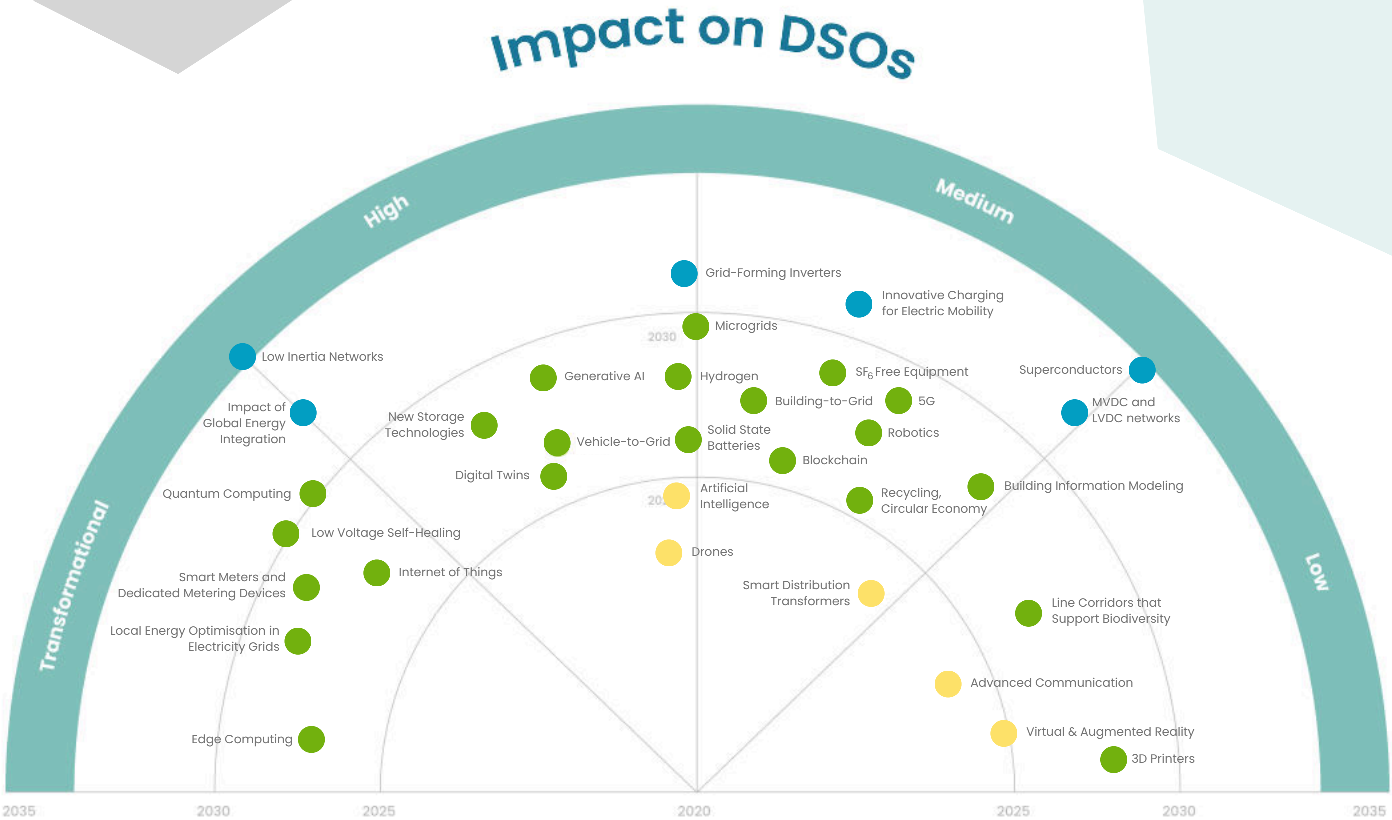
E.DSO Technology Radar



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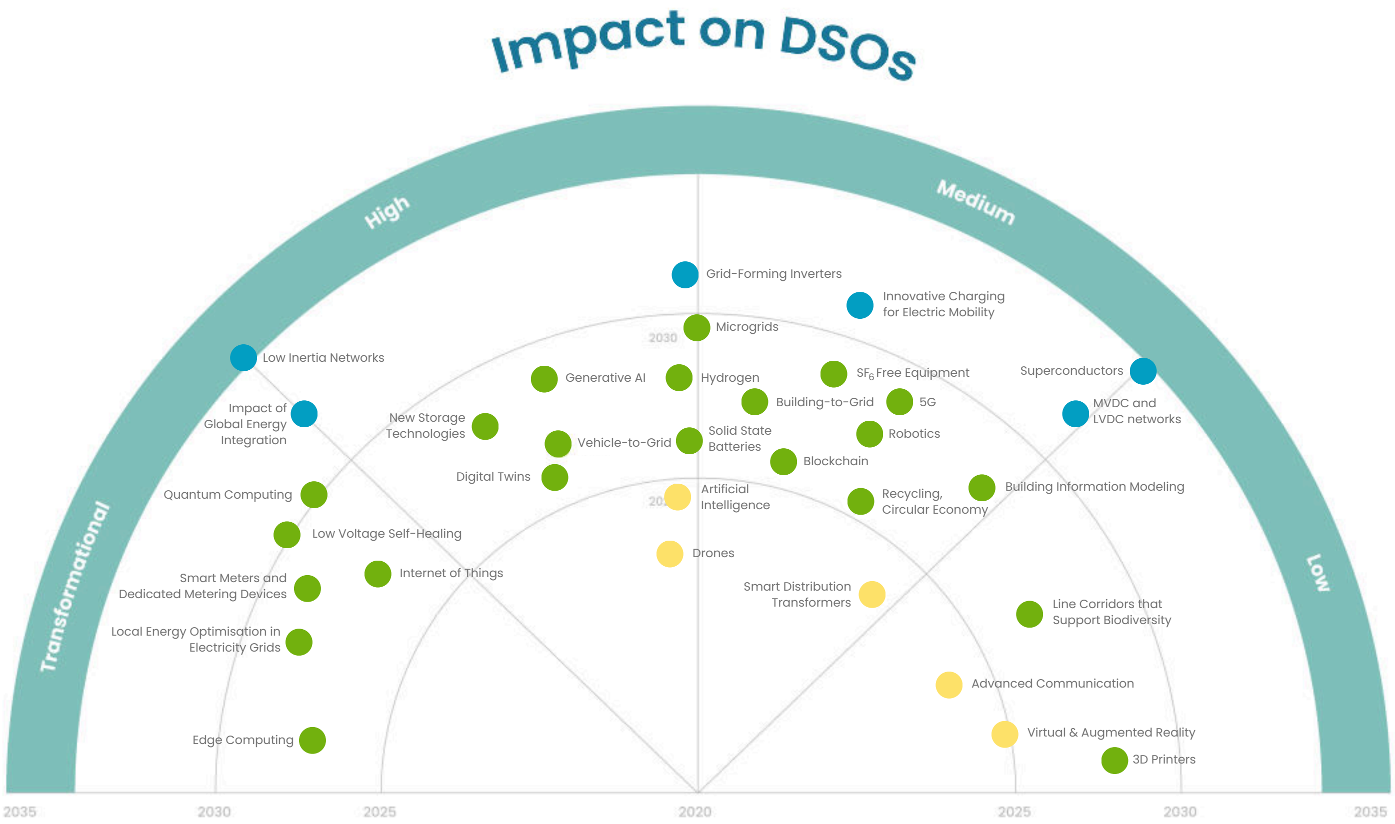
European Distribution System Operators (E.DSO) gathers 36 leading electricity distribution system operators (DSOs), including 2 national associations, cooperating to ensure the reliability of Europe's electricity supply for consumers and enabling their active participation in our energy system.

This is the fourth edition of the E.DSO Technology Radar. You can submit comments and suggestions on this work at techradar@edsoforsmartgrids.eu.

Publishing date of this document: **10 March 2025**
Last update of the Technology Radar: **14 February 2025**

About the Technology Radar



European Distribution System Operators (E.DSO) promotes and enables customer empowerment and the increase in the use of clean energy sources through electrification, the development of smart and digital grid technologies in real-life situations, new market designs and regulation. E.DSO and its members are committed to taking on the huge challenges associated with realising the Energy Union, built on the EU's ambitious energy, climate, security of supply, jobs and growth objectives. This involves ensuring the reliability and security of Europe's electricity supply to consumers while enabling them to take a more active part in our energy system.

The current technological landscape is very uncertain, marked by numerous and rapid developments.

The current period is characterised by numerous and rapid technological developments and possible disruptions, particularly in the energy and Information Technology (IT) sectors. These transformations potentially have a significant impact on DSOs. They must therefore prepare for it, which sometimes imposes difficult choices between the subjects on which to work as a priority.

A Technology Radar has been prepared with the objective of identifying and analysing trends and stimulating innovation.

The Technology Radar's ambition is to evaluate technological topics that have a potential impact on DSOs and their ecosystem (public authorities, suppliers, customers, and employees).

The objectives are:

- Early identification of new technologies, technological trends and potential disruptions
- Increased awareness of the opportunities and threats associated with emerging technological developments
- Stimulation of innovation by combining technology reports with business potential assessment.

For each trend, a factsheet has been drawn up summarising the key elements relating to the technology considered, the developments in progress as well as the analysis of potential impacts for the DSOs. These may consist, for example, of a change in their business model, prospects for productivity gains or opportunities to develop new services.

An aggregated view of all ongoing trends has been constructed by positioning each technology on a diagram according to estimates of industrial maturity time and magnitude of impact on DSOs. This helps to visualise key technologies as they relate to DSO activities. It should be noted that the position of each technology on this diagram is often only indicative and could be the subject of endless debate, in particular for technologies, such as artificial intelligence, which are already widely used and which however are subject to potentially disruptive new developments.

The trends analysed cover in particular energy systems, digital technologies, and the various emerging solutions serving operational performance.

The task was carried out in an effective way by a network of high-level experts.

A dedicated Task Force organised within the E.DSO Technology & Knowledge Sharing Committee and including high-level experts from a large set of European DSOs was set up to produce the Technology Radar. The sourcing and analysis of technologies has been facilitated by reaching, through the network of technology scouts, the best sources of information.

The members of the Task Force are:

- Co-convenors: Pierre Mallet and Anne-Laure Popelin (Enedis).
- Members: Alessandro Cirocco (Unareti), Andrea Ruffini (Unareti), Angeliki Gialketsi (HEDNO), Antonio Castellanos (Enel Grids), Aris Dandens (Sadales Tīkls), Diego Raggini (Unareti), Enrique Garcia (i-DE), Ewa Mataczynska (PGE Dystrybucja), Gerald Käferle (Netz NÖ), Jan Kůla (ČEZ Distribuce), Mariano Gaudó (UFD), Mark den Brok (Stedin), Nuran Martin (Stedin), Peteris Lusis (Sadales tīkls) Raquel Gómez Martín (E-REDES), Rene Kuczkowski (Enea Operator), Ricardo Almeida Henriques (E-REDES), Samuele Giovannetti (Enel Grids), Sergii Tankevych (DTEK), Thomas Börmans (E.ON), Thomas Buisseret (ORES), Wouter van den Akker (Alliander).

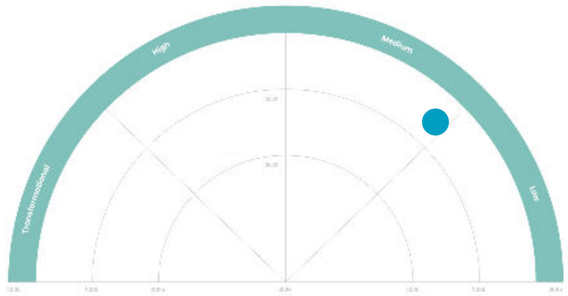
Regular updating is essential.

Given the rapid evolution of technologies, E.DSO plans to carry out a regular update of its Technology Radar.

Last update: 14 Feburary 2025

Network Technologies

1. MVDC and LVDC Networks



Although the transmission and distribution of electricity are almost exclusively carried out in Alternating Current (AC), certain trends call for a reconsideration of the interest in **Direct Current** (DC): (1) renewable energy (photovoltaic, PV, and wind) and batteries (in particular electric vehicles) operate natively in DC, and the acceleration of renewable energy uptake reinforces this interest, (2) the proportion of energy consumed in DC at home is high (50% in 2018) and growing sharply (80% by 2030) and (3) innovation and falling costs in power electronics are making the use of DC increasingly economical. The use of direct current could allow limiting conversions on the distribution network, be a source of simplification and improve the energy efficiency of the electrical system.

Highlights

DC solutions, particularly for the distribution network, are raising great interest, with numerous demonstrators worldwide and, as it appears, a proactive industrial policy in China. Standardisation of DC networks is of critical importance, even more so for Low Voltage DC (LVDC) to enable the development of appliances. The International Electrotechnical Commission (IEC), and the Institute of Electrical and Electronics Engineers (IEEE) have all started standardisation work on Medium Voltage (MV) and LVDC networks.

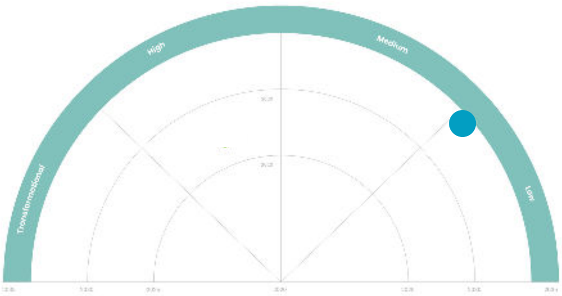
Challenges and opportunities for DSOs

- **DC grids have several challenges to overcome**. Firstly, protection systems and DC circuit breakers need further development.
- There is a general **lack of standardisation** (especially in terms of voltage levels, other specifications, interoperability, and commissioning procedures), and DC installation costs are currently high due to the required power converters.
- Power converters are still not as efficient as AC transformers and have a lower lifespan.
- For **wind or PV plants, storage units or charging stations** a DC connection could be a relevant solution from a technical-economic point of view.
- **Microgrids.** MVDC or LVDC or hybrid microgrids could be developed.
- **Control of power flows.** A DC line could allow connecting two areas by controlling the flows between them.

E.DSO considerations

- DSOs should carry out the analyses and implement the demonstrators necessary to identify the relevant use cases of DC links.
- DSOs should master the technical, economic and regulatory aspects of DC networks.
- DSOs should mobilise to play an active role in the development of standards for DC distribution networks.
- To ensure the safety of operations (power protection and control, etc.) experience needs to be gained via pilot projects.

2. Superconductors



Some metals cooled to very low temperatures (typically between -272 and -240°C) acquire the superconducting state, i.e. the ability to conduct electric current without resistance and, thus, without energy loss. **Superconductivity** has reached the industrial stage in some sectors for the production of intense magnetic fields such as medical imaging, particle accelerators and tokamaks. The applications of superconductivity to grid cables and current limiters have been the subject of experiments after the discovery in the mid-1980s of "high temperature" superconductivity (-196°C) which allows the use of liquid nitrogen for cryogenic purposes. Superconducting cables carry up to 5 times more energy than standard cables.

Highlights

Tests have been conducted over the past fifteen years (Long Island 2008: 600 m, 138 kV, 574 MW; Essen 2014: 1000 m, 10 kV, 40 MW). Links have recently been put into service or are planned: Shingal/Korea 2019: 1000 m, 23 k, 50 MW; Shanghai 2021: 1200 m, 35 kV, 80 MW; Chicago 2021: ~ 100 m, 12 kV, 62 MW; Paris/Gare Montparnasse link project, 2 links of 80m, 1500V DC, 5MW). Experiments with current limiters (10 kV to 138 kV, from a few MVA to a few tens of MVA) have taken place in the USA, Asia (Korea, Japan, China), Germany and the United Kingdom since the 2010s, without leading to the deployment of these solutions.

Challenges and opportunities for DSOs

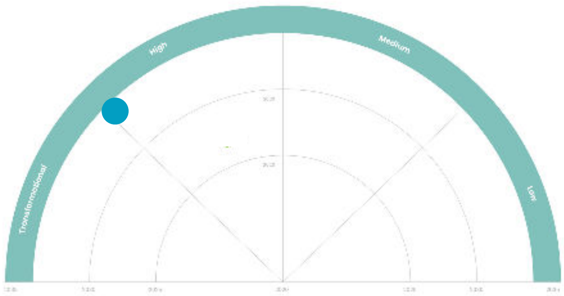
- **Potential use cases for DSOs**: transfer of high power in a congested area (superconducting cables) or, in certain network configurations, coupling between primary substation transformers (superconducting limiters).
- Superconducting cables raise questions about operation, maintenance and safety of hybrid networks.

E.DSO considerations

- DSOs must regularly assess the maturity of superconductive technologies.

Last update: 28 September 2023

Power System Technologies



The kinetic energy of synchronous rotating machines is crucial for the stability of the power system. Current grid control and backup methods are based on this physical characteristic. In the case of solar and wind power plants, the production is injected into the grid through electronic circuits that have no **inertia** and therefore do not contribute to grid stability. As a consequence, the massive development of renewable energy solutions and other resources connected by power electronics leads to a decrease in the share of synchronous rotating machines in the electrical system that will cause a change in grid control and backup methods.

Highlights

Today, the inverters of renewable energies behave in a **grid-following** way. They synchronise themselves with the grid to produce the desired active and reactive power (depending on the primary resource). Depending on the connection level and requirements, they can “support" the grid by providing certain system services (voltage). European grid codes require some new groups to know how to provide system service frequency which requires **grid-forming inverters (and other smart functions: reactive power at night, etc.)**.

Challenges and opportunities for DSOs

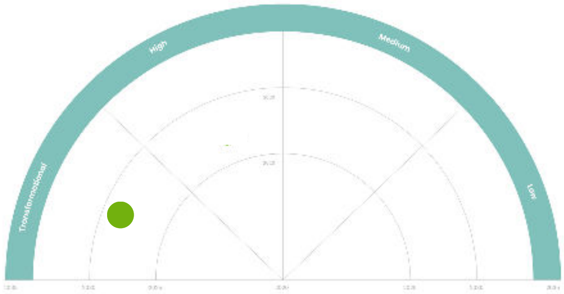
- What are the **critical thresholds** beyond which the **safety criteria** and the **collapse mode** of the system change?
- What are the **solutions to ensure the stability** of the operation of an electrical system with lower inertia?
- Which **solutions are there to restore the system** after a generalised incident?

E.DSO considerations

- In terms of grid stability, in the context of high penetration of renewable sources (partly connected to the distribution grid), the **coordination between TSOs and DSOs** becomes fundamental.
- DSOs must undertake an ambitious research and development program to find solutions to operate a low-inertia electrical system with the level of reliability and resilience required. Part of the work will have to be carried out in cooperation with the TSOs.

Last update: 28 September 2023

4. Local Energy Optimisation in Electricity Grids



Local energy optimisation in electricity grids encompasses all technologies on the low voltage (LV) network that help ensure the **integration** of energy is carried out with minimal impact on supply quality. In the case of **photovoltaic (PV) generation** in LV networks, issues such as overvoltages and network instabilities may arise due to excessive generation during peak hours, which often coincide with low demand. Similarly, the gradual deployment of **electric vehicle (EV) charging points**, with increasingly higher power, can cause instabilities. In the current scenario of growing **electrification of demand**, all these aspects should be addressed.

Highlights

The total **PV energy capacity** in Europe is experiencing substantial growth, with annual additions hitting record highs and the total capacity projected to reach **405 GW by 2027**. Similarly, the number of EV charging points is expanding rapidly and is expected to exceed **1.2 million by 2025** due to significant investments and supportive policies in the sector. These developments reflect Europe's strong commitment to enhancing renewable energy infrastructure and aligning with broader climate and energy security goals (source: IEA).

Opportunities for DSOs

- The installation of **smart meters**, with some countries currently engaged in deploying their second generation, will allow DSOs to understand what is happening on the grid. The use of **Artificial Intelligence (AI) to make predictions and analyses will be necessary for planning LV networks** according to their needs.

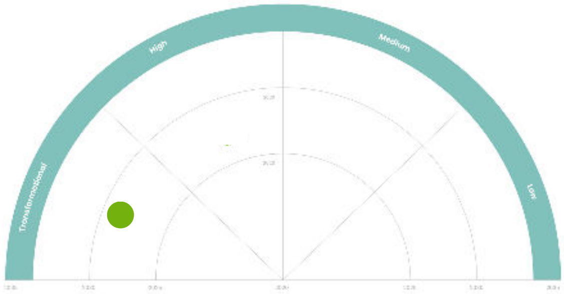
Challenges for DSOs

- To ensure proper operation of the network, DSOs need, among others, to **enhance monitoring of LV networks**.
- The **variability of energy flows** makes it necessary to monitor information on **transformers in secondary substations** as well as the **headers of all LV feeders**.
- The presence of new actors, services, and modes of access to the grid, such as **local flexibility markets, flexible connections, and energy communities**, will require DSOs to integrate them into their planning, operation, and maintenance processes. This will also necessitate technological and operational integration.

E.DSO considerations

E.DSO recommends to:

4. Local Energy Optimisation in Electricity Grids



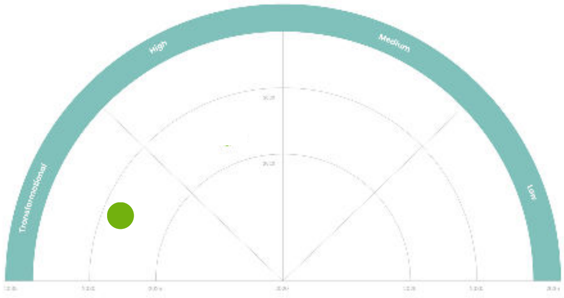
- Strengthen the grid through **investments in MV/LV grids** for **integrating new distributed resources** and **expanding** distribution networks.
- Use **flexible transformer regulation** to adjust voltage dynamically in response to fluctuating demand and distributed energy resource (DER) generation, enhancing grid stability and efficiency.
- Employ **smart transformers, LV balancers and regulators** to maintain voltage within acceptable limits, crucial in high DER penetration areas prone to **voltage fluctuations**.
- Utilise **local flexibility mechanisms** like **demand response** programs and **energy storage** to manage **grid congestion** and ensure **voltage stability** during peak periods and unexpected events.

Potential use cases

- **Real-time Monitoring and Predictive Maintenance**: Implementing advanced monitoring systems on LV networks and secondary substations to increase grid reliability, reduce maintenance costs, and improve response times.
- **Smart Meter Integration and Data Analytics**: Deploying second-generation smart meters to gather detailed consumption and generation data, enhancing energy flow visibility, improving demand forecasting, and optimising distribution.
- **Demand Response and Local Flexibility Markets**: Creating local flexibility markets for demand response programs to improve grid stability, integrate renewable energy sources, and increase energy market participation.
- **Integration of EV Charging Infrastructure**: Coordinating the deployment and operation of EV charging points with existing grid infrastructure to ensure smooth EV integration, reduce network overload risk, and support electric mobility.
- **AI-Driven Network Planning and Optimisation**: Using AI to analyse data for optimising LV network planning and operation, leading to efficient resource allocation, reduced operational costs, and enhanced resilience.
- **Energy Communities and Local Flexibility**: Facilitating the establishment of energy communities to contribute to local flexibility in the grid, increasing energy independence, better utilising renewable energy, and enhancing grid stability.

Ongoing projects

- **Spanish DSOs (i-DE, e-distribución, E-Redes, UFD, …).** In Spain, the deployment of residential smart meters (<15 kW) was completed in 2018. When these smart meters reach 15 years of age, they must be replaced with new ones. This new meter replacement plan is an opportunity for all DSOs, which use power line communications (PLC), to digitise their secondary substations and feeders with



Ongoing projects (continue)

new technologies. The Spanish Government has launched a call for projects with regulatory exemptions (i.e., sandboxes) which was participated by all DSOs. A resolution focused on flexible connections and local flexibility markets is expected in the near future.

- **ORES** has developed a neutral compensator (**Equi-8**) that addresses voltage imbalances in three-phase LV networks, particularly in rural areas with few customers. This redistributes current across phases and between network and compensator neutrals, reducing voltage variation by a factor of 2-3. Voltage regulators are installed to stabilize line voltage in LV networks impacted by new assets like EVs and PV systems. These regulators adjust voltage per phase, with two versions available for different network types. ORES plans to install 20 regulators in 2024 and 50 more in 2025. In addition to this, ORES **Solormax** project uses AI to optimise solar production, preventing grid disconnections by modulating inverters in real-time.

Last update: 4 October 2024

5. Impact of Global Energy Integration

The **integration of various energy sources into the electricity grid** represents a transformative shift toward a more sustainable energy system. By connecting the electricity, heating, cooling, and transportation sectors, a process known as **sector coupling**, the grid becomes more flexible and capable of managing fluctuating demand and supply. This integration enhances efficiency, reduces carbon emissions, and strengthens energy security. However, this also introduces complexities in grid management, requiring new infrastructure, advanced technologies, and regulatory adjustments to maintain grid stability and reliability. As the share of renewable energy in the electricity sector continues to grow, other sectors, such as transport, buildings, and industry, remain heavily dependent on fossil fuels. The decarbonization of these sectors can either happen through electrification or by shifting from fossil fuels to renewable gases like hydrogen or renewable liquid fuels. The conversion between electricity and these gases can further increase storage capacity and add flexibility to the energy system.

Highlights

Sector coupling is crucial for reaching the EU climate targets, including the reduction of greenhouse gas emissions by 55% by 2030. According to the specific goals set by the European Green Deal and REPowerEU, by 2030, 30 million electric vehicles (EVs) should be on the road while 40% of residential heating should be powered by heat pumps. Additionally, district heating and cooling networks are expected to account for 25% of the EU's energy demand by 2030, necessitating robust grid management to handle the increasing and diversified energy load.

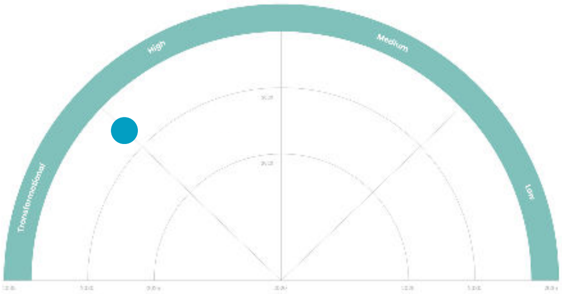
Opportunities for DSOs

- Sector integration enhances grid efficiency, stability, and energy security by diversifying energy sources and optimising the utilization of renewables
- The incorporation of EVs, heat pumps, and district heating systems provides the grid with essential flexibility, facilitating the balance between supply and demand. Furthermore, this integration fosters innovation and creates new business models, contributing to economic growth within the energy sector.

Challenges for DSOs

- The integration of multiple sectors into the electricity grid presents challenges, including the potential emergence of grid congestion and the complexities of managing decentralized and variable energy sources.
- Significant investments in grid modernization are essential, particularly in digital technologies that enable real-time monitoring and dynamic network management.
- Additionally, regulatory frameworks must be updated to support this transition and ensure grid stability and reliability under these new conditions.

5. Impact of Global Energy Integration



E.DSO Consideration

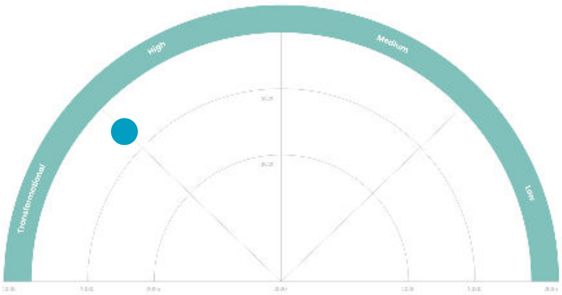
- Distribution System Operators (DSOs) must invest in advanced grid technologies to effectively manage the increased complexity of energy flows resulting from sector coupling. Their application should serve, among others, the development of smart grids, the enhancement of real-time monitoring capabilities, and the incorporation of decentralised energy sources.
- While the necessary technologies are available, integrating all these sources complicates their management.
- DSOs must collaborate closely with regulators to ensure that supportive policies are in place, facilitating the successful integration of EVs, heat pumps, and district heating systems into the grid.

Potential use cases

- **Smart grid management and real-time monitoring**: Use artificial intelligence (AI)and real-time data to balance supply and demand, detect issues promptly, prevent blackouts, and reduce energy losses.
- **Vehicle-to-Grid (V2G) and smart EV charging**: Use EV batteries as grid storage during off-peak hours and coordinate charging schedules to prevent grid overload and enhance flexibility.
- **Heat pump and building load optimisation**: Optimise heat pumps and building-level energy demand to avoid grid congestion during peak times, using predictive data to manage electrification impacts.
- **Renewable energy integration and forecasting**: Enable large-scale integration of solar and wind farms while improving grid planning through accurate generation forecasting.
- **Energy storage and flexibility solutions**: Deploy batteries strategically to enhance resilience, and use Power-to-Gas, Power-to-X, and seasonal gas storage to convert surplus electricity into hydrogen or synthetic fuels, contributing to grid flexibility and seasonal balancing.
- **Promoting Electrification**: Encourage the adoption of electric technologies to reduce carbon emissions and improve energy efficiency across sectors.
- **Cross-sector optimisation**: Harness synergies across energy sectors by using technologies like heat pumps that respond to electricity market signals to efficiently supply district heating networks with storage. Additionally, incorporate insights into the projected growth of district heating and gas networks to adapt long-term electricity investment plans, ensuring aligned infrastructure development and optimised resource allocation.

Ongoing projects

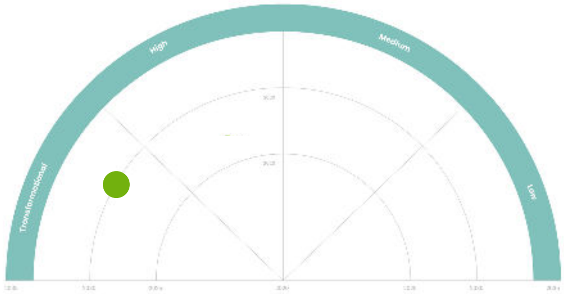
- ORES's **FlexmyHeat** project combines heat pumps with storage tools to stabilize the power system in Belgium. In response to increasing electricity demand and renewable generation, this project assesses how these technologies can offer flexibility to the grid.
- Stedin is implementing several projects on sector coupling:
  - **BEHeaT**, combining intelligent buildings, heat storage, heat networks and electricity grids.



- **DEMOSES**, developing a coupling methodology for heat, electricity, and green gas distribution grids.
- **ROBUST**, testing sector coupling at the city and regional levels, including the deployment of large-scale bi-directional V2G.

- Enedis is participating in the European project **ACCU** (Interreg Europe programme). A demonstrator is foreseen in the North of France, in the city of Fourmies, focusing on energy communities and the synergies between power and heat networks.

Last update: 14 February 2025



Self-healing is the ability of the distribution network to automatically detect, isolate faults and restore service to its normal state. A combination of sensors, software algorithms, local protection systems and automated switches is applied, e.g., breaking the circuit automatically and safely under abnormal conditions such as overloads and short circuit currents. **Low voltage (LV) self-healing** principally uses healthy sections to assist the loads in a faulty section and isolate the fault from the rest of the circuit. Service restoration is performed by automatic reclosing and/or manually by human operators. Centralised and decentralised architectures for self-healing are possible. In the latter case, intelligence is distributed amongst several nodes. It is necessary to distinguish between overhead and underground network structures which are both present in the current power systems in Europe, implying different designs for LV self-healing.

Highlights

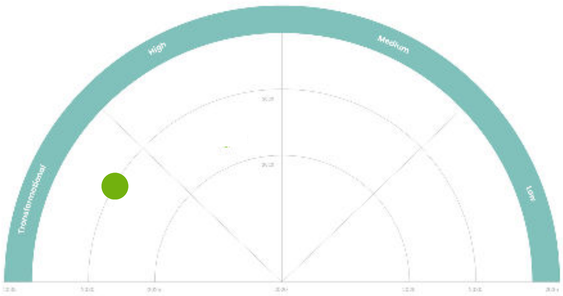
Regulatory incentives may need to be designed for the scalability of LV self-healing in case it is proven as beneficial to society.

Opportunities for DSOs

- Self-healing allows for **quicker fault detection and isolation** when combined with adequate measurements and smart metering, possibly providing additional insights into the faults. The reduction of fault duration and impact leads to improved service quality. Fault detection and insights are not exclusively linked to self-healing itself, but offer an integral approach with other aspects of the smart grid.
- Impacts related to extreme weather events (for overhead grids) or cyberattacks can be automatically reconfigured and restored, improving **resilience**. For normal faults, self-healing helps improve power quality, identify operational problems and provide efficiency in solving problems.

Challenges for DSOs

- **Business case**. At the LV level utilities generally do not have equipment providing data on transformers (voltage, current, power) nor the possibility of remote opening and closing. Benefits, such as potential CAIDI-related improvements, should overweigh costs for investments needed for more intelligence. Potential benefits could also be realised in terms of effective deployment flexibility and avoiding or postponing grid reinforcements.
- Not all grid structures are suitable for self-healing grid functionalities. For instance, switching is not directly suitable in radial networks, but more suitable in a ring or a meshed structure. Moreover, activation of flexibility from decentralised generation can be challenging because the detection system may not be fit for the purpose. Post-fault schemes need to be defined.
- **Technological developments for sensors, actuators for automation and remote control**. The quality of telecommunication solutions should support real-time interaction between components that functions in all situations. The management of decentralised intelligence, update and maintenance of software and cybersecurity in general are also a concern.



Challenges for DSOs (continue)

- A balance between a centralised and decentralised architecture should be sought for automatic intervention.
- **Organisational**. Changing fault handling and restoration requires active participation and confidence in the solution within the DSOs.

E.DSO considerations

- At the moment, self-healing is mainly applied to medium voltage (MV) grids, given the network structure, design of switches, protections and the impact on connected parties, providing a better business case than at LV. Implementation of LV self-healing is in its early stages, especially because it is not directly suitable for radial networks, business case aspects etc.
- Operational experience is needed for full-fledged implementation of self-healing. A gradual implementation from a partial to fully automatic mechanism can be considered together with a gradual deployment of monitoring and control devices for increased electric vehicle (EV) and distributed energy resource (DER) penetration.

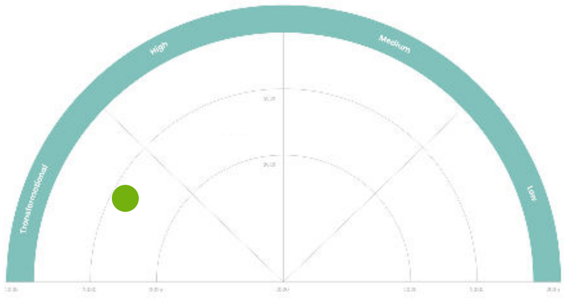
Potential use cases

- **Self-healing through microgrid and distributed battery energy storage systems (BESS)**. Decentralised control architecture by using DER (such as BESS) to enable islanded operation of the LV network, when a fault occurs on the upstream network.
- **Supply of critical clients** (police stations, hospitals, etc.) connected to the LV grid. Non-discriminatory criteria need to be evaluated at the national level.
- An integral smart grid approach, not limited to but including self-healing, could help balance loads from congested networks (e.g., with high concentration of EVs, heat pumps etc.) with other networks with excess capacity and, hence, potentially reduce/postpone grid reinforcement needs.
- For LV grids, resettable fuses are used (e.g., by Stedin) in LV cables after dormancy due to previously detected faults, which are difficult to identify. The automatic fuse responds to the set short-circuit characteristics and automatically switches on again after a few seconds.

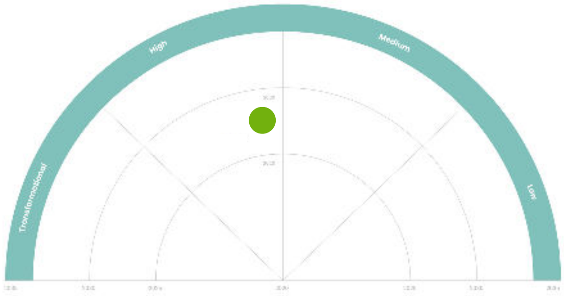
Ongoing projects

- **RESOLVD** Horizon 2020 project (more info).
- Stedin and E-REDES do not have, nor had in the past, self-healing projects at the LV level but only at the MV level. UFD does not have self-healing projects either at MV or at LV. As indicated, the LV network must be meshed, and it is necessary to install automatic switches in the LV panels of secondary substations.

Last update: 17 May 2024



More information on this technology will be available with the next updates of the Technology Radar.



Today, **hydrogen** (H_2) is almost exclusively used in industry, especially the chemical industry, metallurgy and refining. Currently, it is 96% produced from fossil fuels. Recent technological advances have improved the yields and reliability of water electrolysis processes. H_2 can thus be produced from decarbonised or renewable electricity. As a consequence, the significant role of the hydrogen sector in the decarbonisation of the economy through its chaining with the electricity sector leads DSOs to study the impact of the development and integration of H_2 technologies and systems (electrolysers, storage, fuel cells in particular) in the electricity system.

Highlights

To meet the full projected H_2 demand in Europe by 2050 (2150 - 2750 TWh), it would take about 2900 - 3800 TWh of electricity. Despite announcements of gigawatts of electrolysers being installed over the next decade, operational electrolyser capacity is yet to reach 100 MW across Europe. While 48% of European electrolyser capacity is in Germany, no other country has more than 10 MW installed as of today. Around one-third of the installed capacity is providing some form of ancillary service to the electricity system.

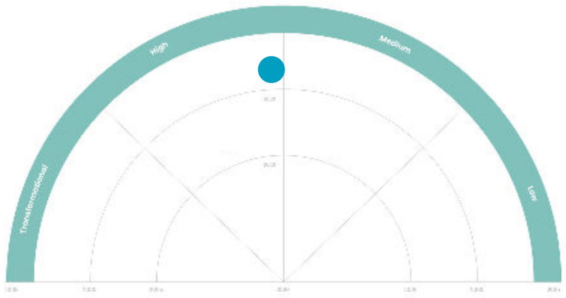
Challenges and opportunities for DSOs

- **Connection**: How big will electrolysers be? Will they be close to RES-based production or uses?
- **Electricity consumption**: What uses are likely to develop? What will be the impact on electricity consumption?
- **Flexibility/Storage**: What flexibility services could be provided and under what conditions?
- **Operations**: What will be the impact of H_2 assets on network operation and security?
- **Sector coupling**: Will H_2 bring momentum to the acceleration of sector coupling?
- **Network planning**: What will be the impact on the development of electricity networks? How will the current plans to reinforce the grid to integrate EVs (high-power chargers) be affected by the penetration of hydrogen in mobility?
- **Environment**: It should also be noted that the development of heavy mobility and H_2 mobile generators can contribute to the decarbonisation of DSOs' activities.

E.DSO considerations

- H_2 could be a solution to decarbonise heavy-duty transport, as we do not know today which will be the winning option between H_2 and batteries. For light-duty vehicles, a clear choice has already been made in favour of batteries.
- There is no common view on the optimal electrolysers' location. Most E.DSO members expect electrolysers to be installed next to electrical production sites (particularly renewable ones). However, some of them expect electrolysers to be installed next to uses to avoid H_2 transport and distribution.
- Considering gas transport and distribution, reports show that H_2 can be quite easily put in modern gas pipelines. This will be more complicated for old pipes but still feasible.
- There is a common view that changing home appliances would be a tremendous challenge.

9. Grid-Forming Inverters



In power systems undergoing a transition to net-zero carbon emissions, **inverter-based resources** must provide a new type of service to maintain an adequate level of security and quality of service. For this reason, in recent years, the grid control concept of so-called **grid-forming (GFM)** is regarded as an alternative means to ensure the security of the power system. GFM involves voltage and frequency regulation and the improvement of angular stability in the grid by power electronic converters. The reduced mass inertia of the rotating component of synchronous generators should be replaced by the equivalent behaviour of grid-forming inverters, i.e. the so-called **electrical or (virtual) inertia**.

Highlights

Inverters are characterized by little or no energy storage capacity, on the other hand, they are actuated at much shorter time intervals than synchronous machines, which store kinetic energy depending on the moment of inertia of the rotor. Hence, the optimal control of properly built and configured inverters is considered one of the key challenges in the massive integration of renewable energy sources into existing power grids. The control of inverters can follow two different functions:

- The **grid-forming function**, which maintains a constant internal voltage angle and frequency, controlled to maintain synchronism with other equipment and regulate the active and reactive power of the inverter during the sub-transition interval. The function can additionally provide emergency start-up and continue operation even in the absence of synchronous generators.
- The **grid-following function**, which maintains a constant value of output current to control the reactive and active power injected by the inverter source into the grid during the time interval from sub-transition to transition state. These inverters are inherently dependent on the strength of the grid to which they are connected and cannot operate in island mode or provide emergency start-up.

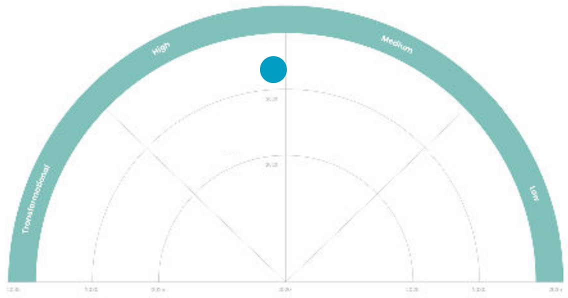
While inverters are currently set on grid-following mode, discussions are underway to introduce obligations relating to GFM in the new Network Code on Requirements for Generators (RfG2).

Challenges and opportunities for DSOs

For an energy supply system that is 100% renewable, GFM solutions are a guarantee of grid quality and stability, as they positively affect the following factors: inertia, system resilience, short-circuit power, system restoration, power system stabilization, and power quality. The use of such functionalities could be an alternative to building new lines, reduce the need for activities of grid reinforcement and redistribution, ensure the stability of an electricity grid fully powered by clean energy, and guarantee the security of the power supply. As one of the goals of this function is frequency system control, the implementation of solutions based on grid-forming should be carried out in close cooperation between TSOs and DSOs.

E.DSO considerations

A potential topic for deeper exploration at the Association level is preparing recommendations for possible future mass application of GFM in distribution grids. Care should be taken to ensure that the provisions of the RfG2 code relating to GFM do not have unjustified costly implications for DSOs.



Potential use cases

- Creating (forming) system voltage.
- Contributing to fault level (short circuit power).
- Contributing to total system inertia.
- Supporting system survival to enable the effective operation of low-frequency demand disconnection for rare system splits.
- Acting as a sink to counter harmonics and inter-harmonics in system voltage.
- Acting as a sink to counter any unbalance in system voltage.
- Preventing adverse control system interactions.

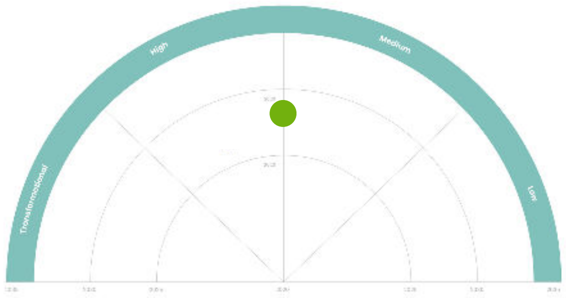
Ongoing projects

Enedis has funded several research works on the topic of GFM:

- Arshpreet Singh PhD thesis "Stability of electrical distribution grids in the presence of renewable energies" (2023): this thesis provided a study of slow-interaction converter-driven stability in medium-voltage distribution grids with inverter-based resources, assessing the impact of both grid-following and grid-forming operation modes.
- Jane Marchand PhD thesis "Black start and stable operation of a portion of the low voltage grid in islanded mode using local renewable energy production" (2024): this thesis provided a study of solutions to achieve the re-energisation of islanded grids by using the available local renewable power generation. This requires changing the controllers of some of the currently grid-following residential photovoltaic inverters to grid-forming control mode so that they can provide black-start capabilities and impose frequency and voltage.

Last update: 14 February 2025

10. Microgrids



A **microgrid** is a group of interconnected loads and distributed energy resources with defined electrical boundaries forming a local electric power system at distribution voltage levels, that acts as a single controllable entity and is capable of operating in island mode, no matter if it is standalone or grid-connected (IEC 62898). When operating in islanded mode, microgrids can manage and optimise supply and demand (energy management system) and regulate demand locally. When operating in connected mode they may also aim to offer new services (provision of flexibilities, congestion management, reactive power management, etc.). The main objectives of microgrids are to improve resilience and decarbonise production.

Highlights

During periods when they are disconnected from the grid, microgrids operate in the same way as islands and isolated sites, which always produce their own electricity. Today, the strong development of renewable energy represents an opportunity to make these installations less costly and more respectful of the environment. The global microgrid market is expected to grow at a high annual rate (estimated at 10% in Europe over the period 2022-2030). Market growth is driven by the need to incorporate renewable energy and the rapid adoption of electric vehicles as well as high energy prices. Furthermore, the threat of cyber-attacks, climate hazards and geopolitical developments are stimulating the desire for energy independence.

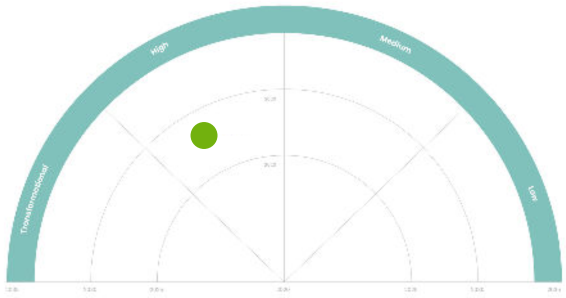
Challenges and opportunities for DSOs

- Operating microgrids requires **local energy management systems** to deal with supply/demand equilibrium.
- **Protection systems** have to be updated to enable safe operations in islanded mode.
- Appropriate technical provisions are required to enable **black start**.
- Connection and disconnection of microgrids to the grid can generate local instabilities.
- The potential benefits of microgrids are technical (peak shaving, reduced energy losses, voltage regulation, etc.), environmental and economic (for participants, etc.), but the technical and contractual conditions for making these benefits effective have yet to be clarified.

E.DSO considerations

- Microgrids are still complex and expensive solutions to implement and they are not cost-effective if the grid is of good quality.
- The technical and economic competitiveness of the electricity network is therefore not called into question.
- However, in some cases, microgrids are an interesting resilience solution.

Last update: 28 September 2023



Efficient energy **storage technology** is needed to overcome fluctuations in renewable energy supply and decrease our reliance on fossil fuels. Storage could provide important system services that range from short-term balancing and operating reserves, and ancillary services for grid stability to long-term energy storage and restoring grid operations following a blackout. Storage can help manage congestion and voltage at different timescales in the distribution network. In some cases, it could defer or even reduce the need to reinforce the network.

Highlights

Pumped-storage hydropower is the most widely used storage technology. Batteries are the most scalable type of grid-scale storage and the market has seen their strong growth in recent years. Other storage technologies include compressed air, gravity storage, superconducting magnetic energy storage, flywheels and hydrogen but these play a comparatively small role in current power systems. Up to date, apart from pumped-storage hydropower, technologies that allow for inter-seasonal or even inter-annual storage are not yet mature. The scarcity and environmental concerns related to raw materials needed to manufacture storage solutions need to be taken into account, particularly for batteries. Article 36 of the Electricity Directive restricts DSOs from owning, developing, managing or operating storage facilities, although some exceptions are possible due to efficient, reliable, safe operations etc.

Challenges and opportunities for DSOs

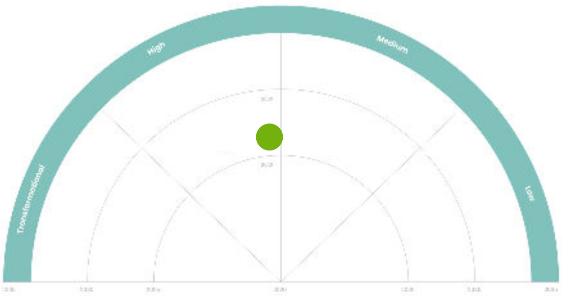
- In addition to the technical and economic performance of storage technologies, their geographical positioning in relation to the distribution grid will be essential for the optimisation of the electricity system.
- The development of storage facilities coupled with renewable facilities can change the management of electricity flows locally.
- The development of storage facilities coupled locally with production can facilitate microgrid emergence.
- Right sizing and location of storage systems in the distribution grid is an important consideration.
- Contractual agreements between DSOs and private parties owning an operating storage are essential to align incentives.

E.DSO considerations

- DSOs must follow the technological advances of the various storage solutions in order to anticipate the possible impact of the development of these on power distribution systems and networks.
- Safety aspects of the various storage technologies, particularly batteries, are important considerations for DSOs.

Last update: 28 September 2023

12. Solid State Batteries



A **solid-state battery** uses solid electrodes and electrolytes, rather than the liquid electrolytes or polymer gels found in lithium-ion or lithium-polymer batteries. Solid-state batteries promise higher energy density than Li-ion batteries, which use a liquid electrolyte solution, as well as increased fast charging capabilities. They also entail no risk of explosion or fire, so there is no need for safety components, saving space. Worldwide efforts to make solid-state batteries a potentially safe and stable high-energy, high-throughput electrochemical storage technology are still hampered by problems of long-term performance, specific power and economic viability.

Highlights

- Solid-state batteries are expensive compared to other available alternatives such as lithium batteries. Solid-state battery prices are estimated to range from $800/kWh to $400/kWh by 2026, compared to liquid electrolyte batteries, which are currently around $156/kWh.
- EV range is limited by the energy density of the batteries and the charging rate. The energy density of solid-state batteries could be twice that of current lithium-ion batteries. Announced charging times are 10 minutes for 80% of capacity (Volkswagen in partnership with QantumSpace).
- Some solid-state battery technologies suffer from the same supply-side vulnerabilities as conventional technologies (cobalt, lithium, etc.).
- Toyota announced to be in a leading position to achieve the first functional mass-produced solid-state battery and is to be the first company to sell an electric vehicle equipped with a solid-state battery by mid-2020s.

Challenges and opportunities for DSOs

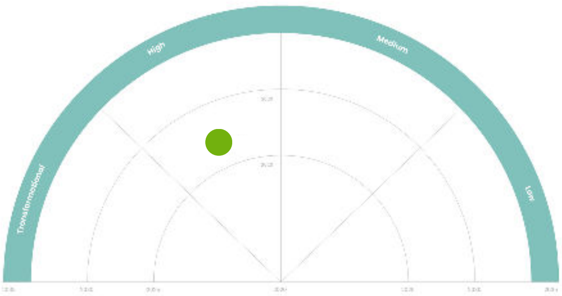
- Solid-state batteries could **accelerate the development of electric vehicles**.
- Solid-state batteries could **escalate the power of charging stations on major roads**.
- Thousands of batteries are installed on grids to provide autonomy to control and protect equipment. The use of solid-state batteries would allow DSOs to extend battery lifespan and improve maintenance.
- If DC solutions are adopted, several challenges must be overcome: further development of protection systems and DC circuit breakers, lack of standardisation (especially in terms of voltage levels, other specifications, interoperability, and commissioning procedures), and DC installation high costs.

E.DSO considerations

- DSOs must prepare for a scenario of the emergence of solid-state batteries by analysing the impact on investment needs, load management, etc.
- DSOs will have to perform numerous tests on solid-state batteries prior to their widespread deployment on grids.

Last update: 28 September 2023

13. Vehicle-to-Grid



The concept of **Vehicle-to-Grid (V2G)** is very similar to the one of smart charging. Smart charging, also known as V1G, allows deciding how much capacity/energy to allocate to Electric Vehicle (EV) charging in real-time. V2G solutions go further and add the ability to redirect energy from a battery to the power grid to balance the network, especially when demand suddenly increases. Vehicle-to-Everything (V2X) is not very different from V2G and includes V2H (Vehicle-to-Home), V2B (Vehicle-to-Building), and V2G.

Highlights

The transportation sector is undergoing a revolution that can be seen in the growing number of electric vehicles on our roads. In addition to having a much smaller ecological footprint than combustion vehicles, electric car batteries represent an energy storage option. Globally, 140 to 240 million electric vehicles are expected to be on the road by 2030. That means there will be at least 140 million energy sources on wheels, totalling about 7 TWh of storage capacity. Today, only a few models are compatible with V2G technology. New (distributed) energy sources like V2G are challenged to compete in traditional energy markets that are not fully aligned with their capabilities. Energy regulation is complex and provides an obstacle for emerging technologies like smart car charging and V2G to make an immediate impact.

Challenges and opportunities for DSOs

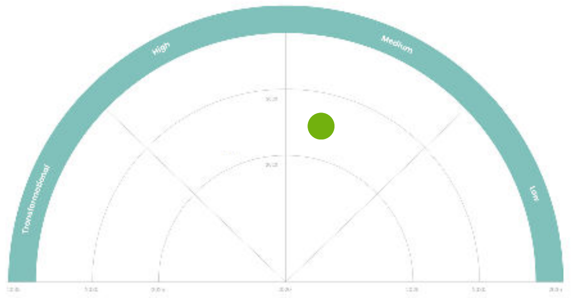
- V2G's impact on power quality and voltage control has to be analysed.
- Connection solutions have to be defined for V2G (DC or AC).
- V2G emphasise (sub-)metering (DC or AC) needs.
- The capacity of V2G, on top of smart charging, to meet local congestion and curtailment needs and its implementation must be studied.
- The capacity of V2G to provide reserve and frequency services has to be studied.
- An energy aggregator can combine EV batteries and other distributed energy assets, such as solar and home batteries, into Virtual Power Plants (VPPs) that can supply and trade energy on electricity markets. DSOs have to investigate the load profiles of such VPPs.
- DSO's technical and functional ways to call V2G have to be defined.

E.DSO considerations

- The outlook for V2X has yet to be clarified.
- In particular, the contribution of V2G in addition to smart charging must be specified.
- V2X services for other energy operators must not cause or aggravate congestion on the electricity network.
- V2X are to be incorporated in the Network Code on Requirements for Generators.

Last update: 28 September 2023

14. Building-to-Grid



Building-to-Grid (B2G) involves integrating buildings bidirectionally with the electrical grid, allowing them **not only to consume but also to generate** electricity using technologies like **renewable energy** and **storage systems**. Digitalisation facilitates grid and building integration. This approach **creates opportunities for buildings** to generate new value streams through energy services. B2G activities include **participation in demand response**, distributed **energy generation** (e.g., through renewables such as photovoltaics), or **storage** (e.g., thermal storage such as making ice for air conditioning or hot water storage), as well as diagnostics and energy efficiency analysis within the building itself.

Highlights

42% of energy consumed in the EU in 2021 was used in buildings. More or less 80% of the energy consumed in EU households is used for heating, cooling and hot water. 85% of EU buildings were built before 2000 and, amongst those, 75% have a poor energy performance. Acting on the energy efficiency of buildings is therefore key to saving energy and achieving a zero-emission and fully decarbonised building stock by 2050.

Opportunities for DSOs

- Modern buildings utilise **Building Management Systems** (BMS) and Energy Management Systems (EMS) equipped with sensors and actuators to control indoor environments and manage energy consumption.
- Distribution-level **ancillary services** can enhance the reliability and resilience of the grid, especially at the local distribution network level.
- DSOs can significantly contribute to reducing the energy consumption of buildings. **Smart meters** enable them to provide data for assessing the energy performance of buildings and identifying those in need of priority renovation.

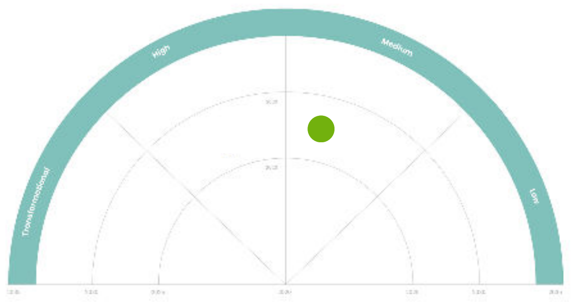
Challenges for DSOs

- Real-time coordination. direct control or through aggregators.
- Cybersecurity. Future B2G interactions will be governed by a set of grid codes covering the electrical and cybersecurity aspects.
- Interoperability. The existing building stock is dominated by legacy systems.
- The standards defining the protocols for data exchange in buildings must allow the integration of the meters operated by DSOs into the system constituted by the intelligent building.

E.DSO considerations

- The objectives of suppliers/retailers and DSOs do not align in the context of B2G integration. For example, suppliers/retailers might aim to balance trading commitments in the energy market using buildings. On the other hand, DSOs may seek to balance local consumption with distribution grid capacity limits.

14. Building-to-Grid



E.DSO considerations (continue)

- E.DSO acknowledges that future grid operations will need to facilitate the integration of **all types of demand-side users, including buildings**, to allow their participation and equitably measure their impact across the power system. The future interactions of building-to-grid should ensure an **efficient financial and functional integration** for a participatory and competitive future electricity market.

Potential use cases

- **Network congestion support.** Turning buildings into already deployed, low-cost storage options for the grid, ready to balance both peaks and valleys of demand in a seamless, automated fashion.
- **Voltage control.** Buildings could assist in voltage control, particularly in networks with significant voltage fluctuations.
- **Demand reduction during scheduled maintenance.** Buildings can contribute to demand reduction during scheduled maintenance work on the network.
- **Resilience and emergency power.** Buildings can serve as sources of emergency power during grid outages, enhancing the resilience of critical infrastructure and supporting community resilience.
- **Electric vehicle (EV) integration**: Buildings can support the charging infrastructure for EVs, optimising energy usage and potentially providing energy back to the grid during times of high demand.

Ongoing projects

- **InterConnect.** Approved by the European Commission under the Horizon 2020 programme, InterConnect gathers 50 European entities to develop and demonstrate advanced solutions for connecting and converging digital homes and buildings with the electricity sector (more info).
- **Platone**, a four-year Horizon 2020 project, focused on enhancing the observability and flexibility of renewable energy resources. The consortium developed advanced management platforms for an open grid market, prioritising user needs. One solution involved installing edge devices at customer sites to collect metering data and receive flexibility activation commands from smart meters (more info).
- **EVELIXIA** unites 36 organisations across 12 EU countries to transform buildings into energy-efficient, connected, smart, and flexible nodes. The project focuses on five Innovation Pathways, deploying solutions in seven countries for B2G and Grid-to-Building (G2B) services (more info).
- **WeForming.** The project seeks to revolutionise energy management in buildings by creating Intelligent Grid-interactive Efficient Buildings (more info).
- **EV4EU.** Funded by the Horizon Europe program, EV4EU aims to implement bottom-up and user-centric Vehicle-to-Everything (V2X) management strategies creating the conditions for electric vehicle mass deployment. It includes V2X in buildings (more info).

Last update: 17 May 2024

15. Smart Distribution Transformers

Today's MV/LV **distribution transformers** (DTs) maintain a design that has remained largely unchanged for nearly two centuries. The evolution of these transformers has primarily occurred in the areas of materials and efficiency, where the Eco-design directive has led to a significant reduction in losses. Over the past decade, the main innovation in this field has been in voltage regulation, where **on-load tap changer (OLTC) systems** have gained support among worldwide DSOs. In this context, a potential game-changer could be the energy transition and the need to connect and operate high volumes of photovoltaic (PV) generators and new loads such as heat pumps and electric vehicles (EVs). This could lead to more frequent voltage fluctuations, changes in current direction, and power quality (PQ) issues than DSOs currently experience.

Highlights

The evolution of DTs to solid-state **smart DTs** could leverage on power electronics with multiple-stage AC/DC active rectifiers, DC/DC converters, DC/AC grid-tied inverters and storage as an option. Required features might be voltage regulation, phase balancing, load balancing, power factor control, harmonics correction all together controlled by advanced artificial intelligence (AI) based on precise measurements. These functionalities are currently being developed in different designs and piloted in distribution grids. Traditional alternatives, such as reinforcing low voltage (LV) lines, may represent a significant investment, for which OLTC transformers may be, in some instances, an efficient and competitive solution to avoid voltage saturations in LV networks.

Opportunities for DSOs

- **Solving multiple LV issues** with one technical solution and in one location.
- **Cost reduction** compared to traditional network reinforcement solutions.
- Improvement in **preventive maintenance** strategies.
- **Lower financial outlay** compared to the need for grid modernisation.
- **Faster response to voltage changes** caused by large distributed energy resource (DER) fluctuations.
- **Lower handling costs** (no need to hire crews to change taps).

Challenges for DSOs

- Presumed **price increase** in comparison with traditional DTs.
- **Lower lifetime** (traditional DTs are expected to stay in the grid for 30-40 years).
- **Lower reliability** due to significant technical complexity.
- Possible additional **technical losses in the electricity conversion** which is strictly against EU policies.

15. Smart Distribution Transformers

EDSO considerations

E.DSO recommends to:

- Cooperate with universities, research organisations and start-ups on innovative solutions and test them in real grids.
- Embrace OLTC on DTs and voltage regulation by autonomous functions of smart inverters as a standard and thus solve the majority of LV grid voltage issues with existing technologies.

Potential use cases

- **Quality of service.** Grid monitoring and automation will allow better handling of contingencies and non-programmed tasks. If these are detected and located before customers notice them, the response time will improve significantly while possible customer complaints will be reduced.
- **Technical losses reduction and lower grid saturation.** Addressing phase or feeder unbalances will allow to improve high losses situations with efficient solutions.
- **Non-technical losses reduction.** The possibility to monitor the amount of energy delivered from a secondary substation compared with the consumed energy from the customers will simplify the detection of issues.
- **Grid saturation improvement.** The monitoring of all different feeders will allow balancing the grid and reducing the number of saturated cables.
- **Maintenance and renovation.** The prediction of unwanted situations (e.g., grid faults) together with a constant analysis of grid information will allow improving preventive maintenance strategies, reinforcement and renovation, prioritisation of on-site tasks to reduce mistakes and extend the expected life of assets expected. The final goal will be to implement automated maintenance schedules.
- **Planning improvement.** With new loads such as EVs and distributed generation connecting to the grid, it will be possible and necessary to analyse future grid saturations in advance through constant energy and power flow measurements.

Ongoing projects

- All **Spanish DSOs** are working on a flexible solution for monitoring and automating the LV network., while sharing experiences, use cases, technical information as well as lessons learned. In this context, **i-DE** is deploying smart DTs in an industrialised way, prioritising secondary substations with voltage problems. Furthermore, the **dynamic setpoint method** developed by i-DE's Innovation Hub is used to improve automatic regulation algorithms, obtaining real-time data from smart meters and LV elements in the grid to improve que real-time regulation of the smart DTs.

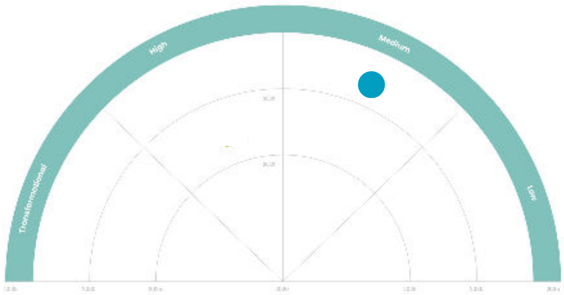
15. Smart Distribution Transformers

Ongoing projects (continue)

- 50 OLTC will be tested in 2024 on **ORES** network in the most problematic LV circuits and for MV voltage management. These proofs of concept are only carried out on circuits where there is sufficient penetration of communicating meters.
- Several proof of concepts have been undertaken by **Enedis** to test MV/LV transformers equipped with OLTC. The results confirmed that this solution is effective to solve voltage issues but the cost, up to now, is still too high compared with the cost of other options.
- **PGE Dystrybucja** will install a 630 kVA OLTC transformer in combination with a power electronic voltage regulator installed in the area supplied by the OLTC transformer. The installation site will be matched to the conditions and needs of the grid in the area so to optimise the grid use of and solve the voltage problems that occur due to high PV saturation.

Last update: 4 October 2024

16. Innovative Charging for Electric Mobility



To get around the constraints of wired charging, **innovative charging solutions** for electric mobility are being researched and experimented. Static and dynamic wireless charging solutions at urban and high-speed operation are being tested in Europe, Asia and the USA:

- Stationary induction charging solutions are being studied, typically for charging taxis or buses while waiting at the station.
- Concerning dynamic charging, two main technology families stand out: **induction charging** and, more specifically for heavy-duty transport, sliding contact charging via a **rail solution or via a pantograph**.

Dynamic charging solutions involve significant investment costs for road infrastructure which is a significant drawback for massive road projects.

Highlights

Dynamic charging will be distributed over long distances and effectively be connected to several points in the grid. Considering inductive charging, the efficiency of the energy flow is comparable to the typical efficiency of fast charging. To limit power losses and facilitate integration with renewable energy sources, inductive solutions are generally DC-based.

Challenges and opportunities for DSOs

- Beyond the general question of **network investments** and **power connection** adapted to support the development of electric mobility, dynamic charging raises the question of **defining connection solutions adapted to linear infrastructures** (AC or DC delivery, etc.).

If DC solutions are adopted:

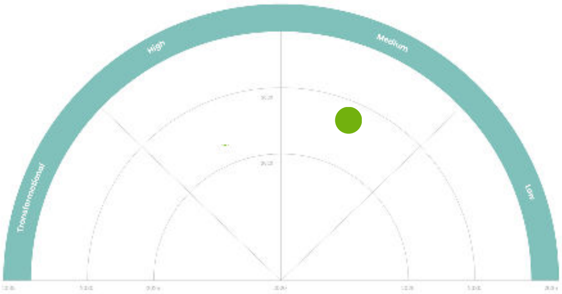
- **DC grids have several challenges to overcome**: protection systems and DC circuit breakers need further development.
- There is a general **lack of standardisation** (especially in terms of voltage levels, other specifications, interoperability, and commissioning procedures), and DC installation **costs are currently high** due to the power converters that are required.
- Power converters are also still not as efficient as AC transformers and have a lower lifespan.

E.DSO considerations

- In collaboration with the stakeholders concerned (car and truck manufacturers, road infrastructure managers, etc.), DSOs should carry out the analyses and implement the demonstrators necessary to identify the relevant solutions and assess the impact of innovative charging options on the distribution network.
- The impact of high-power charging by induction on the grid has to be examined.
- The coupling between storage and charging solutions should be studied.
- Concerning linear charging infrastructures, the DSO perimeter has to be examined and clarified.

Last update: 28 September 2023

Sustainable Development



Technologies containing **SF_6** are widely used in electricity networks, mostly at Medium Voltage (MV) and Low Voltage (LV) levels. These technologies are used in switchgear to isolate and protect different sections of the grid such as switchboards, circuit breakers, metal-enclosed switchgear, and gas-isolated switchgear, amongst others. SF_6, according to the USA Intergovernmental Panel on Climate Change, has the highest global warming potential (GWP), 23000-25000 times higher than CO_2. The gas also has an atmospheric lifetime of 3200 years. According to Schneider Electric, over 30 million units worldwide of MV switchgear use SF_6, and 10 million of these units are in the EU Member States, containing in total more than 8600 tons of SF_6.

Highlights

The electricity distribution and transmission systems are responsible for 80% of SF_6 emissions. According to the LIFE SF6-FREE HV BREAKER project, considering only HV lines, 33 tons of SF_6 are released across Europe every year. The new F-Gas Regulation will introduce a full ban for MV switchgear relying on F-gases, with a gradual phase-out by 2030, and a ban for HV switchgear by 2032.

Opportunities for DSOs

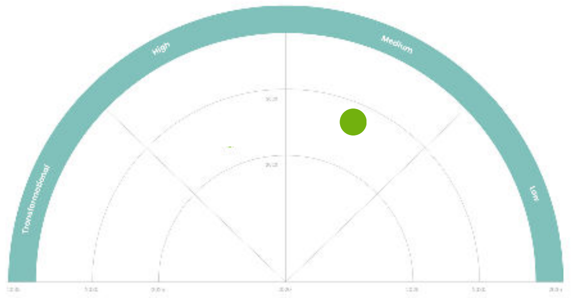
- Contributing to the **reduction of greenhouse gas emissions**.
- Potential to develop **innovative solutions**.

Challenges for DSOs

- Market Availability. Not enough switchgear manufacturers with SF_6-free solutions are available on the market compliant with the F-gas Regulation. Hence, insufficient production capacities will lead to delays in grid expansion.
- Potential cost increase on new technology purchasing, existing infrastructure upgrading, installation, maintenance and training.
- Finding current SF_6 equipment replacements with similar performance characteristics.
- Maintenance of existing SF_6-based installations until the end of their lifetime.

E.DSO considerations

- DSOs are committed to the transition to an SF_6-free grid.
- It is necessary to have a close interaction with the equipment manufacturers so that the development and deployment of SF_6-free solutions can be accelerated and addressed in an effective way.
- All technical grid equipment, including switchgear and circuit breakers, must meet strong reliability criteria throughout their entire life cycle. With this, any future SF_6 solution must be proven to be as reliable, cost-effective, and safe as currently deployed SF_6-based technology.
- Research and experimentation between transmission and distribution equipment manufacturers and end-users on SF_6-free solutions should be enhanced.

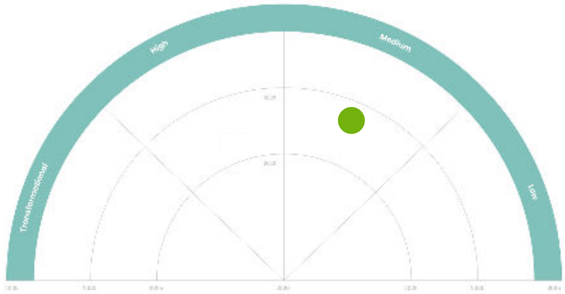


Potential use cases

- **Air-insulated Switchgear (AIS).** Usage of air as insulation medium instead of SF_6 in circuit breakers, disconnect switches, and busbars, amongst others.
- **Gas-insulated Switchgear (GIS).** Alternative gases such N_2 and a mixture of dry air and synthetic gases are being used as insulation gases instead of SF_6.
- **Solid-insulated Systems (SIS).** Solid insulation materials can replace SF_6 in some applications due to their electric insulation properties.
- **Vacuum-insulated Switchgear (VIS).** Usage of a vacuum environment as an insulation medium instead of SF_6. As an example, on circuit breakers, the arc extinction and current interruption are done in a vacuum environment. VIS is a viable option since it offers good insulation properties.

Ongoing projects

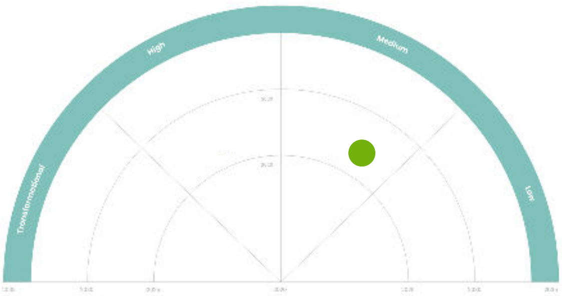
- **LIFE SF6-Free** is deploying SF_6-free MV switchgear pilot installations and developing innovative MV SF technology with Shunt Vacuum Interruption (SVI) (more info).
- **LIFE SF6-Free HV Breaker** aims at combining a viable gas alternative to SF_6 with an improved interrupting unit technology suitable for an outdoor high voltage live tank circuit breaker (HVLTCB) operating from 245 kV/50 kA to 550 kV/50 kA (more info).
- Enedis is carrying out experimentation works on SF_6-free alternative solutions. These works allow the qualification of alternative solutions to SF_6, such as **AIS for higher voltage primary substations with vacuum interruption**. Furthermore, Enedis no longer installs new electrical 24 kV switchboards with SF_6 in its primary substations since 2021.
- E-REDES has been testing various SF_6-free solutions together with manufacturers and technology providers since 2021.
  - A new type of **SF_6-free MV switchgear with vacuum switching and solid insulation media** (up to 24kV) is being tested in the framework of the NextStep project, serving as the test bed for E-REDES' first SF_6-free MV secondary substation switchgear integrated with Internet of Things (diagnosis of insulation condition and MV condition).
  - An **SF_6-free secondary substation protection** is being tested in three 15/10kV secondary substations to validate the technological performance of a secondary distribution cell without SF_6 with remote control and integrated network protection.
  - Another pilot is being performed on a 15/10kV secondary substation to validate the technological performance of an **SF_6-free secondary distribution cell with integrated remote control**.
  - The technological performance of a **primary distribution cell without SF_6** as an alternative to the current AIS is being validated in a 60/30kV substation and a 15/10kV secondary substation.
  - E-REDES is also evaluating HV alternative solutions to comply with regulatory provisions for the technological phase-out of SF_6 solutions.



Ongoing projects (continue)

- E-REDES Spain is testing various SF_6-free solutions:
  - **Remote-controlled modular cells with vacuum cut-off technology** integrated into the MV distribution network.
  - **SF_6-free modular line cells** sewn to an SF_6 protection cubicle in a transformer substation.
  - **SF_6-free modular protection cabinets**.
  - Automated secondary distribution **MV switchgear with dry air insulation and vacuum cut-off technology.**
- Enel is currently trialling, mainly in Spain and Italy, SF_6-free equipment both at the MV (up to 24KV) and HV levels (up to 145KV). During 2019 and 2020, thanks to an open innovation approach, Enel involved two of the main suppliers of MV and HV equipment in developing SF_6-free projects in compliance with their current technical requirements. The installation of twenty **MV Ring Main Units** (RMU) at 24 kV **with alternative gas insulation** was conducted in Italy and Spain, while five **HV circuit breakers** at 145 kV **with dry air insulation** were installed in Spain.
- E.ON grid operators are currently running different pilot projects at MV and HV levels using dry air and vacuum for insulation and braking respectively.
  - At the MV level, a complete primary substation has been installed with **'AirPlus' technology** and an existing primary substation has been enlarged with two **dry air insulated switch panels** (both operating at 24 kV).
  - On higher voltage levels (i.e. at 110 kV), two **SF_6-free switch panels** have been installed with a 145 kV **dry insulation with a vacuum circuit breaker** respectively, complemented by **dry air instrument transformer sets** enabling remote online performance monitoring.
- i-DE is currently testing SF_6-free equipment at MV (on secondary substations at 24 kV) and HV (on primary substations at 132 kV) in collaboration with different manufacturers with the purpose of developing and reaching market maturity for these products.
  - MV trials use **dry air with vacuum breaking**, while HV trials use an **alternative fluorine gas**.
  - Available SF_6-free technologies are being analysed, but none of them have been found ready for a successful implementation on the network yet.
  - i-DE has been committing to the verified end-of-life management of SF_6 switchgear since the mid-90s, providing recycled SF_6 for maintenance.

Last update: 17 May 2024



Circular economy is a model of production and consumption which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. DSOs wish to reduce the environmental footprint of their activity: this includes their carbon footprint but also the impact of other products (lead, single-use plastic, etc.) and more generally the consumption of natural resources. Resource consumption takes place during network operation but also during the construction of new structures. An effective way to reduce the DSO footprint is to reuse existing equipment as much as possible. Many innovations must be developed to progress in the desired direction.

Highlights

The European Commission adopted the new circular economy action plan (CEAP) in March 2020. This is one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth. The EU transition to a circular economy will reduce pressure on natural resources and will create sustainable growth and jobs. It is also a prerequisite to achieve the EU 2050 climate neutrality target and to halt biodiversity loss.

Opportunities for DSOs

- Reduction of carbon emissions.
- Reduction of the consumption of rare resources.
- Improvement of corporate image through commitment to the ecological transition.

Challenges for DSOs

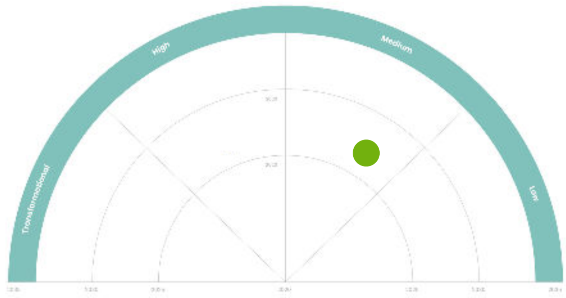
- Possible increase in costs.
- Impact on OPEX/CAPEX balance.
- Control of component reliability and warranty management.
- Creation of the industrial sector necessary to support these objectives.

E.DSO considerations

- DSOs must aim to reuse materials as much as technically and economically possible: incorporation of **recycled materials** in the manufacturing of equipment, **repair of components** (including old ones) when possible, etc.
- The **network tariff provisions**, and in particular those relating to the remuneration of investments, must encourage DSOs to take action in the fields of recycling and circular economy.
- DSOs must undertake, in conjunction with component suppliers, research and development work to find solutions allowing **components to be reused** as much as possible.

Potential use cases

- Use of cables partly made from recycled materials.
- Refurbishment of end-of-life transformers.
- Repair of equipment in primary and secondary substations, including old one.



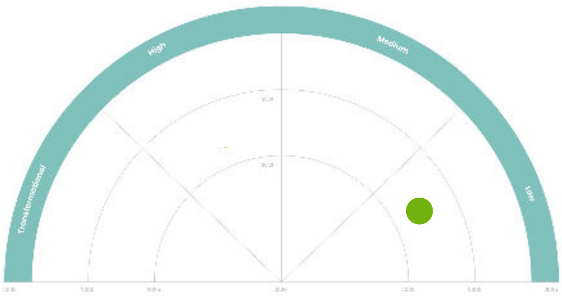
- Reuse of some of the components (e.g., metallic cable support) during the renovation of old overhead lines.

Ongoing projects

- **Enedis** is carrying out the following projects related to recycling and circular economy:
  - Retrofit of the mobile part of certain medium voltage (MV) circuit breakers (the fixed part is retained, even beyond 20 years).
  - Transition from cutting in SF to cutting in vacuum while retaining the fixed part of the initial MV circuit breaker.
  - Repair of MV/LV transformers.
  - Scheduled renovation of HV/MV transformers (lifespan extended by 15 years).
  - Scheduled renovation of MV overhead lines (lifespan extended by 25 years).
- **Stedin** focuses on the "front-end" of their processes where they can identify several opportunities for increasing sustainability. Examples[6] include adjusting specifications to avoid undesirable materials, adopting designs that require fewer materials, including sustainability as a criterion in the selection of products, and challenging suppliers to develop sustainable alternatives. Plenty of attention is being paid to cables and buildings, as these are areas in which a huge impact can be achieved.
- The **EDP networks platform**, which is currently operating in Portugal (E-REDES), Spain and Brazil, is developing a 2-year Iberian project on circular economy, based on the EDP group policy, with seven axes of action: efficiency in the use of resources and materials, product longevity, digitalisation, resource valorisation, new business models, circular supplies and influence/awareness. The main goal is to achieve an 85% operational waste valorization by 2026 and an 85% increase in the total waste recycled from operations by 2025. In this project, the circularity and carbon footprint of the network assets were assessed, and an implementation roadmap was designed, and is currently being implemented.
- **E.ON** is carrying out several activities related to recycling and circular economy: using circular wooden poles for overhead lines, refurbishing old transformers, reusing transformer oil, introducing an internal platform to reuse components and repairing high voltage (HV) transformers, introducing sustainability targets on circularity in planning.
- **ORES** is reconditioning (i.e., replacing insulators with plugs to avoid direct HV contact) transformers that have reached a certain age but which are not at the end of their life yet.

Last update: 4 October 2024

19. Line Corridors that Support Biodiversity



Line corridors that support biodiversity refer to the cleared areas beneath and around **overhead power lines** that, when managed sustainably, can become valuable habitats for various species and contribute to biodiversity conservation. These strips of land, typically maintained to prevent vegetation from interfering with power lines, have the potential to serve as **ecological corridors**, connecting fragmented ecosystems and supporting the movement of wildlife and the growth of native plants. In the context of electrical distribution networks, these areas can be managed through practices such as **selective vegetation maintenance, the introduction of native species, and the creation of specific habitats**, turning utility corridors into spaces that enhance both environmental sustainability and operational safety.

Highlights

The **EU's Biodiversity Strategy for 2030** aims to reverse biodiversity loss by enhancing protected areas, restoring ecosystems, and introducing binding restoration targets through the Nature Restoration Law. The strategy focuses on **expanding the Natura 2000 network**, improving agricultural and forestry practices, and integrating nature-based solutions like carbon-capturing ecosystems. It supports green investments and ensures legal frameworks for habitat restoration. This initiative aligns with the European Green Deal and other sustainability policies and will receive substantial funding.

Opportunities for DSOs

- **Sustainability goals**: Supporting biodiversity helps DSOs meet environmental regulations.
- **Connectivity**: These line corridors can connect ecosystems, aiding wildlife movement and promoting a healthier environment.

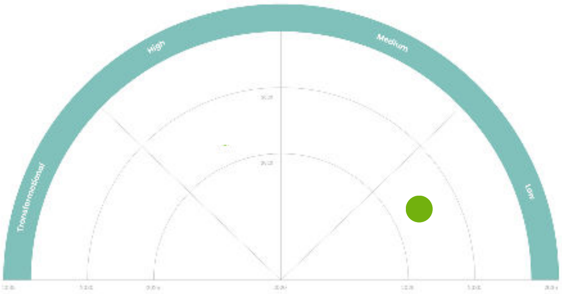
Challenges for DSOs

- **Balancing safety and biodiversity**: DSOs need to ensure the corridors don't interfere with grid safety.
- **Increased costs**: Implementing biodiversity initiatives may require additional investment.
- **Regulatory complexity**: Keeping up with changing regulations can add complexity.
- **Continuous management**: Managing these areas requires continuous monitoring and resources.
- **Need for coordination** with other environmental protection authorities.

E.DSO considerations

- E.DSO wishes to promote the development of exchanges of experience and the sharing of good practices between E.DSO members on these solutions.
- A balance must be found to promote biodiversity without affecting the security of the electricity distribution system and while remaining attentive to costs and therefore to the level of distribution fees paid by network users.

19. Line Corridors that Support Biodiversity



Potential use cases

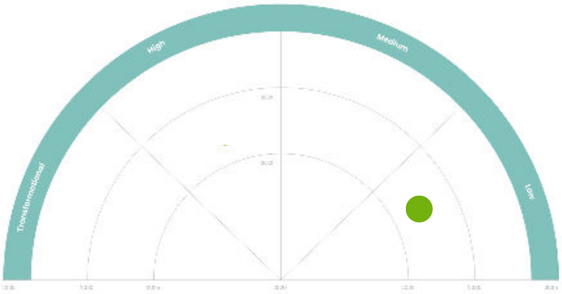
- Installation of nests or other animal facilities on top of power poles.
- Coordination with other public/private environmental protection authorities.
- Use of ecologically-friendly equipment (e.g. pesticide-free).
- Taking biodiversity into account in public lighting projects (light pollution, etc.).
- Promoting efficiency in vegetation management, potentially through the use of artificial intelligence (AI).
- Promoting network security-related projects to prevent natural hazards.

Ongoing projects

- ORES promoted the following initiatives:
  - A **ban** (admittedly, in application of the law) **of the use of pesticides** in third-party contracts for the management/maintenance of the surroundings of their facilities, sites and posts and the application of a late mowing policy in some of these locations.
  - The **installation of two stork nests** at the top of electricity poles on their network in collaboration with local wildlife protection associations and the Royal Ornithological League. The aim was to ensure the safety of Ores's installations and the birds in places where they could nest "erratically", potentially causing power failures and bird mortality. The initiative was crowned with success, with the birth of two stork chicks in one of the two nests in 2023.
  - A number of initiatives have also been undertaken in the field of **smart lighting**:
    - The production of a 'Vade-mecum for taking biodiversity into account in public lighting projects', which was put online and published for local authorities by the Walloon public service.
    - The promotion of the 'black grid' to local authorities to reduce light pollution.

- UFD has committed to environmental protection through several innovative projects. These include **advanced vegetation management** with drones, AI, and LiDAR, **fire and smoke detection** for early incident response, and the **reduction of electrocution risks** for raptors by replacing insulators with anti-perching devices, all in alignment with regional environmental plans.

- Netz Niederösterreich has been consulting ecologists, biologists and planners to find a line corridor that respects nature and its biodiversity in sensitive areas. In terms of bird protection, the DSO has been:
  - Marking the wires of 110-kV-power lines with **bird protection flags** to prevent collisions in sensitive and/or highly frequented habitats.
  - Installing new 20-kV-power lines underground to **prevent bird collisions**.
  - Financially supporting research programmes, to ensure the **cross-border bird protection** of endangered species. For example, the DSO co-finances the **LIFE EUROKITE** project (2017-2027) that researches the mortality of red kites by using telemetry.

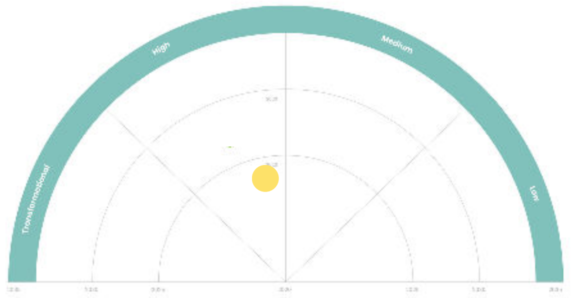


  - Performing forestry maintenance such as tree felling outside of the breeding season.
  - Reforestation of native, site-adapted species in case the line corridor runs through forest areas.

- Enedis is a partner in two projects financed by the LIFE Programme of the European Union that support biodiversity:
  - **SafeLife4birds**, which goal is to reduce the mortality of 13 bird species against power lines by tackling bird collision, electrocution and disturbance during the breeding season as well as improve and share knowledge across Europe.
  - **LIFE GYPACT**, which goal is to restore and conserve bearded vultures and improve the viability of bird populations.

Last update: 14 February 2025

Information Technology and Telecommunications



Artificial Intelligence (AI) is an interdisciplinary field that combines theory and practice. AI is about assisting human activities, mainly via software, and, in some cases, even replacing them. AI involves the use of information systems, data within management systems and dedicated algorithms and is often applied in classification, prediction and forecasting use cases. AI performance is based on the combination of the availability of a large amount of data, large computing capacity, and machine learning algorithms. As distribution networks are generating a growing amount of data, due to the deployment of smart meters and increased measurement and communication capabilities, DSOs have early on considered AI solutions.

Highlights

For the European Parliament, artificial intelligence represents any tool used by a machine to "reproduce human-related behaviours, such as reasoning, planning and creativity". The AI Act is a proposed European law on artificial intelligence – the first law on AI by a major regulator anywhere. The law assigns applications of AI to three risk categories. First, applications and systems that create an unacceptable risk are banned. Second, high-risk applications are subject to specific legal requirements. Lastly, applications not explicitly banned or listed as high-risk are largely left unregulated.

Opportunities for DSOs

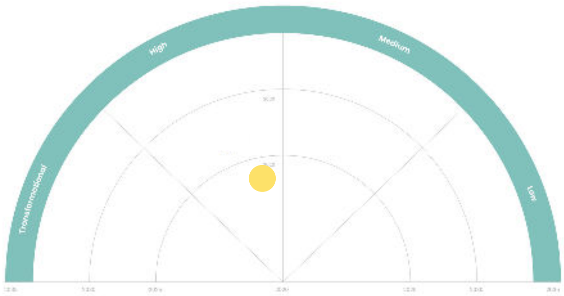
- **Enhance demand/supply forecasting and decision-making**: adjust distribution, increase flexibility and minimise the risk of blackouts.
- Support DSOs in **integrating** (distributed) **renewable energy sources** into the grid.
- **Reduce the risk of grid failures** by performing timely maintenance by using intelligent, predictive algorithms detecting anomalies in the grid.
- **Enhance** the **productivity** of employees by automating & augmenting repetitive and data-intensive tasks.

Challenges for DSOs

- **Data Privacy**. Handling sensitive grid data while maintaining privacy is essential.
- **Cybersecurity**. Protecting AI systems from cyber threats is critical to ensure grid reliability.
- **Data quality**. AI relies on high-quality training and input data (e.g. grid data).
- Integrating AI into distribution grids involves managing distributed energy resources (DERs), ensuring seamless coordination and optimisation.

E.DSO considerations

- The performance of AI solutions is directly based on data availability and quality and increasing data privacy concerns.
- Facilitating and accelerating the industrialisation of AI solutions into core information systems has become one of the main challenges of industrial AI.
- AI algorithm performance control requires special attention and dedicated monitoring tools.
- As AI technologies require specific skills, companies should develop dedicated training programs.



E.DSO considerations (continue)

- The development and implementation of AI solutions must be carried out with the aim of reducing carbon footprint.
- Particular attention must be paid to the ethical aspect of AI (potential concerns about justice, fairness, accountability, etc.).
- European legal texts under preparation must account for the specificities of DSOs.

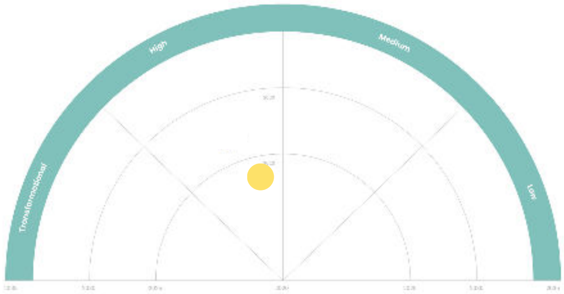
Potential use cases

- **Production and demand forecast**: AI combined with classical solutions may improve forecast quality.
- **Congestion management prediction**: determining how much flexibility is needed in the future.
- **Distributed Energy Resources (DER)/Flexibility**: AI allows handling the increasing complexity of network control due to DER variability, e.g. determining the available power for charge point providers.
- **Network development studies**: AI enables the realisation of network development studies accounting for technical constraints, and technological and sociological hypotheses.
- **Asset management**: the performance of AI in image processing enables automatic diagnosis to enhance programmed renovation. The learning capacity of AI allows, in some cases, to perform predictive maintenance.
- **Image recognition**: for instance, electricity energy meter & components recognition from meter photos, detecting assets on technical drawings.
- **Operation and employee support**: AI could augment the capabilities of maintenance technicians, customer advisors and support function employees.
- **Network control & outage prediction**: AI could augment the capabilities of control rooms (fault location, DER integration). AI solutions will enable precise LV massive control.

Ongoing projects

- **Production and demand forecast:**
  - **SYPEL** predicts consumption, production, and losses in Enedis' electrical network on a national scale.
  - **PREDIS** by E-REDES provides short-term forecasts of load and generation in the high voltage (HV) and medium voltage (MV) network through advanced analytics models allowing behavioural estimation for around 100'000 customers up to 5 days in advance (more info).
- **Congestion management prediction:**
  - Stedin uses AI to determine **future flexible power needs** for congestion management and to **predict transformer and (sub)station load** through day-ahead forecasting.
  - **O-One** (Ores Operation Network Expert) is used by Ores to manage congestion (from risk assessment in the short-term to curtailment and monitoring) at the TSO-DSO interface in the HV network due to connected generation (more info).
- **Distributed Energy Resources (DER)/Flexibility:**

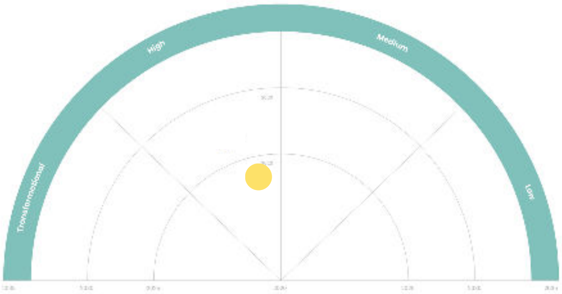
20. Artificial Intelligence



Ongoing projects (continue)

- Stedin currently uses AI to determine **available power for electric vehicle charging** on more than 400 charging poles in the Utrecht and Rotterdam provinces in the Netherlands.
- To cope with the low availability of monitoring technologies at lower voltage levels, EnBW AG uses AI to read available measurement data (20 to 30% of all nodes) to **predict network utilisation** in the whole region. The application supports grid monitoring in a context of high DER penetration and increasing regional load peaks.

- **Network development studies:**
  - Stedin uses AI to **automatically create grid designs** for newly built residential areas and define the **optimal location of MV stations**, reducing engineering time and shortening grid length.
- **Asset management:**
  - The **Analytics4Assets** initiative by E-REDES uses advanced analytics models to forecast the behaviour of technical assets (AT/MV Power Transformers, HV Circuit Breakers and HV Lines), anticipating failures and optimising investment and maintenance plans.
  - Several DSO initiatives make use of AI combined with drone visual inspections to detect anomalies on HV and MV overhead lines. Examples include the **GridDrone project** by E-Redes (more info here and here), the **DALI project** from UFD (more info here and here) and Enedis' **DORA platform**.
- **Image recognition:**
  - With **Dataposte**, Enedis uses image recognition to control and ensure the reliability of network equipment image collection.
  - E-REDES uses a neural network algorithm to **detect meter installations** in photographs sent by service providers and validate their work.
- **Operation and employee support**:
  - Netze BW uses AI to independently **evaluate meter readings reported by customers** and record plausibility checks for correctness (more info).
  - ESO developed a machine learning model to **assess the quality of network documentation**, identify errors (e.g., inaccuracies in electrical addresses, lengths, diagrams, etc.) and take corrective actions.
  - The **Analytics4Vegetation** initiative, fully deployed on the E-REDES network in Portugal, predicts vegetation growth with respect to the surrounding electrical infrastructure to automatically plan, prioritise and generate vegetation cut orders (more info).
  - Enedis AI-based tool **ARIIA** analyses requests for field intervention and assigns a probability of non-success (e.g. due to poor definition), limiting unnecessary travel for field operators.
  - E-REDES is piloting a project to **automate the validation of grid connection request documents**, reducing process time and improving result consistency.
  - An AI tool for determining the **probability of network damage and excavation risk** due to digging activities is planned to go live on the entire Stedin network.

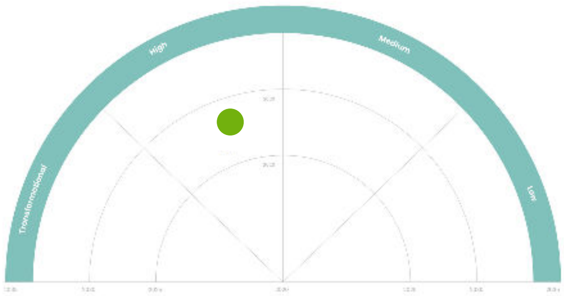


Ongoing projects (continue)

- **Network control & outage prediction:**
    - Before a storm, the **Windy** tool of Enedis uses meteorological data to predict the number of outages on overhead power lines with 90% accuracy, enabling better crisis preparation and faster restoration.
    - E-Redes developed a solution to **predict possible neutral loss** situations based on the events generated by smart meters before their occurrence.
    - ESO created a machine learning-based system that provides **alerts for potential large-scale mass power outages** in the 10 kV overhead line network considering weather forecasts, historical data, and technical network parameters.
    - Enedis' **Cartoline Low Voltage** uses AI to analyse voltage-related data observed by Linky smart meters to foresee future incidents that could lead to power outages and schedule preventive interventions from field technicians (more info).

Last update: 17 May 2024

21. Generative AI



Generative AI refers to Artificial Intelligence (AI) and Machine Learning algorithms that use existing content to generate new content. Generative AI can generate text, sound, images, etc. Based on models stored in a database, it can produce its own similar model. For example, today's artificial intelligence systems can be trained to recognize a distribution network component in images, whereas generative AI systems can be trained to generate an image of a distribution network component. Generative AI is likely to have the biggest impact on knowledge work, particularly activities involving decision-making and collaboration, which previously had the lowest potential for automation.

Highlights

According to Bloomberg Intelligence, the generative AI market will reach $1300 billion by 2032. It was close to $40 billion in 2022 and should reach $67 billion in 2023. The rapid growth of the generative AI market is best illustrated by the success of ChatGPT. When it was launched in 2022, ChatGPT had one million users in 5 days. The EU AI Act adopted by the Parliament in March 2024 contains specific requirements for generative AI.

Opportunities for DSOs

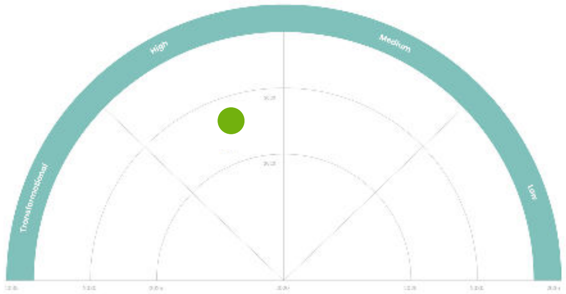
- **Enhance employee productivity** across DSO processes. Generative AI has the potential to automate routine, repetitive content-related tasks and augment work activities that require problem-solving and abstract reasoning skills.
- **Support personal experiences**. Generative AI can tailor content, products, and services to individual preferences for DSO customers, partners and employees.
- **Automate human-like content creation**, support informed decision-making and augment human creativity across DSO processes.
- **Augment software development**.

Challenges for DSOs

- The use of generative AI will require specialised resources and adapted validation processes (bias/accuracy monitoring, privacy and security management) before establishing confidence in processes critical to the distributor.
- **Data quality**. Generative AI relies on high-quality training and input data (e.g., grid data).
- **Intellectual property**. Information entered in generative AI services can become part of its training set, determining ownership of content created by generative AI is complex.

E.DSO considerations

- Generative AI solution performances are directly based on data availability and quality and emphasise data privacy concerns.
- Generative AI algorithm performance control requires special attention and dedicated monitoring tools.



E.DSO considerations (continue)

- Generative AI technologies require specific skills and companies will have to develop specific training programs.
- Development and implementation of Generative AI solutions must be carried out with the aim of reducing their carbon footprint.
- Particular attention must be paid to the ethical aspect of Generative AI (potential concerns about justice, fairness, accountability etc...).
- It will be necessary to ensure that the results of Generative AI are always identified as being generated by a machine.
- It will be necessary to ensure that a "human is in the loop" when Generative AI is used for decision-making and communication.

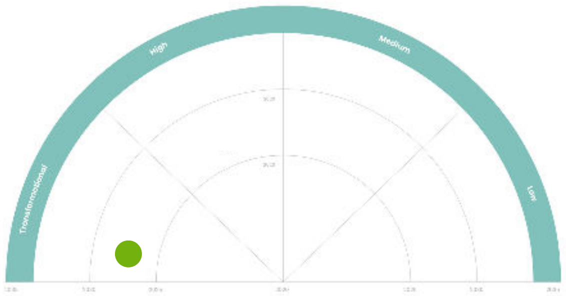
Potential use cases

- **Improve knowledge management**: retrieve stored internal knowledge for better-informed decisions across DSO processes, clarify complex regulations etc.
- Boost grid management and operations by **automating & augmenting tasks**: incident planning & response, network development studies, grid engineering, asset performance & planning, demand load forecasting, network control, etc.
- **Enhance customer experience** by generating personalized content, recommendations, and automating responses to customer requests.
- **Faster product- and software engineering**: create novel designs, prototypes, code and testing them.

Ongoing projects

- Stedin is piloting virtual assistants for **knowledge discovery and augmenting content creation** (e.g. question and answer to internal data including grid data, creating minutes of meetings, and drafting documents) to boost the productivity and creativity primarily of office workers.
- Enedis **DeepCourboGen** is a synthetic load curve generator that preserves the statistical distribution of real curves while completely masking actual data.
- ČEZ Distribuce developed a proof of concept including the dedicated implementation of an OpenAI-based Generative AI model as a **chatbot for connection requirements information** prepared for customers and tested by internal employees. Future features include a chatbot integrated into the public website, analytics of customer feedback, an internal chatbot for corporate documentation, Human Resources (HR) onboarding etc.
- UFD is working on two projects to leverage generative AI. Both projects aim to provide UFD **call center and control room** operators with a **co-pilot** to support their activity and personalize responses to customer calls and incidents, respectively. Additionally, it is planned to use AI as a simple manager for advanced queries to the UFD information repository.

Last update: 17 May 2024



Edge computing refers to a distributed computing architecture characterised by decentralised processing power. Specifically, it enables data to be processed directly by the device that generates it or by a local computer. In this scenario, there is no longer a need to transmit large volumes of data to a remote data centre for analysis. Edge computing facilitates real-time processing of data in large quantities, as close as possible to its source, leading to reduced bandwidth usage, lower latency, and the necessary security layer for handling sensitive data. This technology is primarily prevalent in the Internet of Things (IoT) domain, where it competes with cloud computing.

Highlights

Edge computing is evolving as new technologies such as artificial intelligence and machine learning bring new data analysis capabilities to the table, and emerging business models such as IoT as a service enable solution providers to deliver innovative offerings in new ways. With an average increase of 16% per year, spending on edge computing totalled $40 billion in 2022 in Europe and should reach $64 billion in 2025. Service providers, editors and manufacturers are sharpening their offers to meet the growing demand from companies.

Opportunities for DSOs

- The enhancement of computing capabilities enables the **execution of complex distributed analyses**, especially in primary and secondary substations.
- Provides **flexibility** to the network and minimises reaction times by enabling local decision-making.
- Facilitates the **autonomous operation** of the medium (MV) and low-voltage (LV) network.
- Addresses **cybersecurity** concerns.
- Optimises **data storage**.

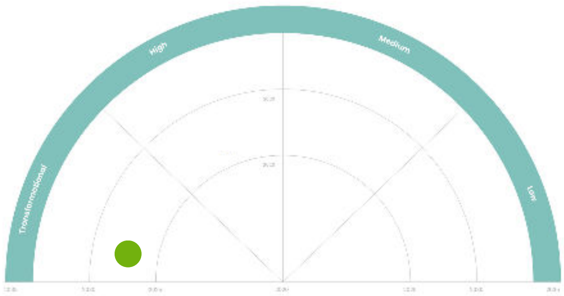
Challenges for DSOs

- Equipment lifecycle.
- Increased likelihood of failure and difficulty in settling responsibilities. This is attributed to the integration of currently independent devices, resulting from the integration of various use cases.

E.DSO considerations

- DSOs should conduct analyses and implement demonstrators to identify relevant use cases for edge computing.
- The technical benefits of edge computing solutions are evident for secondary substations. It is necessary to be monetised.
- DSOs should also recognise the contribution of such solutions at primary substations and throughout the network.
- Active participation in ongoing industry discussions is crucial for DSOs. These discussions should encompass governance and standards, including aspects such as cybersecurity, software solutions, and the definition of future standards.

22. Edge Computing



E.DSO considerations (continue)

- Participation is vital to advocate for the specific requirements of DSOs.
- DSOs need to develop a comprehensive security strategy for edge computing.

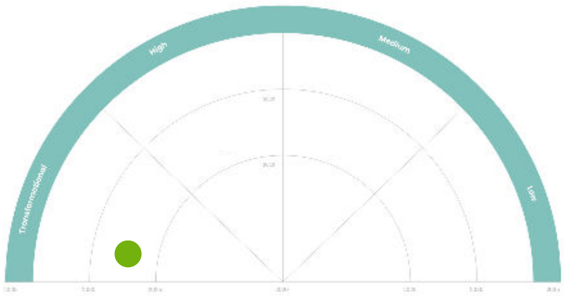
Potential use cases

- **Data concentrator.** This system collects and aggregates data from various sources in the power grid, mainly smart meters, serving as a centralised point for managing and distributing information.
- **Advanced LV monitoring.** Monitoring of all LV circuits in the secondary substations.
- **Power grid prediction.** Load flow simulation, technical loss balance, transformer saturation, network capacity analysis, voltage mapping, and low-voltage line base balancing.
- **Asset management in secondary substations.** Inventory and lifespan estimation, self-diagnosis, remote equipment reboot.
- **Power grid automatisation.** Anomaly detection in LV, insulation fault detection, anomaly detection in MV, cutting, reconnection and load balancing.
- **Communication network analytics.** Topology connectivity meters, fraud detection and prevention, noise detection in power-line communication (PLC) network.
- **Energy management.** Local demand management, flexible generation power, distributed flexibility, integration of storage systems.
- **Physical security/access control.**
- **Video analysis for visual monitoring.**

Ongoing projects

- The **E4S Alliance** (Edge for Smart Secondary Substation) deserves special mention. E4S works on defining a standards-based, open, interoperable, and secure architecture to enhance the automation, scalability, security, and manageability of secondary substations worldwide. Involved DSOs are i-DE, E-EDES, Enedis and UFD (more info).
- i-DE and Iberdrola Group:
  - **E4S** (role: DSO) with a pending demonstration pilot during the second half of 2024.
  - **VIRTGRID** (role: external validator DSO).
  - **IA4TES** (role: promoter), testing Artificial Intelligence (AI) use cases and software applicable to the edge.
  - **SEC2GRID** (role: external DSO validator), testing cybersecurity in distributed environments and virtualisation of cyber use cases.
  - **Virtual Data Concentrator** (internal development pilot at i-DE).
  - **DPP solution** (2032). RFI analysis and evaluation of state-of-the-art edge computing solutions to adapt to the DSO environment.
  - **MiDE4S** (2021). Demonstrative piloting of Minsait solution in i-DE's environment.
- UFD and Naturgy Group:

22. Edge Computing

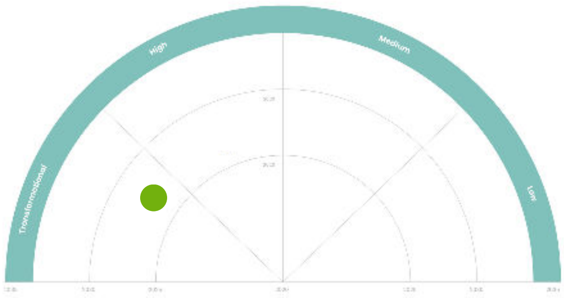


- **E4S** (role: DSO) with a pending demonstration pilot during the second half of 2024.
- A field pilot for **on-load tap changers (OLTC) and smart fuse integration** is under definition.

- Stedin:
  - Piloting AI on the edge with **high frequency or real-time data collection** (from sensors, microphones and thermal cameras) **in substations** primarily for asset management and prediction.
  - Piloting **modular architectures on edge computers** to test security risks and flexibility benefits.

Last update: 17 May 2024

23. Internet of Things



The **Internet of Things (IoT)** is an infrastructure of interconnected objects (mainly sensors and equipment), that contains embedded technologies to sense, communicate, process information, react and interact with each other or the external environment to create value from this interaction. IoT solutions encompass sensors, Information Technology (IT) and Operational Technology (OT) systems, communications, data storage and analysis, including artificial intelligence (AI). Increasingly, various industries are using IoT to operate more efficiently, deliver enhanced customer service, improve decision-making and increase the value of the business. With IoT, data is transferable over a network without requiring human-to-human or human-to-computer interactions.

Highlights

According to Gartner's Utilities 2024 CIO Agenda Insights and Data, 56% of utility respondents indicate increasing investment in IoT, with enterprises varying widely on their IoT maturity. Larger utilities have ongoing IoT-enabled initiatives for use cases, ranging from incremental benefits (for example, asset optimization or regulatory reporting) to transformative benefits (for example, dynamic operations of renewable assets). Factors such as falling costs of technology, a large number of vendors, and relative ease of deployment for new use cases and experimentation are accelerating IoT adoption. Due to a larger addressable market and R&D funding, the price/performance of IoT solutions is improving faster than utility vertical solutions, such as advanced metering infrastructure (AMI) or (supervisory control and data acquisition) SCADA. IoT applications could sharply increase in the future with the development of edge computing and 5G.

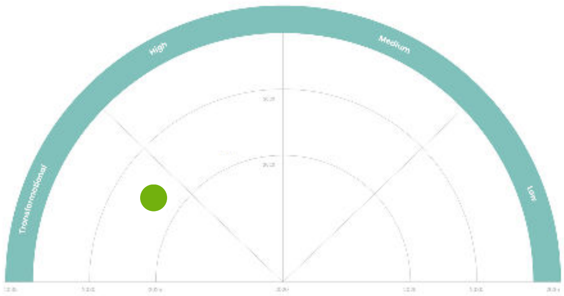
Opportunities and challenges for DSOs

- IoT could bring benefits with voltage quality analyses in different nodes and voltage loss per phase and Last Gasp.
- IoT facilitates real-time monitoring (power quality, asset characteristics, etc.).
- IoT enables powerful asset management solutions (power transformers, overhead lines, partial discharges, etc.).
- IoT could be used in the future for the implementation of decentralised flexibilities (including V1G/V2G).
- IoT facilitates the integration of power and utility OT, IT, consumer technology (CT), and engineering/energy technology (ET).
- The lifetime of IoT devices is assumed to be shorter than the lifetime of usual equipment.

E.DSO considerations

- IoT is an already available and widely used technology. Its applications could sharply increase in the future with the development of smart secondary substations and smart Low Voltage (LV) networks.
- IoT will bring the most benefits at low and medium voltage levels. The greatest benefits from IoT will come from:
  - Substation monitoring, followed by monitoring of transformers and power quality measurements.
  - Congestion management and implementation of flexibilities.

23. Internet of Things



- The successful implementation of IoT needs to bridge the cultural differences between IT and OT operations.
- As IoT devices make new and different cyberattacks possible, cybersecurity is a major issue.

Potential use cases

- **Grid monitoring**: IoT sensors monitor the health of the grid infrastructure (e.g. power quality, monitoring transformers), detecting faults and predicting maintenance needs to prevent outages.
- **Predictive maintenance**: IoT devices can predict equipment failures before they happen by analyzing data from sensors. This reduces downtime and maintenance costs.
- **Renewable energy integration**: IoT helps in managing the variability of renewable energy sources like solar and wind by optimizing their integration into the grid.
- **Electric vehicle (EV) charging**: IoT can manage EV charging by monitoring charge levels, optimising charging times, and integrating with the grid to balance demand and supply.
- **Energy theft prevention**: IoT-enabled smart grids can detect and prevent energy theft, saving significant costs
- In combination with IoT, **smart meters** provide real-time data on energy consumption, allowing for better demand management and dynamic pricing. The separate *smart meters and dedicated metering devices* factsheet, to be available in the upcoming Radar editions, will provide further detail on this.

Ongoing projects

- Enedis developed **SmartConnect**, an IoT platform for the management of more than 100'000 connected objects. The main IoT solutions that are industrialised by Enedis include the monitoring of primary station transformers, surge arresters, fault localisation indicators, flood detectors and mobile generators.
- The **GridWise project** integrates information and operational technology to effectively monitor E-REDES's transformer substations. By employing advanced technologies such as AI, IoT, big data analytics, and edge computing, GridWise performs continuous monitoring of LV circuits to guarantee power quality parameters, detect faults, and identify non-technical losses such as theft or fraud.
- E-REDES has also launched the **Distribution Network Webcams project** aimed at developing a dashboard for detecting, classifying and managing substation alarms.
- Stedin is running several innovation projects that leverage IoT (sensors) for grid monitoring and predictive maintenance. Use cases include climate monitoring, underground temperature monitoring and monitoring transformers.
- Netz Niederösterreich's **PQsmart project** leverages 10-minute voltage profiles from smart meters to detect voltage limit violations, perform predictive maintenance, identify defective components, and optimize LV switch states.

UFD is implementing the **Fire Detection** solution, a system leveraging AI and IoT to safeguard large forested areas from wildfires. The system utilises electrical towers and power lines as monitoring platforms. The initial deployment phase covers approximately 430 km² in Ourense, Galicia.

Quantum computing (QC) uses the quantum properties of matter (superposition states, interference and entanglement) to perform calculations with qubits. To this end, four technologies are competing: superconduction qubits, silicon qubits, trapped ion qubits and photonic qubits. Although a universal quantum computer, able to solve any problem through quantum algorithms, is not yet available, progress is being made and the industry is working with researchers to create quantum computers adapted to solve useful problems and thus benefit from a real quantum advantage. While QC technologies are not yet mature and their development may entail uncertainties, it is anticipated that within the next 10 years, QC will revolutionise a number of fields: simulation, optimisation, machine learning and cryptography.

Highlights

As of 2023, GAFAM and numerous start-ups are offering Quantum Computing-as-a-Service to demystify quantum computing. The quantum advantage should be indisputable within 5 years and this explains the interest shown by governments and the funds raised in start-ups. By way of example, start-ups Pasqal (France) and IQM (Finland) raised respectively €100 million and €128 million in 2022. QC can bring opportunities to DSOs for real-time operations and control of the grid. Yet, the risks it poses in the cybersecurity domain necessitate DSOs to take an interest in these technologies.

Opportunities for DSOs

- **Enhancing scalability and efficiency for detailed power system simulations**, e.g., optimal power flow.
- **Facilitating real-time system operations, protection and control** (power flow, voltage control, coordination for advanced relays and protection devices, etc.).
- **Facilitating local energy optimisation** by aggregation of large-scale distributed energy resources (DERs), and detailed modelling of battery energy storage systems.
- **Enhancing machine-learning-based models and forecasting**.
- **Enhancing data security by quantum encryption and potential integration with blockchain**.

Challenges for DSOs

- **Integration with existing ICT systems,** i.e., integration of QC with classical computing-based existing systems. Hybrid quantum-classical systems are being developed in the transition phase.
- **Cybersecurity**: Existing cryptographic protocols are based on classical encryption. Development of quantum-proof (or post-quantum) cryptography (PQC) could be needed.
- **Interpretability and complexity**: The complexity of algorithms and their probabilistic nature make it challenging to interpret results and track/ solve encountered problems. Explainable artificial intelligence for QC can address some of these challenges.

24. Quantum Computing

EDSO considerations

Data security is an integral part of the DSO business. DSOs need to keep a close eye on the development of quantum algorithms, which could render conventional methods of encrypting and protecting data obsolete. Therefore, DSOs may need to invest resources in developing PQC.

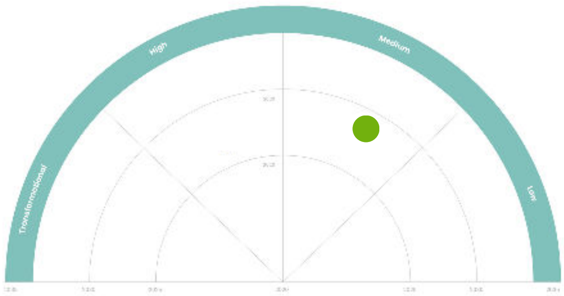
Potential use cases

- **Cryptography**: cybersecurity of assets and encrypted communications for the essential service operator and quantum-based encryption to secure large quantities of data.
- **Simulations**, e.g., stochastic studies of large and interconnected systems and their detailed modelling involving network constraints and potential reconfigurations of network constraint situations.
- **Local energy optimisation**: local power flow and voltage management with large-scale aggregation of distributed energy resources and detailed modelling of battery storage systems.
- **Machine learning**: improving the assessment of equipment condition based on image processing, predictive maintenance, Fault Location, Isolation, and Service Restoration (FLISR) algorithms, load forecasting - especially enhanced weather forecasting - and hence, wind, and solar generation, improving chatbots for the relations with customers, etc.
- **Real-time optimisation capability for network operation, protection and control,** e.g., minimal technical losses, system costs or maximal usage of sustainable resources, voltage/ load control, coordination for advanced protection devices and controls Advanced FLISR Algorithms, etc.).

Ongoing projects

Several DSOs are carrying out technological monitoring activities, but none have mentioned any ongoing projects in the field of QC.

Last update: 14 February 2025



5G is the next-generation wireless network technology. This will be faster and able to handle more connected devices than the existing 4G LTE network. Key benefits of 5G are **ultra-low latency** (~1ms vs. 100ms for 4G), **speed** (Higher than 1Gbps vs. 100Mbps for 4G) and **connectivity** (~1'000'000 devices / km2 vs. 100'000 for 4G). These developments are accompanied by disruptive technological choices opening up new possibilities:

- **New frequencies and smart antennas**: capable of managing energy in point-to-point mode between users and radio relay (beamforming).
- **Virtualisation technologies**: distributed architecture allowing direct local processing of data for faster local actions (distributed intelligence).
- **Network slicing**: management of different classes and types of services according to user needs.

Highlights

Since 2022, all European countries have a commercial 5G service available at least in part of the country. Close to 256'074 5G base stations are now active in the EU and approximately 72% of the EU's population is covered by at least one 5G network.

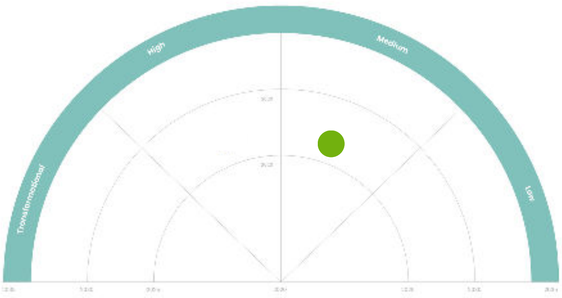
Challenges and opportunities for DSOs

- **Distributed Energy Resources (DER)/Flexibility**: 5G could facilitate DER management connection by offering solutions to activate flexibilities on LV and MV networks.
- **Metering**: 5G could enable remote, smart or real-time metering where Broadband over Power Line is off-limits.
- **Network management**: 5G-connected sensors to the distribution network could enhance advanced automation and control functions like Fault Location Isolation and Service Restoration. 5G could provide new solutions to set up differential protections for MV and LV lines.
- **Asset management**: Sensors connected in 5G to network assets could help monitor health indexes for safety, preventive maintenance and prevent thefts. Combined with drones, 5G could facilitate component diagnosis.
- **Operation**: 5G could facilitate remote crew supervision support and supervision on the field.

E.DSO considerations

- European DSOs usually rely on telecom operators and do not operate wide private telecom networks.
- 2G and 3G shutdown could lead to faster implementation by DSOs of 5G-based solutions.
- The decision of DSOs to use 5G to control critical assets will depend on guaranteed levels of reliability and resilience.
- The energy impact of the 5G rollout has to be documented as DSOs try to reduce their carbon footprint.
- Specific attention to cybersecurity issues will be necessary since many patents on 5G are held by non-European players. Furthermore, 5G cybersecurity needs some significant improvements: secured routing points, real-time cybersecurity adapted to 5G speed, and unsecured connected assets.

Last update: 28 September 2023



Blockchain is a transparent, secure information storage and transmission technology. It is a secure, distributed database containing the history of all exchanges made between its users since its creation: it is shared by its various users, without intermediaries, enabling everyone to check the validity of the chain. There are public blockchains, open to all, and private blockchains, whose access and use are limited to a certain number of players. In addition to cryptocurrencies, blockchain has numerous applications in the supply chain, healthcare, digital identity, asset transfer (real estate titles, shares, bonds, etc.), the Internet of Things, etc. Democratisation and decentralisation of the utility marketplace could be key drivers for the adoption of blockchain.

Highlights

In 2021, the total spending on various blockchain solutions worldwide reached $6.6 billion. According to Statista, the global spending will reach nearly $19 billion by 2024. However, the commercial added value of the technology could be much higher, reaching $176 billion by 2025 and exceeding $3.1 trillion by 2030, according to Gartner estimates. In 2017, a McKinsey study determined that blockchain could increase industry productivity by up to 9% and boost cost savings by 7%, all by simply improving progress tracking and the accuracy of cost and schedule estimates.

Challenges and opportunities for DSOs

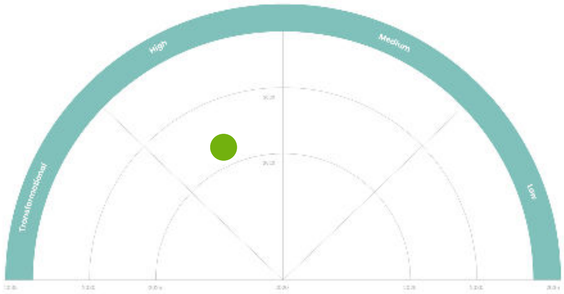
As a certification tool, blockchain technology could contribute to the creation of new services:

- **Certification of green and local consumption**, obtaining consent from customers to give new service providers access to their energy data, confidential calculation to produce inter-sectoral balances on multi-DRM, DSO/TSO perimeters, development of services in energy DataSpaces, etc.
- **Monitoring transactions**, including peer-to-peer (P2P) exchanges, on transactive energy markets.
- Automated certification of fieldwork carried out by different contracting companies.

E.DSO considerations

- DSOs must follow technological and regulatory developments related to blockchain in order to make the most of these advances to improve their operational performance.
- Blockchain technology consumes a lot of energy. In the context of global warming, this point needs to be improved to make this technology compatible with the ecological transition.
- Blockchain cybersecurity raises new problems that have to be addressed.
- DSOs, which are responsible for metering data, could take advantage of blockchain to carry out this task more effectively.

Last update: 28 September 2023



Digital twins (DTs) are virtual representations used for understanding, monitoring, diagnosing, simulating and forecasting installations, processes and, ultimately, an entire system such as the European electricity or energy system. DTs are emerging as future tools for improving performance, for example, through outage anticipation and increasing resilience through remote automatic control and near real-time decision-making support. Their aim is both to enable operations to be represented as closely as possible to reality and to improve the lifecycle of structures, by making use of digitally mapped descriptive data. DTs include four core technologies: the **Internet of Things (IoT)**, **simulations** (using 3D modelling where appropriate), **artificial intelligence (AI)**, and **cloud**.

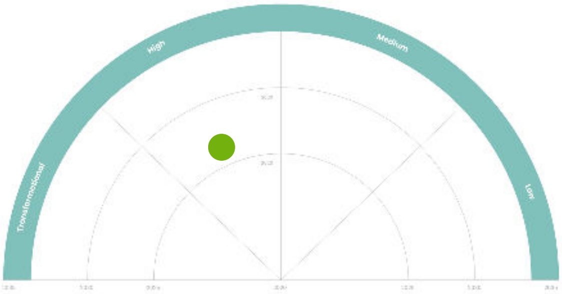
Highlights

According to Fortune Business Insights, the world digital twin market size was valued at $8.60 billion in 2022 and is projected to grow from $11.51 billion in 2023 to $137.67 billion by 2030. In December 2022, the DSO Entity and ENTSO-E have signed a Declaration of Intent (DoI) to support the development of a Digital Twin of the European Electricity Grid in the presence of the European Commissioner Kadri Simson. The DoI defines the cooperation framework to achieve this result, in alignment with the five areas defined in the Digitalising the energy system - EU action plan: (1) observability and controllability; (2) efficient infrastructure and network planning; (3) operations and simulations for a more resilient grid; (4) active system management and forecasting to support flexibility and demand response; and (5) data exchange between TSOs and DSOs.

Challenges and opportunities for DSOs

- The **acquisition of more comprehensive, reliable, and enhanced asset data** presents both a challenge and an opportunity for DSOs. The challenge lies in the collection and management of such vast amounts of data, while the opportunity lies in the potential insights and improvements this data can bring to operations.
- Using DTs at different geographical scales could help to determine with greater precision the **real capacity for integrating renewable energy sources** into the grid, and the rate at which they can be incorporated.
- The DTs should **enable DSOs to work better with their partners**: the ability to integrate into third-party ecosystems, extended businesses for DSO activities, market platforms, smart city platforms, etc.
- The **development of DSO use cases** (including augmented reality and virtual reality) in various businesses: engineering, operations (predictive maintenance, training, safety), driving, and external relations (service providers, cities, customers/suppliers), offers a multitude of opportunities for innovation and improved service delivery. However, it also presents challenges in terms of technological development and implementation.
- Relying on **high-performance, scalable infrastructures** to exploit an ever-increasing amount and variety of internal and external data (Lidar point clouds, 3D, new sensors, etc.) is a significant challenge due to the technical requirements and potential costs involved. However, it also presents an opportunity for DSOs to leverage this data for improved decision-making and operational efficiency.

27. Digital Twins

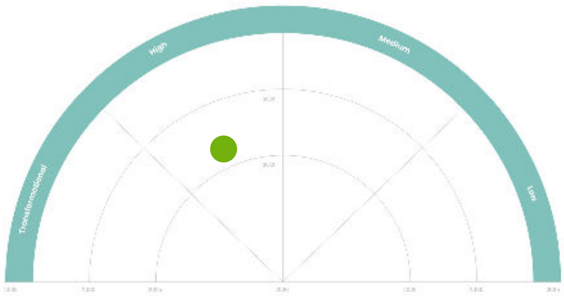


E.DSO considerations

- DSOs must follow technological and regulatory developments throughout the different sectors related to DTs to make the most out of these advances and improve their operational performance.
- DSOs must define the functional requirements of DTs for their needs (physical asset, digital model of the asset, data flow linking the two, continuous mirroring of the asset in the digital model, feedback loop, continuous operation, etc.).
- Before embarking on the previously described process, DSOs will have to ensure that the development of the DT of the European electricity grid promoted by the European Commission is consistent with the industrial realities of network management. The organisation of data sharing between DSOs, TSOs and market players, as well as the preservation of privacy, will be a crucial aspects of this project.
- It is necessary for DSOs to reach a consensus on the definition and position of the DT concept, and to facilitate an exchange of best practices. On this note, a stronger push and funding opportunities for DT projects should be foreseen, to not only allow an in-depth exploitation of the different potential use cases of the DT, but also to allow higher scalability and replicability of the DT solutions.
- DT solutions should be interoperable and should use open-source components when they are valuable.

Potential use cases

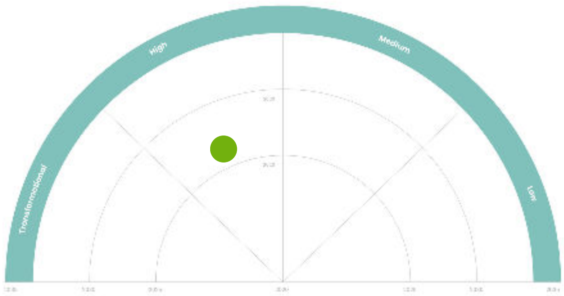
- **Grid Optimisation.** DTs can simulate the entire value chain of power grids, encompassing electricity generation, transmission, distribution, and consumption, with the aim of enhancing grid performance.
- **Active System Management.** DTs can be utilised to forecast, simulate, and optimise power flows. With the aid of simulation tools and improved data exchange among energy stakeholders, the assessment of flexibility needs can be enhanced.
- **Asset management.** DTs offer virtual representations of electricity asset models, which can be employed to monitor the health status of the asset and predict when maintenance is required.
- **Cyber-physical grid resilience and security.** DTs provide essential tools to simulate and analyse potential vulnerabilities and cyber-attacks in a controlled environment, thereby bolstering grid resilience.
- **Network planning.** DTs could serve as a planning tool for DSOs as they provide modelling and simulation tools to calculate and visualise the grid hosting capacity. They can test different scenarios to determine the impact of adding additional loads on the grid, thereby helping to draw conclusions on the best alternative for the future grid, which could include network upgrades, the use of flexibility, and non-firm connections, amongst others.
- **TSO-DSO coordination.** DTs can facilitate data exchange between SOs in order to enhance grid management, allowing optimal power flow calculation which improves the system security.
- **Training and Education**. DTs can be used to create realistic training scenarios for operators, helping them understand how the system reacts under different conditions.
- **Disaster Response**. In the event of a natural disaster or major system failure, DTs can be used to simulate and plan the most effective response strategies.



- **Energy Efficiency.** By simulating energy usage patterns, DTs can help identify areas where energy efficiency can be improved, leading to cost savings and reduced environmental impact.

Ongoing projects

- The TwinEU project aims to enable the utilisation of new technologies to foster an advanced concept of DT, while determining the conditions for interoperability, data and model exchanges through standard interfaces and open application programming interface (APIs) to external actors.
- **E.ON**'s Intelligent Grid Platform is a smart grid technology platform that unites grid data and allows for the digitalisation and automation of the processes related to grid impact studies, short- and long-term grid planning, and grid monitoring. The platform provides digital and automated handling of all processes related to the integration of new distributed generators, battery storage and consumers into the power grid. Moreover, the platform allows providing full transparency on the possibility to integrate additional distributed energy resources (DERs) into the grid and effectively manage connections requests.
- **E-REDES** is carrying out several initiatives in the field of DTs:
  - **DPlan** (network power flow program), consists of optimisation models for network structure and reactive compensation. It allows anticipating contingencies in the high voltage (HV) and medium voltage (MV) network and solving them before they occur. Furthermore, it has the capacity to assess the failure risk of HV and MV assets in accordance with the Common Network Asset Indices Methodology.
  - **Analytics4Assets** is an AI initiative based on advanced analytics models to forecast the behaviour of technical assets over time. It covers 3 types of assets: HV/MV power transformers; HV circuit breakers and HV lines. Analytics4Assets allows anticipating failures and optimising investment and maintenance plans, contributing to better asset management, quality of service and maximization of asset lifetime.
  - **LiveGrid** is an interactive system that guarantees the real-time monitoring of occurrences, thus allowing a clear and detailed visibility of the real-time situation of the distribution grid. The system includes dashboards for the visualisation of important indicators and metrics for the operational management of the system and maps to visualise the networks affected by outages. LiveGrid enables the visualisation of layers from official/external sources, thus contributing to a proactive analysis of scheduled work and potential constraints on the network.
  - **GridView** is a solution providing schematics and recorded data of the electrical network, its geographical context on the ground, as well as online real-time information on the operational status of the network.
  - **VEGA** predicts vegetation distance anomalies through correlation of multiple sources and predictive and prescriptive analytics models. It is used to plan and prioritise all tasks and generate vegetation cutting orders automatically. The solutions includes customised dashboards with financial, vegetation risk, and operational information, supporting prompt decision making.

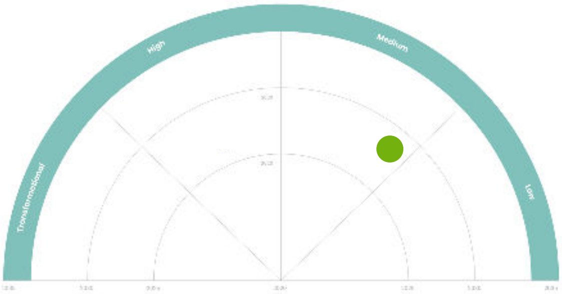


Ongoing projects (continue)

- **PREDIS** is an AI initiative based on advanced analytics models to carry out short-term forecasts and estimate load and generation at all the various points of the HV and MV network. It includes models to estimate the active and reactive power of load, load with photovoltaic (PV) generation, wind generation, hydro generation, thermal generation and cogeneration. PREDIS allows estimating the behavior of over a hundred thousand customers for in the near future (several days).

- **ORES** has developed the following DT applications:
  - The **PSI Grid Connect DT (Solormax project)** provides a dynamic (near to real-time) digital representation of a low voltage (LV) circuit by using sensors placed on smart meters. It is tested in a pilot project to manage over-voltages caused by PV panels.
  - ORES **ADMS (Advanced Distribution Management System)** combines several applications, such as monitoring, control or outage management. This system will be operational for ORES from 2025.
  - **Neplan** is a software tool used to analyse, plan, optimise and simulate electrical networks. The tool is already used in the ORES business-as-usual.
- Lastly, **Enedis** has developed the following applications:
- **Asset Management Digital Twin.** Enedis' GIS network database allows for probabilistic simulations used for network development planning and maintenance optimisation. The database includes AI technologies (e.g., photo library used for automatized overhead line components diagnostics.
- **Digital Twin for operational planning and Network Control.** Enedis's DT for operational planning and network control includes functionalities for supervisory control and data acquisition (SCADA), fault location, isolation and service restoration (FLISR) and distributed energy resources management system (DERMS) (i.e, production and demand forecast, network congestions identification and management, flexibility management, etc.).

Last update: 4 October 2024



Building Information Modeling (BIM) is an approach to sharing information about a construction project throughout its life cycle, from design to demolition. The core of the approach is a structured, 3D digital model that brings together several types of information about the built asset. This digital model enables those who interact with the building to optimise their actions and maximise the overall value of the asset. This approach, which originated in the building sector, is now being extended to heavy infrastructure (bridges, ports, railways, roads) and to the energy sector (equipment, sites, networks). This is now known by many stakeholders as City Information Model (CIM) (not to be confused with the Common Information Model, CIM, a standard developed by the electric power industry and officially adopted by IEC). BIM is a reality in the world of design and construction/renovation and is gradually being extended to the operational maintenance professions, becoming digital twins, with the acquisition of operational data.

Highlights

The importance of energy analysis in building design has grown, but it is still mostly done by simple static calculations or estimates. By utilising BIM as a data source for energy analysis, the data input will be more efficient and the existing data more reusable to perform accurate dynamic simulations to verify the thermal performance of buildings throughout their life cycle.

Challenges and opportunities for DSOs

BIM offers great potential for **improving construction** management (e.g. construction and procurement planning) **and operation/maintenance management**. Adopting the BIM approach presents opportunities for DSOs in terms of:

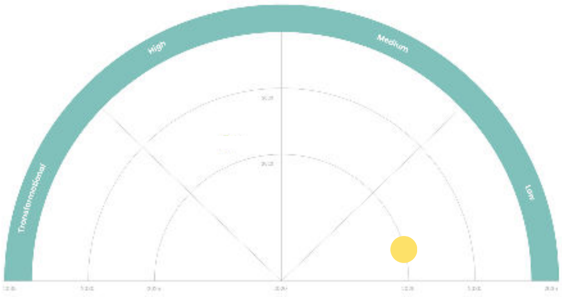
- Ability to exchange with partners in the development/engineering phases of DSOs' projects or projects that have an impact on DSOs.
- Better detection and sharing of constraints in the upstream design phases.
- Acquisition of more reliable (digital continuum) and enhanced (3D) asset data.

However, the development of BIM impacts the role of the different stakeholders and may limit DSOs' autonomy in terms of network design, first in buildings and then in neighbourhoods.

E.DSO considerations

- DSOs must follow technological and regulatory developments related to BIM in order to make the most of these advances to improve their operational performance.
- DSOs must ensure that the development of BIM does not imply a detrimental loss of autonomy.
- DSOs have invested heavily in their current knowledge, processes and culture (engineering, construction, operation), which could complicate adapting to the new working methods required by BIM.

Last update: 28 September 2023



Virtual Reality (VR) refers to simulation technology, popularised by the gaming sector, which immerses a person in a digitally created artificial world, either realistic or imaginary. Other implementations such as **Augmented Reality (AR)** and Mixed Reality have also emerged. The current barriers, particularly in terms of reproducing the physical interaction (touch, force feedback, etc.) between the individual and the digital environment in which they are evolving, and the cost, are set to be overcome in the coming years.

Highlights

According to Statista, revenue in the Augmented and Virtual Reality market is projected to reach US$8.02bn in 2023 and US$13.61bn by 2027. Increasing use of VR in instructional training, such as for field workers, engineers, mechanics, pilots, defence personnel, and technicians in various industrial sectors, is propelling the market's growth.

Challenges and opportunities for DSOs

- Procedural training is the first application of virtual reality, making it possible to put people into situations without the associated risks.
- VR tools also enable the remote provision of assistance by experts to field technicians during the operation of their tasks
- Discovery in immersive mode also enables businesses to showcase their activities to a non-expert audience.
- In the longer term, the technical advances expected will greatly extend the capacity for remote robot control and virtual collaborative work.
- Cooperation with AR tech companies brings challenges in the usage of a device (e.g. Hololens 2) which is not prepared for a massive rollout for electrician field workers (helmet, difficult environment electromagnetic field, complicated structure of substations).

E.DSO considerations

- DSOs must follow technological developments relating to Virtual Reality in order to make the most of these advances to improve their operational performance.
- The intensive use of virtual reality can lead to visual fatigue, dizziness, and even isolation. Therefore, its use should be balanced.
- Using AR in substations or in the field shows workers additional data (technical attributes, status, safety warnings etc.) which is very difficult regarding data quality and (near) online integration.

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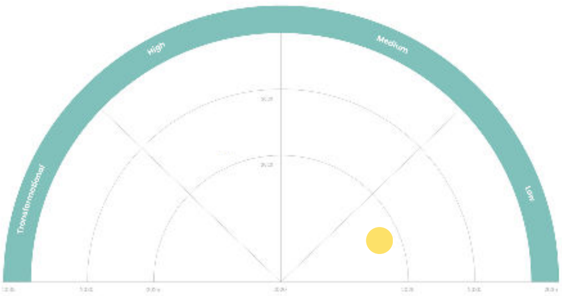


Disclaimer: In future versions of the Technology Radar, Task Force 6 will consider the creation of separate factsheets for different advanced communication technologies to reflect the differences in their application, impact and timelines.

Advanced communication refers to the use of emerging data communication technologies to enhance the efficient, reliable, and secure exchange of information between devices, systems, and users connected to the electricity grid. Beyond 5G and Internet of Things (IoT), which are separately tracked on this Technology Radar, advanced communication includes technologies such as:

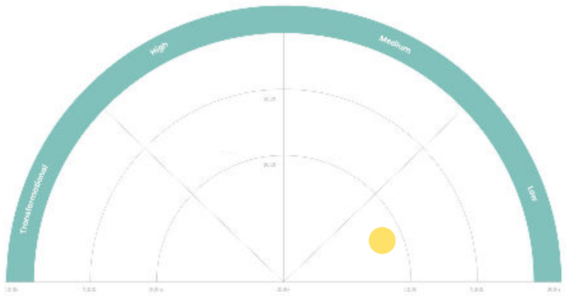
- **6G**, which will potentially provide ultra-low latency and massive connectivity for real-time grid management. 6G will succeed 5G and is expected to become available around 2030, offering 10 times faster connectivity, better reliability and lower latency compared to 5G.
- **(Low Earth orbit) satellite communication**, which ensures wide coverage and communication resilience, especially in remote areas or during disasters.
- **Low-power wide-area networks (LPWAN)**, such as LoRa, NB-IoT or LTE-M over 450Mhz, providing long-range IoT connectivity for applications that require low bandwidth and long battery life.
- **Power Line Communication (PLC)**, divided into narrowband and broadband PLC, which uses existing electrical power conductors as physical communication media. PLC does not require the deployment of new infrastructure, is highly reliable and enables DSOs to have full control over their communications.
- **Quantum communication/networking**, which leverages the principles of quantum mechanics to transmit information in an ultra-secure and efficient way.

Highlights

As more distributed energy resources (DERs) are integrated into the grid and as climate change causes more frequent severe weather events, maintaining a resilient and reliable energy infrastructure will require robust secure data communication systems designed to meet performance requirements. Today, DSOs depend upon a wide variety of communication technologies to support existing operations (including metering, substation monitoring/automation, protection systems, and generation dispatch) each with its unique communication system needs. Advancing grid operations and service paradigms, such as generation and demand coordination of large numbers of DERswith different ownership, will challenge and alter existing operational processes as more data will be exchanged. This will drive the deployment of new communication technologies with different performance and security characteristics (source: US Department of Energy, Office of Electricity).

Challenges and opportunities for DSOs

- Advancements in communication technologies can significantly enhance the efficiency, security, and reliability of electricity distribution systems, paving the way for smarter and more resilient grids.



Challenges and opportunities for DSOs (continue)

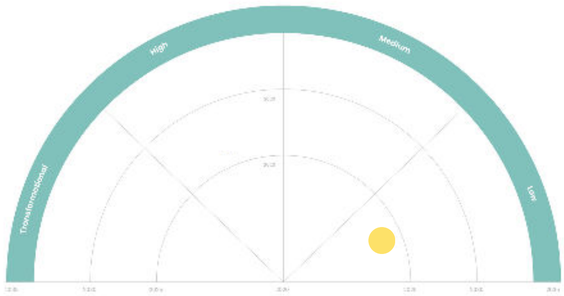
- Some solutions will be relatively straightforward and can be achieved by using standard products from a third-party communications provider. However, if more control by the DSO is desired, or the products being offered do not meet their requirements, the implementation of new solutions will become more complex.
- Several communication technologies, such as low-orbit earth satellite communications, are mainly provided by non-EU parties. This might result in an increasing dependence on foreign parties for the operation of critical infrastructure. The potential sovereignty risk is that DSOs lose control and autonomy over their data, operations and technology.

E.DSO considerations

- As many of these emerging communication technologies are not yet available, DSOs must follow technological and regulatory developments in the field.
- No single "silver bullet" exists for communications technology for grid operations. It is recommended to apply the appropriate communication technology to support grid requirements by (source: US Department of Energy, Office of Electricity):
  - Understanding the strengths and weaknesses of different communication technologies. This will be increasingly important as the grid evolves to support and rely upon distributed generation.
  - Identifying the grid services or processes (e.g. SCADA, protection, metering) that need communication support and determining associated communication requirements (such as latency, throughput, bandwidth, availability, and security)
  - Determining the current state of communication technologies at the DSO.

Potential use cases

- **Real-Time Monitoring**: Provide high-speed, secure, low-latency communication for real-time monitoring and control of grid operations. (e.g. 6G, quantum communication, broadband power line communication)
- **DER Management**: Support the integration and management of distributed energy resources, such as solar panels, battery storage systems and electric vehicles (e.g. with 6Gand broadband PLC).
- **Advanced Metering Infrastructure (AMI)**: Enhance the capabilities of AMI with faster collection and processing of data from smart meters and sensors. (e.g. with 6G, broadband PLC, LPWAN).
- **Cybersecurity**: Protect sensitive data from cyber-attacks (e.g., with quantum communication/networking).
- **Remote Monitoring and Control**: Satellite communication provides reliable connectivity for remote substations and power generation plants, enabling real-time monitoring and control. This is crucial for areas where terrestrial communication infrastructure is lacking.



Potential use cases (continue)

- **Disaster Recovery and Resilience**: In the event of natural disasters or other emergencies, satellite communication can serve as a backup to terrestrial networks, ensuring continuous operation and quick recovery of the grid.

Ongoing projects

- Enedis is testing the use of 5G to replace wired technologies and ensure low-latency connectivity with decentralized generation for anti-islanding systems.

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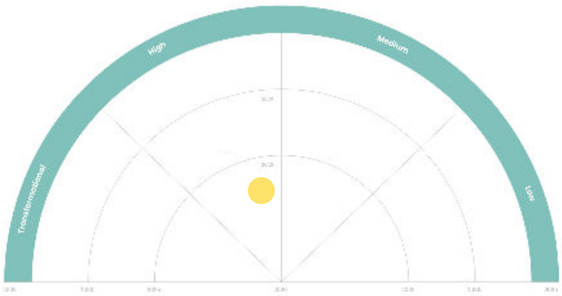
Other Technologies



Originally developed for military applications, **drones** have found their way into many fields due to the improved levels of safety and efficiency they bring. These robotic unmanned aerial vehicles (UAVs) operate without a pilot on board and with different levels of autonomy. Initially focused on image capture, their uses are set to expand thanks to the expected progress in drone systems (ability to fly longer distances), Artificial Intelligence (image processing, guidance, etc.), sensors (miniaturisation of lidar, etc.), telecommunication (5G, etc.), and technical action capabilities (manipulator arms, etc.). The development of the use of drones is highly dependent on regulations, which lay down strict rules that vary considerably depending on whether or not the operator is flying within sight of the UAV.

Highlights

The European Drone Strategy 2.0 sets out a vision for the further development of the European drone market. The new Strategy builds on the EU's safety framework for operating and setting the technical requirements of drones and lays down how Europe can pursue large-scale commercial drone operations while offering new opportunities in the sector. The Strategy envisions the following drone services becoming part of European life by 2030: emergency services, mapping, imaging, inspection and surveillance within the applicable legal frameworks by civil drones, as well as the urgent delivery of small consignments, such as biological samples or medicines.

Opportunities for DSOs

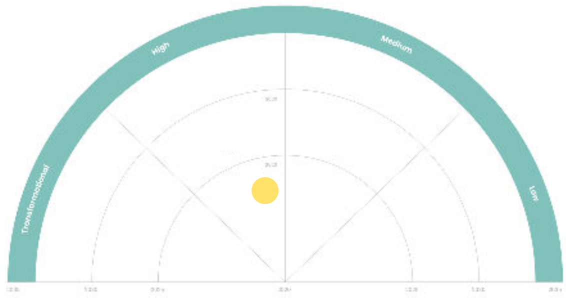
- Lightweight drones open up the prospect of improved pruning monitoring, post-storm and post-failure diagnostics, and automated infrastructure monitoring and diagnostics.
- Drones offer (important) benefits to utility field operations, and can acquire larger volumes of data more reliably and rapidly in inaccessible or hazardous locations than on-site humans.
- Drones can increase the quality and response time in infrastructure monitoring while minimising material and human resources and monitoring costs.

Challenges for DSOs

- The usage of drones for vegetation and infrastructure monitoring still poses regulatory challenges.
- Drones have limited power and useful flight time.

E.DSO considerations

- DSOs must follow technological and regulatory developments relating to drones, making the most of these advances to improve their operational performance.
- DSOs must understand the evolving requirements for data aggregation, analysis and integration with other IT systems and provide the necessary tools in line with security and governance guidelines.
- DSOs should work together to promote regulatory changes throughout the European Union that would facilitate the use of drones.
- DSOs should present recommendations regarding insourcing or outsourcing drone usage (e.g. Drones as a standard tool vs. drones as a service based on service-level agreements).



Potential use cases

- Aerial network inspection, both visual and thermal.
- Remote asset monitoring, including in areas with limited access.
- Vegetation management.
- Unmanned tree pruning using drones.
- Digital network mapping and Geographic Information System (GIS) applications.
- Supervision of maintenance and development works.
- Emergency response and damage assessment.
- Insulator cleaning by drones in inaccessible areas.

Ongoing projects

- **ALTITUDE project,** automatic aerial network inspection using drones and machine learning. In ALTITUDE, HEDNO serves as the pilot user. Other project partners are Renel (project promoter), Innora and SciDrones (more info).
- E-REDES **GridDrone project.** E-REDES decided to carry out a pilot project with an Estonian company, Hepta Airborne, where it inspected 1000 km of HV and MV network in the districts of Viseu and Coimbra (PT). The results of this project were evaluated internally, with the help of members of the Vegetation Management Department (DGV) of E-REDES and EDP Labelec, with the service currently provided always at quality standards (more info).
- E-REDES **E-Drone project,** carrying out inspections of network assets using commercial drones. For this project, it was necessary to complete the process of acquiring the drones, taking out civil liability insurance, training the pilots, obtaining the respective licences, registering E-REDES as a drone operator with the National Civil Aviation Authority (ANAC) and the National Aeronautical Authority (AAN) and, finally, appointing an operational manager. The use of this technology allowed for carrying out a detailed inspection of the network and visualising all the asset components. At the forefront of innovation, E-REDES uses and adapts innovative solutions for the inspection of its technical assets (more info).
- UFD, through its **GALA** (Advanced Overhead Lines Management) and **DALI** (Drone & AI Line Inspection) projects, carries out vegetation management and oversees inspections, preventive maintenance, and predictive maintenance based on risk management using drones Beyond Visual Line of Sight (BVLOS). This is achieved through the construction of the digital twin of its entire high and medium voltage network, as well as the utilisation of various recognition algorithms employing AI (more info).
- ČEZ Distribuce conducts **aerial LiDAR inspections of lines and substations and scans for pruning planning**. Currently, this is partially used as a business-as-usual solution, generating cost savings thanks to higher precision on what vegetation needs to be cut.

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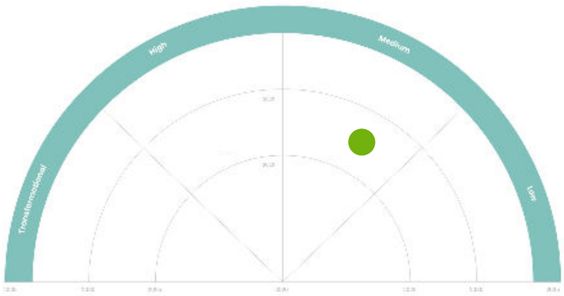

Robotics is used in multiple fields (industrial, agricultural, domestic, scientific, educational, medical, military, leisure, service, transport robotics, etc.). It is a science of technological integration at the crossroads of mechanics, electronics, computer science and networks, in particular communication. The desire to relocate production to Western countries and the ageing of the population are drivers of the revival of robotics, especially since the key technologies of robotics are experiencing spectacular advances: the rise of artificial intelligence, the sophistication of sensors, improved battery efficiency, IoT, 5G, etc.

Highlights

- The global Industrial Robots Market was valued at USD 45.1 Billion in 2021 and is all set to surpass USD 89.4 Billion by 2028. China has been the leading country in the industrial robot market for several years, with a revenue of more than 12 billion USD, accounting for 38% of the market share globally.
- Fanuc, ABB, KUKA, and Yashakawa are the four major suppliers in the market, accounting for around 56% of the global market share.
- On the proposal of the Chinese national committee, which will act as its secretariat, the IEC has created a new technical committee on robotic systems for the electrical industry, including distribution networks.

Challenges and opportunities for DSOs

- Industrial robots are able to operate in high-risk environments (live work), support heavy loads, perform arduous tasks and be available 24 hours a day, 7 days a week. Driven by an operator or autonomous and capable of adapting to their environment, they should **enable DSOs to improve health, safety and productivity**.
- Up to date, robots are generally used in controlled and restricted areas. **DSO operation fields are various and usually not completely controlled**. Under these circumstances adaptation and security are major challenges.

E.DSO considerations

- DSOs must **identify tasks that can be robotised** in their businesses in order to test available solutions, develop new ones and assess the associated gains and performance.
- The main usages for distribution networks are potentially related to maintenance and inspection.

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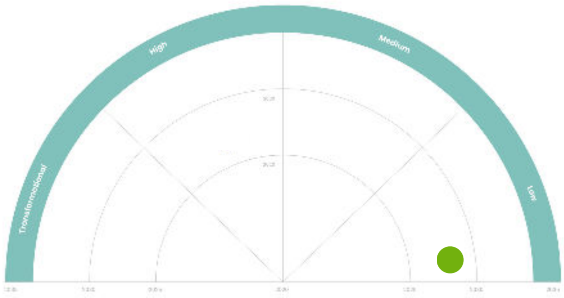
33. 3D Printers



3D printing enables the production of complex designs and shapes. Initial limits of 3D printing have been pushed back, both in the size of the objects to be produced and in the materials used (stainless steel, plastic, glass, metal, concrete, eco-materials, etc.). However, despite these advancements, the technology still faces significant challenges, including high costs, low printing speed, limited part sizes, and strength.

Highlights

The European 3D Printing Market was valued at USD 4.61 billion in 2020 and is expected to reach USD 10.12 billion by 2026. The highest demand in Europe comes from small and medium-sized businesses that are in need of high-speed, reliable and low-cost prototypes. This concerns numerous sectors, particularly automotive, healthcare, aerospace and defence.

Challenges and opportunities for DSOs

- 3D printing allows the production of small series of parts that are no longer manufactured in order to extend the life of devices, starting with rather simple devices and gradually moving to more complex ones (e.g., replacing first a hinge or a cabinet door, and later a part of an MV breaker).
- 3D printers would allow, among other things, the creation of several prototypes of equipment prior to their mass production.
- Advanced 3D printing of IoT devices and embedded sensors would entail the creation of parts and products with embedded electronics.

E.DSO considerations

- The solutions offered by 3D printers could contribute to the objectives of reducing the environmental footprint of DSOs by facilitating repair and reuse approaches.
- DSOs must follow technological developments related to 3D printers in order to make the most of these advances and improve their operational performance.
- The viability of industrial 3D printing technologies on specific use cases has yet to be validated.

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E.DSO - European Distribution System Operators
Rue de la Loi 82, 1040 Brussels, Belgium
+32 (0) 2 737 1340
info@edsoforsmartgrids.eu

www.edsoforsmartgrids.eu

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