E.DSO Technology Paper

Experiences for Optimising Renewables' Integration in the Distribution Grid

September, 2023

Acknowledgements

This report was prepared by members of the European Distribution System Operators (E.DSO) Technology and Knowledge Sharing (T&KS) Committee in collaboration with McKinsey & Company.

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List of Abbreviations

ADMS	Advanced Distribution Management System
ANM	Adaptive Network Management
BESS	Battery Energy Storage Systems
DER	Distributed Energy Resource
DSO	Distribution System Operator
EHV	Extra High Voltage
EU	Europe/European
EV	Electric Vehicle
HV	High Voltage
ICCP	Inter-Control Center Communications Protocol
LAN	Local Area Network
LV	Low Voltage
MV	Medium Voltage
NRA	National Regulatory Authority
P(V)	Active Power
PV	Photovoltaic
Q(V)	Reactive Power
RES	Renewable Energy Source
RPA	Robot Process Automation
SCADA	Supervisory Control and Data Acquisition
T&KS	Technology and Knowledge Sharing
TSO	Transmission System Operator

Introduction

European power distribution grids are at the forefront of a transformative era where they face the challenge of accommodating a rapid scale-up of RES. Power networks are already facing a number of challenges to cope with the energy transition. At the same time, the pressure on grids is expected to increase even more as forecasts [1] predict that, by 2050, electricity demand will have surged to twice the levels of 2020. Concurrently, the drive towards decarbonization has set limits on the capacity of conventional power generation, paving the way for a massive deployment of renewables as part of the roadmap to meet European emissions targets. Consequently, the capacity for intermittent generation [1] is projected to experience a fivefold upswing in Europe by 2050 (Figure 1). This increase in intermittent generation is leading to two main technical challenges that need to be addressed when integrating RES into the grid:

- **Network Inadequacy.** The challenge of handling new supply connections is mainly driven by (1) the lack of physical network capacity for new supply and demand connections (i.e., substations connection capacity), (2) the inability to optimize current grid capacity due to inefficient grid setup (i.e., fossil generation-oriented grids) and operational bottlenecks, and (3) the limited efficiency in building new grid capacity mainly due to lengthy construction and property process. Network inadequacy could lead to longer lead times for supply and demand connections, curtailments of renewables power output, increased development cost of renewable projects and/or delayed phase-out of emitting technologies. Network inadequacy causes connection delays around the world, with almost 1’000 GW of solar (close to four times the amount of new solar capacity globally installed in 2022) and 500 GW of wind projects stalling in the interconnection queue across the United States and Europe (five times as much as was built in 2022) [2].
- **Network Instability.** The second challenge of dealing with an increasing RES penetration is related to the higher frequency and voltage variability of intermittent power sources (e.g., solar and wind) and decreasing ability to stabilize the system due to phase-out of current balancing

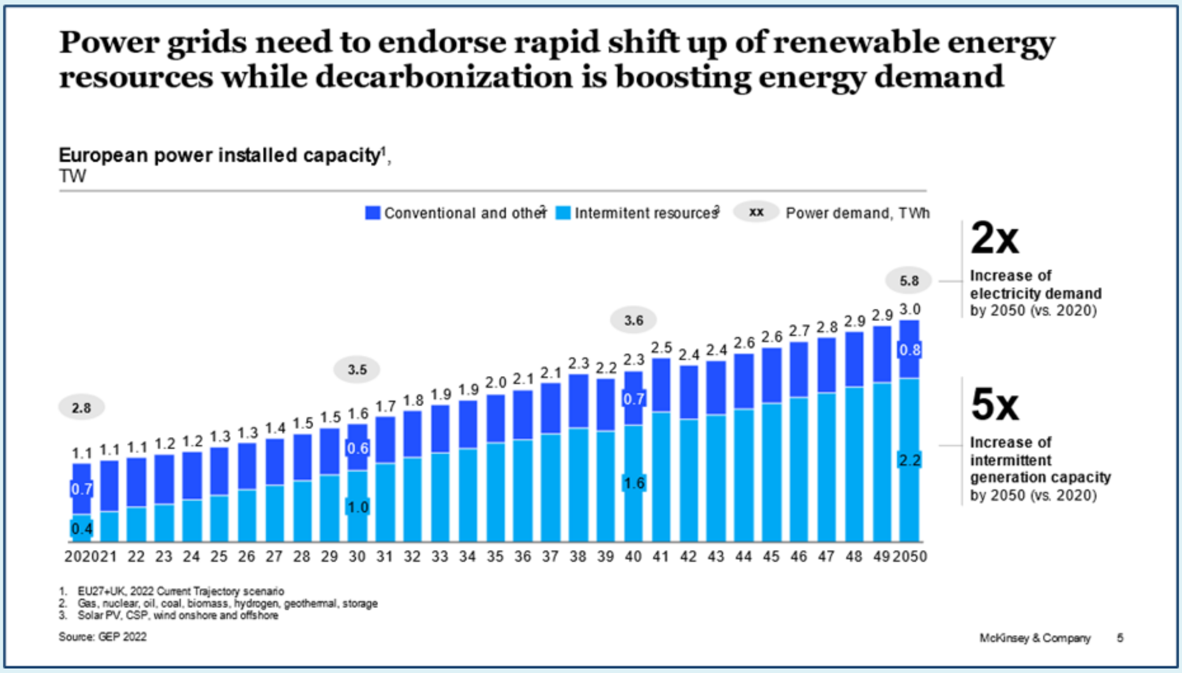
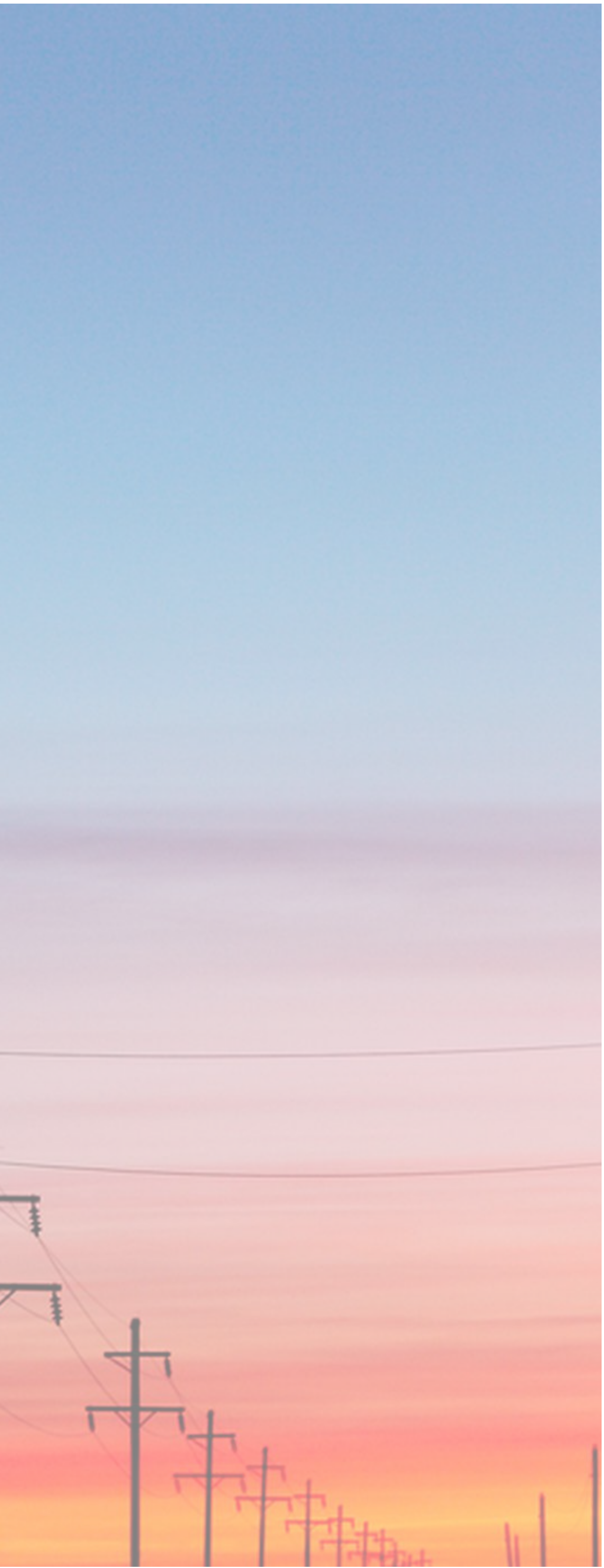


Figure 1: Forecasts of installed capacity of the European power grid until 2050 [1].

[1] McKinsey, “*Global Energy Perspective 2022*”, 2022. Available: **here**.

[2] Bloomberg, *“A Power Grid Long Enough to Reach the Sun Is Key to the Climate Fight”,* 2023. Available: **here**.



assets such as thermal generation. Network instability could lead to an increasing need for more complex grid operations and a need to restructure the coordination process among DSOs and TSOs. An illustrative example of network instability is the major blackout that happened in the UK in 2019, caused by the unexpected shutdowns of the Hornsea offshore wind farm and the Little Barford gas-fired power plant. National Grid data showed that both of the generators dropped from the grid at around the same time. The twin outages caused a sudden loss of frequency of the electricity grid to below 49Hz, which caused certain parts of the network to disconnect automatically, causing the blackout. This event impacted ~ 1 million electricity customers (households, businesses, transport, industries) during 40 minutes across different regions (i.e., Wales, south-west England Midlands, Yorkshire, north-east England and north-west England) [3].

In addition, grid operators face multiple challenges along the value chain that put them at risk of not being “ahead of the renewable train”:

- **Planning.** Complex power flow models in use struggle to handle the long timeframes and uncertainties of modern grids related to demand and supply growth trends and the future regulatory landscape.
- **Connection.** Challenges in connection prioritization emerge due to insufficient digitization of the overall process and a lack of standardization in the equipment needed to carry out procurement and permitting processes.
- **Operation.** Heavily centralized processes and limited data availability lead to insufficient operational visibility that affects system stability.

Looking at the goals and challenges ahead of us, it becomes clear that this is the time for grid operators and policymakers to rethink current planning, connection, and operation processes as well as to take responsibility for coordinating among energy system stakeholders to construct a future-proof 21st century power grid.

[3] Ofgem, *“9 August 2019 power outage report”*, 2020. Available: **here.**

Recognizing the significance of knowledge sharing in this relevant topic, which is a common challenge for European DSOs, E.DSO has launched a survey among its members, encouraging them to contribute with their insights and experiences regarding DERs connection. The survey aims to identify the main hurdles faced by DSOs and understand the measures applied to address these challenges effectively. By promoting collaboration and information exchange, E.DSO aims to create a comprehensive understanding of the obstacles encountered during DERs' connection. The survey provides a platform for members to share their knowledge and experiences, highlighting common issues such as grid integration, technical compatibility, construction and regulatory constraints. This knowledge-sharing initiative allows E.DSO to identify the main hurdles faced by its members and gain valuable insights into the measures being implemented to overcome them. The main message of the survey is that most stakeholders have high expectations regarding grid connection lead times (Figure 2). These are usually longer than wanted due to various bottlenecks.

Identified bottlenecks:

- Poor qualification of plant connection technical project designers and errors in the projects.
- Pre-occupied capacity of the grid although not yet physically congested.
- Grid simulation capacity.
- Permitting.
- Delivery times of equipment.
- Limited number of contractors to perform grid reinforcement works.

Grid connection lead times are influenced by many factors (Figure 3) and DSOs' have put in place several measures to minimize grid connection lead times. The most relevant ones are listed below.

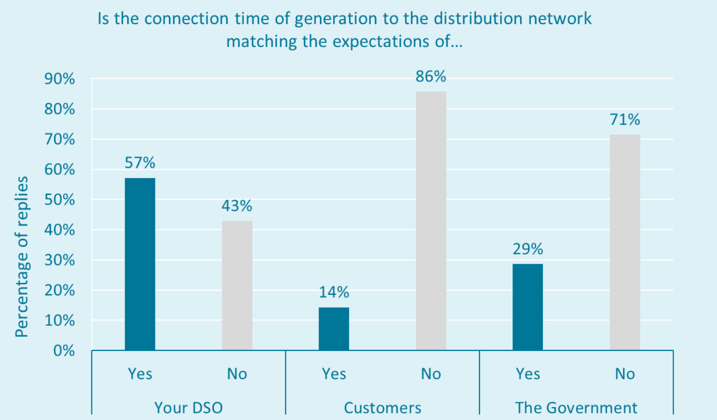


Figure 2: Connection times expectations of stakeholders.

Measures put in place to decrease DER connection lead times:

- Interest, attract, train and retain more field engineers.
- Set up campaigns for material sourcing.
- Set up agreements with governments to speed up permission processes.
- Digitalize plant connection acceptance process.
- Monitor the connection processes to identify time-consuming tasks.
- Increase equipment availability.
- Cluster in areas and set slot times.
- Automate capacity solutions.
- Set up flexibility markets.
- Upgrade the grid in advance.
- Optimize connection requirements and hosting capacity calculations.
- Perform inverter lab testing.
- Optimize the operation of the grid.

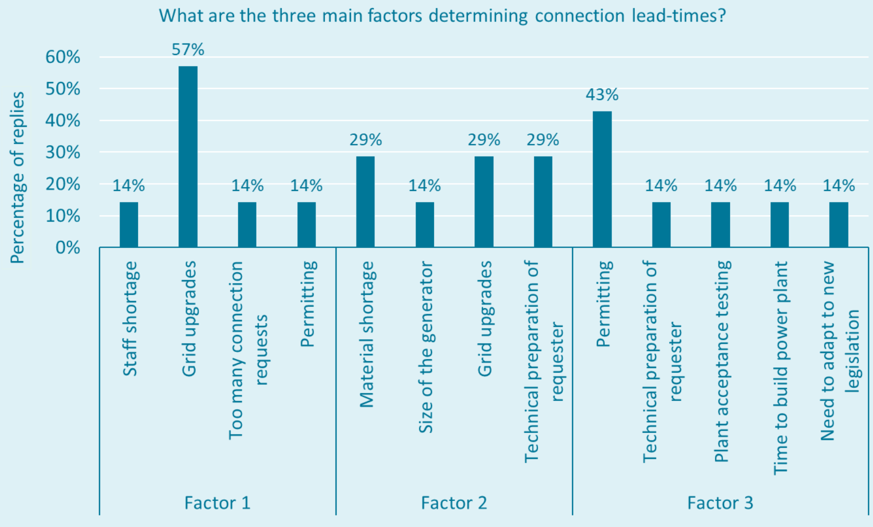


Figure 3: Factors determining connection lead times

Findings and Recommendations

DSOs around Europe are facing similar challenges in facilitating the energy transition by connecting more DERs to the distribution network. A comprehensive DSO survey conducted by E.DSO showed that connection lead times are higher than what the main stakeholders desire. DSOs have tackled these issues using different approaches, adapted to the regulatory framework of each country.

E.DSO T&KS Committee carried out a session on this subject to promote knowledge sharing between its members and to identify key insights gained from the various practical experiences of DSOs. The outcomes of the session and work reported in this paper led to the formulation of the following recommendations to support the connection of more DERs to the existing network and the minimization of their connection lead times.

Permitting and Regulation.

- Reduce permitting times, mainly through automation and digitalization. More information and higher visibility to the customer could help to speed up the connection process.
- Put in place transparent, and ideally EU-harmonized, rules for congestion management to facilitate the use of non-firm connections.
- Set transparent rules for handling connection queues, improving information to the client and minimizing the possibility of litigation.
- Define a clear and transparent network planning and prioritization framework to improve the availability of information on planning criteria and transparency about the zones.

Technical Skills.

- Support the improvement of technical skills of the client service providers, for instance by setting up an online or "in person" training to certify the skills and knowledge necessary to carry out grid connection processes.
- Promote education programmes to face the increasing demand for specialized personnel in the market.

Grid Management and Planning.

- Evaluate using non-firm connections. While some EU countries already implemented non-firm contracts and day ahead or intraday markets, many others have not or are still in preparatory phases. This tool will support improved prediction and avoidance of situations which would normally lead to emergency RES curtailment or redispatch, ultimately causing high financial compensations paid by all network customers.
- Introduce reactive power management (e.g., volt-var control (voltage setpoint), reactive power flow minimization), to ensure that network voltage remains within the correct parameters and that less network capacity is used by reactive power flows.
- Improve transparency on grid upgrade information from planning to execution to allow for expectation management for DERs connection.

DER Advanced Functionalities and Digitalization.

- Implement droop control to handle massive instalments of "fit and inform" productions and use advanced functionalities to support network management.
- Digitalise DER connection to improve transparency in the overall process.
- Set up and regularly update accurate DER and hosting capacity maps to improve transparency for potential owners of DER generation stations.
- Integrate typical technical solutions for point of connection and communication with DSO SCADA systems to avoid customization and the need for specific training of suppliers.
- Leverage smart network control and ADMS to achieve integrated and real-time observability and control for the entire distribution network, acting both on traditional network assets and DER.
- Use smart inverter functions at LV level to facilitate grid management and, in turn, possibly enable additional DERs connection.
- Implement market-based flexibility mechanisms to minimize the consequences of curtailment needs on grid customers.
- Introduce automated grid simulations to improve the use of flexibility and avoid DERs involuntary curtailment.

E-REDES Case

DSO/TSO coordination for non-firm DER connection in Portugal

There is an EU-wide and Portuguese objective to increase the DER installed in the grid to reduce emissions of traditional generation sources. One of the main obstacles to DER connection is the need for grid reinforcements and permitting of new electrical infrastructure. So, there is pressure for higher usage of the existing grid, even if it is unable to support the power injection in all scenarios.

Portuguese legislation is being adapted to allow non-firm connections for generation and consumption. In January 2022, a law holding the generic principles for non-firm connections was approved and the NRA put out various related regulations into public consultation.

E-Redes, the only DSO in mainland Portugal, and the TSO worked for several months on establishing the principles for a coordination framework of non-firm generation management preserving both system operator needs (congestion management for the DSO and balancing for the TSO). This agreement has already been presented to the government and the NRA and has been well received.

Existing markets in the Iberian Peninsula (Figure 4):

- Retail Market, which runs on the previous day (day ahead).
- Retail Market, which runs during the day (intraday).
- Ancillary services market, which runs during the day (intraday).

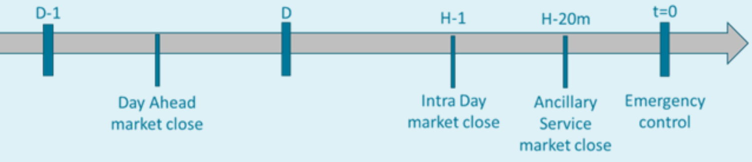


Figure 4: Timeline of market closure in the Iberian Peninsula

By using the existing markets, it is possible to achieve a faster solution for managing non-firm generation. There are several time frames to determine network constraints and, subsequently, identify the necessary generation limitations and impose them through the markets (Figure 5).

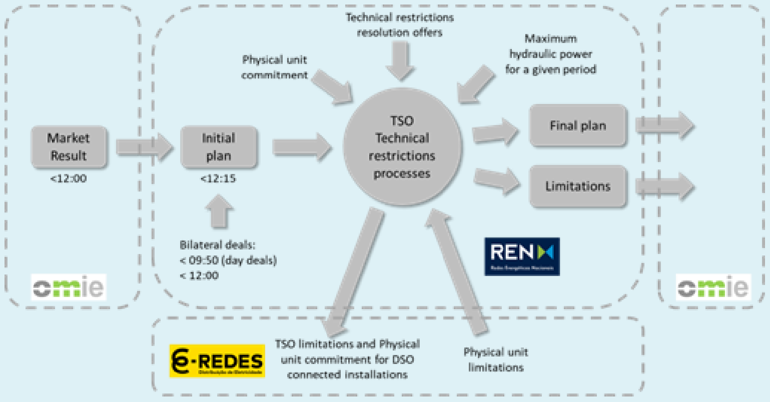


Figure 5: Diagram of the day-ahead market interactions.

However, markets also have their limitations and, for that reason, emergency control must always exist (Figure 6).

As the next step, the NRA will coordinate a working group with the DSO and TSO to adapt legislation to reflect the agreement. New DSO/TSO communication interfaces will need to be established: a day-ahead market bidirectional interface; an intraday market bidirectional Interface, an ancillary services market bidirectional interface; updates to the ICCP link for the emergency control mutual information; a shared database of qualified generation stations with common IDs.

For the DSO it is now important to:

- Establish an end-to-end technical validation process with adequate tools and data quality.
- Establish a stakeholder transparency communication process to present justifications for DSO-imposed generation limitations.

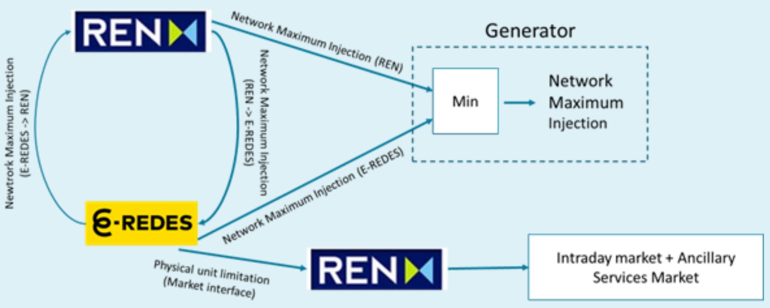


Figure 6: Diagram of emergency control interaction

CEZ Distribuce Case

Technical solutions for increasing hosting capacity in the Czech Republic

CEZ Distribuce and the other two main DSOs in the Czech Republic are facing a ramp-up of renewables, mainly small rooftop and big solar power plants. In 2022 the number of renewable connection requests increased by over 300% in comparison with 2021 and, in 2023, CEZ Distribuce predicts receiving more than 100’000 requests. According to the EU and Czech national strategy, the plan is to integrate 277’000 assets meaning 11’000 MW of new RES by the end of the decade. This will constitute a tenfold increase in installed power compared to 2021 (Figure 7).

Currently, halfway through 2023, the total reserved power with paid connection fees adds up to more than 12 GW and only 0,5% of all requests were rejected. Every connection assessment needs to fulfil a series of technical checks, mainly:

- Limits of nodal areas (EHV/HV).
- National balance limits (defined by TSO).
- Primary substations capacity (HV/MV).
- Line capacity (HV, MV, LV).
- Electricity power quality parameters impact.
- Voltage changes by measurement or calculation.

To increase hosting capacity and fasten the connection process, several technical solutions were implemented or are being evaluated for future deployment:

- Autonomous Q(V) and P(V) functions implemented in LV PV inverters (tested and certificated in lab) to increase hosting capacity up to 75%.
- DER with Volt/VAr control system in MV grids (voltage set-points) to enable a hosting capacity increase of up to 90%.

CEZ Distribuce is also developing new ideas on how to improve the current situation and integrate even more renewables. These include:

- Competence in buying RES flexibility as an eligible cost for DSOs.
- Flexible contracts when the requested power is not connectable.
- Option to limit RES generation as mandatory support for emergency control.
- Couple RES and BESS to limit the installed power to a 50% maximum, resulting in a 43% increase in hosting capacity.
- Certification of inverter lab testing.
- Invertor smart functions supervision by smart meter alarms.
- Update of connection calculation methodologies by changing cos phi.
- Grid hosting capacity calculations based on topological Digital Twin and calculations.
- New web-based map tool providing relevant information about available hosting capacity.

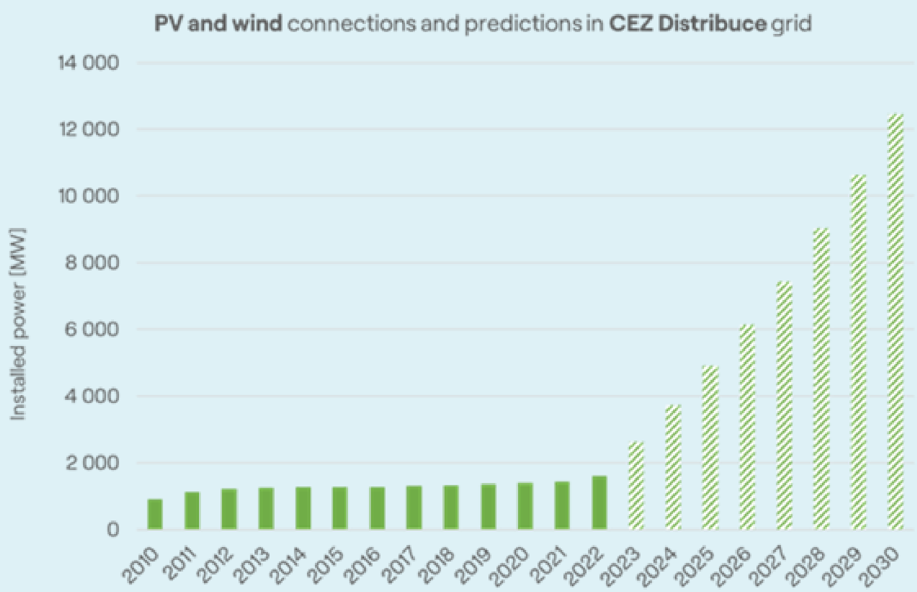


Figure 7: PV and wind connections and predictions in CEZ Distribuce grid until 2030.

Stedin Case

Managing network capacity in the Netherlands: expanding grids, increasing utilization of existing ones and co-creating solutions

The Netherlands has witnessed a spectacular growth in demand for DSO grid connections and transport capacity in the last few years. Wind and solar, EVs and heat pumps: all these technologies are on the rise. Stedin has experienced a 30% growth in customers' connection requests in 2022 compared to 2021 [4]. Growth figures for the other Dutch DSOs are similar. Given the ambitious targets for the electrification of industry, residential heating, transport and agriculture, this acceleration is expected to continue at least until 2030. Until that year, Stedin expects a growth of decentral PV production from 2.3GW to 6.8GW and to have over 300.000 EV charging stations connected (Figure 8).

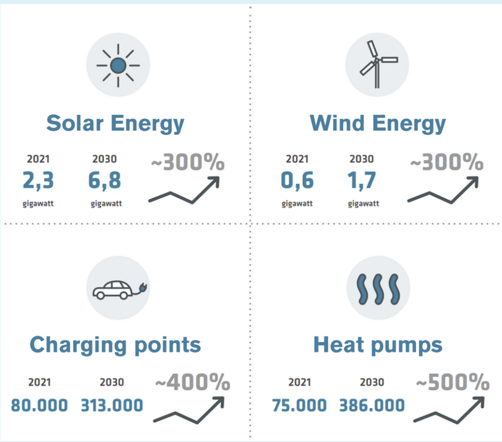


Figure 8: Stedin 2022 - 2030 connection forecast for decentral production, EV and heat pumps.

Investments in Network Capacity.

This increase in demand requires significant network capacity upgrades [5]. In the past few years, the investment levels have already grown significantly. By 2030, Stedin predicts that it will have to invest €8 billion to expand and create the necessary capacity in its grids. A large proportion of the main distribution stations will undergo a capacity upgrade, while thousands of new substations will be required in urban areas.

Network Loading, Congestion Management and National Action Plan.

Despite these extra investments, there is a shortage of transport capacity in the Dutch power networks. Today, a significant part of the Dutch networks are congested, with limited or no hosting capacity left, and new customers' connections would have to wait until the capacity upgrades have been completed. Stedin itself has several congestion areas. In 2022, the Dutch regulator ACM published updated legislation on congestion management. This provides definitions of network capacity, rules for communicating and allocating scarce network capacity, rules for prioritisation and waiting lists and the mandatory investigation of possibilities to use local flexibility markets. Additionally, a **network capacity map** was developed, providing actual insight into network loading status across the Netherlands (Figure 9). At the end of 2022, the national action plan network capacity (LAN) was initiated. The programme brings together national and regional governments, the regulator, the DSOs, the TSO and last but certainly not least the (associations of) network users. The joint goal of the programme is to manage and solve issues with network scarcity and improve the alignment between customers' demand and network investments in its grids. A large proportion of the main distribution stations will undergo a capacity upgrade, while thousands of new substations will be required in urban areas.

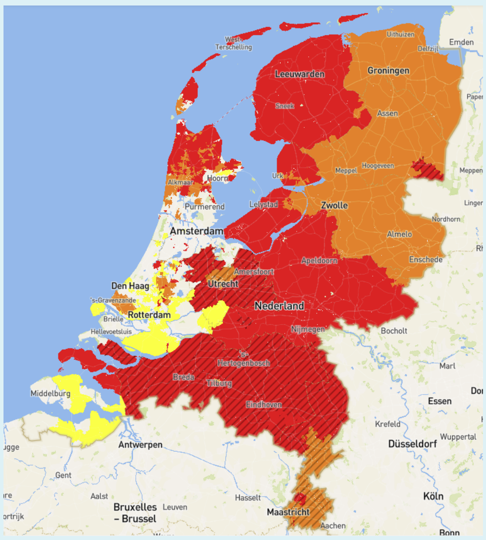


Figure 9: Network capacity map of the Netherlands.

[4] Stedin Groep, "*Government reserves €500 million for strengthening Stedin Group's equity*", 2023. Available: **here**.

[5] De Volkskrant, "*Grid operator Stedin sees acceleration of energy transition: applications for new connection tripled*", 2023. Available: **here**.

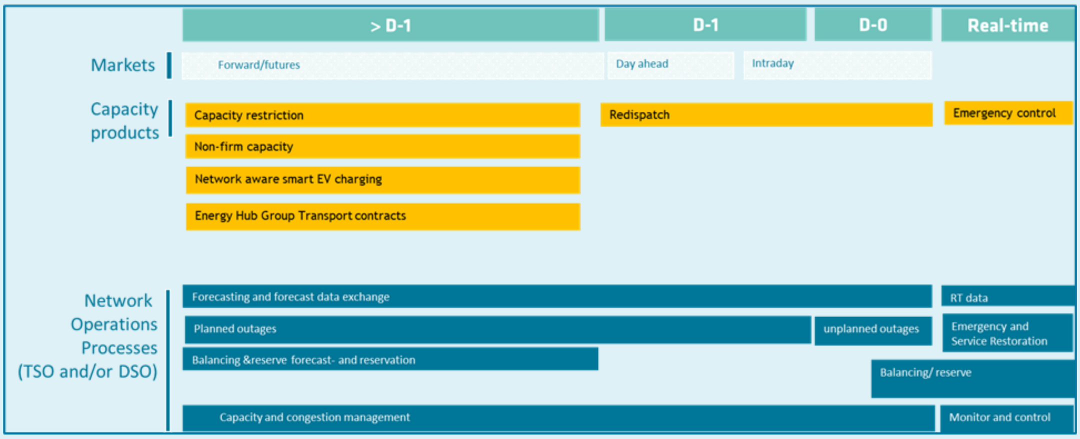


Figure 10: Solutions to increase utilisation of existing networks.

Key bottlenecks and solutions to manage them.

Having a densely populated service area, space is scarce and needs to be planned carefully. Therefore, area planning is a key factor in network investment planning. Better coordination of area planning and permitting procedures between (local) governments, market parties and network operators is fundamental. To plan and execute the required network expansions, sufficient technical staff and financial resources are required. On the technical level, Stedin is looking into component standardisation such as for standardised and modular substations. A second pillar to solve network capacity issues is to increase the utilisation of the existing networks, for instance, by providing incentives to network users to become more flexible on their energy use through increased self-consumption or by shifting network load to off-peak hours. Further refinement and development of congestion management, network-aware smart charging and the introduction of energy hubs in industrial zones are also considered (Figure 10).

Co-creation.

Many of the proposed solutions are developed in co-creation between Stedin and its customers, with the other network operators or with the regulator (Figure 11). An example of this is GOPACS, a TSO/DSO/Market coordination platform for congestion management services that provides market-based redispatch and restriction services. Another example is DER control [6], a standard DER network interface for (real-time) integration, which provides emergency power control and network-aware smart charging, facilitating the integration of EV charging infrastructure into LV grids.

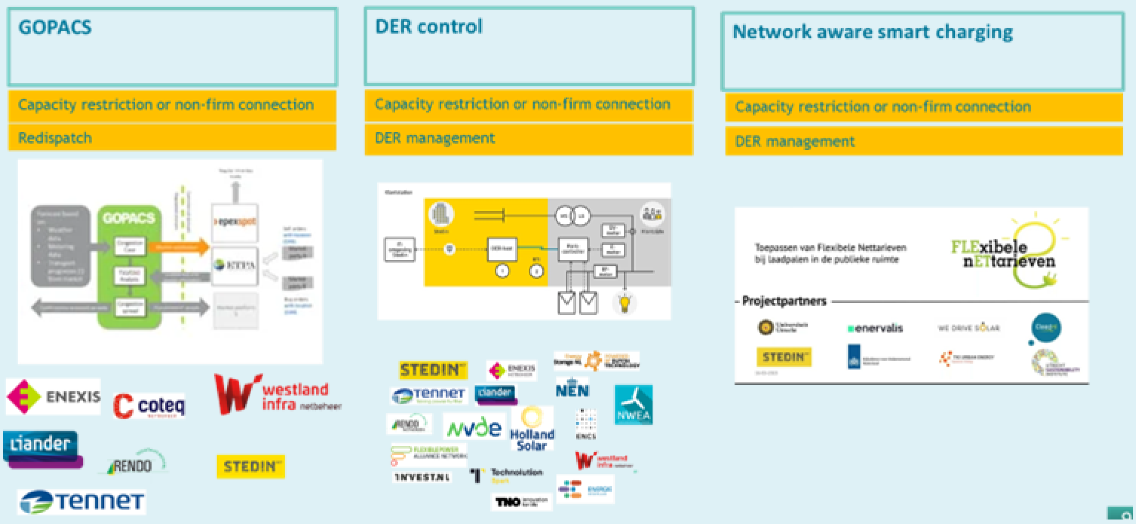


Figure 11: Stedin co-created solutions.

[6] Netbeheer Nederland, "*Real Time Interface*", 2023. Available: here.

ESO Case

Addressing connection lead times and hosting capacity challenges in Lithuania amidst high prosumer growth

Lithuania is currently undergoing a significant shift in its energy landscape in order to achieve its goal of attaining national energy independence. One key aspect of this transition is the rapid growth of rooftop PV systems, also known as prosumers. Over the past few years, the total installed capacity of these systems has increased dramatically, surging from 10 MW in 2018 to over 670 MW as of June 2023 (Figure 12). Dramatic growth can be attributed to the financial government support provided for PV installations, with a subsidy of 323 Euros per kilowatt.

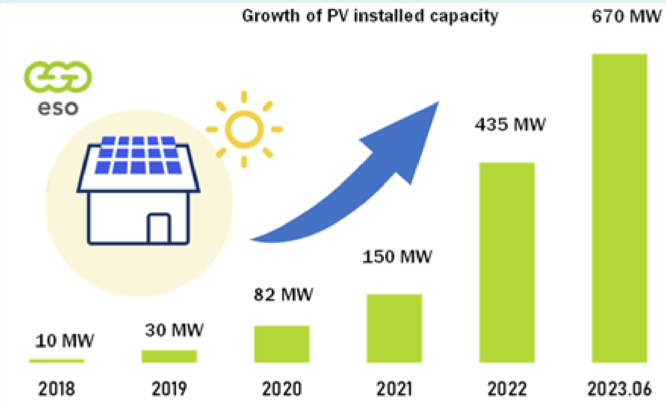


Figure 12: Increase in rooftop PV systems in Lithuania over the 2018-2023 period.

However, this remarkable expansion of renewable energy resources has had negative impacts on the distribution grid managed by AB Energijos skirstymo operatorius (ESO). Several challenges have arisen as a result:

- **Voltage issues.** The proliferation of PV installations has led to voltage problems within the grid. This, in turn, hampers the ability to establish new PV connections. It becomes increasingly challenging to provide electricity to customers while adhering to EN 50160 requirements, which define acceptable levels of voltage quality.

- **Limited capacity on medium voltage grid and 110 kV primary substations.** The capacity of the medium voltage grid and the 110 kV primary substations is constrained. This limitation poses difficulties in accommodating the growing number of PV installations and their associated power generation.

- **Delays in grid connection assessment.** The escalating number of grid connection requests has resulted in longer assessment times. For prosumer connections with a capacity of up to 10 kW, the average connection assessment period has increased from 6 days in 2021 to 26 days in 2022.

In summary, Lithuania is currently in the midst of a significant energy transition aimed at achieving energy independence. While the rapid growth of PV installations has brought numerous benefits, it has also presented challenges for the distribution grid, including voltage issues, limited capacity in key areas, and delays in assessing grid connection requests.

To address these issues, several solutions have been implemented:

- **Digitization and automation of the evaluation process.** By digitizing and automating the assessment of new connection requests, the evaluation process can be streamlined, reducing the lead time and increasing efficiency. This was achieved by using RPA tools to run automated grid load flow calculations. In the past year, about 20% of the new connection requests were processed automatically with the help of “robots”.

- **Implementation of new grid planning practices and strategies.** The grid planning practices need to be updated to address the challenges posed by increased DER capacity.New practices, for instance, include using larger minimum cable cross-sections, which can handle higher power flows, and employing distribution transformers that are better suited for DER integration.

- **Grid topology-based DER hosting capacity maps.** Grid topology-based maps that indicate the hosting capacity for DER have been kept up-to-date to support decision-making. These maps provide information on areas where new DER connections can be accommodated without causing voltage issues or overloading the grid [7].

- **Utilization of smart inverter functionalities and reactive power control.** To support grid voltage and mitigate voltage issues caused by DER, the capabilities of connected type A generating units can be exploited. Smart inverter functionalities can be utilized to provide reactive power control, helping to regulate and stabilize grid voltage.

- **Cable pooling and hybrid plant connections.** To maximize the efficiency of the existing energy distribution infrastructure, different renewable technology installations, such as wind and solar power plants located in proximity, can share a single connection point to inject their generated electricity into the grid. This approach, known as cable pooling or hybrid plant connections, optimizes the use of existing grid capacity and infrastructure.

- **ANM for non-firm connections.** Non-firm connections, which are subject to curtailment during grid congestion events, can be supervised using adaptive network management technology. ANM allows for dynamic monitoring of grid conditions and curtails generation from non-firm connections when congestion occurs, ensuring grid stability.

[7] ESO grid topology-based DER hosting capacity map is available here.