Mission Innovation
Green Powered Future Mission Workshop
Policy and Technology for Grid Flexibility and Stability
March 12 (Tue.) – 13 (Wed.), 2024

Day 1 – March 12 (Tuesday)
8:00-10:00 US (EDT) / 12:00-14:00 UK / 13:00-15:00 Europe (CET) / 17:30-19:30 India / 20:00-22:00 China / 21:00-23:00 Japan / 23:00-01:00(+1) Australia (AEDT)

1) **Host's Welcome**

Koichi INOUE
Mission Innovation Steering Committee Member
Director, International Affairs Office, Industrial Science,
Technology and Environment Policy Bureau,
Ministry of Economy, Trade and Industry, Japan

This is the second online workshop focusing on the promotion of variable renewable energy sources. This session covers the grid flexibility and stability necessary for the integration of VREs into power systems.

2) **Opening Statement**

Luciano MARTINI
Director, Mission Innovation "Green Powered Future Mission"
Director, Transmission and Distribution Technology Department
Ricerca sul Sistema Energetico (RSE), Italy

Mission Innovation is a global initiative launched in Paris in 2021 to accelerate the development and deployment of renewable and clean energy sources. The Green Powered Future Mission (GPFM) was launched in June 2021 along with the Zero Emission Shipping and Green Nitrogen missions, followed by four more for a total of seven missions.

The main goal of the Green Powered Future Mission is to demonstrate that by 2030, systems in different geographies and climates will be able to effectively, reliably, and cost efficiently run with up to 100% variable renewable energy. GPFM is a strong coalition comprising of public-private partnerships between member countries, key private sector interests, and international organizations.

GPFM is organized around three RNI pillars: affordable and reliable VRE, system flexibility and market design, and data and digitalization for system integration. Our systems must have flexibility to be able to accommodate a larger amount of renewables and fully decarbonize as needed to reach targets for net zero by 2050. Strategy reports from IEA and IRENA stress the importance of power systems becoming more flexible to guarantee adequate system stability and point out the critical challenges that must be addressed.

3) **Global View**

a) Grid Flexibility Needs for Tripling Renewable Energy Capacity by 2023

Paolo FRANKL
Head of the Renewable Energy Division
International Energy Agency (IEA)

At COP28, an agreement was reached to triple renewables capacity by 2030 to more than 11,000 gigawatts, in line with the IEA net zero scenario and the IRENA world energy transition outlook.

The world will install more renewables in the next five years than in the last 100 years, mainly driven by solar and wind. This creates challenges for system integration. The IEA has a framework to explain the main challenges and solutions that systems around the world are going to experience as they integrate more VRE. The speed at which this is happening is accelerating, bringing new challenges that will require different solutions and technologies that need to be implemented both in the short and long-term to provide the flexibility that allows the system to integrate these renewables.

The IEA has published an analysis on seasonal variability looking at the role of thermal power plants in systems at high levels of VRE and the kind of services that can be provided. One of the key technologies is the grid infrastructure itself, which is a key focus for the IEA. For electricity grids to become an enabling factor for the electricity decarbonization transition, the development of power grids must be accelerated hand in hand with the development of other technologies and product flexibility such as storage and digitalization.

For countries to meet their climate targets, the length of the world's electricity grids need to be doubled in the coming two decades to 50 million kilometers. Additionally, roughly 30 million kilometers will need to be replaced or refurbished, for a total of 80 million kilometers of grids of transmission and distribution that need to be either expanded or replaced. Despite a doubling in renewables investment over the last decade, investment in grids has remained relatively stable. To reach climate targets by 2030, we need to see the investment in grids reach up to $600 billion per year.

The IEA issues a call to action across six pillars, including planning, digitalization, regulatory frameworks, and workforce development, to unlock the potential of grids, shifting them towards being a key flexibility provider for the integration of renewables. The IEA has launched the Renewable Energy Progress Tracker online covering around 60 countries, and by the end of the year the RISE unit will publish a new publication on renewables integration, looking at best practices around the world and at the frontiers of renewables integration going forward politically.

<u>Q&A</u>

Q: How can we attract investors to invest in grid stability and flexibility?
A: It depends on the region. In emerging economies that have problems accessing financing, creating alliances and policies that can support the de-risking of these investments, bringing in private money where necessary, and creating frameworks for the remuneration of grid companies that are transparent and cost-reflective can help. The role of concessional and blended finance is going to be extremely important in supporting this. In advanced economies, the challenges include cross-sector planning, regulatory frameworks, and streamlining administrative procedures.

b) Tripling Renewables: Powering the Future with Grid Modernization Solutions for Reliability and Stability

Simon BENMARRAZE
Team Lead Technology and Infrastructure
International Renewable Energy Agency (IRENA)

Grid modernization is essential to the transition to clean energy. Grids must be upgraded in order to seamlessly integrate variable power sources and ensure reliable, affordable energy while achieving crucial climate goals. There are three main goals to do this. Firstly, expanding the grid to reach areas with high renewable energy potential. Secondly, integrating long-duration storage solutions to balance out the variability of renewables. Thirdly, implementing smart grid technology to optimize the entire power system for efficiency, reliability and to accommodate a high share of variable renewables. The Global Renewable Energy and Energy Efficiency Pledge (GREEEP) made at COP28 demonstrates a global commitment to accelerating this transition.

Renewables are the most easily deployable solutions to cut emissions while also providing significant economic and social benefits. However, traditional grids were designed for large, centralized power plants with predictable one-way energy flows and aren't compatible with the flexible and the multi-directional energy sources powering our future. This model presents limitations in fully optimizing the economic value derived from renewables.

Investing in grid modernization solutions is key to building a resilient, competitive energy system powered by renewables, requiring both technical and policy innovation, and proactive action from government, industry and stakeholders across sectors to streamline the grid modernization process.

Significant investment is required, which can also be a golden economic opportunity. A mix of public and private investment is essential, as well as a collaborative and unified approach bringing together regulators and policymakers, utilities, technology providers, and industry. Grid modernization, in the context of the tripling pledge, is the cornerstone on which we build our clean energy future.

Q&A

Q: What role does long-term energy storage play in renewable energy integration?
A: Solar and wind generation can be highly variable, and long-term storage can absorb the surplus when generation exceeds demand as well as ensure a stable power supply by dispatching energy when renewable output is low. Long-term storage needs to be better recognized as a buffer to prevent blackouts in the case of an unexpected power plant failure or sudden demand surge, as well as being a crucial reserve to maintain power supply and resilience against extreme weather.

4) Country Perspectives and Related Policy

a) Australian perspectives and policy

Peta OLESEN
Director, Net Zero Innovation
Department of Climate Change, Energy, the Environment and Water (DCCEEW), Australia

In Australia, the government is responsible for establishing policies and plans through the Department of Climate Change and Energy. As well as the Paris Agreement, Australia has also legislated an emissions reductions target of 43% on 2005 levels by 2030. Central to achieving this is capitalizing on the country's potential for renewable energy and reaching a national renewable energy target of 82% by 2030. This will require a coordinated whole-of-system effort to realize government investment, leverage private sector spending, and capitalize on renewable energy potential.

The key major policy is Powering Australia, a broad plan investing $23 billion in growing and modernizing the electricity grid to accelerate emissions reductions and deliver reliable and affordable energy. Other policies include the National Energy Transformation Partnerships, Delivering Critical Market Reforms, and the Electricity and Energy Sector Decarbonization Plan.

In 2022 renewables provided almost 36% of Australia's electricity generation and this is estimated to have increased to 39% in 2023. Australia's energy market operator (AEMO) oversees the national electricity market and develops the integrated system plan, identifying the optimal investment in generation, storage, transmission, and system services that would deliver the lowest cost, most secure and reliable energy system.

To reach 100% renewables, key priorities for Australia in the near term are to deliver on generation, transmission, and storage. Electrification of transport industries, homes, and workplaces will almost double electricity demand by 2050, meaning that renewable generation capacity needs to double every decade. The most pressing need for Australia is deep storage capacity to ensure resilience and reliability in the grids as coal powered generation is completely phased out.

Rewiring the Nation, a key program to facilitate the building out of the grid, is already underway, investing $20 billion to modernize the electricity grid and deliver new and upgraded transmission infrastructure. Renewable Energy Zones are being identified where clusters of large-scale renewable energy projects can be developed. The Capacity Investment Scheme was released at the end of 2023 to provide a national framework to encourage new investment in renewable capacity, such as wind and solar, as well as clean dispatchable capacity such as battery storage.

South Australia is at the forefront of the global energy transition, having become one of the world's most decarbonized grids, and the region has brought forward its goal of reaching 100% renewable energy penetration from 2030 to 2027. We plan to track these developments over the next few years and feed this back into the GPFM.

Q&A

Q: How did you achieve the big jump in storage capacity needed to reinforce the grid?
A: The mechanism is the capacity investment scheme that will underwrite investment, including in battery deployment. We are going to be relying on location-based large-scale batteries.

b) **Challenges for Brazilian Grid Flexibility due to Increased VRE Share**
Andressa SOARES DOS SANTOS
Energy Research Analyst
EPE, Brazil

The Brazilian electricity matrix has always been predominantly renewable. 80% of the country's installed capacity is from renewable energy, particularly wind and solar. This is changing the load profile, and every power system's net load profile has been affected by the new variable renewables. It is now necessary to discover the requirements of the system and how to deal with these.

Brazil is a very large and tropical country, and the load centers are affected differently depending on the season. Resources that can provide the needed flexibility include hydro and thermal power plants as well as additional resources such as small hydro, biomass, distributed resources, batteries, and Pumped Storage Hydropower (PSH). One issue now being faced is that the regulatory framework needs to be modernized to absorb and develop these technologies.

Improvements and challenges are mapped by effort and impact. The proposed methodology for assessing flexibility requirements and resources seeks to broaden the discussion, to step up from a qualitative talk to a quantitative talk. It is important to unlock the potential of existing flexible resources. Negative ramps should be investigated to assess the ability to decrease overgeneration to match net load reduction. Grid flexibility must be monitored, and remuneration and regulation implemented to make it an attractive business prospect.

Q&A

Q: Does the exercise cover the whole nation or are you just focusing on certain parts of Brazil?
A: The exercise covers all of Brazil as it is now an integrated power system. When a region doesn't have the resources, it can be exported from another.

Q: Brazil currently has a high percentage of renewables, so what is the national target for 2030 and 2050, and how will these be achieved? What is the future energy portfolio of Brazil?
A: Brazil will continue its pace on the renewable matrix with growth in solar and wind generation. We are monitoring and assessing what kinds of requirements our power system has.

Q: Could you tell us a little about insufficient ramping resources expectation (IRRE) and expected flexibility short haul (EFS)?
A: These are two measures in the NREL that was made to assess the flexibility of a power system. The IRRE is measuring the frequency and the existence or absence of flexibility. EFS measures how much power was lost when flexibility could not be achieved. These are two quantitative measures that can give a good insight into what is happening in a power system.

c) Technological demonstration on utilization of DER for flexibility in Japan

Kotaro SASAKI
Deputy Director, Advanced Energy Systems and Structure Division
Agency for Natural Resources and Energy
Ministry of Economy, Trade and Industry (METI), Japan

Japan's energy system is undergoing a transformation from centralized to decentralized. Structural changes in the energy system are taking place following the power system reform, including the use of Distributed Energy Resources (DERs). It is important to secure and utilize DERs, create various business models, and stabilize energy supply and demand.

Currently, Japan's grid access system is undergoing a review to optimize costs and minimize constraints. Grid access has been based on a firm-access connection scheme, in which capacity is secured by application for connection contracts. Efforts are being made to enable the flow of more electricity by making use of available capacity to mitigate congestion due to system capacity constraints, by making it possible to connect new power sources to the grid and control its output when there is congestion from other power sources in operation.

Distribution systems are expected to utilize DERs flexibility to mitigate congestion, but there are no schemes to utilize it yet. Grid congestion has been avoided by performing grid reinforcement on distribution systems without non-firm access connections. DERs can be used to avoid exceeding transmission capacity by recharging batteries when the actual power flow is expected to exceed the transmission capacity, and this can enable low-cost and early grid congestion mitigation and expansion of renewable energy while avoiding grid reinforcement.

The challenge in utilizing DERs flexibility is that they require the development of a system between TSO/DSO and aggregators. Currently, aggregators develop and operate their own distributed resource management and control systems, called DERMS, which control and aggregate DERs to provide supply and coordination power to the electricity market. However, the DERMS system does not have the capability to acquire and forecast the status of grid congestion. To avoid grid congestion when utilizing DERs, it is necessary to build a new local flexibility system to enable control according to the power current.

METI and NEDO are currently developing a DERs flexibility system for technical demonstration. In addition, a new DERs flexibility utilization platform is being developed to connect the TSO/DSO control system and the aggregator's system. A platform that has a DER solicitation function for TSO/DSO and a bidding function for aggregators to determine the approximate quantity of DER in the market has also been introduced. A full-scale field demonstration is planned for 2024, with the goal of linking results to the effective utilization of DERs through enabling aggregators and others to connect to the DERs flexibility system.

Q&A

Q: Do you have any dynamic measures for changing electric supplies so we can change people's behavior or demand?
A: It is a bit challenging to change people's behaviors or other social systems. Japan is an island, and it is very important to stabilize the grid. We are also supporting some microgrid demonstration projects in regional areas.

d) Draft update of NECP 2023-2030: The challenge of electrification of final demand

Jesús PULIDO
Deputy Directorate-General for Energy Foresight, Strategy and Regulation
Ministry for the Ecological Transition and the Demographic Challenge, Spain

The final version of Spain's 2023 National Energy and Climate Plan (NECP) will be sent before June 2024, which will include changes such as the modernization of the economy and opportunities in the modeling process. The updated Spanish NECP is a more ambitious and socially responsible energy and national energy climate plan that is adapted to the transformation of the energy system since 2020 while strengthening the measures included in the previous NECP.

The NECP has been drafted under a changing European decarbonization context. The main new objectives are a 32% reduction in greenhouse gas emissions compared to 1990, an improvement of energy efficiency up to 44%, 81% renewables in electricity generation (up from 74% in NECP 2020) and 48% renewables in final energy use (up from 42% in NECP 2020). The NECP predicts that the percentage of renewable energy generation will increase from 37% in 2019 to 81% by 2030. The main technologies considered for this electricity generation are wind and solar PVs.

There are 16 measures in the NECP connected to electricity grids. The main ones include the development of new electricity generation facilities with renewables, energy storage that contributes to the management of electricity grids, and a plan for development of the electrical energy transport network. Energy storage is key for this transition, and the Energy Storage Strategy forecast of 20 GW by 2030 has been upgraded to 22 GW. Industry will also be very important, and the industrial decarbonization strategic plan, known as PERTE, envisions a total investment of 11.5 billion euros.

Q&A

Q: Do you have any technology portfolio for achieving the 22 GW storage? What kind of technology are you going to use?
A: Spain has hydropower and solar thermal energy, and we are also considering thermal storage in molten salts. We are launching several programs around meter technology, and we are also considering batteries. We will try to cover all the technologies available for storage.

e) UK leadership in domestic Demand Side Response standardization and grid flexibility innovation

Laura SCHADE
Senior Energy Engineer
Department for Energy Security and Net Zero, UK

Pillar three of the GPFM, on data and digitalization for system integration, intends to accelerate the digitalization of energy systems through the development of interoperable data exchange and effective energy system integration. The two main innovation priorities are ensuring compliance with international standards to enable interoperability and data sharing and increasing coordination and speed of responsiveness across flexible assets. To meet the target of net zero emissions by

2050, the UK must shift away from fossil fuels and use low carbon sources of energy for flexibility. This means more intermittent and inflexible generation, particularly from wind and solar, as well as increased electricity demand as we electrify transport and heat.

Low carbon sources will be used in a smart way, enabled by data and digitalization. Standards can really help lower the cost and promote innovation in technologies as well as help to accelerate the uptake of safe and interoperable smart products and services. They can also be referenced in regulation and be promoted for international adoption.

The British Standards Institute has published two standards; Publicly Available Specification (PAS) 1878, a specification for energy smart appliances (ESAs), and PAS 1879, an entity level PAS that can integrate together and provide an end-to-end technical framework from the smart appliances for DSR. The development of these standards was industry-led and sponsored by the UK government. Published in 2021, the Smart System Flexibility Plan states that the government will work with industry to support the uptake of PAS 1878 and 1879 for energy smart appliances.

The standards are underpinned by four key policy principles: interoperability, data privacy, grid stability, and cybersecurity. The standards specify a DSR framework and provide details for cold response services, but also allow for other types of routine DSR services to be built on top. There are two key DSR service types: routine and response.

In terms of regulatory actions to incentivize domestic DSR, the Smart Charge Point Regulations were published in 2021 and are fully compatible with PAS 1878. A consultation on delivering a smart and secure energy system was published in 2022, and under the technical framework section the government proposed for smart appliances to meet regulatory requirements to a standard based on PAS 1878.

The PAS only standardizes minimum requirements to enable domestic DSR and is fully compatible with other international standards. The British Standard Institution is exploring how PAS 1878 can be internationalized. International compatibility is very important and this PAS defines a common data and information model and enables interoperability with DSR service providers through the use of OpenADR.

<u>Q&A</u>

Q: You mentioned cyber security and safety. What measures are you going to have for the protection of the grid?

A: PAS 1878 includes key elements of cyber security such as encryption and PKI certificates. There are also key elements that try to tackle some of the grid stability issues that may arise because of the proliferation of smart appliances on the network such as randomized delay to mitigate the risks of a set tariff.

Day 2 – March 13 (Wednesday)

8:00-10:15 US (EDT) / 12:00-14:15 UK / 13:00-15:15 Europe (CET) / 17:30-19:45 India / 20:00-22:15 China / 21:00-23:15 Japan / 23:00-01:15(+1) Australia (AEDT)

5) **Technology Session 1: Electricity Storage**

a) **Large Scale Sodium-Sulfur Batter (NAS®) and its application**

Kenshin KITOU
Senior Manager, Global Business Creation, Corporate NV Creation
NGK Insulators, LTD. (Japan)

NGK Insulators have developed a large-scale sodium-sulfur battery, NAS, which realizes large-capacity storage and can smooth the power load resulting in energy conservation and reduction of power peaks, thereby contributing to grid stability and safety.

NAS Batteries charge and discharge in response to power generation conditions, stabilizing the output of renewable energy. They can provide supplementation for vulnerable power infrastructure such as in mountain regions and islands and be an effective part of micro-grids for the stable supply of self-sufficient energy in these remote areas. They can also support the operation of smart grids for the interchange of power within smart cities as well as being able to supply around 60% of normal amount for three days when supply is disrupted due to natural disaster.

The battery operates on a charge and discharge by chemical reaction between Na/S electrodes, using sodium for negative and sulfur for positive. The key component is the Beta Alumina (solid electrolyte) ceramics tube. This results in a smooth chemical reaction, and no rare materials are used. The batteries have a long discharge duration with high energy density and a long life of 20 years or 7,300 cycles.

NGK started R&D of NAS battery with TEPCO in 1984 and commercialized it in 2002, designed for grid usage from the beginning. The 20ft container type Plug and Play battery was released in 2015 with 6 modules inside the container. In terms of safety, UL9540A test reports have been obtained at the cell, module, and installation level. Due to the large capacity, the NAS battery system is suitable for multi-purpose use: generation, transmission/distribution, retain, and end-user.

The NAS battery has applications for renewable energy applications, such as smoothing for wind power, absorbing over-generation of power as seen in Kyushu, and mitigating transmission congestion as seen in Italy. NAS batteries have also been used in Abu Dhabi for grid-scaled load leveling and demand management. They experience no degradation in high ambient temperatures, so they are suitable for use in the desert as well as in cold regions.

Since June 1019 NGK has partnered with BASF in Germany as their global sales partner.

b) Energy Storage Systems (Flow Battery Systems) for Expanding the Renewable Energy Implementation

Arata DOI
Manager, Strategic Business Planning Group,
Flow Battery Systems Business Planning Department, Energy Systems Division
Sumitomo Electric Industries (Japan)

The Sumitomo Group has 400 years of history. Sumitomo Electric was established in 1897 in Osaka and now has business operations in 40 countries around the world, working on core technologies for the energy sector. Recently the company has been developing battery systems to meet growing need.

The Redox Flow Battery System, or RFB, operates on the principles of redox (reduction/oxidation and flow (flowing active materials). The reactions are carried out only with the exchange of ions, and because this does not deteriorate the electrolyte, it can be used semi-permanently. The battery is highly safe as it uses non-flammable electrolytes (vanadium sulfite), and even if positive and negative liquids are mixed, they will not ignite. It also uses flame-retardant materials and is US safety standard UL1973 certified. The battery systems can be installed anywhere, including underground. The RFB has a long shelf life of over 20 years with no degradation and an unlimited charging/discharging cycle. The electrolyte can be reused after decommissioning, making it eco-friendly.

The RFB supplies electrolyte to each cell stack from a single tank, meaning that the state of charge is the same for all cells and it is easy to accurately measure the remaining charge. The flexible design separates power (MW) and capacity (MWh), making it possible to increase capacity independently, either increasing the amount of cell stacks or increasing electrolyte by enlarging electrolyte tank. This results in a low life-cycle cost with long-term capacity.

Sumitomo Electric has supplied RFB to 36 projects worldwide across 6 countries with a total of 47MW and 162MWh.

Q: There are many types of flow batteries; what is the advantage of Sumitomo's RFB?
A: The electrolyte is reusable as there is no deterioration. It is capable of long-duration energy-storage usage.

c) Lithium-Ion batteries for Energy Storage

Hong LI
Researcher, the Institute of Physics
Chinese Academy of Sciences

Lithium batteries are a very important technology that will support the development of many fields including transportation, renewable energy, and

industry. China has a national five-year target to reduce the cost of lithium battery for energy storage, extend the service life and cycle life, scale up single stations, and improve safety while also improving intelligent control and testing and smart sensors. To do this, the Chinese Academy of Science in collaboration with other partners have developed many key materials and technologies. Examples of these include:
a solid electrolyte coated separator that can improve safety and cycle life; new materials like metal plasticized current collector (MPCC) which can improve safety; new thermal block layer materials.

Other research and development that has taken place includes:

- Pioneering the zero auxiliary power solar energy storage DC coupling system.
- Innovations on blade batteries with higher energy density and lower cost.
- Developing safe electrolytes for lithium batteries using machine learning and AI.
- Internal wireless sensors that allow real-time monitoring of internal signals, which is in the process of being commercialized for lithium batteries.
- Power failure detection based on smart sensors.
- IOP-CAS/WeLion developed hybrid solid-liquid batteries; in-situ solidification can solve the key issues of solid-solid interface contact and balance multiple factors. These have been demonstrated and applied to energy storage systems on the power grid and user sides.
- Developed a novel oxide-type solid electrolyte, metal chloride solid electrolyte, and VIGLAS viscoelastic inorganic glass electrolyte.
- Launched the world's first Na-ion battery system for energy storage from IOP-CAS/HiNa, which combined with municipal electricity, photovoltaic and charging facilities to form a micro-grid. The energy efficiency of the system could reach 86.8%.

Q&A

Q: Will the database of electrolytes be in the public domain, are you still working on it
A: One paper has already been published and the database will be open as the Chinese Academy of Sciences is a public institute. It's become a very big database and will be open to international collaborators.

d) Research Progress in Advanced Compressed Air Energy Storage System

Haisheng CHEN
Director, Researcher
Institute of Engineering Thermophysics, Chinese Academy of Sciences

Energy storage is the process of storing energy in a certain form through a medium or device and releasing it in a specific form when needed. Broadly, there are two forms: electricity storage and thermal energy storage. Electricity storage encompasses physical storage of electricity and chemical power storage.

Compressed air is one of the main promising technologies of physical storage solutions. During off-peak time air is compressed and stored in a cavern, in peak times compressed air is released to drive a turbine and electricity produced is delivered to the grid. The advantages are high power rating (100MW) low cost, long lifetime (30-50 years) and unlimited storage duration. According to reports by the IEA and DOE, CAES can offer the lowest capital installation cost and levelized storage cost. There are currently two state-of-the art conventional CAES plants in operation in Germany and the USA. However, the main disadvantages of conventional CAES are that it relies on bulk cavern and fossil fuels, and the low efficiency compared to batteries.

The overall strategy is to develop a new form called Advanced CAES that uses high efficiency compression and expansion, heat transfer and storage at supercritical state to improve system efficiency, liquid/high pressure storage to avoid bulk storage cavern, and recycling of compression heat to avoid fossil fuel.

There are three major challenges to study and come up with solutions to. First is the complex coupling of key processes and energy transmission mechanism of the system. Researchers have come up with a new methodology called the corresponding-point methodology for compressed air energy storage systems. Secondly is how to achieve high efficiency under wide working conditions and high-pressure conditions during compression and expansion. A systematic study uncovered the vortex dynamics mechanism for flow loss in high-loaded cascade. Thirdly, the flow and heat transfer/storage characteristics of high-pressure fluids are complex and unclear. Systematic studies have been conducted and obtained results. Key technologies have been developed and tested in response to these findings.

Integration and demonstration are proceeding apace with China's first commercial CAES plant going into operation in 2021 with an efficiency of 60.7%. The world's first 100MC ACAES plant went into commercial operation in 2022 with an efficiency of 70.2%. 5 projects have been completed at a scale of 123MW with more under construction or approved with a total of 4200MW.

6) **Technology Session 2: Flexibility Sources and Solutions**

Value chain mapping of Energy Storage technologies and solutions for flexibility in Spain

Luis Manuel SANTOS MORO
Director of Innovation
EDP, Spain

EDP is a global player in the energy sector with activities across the full electricity value chain and present in four regions. GPFM has identified 50 urgent innovation priorities, 29 of which are focused on system flexibility and market design. Spain contributed 23 projects to NPRt focusing on the role of technological platforms.

The Spanish Technological Platform for future grids, FutuRed, was founded in 2005. In 2021 it published a report on flexibility services and technical solutions for DSOs in Spain. Batteries were identified as one important technical solution. In 2023 FutuRed published an assessment of seven use cases and eleven projects addressing flexibility issues of energy storage. There is currently a mismatch between projects and technology and use cases.

Another Spanish technological platform in energy storage with almost 100 members is BatteryPlat, which deals not only with batteries but the entire spectrum of energy storage technologies. Several studies have been conducted, showing that 75% of projects are devoted to electrochemical energy storage with 32% of these on lithium ion.

Technology platforms in Spain provide robust engagement with GPFM and its urgent innovation priority of flexibility, and several projects in Spain address these issues using batteries. Evolution towards flexibility markets will increase the viability of projects, and the value chain of energy storage in Spain is open for niche innovation.

Q&A

Q: What is the Spanish government going to do next to ensure full supply chain for chemical storage technology?

A: There is a lack of academic and industry expertise in raw materials. There is a question of technical policy and whether Spain wants manufacturers with a full range of capabilities or to focus only on upper side of the value chain, i.e. on system integration, decommissioning, and recycling. The value chain is currently linear but should be improved to be circular so materials can be recycled. This is a potential path for Europe to increase science and technology in the recycling and reuse of second life materials.

a) Dynamic Operating Envelopes: An Australian gateway to DER flexibility markets

Julio BRASLAVSKY
Principal Research Scientist
CSIRO, Australia

Australia has seen strong growth in solar photovoltaic generation of about 12% per year over the past 5 years, predominantly in small systems such as rooftop solar panels. As of December 2023, there were over 3.6 million PV installations with a combined capacity of over 34.4 gigawatts. By the end of 2023, 72.1% of

Australia's power came from renewable energy, and 100% is expected by 2025. The current future projection from AEMO in the Integrated System Plan shows huge growth in wind and solar. The challenges are the integration of these resources and the decommissioning of the previously predominant sources of electricity coal and gas.

Consumer Distributed Energy Resources (CER or DER) are technologies and services that can either use, control, generate or store energy and are connected to the electricity distribution network. They include rooftop solar PV panels, home energy storage systems, electric vehicles, and other flexible loads such as air conditioners and hot water systems. These systems must be integrated into the electric system.

DER drive power system decarbonization and lower energy costs but can also introduce network operation challenges such as power quality issues, increased power losses, and accelerated ageing of distribution transformers due to the tension between the grid and the home. Many of these challenges can be efficiently addressed through DER integration strategies based on careful coordination between transmission system operators, distribution system operators, DER aggregators and Virtual Power Plants, and market operators. Actions identified by OpEN include DSOs defining network visibility requirements and network export constraints, defined communication requirements for operating envelopes, and establishing an industry guideline for operating envelopes for export limits.

Dynamic Operating Envelopes (DOEs) are central to the Australian strategy for DER integration. DOEs define the limits on the amount of electric power a customer can import from and export to the distribution grid at a point in time and are implemented via flexible connection agreements to manage DER operation within the DOE limits. These limits are dynamic and can vary according to local grid conditions. DOEs can be used by network operators to communicate dispatchable DER capacity to aggregators or customers without further consideration of network constraints. Project EDGE, an Energy Demand and Generation Exchange pilot, has just concluded and showed the value opportunities of DER integration and the necessity of a customer-centered role.

b) Power System Flexibility to Enable the Energy Transition

Nicola ROSSI
Head of Innovation
Enel Group, Italy

Enel Group is a global energy player present in 29 countries with 62 million customers. Energy transition is not a linear, and a changing macroeconomic context has resulted in a temporary setback in some trends in the short term, with GDP growth slowdown curbing power demand, geopolitical uncertainties spurring gas price volatility reflected in power prices, and inflationary pressures and higher interest rates causing an increase in the costs of supply and financing. However, this has not impacted the medium-term direction, changes in household energy consumption behaviors will drive an increase in power demand while the need for clean energy independence and regulatory pressure will accelerate renewables penetration. Long-term needs will include distributed energy connections as the increase of renewables in the energy mix strengthens the role of distribution grids, adequate returns on renewables even as they remain competitive, and systems flexibility with battery storage playing an increased role to tackle renewables' intermittency and guarantee security of supply.

Energy storage plays a strategic role in enabling the transition to renewables and achieving policy goals. From 2024-26, 13% of Enel's total investments in RES will be in new storage capacity with 2GW of additional batteries. New chemical technologies for long-duration storage are emerging such as aqueous electrolyte batteries and Redox-Flow batteries, as well as other kinds such as gravitational storage and liquefied CO2 storage. These are suitable for intra-day energy shifting and will drive competitiveness due to their cost, safety, sustainability, and independence from critical raw materials. Operation of Enel's first vanadium flow battery with 1.1 MW/ 5.5 MWh began in February 2024 in Baleares.

Flexibility of the power system concerns the entire value chain. In generation, Enel is making use of grid-friendly inverters, advanced process control, hybridization, and power converters. The flexibility of existing assets can be improved with new technologies, such as implementing hydraulic short circuits and variable speed generators in hydro plants. Enel is carrying out pilot projects in several countries collaborating with distributors, aggregators, and customers to demonstrate the possibility of flexibly managing DERs to optimize the operation of the grid, thereby avoiding congestion and increasing efficiency. When it comes to demand-side flexibility, Enel operates over 75 active programs and manages over 9 GW of flexibility worldwide. Projects include residential aggregation, flexibility services at DSO level, and the InterStore Horizon EU project.

c) Connect and Manage Projects in Japan

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In Japan, renewables accounted for 19.8% of power generation in 2020 and are expected to reach 36~38% by 2030 with wind and PV accounting for the majority. However, there are many challenges with implanting these into the power grid, one being grid capacity constraint.

Operating capacity is determined in advance to enable stable operation, and the amount of capacity that can be additionally interconnected is determined by annual maximum power flow. Power flow will increase in line with renewables penetration, but if there is no available capacity then the network will require reinforcement to interconnect new generators. However, reinforcement of transmission networks will be cost and time intensive.

Looking toward 2050, NEDO is conducting R&D activities to integrate a high ratio of variable renewables to the grid through planning and designing electric power systems that can accommodate large amounts of renewables. One of the solutions for economically and quickly accelerating additional interconnection of renewables with maximum utilization of the grid is non-firm connection. This is an initiative to enable new generators to come online and operate within the scope of available capacity on the assumption that output will be curtailed if operational capacity is expected to be exceeded during normal operating times. The non-firm connection scheme was introduced in 2021, but there was no system for management. NEDO undertook an 8-billion-yen project to develop a system for non-firm connection and management and demonstrated it through field tests. System functionality has been verified and operation will start in 2024.

For more effective utilization of renewable power generation, operations must be controlled to match supply and demand. As a solution for maximum utilization of the grid, NEDO is developing a DER flexibility system to mitigate congestion in distribution systems caused by renewables by monitoring the operational status of DERs and controlling them to shift demand without resorting to curtailment of RE output. A field demonstration test will be conducted in 2024.

NEDO's Connect and Manage 2.0 Project is scheduled for 2024-38 with a budget of around 24.1 billion yen to carry out technological developments to ensure and optimize the flexibility of power grids, reduce integration costs, and promote the interconnection of RE. NEDO will also conduct nationwide optimization calculations for unit commitment and economic dispatch and conduct feasibility studies to optimally control generators and DERs.

7) **Technology Session 3: Grid Stability (Inertia Management, Smart Inverters, Grid forming converters)**

a) **Full-DC-link integration of VRE: A novel solution for improving grid stability**

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China has a huge installation of wind and solar PV and is aiming for over 1.2TW in 2030 and 4~6TW when carbon neutral. There is a plan to develop giant renewable bases in the Gobi Desert as well as offshore bases in eastern China, however there is a challenge with integrating them into weak power grids. The technical challenges can be divided into three types: stability, efficiency, and cost. The proposed solution is a full-dc-link integrated renewable power system. This system collects and transmits electricity through full DC-link with a DC-DC converter core to boost the LVDC power generated from PV arrays or wind turbines to medium voltage-DC or high voltage-DC feeding into the grid side. Compared to regular AC integration solutions, this would result in a 50% reduction in connection equipment, a one third reduction in power cables, leading to better stability with a low risk of voltage issues and less O&M due to the unified converter for PV and wind.

The RD&D approach is based on the modularized approach where both centralized and series solutions are investigated, and six key technical issues of bulk power, high voltage, high ratio, high efficiency, high reliability, and high-power density are highlighted

The design of the crucial DC to DC conversion module has gone through several iterations. The latest version has 100kW of power, 99.3% efficiency, and 0.65W/cm3 power density. It is still being improved upon A booster with full bridge isolation conversion (BFBIC) circuit, wide range "soft switches" and insulation and cooling were developed to achieve high efficiency, insulation, voltage level, and power density.

At the system level, two system structures, centralized and series, are under R&D. In line with the complex operating conditions of multiple converters in series/parallel, a multi-mode coordinated control strategy is being developed to achieve system reliability and efficiency. Several demonstrations have been built including one in Dali, Yunnan in 2020 with operating verification for 50 days. It operated reliably and with good typical output performance indicators.

Through extensive R&D work, the FDC solution has gone from experiment stage to demonstration and shown its advantages in terms of conciseness, reliability, stability, and efficiency.

b) Grid Forming Converters: Advanced capabilities for grid stability with high penetration of Renewable Energy

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Renewables are connected to the power grid using inverters. Further expansion of renewable energy will increase the number of inverter-based resources (IBR), including storage batteries. When IBRs dominate the power supply, the power system can fall below the minimum level of system stability and in the worst case even lead to blackouts. Grid-forming (GFM) inverters with functions equivalent to synchronous generators will be needed for a high penetration of renewable energy.

Discussions on rules, requirements, and specifications are underway worldwide and the implementation is progressing from demonstration to operation. The UK's National Grid ESO issued the world's first grid code for introducing grid form inverter in 2022, and in Europe, ACER is considering making GFM mandatory through the Grid Code.

The Japanese government is promoting technological development to resolve grid constraints that are barriers to introducing renewables. The policies are aimed at revising the grid code in the 2030s. To this end, NEDO is conducting R&D for the practical application of grid-form inverters under the NEDO STREAM project, focusing on future-generation power network stabilization technology development for utilization of renewable energy as the major power source. One project is the development of grid form inverters which consists of three major Work Packages. WP1 focuses on formulating requirements and specifications and developing prototypes. WP2 involves developing and standardizing test methods by evaluating and testing the developed prototypes through both laboratory and demo field testing. WP3 is concerned with conducting impact assessments through simulations. The aim is to provide a proposal and data for the standard and provide evidence and a report for revision of the Grid Code.

A working draft of requirements and specifications is in progress with projected publication in 2024, after which prototypes will be tested based on these specifications. The project is the first in the world to study GFM for distribution systems. Performance tests will determine the detailed required specifications and will be fed back into revisions of the draft.

Lab tests were conducted at FREA Smart Systems Research Facility, which opened in 2016 as one of the world's largest test facilities with a grid simulator and is currently being expanded under the International Standard and Certification Center Development Project for Promoting Carbon Neutrality of METI.

8) **Future Perspectives – GPFM**

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GPFM had a busy year in 2023, actively participating at CEM14/MI-8 in Goa, India in July 2023 and successfully releasing the National Pilots Report, a key milestone toward the Flagship Project 1 "5 Demos in Five Continents". The Report collated information on 80 ongoing and planned pilots from around the world, with 56 of them addressing topics of flexibility and stability.

The Mission was also active at COP28 in Dubai, releasing a demo version of the GPFM Toolbox, an internet-based knowledge-sharing platform, and the Annual Report 2023 summarizing the main achievements of the Mission in 2023 and presenting the progress made in comparison to the Action Plan to show that global partners and projects are on track to meet ambitious targets.

The first International Workshop, held in Yancheng China, resulted in endorsement by high-level government and ministry representatives from GPFM coalition member's countries.

In terms of plans for 2024, GPFM intends to advance the "5 Demos in Five Continents" project by progressing with monitoring and sharing knowledge and information, engaging in a multilateral research program, releasing the Annal Report 2024 and the Action Plan 2025-2027, host a series of online seminars to share knowledge and run the second Yancheng International Workshop "MI Green Power Innovation Conference".

The first Joint Call Module organized between GPFM and CETPartnership has been successful with 22 applications covering important aspects in line with innovation priorities. The second Joint Call Module will be launched by September 2024 covering the main R&I themes such as stability and flexibility.