Net-Zero Smart Grids and Technological Energy Storage

Background

At approximately 117 million metric tons, electricity accounts for 42.8% of Taiwan's emissions. In addition, electricity demand is projected to more than double by 2050 due to the continued development of high-tech industries such as semiconductors and artificial intelligence (AI), and the electrification of end use sectors as part of the net-zero transition. As such, there is an urgent need to strengthen electrical grids to maximize the supply of zero-carbon electricity because the power sector must decarbonize to achieve net-zero targets. In the medium to long term, the scale of photovoltaics, offshore wind power, other foresight energy sources, and energy storage installations will grow significantly. Over this same period, the decarbonization of transportation and industry will also drive a substantial increase in new types of electrical loads.

The highly decentralized nature of consumption and generation in diverse renewable energy sources, emerging power generation, energy storage, and demand response resources requires the adoption of a variety of digital technologies such as stronger ICT, control, and data to enhance system integration and coordination. As the costs of installing distributed renewable energy, energy storage, and energy management systems decrease, the willingness of users to transform into prosumers (producer-consumers) increases. A well-functioning electricity market is needed to attract more user-side resources to support grid operations. In response to the net-zero emissions target of decarbonizing the power sector, the development of “Net-Zero Smart Grid “aims to support maximizing zero-carbon electricity supply to the grid by balancing electricity supply stability of emerging technologies with electric power quality. Demonstration projects will also help build a smart energy industry ecosystem and a diversified electricity market by validating related technologies, standards, and regulations.

The formation of a net-zero smart grid market relies on robust regulations and public sector investment. Taiwan is currently advancing the "Grid Resilience Construction Plan" to upgrade its electrical infrastructure, with emerging Solid-State Transformer (SST) technologies and application concepts under active development. In this context, "Power Semiconductors" serve as a cornerstone for supporting smart grids and constructing critical hardware modules and systems.

The "Net-Zero Smart Grid Technology Development Flagship Project" builds upon the "Smart Grid Master Plan" to drive industrial growth. By leveraging national strengths in ICT and semiconductor technologies, the project sets two primary targets: first, to enhance the resilience and reliability of power systems with high renewable energy penetration, increasing the grid's renewable energy tolerance from the current 30% to over 70%; and second, to bridge domestic semiconductor and ICT advantages to forge a resilient smart power system supply chain. These efforts aim to secure a first-mover advantage in the evolving smart power industrial ecosystem under the net-zero transition.

Global Outlook and Domestic Progress

To achieve net-zero emissions by 2050, countries such as the US, Europe, and Japan, are committed to providing carbon-free energy by creating digital smart grids in the future that are powered by distributed resources.

In 2020, the Executive Yuan approved the “Smart Grid Master Plan,”which established Taiwan's research and development capabilities in smart grid systems by allocating funding towards the development of technologies such as high-power conversion systems, electric vehicle charging systems, grid dispatching/frequency regulation, substation visualization, distance relay protection and coordination, and microgrids. In 2022, the Taiwan Power Company launched the“Enhancing Power Grid Resilience Construction Plan,”which allocated NT$564.5 billion to strengthen smart meters, feeder automation, regional energy storage systems, and transmission line installation. By 2021, Taiwan had established an energy trading platform, and by 2023, the total participation in the ancillary services market reached 900 MW, with a trading volume of approximately NT$2 billion.

Since 2025, the Energy Administration of the Ministry of Economic Affairs (MOEA) has implemented the "Flagship Action Plan for Technological Energy Storage and Carbon Reduction." Aimed at encouraging diversified energy development, the plan incentivizes domestic enterprises to adopt stationary fuel cell power systems utilizing hydrogen. These systems serve as autonomous or emergency backup power, with implementation prioritized for AI industries, data centers, and semiconductor manufacturing. Science and industrial parks are designated as priority sites for installation to increase the ratio of self-generation and self-consumption while expanding domestic decentralized power sources, thereby further enhancing grid resilience. The plan identifies energy storage systems (ESS) as a vital supporting measure for long-term net-zero trends and renewable energy development. Leveraging their high flexibility and low operational constraints, these systems provide ancillary services necessary for power system stability—particularly in scenarios with high renewable energy penetration—by enabling real-time balancing of power supply and demand. For utilities, ESS can defer investments in transmission and distribution infrastructure while alleviating grid congestion.

Strategic Planning Frameworks

Net-Zero transition requires a fundamental transformation of the power system, which includes the implementation of high-quality digitalization and new types of power infrastructure across all areas of the grid, from generation and transmission, to distribution and end-use. Thus, it is necessary to expand the development, demonstration, and installation of smarter, more flexible grid hardware and software systems to accommodate the large-scale installation of renewable energy, enhance energy supply security, and strengthen the resilience of the power system.

Taking into account national geopolitical risks, future electricity demand growth, the planned proportion of energy sources, the characteristics of regional electricity generation and consumption, as well as Taiwan's global capabilities in ICT, semiconductors, AI, and power electronics, the overall strategy for promoting“Net-Zero Smart Grid” includes establishing a collaboration mechanism between power companies and academia. This will guide the development of emerging grid technologies while helping to maximize zero-carbon power supply and ensure power quality as well as power supply stability.

The development plan includes foresight technologies such as solid-state power electronics transforming equipment and systems, diverse virtual power plants and power market applications, distribution-level net-zero microgrids, Grid-Interactive Efficient Buildings (GEB), integrated solar-storage systems, and deep energy-saving AC/DC hybrid power supply systems. In addition, Integrated Resource Planning (IRP) and pilot/demonstration projects will promote the creation of an industry ecosystem and market development for smart energy by supporting the validation of relevant technologies, standards, and regulations. This aims to drive the formation of an industrial ecosystem through investments in public utilities and a diverse product market for power.

Strategy 1: Diverse virtual power plants and electricity market applications to promote regional power balance

A virtual power plant can aggregate distributed renewable energy, emerging power sources, energy storage, and demand response, while establishing a diverse power market with multiple products. Such mechanism will allow for more market participants on both the supply and demand sides while expanding the types and scale of resources that can support grid operations. In addition, this strategy includes the development of foresight technologies throughout Taiwan such as Grid-Interactive Efficient Buildings (GEB), integrated solar-storage systems, and deep energy-saving AC/DC hybrid power supply systems. The expected outcomes are as follows: (1) Reduce the peak annual load growth rate while alleviating the pressure on land and space required for the development of generation, transmission, and distribution facilities. (2) Increase the grid integration capacity of renewable energy, expand the supply of zero-carbon electricity, and reduce the carbon footprint of relevant products. (3) Enhance grid resilience by expanding civic participation in the energy market in areas such as decentralized private energy storage and demand response. (4) Improve power reliability by increasing the demand-side capacity of zero-carbon backup power. (5) Reduce the risk of large-scale blackouts while minimizing cross-regional transmission and distribution losses by balancing regional grid supply and demand.

Strategy 2: Support the development of next-generation power grids by leveraging the advantages of power electronics and semiconductors to develop solid-state power electronic transformer equipment and systems

A Solid State Power Substation (SSPS) is defined as an integrated substation or"grid node"equipped with high-voltage power electronic converters that provide system advantages and support grid upgrades. A SSPS Converter is a highly modular, scalable, flexible, and adaptable power module system that can be used in all substation applications. SSP S Conver ters will improve system integration efficiency as well as grid flexibility and resilience by serving as power routers or hubs that offer smart control and regulation, online diagnostics and protection, and online updates.

SSPS Converters enhance overall system efficiency by integrating various types of power equipment. In the short term, this strategy will focus on the development and practical research of SSPS technology. In the medium to long term, SSPS Converters can enhance electrical isolation and provide smart regulation, diagnostics, and troubleshooting by acting as an interface between distributed power sources, medium- to high-voltage systems of power companies, DC power sources (such as solar PV and energy storage facilities), and AC power sources.

Strategy 3: Integrate the domestic smart low-carbon energy industry ecosystem by establishing a demonstration for net-zero micro-grid power distribution

The concept of a microgrid is put into practice by aggregating distributed energy resources (generation, storage, and load) to build the resilience needed for energy security. In tackling climate change, microgrids can become resilient, carbon-free power delivery systems that offer potential solutions to the challenges of net-zero transition. Decarbonizing microgrids requires three key elements: (1) Maximizing the generation of renewable power, (2) Managing storage and flexible loads to balance the variability and intermittency of renewable energy, and (3) Introducing new clean energy sources, including hydrogen-based power generation equipment and small, modular reactors. The promotion of distribution-level net-zero microgrid demonstration will support research on the smart management of distributed energy and storage systems, advanced distribution management systems, and wide-area monitoring systems.

The "Flagship Action Plan for Technological Energy Storage and Carbon Reduction," administered by the Energy Administration, currently focuses on promoting Behind-the-Meter (BTM) energy storage systems for manufacturers in industrial parks. Given the critical demand for microgrids and storage technologies in remote areas, it is recommended to expand future initiatives to include remote villages, offshore islands, and residential communities. These initiatives should integrate local renewable resources with load management to implement distribution-level technological storage and multi-microgrid demonstration projects capable of sustained islanded operation.

Such efforts aim to enhance energy resilience and power continuity during disaster scenarios, ensuring a stable supply for critical infrastructure and essential residential needs. Beyond expanding the application scope of these technologies and establishing diverse demonstration cases, this approach will further support the realization of national policy goals, including the net-zero transition and balanced regional development.

Strategy 4: Strengthen Integrated Resource Planning (IRP) capabilities to promote the integration and utilization of diverse renewable and low-carbon energy sources

Enhance whole-system planning capabilities. Use scientific methods to explore the appropriateness of resources and optimal supply-demand ratios. Help achieve Taiwan's 2050 optimal power mix by promoting the integrated application of diverse low-carbon energy sources, assessing cost-effectiveness, and ensuring economic feasibility and alignment with carbon reduction requirements.

Strategy 5: Integrate domestic capabilities throughout government-industry-university-institute to promote and implement international cooperation

The promotion of Net-Zero Smart Grid requires interdisciplinary talent in areas such as power electronics, power systems, semiconductors, chemistry, physics, and materials science. It is essential to continuously foster cooperation mechanisms between government, industries, universities and institutes to attract talent into these relevant fields. Additionally, strengthening exchanges with institutions from technologically leading countries such as the US and Japan will promote bilateral technical research discussions and collaborative demonstration projects.

Strategy 6: Establish a market mechanism for full-time 24/7 grid decarbonization

Taiwan must accelerate the decarbonization of its energy system to help prevent the impacts of climate change. However, during periods when variable renewable energy sources are in low supply, conventional resources are used to meet electricity demand, which is inconsistent with overall net-zero policy goals. However, widely incorporating carbon-free power sources while including new forms of carbon-free electricity to ensure consistency with the timing and location of power generation and consumption still poses significant challenges in promoting the decarbonization of the power system.

Thus, the “Establishment of an Around-the-Clock Market Mechanism to Decarbonize Grids” plan aims to develop green power trading systems and platforms, a carbon-free power certificate system (for non-renewable energy electricity trading), low-carbon fuel certification, and an advanced ancillary service system. This will enhance the certification and trading mechanisms for low-carbon energy while leveraging market resources to enable around-the-clock low- carbon energy.

Potential Benefits

The National Project of Hope has set the strategic focus of “Building Smart and Shared Green Energy,” with plans to promote resilient grids, advanced energy storage, power decarbonization, and microgrids. The hybrid issue of “Net-Zero Smart Grid” also aligns with the strategic focus of the National Project of Hope's “Building Smart and Shared Green Energy.” The initiatives under this strategy can strengthen the grid's supply of stable net-zero power and expand the use of diverse digital technologies, such as ICT, control, and data, that enhance system integration and dispatch capabilities. The ongoing development of independent regional grid technologies will further enhance grid resilience. In addition, a well-functioning power market will help Taiwan steadily achieve its 2050 goals by attracting more user-side resources to support grid operations.

The first phase (2025-2029) of the “Greater South Smart-Tech Industrial Ecosystem” project has also incorporated the strategic direction of the hybrid “Net-Zero Smart Grid” issue. The project will utilize the Shalun Green Energy Science City as a demonstration site to assist power companies in expanding user-side dispatchable resources by building an integrated cross-domain microgrid energy management system. The plan also aims to develop energy management strategies that combine different types of users, such as shopping malls, office buildings, and factories, while incorporating a diverse set of power resources such as photovoltaics, green hydrogen/ammonia production electrolysis equipment, energy storage, electric vehicles, fuel cells, and general load regulation.

A diverse set of flexible load elements and grid-forming technologies on the load side that enhances the reliability of user-end dispatchable capacity will create a grid with high renewable energy hosting capacity. Planned development includes an integrated system for distributed solar-storage, decentralized energy dispatch management for grid-interactive efficient buildings, research on deep energy-saving AC/DC hybrid power supply systems, optimized control for the capacity of ice storage and manufacturing systems, control technology for grid load with a high proportion of green energy, smart net-zero microgrid energy management systems, a blockchain-based virtual power plant management and trading platform, and an around-the-clock carbon-free electricity matching and trading mechanism.

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