International Smart Grid Action Network (ISGAN)

Working Group 9: Flexibility Markets

Integrating Flexible Resources into Distribution Network Planning

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This brochure presents the insights gathered as part of the ISGAN WG9 Task, drawn from stakeholder engagements with representatives from Austria, Switzerland, Belgium, Japan, the Republic of Korea, the United Kingdom, and Spain. As energy systems undergo rapid transformation due to increasing electrification and the integration of distributed energy resources, traditional distribution network planning faces new challenges. This document explores how flexible resources, such as demand response, battery storage, and advanced grid management strategies, can be effectively incorporated into distribution networks. By analyzing regulatory frameworks, technological advancements, and real-world case studies, the findings aim to support decision-makers in navigating the ever-changing landscape of grid planning and ensuring resilient, efficient, and future-proof electricity networks.

The ongoing trends of electrification of energy demand and decentralization of (renewable) power generation, which make up two essential pillars of the energy transition, are **challenging the traditional approach that the utilities use to perform long-term planning of electricity distribution networks**. Anticipating an expected increase in electricity demand, driven by population trends (such as urbanization) and other economic factors, and accordingly expanding the distribution grid such that it can accommodate the expected demand peak is no longer an easy task for distribution utilities. The integration of new technologies, such as rooftop photovoltaic (PV) systems, heat pumps (HP), electric vehicles (EVs), and battery energy storage systems (BESS), often paired with PV installations, into medium voltage (MV) and low voltage (LV) grids is occurring at an accelerating pace. This rapid, often unpredictable growth can outpace the utility's ability to manage, since it may extend beyond the control of the utility and its capabilities, such as observability. These emerging technologies hold the potential for grid-friendly integration, however, if not managed, their integration could also lead to network violations. In some cases, they are already causing such issues, as they can significantly exceed the grid loading limits that were originally anticipated during network planning. The challenge for distribution system operators (DSOs) is to incorporate these technologies accurately and realistically into their planning processes. Furthermore, a high response rate of controllable loads, particularly EVs, to time-of-use tariffs can drive higher network peaks by reducing natural diversity and synchronizing consumption during low-cost periods.

Given these challenges, innovative solutions are essential to maintaining network stability while accommodating the shift toward decentralized energy production and consumption. This requires advanced grid planning methodologies that integrate digitalization, enhanced forecasting, and real-time monitoring systems. Equally important is the evolution of regulatory frameworks to incentivize demand-side flexibility solutions, such as dynamic pricing, grid-interactive buildings, and vehicle-to-grid (V2G) capabilities. By aligning policy support with technological advancements, the grid can become more adaptive and resilient.

One of the key challenges in managing decentralized energy systems is preventing network violations. **Network violations** arise not only from exceeding the thermal limits of cables and transformers, a challenge typically managed through conventional congestion management, but also significantly from overvoltage or undervoltage, particularly in low-voltage (LV) networks. Possible measures to avoid these violations are shown in Figure 1.

Current planning principles are deeply rooted in historical approaches that are influenced by traditional load/generation ratios, voltage band management for both MV and LV, selected overhead line and cable cross-sections, and the share of cables versus overhead lines. The operating mode of the MV grid, including considerations like (n-1) safety operation, is another key aspect. To create network development plans, larger DSOs across Europe typically begin by conducting load flow simulations which consider current and future load and generation scenarios. However, smaller DSOs faced with data limitations often lack information such as historical data, accurate grid models, and network visibility to perform such simulations effectively. On the other hand, distributed technologies offer a high potential for grid-friendly integration, as they can offer a significant amount of flexibility if they are controllable. In addition to shifting active power consumption and/or injections, reactive flexibility is crucial and should not be overlooked, as it has the potential to significantly contribute to managing voltages and currents. The challenge and opportunity for DSOs is to incorporate the flexibility potential of distributed technologies accurately and realistically into their planning processes, resulting in future-proof distribution planning processes.

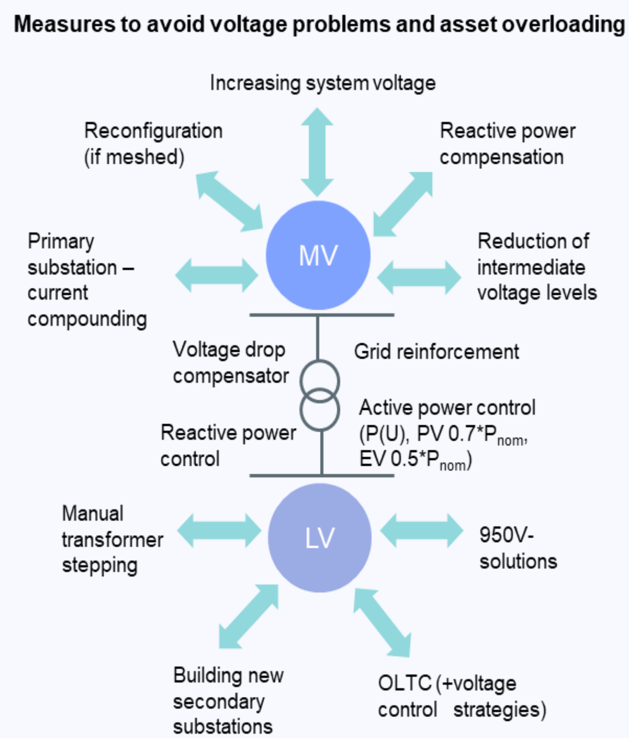

Figure 1 Measures to avoid voltage problems and overloading

There are many challenges faced by DSOs when considering flexibility utilization in the planning processes, with uncertainty surrounding the availability of flexibility being a major obstacle. However, consulting studies are underway or in their final phases, and preparations are being made to incorporate flexibility in the future. Various studies[1,2,3] and research projects are also addressing this issue, offering key findings and lessons learned that are presented in this fact sheet. Additionally, regulations designed to enforce the consideration of flexibility are summarized in Figure 2.

[1] ENTSOE-E, system Flexibility needs for the energy transition, https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/System_Needs/entso-e_System_Needs_Energy_Transition_v10.pdf
[2] Suna, D., Totschnig, G., Schöniger, F., Resch, G., Spreitzhofer, J., & Esterl, T. (2022). Assessment of flexibility needs and options for a 100% renewable electricity system by 2030 in Austria. Smart Energy, 6, 1-10. https://doi.org/10.1016/j.segy.2022.100077
[3] E. Hillberg, Flexibility needs in the future power system https://www.iea-isgan.org/wp-content/uploads/2019/03/ISGAN_DiscussionPaper_Flexibility_Needs_In_Future_Power_Systems_2019.pdf

EU Regulation

Electricity Directive: Member States shall provide the regulatory framework to allow and provide incentives to DSOs to procure flexibility services in their areas to improve efficiencies in the operation and development of the distribution system. DSOs shall be able to procure such services of distributed generation, demand response or energy storage providers and shall promote the uptake of energy efficiency measures, where such services cost-effectively alleviate the need to upgrade electricity capacity and support the efficient and secure operation.

The development of a distribution system shall be based on a transparent network development plan that shall provide transparency on medium and long-term flexibility services needed.

Network Code on Demand Response: This binding code aims to enhance the flexibility and responsiveness of the grid. DSOs at national level shall introduce transparent distribution network development plan ('DNDP'), including their assumptions to identify network development projects.

It shall consider characteristics at national and at DSO level, 'local services' and be coordinated with the TSO. It shall contain an assessment made by DSOs of current and predicted local services needs for solving congestion and/or voltage issues in their grid, a general description of how the cost-effectiveness of local services is assessed, and information on future local services needs in the medium and long-term of their grid.

Grid Action Plan: The Grid Action Plan[4] is a strategic document and is non-binding. It provides guidelines and recommendations to promote flexibility and efficiency in the European power grid but does not have legal obligations.

Non- EU Regulation

Switzerland: The NOVA principle ("Netz Optimierung vor Ausbau" or network optimization before upgrade) is recommended by the Swiss federal authorities. This principle emphasizes optimizing existing network infrastructure before considering upgrades. However, it is not a legal obligation for Swiss DSOs.

United Kingdom: Distribution Network Operators (DNOs) have a regulatory obligation to plan and develop their systems. For instance, the UK DSO 'UK Power Networks' engages in long-term planning of their distribution network. They share these plans with stakeholders through their Long-Term Development Statement and the Network Development Plan.

Japan: In Japan, the approach to addressing grid congestion involves upgrading distribution networks while maximizing the utilization of existing transmission networks. Japan's transmission grid is divided into bulk networks and local networks. The interconnection voltages of local network ranges from 22 kV to 154 kV. This voltage range is considered equivalent to distribution networks in Europe. Non-firm connections have been introduced in Japan's local networks since 2023.

Republic of Korea: The Special Act was introduced to enable the integration of distributed energy sources. This legislation aims to avoid the construction of large-scale transmission networks, which are costly and often lead to societal conflicts. Additionally, increasingly severe weather conditions are causing frequency fluctuations, raising concerns about grid stability. To enhance resilience, the DSO is incorporating more flexibility through demand response initiatives.

Figure 2 Comparison of regulations in EU and non-EU countries to enforce flexibility consideration in grid planning

4 Directive (EU) 2019/944 of the European Parliament and of the Council 5 June 2019, internal market for electricity, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02019L0944-20220623
5 Action Plan, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6044

No two grids are alike: Variability in Capacity, Flexibility, and Future Potential.

Grid capacities vary widely; some networks have ample capacity until 2050, while others are already nearing their limits**.** Key drivers for grid investment depend on temporal and spatial factors, which are influenced by renewable energy targets and the adoption of technologies like PV, EVs, and HPs, as well as the utilization of potential flexibility and the overall use of the grid. Other factors include aging infrastructure, investments in digitalization, grid resilience, and reliability, and electrification of cities and industry.

Key drivers of grid investment

Technological drivers | **Policy targets** | **Regional challenges** | **Grid utilization**

Technological drivers: Demand peaks (peaks from withdrawing energy from the grid) can drive grid investments, but most studies suggest that injection peaks (from high PV generation) may soon become more problematic. In the long term, distributed PV systems might be the primary driver of grid reinforcement (as shown in various studies in Switzerland[6]). Austrian studies suggest that the main driver for grid expansion requirements on MV grids is mainly due to PV integration, while private EVs are the main driver in the LV grid[7]. Synergy effects for network reinforcement requirements for the integration of new technologies are, therefore, important to consider.

Policy targets: Renewable investments depend highly on specific targets for PV and Wind energy and EV adoption strategies, which can vary between countries. In Switzerland, for example, targets are more biased towards PV rather than Wind. In general, European countries also have policy targets to incorporate flexibility in the low-voltage grids.

Regional Challenges: Geographic and spatial differences mean that network violations occur in some areas sooner than in others. The impact varies based on factors such as rural versus urban locations, distribution of generation and demand, dimensioning of the grid, and the spatial distribution of flexibility. In this regard, the integration of these technologies may lead to certain areas of the network being more prone to experiencing network violations. Improving network visibility is essential for monitoring real-time data, detecting issues early, and managing the integration of renewables and flexibility (Austria and Belgium).

Grid utilization: An increase in utilization rates of grid assets could be considered. This would involve increasing the median loading of cables and transformers, particularly in LV grids, from approximately 30-40% to 60-70%, with the possibility of allowing full 100% loading for limited times.

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[6] https://www.fen.ethz.ch/

[7] Project 567 Methods and future scenarios for strategic network development in distribution network levels 5, 6 and 7, https://projekte.ffg.at/projekt/4148327

Flexibility: Deferral or a replacement for network reinforcement?

The role and effectiveness of flexibility in reducing or deferring network investments, addressing grid challenges, and its potential and limitations to fully replace traditional grid reinforcement strategies have been investigated in several studies. There are various aspects and findings around this question, including:

- **Location and Grid Structure:** The effectiveness of using flexibility to replace or delay network reinforcement is highly dependent on the specific characteristics of the grid and the location of the flexibility resources. Grids with varying demand, supply, and geographic constraints may require different amounts, levels, and types of flexibility.
- **Investment Reduction and Deferral:** While flexibility (from demand and PV) cannot eliminate the need for investments in network components such as cables and transformers, it can reduce the number of such investments and can help defer or postpone the timing of these investments (Austria[8], Switzerland[9], Spain[10,11,12,13]).
- **Limitations of Demand-Side Flexibility:** Managing PV-driven grid violations at times of peak PV generation through demand-side flexibility has clear limitations and is case-dependent. It is generally more effective for managing large cooling loads or private EV charging during work hours (Switzerland). Smaller flexibilities sometimes may not be sufficient to address the peak generation, highlighting the need for additional solutions or investments to manage these challenges effectively.
- **PV and Battery Storage:** Integrating PV systems with BESS or installing utility-scale batteries can help regulate maximum PV injections, thereby mitigating some of the strain on the grid (Switzerland). A dedicated utility-scale BESS is usually not a cost-effective way to delay grid upgrades, as financial returns are limited. In a Spanish MV network case study[11], peak shaving with BESS was used to delay grid reinforcements. This approach was only shown to be economically viable when considering only the cycle costs associated with this specific use, particularly in low load growth areas. If allowed by regulation[14], DSOs could combine this application with other power system benefits (e.g. reliability) or procure flexibility services from third-party owned BESS. Stacking grid services is key to making BESS a cost-effective alternative.
- **Energy Communities:** The question of whether larger volumes of flexibility bear an opportunity to reduce the injection peak in energy communities has been investigated in several projects. This effect is mainly visible in the long term when flexibility becomes more available. However, concepts like these cannot change demand peaks. Incentives to monitor and reduce system peaks may be necessary. (Belgium[15])
- **Additional Focus on Reactive Flexibility:** It is also important to consider reactive flexibility solutions such as voltage-regulating and on-load tap-changing transformers, or reactive power provision by solar PV systems.
- **Include many small measures:** Accepting a certain level of PV curtailment can be economically beneficial. For instance, curtailing 30% of maximum PV power may lead to only a 3% energy loss, suggesting that such measures can be cost-effective and could also enhance greater system flexibility.

> **Flexibility can help postpone grid investments.** It may not always be economically optimal if the interim cost of flexibility outweighs the benefits of postponement. However, flexibility can be crucial for practical feasibility. Grid reinforcement is often constrained by available resources, personnel, and regulatory approvals. **Flexibility mechanisms in distribution networks play a vital role in effectively managing increasing uncertainties and rapid changes.**

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[8] Project 567 Methods and future scenarios for strategic network development in distribution network levels 5, 6 and 7, https://projekte.ffg.at/projekt/4148327
[9] ETH Zurich Research Center for Energy Networks, https://www.fen.ethz.ch/
[10] M. Martínez et al. Distributed battery energy storage systems for deferring distribution network reinforcements under sustained load growth scenarios. Journal of Energy Storage, Volume 100, Part A, 2024,
[11] D. Ziegler et al., Methodology for integrating flexibility into realistic large-scale distribution network planning using Tabu search. International Journal of Electrical Power & Energy Systems. Vol. 152, pp. 109201-1 - 109201-13, Oct. 2023.
[12] FLEXENER project: https://www.iit.comillas.edu/proyectos/mostrar_proyecto.php.en?nombre_abreviado=FLEXENER_IBD-GEN_ESCENARIOS
[13] AD-GRHD project: https://ingelectus.com/ad-grhid-en/
[14] This is not allowed (by default) in the EU. Article 36 of Directive (EU) 2019/944 states that DSOs cannot own, develop, manage, or operate BESSs unless they are fully integrated network components (not used to buy or sell energy on electricity markets) and receive approval from NRA
[15] Study executed on demand of VREG (Flemish Regulator) AD-GRHD project: https://ingelectus.com/ad-grhid-en/