the interconnected bulk power system is on a path toward stronger transmission capacity with the previous expansion decisions made.

Goal TC2:

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

Actions:

1. Create a comprehensive set of scenarios in which expected utility-scale VRE generation across the entire system varies from the full expected range of VRE (0 to maximum for a feasible dispatch), in a 1-year horizon, and the internal generation inside each electrical area is either at its maximum capacity or minimum with detailed expected grid topology in 10 years.
2. Perform a full contingency analysis under different interregional planned outages (degraded grid) and corroborate that there are no elements that cause thermal constraints associated with VRE sources (i.e., reducing VRE will alleviate the thermal constraint).

Outcome:

Strong interregional interconnection will allow generation dispersed across large areas to be transferred across the entire system even during maintenance work that degrades the grid, strengthening the ability of the system to maintain safe and reliable operation.

Goal TC3:

Where feasible and applicable, establish or reinforce cross-border interconnections with neighboring systems to provide sufficient support for ancillary services (power balancing) and bulk energy imports/exports.

Actions:

1. Create a comprehensive model-based assessment of all expected grid conditions (and market conditions, where appropriate) in the next 10 years with and without planned cross-border interconnections to assess adequacy, stability, and pricing conditions of the system under these scenarios (holding other input assumptions constant to isolate the potential impacts of increased interconnection with neighboring systems).
2. Study the effect on expected system adequacy, stability, and pricing with and without cross-border interconnections (capturing the potential benefits of high-voltage AC and high-voltage DC interconnections).
3. Corroborate that better performance is found with cross-border interconnections.

Outcome:

Corroborate the importance of existing interconnections with neighboring systems to provide an improvement in energy efficiency and stability.

Power Flexibility

This characteristic refers to the ability of the system to maintain the generation-demand balance under different scenarios, guaranteeing frequency stability and reliable operation.

Goal PF1:

Define fast ramping as a system need (an ancillary service) to ensure secure operations with increasing VRE variability, building on current efforts and the existing ability to handle VRE production changes during low-demand periods.

Actions:

1. Create a generation and demand forecast for a typical future 24-hour operating scenario in which weather conditions and electrical demand profile forecasts are considered with their respective uncertainties for a 5-15-minute-ahead forecast together with ramping capabilities of existing flexibility providers (most likely generators).
2. Calculate the quantity of available reserves needed to maintain stable and secure operations during the highest residual demand ramp periods (typically sunset hours when solar photovoltaics is dominant).

3. Get the 95th percentile value (typical) of spinning reserves needed along the studied horizon and evaluate the costs associated with this quantity of reserve.
4. Repeat Actions 2 and 3 but considering new technologies like synchronous condensers, flywheels, energy storage systems, demand response, and generators, that can participate in the provision of active power as fast as 2 minutes and hold for typically 15 minutes.

Outcome:

Prove the cost-benefit effectiveness of having the provision of fast active power to cope with fast variations of VRE resources and initiate the processes needed to require this ancillary service.

Goal PF2:

Establish close-to-real-time dispatch mechanisms (less than 1 hour).

Actions:

1. Repeat Actions 1–3 from Goal PF1 but consider weather conditions and electrical demand profile forecast uncertainties at a sub-hourly level (5–30-minute-ahead forecast).
2. Asses the capability of existing generation to respond to less than 1-hour dispatch mechanisms (5-30 minutes).
3. Formalize a process to create closer-to-real-time dispatch mechanisms with the statutory procedure appropriate to the system.

Outcome:

Demonstrate the benefits of less than 1-hour dispatch mechanisms in economic efficiency and system reliability.

Goal PF3:

Deploy storage technologies on the grid that help avoid curtailments or unserved energy in short time frames (<10 hours).

Actions:

1. Identify critical scenarios in which single contingencies might cause either generation curtailment or demand being unserved in future scenarios (10 years).
2. Identify the most sensitive locations on the bulk interconnected power system to potentially deploy dynamic components capable of dynamically injecting/absorbing energy to ensure reliability.
3. Compare the cost of installing these dynamic components, including energy storage systems, relative to alternative solutions.
4. Establish and formalize a mechanism for building cost-effective solutions found in the previous steps.

Outcome:

Maintain supply to regional security standards at all times, even in localized parts of the grid where large variations of generation, demand, or single contingencies might cause unserved energy.

Goal PF4:

Develop robust solar and wind generation, ramps, and residual demand forecasts (mean absolute error below 5%).

Actions:

1. Develop a set of tools to forecast (ensembles): Numerical weather prediction models, statistical approaches, hybrid models, sky imagers and satellite imaging, and machine learning models.
2. Benchmark the performance of these tools against each other specifically for wind and solar resource expectations (forecasts for 5 minutes, 1 hour, 1 day, 1 week).
3. Select the methodologies (and supporting ensembles) that perform better in the appropriate time frames (i.e., able to achieve a mean absolute error below 5%).
4. Implement the selected methodologies in sandbox environment for an initial period (6–12 months) followed by deployment into production for normal operations.

Outcome:

Strong weather forecast of wind and solar resources as well as demand as a key contributor for secure and economic operations.

Goal PF5:

Develop clear grid code rules to incentivize dynamic containment services from all potential providers (e.g., generators, synchronous condensers, energy storage, flywheels, or others).

Actions:

1. Create, within a phasor domain simulation tool (positive sequence), scenarios of high VRE and high/low demand. Perform dynamic simulations of the loss of the largest conventional generator and the loss of the maximum VRE sources possible through the loss of a common component.

2. Ensure that fault ride-through characteristics and the suite of active and reactive power supply capabilities of VRE are properly modeled.
3. Check that the frequency is contained and no under-frequency load shedding stage is activated.

Outcome:

Demonstrate that, even under the high-stress scenarios, enough reserves are available to maintain frequency stability due to the fast provision of active power.

Goal PF6:

Establish strong and clear rules and incentives for demand response, and, at minimum, implement projects that enable demand-side response to adjust electricity consumption in response to grid conditions.

Actions:

1. Repeat Actions 1–4 in Goal PF1 with demand-side response represented based on capabilities and/or system needs.
2. Repeat Actions 1–3 of Goal PF5 with demand-side response modeled in phasor domain simulation models.
3. Engage with distribution system operators (DSOs) and relevant regulatory entities to assess hardware, software, and communication tools to enable demand-side response based on the characteristics defined in Actions 1 and 2.
4. Clarify the remuneration of such improvements with DSOs and regulators to establish the role of demand-side response.

Outcome:

Unveil the importance of demand response as a key aspect of power flexibility as well as unlock the modeling simulation capabilities of personnel; additionally, start the engagement with DSOs, as it is crucial.

Goal PF7:

Formalize DSO-transmission system operator (TSO) cooperation through structured collaboration. response to grid conditions.

Actions:

1. Quantify the level of distributed energy resource (DER) penetration expected in the coming 10 years.
2. Repeat Actions 1 and 2 in Goal PF5 with some level of DER aggregation properly included in the simulation tool.
3. Create a sensitivity analysis in which DER compliance is investigated.
4. Quantify the energy stored in DERs to provide system flexibility.
5. Quantify the impact of DER noncompliance with the current grid code to the system stability and the possible help these can provide to the system.

Outcome:

Create a DSO-TSO working group and a clear cooperation framework to enable complex operation between operators across all voltage levels in the system.

System Security

This characteristic refers to the ability of the system to provide active and reactive power in different time frames, to provide damping capabilities to avoid local or systemic instabilities or violations of statutory levels of voltage, frequency, and power quality.

Goal SS1:

Establish strong electrical model requirements for electromagnetic transient (EMT), root mean square, and powerflow simulations.

Actions:

1. Identify the system components that might be involved in converter-driven or resonance stability (e.g., series compensated lines near generators, IBRs in parts of the grid that can be weak under certain operating conditions, points of common coupling with high numbers of IBRs, etc.).
2. Assess the impact of losing such components in the stability of the grid in high-VRE and high/low-demand operating scenarios.
3. Use this result to justify the need for detailed simulations to avoid instabilities in the grid and formalize the need to get detailed parameters of electrical components in the grid from owners/operators to be able to perform such detailed simulations.

Outcome:

Convey to decision makers and industry incumbents the technical importance of EMT simulations and initiate efforts to address the requirements for their successful implementation.

Goal SS2:

Maintain highly trained personnel to perform demanding electrical, energy, and market modeling work, with EMT training underway.

Actions:

1. Identify the horizon at which EMT simulations will be performed in your system.
2. Create or select the responsible team for EMT analysis in the appropriate time horizon and complement the team with highly motivated volunteers within the system operator (potential external support for on-the-job training and technical support could be valuable in this new domain).

Outcome:

Work on developing human capabilities to operate high-VRE systems, including training personnel in novel simulation techniques.

Goal SS3:

Implement advanced monitoring techniques of 100% of the bulk power system in the form of supervisory control and data acquisition (SCADA) and/or wide-area monitoring system.

Actions:

1. Quantify the ability to estimate the state of the bulk interconnected system, voltage magnitudes, and angles at all buses and power flows at all circuits, using the available measurements.
2. If the estimated visibility is less than 100%, important measures should be identified to install monitoring devices to be part of the SCADA and/or wide-area monitoring systems.
3. Demonstrate the importance of high observability in the system to stakeholders to work with incumbent companies with the proper funds to solve the missing measurements in the system.

Outcome:

Bridge the gap between transmission companies and TSOs for missing telemetry data (where appropriate) to ensure high levels of observability.

Goal SS4:

Ensure tools and methodologies are available and ready to find oscillation sources to prevent their occurrence in real-time operations.

Actions:

1. Establish a strong validation process for the EMT model of the system.
2. In the deployed EMT tool at the system operator, create scenarios with high VRE generation and set up likely operating scenarios.
3. Use tools such as grid impedance with frequency scans, modal analysis, or others to find oscillation sources.

Outcome:

Create or deploy the needed tools and methodologies to find oscillation sources. Actual oscillations might still occur but can be identified and managed.

Goal SS5:

Establish strong rules to obtain ancillary services like inertia, short-circuit current, and active/reactive power to support system stability.

Actions:

1. Create scenarios for short-circuit calculation with high VRE generation based on future expectations.
2. Compute system strength metrics and in those where a weak system is found, take the operational actions (if any) to overcome the risk with existing equipment or network reconfiguration.
3. Perform dynamic simulations with the outage of a large conventional unit component to assess the performance of the frequency. If low frequency nadir or high rate of change of frequency are found, implement the operational actions available to overcome the risk with existing equipment.
4. If the previous actions do not sufficiently improve frequency metrics, proceed to model the installation of dynamic compensation equipment in the scenarios.
5. Assess the benefits, costs, and impacts on stability of having these ancillary services in place.

Outcome:

Accelerate the inclusion of dynamic compensation equipment in the system and establish an industry shift toward the ancillary services needed to operate the system in a reliable and stable manner.

Goal SS6:

Enable VRE sources connected to the interconnected bulk power system to provide ancillary services for frequency containment and voltage stability across a wide range of timescales; extend capabilities, testing, requirements, and incentives to those connected at lower voltage levels.

Actions:

1. Corroborate the existence of procedures to check grid code compliance with established high and low voltage ride-through, fast reactive power supply, active power supply in cases of frequency deviations, and others.
2. Repeat Actions 1–4 in Goal PF7 with the assumption that no generator connected at distribution level complies with utility-scale grid code requirements.
3. Quantify the impact on voltage and frequency stability.
4. Use the results to establish potential changes in grid codes for generators connected at distribution level or create appropriate incentive structures for their development.

Outcome:

Show the importance of VRE grid code compliance at all voltage levels for stability. This could enable the creation of incentives to provide these services.

Goal SS7:

Study the deployment of grid-forming IBRs in strategic parts of the interconnected bulk power system to support operation under low system strength and help with black start, building on existing plans to study their role in enhancing system stability.

Actions:

1. Perform restoration analysis with and without grid-forming capabilities for the IBRs in the system.
2. Compare the routes and costs associated with having grid-forming capabilities within the grid.

Outcome:

Initiate the process of exploring the utilization of innovative technologies aimed at achieving reduced operational expenditures and enhancing operational stability and resilience.

Goal SS8:

Encourage and ensure distribution entities act as DSOs (active system operators) with an existing or planned electrical model of their low-voltage grid to conduct reliability and stability simulations.

Actions:

1. Engage with DSOs to assess the modeling and simulation capabilities for their grid.
2. Work with regulators, planners, and DSOs to decide on a plan to enable DSOs to acquire the hardware, software, and knowledge needed to function as an active operator with planning capabilities of their systems.

Outcome:

Initiate the process to empower DSOs around the complex analysis that they are required to perform in their system, which was traditionally not done but which is required given the increased complexities of low-voltage systems.

Goal SS9:

Encourage and ensure that DSOs verify that DERs comply with regulations related to voltage and frequency support, as well as ride-through capabilities.

Actions:

1. Engage with DSOs to assess their capabilities to receive, check, and emit a concept regarding grid code compliance for generators in their system.
2. Repeat Action 2 from Goal SS8.

Outcome:

Initiate the process to empower DSOs around the complex analysis that they are required to perform in their system, which was traditionally not done but which is required from them given the increased complexities of low-voltage systems.

Goal SS10:

Establish strong methods to assess the adequate participation of each resource in the system to support the provision of ancillary services.

Actions:

1. Identify the requirements that current regulations impose on each resource (quantity, settlement time, and hold time).
2. Evaluate the feasibility of measuring the specified requirements using existing system monitoring technologies, such as SCADA. If the SCADA data acquisition rate proves inadequate, initiate a process to either upgrade to a wide-area monitoring system or implement offline data collection methods from generation units.

3. Create an automated way to gather the needed data of each resource after a triggering event (frequency or voltage out of ranges).
4. Develop an automated verification routine under the collected data that can provide a failure or pass grade to each resource about the expected behavior following a triggering event according to existing requirements.
5. Use the established regulatory pathways to enforce compliance from all units.

Outcome:

Establish a robust methodology that can provide supporting data about the proper performance of the IBRs in abnormal conditions according to existing regulations.

Energy Sufficiency

This characteristic refers to the ability of the system to ensure the future supply of electricity in the medium and long term (i.e., the availability of primary energy [fuel, water, sun, wind, etc.]).

Goal ES1:

Ensure that VRE is dispersed across the entire system as much as possible.

Actions:

1. Create a comprehensive set of 24-hour operating scenarios for a typical year in which high demand and low availability (or high prices) of the main source of energy, besides VRE, is expected.
2. Evaluate the availability of the system to ensure the supply of electricity, in an economic and reliable way, in all electrical areas of the system under different conditions (N-1, and N-1-1).
3. If any deficiency is found, assess the possibility of installing VRE resources in areas where supply might be challenging in these scenarios.

Outcome:

Assess the ability of the system to ensure the future supply of electricity under different conditions by having an appropriate system-specific distribution of VRE sources.

Goal ES2:

Ensure that VRE generation has complementary behavior when both are deployed across the system or alternately are managed operationally to benefit from their complementarity.

Actions:

1. Collect historical data of wind and solar and create a forecast based on this data for future scenarios.
2. Create a temporal correlation analysis of forecasted data considering geographic distribution of resources within the system.
3. Identify regions where solar and wind resources exhibit high temporal and spatial complementarity.
4. Assess the importance of the level of complementarity found to ensure supply with VRE in the system.
5. If this value is low, then formalize a plan to expand installed capacity of VRE appropriately to improve complementarity.

Outcome:

Assess the ability of wind and solar resources to complement the scarcity of the other (solar/wind) on the temporal and/or spatial scale to help improve system operability.

Goal ES3:

Improve short-term (<24 hours) demand forecasts to achieve a mean absolute error <5%, medium-term (<10 days) forecasts to achieve a mean absolute error <10%, and long-term (>10 days) forecasts to achieve a confidence interval of ±10% around predicted peak demand, particularly considering the electrification of transportation and/or buildings.

Actions:

1. Establish a multisectoral working group with different actors in the electricity sector (including DSOs, building administrators, public transportation entities, vehicle manufacturers, etc.)
2. Work together to establish a sustainable way to gather and share information regarding smart meter data, building energy management system data, electric vehicle charging station data, etc.
3. Work with DSOs to map the impact of this information on their low-voltage system demand forecast and establish a sustainable way to share this information in a good example of DSO-TSO cooperation.
4. Include the new information in advanced modeling techniques that have been proved to work in the past for demand forecasting in the system.

Outcome:

Establish an effective and reliable source of information to account for electrification of transportation and buildings in the demand forecast such that the uncertainty can be handled accordingly.

References

[1] Hillberg, E., et al. 2019. *Flexibility needs in the future power system*. https://www.iea-isgan.org/wp-content/uploads/2019/03/ISGAN_DiscussionPaper_Flexibility_Needs_In_Future_Power_Systems_2019.pdf.

[2] Moreira, Carlos, et al. 2020. *D2.1 Flexibility, technologies and scenarios for hydro power*. https://cdn.prod.website-filescom/63191669bac853a1f34d1e88/6350180d1d5a109712a46fb5_XFLEX%2BHYDRO-2020-T2.1-20-08-01-01-D2.1%2BFlexibility%2Btechnologies%2Band%2Bscenarios%2Bfor%2Bhydropower%2B(2).pdf.

[3] International Energy Agency (IEA). 2024. "Integrating Solar and Wind Global experience and emerging challenges." https://www.iea.org/reports/integrating-solar-and-wind.

For More Information

Get involved with Global Power System Transformation Consortium (G-PST): https://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.

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