# SINGAPORE'S FUTURE GRID CAPABILITIES ROADMAP

1 April 2025

ENERGY MARKET AUTHORITY
991G Alexandra Road
#01-29 Singapore 238164
**www.ema.gov.sg**

**Disclaimer:**

The information in this document is subject to change and shall not be treated as constituting any advice to any person. It does not in any way bind the Energy Market Authority to grant any approval or official permission for any matter, including but not limited to the grant of any exemption nor to the terms of any exemption. The Energy Market Authority reserves the right to change its policies and/or to amend any information in this document without prior notice. Persons who may be in doubt about how the information in this document may affect them or their commercial activities are advised to seek independent legal advice or any other professional advice as they may deem appropriate. The Energy Market Authority shall not be responsible or liable for any consequences (financial or otherwise) or any damage or loss suffered, directly or indirectly, by any person resulting or arising from the use of or reliance on any information in this document.

**Acknowledgements**

The Energy Market Authority would like to extend our appreciation to the speakers and participants of the Smart Grid workshop on 27 September 2024, and to the Energy Research Institute at Nanyang Technological University for co-organising the workshop. These contributions have been essential in shaping our Future Grid Capabilities Roadmap.

## SINGAPORE'S FUTURE GRID CAPABILITIES ROADMAP

### The Changing Context of Our Power System

1. The power sector plays a key role in Singapore's endeavour to achieve net zero carbon emissions by 2050, as it currently contributes about 40% of our emissions. As we transit to a low carbon future, our supply mix will become more diverse with the deployment of more domestic solar and electricity imports based on renewable sources. This will pose challenges to our electricity grid, as the intermittent nature of renewables will impact the stability of our electricity grid. The amount of inertia, or the energy stored in large rotating generators that stabilises and manages fluctuations in electricity supply and demand, will reduce as we scale up the deployment of solar and electricity imports. Our grid will also become more complex with more distributed energy resources (DERs) such as rooftop solar photovoltaics (PV), battery energy storage systems (BESS), and electric vehicle (EV) chargers, and as our system peak electricity demand grows at a forecasted annual rate of 3.7% - 5.7% over the next six years.

2. These challenges will be more pronounced in extreme scenarios, such as extended periods of bad weather resulting in a significant reduction in solar energy output, or unforeseen disruptions to imported electricity (see Table 1).

Table 1: Scenarios and challenges

| S/N | Scenarios | Challenges |
|---|---|---|
| 1 | High electricity demand with low Renewable Energy (RE) output | High electricity demand during peak periods, coupled with low RE, may cause grid congestion if there is insufficient capacity in the transmission or distribution network to deliver power to consumers. |
| 2 | Low electricity demand with high RE output | Solar intermittency can cause sudden imbalances in electricity supply and demand. This may lead to frequency and voltage fluctuations in the grid, which may cause instability. High RE output may also reduce the number of conventional thermal generators providing inertia to stabilise the grid. |

| | | |
|---|---|---|
| 3 | Sudden change in regional weather | The grid needs to be able to respond quickly to changes in electricity supply due to the variable nature of electricity imports from renewable resources. |
| 4 | Interconnector disruption | A disruption to an interconnector can cause a sudden mismatch between electricity supply and demand. This may lead to frequency and voltage fluctuations in the grid, which may cause instability. |

**The Need to Transform Our Grid**

3. We have taken initial steps to develop capabilities to transform our future grid to manage these challenges. For instance, the Energy Market Authority (EMA) is working with SP Group (SP) to support research and development (R&D) efforts to develop a digital twin of our power grid, which will allow SP to plan and operate our power grid more effectively and efficiently. SP is also developing a distributed energy resource management system (DERMS), which will allow it to manage the impact of the proliferation of DERs on the grid.

4. More needs to be done to plan for increasingly significant system stresses as we scale up the deployment of domestic solar and electricity imports. EMA and SP have identified three focus areas to transform our electricity grid to manage these challenges, and harness opportunities to advance the transition towards a more sustainable energy future (see Table 2).

Table 2: Focus areas to transform our electricity grid

| S/N | Focus areas |
|---|---|
| 1 | Harness the flexibility of DERs to manage their impact on the grid |
| 2 | Enhance grid planning and operations capabilities with technology |
| 3 | Explore solutions to provide new system needs during periods of high RE penetration, such as inertia management |

**Focus 1: Harness the Flexibility of DERs to Manage Impact on the Grid**

5. DERs are small generation, storage, or load facilities installed by consumers. These include rooftop solar panels, small batteries for storage or backup, and EV chargers. We will see a proliferation of DERs as Singapore

moves towards net-zero emissions by 2050. Today, we have deployed 13,800 EV chargers and installed over 1 gigawatt peak of solar capacity within Singapore. Some consumers may deploy BESS as they become cheaper. If well managed, these DERs have the potential to enhance grid resilience by providing energy, ancillary services, or demand response to smoothen peak periods.

6. SP has embarked on DERMS pilots to monitor and manage DERs and to enable effective network design and planning. By using real-time monitoring and control capabilities, SP aims to manage the impact from the growing number of DER connections in the grid. This will address challenges arising from fluctuations caused by solar intermittency and mitigate potential grid constraints from rising EV charging demand. In addition, SP and EMA will explore communication standards and solutions to facilitate reliable and secure information exchange between DERMS platform and DERs to enable real-time coordination.

7. EMA has worked with the Land Transport Authority, Public Sector Science and Technology Policy and Plans Office and the Agency for Science, Technology and Research (A*STAR) to develop the Singapore Integrated Transport and Energy Model (SITEM), to support Singapore's transition to EVs. SITEM is the first high-fidelity, island-wide simulation of EV transport in Singapore.[1] Through advanced scenario modelling and simulation, SITEM has projected long-term EV charging demand to help agencies better plan the roll-out of EV charging infrastructure and manage upgrades to the grid. Agencies have commenced the second phase of SITEM, which aims to enhance model fidelity and evaluate the benefits and impact of smart and bi-directional EV charging to the grid, such as the feasibility of using smart charging to shift EV charging demand away from peak periods.

8. Virtual Power Plants (VPPs) are also an important enabler to harness the flexibility of DERs to provide useful grid services to manage solar intermittency, system peaks and grid balancing. This is done through controlling, optimising, and aggregating a network of DERs across various locations to operate akin to a single generator. DERs may not be able to individually provide services to the grid, due to reliability issues and the cost-effectiveness of control systems such

[1] The SITEM model and the network twin is under development by the Institute of High Performance Computing of A*STAR, in collaboration with its technology partner TUMCREATE Ltd.

as energy management systems and pilot wires. VPPs have shown to be capable of contributing to system needs in other jurisdictions such as the US and Australia, for example by regulating the frequency of the grid. In view of the potential benefits VPPs can bring to the power system, EMA intends to pilot VPPs via a regulatory sandbox, to inform the regulatory framework to enable VPPs to participate in the Singapore Wholesale Electricity Market to provide energy and ancillary services.

**Focus 2: Enhance Grid Planning and Operations Capabilities through Technology**

9. EMA and SP have initiated the development of a grid digital twin to maintain grid reliability and optimise grid investments for the future. This includes an asset twin which monitors the health of critical grid assets, and a network twin to model and simulate how DERs affect the grid. With decreasing cost of sensors and the technological breakthrough in computation, SP also plans to advance the digital capabilities of digital twins by deploying sensors and Artificial Intelligence (AI) to provide strategic insights into asset and grid conditions.

10. SP also plans to enhance grid monitoring capabilities in the distribution network to manage potential network constraints and congestions. For example, in areas with high concentration of DERs, a surge in solar PV generation or EV charging demand can potentially overload transformers and distribution cables, causing network congestion. The network may also have insufficient capacity to accommodate new DER connections. SP will deploy sensors and collect data at the distribution network to forecast the power flow from DERs and project available network capacity. This will allow SP to identify potential constraints ahead of time and make informed decisions on network planning and grid infrastructure upgrades.

11. SP’s workforce will be equipped with digital tools that are integral to augmenting and optimising manpower resources for essential tasks in substations such as inspection and maintenance. SP currently maintains more than 11,000 substations and 28,000 km of underground cables in Singapore. SP has piloted the use of digital applications, inspection drones and robots, and Augmented Reality tools to assist in daily inspection and critical maintenance procedures. For

the next phase of these pilots, SP will use AI to increase the efficiency and effectiveness of field operations and maintenance tasks and optimise resources.

**Focus 3: Manage New System Needs Such as Inertia**

12. EMA will explore both supply and demand side measures to make up for the loss of inertia from thermal power plants as we scale up domestic solar and electricity imports. On the supply side, technologies such as synchronous condensers with flywheel and advanced inverters can provide inertia. Synchronous condensers with flywheel are large rotating machines which act as "shock absorbers" for the grid, to smoothen frequency and voltage fluctuations and maintain grid stability. Advanced inverters, which convert the direct current from solar panels and batteries into alternating current used by the grid and act as a voltage source, also have the capability to help manage voltage and frequency and provide synthetic inertia.

13. On the demand side, industrial facilities with large rotating equipment, such as motors, pumps, and compressors, may have inherent inertia that could help stabilise the grid during frequency disturbances. These industrial loads can potentially provide inertia in response to grid frequency changes.

14. EMA will study the feasibility of various supply and demand side solutions to provide inertia, and solutions for measurement of inertia. This includes proof-of-concept and proof-of-value test-beds to understand the technical performance and economic feasibility of emerging solutions such as advanced inverters. We will also collaborate with international and industry stakeholders to stay abreast of the latest technological developments and build our capabilities to be ready to adopt and integrate these technologies in our power system when they are needed.

## Our Future Grid Capabilities Roadmap

15. As part of the future grid roadmap, a mix of R&D, proof-of-concept, proof-of-value, and deployment efforts are needed to develop capabilities to transform our grid.

16. EMA, SP, and agencies (e.g., A*STAR) will support R&D efforts in the following areas:

a. Carry out second phase of SITEM, which will evaluate the benefits and impact of smart and bi-directional charging to the grid;
b. Explore communication standards and solutions to facilitate reliable and secure information exchange between DERMS platform and DERs to enable real-time coordination; and
c. Advance capabilities of digital twins by deploying sensors and AI to provide strategic insights into asset and grid conditions.

17. SP will focus on technology development for the following areas:

a. Enhance grid monitoring and control capabilities in the distribution management system to manage the increasing complexity in grid operations; and
b. Use AI to increase the efficiency and effectiveness of field operations and maintenance tasks.

18. EMA will undertake proof-of-concept and proof-of value pilots for the following areas:

a. Pilot VPPs via a regulatory sandbox, to inform the regulatory framework to enable VPPs to participate in the Singapore Wholesale Electricity Market to provide energy and ancillary services; and
b. Carry out test-beds to understand the technical performance and economic feasibility of emerging solutions such as advanced inverters and demand-side solutions to provide inertia.

19. EMA and SP will continue working with the industry and research community to refine this roadmap, to meet the evolving needs of our future grid.