eurelectric

Technologies supporting GRIDS FOR SPEED

Eurelectric report

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Eurelectric represents the interests of the electricity industry in Europe. Our work covers all major issues affecting our sector. Our members represent the electricity industry in over 30 European countries.

We cover the entire industry from electricity generation and markets to distribution networks and customer issues. We also have affiliates active on several other continents and business associates from a wide variety of sectors with a direct interest in the electricity industry.

We stand for

The vision of the European power sector is to enable and sustain:
- A vibrant competitive European economy, reliably powered by clean, carbon-neutral energy
- A smart, energy efficient and truly sustainable society for all citizens of Europe

We are committed to lead a cost-effective energy transition by:

investing in clean power generation and transition-enabling solutions, to reduce emissions and actively pursue efforts to become carbon-neutral well before mid-century, taking into account different starting points and commercial availability of key transition technologies;

transforming the energy system to make it more responsive, resilient and efficient. This includes increased use of renewable energy, digitalisation, demand side response and reinforcement of grids so they can function as platforms and enablers for customers, cities and communities;

accelerating the energy transition in other economic sectors by offering competitive electricity as a transformation tool for transport, heating and industry;

embedding sustainability in all parts of our value chain and take measures to support the transformation of existing assets towards a zero carbon society;

innovating to discover the cutting-edge business models and develop the breakthrough technologies that are indispensable to allow our industry to lead this transition.

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WG Sustainable Network Technology

with significant contribution from Hitachi Energy and valuable support from Paul Micallef and Steve Heinen from EY

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EXECUTIVE SUMMARY

The energy transition is driving an urgent need for significant grid investments to accommodate the shift toward renewable energy sources (RES) and electrification to increase Europe's energy sovereignty and reach decarbonisation goals. As part of this shift, the Grids for Speed[1] (2024) report **quantified the investment need of €67 billion annually on distribution system operator (DSO) level in EU27 and Norway until 2050. The study also identified that a balanced combination of three key strategies can help address the grid challenge whilst reducing its costs: anticipatory investments, grid-friendly flexibility and asset performance excellence.** Technologies supporting Grids for Speed (GFS-T) can also play a key role in driving the uptake of these strategies.

The modern distribution grid faces several challenges all of which are increasing the overall complexity of the grid. These include increased variability in energy supply, rising connection requests, ageing infrastructure, congestion, low grid observability in low voltage (LV) networks and the need for improved data exchange, increasing cyber-attacks and extreme weather events. GFS-Ts, alongside digitalisation, are crucial for addressing these challenges; especially in existing transport corridors. Digitalisation serves as both a prerequisite for deploying GFS-Ts and as a driver for the development of new solutions.

This report describes commercially available GFS-Ts that Eurelectric DSOs have found useful. It is not an exhaustive report and excludes purely software-based solutions and grid flexibility measures. Six key technologies are highlighted as good examples: **On Load Tap Changer transformers**, **Line Voltage Regulators**, **Dynamic Line Rating**, **Automatic Network Reconfiguration**, **High Temperature Low Sag Conductors** and **Flexible Alternating Current Transmission Systems**. These technologies are designed to increase grid capacity and performance, for example, by using real-time data and analytics to optimise load management or adjusting power flow capacity based on real-time conditions.

From a system value perspective, GFS-Ts offer technological, economic, societal and environmental benefits. These technologies enable better voltage regulation, more efficient use of existing assets and help avoid costly new infrastructure investments – in short: they create much-needed additional capacity (potentially at higher speed than more classical expansion). By optimising grid performance, they help in paving the way to a more resilient, efficient and sustainable energy system.

The usage of these technologies can drive investments just as a more classical expansion strategy. Therefore, first and foremost all areas of possible regulatory improvements that were identified within GFS remain relevant in the context of faster technology adoption. Secondly, to accelerate the deployment of GFS-Ts, five key enablers were identified. First, policy and regulation should adopt a forward-looking approach that incentivises investments in GFS-T or, at a minimum, address certain existing disincentives, particularly if increased GFS-T usage also raises operational expenses. Second, investment strategies are necessary to support the financial viability of these technologies. Inter alia concept like benefit sharing as proposed by

[1] Grids for Speed, Eurelectric, 2024, https://powersummit2024.eurelectric.org/grids-for-speed/

ACER as a new tool for TSO regulation need to be explored also in the distribution realm – especially with regards to high voltage grids and their expansion needs. Third, standardisation and interoperability shall be considered during the development of such technologies. Fourth, fostering collaboration and partnerships among stakeholders will drive innovation. Finally, ensuring a skilled workforce capable of implementing and managing these advanced technologies is essential. To illustrate the practical application of these technologies, the report includes two case studies in the Annex provided by DSOs. A broader range of DSO examples can be found on the Grids for Speed website under the Case Studies section.

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Background

European countries have dramatically accelerated the integration of variable renewables onto the power grid in recent years and face an even greater need for additional renewables deployment over the next 25 years. Simultaneously, thanks to decarbonisation drivers and technology innovation, stakeholders are investing heavily in the electrification of transport, heating and industry. Other new types of loads such as data centres are an additional challenge to the power system. Major distribution and transmission infrastructure development, as well as storage deployment, will be needed to accommodate the new generation and demand connections being requested.

Until recently the role of power grids was under-appreciated. However, it is now clear that Europe's grid infrastructure will need to be expanded, refurbished and modernised to meet its climate and energy targets. By 2050, electricity will need to make up around 60% of Europe's final energy consumption compared to a stagnating rate of 23% today. Electricity is becoming the backbone of the evolving energy system and power grids are a crucial part of this transition. For the EU27 alone, the European Commission estimates that €584 billion in investments are necessary for the electricity grids between 2022-2030. Of this amount, around €375-425 billions of investment in distribution grids, over 40% of which are over 40 years old, is necessary by 2030[2].

Eurelectric launched its **Grids for Speed** study in May 2024. The study quantified DSOs' investment needs until 2050 at a European level (EU27+Norway) following the REPowerEU scenario of Eurelectric's Decarbonisation Speedways[3] report (a scenario which complies with Fit For 55 and REPowerEU policy packages). The study concludes that €67 billion is needed annually between 2025-2050 for EU27 and Norwegian DSOs to replace ageing assets, modernise and strategically ramp up their network to meet the needs of their customers (network users) and comply with the decarbonisation and electrification trajectories set out in the policies above.

The report identifies three strategies which have the potential of decreasing the above investment number to €55 billion annually. These strategies are **anticipatory investments**, **asset performance excellence** and **grid friendly flexibility**, and the study identifies that the combination of these three strategies is the most efficient and forward-looking strategy.

As a continuation of these findings from *Grids for Speed*, this report aims to give a high-level overview of the GFS-Ts which can decrease the above investment needs, by making better use of existing infrastructure, thereby possibly allowing for more speedy capacity additions, and addressing some of the challenges being experienced by the grid operators.

The GFS-Ts described here have been collected based on Eurelectric's Members' technical expertise. The report only includes solutions at a high **Technology Readiness Level (TLR), above level 8,** which are either **commercially available** or are in **pilot** phase i.e., which are ready for deployment. Purely software-driven solutions have been analysed in Eurelectric's Wired for Tomorrow[4] report and are thus not revisited here. Combining GFS-T with more observability and other digitalisation benefits can create additional possibilities.

[2] EU Action Plan for Grids, European Commission, 2023 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A757%3AFIN&qid=1701167355682
[3] Decarbonisation Speedways, Eurelectric, 2023 https://www.eurelectric.org/publications/decarbonisation-speedways-full-report/
[4] Wired for Tomorrow, Eurelectric, 2024, https://powersummit2024.eurelectric.org/wired-for-tomorrow/

Chapter 1: Introduction

Grids are the backbone of the electricity system, delivering electric power from where it is generated to homes, industrial complexes, offices and hospitals. After over a century of this approach, we are experiencing a paradigm shift. Distributed and renewable energy sources (DRES) are connecting increasingly to the distribution grid – i.e., more rooftop solar panels are being installed. In parallel, electric vehicle (EV) chargers, heat pumps and storage solutions are being deployed enabling domestic, commercial and small-scale industrial consumers to become prosumers. With these developments, the end user is no longer only a stakeholder at the end of a power line but a central participant in the power system.

This paradigm shift is having an impact on the planning, development, operation, control and protection of the power system. Previously, power systems were built around large, centralised power plants which fed power down through transmission and distribution wires to passive consumers. Today, homes, industries and businesses can feed power back up through those same wires. Therefore, an active distribution system facilitating bidirectional flows is crucial. About two thirds of future renewable generation and electricity storage will be connected to the distribution grid level in 2030[4], meaning that the role of DSOs will become increasingly crucial in enabling the transition.

This development pressurises the distribution grids, driving expansion, digitalisation and usage of flexibility to create an efficient distribution system of the future. More capacity is needed, and more complexity is introduced. Europe's distribution grids are facing several challenges:

- **Variability:** The growth of intermittent energy sources, such as solar and wind, is placing additional strain on existing grid infrastructure and reducing the grid's inertia, which is essential for stable operations. Additionally, the increasing demand from EV charging contributes to less predictable intraday and seasonal load patterns, further complicating grid planning and operations.
- **Growth**: Increasing connection requests from distributed energy resources (DERs) such as wind and solar is also putting pressure on existing grid infrastructure, driving more requests and the buildout of new distribution infrastructure which can take many years to plan, site, permit and gain community acceptance. If the grid operators do not increase capacity, grid congestion occurs, which is an increasingly common issue. A similar development is going on in areas that still need to electrify heat with regards to demand.
- **Ageing grids:** 30% of Europe's distribution grids are over 40 years old according to Eurelectric's GFS study, often requiring replacement, or modernisation, to handle increasing consumption and generation as well as more complexity.
- **Lack of grid observability:** There is not sufficient visibility/observability across LV distribution grids making grid operations challenging during faults or outages.
- **Data exchange**: Increasing interactions between network customers, the distribution grid and transmission system operators (TSOs) can be complex to manage, particularly where grid observability is inadequate.
- **External threats:** The distribution grid is now increasingly challenged by a combination of cyber-attacks, physical attacks on equipment and extreme climate-related events such as flooding or wildfires.

Context of implementing GFS-Ts

GFS-Ts are emerging as a set of solutions which, supported by a family of technologies that includes sensors, power flow control devices and analytical tools, can improve how existing grids optimise the delivery of electricity. Additional potential can be found in increasing the temperature resistance of conductors and cables – thereby increasing capacity in line with security regulations. While these technologies are not a fix-all solution to all grid challenges, they will help with the integration of variable renewables onto the grid. They will also help facilitate the electrification of loads with different behaviours through increasing flow management and more efficient utilisation of existing grid capacity. However, it is important to recognise that each market in Europe is unique, with their own distribution grids and challenges. System operators must consider their own circumstances carefully to understand where one or more GFS-Ts can adequately address the existing challenge while optimising investments.

The following six GFS-Ts will be focused on in this report:

1. On Load Tap Changer transformers	2. Line Voltage regulators	3. Dynamic Line Rating
4. Automatic Network Reconfiguration	5. High temperature low sag lines	6. Flexible Alternating Current Transmission Solutions

It is important to note that this report does not aim to provide an exhaustive list of technologies currently in use among European DSOs. Additionally, it does not aim to evaluate the efficiency of these technologies, as what works effectively in one network environment may not be suitable or efficient in another, depending on network conditions and topology, and outside effects like weather. In GFS, Eurelectric introduced the concept of DSO archetypes which is also useful to comprehend the mechanisms at work here: different archetypes of DSO will find different technologies more or less useful – for instance a DSO that is very much driven by an expansion of wind farms and uses overhead lines should probably find the introduction of dynamic line rating useful (as the wind naturally also cools the conductors). A DSO that is predominantly driven by a PV expansion will have less use for the same technology as less ambient cooling will be available when the feed-in peaks.

The necessary precursor is digitalisation

Digitalisation is a fundamental prerequisite for implementing GFS-Ts, enabling real-time monitoring, control, management and decision-making, which are critical for optimising grid performance. Key tools for digitalisation include having systems in place managing and controlling the grid, using Supervisory Control and Data Acquisition (SCADA) systems and Advanced Distribution Management Systems (ADMS). To be able to feed accurate data to these systems, the collection of data through smart meters, sensors and other dedicated remote control and metering devices is key. In addition, a robust and secure communication system is equally essential to ensure seamless data transmission between devices, substations and control centres. Moreover, Geographic Information Systems (GIS) are useful for mapping and visualising grid infrastructure, forming the data basis of all other digital network solutions. The implementation of digitalisation measures is further described in the **Wired for Tomorrow** study of Eurelectric.

As digitalisation advances, the possibility of utilising both information technologies (IT) and operational technologies (OT) is becoming more prominent, driving the adoption of GFS-Ts. This allows DSOs to make informed decisions, optimise operational expenses, and maximise grid utilisation. For example, modern transformers are now equipped with advanced hardware and software to monitor, report and analyse their performance. These components can be integrated into new transformers or retrofitted onto existing ones. Sensors collect data, which is then processed to provide actionable insights, helping DSOs improve their decision-making by enhancing their understanding of transformer and grid performance.

Asset management strategies for integrating GFS-Ts

When integrating GFS-Ts into the grid, asset management strategies can range between two extremes: standardisation with default installation versus retrofitting only where needed. Standardising GFS-Ts and making them a part of default installations represents a slow, progressive rollout. This approach is cost-efficient over the long term, as economies of scale drive down the price of technologies, and operational efficiencies are gained through widespread use. However, the pace of improvement is gradual, and the benefits of GFS-Ts may not be fully realised for some time.

On the other end of the spectrum, retrofitting GFS-Ts only where needed allows for a targeted, strategic approach that addresses the most pressing grid challenges first. This method incurs higher costs due to the customised nature of each installation and the lack of standardisation. However, it ensures that investments are made where they can have the most immediate and significant impact, providing a faster response to the grid's most critical needs.

In practice, a balanced asset management strategy will involve a combination of both approaches and therefore introduce GFS-T also in the standard toolbox of the grid planners. Standardisation can be pursued for technologies with clear, widespread benefits, while selective retrofitting can be applied to address unique challenges or opportunities within the grid. This hybrid strategy allows for the cost efficiencies of standardisation while still enabling rapid response to specific issues through targeted retrofits.

Chapter 2: Exploring the technologies supporting the GFS trajectory

The GFS-Ts were selected by Eurelectric's DSO members based on their being the most useful technologies falling under the criteria below:

1) **Commercially available technical solutions used by distribution system operators (DSOs) at a high readiness level, above TRL 8, which are either already in use (rolled out), or in pilot phase.** The analysed technologies serve as examples of how technologies address current network challenges. The exhaustive list of technologies is constantly evolving with technological advancement.
2) **The pure software solutions are deliberately excluded** as they have been analysed in Eurelectric's Wired for Tomorrow[5] report.
3) **Flexibility solutions such as grid-friendly flexibility markets and flexible connection agreements are not in the scope of this report** due to the focus on GFS-Ts. However, flexibility remains an important capacity-utilisation solution for DSOs.

While noting that this report includes only commercially available solutions, it is emphasised that innovation and new technologies will add to the full array of tools necessary to reach net zero by 2050. This means that the report only covers part of the solutions to optimising costs and increasing capacity. Other possible solutions with lower TRL and future potential include robotics, superconductors, SSTs and SSCBs.

While GFS-Ts offer promising solutions for improving energy infrastructure, their implementation will need analysis on a case-by-case basis. These technologies may not always be suitable or deliver the anticipated results in every scenario and for every DSO. To ensure their effectiveness and alignment with specific objectives, a thorough planning and feasibility study is essential to identify where a specific DSO will have most use for their application. This process should account for the unique technical, environmental, societal, and economic factors of each application, guaranteeing that the chosen technologies are well-matched to the context and capable of delivering sustainable, reliable outcomes.

2.1 On Load Tap Changer transformers

Maintaining a stable grid voltage is essential for protecting both grid and consumer equipment, minimising the risk of outages and system failures and reducing operational costs. While both grid disturbances, such as transformer failures or line faults, and load variations have always caused the grid voltage to fluctuate, there are now additional factors to consider. The variability in power generation from RES like wind and solar can also contribute to voltage fluctuations, as can more regular switching on and off new, and more dynamic, loads such as EV charging.

A common method for regulating power system voltage is via transformer regulation, using a tap changer. This can be done either manually or using On Load Tap Changers (OLTCs). Manual tap changers are useful in situations where voltage adjustments are infrequent. The transformer must be switched off before changing the tap position, meaning the power supply must be interrupted. An OLTC is a particular type of tap changer used in applications where a supply interruption during a tap change is unacceptable, and the load varies frequently. OLTCs are ideal for power systems where maintaining a stable voltage is crucial despite fluctuating generation from variable renewables combined with fluctuating load.

OLTCs are standard in ultra-high-/high-voltage (UHV/HV) and high-/medium-voltage (HV/MV) substations. They are becoming more commonly used in medium-/low-voltage (MV/LV) substations, particularly since manual tap changing of MV/LV transformers is becoming less effective as the deployment of clean technologies such as solar PV and EVs increases.

Good practices of application:
OLTCs allow for dynamic voltage control. During a period of high generation and low demand, in order to maximise solar feed-in, a DSO would tap down the relevant transformer (i.e., allow more voltage rise while staying in limit). On the other hand, during peak demand, a DSO would tap the transformer position up to maximise EV penetration (i.e., allow more voltage drop while staying in limit). This becomes highly inefficient, and practically infeasible, if carried out manually due to the increasing occurrences of such situations. If the tap positions can be dynamically changed via OLTCs, then on sunny days with low demand, the transformer will tap down to maximise solar feed-in, while on cloudy days with high demand, the transformer will tap up to maximise load offtake.

Challenges of application:
Careful planning is required to effectively utilise OLTCs in power systems, particularly given that OLTCs are more complex to install, operate and maintain than manual tap changers. Installation requires skilled resources; operation requires advanced monitoring and control systems; and maintenance requires new asset management strategies. In addition, proper coordination between OLTCs and other grid equipment such as smart inverters is important for optimal system performance. Another challenge to be considered is how to scale the installation of OLTCs across the distribution system given the number of impacted secondary substations across Europe.

2.2 Line Voltage Regulators

Local distribution grids are changing considerably as the complexity is increasing. Voltage fluctuations that exceed the permitted deviation from the distribution grid's nominal voltage are occurring more frequently, which are the same voltage issues as described in the previous section. As a result, the feed-in power from renewables must often be limited or interrupted, to comply with the allowed voltage range. Feeding full power to the grid without taking such measures could result in adverse grid conditions / voltage deviations and failure of customer installations as well as the disconnection of inverter-based generators.

While a new feeder or grid extension would solve some of these challenges, an in-line voltage regulator, also called line voltage regulator (LVR), is also a viable option depending on the specific needs of the grid. This technology is proven in practice and is widely used by DSOs. It works to solve the voltage fluctuation by producing a specified output voltage that remains stable through changes in load current and input voltage. These solutions are relatively low cost and, in addition, voltage regulation in the MV network often simultaneously solves voltage problems in the lower-level LV networks. A second use of this technology is for very long lines, such as electrification of distant areas or island interconnection to a mainland system. With this technology, utilisation of cables can be improved and can subsequently delay or even avoid the need for costly installation of additional cables.

Good practices of application:
The LVR provides additional voltage stability by increasing voltage headroom on an LV or MV line, within a certain range, helping to maintain optimal voltage levels under fluctuating loads and generation.

An LV LVR can be installed in standard LV cable distribution cabinets. In most cases utilities do not need to get special permission to carry out such installations and LV LVR installations can therefore be realised very quickly. The MV LVR is installed in a concrete substation, completely mounted, and only the MV cables need to be connected to the integrated MV switchgear. In both cases the LVR can easily be relocated and installed at another location if the grid situation changes, or further connection of generators requires a reinforcement of the grid.

Challenges of application:
If demand or local generation continue to grow significantly, more substantial grid upgrades or reconfigurations may be necessary. Once these larger improvements are made, the LVR may become redundant, and the DSO must decide whether to keep it in place, redeploy it to a more suitable location, or decommission it entirely.

A full lifecycle options analysis, based on a detailed voltage measurement, long-term load forecast and power flow assessment, is required to adequately compare the utilisation of an LVR against other alternatives such as line upgrade, battery installation, or line reconfiguration.

2.3 Dynamic Line Rating

The thermal capacity of an overhead distribution power line can vary in real-time, depending on environmental conditions, such as temperature, solar radiation and wind speed and direction. The external conditions affect conductor temperature and how far the line hangs down, i.e. its sag which is a major limitation as too low lines are potentially hazardous for their environment.
Normally, grid operators apply a conservative and "static" line rating determined based on calculations for a certain set of external conditions in the design process. The line rating is the maximum amount of power allowed on the line.

By deploying DLRs on select lines, these lines can more fully utilise their potential as compared to the limits of their static line rating (SLR). For instance, on a cool, cloudy and windy day, more power can flow through an overhead line than on a hot, sunny and calm day. Nowadays, DLR technologies are well proven, sensor-based and either integrated with or connected to SCADA and energy management systems (EMS). The technology can help preventing overloads and enhancing distribution usage, thus reducing the risk of power cuts.

With more wind and solar connecting to the distribution grids, congestion occurs more frequently and subsequently increases the risk of curtailment for renewable energy sources. DLR effectively addresses this issue by maximising renewable energy feed-in. Therefore, DLR is most useful in specific lines, and a comprehensive analysis is needed to identify the optimal locations.

Good practices of application:

- Congestion management, interconnectors optimisation and renewables integration are obvious use cases for DLRs, with typically short pay–back periods. Congestion means that the lines connecting the renewables to the grid have reached their limit due to high amounts of power flowing through them.
- DLR can be leveraged in conjunction with active network configuration across a power system. DLRs will identify headroom on lines or cables across the system while network configuration could then balance overloaded lines and under-used corridors.
- While DLR is typically great at providing additional headroom in an overhead line for wind power, given that wind-induced cooling of the line and high wind generation correlate, it will provide limited additional capacity for solar integration on a sunny calm day.

- DLR can support DSOs with forecasting activities. For this, it is important to identify and develop technologies (e.g. advanced SCADA) that will allow the use of data obtained in this way to forecast the operation of individual fragments and the network as a whole.

Challenges of application:
Ambient conditions could require a decrease in line rating below the SLR. While this would increase congestion costs and potential curtailment during these hours—thus increasing system costs as well, it should also yield reliability benefits as the system operator has increased visibility to operate the grid in a manner which avoids equipment failures or safety risks. These occurrences are mainly during times when wind speeds are lower and do not cool the lines as much, combined with higher ambient temperatures.

2.4 Automatic Network Reconfiguration

The manual reconfiguration of radial distribution networks is a standard solution implemented by DSOs for improving the performance of distribution networks. Reconfiguration occurs when a utility switches load or generation onto adjacent distribution lines to avoid constraints on the original line or substation. The change in the network configuration is performed by opening and closing switches across the network.

As the power system increases in complexity, the benefits of automatic network reconfiguration such as speed of deployment and data-based decision making becomes more relevant. Beyond being able to help a network recover efficiently after a fault, automatic network reconfiguration can also relieve overloading or congestion of distribution network components in real-time. It can also enable near-term progress on, for example, EV adoption or distributed generation integration. Adaptive network reconfiguration is a further evolution which uses real-time data and advanced algorithms to continuously optimise the network configuration.

For automatic or adaptive network reconfiguration to work, equipment such as automatic reclosers and smart switches must be installed across the network. Systems will need to be set up within the DSO control room, based on algorithms and digital communication technology, which are integrated into existing control and protection systems and can communicate with connected devices and switchgear out on the network.

For example, an automatic circuit recloser is a piece of switchgear used on overhead electricity distribution networks which can detect and interrupt fault currents. While their main function is protection, automatic reclosers allow for remote monitoring and control which is necessary for automatic network reconfiguration. Smart switches are advanced devices which help manage the load distribution across the network. They can be controlled remotely and use digital communication technology to detect and react to changes on the network, opening and closing as needed. For the application of automatic or adaptive network reconfiguration, hardware devices such as automatic reclosers or smart switches are essential.

Good practices of application:
Where manual onsite network reconfiguration is required in case a power failure, the availability of a local operation team can affect the time it takes for the grid to be restored to a normal state. Implementing automatic network reconfiguration approaches enables the efficient detection and isolation of faults, followed by fast adaptation of equipment to avoid or reduce power outages.

Challenges of application:
Automatic network reconfiguration is only possible in meshed topologies, whereas most LV networks are radial in nature. Creating "partly meshed" LV networks can raise some occupational health and safety concerns, as dynamically changing the affected network sections could pose additional risks. Therefore, it could require reskilling and new health and safety processes for working on site.

Automatic network reconfigurations could drive grid infrastructure investment. For example, reconfiguring LV network topology to facilitate automatic network reconfiguration would require grid infrastructure investment, e.g., the addition of new feeders and in some cases even substations. Automatic network reconfiguration also requires both visibility and controllability of the network which may also drive some initial investment, particularly at lower voltages.

2.5 High Temperature Low Sag Conductors (HTLS)

High Temperature Low Sag (HTLS) conductors are specifically engineered to handle higher operating temperatures with minimal sag compared to conventional conductors. Traditional aluminium conductors tend to sag significantly under high temperatures leading to reduced clearance, posing safety risks and limiting the amount of power that can be transmitted.

HTLS conductors are designed to operate efficiently at temperatures up to 210-250°C, compared to the typical 80°C and above for conventional conductors. This increased temperature tolerance is mainly achieved using advanced materials. Their higher operational temperature comes at the price of higher losses.

HTLS conductors are used for reconductoring, for the uprating of existing lines, as well as for new lines. They are often "tailor-made" for a project and each project must be investigated on a case-to-case basis.

Good practices of application:
Upgrading existing distribution lines by replacing traditional conductors with HTLS conductors, utilities can significantly boost the capacity of existing lines, enhancing grid reliability and meeting the rising power demand. The use of high-temperature conductors allows the use of existing tower structures and only the replacement of conductors and necessary fittings, thereby increasing not only capacity but also reducing the cost and time associated with the reinforcement process.

Addressing urban distribution challenges by acquiring permits and approvals for new distribution lines is often time-consuming, particularly in urban areas. HTLS conductors enable DSOs to upgrade existing lines and increase capacity within the same footprint if the old poles can carry the additional weight. This minimises disruption to urban environments.

Enhancing grid resilience by offering higher thermal capacity and reduced sag, HTLS conductors help prevent outages and maintain power delivery during peak demand periods or adverse conditions. Their durability and resistance to environmental stressors due to the advanced materials incorporated in the design process also enhance the overall reliability of the distribution network.

2.6 Flexible Alternating Current Transmission Systems

With the increasing penetration of distributed generation, voltage sag and flicker are now common power quality problems observed on the distribution network. These power quality problems impact businesses daily across the network.

FACTS refers to a group of solutions which use power electronics based controllable systems. These solutions can enhance the distribution system operators' ability to control real and reactive power flow across the grid. While FACTS were initially designed for transmission systems, they are now increasingly being scaled across distribution systems.

Examples of FACTS solutions for use on the distribution system include Static Var Compensators (SVCs) and Distribution STATCOMs (or Static Synchronous Compensators) which can stabilise voltage levels and improve power quality in the distribution grid by providing dynamic reactive power support.

Good practices of application:
A Distribution STATCOM can be used to support solar power integration on the distribution system. Most of today's grid-connected photovoltaic (PV) inverters only inject active power into the grid and do not contribute to the reactive power needs of the system, thus lowering the power factor. Solar power can also result in voltage instability, e.g. increasing the voltage during periods of high generation and low load. A Distribution STATCOM can improve the power factor and the voltage stability. Distribution STATCOMs are a low loss technology and have relatively small footprints for ease of installation either indoors or outdoors.

Disadvantages of application:
While Distribution STATCOMs are commercially available, they are not yet widely deployed across distribution systems. As grid complexity increases with the influx of distributed renewables, FACTS devices such as Distribution STATCOMs and SVCs, which offer power quality improvements, are becoming more commonplace and utilities are becoming more familiar with their operation.

Chapter 3: System value of GFS-Ts

Chapter 3 provides a qualitative system value overview for policymakers which incorporates the technical, economic, environmental and societal benefits of each of the chosen GFS-Ts. System Value is a holistic approach that evaluates economic, environmental, social, and technical outcomes of potential energy solutions. The approach aims to shift political and commercial focus beyond cost to include value.

While these GFS-Ts offer significant system value benefits, it should be noted, as mentioned above, that the application of one of these technologies (or multiple) should also be subject to specific cost benefit analyses depending on the power system they are being applied to.
The table below identifies possible technical, economic, environmental and societal benefits which could result from the application of a particular GTS-T. Through a qualitative analysis of each GFS-Ts, a summary overview of the system value of each is provided.

New technologies supporting Grids for Speed	Technical Benefits - More precise voltage regulation - Greater Renewables Integration / Congestion relief - Improved power quality - Improved grid flexibility or resilience - Greater utilisation of existing assets	Economic Benefits - Avoid or defer capital expenditure - Reduced footprint leading to cost savings - Reduce balancing / redispatch costs - Improve industry competitiveness	Environmental Benefits - Results in lower emissions (e.g. CO2, SF6, etc) - Reduced water needs - Increased life cycle of materials	Societal Benefits - Improves air quality - Optimises infrastructure build-out resulting in less societal impact - Can reduce wholesale electricity prices - Reduces risk of domestic outages or equipment damage
On-load Tap Changers	✓ More precise voltage regulation ✓ Improved power quality ✓ Greater utilisation of existing assets ✓ Maximise capacity for new connections	✓ Avoid or defer capital expenditure ✓ Improve industry competitiveness	✓ Results in lower emissions	✓ Improves air quality ✓ Optimises infrastructure build-out resulting in less societal impact ✓ Reduces risk of domestic outages or equipment damage
Line Voltage Regulators	✓ More precise voltage regulation ✓ Improved power quality ✓ Greater Renewables Integration / Congestion relief	✓ Avoid or defer capital expenditure	✓ Results in lower emissions	✓ Optimises infrastructure build-out resulting in less societal impact ✓ impact ✓ Reduces risk of domestic outages or equipment damage
Dynamic Line Rating	✓ Greater Renewables Integration / Congestion relief ✓ Maximise capacity for new connections ✓ Improved grid flexibility or resilience ✓ Greater utilisation of existing assets	✓ Avoid or defer capital expenditure ✓ Reduced footprint leading to cost savings ✓ Reduce balancing / redispatch costs	✓ Results in lower emissions ✓ Increases life cycle of materials	✓ Improves air quality ✓ Optimises infrastructure build-out resulting in less societal impact

New technologies supporting Grids for Speed	Technical Benefits - More precise voltage regulation - Greater Renewables Integration / Congestion relief - Improved power quality - Improved grid flexibility or resilience - Greater utilisation of existing assets	Economic Benefits - Avoid or defer capital expenditure - Reduced footprint leading to cost savings - Reduce balancing / redispatch costs - Improve industry competitiveness	Environmental Benefits - Results in lower emissions (e.g. CO_2, SF_6, etc) - Reduced water needs - Increased life cycle of materials	Societal Benefits - Improves air quality - Optimises infrastructure build-out resulting in less societal impact - Can reduce wholesale electricity prices - Reduces risk of domestic outages or equipment damage
Automatic Network Reconfiguration	✓ Greater Renewables Integration / Congestion relief ✓ Improved grid flexibility or resilience ✓ Greater utilisation of existing assets	✓ Reduce balancing/redispatch costs ✓ Improve industry competitiveness	✓ Results in lower emissions	✓ Improves air quality ✓ Optimises infrastructure build-out resulting in less societal impact ✓ Can reduce wholesale electricity prices ✓ Reduces risk of domestic outages or equipment damage
HTLS Conductors	✓ Greater Renewables Integration / Congestion relief ✓ Greater utilisation of existing assets	✓ Avoid or defer capital expenditure ✓ Reduced footprint leading to cost savings	✓ Results in lower emissions ✓ Increased life cycle of materials	✓ Improves air quality ✓ Optimises infrastructure build-out resulting in less societal impact ✓ Can reduce wholesale electricity prices
FACTS	✓ Improved power quality ✓ Improved grid flexibility or resilience ✓ Greater Renewables Integration / Congestion relief	✓ Improve industry competitiveness	✓ Results in lower emissions (e.g. CO_2, SF_6, etc)	✓ Improves air quality ✓ Optimises infrastructure build-out resulting in less societal impact

Chapter 4: Enablers

Deploying commercially available GFS-Ts today from DLRs to OLTCs to FACTS, will deliver comprehensive system value. However, deployment at speed and scale must be a priority to leverage this value. This chapter describes five key enablers which can accelerate the deployment of GFS-Ts:

1. Policy and regulation
2. Innovative investment strategies
3. Standardisation and interoperability
4. Collaboration and partnerships
5. Skills

Policy and regulation

In Europe, innovative policy and incentives in regulation will be essential to speed up the expansion of the electricity infrastructure making use both of classical expansion and the installation of innovative technologies, such as the above listed examples of GFS-Ts. It is important to understand that the usage of GFS-T causes investments just as a more classical expansion strategy. Therefore, first and foremost all areas of possible regulatory improvements that were identified within GFS remain relevant also in the context of faster technology adaption. Investments need to be recognised and turned into revenues quickly as time delay cause a burden on realised returns. A competitive regulatory return for all investments is needed to make grids attractive to investors. Finally, as many of the GFS-T also dependent on additional OPEX (for communications, IT etc.) it is advisable to consider a more frequent adjustment of OPEX at least in those dimensions that are being changed by the introduction of GFS-T to avoid disincentives. Additionally, appropriate forward-looking regulatory frameworks must be developed to incentivise GFS-Ts.

As discussed in the GFS study, an evolution of regulation is needed and possible in the next 3-5 years as many members start new regulatory periods anyway. Such a development is also mandated by the new Electricity Regulation (EU) 2024/1747[5]. NRAs should treat CAPEX and OPEX equally (e.g., with regards to eventual time-delays in their reimbursement), to avoid disadvantages from additional OPEX expenditures such as digitalisation measures. Eurelectric recommends adding regulatory incentives to support the uptake of technological solutions with a technologically neutral approach. In addition, financial or technical support in the form of a time-restricted regulatory sandboxes could be useful tools. Looking at the next MFF, the EU needs to be mindful of distribution expansion needs and their technological challenges going forward. Regulations, incentives and funding to support GFS-Ts are also needed. Finally, the continuous roll-out of these technologies will not prove useful if permit granting processes and supply chain issues are not managed in a timely manner.

As introduced by ACER, "benefit sharing" i.e., actively incentivising SOs to use cheaper and quicker solutions to meet their expansion needs, should be analysed also for DSO high voltage grids. The discussion for TSO and their regulation is far from finished but it is certainly important to create a level playing field for all HV grid operators in Europe.
Regulations should empower national dialogue and decision-making between Member States, NRAs, TSOs and DSOs and account for national differences.

Innovative investment strategies

Innovative investment strategies are required from DSOs to fully leverage the opportunities associated with the massive electrification being expected, as well as the influx of renewables on to the distribution network.

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[5] Article 18 of Regulation (EU) 2024/1747 of the European Parliament and of the Council of 13 June 2024 amending Regulations (EU) 2019/942 and (EU) 2019/943

There is a need to evolve beyond existing investment strategies. As laid out in Eurelectric's **Grids for Speed** study, incremental investment is no longer enough. The level of acceptable uncertainty must increase, otherwise the grid will not be built in time to facilitate the ongoing transformation of the power system. Allowing anticipatory investments, i.e. investments in grid development based on reasonable expectations of the future needs, in national regulation is essential.

We must shift from an approach based on 'current asset performance' to 'asset performance excellence' through thoughtful leveraging of digitalisation solutions, meaning to use existing assets in the most productive way. Grid friendly flexibility solutions are also efficient ways of tackling the transition challenge, but incentives are lacking for grid-friendly flexibility solutions. **Grids for Speed** recommends using an optimal combination (depending on country and DSO specifics) of the above three strategies of asset performance excellence, grid friendly flexibility and anticipatory investments. Within the implementation, GFS-Ts are inevitable as technical solutions besides classical grid technologies.

Standardisation could play an important role, while simultaneously recognising that it must be applied at the right level and in the appropriate circumstances.

Standardisation and interoperability

Resilient and diverse supply chains are needed to produce new technologies. Standardisation and interoperability shall be an important area for consideration when developing such technologies.

Collaboration and partnerships

The next generation of multi-stakeholder collaboration must be utilised to accelerate the deployment of GFS-Ts. DSOs and other relevant industry stakeholders, utilities and regulators could work together to streamline the deployment process. Such collaboration and new types of public-private partnerships (PPPs) could also stimulate resource sharing, knowledge sharing and even sharing of experiences with the risks and benefits associated with deploying new technologies.

Skills

Skilled resources will be a key enabler to speed up deployment of GFS-Ts. The skills needed to accelerate the energy transition are changing, along with demographics and employee expectations. Availability of appropriate skills will be a key success factor for the deployment of GFS-Ts at speed and scale. There are four specific areas which will help ensure that the resources and skills are available to continue to design, install and operate both commercially available and new types of GFS-Ts. These fields are how to enhance and make higher education up to date to the needs of the industry; how to ensure that vocational education and training are delivering on specific outcomes; how to foster cross industry transitions including reskilling and upskilling initiatives and how to create a market which is attractive to skilled people.

GFS-Ts offer many distribution system benefits, and the enablers listed above will help DSOs to leverage these benefits. Under the right circumstances, these technologies can optimise investment costs, providing faster and more efficient alternatives to large network capacity upgrades in the short term and can improve operational efficiency through automation and remote control, enabling faster response times, fewer supply interruptions, easier fault localisation and better overall supply quality.

Annex: Technological case studies

The annex contains two practical examples of technologies supporting the GFS trajectory of DSOs on the technologies detailed above. More use DSO cases can be found at the Grids for Speed website under the Case Studies section.

Closed Ring Operation

DSO: Alliander
Voltage level: MV

Challenge

- Closed ring operation optimises the grid topology on 10kV and 20kV voltage level, making more capacity available and solving or preventing quality bottlenecks. This allows more customers to be connected faster, without making in-depth investments.
- The closed ring operations tackles the issue of violating voltage levels in the operation of the grid.

Solution

- Closed ring operation is achieved through the combination of two different digitalisation techniques:
  - At the breakpoint, 3 feeders are connected by an intelligent ring main unit. The breakpoint is broken on t=0 in the event of a failure, causing switching back to radial. And the fault will be disconnected by the existing conventional overcurrent protection relays.
- Smart Cable Guards are used for fault location since traditional fault detectors have become worthless in a network with two-sided short-circuit power supply.
- Analysis software tooling needs to be trained to employees to identify where the closed ring operation can be implemented in the grid.
- There is CAPEX investments for int. ring main unit and Smart Cable Guard and OPEX related to Smart Cable Guard.

Benefits

- Customers, more capacity is expected to be available after implementation, increases ranging from firm power between 500kW to 1MW and non-firm up to 2MW; for non-firm power the Grid as a Service (active capacity management) system needs to be available.
- DSOs, it supports the DSO with investment savings or deferral and provide faster capacity offerings to customers.
- HW installations for intel. ring main unit and Smart Cable Guard can be done within 2weeks, DSO internal processing depends on the company.

Optimising conductor capacity with HTLS

DSO: Bayernwerk & Westnetz
Voltage level: HV

Challenge

- Insufficient (transport) capacity on existing high-voltage lines / corridors because of DRES roll-out leads to connection delays and high redispatch costs.
- Building new lines or installing higher power poles on existing ones is a complex and expensive process, which is subject to official approval procedures.

Solution

- Replacing conventional conductors with high temperature low sag conductors (HTLS) where possible on the existing power poles. They can withstand higher currents and operating temperatures of up to 210°C without sagging too close to the ground.
- Different types of HTLS (definition see CIGRE) already in use at E.ON DSOs.
- Type 2 HTLS (e.g. ZTAHAC) are used if the height of the existing lines above the ground is already sufficient for operating conventional lines at 80°C. The ZTAHAC have the advantage that the handling, fittings and interference suppression are similar to type 1 HTLS already in use for many years which implies that no additional training and special materials need to be provided.
- Type 3 HTLS (e.g. ACR) are used in case the lines have only a small ground clearance.
- It should be noted that HTLS are generally more expensive than conventional conductors and they lead to higher energy losses due to the high temperatures. Therefore, their use should be limited to grid areas, where their benefits outweigh their costs.

Benefits

- Providing the maximum of capacity in existing corridors while using existing poles.
- All conductor changes that are planned at Westnetz will create an additional ~6,500 MVA of capacity in the next three years and at Bayernwerk additional ~10,000 MVA will be created until 2030 according to their respective DNDP.
- Building new lines or upgrading existing ones with higher power. Avoiding or minimising the need for new permitting procedures in the upgrading case.
- Increased hosting capacity for DRES
- Less redispatch interventions, which is a main benefit that is currently not incentivised.

Eurelectric pursues in all its activities the application of the following sustainable development values:

Economic Development

- Growth, added-value, efficiency

Environmental Leadership

- Commitment, innovation, pro-activeness

Social Responsibility

- Transparency, ethics, accountability

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