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Renewable, Regional and Resilient: The Role of Grid-Forming Technology in ASEAN's Energy Sector

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SYNOPSIS

The ASEAN Power Grid initiative aims to enhance regional energy integration, support cross-border electricity trade, and accelerate the adoption of renewable energy. However, integrating diverse national power systems across ASEAN countries presents significant technical challenges. This Policy Brief explores how grid-forming technology, using advanced inverters that can maintain voltage and frequency, can address these challenges. It highlights the role of grid-forming systems in stabilising weak grids, supporting renewables, enabling black start capabilities, and improving disaster resilience. As ASEAN's transition toward a sustainable energy future is taking place, grid-forming technology is important for building a resilient and interconnected electricity network.

KEY POINTS

- Grid-forming technology enables stable and reliable electricity systems with high shares of renewable energy.
- The technology enhances grid stability in a multi-country network like the ASEAN Power Grid, especially when traditional sources of inertia in the grids are reduced.
- Grid-forming systems improve resilience to blackouts, natural disasters and weak grid conditions, including areas with low short-circuit ratios.
- By supporting microgrids, decentralised electrification, and cross-border power trading, grid-forming technology is key to ASEAN's sustainable and inclusive energy transition.

INTRODUCTION

The Association of Southeast Asian Nations (ASEAN) has been actively pursuing regional energy integration through the ASEAN Power Grid (APG) initiative. The APG aims to achieve multiple benefits by interconnecting the power systems of ASEAN member states, including enhancing energy security and promoting renewable energy. This initiative is critical for addressing the region's growing energy demand, reducing reliance on fossil fuels, and achieving sustainable development goals. However, the integration of diverse power systems across ASEAN countries presents significant technical challenges. These include varying grid infrastructures, different operational standards, and the increasing penetration of intermittent renewable energy sources.

To address these challenges, advanced grid technologies, such as grid-forming inverters, are essential. Grid-forming technology refers to advanced power electronics, typically grid-forming inverters and grid-forming energy battery storage systems, which can establish and maintain voltage and frequency in a power grid. Unlike conventional grid-following inverters, grid-forming inverters can independently energise a grid, enabling stable operation even in weak or islanded systems. They provide essential grid support services such as inertia emulation, voltage regulation and fault ride-through capability. These are important for grid stability, reliability and resilience in modern power systems. The Energy Studies Institute organised an inaugural Cross-Border Electricity Trade (CBET) Workshop on January 16–17, 2025, to further facilitate discussions on the grid technologies and APG. The insights in this Policy Brief were informed by this workshop.

ANALYSIS

Integration of Renewable Energy

The ASEAN region holds significant potential for renewable energy such as solar and hydropower. The integration of these resources into national power systems, however, presents substantial challenges. Many renewable energy sites are in remote or rural areas, which are far from demand centres and existing transmission infrastructure. Moreover, variable renewables create concerns over grid reliability and stability.

The Iberian Peninsula blackout in April 2025 offers a cautionary example. The power outage affected large portions of Spain and Portugal, disrupting transport, communications, and essential services for several hours. While the precise cause was a sudden frequency disturbance, it is believed that Spain's high renewable penetration (42.7% of total generation in 2022, well above the global average of 29.4%) likely contributed to the difficulty in containing and recovering from the event. Systems with high shares of solar and wind generation tend to have lower system inertia, making them more sensitive to frequency deviations. As a result, the disturbance quickly propagated and overwhelmed the system's ability to stabilise.

The recovery process, known as a black start, was also complicated. Renewable energy plants typically cannot restart independently without support from a stable grid. With fewer conventional power plants online, the system had to rely on offline gas and hydropower units with longer ramp-up times, delaying full restoration.

In this regard, grid-forming technology offers a transformative solution for overcoming these obstacles. Grid-forming inverters provide voltage and frequency control, enabling them to stabilise the grid even in systems dominated by variable renewables. They function as virtual synchronous generators that mimic the inertia of traditional power plants when fossil fuel generation is being phased out and conventional sources of grid stability are reduced or absent. This is particularly important for many ASEAN countries as renewable transitions are accelerated to meet climate targets. Such innovations will play a central role in enabling the transition towards a more interconnected and sustainable energy future.

Enhancing Grid Stability in a Multi-Country Network

The APG initiative envisions a regionally interconnected electricity network, enabling trade in electricity and optimised resource sharing across national borders. However, considering that power systems are diverse in terms of their distinct operational characteristics and technical standards, system integration can convey a high level of complexity.

Grid-forming technology can play a key role in stabilising such a complex multi-country network. In addition to providing voltage and frequency control during disturbances, grid-forming inverters can damp oscillations that may emerge from the interaction between interconnected grids, especially when traditional inertia sources are lacking. Grid-forming battery energy storage systems equipped with advanced damping control mechanisms can further enhance this functionality. Specifically, these systems include robust low-frequency oscillation suppression features, which help mitigate the risk of wide-area instability. Such measures are indispensable for ASEAN, where energy transition towards renewables is taking place and cross-border interconnections expose power systems to new vulnerabilities like wide-area oscillations and voltage fluctuations.

Supporting Cross-Border Power Trading

A central aim of the APG is to promote cross-border electricity trade, enabling member states to share generation resources, balance supply and demand more efficiently, and reduce overall system costs. However, a highly stable and resilient interconnected grid is needed to achieve them.

Grid-forming technology is essential to support this objective. Grid-forming inverters ensure interconnections remain synchronised and resilient under dynamic operating conditions, such as during voltage ramp-up phases where plants must achieve full operational voltage from zero within minutes under strict criteria. Moreover, the inclusion of black start capabilities in grid-forming systems offers a significant advantage. These features include power restoration without external grid support during regional blackouts, capability of no-load transformer energisation (initially at zero voltage but with loads connected), and safeguards to prevent grid breakdown during restart. This reduces downtime and ensures that cross-border power flows can resume quickly, maintaining trust and operational continuity between trading partners.

With these features, grid-forming technology makes cross-border electricity trading more attractive to ASEAN member states. It strengthens the technical foundation upon which a flexible, sustainable and integrated regional power market can be built.

Addressing Weak Grids and Low Short-Circuit Ratios

A significant challenge in realising the full potential of the APG lies in the presence of weak electrical networks across parts of the region, especially in rural and remote areas. These systems often exhibit low short-circuit ratios (SCRs), which indicate how strong or stable a grid connection is at a specific location. A lower SCR means the grid is less capable of supporting sudden changes in electricity flow, making it more vulnerable to voltage instability, power quality issues and reliability concerns.

Grid-forming technology can offer a robust solution for stabilising weak grids. One key advantage is its ability to withstand changes in grid impedance. Systems equipped with grid-forming inverters can operate reliably across a wide range of SCR values without disconnecting from the grid. During sudden changes in grid impedance, the system preserves its voltage source characteristics, maintaining continuity and stability even under transient conditions. This capability is critical for maintaining seamless operation in regions with fluctuating grid strength, such as areas transitioning between isolated and interconnected states.

Additionally, grid-forming inverters can actively provide voltage support and reactive power compensation, strengthening local grid performance and improving overall power quality. This capability is vital for enabling equitable access to reliable electricity, ensuring that even the most underserved or geographically dispersed communities can gain benefits from the APG.

Enabling Energy Access and Electrification

Despite significant progress in recent years, some remote, rural and island communities still lack access to reliable electricity. Expanding central grid infrastructure to these areas can be technically challenging and economically unfeasible. In this context, decentralised energy solutions such as microgrids have emerged as a practical and scalable approach to closing the energy access gap. Grid-forming technology plays a critical role in enabling such decentralised systems. Its ability to operate in islanded mode allows microgrids to function independently of the main grid, delivering stable and reliable power to off-grid communities.

Moreover, this technology facilitates the integration of distributed energy resources such as solar PV and battery energy storage. These elements are key to building resilient and self-sufficient energy systems to meet local demand sustainably and affordably. By enhancing the functionality and reliability of microgrids, grid-forming systems directly support ASEAN's ambition to achieve universal energy access. This can contribute not only to regional energy goals but also to broader socio-economic development, improving quality of life and fostering inclusive growth in some of the region's most underdeveloped areas.

Resilience to Natural Disasters

Natural disasters pose a significant threat to power systems across the ASEAN region. Typhoons, earthquakes, floods, and other extreme events can cause widespread damage to infrastructure, disrupt electricity supply, and hinder emergency response efforts. In this context, enhancing the resilience of energy systems is vital to protecting lives, supporting recovery, and maintaining economic stability.
Grid-forming technology plays a pivotal role in strengthening disaster resilience. Its rapid fault recovery and black start capabilities allow for fast restoration of power following a system failure or blackout. This reduces

downtime and ensures that affected communities regain access to electricity quickly, supporting both humanitarian and logistical efforts during emergencies.

For ASEAN, where the economic and social impacts of natural disasters can be severe, grid-forming technology offers a robust and adaptable solution. By improving the resilience and autonomy of power systems, it helps safeguard communities and enhances long-term disaster preparedness and response capacity.

CONCLUSION

The successful realisation of the APG hinges on the ability to overcome complex technical challenges arising from diverse national grids, rising renewable energy penetration, and the need for universal energy access. Grid-forming technology emerges as a key enabler in this transformation, offering the capabilities needed to maintain system stability, enhance resilience, and support cross-border integration. Its ability to emulate synchronous generation, manage weak grid conditions, operate in islanded mode and facilitate black start operations makes it uniquely suited for ASEAN's evolving energy landscape. By enabling reliable integration of renewables, supporting decentralised electrification, and ensuring robust performance in the face of natural disasters, grid-forming inverters address both the immediate operational requirements and long-term strategic objectives of the region. They provide the foundation for a resilient, interconnected and flexible power system that can adapt to changing energy demands and environmental conditions. As ASEAN advances towards a low-carbon, inclusive energy future, the deployment of grid-forming technologies will be crucial. They are not only a technical solution but a strategic investment in regional cooperation, energy security, and sustainable development.

WHAT TO LOOK OUT FOR

- Cost trajectory and commercial availability of grid-forming inverters and compatible energy storage systems.
- Development of harmonised technical frameworks in ASEAN regional electricity transmission.
- Real-world trials and demonstration projects of the inclusion of grid-forming technology into the APG.
- Research and development efforts to further refine and optimise grid-forming technology.

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