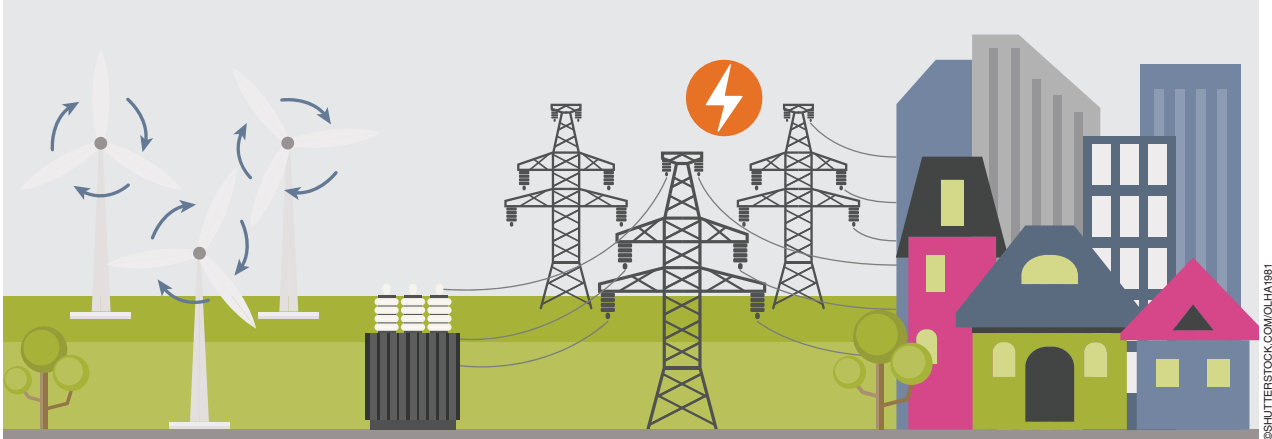


HOW FLEXIBILITY CAN SUPPORT RESILIENCE

A Grid Operation Holistic Perspective

By Antonio Iliceto and Barbara Herndler 



BY INTEGRATING RENEWABLES IN THE era of digitalization, power infrastructure is becoming more connected to ensure a secure, efficient, and decarbonized future system. However, this increased connectivity also makes infrastructure more vulnerable. Over the past decade, geopolitical tensions and concerns about energy security have influenced power systems, prompting energy professionals to explore various solutions for maintaining a reliable and resilient future. Researchers and experts from the International Smart Grid Network (ISGAN), International Council on Large Electric Systems (CIGRE), as well as system operators and communities, are exploring various solutions that focus on flexibility options, resilience, and how these two aspects can support each other. In particular, they continue to work on energy system stakeholders' interaction to identify a key pathway to a clean, reliable, and secure energy future. In ISGAN, the experience from *flexibility definition and characterization* started in 2019, and continued with *flexibility for*

resilience in integrated systems activity supported by the International Energy Agency in 2022; recent outcomes from an ISGAN workshop held in 2023 on the topic of “Flexibility for Resilience and Power System Stakeholder Interaction” are summarized and discussed here. This article presents the results and best practices derived from collaboration and the exchange of experiences between countries. It highlights the potential, role, and actions being taken by various stakeholders, including academia, society, policymakers, regulators, urban planners, system operators, retailers, and consumers, in addressing the urgent need for power system resilience and the critical role of flexibility.

The electrical power system is transitioning to become decarbonized, decentralized, and highly digitalized. The need for the integration of renewable energy sources, timely responses to grid changes, and stakeholder engagement has become pivotal in ensuring the safe and secure supply of electricity. Power system operators are now faced with numerous challenges to incorporate these highly volatile energy sources and increased load demands within

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their networks. Through the optimal use of flexibility, network operators are able to ensure the necessary balance between supply and demand while simultaneously maintaining sufficient network capacity reserves. The need for a dynamic and highly responsive power system has further elaborated the requirement for network resilience. Furthermore, in order to envision this transition, stakeholder interaction emerges as a crucial factor in the collaboration requirements between diverse actors, such as system operators, regulatory bodies, aggregators, industries, and end users. This triad of flexibility, resilience, and stakeholder interaction, as shown in Figure 1, sets the foundation for the transformation toward a sustainable power system.

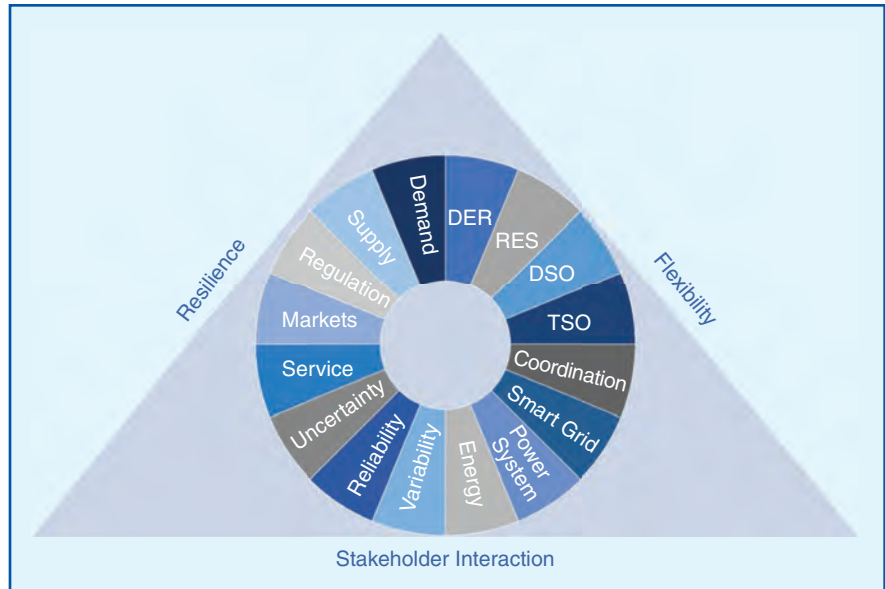


Figure 1. Overview of the modern power system aspects and their relation to resilience, flexibility, and stakeholder interaction. DER: distributed energy resource; DSO: distribution system operator; RES: renewable energy sources; TSO: transmission system operator.

Flexibility and Resilience Perspectives

Flexibility in power systems has traditionally been utilized in the daily grid operation, for balancing power flows, solving congestions, and maintaining stability. The next level of flexibility can now be defined and implemented during the grid planning phase by integrating it into long-term planning processes and market mechanisms. This ensures the procurement and appropriate compensation of flexibility providers, while also enhancing resilience. Figure 2 shows the different typologies of flexibility, according to time and space resolution, as proposed by the International Smart Grid Network (ISGAN)¹ in 2019.

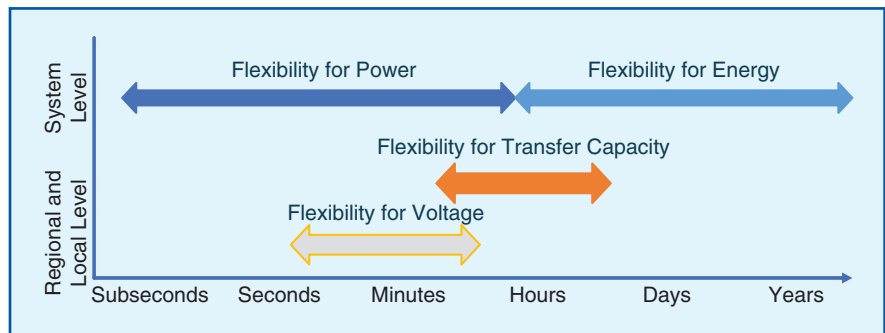


Figure 2. Flexibility characterization in spatial and temporal perspectives.

With the combination of high electrification intensity and grid decarbonization, it is essential to enhance the understanding of how to integrate flexibility and resilience criteria into the electric system. In this context, resilience means the ability of the power system to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, or rapidly recover from those incidents.²

However, a deeper insight is needed to evaluate how the increasing demand for resilience can be more

¹<https://www.iea-isgan.org/about-us/>

²<https://grouper.ieee.org/groups/transformers/subcommittees/distr/C57.167/F18-Definition&QuantificationOfResilience.pdf>

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effectively incorporated into the energy system. This includes the following:

- ✓ system technical performance and grid development, addressing real-time flexibility utilization
- ✓ a costs, benefits, and risks analysis, distributed across all stakeholders involved
- ✓ consumer engagement, tariff design, markets, and roles of service providers or aggregators
- ✓ flexibility solutions integrated into energy systems from decision making through regulatory processes on a country scale
- ✓ power system digitalization including cybersecurity aspects.

Within ISGAN Working Group 6, a new perspective related to data exchange and privacy within smart grids is currently being investigated. System data exchanges and data privacy are crucial for improving resilience toward growing uncertain boundary conditions and for being able to access new flexibility sources. This includes interoperability of implemented and proposed technologies. While numerous standards exist, national, regional, and international standardization processes are ongoing, where lead times are long and proprietary protocols are still pervasive. The need for a comprehensive and sustainable plan for the deployment of these process technologies is critical for a resilient future.

Stakeholder Interaction Perspectives

The electrical system is undergoing a transformation in how power is generated, transmitted, and distributed. As a result, system operators face numerous challenges: technical, information and communication technology-related, regulatory, and economic, while adapting to new technologies and processes that place

the end consumer at the core of the digital and green transition. These changes have also introduced more alternatives for the planning, expansion, and optimization of power systems. This includes integrating renewable energy sources, enhancing grid flexibility, and implementing smart grid solutions. Additionally, it involves adopting innovative approaches, such as nonwire alternatives (e.g., energy storage, demand response, and distributed generation) to improve efficiency, reliability, and resilience while enabling the participation of new market players, including those from sectors beyond the traditional electricity industry. There has been increasing focus on the interaction and data exchange between transmission system operators (TSOs) and distribution system operators (DSOs), where the development of various coordination schemes is being elaborated; Now, the need to extend this coordination to additional stakeholders—such as prosumers,³ aggregators, and operators of other sectors—coupled with the power sector is crucial. Stakeholder interaction is, therefore, key to facilitating and enabling the integration and utilization of flexibility in future power systems.

How Flexibility Can Support Power Grid Resilience

There is a growing need for adequate flexibility to ensure system balancing, manage congestion, and enhance resilience in the face of emergency events while keeping costs affordable. However, traditional sources of flexibility are declining as the transition away from fossil fuels accelerates. In some countries, hydropower currently serves as the primary source of balancing, but this may not be sufficient in the future due to rising demand and the effects of climate change on hydropower resources.

The Next Level of Flexibility

The design and building of new generators and transmission systems is a long-term task, and the investment planning process is the initial step to ensure that the power system will have sufficient flexibility and

³A prosumer is a person or entity that both produces and consumes energy.

resilience. In regulated scenarios, this function was carried out via a centralized planning model in which industry participants and government agencies jointly assessed potential requirements for resiliency. In this regard, it is crucial to generate price signals that guide investment and operational decisions. These signals should reflect the actual needs for flexibility, which vary across different timeframes (from real time to short, medium, and long term). They also depend on performance requirements and technical limitations, often constrained by the energy released. Notwithstanding, sufficient investment in flexibility, the power system may still lack the ability to operate with sufficient resilience. Thus, the resilience dimension must be factored in at the long-term planning stage of power systems. For instance, the requirement for black start resources, based on the system's needs, must be considered during the planning stage to ensure proper integration with the rest of the system. Flexibility is relevant to many aspects of the planning process: Traditional processes focus on ensuring sufficient generation and transmission capacity to reliably meet demand, where the demand is considered to be a purely exogenous variable, inflexible with regard to electricity price, particularly during peak conditions. Processes considering a broader view of resilience consider several elements contributing to the provision of the amount and type of flexibility required: dispatchable generators, flexible loads, storage devices, and flexibility through conversion among different energy forms (heat, molecules). Electric vehicle (EV) batteries, if connected to vehicle-to-grid charging systems, can also provide this service, again with benefits both in terms of flexibility and resilience. The challenging target is then to find the optimal combination ensuring that systems can meet the flexibility required for the successful operation under all scenarios.

Investment planning, in the form of network development plans, should be the result of a procedure that gives an overview of a complete grid development, with particular emphasis on the main transmission and distribution infrastructure, which is required to connect new generation capacity and new loads. Usually, it is necessary to use reference scenarios to identify the technical characteristics of main invest-

System data exchanges and data privacy are crucial for improving resilience toward growing uncertain boundary conditions and for being able to access new flexibility sources.

ments, especially investments that have the technical and economic potential to be deferred or replaced by flexibility means. Indeed, for each network development case, system operators will have to analyze the feasibility and cost-effectiveness of any flexibility solution versus investments in traditional infrastructures. This has a clear impact on grid operators' economics if the tariff system remunerates their capital expenditures and penalizes their operating expenses.

Concrete examples of mechanisms born for flexibility but also improving resilience can be seen in [Figure 3](#).

- ✓ *Load shedding* is still a basic procedure today and is a widely utilized method to ensure the resilience of the power system in case of sudden energy deficit; however, it is a highly impactful and undesirable event, and even interruptible customers, who are voluntarily included in such schemes, wish to minimize the number and duration of these occurrences. In the future, smart load shedding, offering modulated load reductions versus proper compensation on a specific market, represents a paradigmatic case of flexibility (demand response) being conveniently used at the same time for system resilience. The next level is to move away from prescribed obligations and instead empower each customer with the freedom to determine how much of their flexibility they are willing to exchange for appropriate economic compensation.
- ✓ *Black start* capabilities are currently provided only by large generation plants, realizing a top-down process, from the high-voltage network, while in the future, the energy stored in EVs, hydrogen tanks, and heat sinks

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(e.g. underground heat/cool reservoirs utilizing cyclic temperature differences) can trigger bottom-up energization of local grid portions, enhancing the intrinsic resilience of the grid. On top of that, microgrid architecture reduces a blackout footprint straight away. Islanding operation capabilities, in contingency situations, further increase the resilience of the local or regional portion of the electric system to mitigate and recover from large disturbances; in practice, it is the extension of fault-ride-through concept from single devices to entire subsystems or local grids.

- ✓ *N-1* criterion as minimum safety (sometimes *N-2*) is a nonsmart approach to security, implying a nonminimized effort for ensuring

resilience. Extra security margins, especially if a deterministic approach is used instead of a probabilistic one, are a net extra cost to the system. In the future, even *N-0* conditions can become acceptable if the automatic reactions of some flexibility devices or processes are taken into consideration.

In the latter two cases, costly assets are avoided, while resilience resources can be accessed with minimal additional expense, as they are selected and compensated primarily for their flexibility. In the case of load shedding, the asset base remains the same, but the damage of load shedding for the final user (mainly industrial and service plants) is modulated according to a merit order self-decided by the user itself, thereby applying a basic principle of economic efficiency: reaching a given target utilizing the least impacted users (this is dynamic, depending on time and amount of power to be reduced). Intrinsically, this merit order (in practice, an auction of demand response willingness) induces system savings, because the load shedding is selected by the incumbent grid operator along the merit order, starting from the cheapest bids. A complementary way is to adopt flexible connection agreements, which might be more appealing to residential customers.

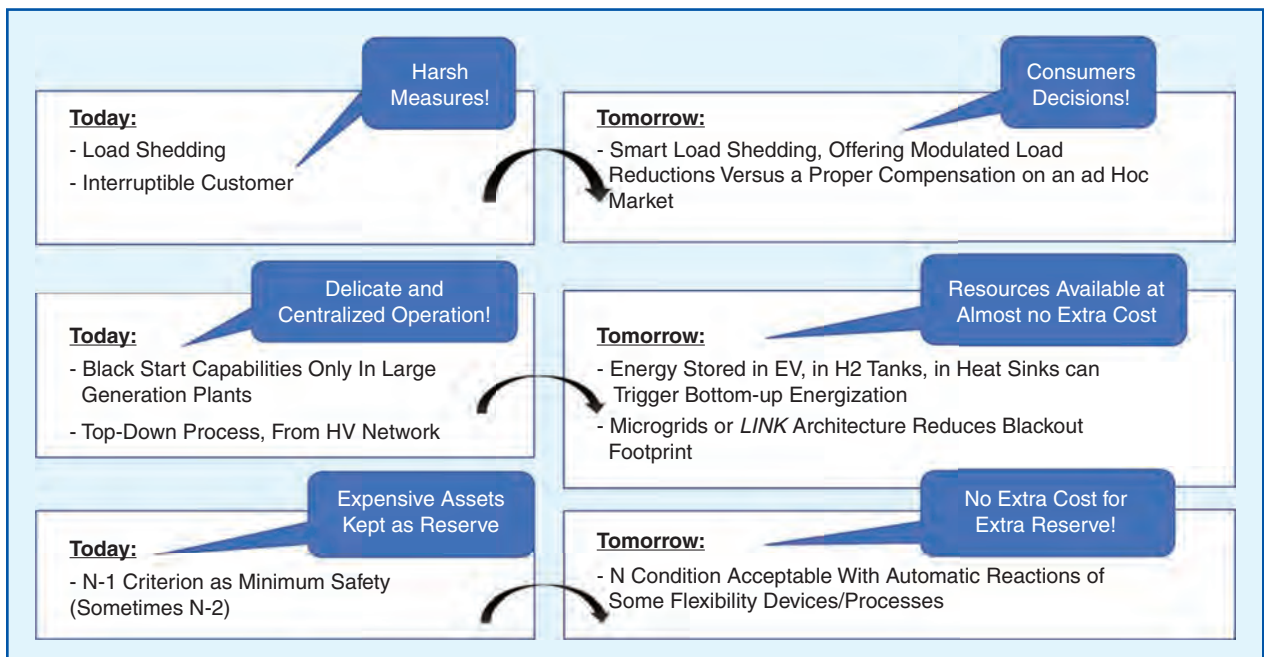


Figure 3. Concrete examples of flexibility that also support resilience. For LINK architecture, see <https://www.powersys-link.com/>. H2, hydrogen; HV, high voltage.

Considerations on a Practical Fast Reserve Use Case

The progressive reduction of system inertia will exacerbate the frequency variations after imbalance events that have to be contained within the very first instants after the event. The required response time is often not compatible with the primary reserve frequency containment reserve (FCR), which requires the full activation time of several of tens of seconds. To ensure frequency stability, it is therefore necessary to introduce a grid service characterized by a full activation time below the one of FCR. This fast reserve service will not replace the FCR but complement it, improving the dynamics of the system response to disturbances, as shown in Figure 4.

As a real example of flexibility means deployed to enhance grid operation, at the same time increasing its degree of resilience, the fast reserve service can be mentioned. This use case stems from the need to limit frequency variations and, therefore, a typical operational need. The identified solution is a new flexibility service, i.e., fast reserve, which effectively meets the identified need to limit frequency variations. Fast reserve service comes as an addition

to traditional forms of flexibility available through the ancillary service market, where additional storage capacity, pumped hydro, and electrochemical, provide the opportunity to shape new flexibility resources in the ancillary services market. This means demand–response, distributed generation, batteries, allowing full use of all available flexibility sources; redesign of products procured on the ancillary services markets to better express the flexibility needs; progressive integration with neighboring countries “EU Internal Market for Ancillary Services.”

The new grid services, fast reserve, also automatically increases the resilience of the system by mitigating:

- ✓ the threat of sudden large events causing high and rapid frequency deviations
- ✓ the stress of a multitude of events potentially combining in a cascade chain.
- ✓ If located properly, the units providing fast reserve can also provide reactive power for voltage support: directly (fast hydro plants with variable speed control) or through grid-forming capabilities, inverter-based batteries, and devices. Indeed, grid forming adds the feature to independently control active

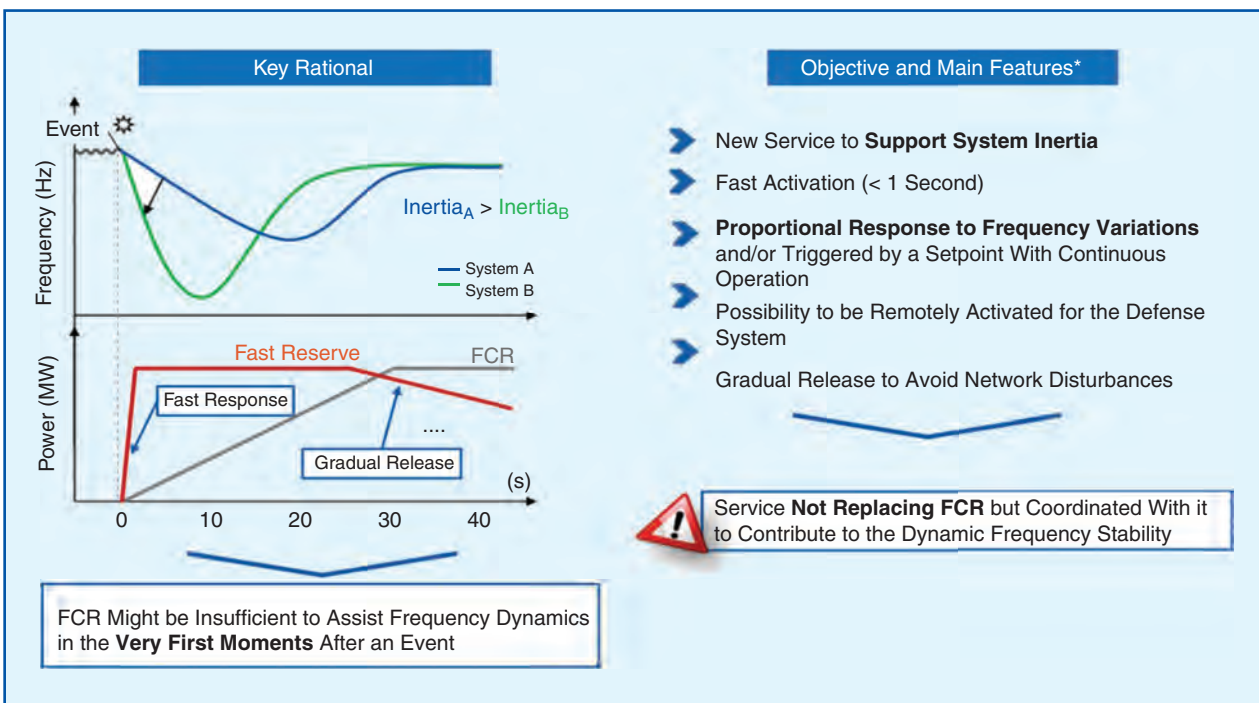


Figure 4. Characteristics of fast reserve service (Terna, auctions for Fast Reserve 2022) .

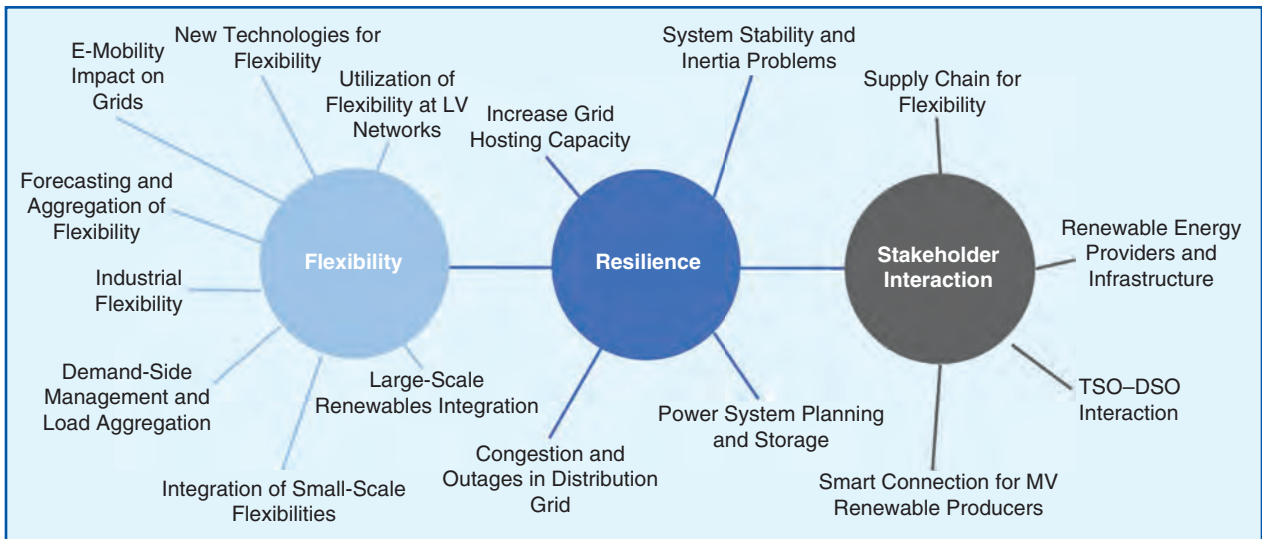


Figure 5. Overview of pilot project activities related to flexibility, resilience, and stakeholder interaction.

and reactive power exchanges with the grid, therefore addressing more cases of effective system needs (frequency and voltage support in all operational quadrants).

It can be concluded that the new grid service, originally designed for pure flexibility reasons, can be tailored also to maximize a resilience increase, i.e., by including the resilience aspects in the frequency stability when designing the auctions for procurement of fast reserve service.

It is then important that the increased resilience is factored into the remuneration of the service, as an additional component of the revenue stack for the flexibility providers. Also, adequacy assessments should properly consider the positive extra resource.

International Experiences and Flexibility Engineering

To evaluate the technical aspects of a solution, such as its engineering complexity and scalability, a pilot project serves as valuable training experience. Through a pilot project, stakeholders can not only validate the viability of their technical solutions prior to their implementation, but also refine and adapt them based on lessons learned, paving the way for successful and informed full-scale deployments. The introductory phase is also critical for mitigating risks of failure, optimizing resource allocation, and learning from real-world conditions. It is also a crucial phase when regulatory modifications are needed, af-

ter proper sandbox experience in either derogation of existing rules or in anticipation of future regulations.

In general, pilot project implementation serves as a strategic entry point for organizations who are seeking to explore, test, and refine technical solutions within specific use cases. This approach involves deploying a small-scale version of a proposed initiative to assess its feasibility, identify potential challenges, and gather valuable insights before committing to a full-scale implementation. Figure 5 provides an overview of some activities and topics addressed within past and current pilot projects from an international perspective (Figure 5).⁴

Many of these endeavors often require a high engineering effort, particularly when implementing highly sophisticated solutions that may encounter scaling issues in the transition from pilot to full-scale deployment. Furthermore, the replicability process and its related aspects also pose an identifiable gap in many of the recent pilot projects. To address this, it can be recommended that a scalability and replicability study should be incorporated as part of the outcomes of the project. The lessons learned from pilot projects are invaluable for developing scalable and replicable processes and implementation road maps that can be applied both regionally and internationally.

⁴Countries that participated in the workshop include: Austria, Australia, France, Germany, Ireland, Israel, Norway, the Netherlands, and the United States.

Stakeholder Interaction and Engagement

As the role of power system stakeholders and system components have transitioned to become more flexible and interactive through the advances in technology, the dynamic interaction between them requires the revision of their roles and responsibilities. Through various demand–response techniques and schemes, the balancing of supply and demand becomes more efficient, especially during times of high peaks of the residual load in the system. Flexible storage devices allow excess energy to be stored during times of low demand and high generation (such as from wind and photovoltaic generation), which can be used at a later time when demand is high, thereby improving grid adequacy. Smart grid technologies have also enabled the integration of flexibility through the deployment of advanced communication and control systems, which can be used to optimize the operation of the network and enhance the communication between system operators and the customer. Within this dynamic landscape of technologies and power system solutions, through the use of flexibility, the need for increased interaction between power system stakeholders becomes a vital component to ensure the safe and secure operations of future power systems. Some notable examples include:

- ✓ *EVs*: The increase in the adoption of EVs and their charging infrastructure has contributed to the increase in load demand, contributing to increased power peaks. New technologies, such as smart charging and vehicle-to-grid, are currently being investigated to provide support to the grid.
- ✓ *Heat pumps*: These provide short-term flexibility by reducing load when required through demand response programs, as well as provide thermal energy storage, which is considered to be a dispatchable heat source.
- ✓ *Battery energy storage systems (BESS)*: BESS provide various forms of network support. As flexible assets, they can store ener-

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gy and discharge it for peak shaving, helping to reduce energy costs while also alleviating network congestion. Additionally, BESS can deliver grid ancillary services, including voltage support, reactive power compensation, fast frequency response, and black start capabilities. However, the availability of these services depends on the specific design and capabilities of the BESS.

- ✓ *Power to gas*: The conversion of excess energy produced from renewable energy sources can be used to produce synthetic fuels. This energy can then be stored until it is needed, thereby contributing toward grid balancing when the stored energy is utilized during times of high demand.
- ✓ *Sector coupling*: This involves utilizing surplus electricity generation to produce green hydrogen, which can then be used in other sectors, such as transportation.
- ✓ *Industries*: In particular, some large industrial customers are considered to have high potential in offering flexibility services to network operators. By strategically adjusting their energy consumption, they can participate in load-shifting applications, provide support to the grid, and offer ancillary services.

To enable successful interaction, it is imperative that the role of each stakeholder is clearly defined as early as possible and that a common language is established to ensure that understanding, communication, and trust are built among them. Within Europe, the roles of various stakeholders can be defined according to the Harmonized

Electricity Market Role Model,⁵ which was further enhanced by the European Commission's BRIDGE⁶ Working Group to include new flexibility roles. For example:

- ✓ flexibility market operator
- ✓ TSO/DSO coordination platform operator
- ✓ flexibility service provider/aggregator
- ✓ local flexibility calculator.

The consideration for the mapping between stakeholders has also been proposed where the following are to be identified: 1) which stakeholder is likely to be affected, 2) which stakeholder influences the implementation, and 3) which stakeholder possesses information or data necessary for the implementation. These interactions can be designed and developed based on a structured framework through the implementation of a coordination scheme. Various coordination schemes have been defined and implemented within several pilot projects, which can be used to offer the TSO and DSO a wide range of system services. Within Europe, the following coordination schemes have been investigated within various pilot projects⁷:

- ✓ centralized TSO flexibility market
- ✓ local (DSO) and global (TSO) flexibility markets with resources sharing
- ✓ local (DSO) and global (TSO) flexibility markets with shared responsibility
- ✓ common TSO/DSO flexibility market.

The benefits of increased stakeholder interaction include⁸: 1) increased utilization of distributed energy resources, 2) increased system flexibility,

and 3) optimized investments in grid infrastructure. Active collaboration between diverse stakeholders based on an approach that recognizes and develops open communication, transparency, and trust is essential to achieve the initiatives of a sustainable, resilient, and low-emission power system. The role of customers, who are increasingly transitioning toward the role of prosumers, are now becoming more active, and therefore increasingly more significant in the modern power system. However, ensuring that the end user continues to actively participate, adequate mechanisms and procedures need to be implemented. The development of effective business models and incentives to offer flexibility needs to be in place to encourage active participation. Furthermore, the implementation of these solutions requires continuous support from regulatory organizations, who serve as enablers in delivering and maintaining regulatory frameworks that are transparent and fair.

The Role of Business Models, Stakeholder Involvement, and Multidisciplinary Aspects

Business models play a pivotal role in the acceleration of the transition toward a more flexible and resilient power system. The development of business models within the energy sector is also influenced by the development and adoption of flexibility solutions. The major risk lies in the fact that if there are insufficient business models, implementation will be hindered. Thus, many pilot projects are now focused on obtaining more insights into the various opportunities of flexibility utilization to establish attractive business models and consider these integral aspects of the project. Currently, many challenges are seen from the system operator's perspective. These include, among others, the increased uncertainties in long-term system planning and the role of flexibilities. The DSO needs to ensure increased participation from flexibility services providers, especially during the tendering phase, to enhance grid reliability, optimize operational efficiency,

⁵European Union Bridge Working Group, "Harmonized Electricity Market Role Model-A Differential Analysis with Respect to the ENTSO-E – ebIX – EFET Model," 2021.

⁶<https://bridge-smart-grid-storage-systems-digital-projects.ec.europa.eu/working-groups>

⁷Silva, R.; Alves, E.; Ferreira, "Characterization of TSO and DSO Grid System Services and TSO-DSO Basic Coordination Mechanisms in the Current Decarbonization Context," *Energies*, 2021.

⁸https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_TSO-DSO_co-operation_2020.pdf?la=en&hash=5D78444F4339DC130204A0F9A99A30753368AABC

and facilitate the seamless integration of renewable energy sources. With an established TSO/DSO interaction process, the flexibility services providers would be able to participate in both the TSO and DSO flexibility markets, which opens the opportunity for additional business models. Additional key challenges and considerations that system operators may face may pertain to the relationship between technical feasibility and regulatory aspects. In some cases, the role of the legislation is often seen as a hindrance to the establishment of business cases. For example, in many countries system operators are not allowed to own storage systems, or regulatory models are oriented to a “one asset–one service” approach.

While a wide range of technical solutions is available, adequate stakeholder involvement must be established not only from a technical perspective but also from nontechnical aspects. This means that the right mechanisms, such as incentives for end-user participation and risk mitigation need to be established. In this regard, one possibility is to consider business models that also serve the customer (in contrast to the energy system).

The role of regulatory sandboxes has become increasingly important to allow for new business models to be investigated within the framework established by regulatory authorities. This provides the opportunity for business models to be tested and evaluated within a controlled environment. This controlled environment allows for the observation of how innovations perform in real-world conditions before widespread implementation. By doing so, the necessary data can be collected, potential risks are identified, and compliance with relevant regulations are established. With this knowledge, regulators are empowered to make decisions that shape the future implementation and success of innovative business models.

Many pilot projects require the perspectives and incorporation of various stakeholders. Thus, there is a need for a multidisciplinary approach that extends beyond the technical domain through the integration of social, cultural, and ethical dimensions. Within highly technical focused proj-

ects, there is often a limitation in the research competencies from nontechnical domains, such as the social sciences and humanities. Through the incorporation of these skill sets within pilot projects, the gap between technical and social aspects can be reduced by gaining an improved understanding of human behavioral aspects associated with the outcomes of the project. To facilitate individuals from various backgrounds, ranging from engineering, information and communication technology, and market expertise, a common language that enhances productive collaboration should be established in the early stages of project development.

Addressing Instruments, Programs, and Communities

Enhancing the knowledge transfer and lessons learned based on the outcomes from pilot projects is one of the key aspects in allowing all stakeholders to make informed strategic decisions when it comes to the future deployment of advanced technology solutions. The identification of key aspects within the projects should be made on a continuous basis and can be disseminated throughout the various phases of the project. Progress reports, milestones, outcomes, and key messages are often documented and can be disseminated through various communication mechanisms, such as publishing on websites, social media platforms, conferences, and hosting of webinars. Ensuring that there is a balance between face-to-face interactions and virtual platforms, along with online resources, enhances the meaningful exchange of knowledge. Additionally, the information that is shared should ideally be detailed enough to be meaningful to expertise while remaining accessible to interested parties. This approach encourages collaboration, learning, and the dissemination of valuable insights across diverse stakeholders in the project. The showcasing of various projects through interactive live demonstrations within communities increases the awareness and knowledge exchange process, particularly for potential future stakeholders who are not directly involved

in the project. The reporting of success stories also provides additional opportunities to encourage new stakeholders to consider the implementation of technology solutions to provide benefits to the power system.

From an international perspective, ISGAN promotes dynamic knowledge exchange, technical assistance, peer review, and activity coordination among its participants and stakeholders from various countries across the world.

Conclusion

Many of the worldwide ongoing initiatives offer valuable insights into the question of how flexibility can enhance resilience. These initiatives highlight the importance and potential value of flexibility that can be unlocked, with several opportunities available for immediate implementation.

The article provides an overview of various aspects obtained from pilot projects targeting the implementation of power system flexibility for resilience and stakeholder interaction perspectives. The content is based on international experiences, which contributes to the topic based on different focus areas: flexibility resources and tools, end-user role, system operation, system planning and market, resilience assessment, and cross-sectoral view. As part of the collaboration and activities within the ISGAN Working Group 6 Transmission and Distribution Systems, a wide range of work has been conducted that explores the interaction of various stakeholders within the power system. Collaboration with several experts from various countries around the world has contributed to the topics of flexibility, resilience, and stakeholder interaction by sharing experiences and lessons learned from demos, pilot projects, and innovation initiatives.

The next level of flexibility is seen as being fully deployed and as a tool utilized for the operation and planning of the power system, being integrated in procedures for long-term planning as well as in tools for stability support. The integrated dependency of flexibility directly impacts the resiliency of the power system; thus, flexibility solutions intended to

provide resilience support must be available, rigid, and secure to provide the trust required for operation and planning.

Acknowledgment

We thank the international organizations to which authors are affiliated through collaborative working groups—European Network of Transmission System Operators for Electricity, International Smart Grid Action Network, International Council on Large Electric Systems (<https://www.cigre.org/GB/about/introducing-cigre>), European Technology and Innovation Platform Smart Networks for Energy Transmission—where these topics are being addressed under systemic perspectives.

For Further Reading

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