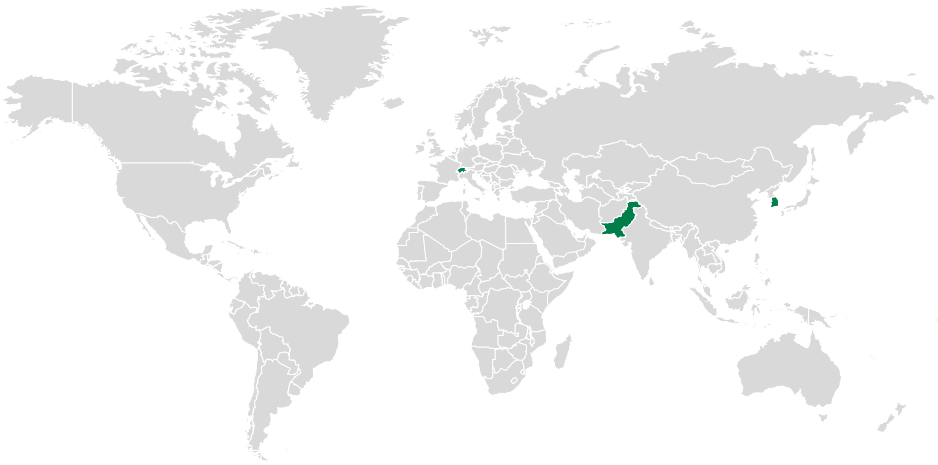
Decarbonization Readiness Assessment Mapping

Archetype: Mover (Stage AB)

Example Mover (Stage AB) System Operator Archetypes Based on Decarbonization Readiness Assessment Mapping:



Pakistan, South Korea, and Switzerland.

Acronyms

ES	energy sufficiency
IBR	inverter-based resource
PF	power flexibility
SS	system security
TC	transmission capacity
VRE	variable renewable energy

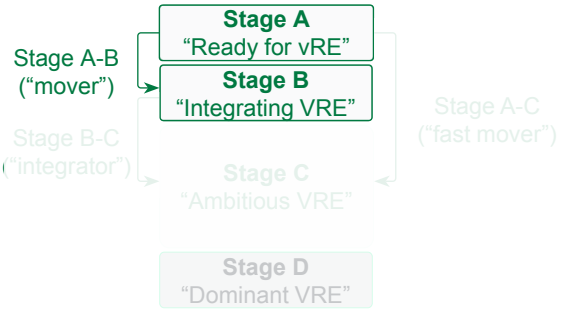


Figure 1. DREAM archetypes.

Attributes/Themes	Stability	Grid Codes and Standards	Services
Business Practices	• Goal PF1 • Goal PF3	• Goal PF2 • Goal SS3	
Facilities and Equipment			• Goal TC1 • Goal TC2 • Goal TC3
Tools, Data, and Methods		• Goal SS1 • Goal SS2	• Goal ES1

Table 1. Summary of Attributes for Stage AB (Mover) 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 a "mover" archetype (Stage AB).

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. 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 a Mover Archetype (Stage AB)?

A Mover (Stage AB) archetype is a system that is starting from a low level of VRE integration but is planning to move toward higher but still modest levels of integration 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**).

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

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 current grid conditions and medium-term planning scenarios.

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, under different demand scenarios with detailed expected grid topology in 10 years.
2. Perform a complete contingency analysis of the interconnected bulk power system (single-circuit contingencies, at least) and identify elements that cause thermal or voltage constraints associated with VRE sources (i.e., reducing VRE will alleviate the constraint).
3. Study the effectiveness of transmission solutions to eliminate such constraints in the form of mitigation actions or expansions (reinforcements on existing circuits, parallel circuits, meshing) and additional mitigation measures like shunt/series compensation (static/dynamic), grid-enhancing technologies, and/or using energy storage systems.

4. Formalize the best solutions with the appropriate statutory procedure (if procedures do not yet exist, these should be developed, promulgated, and maintained).

Outcome:

The deployment of VRE is likely to drive curtailment to avoid some thermal constraints on key circuits; however, a comprehensive set of investigations can identify solutions that would largely eliminate these constraints.

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 or minimum capacity with detailed expected grid topology in 5–10 years.
2. Repeat Actions 2 to 4 from Goal TC1.

Outcome:

Strong interregional interconnection will allow generation dispersed across large areas to be transferred across the entire system, even during planned maintenance work that has the potential to degrade inter-area interconnectivity, strengthening the ability of the system to maintain safe and reliable operations.

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 DC interconnections).
3. If improved performance is observed with cross-border interconnections, analytical methods can be used to evaluate the appropriate level of interconnection and technology choices to inform potential decision-making.
4. Identify the specific geographic (social and environmental), technical, and political challenges of implementing cross-border reinforcements to further inform potential implementation.
5. Formalize plans to build the most appropriate cross-border solutions found using the available statutory procedures of both systems (where procedures do not yet exist, these can be developed, promulgated, and maintained; where procedures are not aligned across systems, both systems can work toward converging on appropriate procedures to inform implementation).

Outcome:

Interconnections with neighboring systems provide an improvement in system efficiency, affordability, 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 forecasts for generation and demand for typical future 24-hour look-ahead operating scenarios (for one or more future years with at least 1-hour resolution) where weather condition forecasts are considered with their respective uncertainties together with ramping capabilities of existing generation resources (and potentially demand-side resources, if available).
2. Calculate the quantity of available reserves needed to maintain stable and secure operations during the highest residual demand ramp periods (typically sunset hours, in which solar photovoltaics are dominant). The

reserve calculation must yield the additional supply-side or demand-side capacity needed to meet risk-adjusted unexpected changes in demand or generation, and therefore should account for forecasting errors in demand, solar, and wind expected output, the loss of the maximum credible amount of generation (including imports from large interconnectors, if they exist), and the amount of power needed with the appropriate speed of response to avoid frequency violations. Quantify these reserve needs using probabilistic approaches for each hour (5th and 95th percentiles, averages, and standard deviations are typical risk-adjusted thresholds used in these analyses).

3. Establish the appropriately risk-adjusted quantity of spinning reserves needed for the look-ahead horizon and evaluate the costs associated with this amount of reserve that is also sufficiently flexible to meet any potentially binding ramping needs.

Outcome:

Formalize the workflow to assess reserve needs in future scenarios, which will unveil a potential increase in operation costs. This should establish the need and expected costs across stakeholders (particularly generators) to plan for operations under fast variation of power with services like fast ramping capabilities.

Goal PF2:

Establish close to real-time dispatch mechanisms (less than 24 hours).

Actions:

1. Repeat Actions 1–3 from Goal PF1 at a sub-hourly level, also considering weather conditions and electrical demand profiles' forecast uncertainties for a less-than-24-hours ahead forecast (intra-day, e.g., 1–8 hours).
2. Assess the capability of existing generation to respond to less-than-24-hour dispatch instructions and/or market processes (1–8 hours).
3. Formalize the workflow needed to support the creation of a day-ahead dispatch market with the statutory procedure in the system.

Outcome:

Demonstrate the ability of closer-to-real-time dispatch to reduce the natural uncertainty existing in day-ahead dispatch and increase operating efficiency and reliability.

Goal PF3:

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

Actions:

1. Create, within phasor domain simulation tools (positive sequence), scenarios of low residual demand (periods of high VRE and low demand). Perform dynamic simulations of the loss of the largest credible contingency (conventional generator(s), largest interconnector, maximum credible quantity of VRE resources) through the loss of a common component (line or transformer, which implies the loss of the highest amount of power).
2. Ensure that fault ride-through characteristics, active and reactive power supply of all generators (especially IBRs, including VRE) are adequately represented and validated against actual real-world performance.
3. Check that system frequency metrics (rate of change of frequency and nadir) are held within safe limits and no under-frequency load shedding stage is activated when the combination of a system disturbance and the largest credible contingency event occurs.
4. Repeat Actions 1 and 2 with future scenarios of resource mix and grid expansions that capture important expected future conditions.
5. If frequency performance metrics like frequency nadir or rate of change of frequency are exceeded beyond acceptable thresholds, then the need for increased frequency support is demonstrated and there is a potential need for fast dynamic response services, as well as the need to establish secure minimum operating conditions (e.g., minimum levels of inertia for any dispatch).
6. Formalize the requirement in a new standard procedure and/or grid code updates.

Outcome:

Demonstrate that, under existing high-stress scenarios, sufficient frequency containment reserves are available in conventional generation to maintain frequency stability. However, future scenarios might require fast frequency response reserves from various resources to prevent exceeding acceptable thresholds and potential frequency collapse.

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:

Include strong electrical model requirements for electromagnetic transient simulations in regulations/procedures, building on existing requirements for phasor domain (root mean square) and steady-state (powerflow and fault) simulations and ongoing plans to expand system security assessments.

Actions:

1. Identify the components on the system that might be involved in converter-driven or resonance stability (e.g., series compensated lines near generators, IBRs in weaker parts of the interconnected bulk power system under most known operating conditions, points of common coupling with large quantities of IBRs, etc.).
2. Assess the impact of credibly losing such components on the stability of the grid in low residual demand conditions (high VRE and low demand).
3. Use these insights to justify the need to undertake detailed simulations to avoid instabilities in the grid and formalize the need to obtain detailed and validated parameters of electrical components in the system from owners/operators to be able to perform such detailed simulations.

Outcome:

Communicate to market participants, decision makers, and new market entrants the importance of electromagnetic transient simulations in a technically sound manner and begin the process of implementing electromagnetic transient investigations where appropriate and on selected parts of the network where potential system security risks have been highlighted.

Goal SS2:

Establish strict grid code requirements to obtain and dispatch ancillary services such as inertia, short-circuit current, and dynamic active/reactive power support to support system stability across different time ranges, in anticipation of future needs and to avoid instability.

Actions:

1. Repeat Actions 1 and 2 in Goal PF2.
2. Perform short-circuit analysis in all important transmission corridors, parameterizing fault-clearing times.
3. Confirm that, in current scenarios, stability is maintained, while in future scenarios there are an important number of operating scenarios where stability and reliability are potentially compromised.

Outcome:

Demonstrate the need to provide ancillary services in periods of high utility-scale VRE and low residual demand in the system.

Goal SS3:

Develop, maintain, and further strengthen methods to assess the adequate participation and capability of each resource in the transmission system to provide required ancillary services.

Actions:

1. Identify the requirements that current regulations/procedures impose upon each resource (quantity, settlement time, and hold time).
2. Evaluate the feasibility of measuring the specified requirements using existing system monitoring technologies, such as supervisory control and data acquisition. If the supervisory control and 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 process to gather the needed data of each resource after a triggering event (frequency or voltage out-of-range conditions).
4. Develop an automated verification routine using the collected data that can provide a failure or pass for each resource about expected behavior following a triggering event according to existing requirements.
5. Use established regulatory processes to enforce compliance from all units.

Outcome:

Establish a robust methodology that can provide data about the expected and proper performance of generators (particularly 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, such as fuel, water, sun, wind, etc.

Goal ES1:

Improve short-term (<24 hours) demand forecasts to achieve mean absolute error <5%, medium-term (<10 days) forecasts to achieve 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 industry working groups (including distribution system operators, building administrators, consumer representatives, public transportation entities, vehicle manufacturers, etc.).
2. Work toward establishing a sustainable process to gather and share information regarding smart meter data, building energy management system data, electric vehicle charging station data, etc.
3. Work with distribution system operators to map the impact of this information into their demand forecast and establish a sustainable process to share this information as a demonstration of improved distribution system operator-transmission system operator cooperation.
4. Include the new information on advanced modeling techniques shown to work in the past for demand forecasting in the interconnected bulk power system.

Outcome:

Establish an effective and reliable source of information to account for new demand and changes in location as well as characteristics of new demand (electrification of industry, transportation, and buildings) in the demand forecast such that 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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