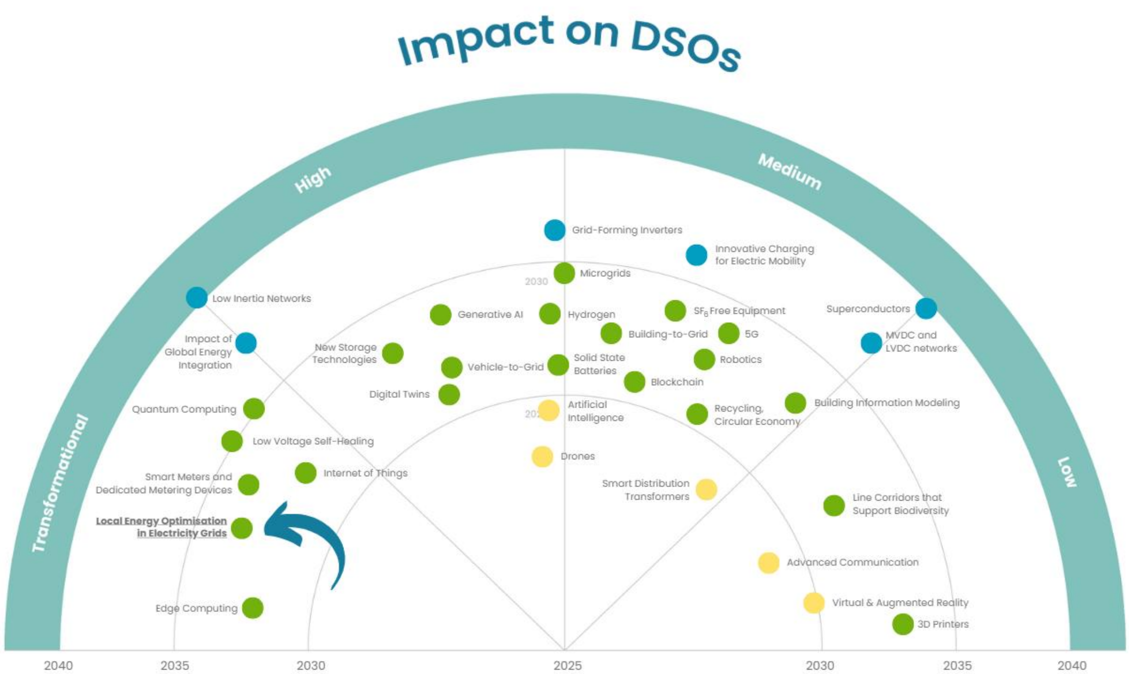
E.DSO Technology Guidelines

Local Energy Optimisation in Electricity Grids



April 2025

Acknowledgements

This paper gathers the outcomes of the work of the Technology and Knowledge Sharing (T&KS) Committee of European Distribution System Operators (E.DSO) on the topic of local energy optimisation in electricity grids. E.DSO gathers 36 leading electricity distribution system operators (DSOs) cooperating to ensure the reliability of Europe's electricity supply for consumers and enabling their active participation in our energy system. The T&KS Committee of E.DSO is the reference point for discussion on technical topics that impact the development of smart distribution grids and aims to provide guidance to E.DSO members as they face the technological challenges brought by the energy transition.

This paper and guidelines build on the valuable contributions of:

- Mariano Gaudó Navarro and Elena Lara Saez (UFD, Spain),
- Wouter van den Akker and Tilla Juhasz (Alliander, The Netherlands),
- Sonja Baumgartner (E.ON, Germany), João Rafael (E-REDES, Portugal),
- Jan Kula (ČEZ Distribuce, Czech Republic),
- Ernestas Zimkus (ESO, Lithuania),
- Gunther Schoovaerts (Fluvius, Belgium),
- Maximilian Urban (Netz Niederösterreich, Austria),
- Pavel Glac (PREdistribuce, Czech Republic),
- Selene Liverani (E.DSO Secretariat),
- All the members of the E.DSO Task Force 6 "Technology Radar".

For further information, please contact Selene Liverani (selene.liverani@edsoforsmartgrids.eu).

1. Introduction

The rapid growth of connected photovoltaic (PV) capacity in Europe, which reached 338 GW[1] by the end of 2024, and the expansion of electric vehicle (EV) charging points, which surpassed 725,000[2] by the same year, reflect the strong commitment of the European Union (EU) to achieving its decarbonisation targets but introduce increasing challenges for Distribution System Operators (DSOs). Issues such as overvoltage and network instability arise at times of peak generation and low demand, calling for increasing monitoring of low voltage (LV) networks, feeders, and secondary substations to ensure proper grid operation. DSOs face the dual challenge of enhancing network observability while integrating new services and actors, including local flexibility markets, flexible connection agreements, and energy communities. Looking towards 2030, the EU aims to achieve 816 GW of installed PV capacity[1] and to deploy 3.5 million public EV charging points to support the growing fleet of electric vehicles[2].

As highlighted in the E.DSO Technology Radar, local energy optimisation in electricity grids focuses on integrating technologies into LV grids while minimising their impact on the quality of power supply. In this context, the combination of smart meter data with novel technologies, including Artificial Intelligence (AI) applications, offers great potential for performing predictions and analyses necessary for planning and managing our rapidly evolving LV networks. E.DSO members consider local energy optimisation as a technological trend which will have a transformational impact on distribution grids in the medium term.

In this context, in December 2024, the E.DSO T&KS Committee organised a knowledge-sharing session to gather and share information on the use of advanced technologies and innovative approaches for improving energy and flexibility management in LV grids. These technology guidelines summarise the findings and recommendations drawn from the session, the Technology Radar work and a members' questionnaire on *local energy optimisation* (Chapter 2). Four innovative Success Cases from E.DSO members are highlighted in Chapter 3, tackling different aspects of the topic:

- Congestion management and public EV charging.
- Decentralised solutions for phase balancing and improving LV grid stability and resilience.
- Contracting flexibility services from aggregators and individual consumers.

Additional insights on these topics are provided at the end of each section of Chapter 3 from the member's survey (in the blue boxes).

2. Findings and recommendations

The optimal integration of distributed energy resources (DERs) in local LV electricity networks presents a multi-faceted challenge. The strategies adopted to achieve this integration necessarily are to take into account regional and national contexts, including the degree of deployment of PV installations and EV charging infrastructure, as well as the laws and regulations put in place in each country. As such, different solutions and approaches are currently being tested, validated and rolled

[1] SolarPower Europe, EU Market Outlook for Solar Power 2024-2028, available here.

[2] International Energy Agency, Global EV Outlook 2024, available here.

out by DSOs across Europe. Based on the experience and knowledge gathered by E.DSO members on the topic, the T&KS Committee formulated the following findings and recommendations.

Investing in grid expansion and digitalisation

- Strengthening **MV and LV grids through targeted investments** is fundamental to support the **integration of new distributed resources** and **expanding** distribution networks.
- The extensive deployment of smart meters enables accurate detection of LV imbalances, facilitating the implementation of data-driven solutions. Additionally, integrating data from **smart meters, feeders, and other sensors installed in secondary substations**, along with the development of digital twins of the network, will be essential for efficiently procuring flexibility based on the real-time status of the grid

Unlocking flexibility in LV grids

- Testing and hands-on experience with contracting flexibility promote the **establishment of local flexibility markets**, allow for the **assessment of market behaviour**, and support the **shaping of new regulatory frameworks**.
- **Dynamic capacity allocation is essential for grid reliability** in contexts of increasing EV charging demand. Its combination with **flexible connection agreements and new tariff structures** for charging infrastructure offers a promising solution for the integration of electromobility.
- The implementation of **local flexibility mechanisms** that leverage **demand response** programs and **energy storage** for managing **grid congestion** and ensure **voltage stability** during periods of peak generation or consumption and unexpected events should be further explored.
- The **adoption of open and standard solutions** supports the growth of the market for flexibility solutions while **lowering costs and accessibility barriers to customers**.

The role of new smart devices

- **Flexible transformer regulation** can be used to dynamically adjust voltage in response to fluctuating demand and DER generation, enhancing grid stability and efficiency.
- The employment of **smart transformers, LV balancers and regulators** is recommended to maintain voltage within acceptable limits, especially in areas characterized by high DER penetration and prone to voltage fluctuations and imbalances.

Key factors for successful optimization strategies

- **Real laboratory testing** and the execution of **proof-of-concept demonstrations in controlled grid areas** play a crucial role in proving novel technical concepts.
- **Scalability and adaptability of solutions are crucial** as the EV and DER markets continues to grow and evolve.
- Continuous improvement of technical solutions is necessary to **comply with current and future laws and guidelines**. Establishing a dialogue with national regulators initiatives undertaken by the DSO, including innovation projects and sandboxes, benefits and supports this alignment.
- The adoption of **easy-to-install technologies** to address issues such as phase imbalance lays

the groundwork for a **scalable, automated, and sustainable power system**.

- The successful results obtained by DSO's partnerships with Charging Point Operators (CPOs), installers of renewable generation systems and local authorities emphasize the **importance of collaboration in scaling innovative solutions**.
- **International exchange and cooperation** support validation and the identification of more resilient solutions.

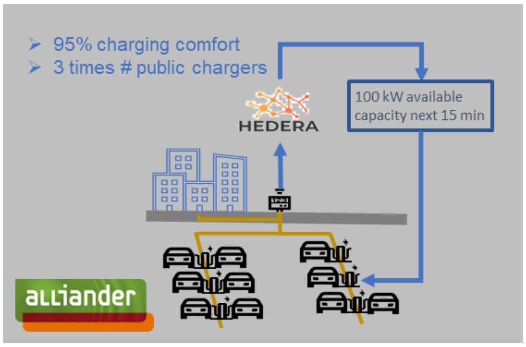
The gathered findings and recommendations will be used as a basis to facilitate benchmarking and experience sharing among E.DSO members on data use and analysis, project results, conclusions, and action plans. Furthermore, this information will support E.DSO and its members in seeking cooperation with manufacturers and accelerating the creation of a joint vision and action agenda.

3. E.DSO Success Cases on local energy optimisation

3.1 Experiences with the integration of public charging of electric vehicles.

Focus Case: Alliander's *Grid Aware Charging*[3].

The challenge: In the pursuit of a more sustainable mobility system, the **electrification of transport** poses challenges to grid stability. Rising EV usage leads to increased electricity demand characterised by large peaks. These charging peaks add a significant strain on **grid congestion**, especially in LV grids. Additionally, the reliability of public EV charging represents an important societal value but poses the challenge of scaling up public charging infrastructure with adequate charging speed while safeguarding the grid constraints.



The solution: For a given LV grid connected to a given MV/LV transformer, Alliander offers a **group contract to a single charging point operator (CPO)**. This contract is characterised by a **firm group capacity** for all the CPO charging points connected to this LV grid. This firm capacity is guaranteed 85% of the time and released on the day ahead. The CPO is then left free to allocate this firm capacity dynamically and in real-time to the various charging points based on user requests, comfort and own contractual conditions. The firm group capacity is significantly smaller than the sum of the technical charging capacity of each charging point so more public chargers can be connected to the LV grid without overload risks. Additionally, to the firm group capacity and according to the current grid status, Alliander can release **near real-time additional non-firm capacity** which the CPO is allowed to use for free.

To assign the group capacity to the CPO, Alliander developed the **HEDERA** (*Hub for Energy Distribution and Excess Resource Allocation*) application in system operations. This addresses the critical challenge of managing grid congestion and optimising energy distribution across various applications, also taking into account the requirements of CPOs for EV charging. Essentially, HEDERA calculates operational constraints within the grid and effectively **communicates the available firm and non-firm capacity to the market participants involved** and ensures reliable charging

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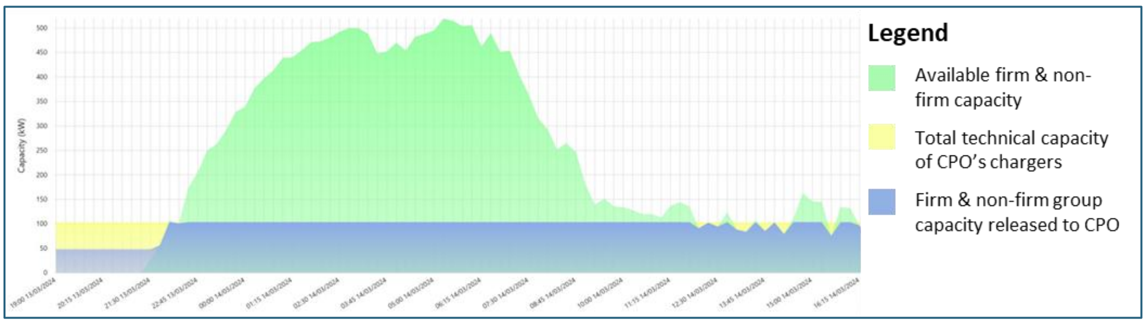
[3] The Grid Aware Charging Success Case can be downloaded here.

experiences while safeguarding grid stability. The iterative process of calculation, communication, and adjustment orchestrated by HEDERA allows for mitigating congestion and preventing overloads in the grid. This enables CPOs to dynamically adjust the charging capacities of EV charging stations in response to near-real-time grid conditions.

Main achievements:

- The combination of the group capacity approach and the extra near-real-time release of non-firm capacity allows offering a **charging comfort above 95%**, meaning that over 95% of the individual charging sessions conclude with the same state of charge as they would have with an uncontrolled 11 kW capacity.
- This grid-friendly charging approach enables the **installation of extra public charging points in the existing LV grid up to a factor of three** while complying with grid constraints and providing acceptable charging comfort levels.



Example of HEDERA capacity allocation to the CPO based on available grid capacity. The extra non-firm capacity released at night (in green) and the dynamic limitation of allocated capacity during day and evening hours are clearly visible.

Key success factors:

- **Adaptive Grid Integration**: Alliander's adaptive grid integration capabilities enable seamless coordination between EV charging and grid operations. These ensure reliable and efficient charging experiences for EV owners while future-proofing the grid against evolving demand patterns.
- **Collaborative Ecosystem**: Through collaboration in driving the adoption of grid-aware charging solutions through strategic partnerships with industry leaders and government agencies, Alliander fosters knowledge exchange, innovation, and standardisation in the EV charging ecosystem.

Way forward: Alliander and the other Dutch DSOs are working together with municipalities to make grid-aware charging the **national standard for public charging**. Municipalities are incorporating this in their public charging tenders as an obligation towards the CPOs. The drafting of a national standard on contracts, technology and communication between the DSO and the CPO is in its initial phase.

Insights on *integration of public charging* from our members' survey: The experience of DSOs with solutions for managing public EV charging demand is varied. Some DSOs are running pilot projects to assess different options for **steering EV charging, both in AC and high-power DC**, to prevent the overload of the transformer stations to which they are connected. In the case of ESO, this includes the assessment of **tariff structures for charging infrastructure** that differentiate from fixed grid capacity fees. While **non-firm, flexible connection options** are being explored by other DSOs, requests for new charging stations are currently mostly managed as connections with firm, guaranteed power. Lastly, ČEZ Distribuce recommends that **CPOs** use **local energy management** as part of their systems. However, the DSO has no visibility over the charging and flexibility strategies put in practice for charging stations connected under the same connection point.

Overall, **cooperation between DSOs and CPOs** is regarded as highly beneficial, from the **grid development planning** phase to the execution of **joint pilots**. Best practices for cooperation range from the creation of a **point of single contact** to streamline communication between the DSO and the CPOs (Fluvius) to the implementation of communication and control systems for limiting the charging power of large hubs in case of **emergency conditions** (ČEZ Distribuce). **Cooperation with municipalities and local authorities** is also pursued to increase the availability of charging infrastructure in cities. In the city of Prague, PREdistribuce is deploying a network of **"EV-ready" public lightning lamps** where public parking is available to facilitate the installation of new charging points.

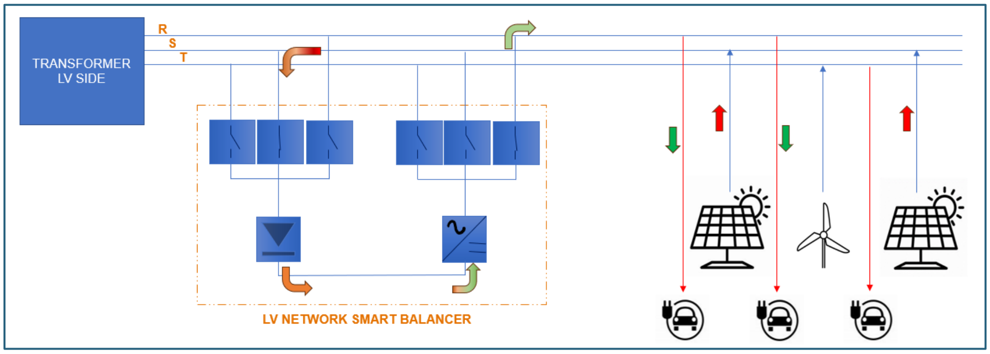
3.2 Experiences with decentralised solutions for improved low-voltage grid stability and resilience.

Focus case: UFD's *LV Network Smart Balancer*[4].

The challenge: **LV networks are unbalanced systems, especially under certain conditions: neutral wire loss, unbalanced charges, distributed generation or networks with long tracts.** In certain situations, these conditions make LV networks sensitive to non-compliance with quality supply requirements. This occurrence mainly affects customers and usually involves compensation costs due to failures or solar inverter disconnections for overvoltage protection, reducing drastically the performance of distributed generation. In this context, a system dealing with smart power transfer among the three phases allows achieving voltage balance in the LV network and transferring energy among generation and consumption units that are not connected to the same phase, substantially increasing the efficiency and flexibility of the grid.

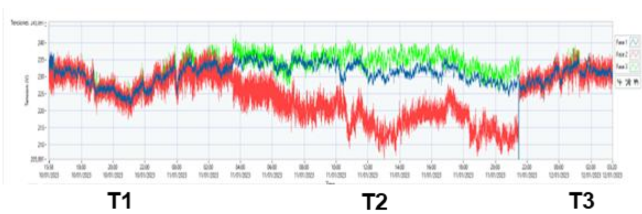
The solution: **The LV Network Smart Balancer was developed to solve problems in LV networks where voltage unbalance issues arise.** The solution was fully designed and produced by the multidisciplinary team specialised in SMART Solutions of the Spanish company Aplicaciones Tecnológicas S.A. which promotes the digitalisation of the energy market through an innovative range of products and services based on distributed monitoring and equipment. The LV Network Smart Balancer deals with smart power transfer between phases by means of distributed equipment installed in an LV network. This system provides a scalable solution by adding as many LV Network Smart Balancers as required and foresees continuous communication to analyse data, algorithm adaptation, diagnosis, and integration of other functionalities (such as energy storage management) in remote and advanced network monitoring.

[4] The LV Network Smart Balancer Success Case can be downloaded here.



Working principle. In this example, the LV Network Smart Balancer allows energy transfer from a high-generation phase (S). to a high-consumption phase (R).

Main achievements: Results achieved at different locations across Spain clearly indicate a **significant reduction** (80% on average) **of over-voltage and under-voltage meter events**, demonstrating the beneficial effect of deploying the system. Besides that, the associated IT platform allows for the evaluation of the voltage values in the LV network, the power transfers and the diagnostic information to manage the system, trigger alerts, develop automatic reports, and more. The LV Network Smart Balancer and its algorithm for Smart Energy Transfer among phases have shown high performances in **managing voltage unbalances**, **bringing flexibility to LV networks** in case of distributed generation, unbalanced consumptions, long LV sections, etc.



Effect of LV Network Smart Balancer.

*At **T1**, the LV Network Smart Balanceris working and balancing the network so, there are no significant voltage differences among phases.*

*At **T2** a manual shutdown was performed so, the natural response of the network appears, showing a strongly marked undervoltage in one of the phases.*

*At **T3**, the equipment was turned on again evidencing its balancing effect.*

POC RESULTS

LOCATION	EVENTS REDUCTION
Madrid 1	-81,73%
Lugo 1	-88,59%
Pontevedra 1	-95,18%
Cuenca 1	-75,75%
A Coruña 1	-100%
Madrid 2	-92,21%
Madrid 3	-75,48%
Madrid 4	-73,91%
Pontevedra 2	-79,38%
Pontevedra 3	-33,95%

Key success factors:

- **Voltage unbalance detection** and determination of power transfer among phases.
- **Power transfer** from high generation phase to high consumption phase.
- **Non-dependence on communications availability**, making the device and its working procedure fully autonomous.
- **Remote access** to adequate algorithm parameters.
- Monitoring of **quality parameters** and **configurable threshold alarms**.

Insights on *decentralised solutions for LV grids* from our members' survey: The sources of phase imbalance at the LV level are mostly identified with **single-phase solar PV** installations or **single-phase heat pumps** connected to the network, resulting in power quality problems such as over- and under-voltages. To prevent the emergence of these issues, Alliander has put in place a set of **recommendations for installers**. Conversely, ESO has shifted from Yyn0 vector-group distribution transformers to Dyn11 designs to reduce voltage imbalances while Fluvius uses zero-point transformers to redistribute the current flowing through the neutral phase over the other phases. On the other hand, different solutions are implemented by DSOs upon the detection of phase imbalance, including the **switch of single-phase connections to a different phase** (Fluvius, Alliander) or the use of **in-line load re-balancers** (Fluvius).

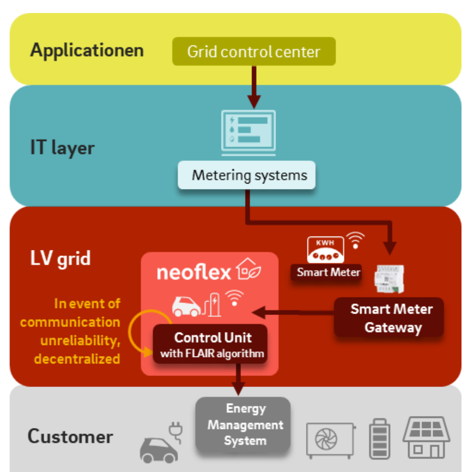
Solutions to address phase imbalance clearly benefit from the **availability of smart meter data**. In the Czech Republic, the installation of smart meters that provide **individual phase measurements** allows for easy identification of the source of the imbalance, significantly reducing the emergence of issues. Another example comes from ESO, which has developed a **phase-balancing recommendation tool** that leverages 10-minute voltage and power data from smart meters.

3.3 Experiences with testing decentralised flexibility solutions for customers.

Focus case: E.ON's *neoflex* [5].

The challenge: The increasing number of decentralised energy resources and the growth of controllable loads, especially EVs and heating pumps, cause new challenges for the stable operation of energy grids. One issue concerns the difficulty in **predicting the feed-in of decentralised energy resources and the consumption of partly flexible loads**. For DSOs, **flexibility management** to reduce power peaks is one possible alternative to grid reinforcement that offers additional flexibility and more resilience for the LV grid. A centralised and grid-oriented flexibility management system is being developed by E.ON, but its successful implementation requires wide-range observability at the LV level. The current challenges are:

- The required **wide-range observability** is **not yet implemented**.
- The **communication connection** between the DSO and the flexible assets is still **partly unreliable**.



The solution: To overcome these challenges, E.ON (especially LEW Verteilnetz) has developed the **neoflex** (*grid-oriented flexibilities*) solution consisting of:

- A **decentralised function** to control flexibilities in a grid-friendly way.
- An algorithm based on real-time and historical voltage measurement data.

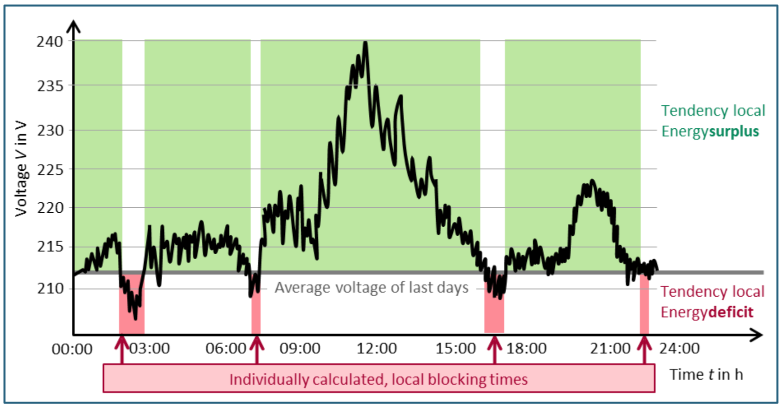
The neoflex algorithm is designed to run in a control unit or, in the future, in smart meter gateways.

[5] The LV Network Smart Balancer Success Case can be downloaded here.

While the system's functioning is **independent of communication reliability**, its integration with the smart meter gateway remains possible. In Germany, this represents an additional fallback solution for centralised control of flexible loads. At the same time, neoflex could be implemented internationally as a new stand-alone solution also for PV systems.

Key success factors:

- Enhancing **LV grid stability and resilience** in rural and urban areas.
- Improving **grid planning and operation security** with and without reliable communication.
- Offering a non-discriminatory, flexible and usable function.
- **Real laboratory testing** as the only way to prove the concept (simulations are not sufficient).



The neoflex algorithm calculates the local and individual blocking times per household based on voltage measurement data.

Way forward:

The next planned steps include:

- German **standardisation** of decentralised functions for flexibility assets.
- Optimisation for **international use** of the function and international real laboratory testing according to diverse and changing requirements.
- Further development of the decentralised algorithm for **smart meter gateways** as a virtual control unit.

- **Optimisation and learnings from wide-range use** of control boxes equipped with the decentralised function.

Insights on *decentralised flexibility solutions* from our members' survey: Real laboratory testing of new solutions is conducted by several DSOs before operational application. The labs are equipped with **real grid equipment and assets** including smart meters, secondary substations, different loads and generation systems. This first testing step is then taken further in the field, where **proof-of-concept demonstrations** are carried out in **controlled grid areas** under different scenarios. As a specific example, Alliander is conducting tests on home energy management systems (HEMS) in collaboration with several companies in living lab sites to explore the behaviour of the developed algorithms and their impact on residents. To this end, the available grid capacity is digitally lowered from Alliander's system operations control interface to investigate the possible reaction of the HEMS integrated controls. This type of test **reduces the risk of overloading or damage to the network** and allows for quick response if an unexpected risk of black-out emerges.

Testing and piloting activities also play a role in ensuring **adherence to existing and future policies and regulations**. Establishing a **dialogue with the national regulator** on undertaken initiatives, including innovation projects, guarantees the alignment with new regulations. Forward-looking strategies also encompass monitoring European regulatory developments and **establishing national and international cooperations** with other grid operators and market party associations to define a **joint vision and action agenda**.

In addition to this, experience sharing among industry experts and technology providers fosters the **adoption of open and standard solutions** which can be easily adopted. The growth of the market for flexibility solutions will, in turn, **lower costs and enhance accessibility to customers**. Beyond E.DSO, our members participate in several cooperation forums such as FutuRed, the Spanish technological platform aimed at providing national guidance on challenges, solutions, and experiences to stakeholders in the power sector.

3.4 Experiences with contracting flexibility services from aggregators and individual asset owners.

Focus case: E-REDES's *FIRMe* [6].

The challenge: The achievement of climate and energy objectives set out by European policy, the National Energy and Climate Plan for 2030 and the goal to reach carbon neutrality by 2050, requires a significant effort from electricity networks for the overall decarbonisation of the electricity system.

Distribution networks are the key to incorporating an exponential growth of decentralised renewables, as well as empowering consumers, making them active agents in the transition of the system. This responsibility requires **new models of network management and**, above all, **planning**. Hence, the DSO is now asked to consider alternatives to investment in new infrastructure, seeking to maximise the hosting capacity of the existing network and to operate more efficiently while contributing to greater integration of renewable energy sources in the territory.

The solution: E-REDES is responding to this challenge by creating the first Portuguese **local market for flexibility services**: the **FIRMe project** (Integrated Flexibility in a Market Regime), which started in March 2023. This mechanism allows the DSO to manage network planning **using flexibility services as a complement to investment** in specific situations of network constraints. This also

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[6] The Grid Aware Charging Success Case can be downloaded here.

enables saving on programmable maintenance costs and improves the quality of service, avoiding outages and even increasing capacity for new connections. The main goal of the project was to learn from, first, the development of REDES internal capabilities across all the different procedures (i.e., planning, procurement, operation, settlement and billing) and, second, the testing of market response and liquidity.

How? By contracting flexibility from aggregators and/or individual owners of consumption, production and storage assets. These market agents make themselves available to manage their assets, reducing consumption or injecting energy into the grid, depending on the needs pre-defined by the DSO.

The contracted flexibility services can be categorised into three different types of products:

- **Restore**: Post-failure service to support the re-establishment of the network after sporadic events resulting from **network failures** (in contingency situations).
- **Dynamic**: Service to respond to constraints during **scheduled unavailability** of national distribution network assets (i.e., maintenance).
- **Secure**: Service to support the operation of the network under normal conditions to manage **consumption peaks** at certain points on the network.
- The set-up of FIRMe followed the following line of action:
- **Identification of opportunities** to provide flexibility services. Eight opportunities, i.e. sites where the procurement of flexibility would be beneficial, were identified in various locations from the north to the south of Portugal (Bragança, Paredes de Coura, São Martinho do Campo, Tondela, Marinha Grande, Bombardeira, Beja, Vila Nova de Milfontes).
- **Procurement of suppliers** for the described flexibility services through auctions. For this purpose, E-REDES used the PICLO platform, a British company specialised in flexibility markets. Any market agent registered on the platform could take part in the auction. Currently, more than 100 different organisations are registered on the platform as potential suppliers for this type of service.
- Conduction of **qualification tests** for the service providers who submitted competitive bids.
- **Signature of bilateral contracts** between E-REDES and the service providers, valid for two years until the end of 2025. Remuneration follows different models for the three services, combining availability and/or activation payments.
- **Utilisation** of contracts within the scope of network operation.

Results: Between July and September 2023, **21 flexibility service providers** (FSPs) tendered in all eight areas identified in the project, using a total of **43 different assets** with a **cumulative power of 36 MW**. In total, the capacity offered was above those recorded from the first editions of the flexibility markets launched in the UK and France.

The 15 FSPs selected out of the total applicants include 12 industrial customers, a producer, an aggregator/trader and a storage developer, securing together seven of the eight identified zones and 29.5 MW of power. The first local flexibility contracts in Portugal were signed in March 2024. The participating pioneers include E-REDES and the offerors (Bragança Municipality, BA Glass Portugal, Tratave -Tratamento de Águas Residuais do Ave, BioSmart - Soluções Ambientais, Vizelpas Flexible Films, Neiperhome, Elergone Energia; Endutex and Águas do Centro Litoral).

Way forward: New auctions are planned for Q3 of 2025.

Insights on *contracting flexibility services* from our members' survey: Beyond Portugal, **market-based approaches for the procurement of flexibility services** are being piloted or developed in several European countries. In the Netherlands, the GOPACS joint platform, participated by all grid operators, allows **coordination of the procurement of energy and congestion market services**. In Austria, the Industry4Redispatch project participated by Netz Niederösterreich is testing the participation of large customer generation units in **day-ahead flexibility markets**. In Spain, the upcoming formal approval of the **first regulatory sandbox focused on flexibility** will see the piloting of **flexible connections and local flexibility markets** by ten DSOs of different sizes under the S2F project. Nevertheless, the establishment of local flexibility markets is still facing some challenges including:

- The **restrictions posed by national regulation**.
- The **limited availability of reliable and affordable flexibility, resulting** in flexibility services being less cost-effective than grid expansion, especially in the longer term.
- The **coordination of balancing responsibilities** when multiple aggregators are acting behind a single customer connection point.
- The **concern of customers owning small-scale assets** that participation in flexibility markets might hinder their commercial production activities.

Among the improvements identified to increase the efficiency of flexibility procurement is the **integration of data collected from feeders and smart meters**, crucial for understanding the status of the grid in real-time. The development of **digital twins** of (LV) networks will be a significant stepping stone in the evolution of flexibility markets. In addition to this, the **combination of flexible tariffs and flexible contracts** could be further explored to incentivise flexibility provision.