Making the most of Europe's grids

Grid optimisation technologies to build a greener Europe

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WindEurope

EXECUTIVE SUMMARY

Large scale electrification of the energy system coupled with deployment of renewables will be required to meet Europe's aim of being climate-neutral by 2050. Electricity demand is expected to increase two to three-fold by 2050. Wind alone could supply close to half of these electricity needs. The European Commission envisages some 700 to 1200 GW of total installed wind capacity, distributed across the power distribution and transmission grid. This is four to six times the existing installed capacity. It envisages some 500GW to 970GW of solar capacity will be installed within the same timeframe.

These new connections will require a significant expansion of the existing power grid to transfer wind and solar power from isolated places to load centres as well as from low price to high price zones with new interconnectors, while ensuring security of supply. A strong reinforcement of power distribution networks will also be required to allow new customers to connect (electric vehicle charging points, data centres…) and to collect power from wind and solar farms.

Developing the grid to meet these requirements has become increasingly difficult. Designating new transmission corridors is very complex and the necessary lead times to commission new infrastructure are very long. This increasingly urgent need coupled with longer lead times to deliver grid infrastructure leads to the inevitable conclusion that **whilst grid expansion is crucial and needs to accelerate, grid optimisation and timely solutions must be addressed first.** We should be exploring ways to maximise the use of the existing grid while complying with safety and security rules. **The transmission grid – existing and under development - must more than ever be utilized to its maximum potential until new transmission assets are built.**

The adoption of new and existing technologies – grid optimisation technologies - can maximise the use of transmission capacity by increasing thermal and/or system limits or optimally addressing conservatively set margins. **This can mitigate renewables variability and accelerate their integration while new reinforced assets are being planned and developed. Most importantly, some grid optimisation technologies can significantly reduce renewables' curtailment while saving customers' money so some of these should be considered as a no-regrets option; the technologies are there and proven.**

This paper identifies **grid optimisation technologies** that with the right regulatory frameworks in place could become widely deployed and immediately maximise the use of current and future transmission capacity. **We must use the upcoming regulatory opportunities (EU Green Deal aligned with the EU recovery package, TEN-E regulation revision, Clean Energy Package implementation) and fit the current framework for this purpose. Grid optimisation technologies need to be incentivised for large-scale deployment to occur.** WindEurope presents in this paper recommendations on how this can be achieved:

- **TSO investments in grid optimisation technologies must be incentivised equally to new grid development.** Regulatory frameworks should incentivise implementation of short- or medium-term solutions that lead to a total cost saving (TOTEX being CAPEX + OPEX) in addition to more traditional long-term focussed investments.
- The use of grid optimisation technologies should be captured in system planning and in system operation to maximise available transfer capacity in both timeframes.
- **The system planning process needs to be a continuous and open process, in line with the EU Green Deal, and it should be flexible to take advantage of technology and policy developments.** TSOs should be able to update their planning choices regularly, when clearly justified through multi-criteria, social welfare-driven CBA processes.
- A change of paradigm towards deeper cooperation and information exchange among stakeholders (generators, technology suppliers, TSOs, DSOs, policy makers…) is essential, both in the planning and operational time frame.
- **Finally, we need to roll out ancillary services that distributed renewable generation assets can provide.** To fully exploit the flexibility potential of wind, market design must be reviewed. Wind generators need to be adequately incentivised to support grid operation whenever and wherever needed.

1 POWER SYSTEM TRANSFORMATION

1.1 Context

Wind and solar will play a very important role in the EU power system as shown in all long-term decarbonisation scenarios, including those from the European Commission (EC).

To meet the 2050 climate target, electricity must increase its role in the overall energy system. Electricity demand will increase two to three-fold by 2050. Wind alone could supply about half of these electricity needs by 2050. The "Clean Planet for All" report[1] envisages some 700 to 1200 GW of total installed wind capacity, distributed all over the power distribution and transmission grid. This is four to six times the existing installed capacity (204GW in 2020)[2]. It envisages some 500GW to 970GW of total installed solar capacity by the same time.

All this will require an important extension of the existing power grid to transfer wind and solar from isolated places (e.g. the Dogger bank at 160km from the English coast), more interconnectors to transfer power from low price[3] to high price zones and to maximise the security of supply, and a strong reinforcement of distribution lines allowing new customers to connect (e.g. electric vehicle charging points, data centers) and collecting electricity from wind and solar farms. The latter are today mainly located in rural areas connected to the distribution grid. Keeping the power system robust and flexible enough to host these changes will become more and more challenging[4].

At the same time, designating new transmission corridors becomes increasingly complex and the necessary lead times to commission the new infrastructure are very long[5,6]. While significant efforts are made to speed up processes[7], energy stakeholders need to find ways to maximise the use of the grid. Moreover, it is time to escalate ancillary services that distributed renewables can provide given that wind farms are soon to become the main EU power source.

1.2 Grid development with high renewable energy share

Every two years ENTSO-E publishes the 10-year network development plan (TYNDP) on how to develop the power grid in the next decade to meet EU long-term energy and climate targets. The 2020 TYNDP - is based on a set of long-term energy scenarios[8].

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[1] EC, "A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" and its accompanying document "In-depth analysis in support of the commission Communication COM (2018) 773", November 2018

[2] WindEurope, "Wind energy in Europe in 2019 - Trends and statistics, February 2020,

[3] Low and high price zones will be more dynamic than today and correlate with regions with renewable excess and renewable deficit and greater amounts of interconnectivity between such regions/zones will be required.

[4] ENTSO-E TG HPoPEIPS, "High Penetration of Power Electronic Interfaced Power Sources and the Potential Contribution of Grid Forming Converters", January 2020

[5] German Federal Ministry for Economic Affairs and Energy, "Electricity grid action plan", 2018

[6] Elia Group, « Future-proofing the EU energy system towards 2030", December 2019

[7] German Federal Ministry for Economic Affairs and Energy, "Expansion of the electricity grid progressing well", March 2020

[8] TYNDP 2020 Scenario Report https://www.entsos-tyndp2020-scenarios.eu/

The Trans-European Energy Networks (TEN-E) regulation[9] identifies priority corridors and thematic areas of trans-European energy infrastructure. It also sets eligibility criteria for the selection of Projects of Common Interest (PCIs). However, these criteria were defined in 2013 with security of supply being the underlying common thread. This approach is no longer in line with the evolution of the energy system over the past years and with the new policy priorities. For instance, the criteria for nominating smart grid projects as PCIs are currently very rigid to enable a pipeline of such projects that would be very beneficial for a long-term cost-effective decarbonisation. Another example is sustainability; this is currently just one of the criteria which PCIs need to meet. In the future, PCI status should only be given to projects that score high on sustainability[10], enabling longer-term economic decarbonisation. A long term game needs a long-term approach.

On this basis, the efficiency of current grid development process at EU level should be improved and adapted to the new framework, not only at EU but also at national level. Certain National Grid Development (NGD) plans are updated every two years and are continuously under consultation (like the TYNPD) while others are updated every 5 to 6 years and have time horizons shorter than 10 years; whichever the frequency, **the planning process needs to be a continuous exercise and its formalisation should be flexible to take advantage of technology and policy developments**. Certain countries/TSOs have already been deploying significant efforts to adapt this process to the new EU decarbonisation objectives. **However, it is imperative to review and improve these processes in line with the EU Green Deal ambitions and with the objective to minimise costs paid by the consumers in all countries.** On this basis, European, national and local authorities should develop measures to accelerate permitting, especially for PCI-labelled projects and to allow TSOs to invest more pro-actively (i.e. instead of waiting for concrete wind projects to materialize, TSOs should be able to invest for hosting the expected wind capacity). **Overall, transparency and continuous communication on the evolution of NDP decisions are key to ensure certainty for the power sector and public acceptance for new investments.**

In most cases, these plans are quite optimistic and practical experience indicates that delays both in the permitting and construction phases are common. WindEurope has serious concerns that grid development cannot keep pace with the rate at which renewables deployment and electrification must advance to meet EU targets. To commission the high amount of grid infrastructure envisaged by the EC, special support in terms of budget allocations and environmental public acceptance should be ensured to accelerate the projects. The estimated expenditures for transmission grid infrastructure (excluding storage) add up to €152bn in the decade 2021-2030 in the EU28 region[11]. About half of these investments are in a very early stage of analysis and labelled 'under consideration' while only 19% have made clear progress and are in a permitting phase or even partly under construction. Public opposition makes permitting for new lines very costly (e.g. when underground cabling alternative is needed) and difficult (time-consuming and complex). Besides, the mechanisms to realize and accelerate these investments are not in place.

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[9] EC, "Regulation (EU) No 347/2013 on guidelines for trans-European energy infrastructure", 2013

[10] WindEurope, "WindEurope response to the consultation of the guidelines for trans-European energy infrastructure (TEN-E)", July 2020

[11] EC, "Investment needs in trans-European energy infrastructure up to 2030 and beyond", July 2017

This will significantly hamper renewable energy deployment. With growing volumes of offshore wind, coastal onshore reinforcements are becoming more and more a priority. In some countries, the lead time for such reinforcements is the main delaying factor for further offshore wind development. Optimising the grid to maximise the use of its actual capacity is key to avoid the grid to be a constraint on economic decarbonisation.

1.3 Grid optimisation as a no-regret option

With the ongoing renewables' integration and demand electrification, the adoption of new types of loads (e.g. electric vehicle charging points), and any outages associated to the upcoming grid development (e.g. during the construction/reinforcement stages), system reliability requirements have been evolving at a fast pace (**Figure 1**). Traditional system planning needs to evolve and will require advanced reliability-based asset management and a better understanding of system limits. Long-term planning should cover at least the same horizon as the EU energy decarbonisation targets (2050). More importantly, long-term planning should follow a multi-scenario approach rather than focusing on only one scenario without assessing the capability to meet the requirements of the others. Considering such aspects and that today the development of new transmission lines takes about 7 to 10 years, **the transmission grid must more than ever be utilised to its maximum potential.**

Figure 1 Total Transfer Capability changes with time[12]

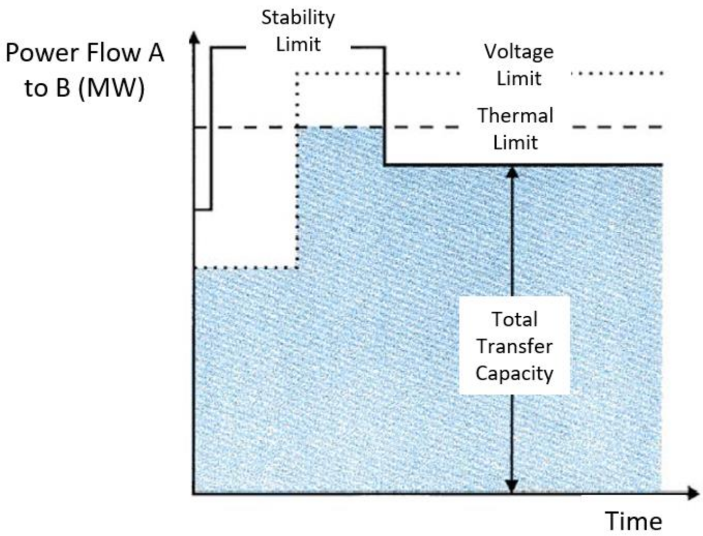


Figure 2 shows the impact of wind generation in Germany on the power flows in the French transmission system today. Power flows in specific corridors – in the centre of France - during high wind generation might be 20 times or more larger than during low wind generation. **Figure 3** shows how significantly the utilisation of an existing French transmission corridor will be increased by 2035[13] as further renewables generation and electrified demand will be added. **These observations show that the current use of the transfer capacity of certain transmission assets could be significantly increased.**

[12] National Renewable Energy Laboratory, "Effective Grid Utilization: A technical assessment and application guide", April 2011-September 2012

[13] RTE, "French Transmission Network development plan", 2019.

It is well-known that the introduction of new technologies (e.g. Dynamic Line Rating (DLR), Flexible AC Transmission Systems, HVDC ….) can maximise the use of transmission capacity by increasing thermal and/or system limits or optimally addressing conservatively set margins[14]. This can certainly accelerate renewables integration while new reinforced assets are being planned and developed. **Most importantly, some grid optimisation technologies can significantly reduce renewables' curtailment[15] while saving customers' money so some of these should be considered as a no-regrets option; many of these technologies are there and have been proven.**

Figure 2 Influence of wind generation in Germany on power flows in the French transmission system (2019)[12]

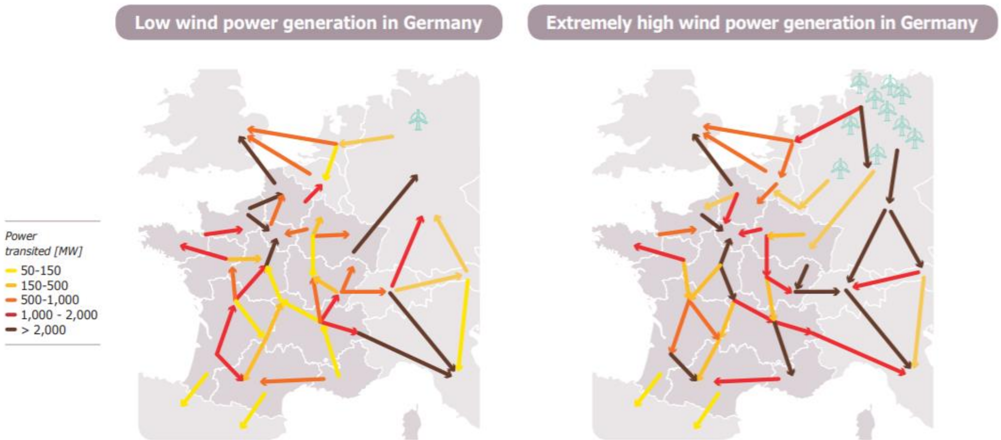
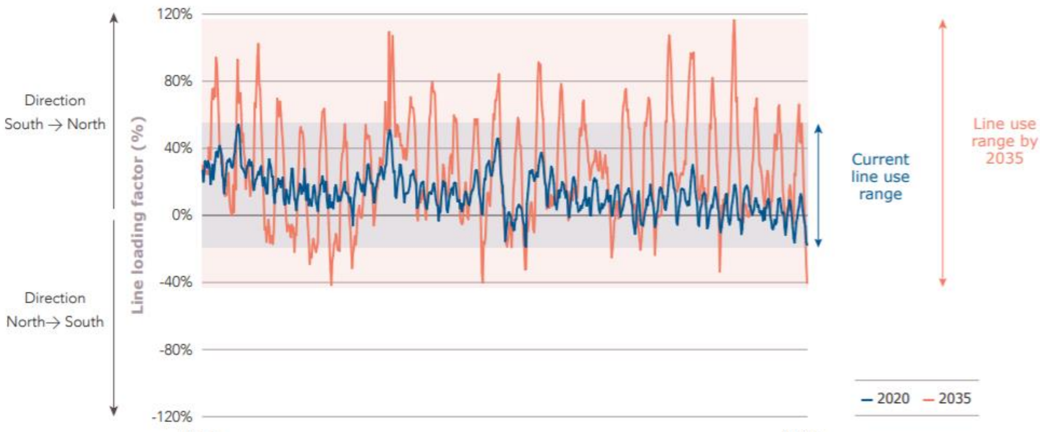


Figure 3 Foreseen evolution of power flows in a French North-South transmission corridor (today versus 2035 horizon)[7]



[14] National Renewable Energy Laboratory, "Effective Grid Utilization: A technical assessment and application guide", April 2011-September 2012

[15] To note the order of magnitude, in Germany the curtailed (by the network operators) volumes of renewables sum up to 3743GWh in 2016, 5518GWh in 2017, 5403GWh in 2018 and 6482GWh in 2019. The respective compensation costs to the plant owners sum up to 372.7M€ in 2016, 609.9M€ in 2017, 635.4M€ in 2018 and 709.5M€ in 2019 (Bundesnetzagentur, "Zahlen zu Netz- und Systemsicherheitsmaßnahmen - Gesamtjahr 2019", 2020)

Indeed, grid optimisation technologies have been deployed and operated for the past couple of decades by some TSOs however their deployment is far from being wide at EU level. Does the current regulatory framework encourage TSOs and DSOs to test and implement such commercially available solutions?

This paper identifies grid optimisation technologies that with the right regulatory frameworks in place would become widely deployed and immediately maximise the use of current and future transmission capacity, based on social welfare-driven, multi-criteria CBAs. The European Green Deal – given its proposed key actions and roadmap[16] – is a prominent opportunity to make the regulatory framework fit for this purpose. It is also imperative to align the Green Deal and the EU recovery package so that investments focus on the latest technological solutions. The implementation of the Clean Energy Package and the transposition of the recast Electricity Directive and Regulation into national law is another opportunity that should not be missed out. Finally, the TEN-E regulation revision (assessment of projects, PCI eligibility criteria in particular for smart grid projects, TYNDP) must highlight the need for transparency and consultation on new technologies and grid optimisation so that TSO's are incentivized to make maximal use of the existing network; the overall PCI eligibility criteria and the TYNDP must be aligned with CBA methodologies and overall energy targets.

1.4 Grid optimisation and the Clean Energy Package

The ongoing implementation of the Clean Energy Package will urge regulatory bodies to embrace grid optimisation.

For example, the recast of the Electricity Directive[17] requests National Regulatory Authorities (NRAs) to ensure the task of monitoring and assessing the development of smart grids by creating and installing monitoring processes in Member States with bi-annual reporting and assessment. In this context TSOs and DSOs will be expected to monitor their performance based on indicators such as their capability to operate lines under Dynamic Line rating (DLR), the development of remote monitoring and real-time control of substations, the reduction of grid losses and the frequency and duration of power interruptions. Recently T&D Europe presented a reflection[18] on a methodology for defining smartness indicators for transmission and distribution grids. Smartness monitoring can be an efficient tool to adjust system planning decisions to evolving optimisation needs.

The i Electricity Regulation forces the removal of priority dispatch for renewables (Article 12) and will be setting new rules for the compensation of curtailed renewable energy (Article 13). TSOs and DSOs will need to guarantee that their networks can transmit electricity from renewables with minimum possible re-dispatching which must not lead to renewables' curtailment exceeding 5% of their annual generated electricity (unless electricity from renewables or high-efficiency cogeneration represents more than 50 % of the annual gross final consumption of electricity in the respective country). At the same time, TSOs will be requested not to limit the volume of interconnection capacity to be made available to market

[16] EC, "Annex to the Communication on the European Green Deal: Roadmap – Key actions", December 2019

[17] Directive (EU) 2019/944 on common rules for the internal market for electricity and amending Directive 2012/27/EU, recital (83)

[18] T&D Europe, "Assessing, monitoring and future proofing European grids: Increasing transparency on the performance of electrical grids within the framework of the European Green Deal", April 2020

participants to less than 70% of interconnectors' transmission capacity as a means of solving congestion or managing flows inside their own bidding zone. Maximising the use of internal grids will become a priority for system operators and NRAs to deal with such requirements.

1.5 The value of cooperation

In addition to regulatory changes, to fully exploit the potential of grid optimisation solutions, a change of paradigm towards deeper cooperation among different stakeholders is essential, both in planning and operational time frame.

On the planning horizon, the development of system planning scenarios must involve all relevant stakeholders at national level (incl. generation and demand stakeholders). This is the only way to align national energy plans with grid infrastructure development.

For an accurate understanding of system needs and operation of connected technologies' (simulation models and interaction studies) an iterative exchange between generators, TSOs and DSOs is becoming crucial. Such approach will lead to clear and harmonized implementation of the grid connection code. In this context, Wind Europe are ENTSO-E are closely working together. Recently a new expert group has been formed on "Interaction Studies and Simulation Models for PGM/HVDC" –in order to improve the exchange of information between TSOs and generators on the operation and interoperability of different technologies. And ENTSO-E is coordinating efforts –to address technical challenges in the development of multi-terminal multi-vendor HVDC systems.

Therefore, cooperation among different stakeholders is a necessity. WindEurope also strongly encourages maximum cooperation between the different system operator units (e.g. system planning and operations units) for taking grid optimisation projects further – mainly the ones deploying more innovative and less well-known technologies. From the grid users' point of view, optimised projects involving different technologies – wind, solar, storage[19,20] – or different stakeholders will also contribute to maximising grid use. Some TSOs have been considering or have already started developing the framework to enable shared grid access points among different entities to maximise the use of grid connections[21, 22].

Finally, a strategic approach for sharing the knowledge that has been gained through new innovative deployments will be beneficial to all stakeholders.

2 GRID OPTIMISATION TECHNOLOGIES

WindEurope has created a library of commercially available technologies under the headline of **grid optimisation technologies**. These **technologies can be deployed to optimise the utilisation of transmission and distribution assets by increasing line transfer capacity, improving controllability of power flows and system parameters, reducing power losses, reducing asset failures and extending their**

[19] WindEurope, "Renewable Hybrid Power Plants: exploring the benefits and market opportunities", July 2019

[20] WindEurope, "Wind energy and on-site energy storage", November 2017

[21] EirGrid SONI, "FlexTech Consultation", 2019

[22] G.Denis, O.Despouys, P.Panciatici, T.Prevost, F.Xavier (RTE),"PE interface to AC grid: grid forming control for a more resilient transmission grid, and a flexible DC connection of grid customers", EC workshop, February 2020

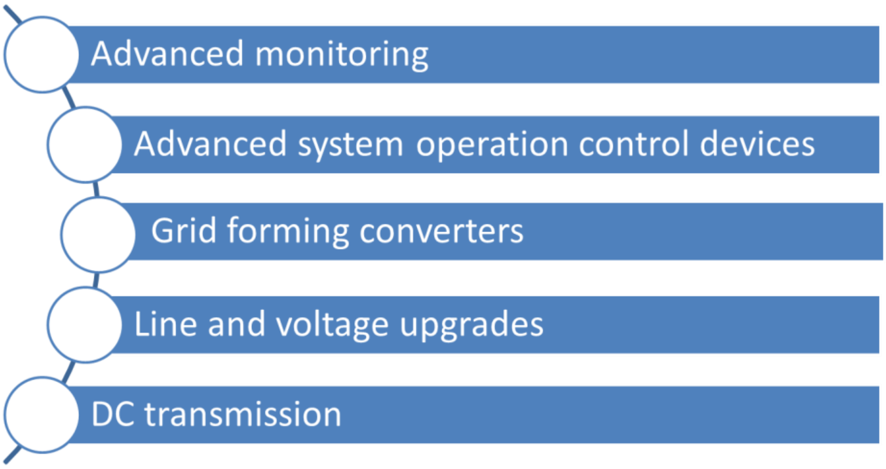
life span, increasing safety margins, improving system resilience and risk mitigation. The specific system benefits that these technologies can provide are discussed in the following paragraphs.

Chapter 2 presents an overview of the identified technologies and insights on how they are presently used in system planning and operation, their expected benefits, and the main barriers to deploy them. Chapter 3 presents WindEurope's recommendations on how the uptake of grid optimisation technologies could be accelerated.

2.1 Library of technologies

We classified the most used grid optimisation technologies into five categories (**Figure 4**) in function of their main benefits. Annex A provides a detailed description of the technologies in each category.

Figure 4 Categories of grid optimisation technologies



2.2 Assessment of the technologies

Based on existing projects and on discussions with selected EU TSOs, this paper qualitatively assesses the technologies. We focus on their expected benefits but also on the ones finally achieved in the discussed cases. We also investigate the challenges that TSOs are experiencing in their implementation and operation.

Table 1 presents a high-level overview of system benefits that grid optimisation technologies can offer, and **Table 2** assigns these benefits to the identified technologies. **Table 3** presents a high-level overview of the barriers to implement them. **Annex B** includes more specific information on the cases studies that WindEurope has discussed with TSOs.

2.2.1 Overview of system benefits

To achieve their expected objectives and defer investments in new assets, grid optimisation technologies are designed to offer one or more direct improvements to specific assets. However, most of them directly or indirectly contribute to a set of different system parameters (**Table 1**):

Table 1 High-level overview of system benefits thanks to grid optimisation technologies

(A)	Increase power transfer capacity	**(F)**	Reduce power losses
(B)	Line sag/clearance monitoring	**(G)**	Improve real-time monitoring
(C)	Increase power flow controllability	**(H)**	Improve system resilience and risk mitigation
(D)	Increase voltage controllability	**(I)**	Higher capacity rating per circuit
(E)	Increase the safety margins	**(J)**	Lower voltage high capacity transmission

2.2.2 Maturity of grid optimisation technologies

We can evaluate the maturity of technologies from two points of view; first, their technical maturity based on their Technology Readiness Level (TRL) and second, the extent to which European TSOs have already used them. All the discussed technologies in this paper except for grid forming converters are fully proven and commercially available (TRL 9). The second type of maturity, a maturity of use, clearly depends on the operational benefits and it deployment so far. Some TSOs have repeatedly deployed a technology in their networks and have developed significant maturity in its use. Other technologies might have been deployed by several TSOs but only in limited cases, so their maturity of use is not that high. As an objective metric for the maturity of use, we suggest assessing to which extent the technology is considered in short- and long-term planning by at least one European TSO.

For example, advanced monitoring technologies such as Dynamic Line Rating (DLR) are commercially available and have been widely used for several years by Elia, Energinet, Tennet and others. In some of these cases DLR is fully integrated in short- and long-term system planning studies. Thus, it partly contributes to economic dispatch and to the deferral of new grid development investments.

Another example is the *grid booster* concept to be deployed by TransnetBW[23] and by TenneT[24] in Germany. Although these projects will be based on the use of battery storage technologies - already widely used at utility scale[25] but not of that high power ratings , the *grid boosters* will not be evaluated for a wide roll-out before different issues such as control system design and validation for that high storage ratings or their interoperability with existing devices are fully proven during the pilot phase.

[23] TSCNET, "TransnetBW's grid booster confirmed", December 2019

[24] TSCNET, "Tennet conducts market survey on grid boosters", February 2020

[25] Energy storage and demand flexibility (EV charging, heat pumps, demand response) can affect power flows, system parameters, reserves and if controlled by the TSO or DSO in a coordinated way these technologies are another strong player in optimising grid use. Table 2 does not expand to all these solutions as grid optimisation technologies but only includes large-scale battery fleet systems coordinated by the TSO to resolve significant grid events (Grid booster/Virtual Power Line)

Table 2 Focus on specific system benefits and maturity of use per technology

Technologies	System benefits	Maturity of use*
ADVANCED MONITORING		
Dynamic Line Rating	(A), (B), (G), (H)	↗↗↗
Transformer Fleet Digitalisation	(A), (G), (H)	↗↗↗
Asset Performance Management	(E)	↗↗↗
ADVANCED SYSTEM OPERATION CONTROL DEVICES**		
Phase-Shifting Transformer	(A), (C), (D), (H)	↗↗↗
Solid-State Transformer	(A), (C), (D), (H)	↗
Static Synchronous Series Compensator	(A), (C), (D), (E), (F), (H)	↗↗↗
Modular Power Flow Control Technology	(A), (C), (D), (E), (F), (H)	↗↗↗
Thyristor-controlled Series Compensator	(A), (D), (E), (H)	↗↗↗
Static Synchronous Compensator (STATCOM)	(A), (C), (D), (E), (F), (H)	↗↗↗
Static VAR Compensator	(A), (C), (D), (E), (F), (H)	↗↗↗
Grid Booster/Virtual power line	(A), (C), (E), (H)	↗
Adaptive Protection Scheme***	(A), (E), (G), (H)	↗↗↗
Synchronous condensers	(A), (E), (H)	↗↗↗
GRID FORMING CONVERTERS	(C), (D), (E), (H)	↗
LINE/VOLTAGE UPGRADES		
High Temperature Low Sag conductors	(A), (B), (F), (I)	↗↗↗
Voltage uprate	(A), (F), (I)	↗↗↗
DC TRANSMISSION		
HVDC technology	(D), (E), (F), (H), (I)	↗↗↗
AC to DC line upgrade	(E), (F)	↗
Superconductor	(D), (F), (I), (J)	↗

* ↗ = pilot projects, ↗↗= widely deployed, ↗↗↗= widely deployed & also integrated in short- and long-term system planning

** We consider that all technologies using dynamic control can increase active power transfer by reducing reactive power transfer and by improving transient stability margins. Therefore benefit (A) has been attributed to all advanced system operation control devices. Also, we consider that all devices using fast dynamic control can increase system resilience[26], so we have attributed benefit (H) to all advanced system operation control devices and HVDC technologies. (to be discussed)

*** The maturity of adaptive protection schemes is considered "↗↗↗" only when these are based on switching pre-calculated settings. In case of such schemes with online re-calculation and coordination, their maturity should be considered "↗".

2.2.3 Overview of implementation barriers

The technical assessment and Cost Benefit Analysis (CBA) of grid optimisation scenarios is the first step for the implementation of such technologies. In most cases, TSOs need to deploy system view assessment also considering the ability of the system to support temporary outages for such deployments – as is the case for new grid development scenarios – and any needs for further equipment to allow their system integration (e.g. additional reactive power compensation). These technical processes are well known to TSO's system planning units. However, the deployment of grid optimisation technologies faces some specific technical challenges listed in **Table 3** together with regulatory and economic challenges. The latter are thoroughly discussed in Chapter 3.

Table 3 High-level overview of barriers in deploying grid optimisation technologies

Technical

- There is a lack of standards covering grid optimisation technologies so any gaps in their qualification with existing standards (or combinations of those) will result in more responsibility on the TSO and higher investment risk, making the case less favourable to the TSO

Regulatory

[26] Electric Power Research Institute, "Electric Power System Resiliency; challenges and opportunities", February 2016

- In some cases, the technical assessment and CBA processes in place do not fit for the evaluation of grid optimisation solutions (e.g. in some cases, grid optimisation technologies are not considered in system planning so the deferral of new grid infrastructure cannot be measured). Especially when system benefits are provided by a combination of new technologies and existing ones, it is difficult to measure the impact of the new ones and justify the investment

- Cost recovery framework is focused on CAPEX-based investments instead of valorising the potential positive impact of the latter on TOTEX-savings (e.g. deferral of new transfer capacity requirements in the long term, OPEX savings in certain cases…)

- The framework is not favourable to the TSO, in terms of liabilities, in case of technical failures or implementation delays in such deployments. On the contrary, TSOs are much more protected when similar problems occur in new assets development

- In some cases, the life-time cost of deploying such technologies may be comparable to building new assets. However, the cost savings thanks to reduced time to roll-out the technology in the grid (while many new lines might face many permitting and acceptance issues) are not factored in the comparison of costs

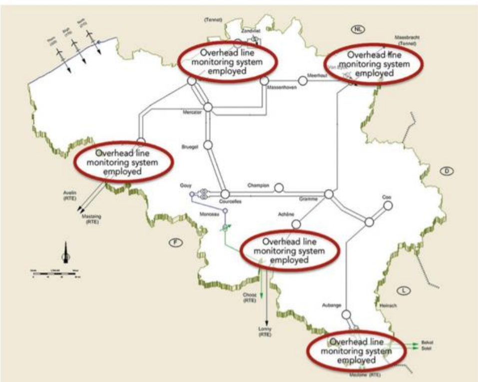
2.3 Case studies

Several grid optimisation projects have been deployed during the last two decades by EU TSOs and DSOs. We present some of them in this section:

2.3.1 Advanced monitoring

Project: Dynamic Line Rating, Belgium

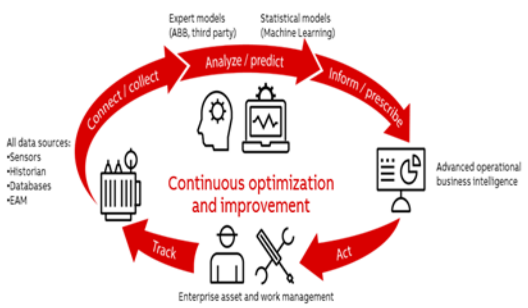
Objective: Elia, the Belgian TSO, has deployed DLR since 2008 for safely optimising the use of selected lines' transmission capacity based on the real-time conditions under which those power lines operate.



Description: Elia uses DLR in a very big share of its overhead lines. The use of the technology is considered in Day and 2 Day Ahead Congestion Forecast (DACF, D2CF), in outage planning and in real-time operation. A line-mounted sensor network has been put in place. The DLR modules have been deployed on the most critical spans of the respective lines for measuring ambient parameters as well as the physical sag of the conductor. Based on these real-time measurements and forecast weather parameters, real-time and forecast ampacity (up to 2 days in advance)) is calculated. The ampacity is the maximum permanent flows that the line can sustain without compromising safety.

Project: Transformer Fleet Digitalisation

Objective: American Electric Power (AEP) one of the largest TSO in North America developed an asset management program[27] for early identification of potential risks of failures for their fleet of transformers and to implement a strategical approach in the planning for CAPEX and OPEX. Transformer health assessment models analyse near real-time data from physical sensors - collected into a data aggregator - and offline historical data.

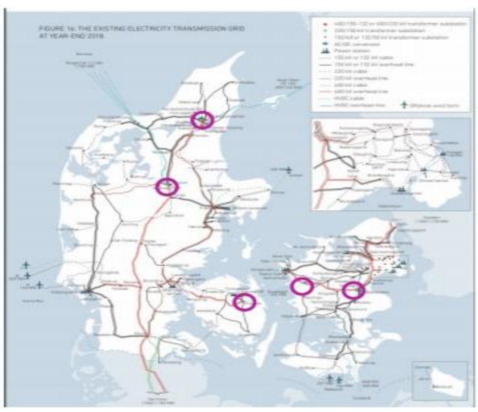


Description: The implemented Asset Performance Management (APM) solution provides actionable analysis results by collecting on-line operational information from the aggregator along with data from various sources - OT data from the historian, offline inspection data, nameplate data - and real-time analysis data through embedded or connected (via REST service) models, e.g. transformer expert models, kinetics models, machine learning models. It also presents the inputs and the results for validation and further analysis, supports generation actions in work management systems (or other action tracking) and tracks actions and risks through resolution. The most important benefit of this solution is the optimisation and anticipated planning of TSO CAPEX and OPEX investments; CAPEX investments are defined depending on real information about the health condition of the transformers fleet and not depending on the Expected Life Cycle of the Transformer. OPEX and maintenance programs can be defined according to a condition-based analysis and not to time-based criteria.

2.3.2 Advanced system operation control devices

Project: Synchronous condensers, Denmark

Objective: Energinet.dk, the Danish TSO, owns and operates 5 synchronous condensers to support continuous voltage control and system stability, given the large number of HDVC interconnections and high wind power integration.



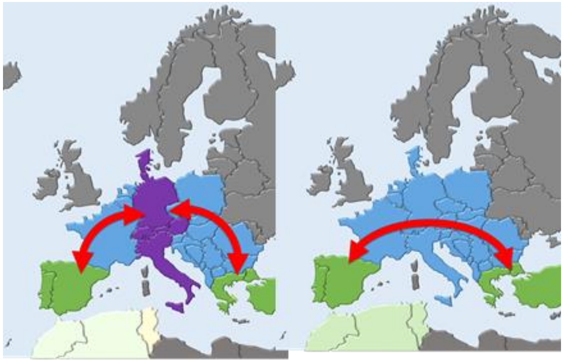
Description: Denmark has no more must-run requirements from conventional plants since 2016 as these were too costly. The plants under must-run requirements were mainly contracted to contribute to short-circuit current and voltage control (steady-state and dynamic). The 5 synchronous condensers were installed in Vr.Hassing (1965/2013) , Tjele (1976/2012), Bjaeverskov (2013) , Herslev (2014), Fraugde (2014) stations. If the primary power stations can sufficiently contribute to power system stability, Energinet will be able to switch off (and compensate) its synchronous condensers[28].

[27] C.Schneider,J.Staninovski,L.Cheim J.Vines, S.Varadan, "Transformer Reliability Taking Predictive Maintenance Program to the Next Level", CIGRE Study Committee A2 - Transformers Colloquium, November 2017

[28] Energinet, "System plan 2018: electricity and gad in Denmark", November 2018

Project: TCSC and STATCOM, Spain

Objective: REE, the Spanish TSO, has deployed one TCSC and several STATCOM devices as oscillation stabilizers[29].



Description: The Spanish power system is located at one of the extreme limits of the EU power system, so it is in a good position for observing and controlling the EU system's stability against inter-area oscillations. To this purpose, the Spanish TSO has proposed to installed a TCSC device to contribute to small signal oscillations damping and sub synchronous resonance damping and several STATCOM devices to contribute to small signal oscillations damping (with a Power Oscillation Damping in Reactive Power control POD-Q) and dynamic voltage control.

Project: Hybrid STATCOM, Germany

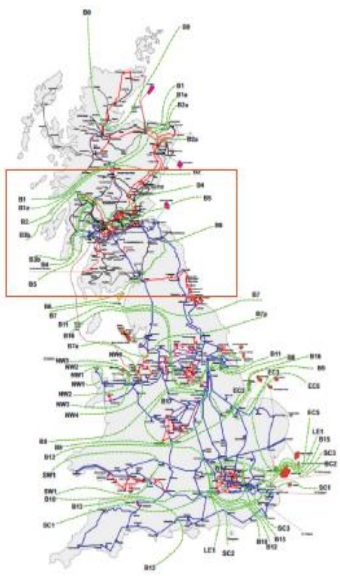
Objective: Tennet, the Dutch-German TSO installed a hybrid STATCOM at the Borken substation in Hessen, Central Germany, to mitigate stability and fluctuation issues.

Description: As Germany's power supply has been changing from a reliance on steady, centralized sources - like nuclear and thermal power - to more volatile and decentralized renewable power supplies, such as wind and solar, the country needs to address stability and fluctuation issues that affect power supplies. As part of the solution, this hybrid Static Compensator (STATCOM) supports the grid with flexible reactive power compensation and dynamic voltage support to stabilize voltage fluctuations caused by the intermittent nature of wind or solar and to reduce the risk of voltage collapse and power outages.

29 REE, "FACTS as oscillation stabilizers", WindEurope Grid Optimisation workshop, January 2020

Project: Modular power flow control technology, multi-site deployment, Great Britain

Objective: National Grid Electricity Transmission UK (NGET) will use modular power flow control technology to increase power transfer capability by making better use of its existing network.



Description: The modular power flow control technology (MPFC) will be installed in 2020 on five 275 kV and 400 kV circuits on NGET network. The technology will help decarbonize the UK electricity grid by enabling greater volumes of renewable power to be efficiently transferred to customers. As the generation and demand connected to the network changes, network power flows change, and circuits can become unequally loaded. Some circuits reach their maximum capacity while others are well below their limits. Installing power flow controllers allows NGET to provide the Electricity System Operator with the tools to quickly reduce the congestion that limits renewable generation, with minimal impact on communities and the environment. The five installations scheduled for 2020 are anticipated to increase boundary capabilities by 1.5 gigawatts in total across three boundaries.

This modular technology comes in very small discrete sizes allowing the TSO to pick the exact amount of power flow control that is needed now rather than size for an uncertain need in 10, 20, 40 years' time. The modularity also allows the TSO to come back later and scale up (or scale down) the installation to meet the systems needs as they evolve in time. This provides both a very economical solution and allows for very past project delivery which in turn can save m€ for customers and

Project: Phase-shifting transformer, Germany

Objective: Ampion, the German TSO will install two high-performance phase-shifting transformers[30] to better control integrating of offshore wind power into the electricity grid.

Description: To control the power flow at the most critical network nodes in Germany, the German Federal Ministry for Economic Affairs and Energy asked German TSOs to place phase-shifting transformers at respective locations as quickly as possible. In this project, the ordered phase-shifting transformers are of 2,494 megavolt amperes (MVA) capacity each, amongst the most powerful in the world, and have the potential to offer savings of more than €100 million over 3 years.

[30] ABB, "ABB wins $30m power equipment order to bolster Germany's renewable energy integration", November 2019

Project: Mobile modular power flow control technology, Greece

IPTO

Objective: IPTO, the Greek TSO has deployed a mobile modular power flow control[31] technology to capture the excess capacity that is available on the 150-kV transmission lines in real time and this way increase the uptake of renewable generation. This year, ESO, the Bulgarian TSO, will use the same unit to tackle similar problems at 110-kV.

Description: The mobile MPFC device has been installed in Peloponnese region that is served solely by a 150-kV transmission system. Because of the congestion issues in this area, the addition of new renewable energy projects has slowed down. The MPFC dynamically changes the line's impedance so power can be pushed off congested overhead lines onto underutilized lines, thereby increases the available transmission capacity of the network. IPTO determined where to install the mobile MPFC based on grid planning simulations which indicated a 17% reduction of the line's loading. The Mobile version of the technology represents a new way to deploy MPFC and was funded as a demonstration project by the EC Horizon 2020. A need was also identified in Bulgaria and the second phase of this project is to redeploy the mobile unit to substation in Dobrich in partnership with ESO. This is part of the FLEXITRANSTORE research project[32].

2.3.3 Grid forming converters

Project: Grid Forming Converters in Dersalloch Wind Park[33], Scotland

SCOTTISHPOWER RENEWABLES

Objective: Following from smaller-scale investigations of grid forming converter control applied to wind turbines in 2017-8, this objective of this project was a much larger trial involving an entire wind farm, owned, and operated by Scottish Power Renewables.

Description: This is the first UK converter-connected wind farm to operate in grid-forming mode, and the largest in the world to date. The 23-turbine, 69MW farm ran in grid-forming mode for approximately 6 weeks, exploring inertia contributions of between H=0.2s and H=8s. A large amount of data was gathered at the turbine and farm level, recording responses both to deliberately-induced scenarios, and also to grid events. A few unscheduled frequency disturbances occurred due to interconnector, CCGT and other trips, to which un-curtailed turbines were able to actively respond. While a significant amount of incremental improvement – software, hardware and energy storage – is still required to deal with the most extreme events which could occur, the turbines are able to provide stable and appropriate response at relatively high inertia levels to the frequency events commonly occurring today.

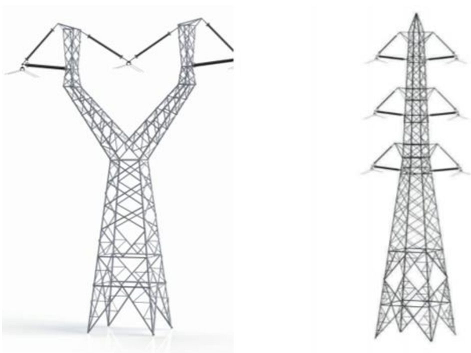
31 T&D World, "Greece Manages Congestion on the Grid", March 2020

32 EU Project "FLEXITRANSTORE"

33 A. Roscoe, P. Brogan, D. Elliott, T. Knueppel, (Siemens Gamesa, United Kingdom), I. Gutierrez (Scottish Power Renewables, United Kingdom), J-C. Perez Campion (Iberdrola Renovables, Spain), R. Da Silva (Scottish Power Renewables, United Kingdom), "Practical Experience of Operating a Grid Forming Wind Park and its Response to System Events", 18th Int. WIW, Dublin, October 2019

2.3.4 Line and voltage upgrades

Project: Voltage uprate, Ireland



Objective: Eirgrid, the Irish TSO has uprated 110kV pylons to 220kV to increase of power transfer capacity of existing circuits whilst simultaneously reducing associated losses by using the existing overhead line route[34].

Description: Thanks to new developments in electrical composite insulators, it is now possible to convert existing 110 kV pylons to 220 kV pylons. This is achieved by replacing the head of the 110 kV pylon with that of a 220kV design. It incorporates specialised composite insulators but retains the existing foundations and base of the pylon. Voltage uprating may allow higher capacities on existing routes and provide a solution if there is a need to increase a circuit's capacity. However, if there is a requirement for an additional circuit to allow for circuit outages this approach would not be a solution.

2.3.5 DC Transmission

Project: HVDC, Netherlands

Objective: TenneT has been deploying several offshore HVDC links to allow for an efficient offshore wind integration in the Netherlands and to Germany.

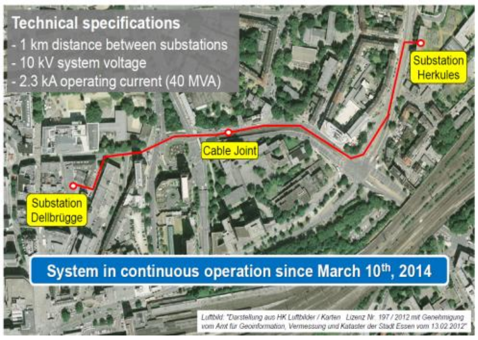
Description: Offshore HVDC links are in the pipeline for connecting 9,6GW of offshore wind energy to the coast of the Netherlands, by 2029, and 9,8GW to the coast of Germany, by 2025. HVDC technology is much more efficient for this purpose compared to AC as it offers better spatial compatibility thanks to higher transmission capacity of the cables and stable long-distance grid operations without requiring reactive power compensation so with minimised losses. TenneT is also working on the standardisation of 2GW AC/DC substation platforms that will allow for a wide deployment of direct wind farms' connection to the respective AC/DC transformer and elimination of the internal wind farm transformer stations.

[34] EirGrid, "Appendix to Ireland's grid development strategy: technical report", January 2017

Project: Ampacity, Germany

Objective: The objective of the project[35] is to develop, manufacture and install a high-temperature superconductor (HTS) system for avoiding high-voltage cables as well as resource and space-consuming substations in the city of Essen, for RWE AG DSO.

AmpaCity installation in Essen, Germany



Description: Essen's distribution network consisted of several 110-kV underground cables supplying 10-kV distribution substations. Due to economic and structural changes in the Ruhr area and the expiring service life of some of the existing assets, larger investments were needed for the refurbishment and modernization of this distribution network. Despite the high effort involved in cooling (as superconductivity only works at very low temperatures), preliminary investigations have shown that superconducting cables are the only sensible way of avoiding high-voltage cables as well as resource and space-consuming substations in inner city areas. The Ampacity project used a 10kV cable as an alternative to a 110kV conventional cable. Operational benefits include increased power density through avoidance of higher voltage levels for distribution, negligible thermal impact on surrounding environment during normal operation, no outer magnetic field, substations required are smaller in volume and cable footprint is smaller, and finally, increased operating safety due to the fault current limitations of HTS cables. The project partners included German Federal ministry for Economic Affairs and Energy, Nexans (technology), Karlsruhe Institute of technology (overall control), Julich (project management), and Leibniz University Hannover (calculations).

3 ALLOW FOR GRID OPTIMISATION

3.1 Opportunity for regulatory framework improvements

Most of grid optimisation technologies are well known in the power transmission sector and have been deployed in several trial projects, e.g. in the context of EU-funded R&D projects - and once qualified in "business as usual" deployments. Still most TSOs are hesitant to invest in their wide deployment; these regards technologies that have been proven to save OPEX and/or contribute to grid development deferral as well as new technologies that have been less frequently applied but are fully commercial. Thus, in our opinion, the hesitation driver is not the maturity of use of these technologies but rather regulatory barriers or lack of incentives for such TSO investments. The EU Green Deal (given its action plan[36] in 2020 and 2021) and the implementation of the recast Electricity Directive[37] (to be transposed to national laws by the end of 2020) are excellent opportunities to fit the regulatory framework for incentivising grid optimisation, based on multi-criteria CBA decisions. The TEN-E regulation revision must highlight the need

[35] Ampacity project, "Advanced Superconducting 10 kV System in the City Centre of Essen, Germany", EUCAS 2015, France, September 2015
[36] EC, "Annex to the Communication on the European Green Deal: Roadmap – Key actions", December 2019
[37] Directive (EU) 2019/944 on common rules for the internal market for electricity and amending Directive 2012/27/EU, recital (83)

for transparency and consultation on new technologies and grid optimisation (e.g. by means of suitable PCI eligibility criteria for smart grid projects) so that TSO's are incentivized to make maximal use of the existing network; the overall PCI eligibility criteria and the TYNDP must be aligned with CBA methodologies and overall energy targets.

TSO investment decisions are driven by the national regulatory regimes which allow a specific revenue based on their CAPEX and OPEX. Such regimes also determine efficiency requirements, adequate rates of return, the TSO regulatory asset base, the depreciation of assets, transmission tariffs and any incentives or penalties to minimise expenses or to increase efficiency[38].

In the past, cost-based[39] regulation approaches were widely used for defining TSO tariffs under which the regulated company had no incentive to minimise its costs as it could increase its profits by simply expanding its assets or cost base (**Figure 5**). To mitigate this drawback, most EU TSOs switched to incentive-based approaches. These incentives are defined at national level and TSOs are allowed some discretion on how to achieve their desired goals. Today cost-plus regulation is an exception among EU TSOs. However, there are cases where such approach still applies and successfully incentivises the TSO to increase efficiency and widely deploy grid optimisation solutions (e.g. Energinet, the Danish TSO).

Figure 5 Regulatory framework types for European TSOs[34]

Cost-based: This model guarantees the TSO or DSO a certain pre-defined rate of return on its regulatory asset base. The regulated company has no incentive to minimise its costs because it can increase its profits by simply expanding the asset or cost base. The **Cost-based Plus** model is another version of the cost-based model in which a pre-defined profit margin is added to the costs of the company.

Incentive-based: This model is based on financial rewards and penalties to induce the TSO or DSO to achieve the desired goals - in form of an efficient cost base - whereby the regulated company is allowed some flexibility in how to achieve them. In general, incentive-based regulation aims at cost control – so that grid users later could benefit from lower costs in a quantitative way through lower tariffs in the future.

In 2019 the EC commissioned a study[40] to understand whether the existing regulatory framework (at national and EU level) incentivises energy infrastructure investments in innovative and security of supply measures that enable TSOs to meet future challenges (and not only short-term objectives). When it comes to security of supply, high level of consistency has been reported among Member States, and National Regulatory Authorities (NRAs) and TSOs are satisfied with the regulatory framework. In the case of innovation, differences among national regulatory frameworks are significant, and NRAs and TSOs clearly see room for improvement. Not only the term for innovation differs from country to country but also the same set of barriers has been repeatedly reported:

(A) There is a bias towards investments in new grid development (CAPEX-based investments) instead of grid optimisation technologies; TSO revenue is generally proportional to the volume of its CAPEX-based investment, but not increased in case of savings in TOTEX. Grid optimisation

[38] Council of EU Energy Regulators, "Report on Regulatory Frameworks for European Energy Networks 2019", 2020

[39] These methods guaranteed TSOs and DSOs a certain predefined rate of return on their regulatory asset base (rate-of-return model) and in some cases an additional predefined profit margin to their costs (cost-plus model). Incentive-based approaches use financial rewards and penalties to induce the TSO to achieve desired efficiency goals.

[40] EC, "Do current regulatory frameworks in the EU support innovation and security of supply in electricity and gas infrastructure?", March 2019

technologies can maximise the use of existing transfer capacity resulting in TOTEX savings or even to the deferral of new capacity requirements in the long term (so potentially lower costs paid by the consumers).

(B) Smart grid technologies reducing need for physical investments threaten (may reduce) TSOs' financial return so they are disincentivised

(C) TSOs are deterred from risky investments due to perceived high project risk and strict penalties for not meeting deadlines; this is another fact not enabling a level-playing field for CAPEX-based investments and grid optimisation solutions

(D) There is no specific provision related to innovation (e.g. allowances, duties…) and no sufficiently clear mandate for TSOs in certain innovative fields; the national implementation of the recast Electricity Directive should resolve this issue by setting clear rules on how NRAs can efficiently monitor and assess the development of smart grids

These factors clearly hamper the wide deployment of grid optimisation technologies whose benefits most of the times lie with Total Cost (TOTEX) reduction (barrier (A)) and potential deferral of physical infrastructure investments (barrier (B)).

A survey[41] ran by the Council of European Energy Regulators (CEER) in 2019 revealed that some TSOs have an efficiency requirement on OPEX and some of them have an efficiency requirement also on CAPEX. For example, the TSO in the UK has an efficiency requirement both on OPEX and CAPEX which is validated through a benchmarking process of the selected investments. The TSO in France has no efficiency requirement on CAPEX but sets efficiency objectives on controllable OPEX that need to be approved by the NRA. The TSO in Portugal has an efficiency factor on CAPEX (=1.5% for lines and 3% for substations) and a yearly one on controllable OPEX (=1.5%).

Interestingly, although most national frameworks include risk mitigation policies for CAPEX-based investments (the rate of return is guaranteed in the long term), the TSOs are insufficiently protected against risks in TOTEX-saving investments, for instance in case of technical failures, delays, or not achieved expected outcome (the rate of return is not guaranteed in the long term but is subject to regular NRA approval) . This fact also restrains TSOs from investing in grid optimisation technologies.

Indeed, NRAs understand very well the cost of new transmission projects (mature technology with enough competitors in the market to guarantee the best market price). They can thus approve CAPEX projects and secure a fix rate of return on that CAPEX (this is comfortable to them because the CAPEX is as low as it gets). For TOTEX-saving projects, which might be the case for grid optimisation technologies, the situation is different. There is less experience with their implementation. TOTEX savings could be delivered by the introduction of a specific technology but isolating the benefits of a specific solution is not straight forward. And how can one measure whether the new technology does indeed deliver on the promised savings? These are the questions NRAs are faced with. As a result, they are less keen on guaranteeing the TSO a fix revenue (ex-ante) until the TSO proves and delivers the promised savings. In some cases, NRAs will not commit to the revenue until the results are shown; this leaves all the investment

[41] Council of EU Energy Regulators, "Report on Regulatory Frameworks for European Energy Networks 2019", Annex 3 - Collected & filled out tables, 2020

risk with the TSO. As a result, many pilot R&D projects do not materialise further. The TSO is not keen on taking the risk all by itself when CAPEX-based investments are an NRA-back stable option.

This collective incentive problem is often referred as the “Averch Johnson” or ‘gold plating” effect and makes electric utilities to disregard TOTEX-saving investments even though they might have done the same job[42] as CAPEX-based ones. An interesting approach is applied in the UK[43]. The UK Office of Gas and Electricity Markets (OFGEM) implements a performance-based model, the RIIO model, that regulates the TSO and DSO revenues in function of three elements (Revenue = Incentives + Innovation + Outputs). This model offers to TSOs and DSOs a greater certainty of rewards for successful innovation.

3.2 Grid optimisation in system planning and operation

However, adapting the cost recovery regulatory framework to reflect such investment needs is not the only necessary update. The use of such technologies and their foreseen benefits should also be reflected in the system planning mechanism and in system operation. Their wide deployment would not only accelerate renewables integration but could also contribute to deferring certain grid expansion or reinforcement projects, to reducing new transfer capacity needs (e.g. new corridors) or to reducing re-dispatching and renewables’ curtailment needs.

Figure 6 shows that the integration of optimisation and savings’ levers in the ten-year grid development strategy of the French transmission system [44] (“*schéma décennal de développement du reseau”*, SDDR), can save more than €10 billion over the next 15 years. Such levers include the large scale use of automation and monitoring technologies, an optimised digitalisation of the grid focusing on areas with high renewables’ share, the prioritised development of certain interconnectors with significant impact in the period 2021 – 2035, the coordinated spatial and temporal planning of the development of offshore energy sources and other. To understand the order of magnitude, one should consider that the planned investments in electricity transmission in relation to annual electricity production are €20bn in France (2021-2030), €61bn in Germany (2020-2030), €5bn in Belgium (2021-2030), €12.4bn in the UK (2021-2026) and €6.2bn in Italy (2019-2023) (**Figure 7**)[45].

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[42] PennState College of Earth and Mineral Sciences, John A.Dutton e-Education Institute, “Introduction to electricity markets: The Averch Johnson Effect”

[43] OFGEM, “Network regulation – the 'RIIO' model”

[44] RTE, “Schéma décennal de développement du réseau”, 2019.

[45] These references are not mentioned for comparing net volumes of investments as the volume of planned investments depends on past investments (over- or under-investment) in each country and should be framed within the social welfare it creates. One should use these references only as an indication for the order of magnitude of estimated savings.

Figure 6 Estimated investment spending on the public transmission system between now and 2035[44]

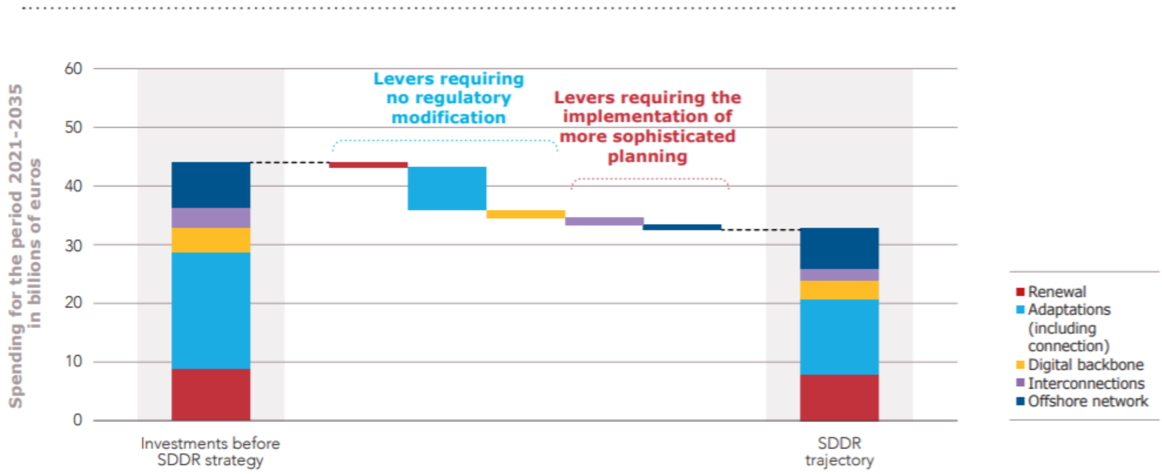
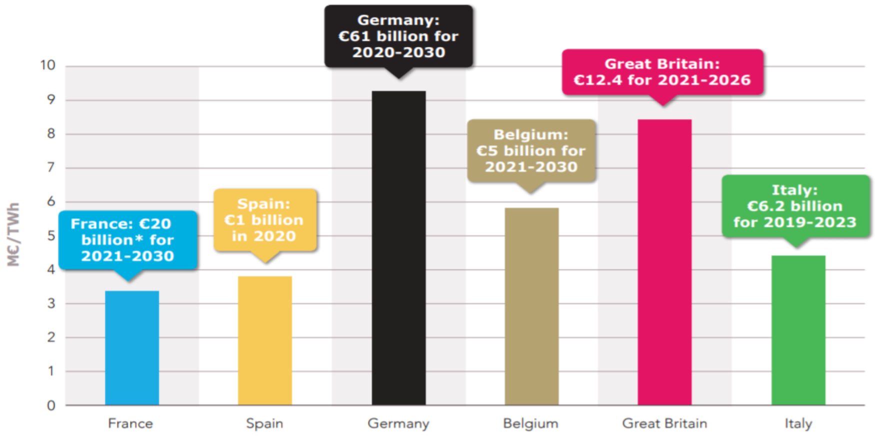


Figure 7 Investments in the electricity transmission system in relation to annual electricity production[46]



Certainly, adapting system planning to reflect new needs given the whole spectrum of short- and long-term uncertainties is a very challenging task. From a technical point of view, how can we capture the difference between the prospective system (planned system) and the real-time conditions during actual operations? This difference will be changing over time since the different system limits will also change with higher renewables' share and new demand patterns. Everyone agrees that additional unscheduled capability could be made available in real-time thanks to grid optimisation technologies. However, to which extent can we quantify and translate into reduced capacity requirements the contribution of grid optimisation technologies? When it comes to system operation, how should the additional capacity released by grid optimisation technologies, e.g. DLR, be used - for Intraday Operation, as a last minute resort (e.g. instead of load shedding) or for day-ahead market trade (e.g. to make financial transactions based on forward energy trade)? Which one will bring higher benefits to the consumer or lower needs for further grid development? To answer such questions, the different TSO units - system planning, market design, control centre - will need to maximise their coordination.

From a regulatory point of view, it is very important that the CBA processes in place - for defining TSO and DSO investments - can capture the potential system benefits from grid optimisation technologies. This might not be the case for all the identified solutions as their cost-saving potential in short timeframes (compared to the long lifetime of transmission assets considered in the CBA) cannon be always valorised in the current CBA processes. CBA should also reflect TOTEX-savings thanks to the reduced time that is needed for rolling-out such technologies in the grid. Finally, these processes should also consider other cost-effectiveness benefits such as the modularity of certain technologies or their mobility giving the TSOs flexibility to move them to different assets in function of actual system needs.

It is also crucial to introduce more flexible system planning mechanisms. In some countries the system planning process is too rigid and set for the next 5-6 years; this makes it difficult to reflect system needs that might arise during this period or the possible deployment of new technological solutions. **TSOs should be able to update their planning choices on a regular basis.** The level of achieved grid optimisation could be assessed as part of the TSO and DSO monitoring task for smart grid developments that is requested by the recast Electricity Directive with bi-annual reporting. Further to the above points, **the TEN-E regulation should set eligibility criteria for smart grid PCIs that will enable a much larger selection of such projects focusing on grid optimisation.**

3.3 Wind power for grid optimisation

The use of grid optimisation technologies can be vital for an efficient operation of the grid with increasing share of renewables, decreasing contribution from conventional synchronous generators and increased power demand. At the same time, the support from renewable energy plants, energy consumers and new technologies needs to step up. Wind energy is a versatile and flexible technology that can provide today ample support with regards to frequency and voltage control[46].

To fully exploit the flexibility potential of wind, the market design must be adapted. Wind generators need to be adequately incentivised to support grid operation whenever and wherever needed. This will enable controlling power flows in line with the physical constraints of the grid and consequently optimising the use of transmission capacity.

Some EU TSOs have designed frequency and voltage control services and recently congestion management services so that wind farms can technically provide and are adequately incentivized to do so. However, in most countries, this is still not the case. Although technical feasibility has been proved, the design of the services or the energy market setup is still very much based on the characteristics, benefits, and limitations of conventional power plants; thus, not adequately incentivizing for wind farms.

Often, this is also the case with Network (or Energy) Management Systems (EMS), the primary tool that TSOs use to manage their grids and hence integrate renewables. Real-time observability and controllability are basic needs to integrate renewables and a must for incentivizing the participation of reenables in system service. Today renewables are marginally modelled and represented in Network Management Systems; their characteristics and controls are not properly integrated. As a result, their potential cannot be fully exploited for optimising grid operation. Another aspect of this are the digital

[46] EirGrid Group, "System Services Compliance Procedures and Reports"

solutions to manage generation fleets (Generation Management Systems - GMS). Today, most of the industry is focusing on the O&M aspect of this management, but interaction between such GMS systems and grid EMS systems is key integration area in the future. The GMS optimises the financial output, ensuring the technical support for grid. A further key integration step to move towards the energy trading of the future and allow renewable integration is coupling the EMS and the market interaction system as recently Ireland's Single Electricity Market Operator (SEMO)[47] did. Another good practice is the Spanish Control Centre for Renewable (CECRE) allowing REE, the Spanish TSO, to have real-time observability (active and reactive power, and voltage real time measures) for any installation or group of installations higher that 1 MW and controllability48 over any generator of capacity higher than 10 MW.

Given the growing share of wind and the expected electrified demand in the next decades, resolving congestion will become more and more challenging and will require strategic regional approach. An interesting concept is the Flex-in-Market model[49] that maximises market-based dispatch and the innovative idea of Dispatch Hubs that give an extra degree of freedom for market to resolve congestions. In cases with insufficient grid hosting capacity, flexible grid access regimes allowing direct grid connection if the generator agrees with specific curtailment terms (instead of waiting for the completion of grid reinforcement) may accelerate wind integration.

Grid stability will also become one of the major power system challenges in the following decades. System operators are on the quest of new sources of inertia contributing to overall system strength and of black-start capabilities. Today, wind farm and PV plant converters can offer limited support in those areas. Both grid requirements and technology need to keep evolving while many questions arise regarding system needs and technology development[50].

In parallel, European TSOs have started applying the new grid connection requirements steaming from the European Network Connection Code[51] (entered into force in May 2019). The challenges are multiple; proving compliance regarding voltage control is not an easy task. Also, there are multiple interactions between new and old wind farms, connected at various voltage levels but all having to comply with different requirements at the same connection point. This is surely one of the biggest challenges in EU power systems for the years to come: translating grid code requirements into real system services and support.

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[47] ABB, "Ireland's Single Electricity Market Operator (SEMO) uses market trading infrastructure platform from ABB"

[48] REE can send a setpoint to renewable power plants connected to the transmission or distribution network (in coordination with the DSO) for reducing their production in less than 15 minutes.

[49] Elia Group, « Future-proofing the EU energy system towards 2030", December 2019

[50] ENTSO-E TG HPoPEIPS, "High Penetration of Power Electronic Interfaced Power Sources and the Potential Contribution of Grid Forming Converters – Outstanding questions", January 2020

[51] EC, "Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators", 2016

4 RECOMMENDATIONS

- **Grid expansion is crucial and needs to accelerate but grid optimisation and timely solutions must be considered first.** Mainly for two reasons; their short deployment time and their potential in reducing overall system costs. We should be exploring ways to maximise the use of the existing grid while complying with safety and security rules.

- **We must use the upcoming regulatory opportunities (EU Green Deal, TEN-E regulation revision, Clean Energy Package implementation) to improve the incentives for the use of grid optimisation technologies. TSO should be incentivised based on** TOTEX-savings instead of a simpler CAPEX-based approach. Adequate risk mitigation policies should be designed also for TOTEX-saving solutions.

- **The use of grid optimisation technologies should be reflected in system planning - as a real alternative to traditional network development solutions - and in system operation;** maximum cooperation among different TSO units (system planning, market design, control centre…) will be needed to fully exploit the potential of grid optimisation technologies.

- **A change of paradigm towards deeper cooperation and information exchange among the different stakeholders (generators, technology suppliers, TSOs, DSOs…) is essential, both in planning and operational time frame.**

- **The system planning mechanism should become more flexible to integrate on time evolving needs of the system or new technology developments**. TSOs should be able to update their planning choices, including the deployment of grid optimisation technologies, when justified based on their efficiency requirements. **The respective CBA process should be able to reflect the benefits offered by grid optimisation solutions**.

- **Smartness monitoring can be an efficient tool to adjust system planning decisions to evolving optimisation needs**. Benchmarking of available technologies must be organised, based on operational experience and open data. A strategic approach for sharing the knowledge that has been gained through new innovative deployments will be beneficial to all stakeholders.

- System planning should focus beyond ten years and look at projects required in 20+ years' time. **We need to optimise modelling and planning of key transmission corridors with adequate capacity for future increases in power flows.**

- **Finally, we need to roll out ancillary services that distributed renewable generation assets can provide.** To fully exploit the flexibility potential of wind, market design must be reviewed. Wind generators need to be adequately incentivised to support grid operation whenever and wherever needed.

ANNEXES

ANNEX A. TECHNOLOGIES DEFINITIONS

Table Technologies definitions

Technologies	Definitions
ADVANCED MONITORING	
Dynamic Line Rating 	Dynamic line rating is a way to operate overhead power lines closer to thermal limits without compromising safety. Real-time monitoring of the line rating and line safety enables control of line load so that it utilizes maximum capacity without exceeding the physical safety limits. Advanced software options offer grid capacity forecasts, for intraday or day-ahead operations. International standards provide guidelines on how to calculate the conductor cooling effect by surrounding environment (Cigré TB 498 and IEEE 738-2012 among others). DLR systems rely on field measurements of actual conductor condition (temperature, sag, clearance) as well as local environmental parameters (solar irradiation, ambient temperature, local wind). Sensors are deployed on critical spans that constrain most the line rating. These are spans that are at high risk to reach the maximum permissible conductor temperature first, due to unfavourable weather conditions, or to reach the maximum permissible sag first, because of clearance limitations. Furthermore, wind is the best ally of DLR because of its significant cooling effect on overhead conductors. However, correct measurement of this parameter bears heavy implications on the stakes of DLR and the correct balance of risks and opportunities. The natural destination of DLR systems is amongst EMS, ADMS or DERMS tools. Therefore, transfer of data streams under standard telecontrol protocols and system integration is the final phase of deployments. This requires technical alignment for data handling and communication arrangements between system vendors and users. Thermal Line Monitoring (LTM) can also be achieved by means of phasor measurements. The function of the LTM application is the online average line temperature calculation based on phasors measured at both ends of the transmission line. For LTM there are no additional sensors necessary along the corridor. With phasor measurements taken by two Phasor Measurement Units (PMUs) at the beginning and end of a transmission line, LTM is the most cost-effective solution for investment and operation. Typically, no costs are incurred for the transmission of the measurement values.

Transformers Fleet Digitalisation[52] 	ETM stands for Electronic Transformer Monitor. Future of an efficient and safe transformer fleet and grid management will be necessarily driven by digitalisation of critical assets to allow TSO to prevent, predict, plan and act. Transformer hub aggregator enables real-time management of a transformer by monitoring key health parameters such as oil temperature, ambient temperature, and load. The modular and scalable design allows also add other relevant monitoring information as DGA, bushing, tap changer condition. Beyond data collection, the intelligence embedded at device level using IEC, IEEE models combined with ML algorithms provide aging models, hot sport calculations, dynamic overloading capabilities with aging considerations. Cybersecure remote communication capabilities allow real-time communication through secured network, cellular or wireless. Firmware updates and modularity allows to add features and sensors as required for a proper life-cycle-management of the assets as they age.
Asset Performance Management[53] 	Asset performance management tools transform real-time and historical asset data into strategic insights on the health of TSO mission critical assets. It consolidates data on the assets and makes it available to key stakeholders on a dynamic and timely basis providing visibility to potential assets failures by evaluating which assets can be extended beyond their expected life and which need to be maintained or replaced. It focuses limited maintenance resources on the assets that need help (critical and poor health) and provides justification to defer maintenance on healthy assets. This solution can be delivered as a service via the cloud (SaaS) or perpetually licensed for an on-premise installation depending on the size of fleet to manage.
ADVANCED SYSTEM OPERATION CONTROL DEVICES	
Phase Shifting Transformer[54,55] 	Phase Shifting Transformers (PSTs) are electro-magnetic devices, like conventional transformers that are introduced in an existing transmission line. A PST contains two sets of windings, one in series and the other in parallel. It controls the power flow by adjusting the phase angle between the sending and the receiving ends of the PST and injecting voltage through the series windings. A PST allows the transmission operator to control the power flow through a transmission line. Using this device, the flow through heavily congested lines can be reduced and shifted to transmission lines with spare capacity. This means that the transfer capacities rise as congestion diminishes. Furthermore, PSTs are relatively inexpensive devices, when compared to new transmission lines, and can often be placed in an existing substation.
Solid-state Transformer[56]	Solid-state transformers are electro-magnetic devices having all the functionalities of conventional transformers but also a set of supplementary benefits such as reduced size, allowing bidirectional flows, providing reactive power compensation, surge protection, mitigation of voltage sags and harmonics, voltage regulation, DC connectivity and reduction of short-circuit currents.

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52 ABB, "Transformer service"

53 ABB, "Ellipse APM User Guide Release 5.2.0.0"

54 National Renewable Energy Laboratory, "Effective Grid Utilization: A technical assessment and application guide", April 2011-September 2012

55 ABB, "Phase-shifting transformers (PST)"

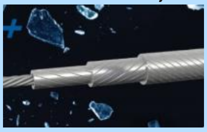
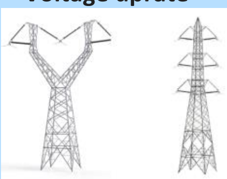
56 R.P.Londero, A.P.C.d.Mello and G.S.da Silva, "Comparison between conventional and solid state transformers in smart distribution grids," 2019 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America), Gramado, Brazil, 2019, pp. 1-6, DOI: 10.1109/ISGT-LA.2019.8895327.

Static Synchronous Series Compensator[39,57] 	The Static Synchronous Series Compensator (SSSC) appears to the system as an adjustable synchronous voltage source connected in series with a transmission line. This connection enables the device to vary the effective impedance of the transmission line by injecting a voltage containing an appropriate phase angle in relation to the line current. The system enhancements include increased power transmission capability, improved system stability, reduced system losses, reduced voltage drop, and optimised (balanced) power flow along parallel lines. SSSC devices can also be used to increase (or decrease) current flow on a line, and even balance the current flows in parallel lines.
Modular power flow control technology [58] 	Modular power flow control technology is a single-phase, modular-SSSC that injects a leading or lagging voltage in quadrature with the line current. Distinct from legacy SSSCs, SmartValve is transformerless and uses an integrated, fast-acting bypass for protection from system faults. A SmartValve deployment is connected in series with a utility facility, operates at line potential and has no connection to ground.
Thyristor-controlled Series Compensator[39, 59] 	The TCSC is an enhanced conventional series capacitor that uses a thyristor-controlled reactor to provide a continuous and rapidly variable series compensation system. In addition to providing the benefit of a fixed series capacitor, TCSC also provides an additional advantage of power flow control by altering the series impedance.
Static Synchronous Compensator (STATCOM)[39, 60] 	STATCOM devices are shunt-connected, reactive-power compensation equipment capable of generating and/or absorbing reactive power. These devices use voltage source converters which make them appear as an adjustable voltage source behind a reactance, and as such do not require capacitor or reactor banks to generate/absorb reactive power. STATCOM devices allow independent control of output current over the entire inductive/capacitive range, irrespective of the system voltage. This means that the STATCOM can provide voltage support during periods of low system voltage (i.e., faults), and in other situations where system voltage collapse is of concern. They can be classified as a voltage controller and are primarily used to improve the voltage stability of the transmission system. Indirect system benefits are also applicable but not necessarily directly attributable to the STATCOM device. (NREL reference).
Static VAR Compensator[39, 61] 	SVC is a shunt-connected, static generator and/or absorber of reactive power, in which the output is varied. SVCs are used mainly to regulate system voltages; these devices combine thyristor-based power electronics with inductors and/or capacitors to rapidly and accurately produce or consume reactive power. SVCs are voltage control devices and can enhance both the steady-state and transient voltage stability of the transmission system.

[57] Electrical India, "Simulation & analysis of static synchronous series compensator", July 2016
[58] Smart Wires, SmartValve
[59] ABB, "Thyristor controlled series compensation"
[60] GE Grid Solutions,"Static Synchronous Compensator"
[61] GE Grid Solutions, "Static Var Compensator"

Grid Booster/Virtual power line[62,63]	Grid boosters/Virtual power lines are large battery storage units, placed at strategically favourable grid nodes, usually at both ends of frequently congested lines, able to support the grid in an N-1 event. Unlike conventional power stations, grid boosters can jump in within a few seconds. They use controllable loads (e.g. a controllable consumer) ahead of the bottleneck in conjunction with an easily activated energy source (such as a big battery) behind the bottleneck. The controllable load takes up the electricity coming in ahead of the bottleneck which cannot be transported any further. The battery supplies the consumers behind the bottleneck with energy after just a few seconds. In this way, the grid boosters can cover the period until conventional power stations can take over. At present, part of the transport capacity available in the transmission system is kept as a security reserve to cope with potential faults, and thus remains unutilised. The quick response time of the grid boosters could enable part of this reserve to be used to transport electricity.
Adaptive Network Protection	Protection schemes on power system level are called System Integrity Protection Schemes (SIPS). SIPS is a concept of using system information from local as well as relevant remote sites. SIPS send this information to a processing location to counteract propagation of the major disturbances in the power system. SIPS is adapted to the power system situational awareness and encompasses with Special Protection Schemes (SPS), Remedial Action Schemes (RAS), additional schemes such as, but not limited to, underfrequency (UF), undervoltage (UV), out-of-step (OOS), etc. Adaptive protection scheme allows to change the coordination of protection schemes to achieve the high availability of power supply and reduce unnecessary trips. An example use case of adaptive protection scheme is the dynamic change of a load encroachment setting based on the available short cut power on a bus node.
Synchronous Condenser[64, 65] 	A synchronous condenser is mainly a generator, such as those used on the central power plants. It provides short-circuit power and reactive power (voltage regulation) to the power system. In power plants the generator is powered by the steam turbine and delivers power to the system. The synchronous condenser is only powered by the power system in style with a conventional electric motor. The main design parameters of a synchronous condenser solution are the short-circuit power, the capacitive and inductive reactive power. Adding short-circuit power to the grid can be considered the main product of a synchronous condenser. Reactive power and voltage control are by-products, which can be provided better and more economically with an SVC or a STATCOM.

[62] German Federal Ministry for Economic Affairs and Energy, "What is a grid booster?", February 2020
[63] Energy Storage, "France's grid battery 'experiments' take aim at creating market fit for carbon neutrality", March 2020
[64] ABB, "Synchronous Condenser System"
[65] Siemens, "400 kV S/S Bjæverskov Synchronous Condenser", September 2012

Grid Forming Converter[66,67] 	Grid-forming control can build a grid voltage and simultaneously synchronize with other converters or generators. Thus, they can work in parallel operation while building the grid voltage. Various implementation concepts for grid-forming controls have been suggested by different authors such as virtual synchronous machines, droop control, direct voltage control or enhanced current control. ENTSO-E divides power park modules into three classes, from which Class 3 can be understood as grid forming, because it includes requirements which mean a grid forming behaviour in its consequence namely to create system voltage, to contribute to inertia and to support first cycle survival. Further requirements for Class 3 are to contribute to fault level, to act as sink for harmonics and unbalances and to prevent adverse controller interactions.
LINE/VOLTAGE UPGRADES	
High Temperature Low Sag conductors[68], [69] 	The capacity of transmission circuits can be increased by replacing the existing conductors with higher capacity conductors. The higher capacity conductors can operate at higher temperatures with lower sag characteristics ensuring critical clearances from trees etc. are maintained. First generation HTLS conductors have been used successfully by EirGrid and ESB Networks since 2011, achieving a 60% increase in capacity on approximately 600km of existing 110 and 220 kV overhead lines.
Voltage uprate[62] 	Voltage uprating offers a rapid increase of power transfer capacity, whilst simultaneously reducing associated losses by using the existing overhead line route. The scale of the increase is approximately proportional to the increase in voltage and a conversion from 220 kV to 400 kV can increase capacity by over 80%. The standard approach to upgrading an existing 220 kV line to 400 kV involves the complete dismantling of the 220 kV line and rebuilding it as a 400 kV line, generally on the same alignment. New developments in electrical composite insulators have introduced the possibility of converting some existing 220 kV pylons to 400 kV pylons by replacing the head of the 220 kV pylon with that of a 400 kV design while retaining the existing foundations and base of the pylon.
DC TRANSMISSION	

[66] B. Weise, A. Korai, A. Constantin (DIgSILENT, Germany), “Comparison of selected grid-forming converter control strategies for use in power electronic dominated power systems”, 18th Int. WIW, Dublin, October 2019

[67] A. Roscoe, P. Brogan, D. Elliott, T. Knueppel, (Siemens Gamesa, United Kingdom), I. Gutierrez (Scottish Power Renewables, United Kingdom), J-C. Perez Campion (Iberdrola Renovables, Spain), R. Da Silva (Scottish Power Renewables, United Kingdom), “Practical Experience of Operating a Grid Forming Wind Park and its Response to System Events”, presentation, 18th Int. WIW, Dublin, October 2019

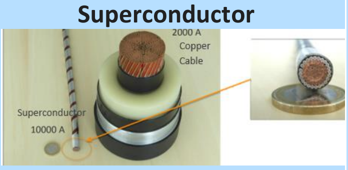
[68] Lamifil, “GAP^{+}: heavy-duty conductor”

[69] EirGrid, “Appendix to Ireland’s grid development strategy: technical report”, January 2017

HVDC technology[70] 	HVDC (High-Voltage Direct Current) is a highly efficient alternative for transmitting large amounts of electricity over long distances and for special purpose applications. HVDC is the method of choice for subsea electrical transmission and the interconnection of asynchronous AC grids, providing efficient, stable transmission and control capability. Two basic converter technologies are used in modern HVDC transmission systems. These are conventional or “classic” line-commutated current source converters (LCCs) and self-commutated voltage source converters (VSCs). LCC-HVDC requires a strong synchronous voltage source in order to operate and is used primarily for connecting remote generation over long distances, grid interconnection and DC links in AC grid, overland or subsea, where conventional AC methods cannot be used. Today there are more than 170 installations in all parts of the world. A classic HVDC transmission typically has a power rating in the range 1’000 – 12’000 MW. They use overhead lines, cables, or a combination of cables and lines. VSC-HVDC is self-commutated with insulated-gate bipolar transistor (IGBT) valves and solid-dielectric extruded HVDC cables. VSC technology can rapidly control both active and reactive power independently of one another. Reactive power can also be controlled at each terminal independent of the DC transmission voltage level. Self-commutation with VSC even permits black start, i.e. the converter can be used to synthesize a balanced set of three phase voltages like a virtual synchronous generator. The dynamic support of the AC voltage at each converter terminal improves the voltage stability and can increase the transfer capability of the sending- and receiving-end AC systems. It can be used for connecting remote generation, grid interconnections, offshore wind connections, embedded DC links in AC grids, power from shore, city centre infeed and connecting remote loads. Presently, the ratings of VSC-HVDC are lower than LCC-HVDC. VSC-HVDC systems are now installed with a rating of 3,000 MW at a transmission voltage of ±525 kV, and higher ratings are under development.
AC to DC line upgrade[71]	In cases where finding corridors for building new overhead lines is difficult, new solutions for the upgrading of existing overhead lines are required. The conversion of existing AC lines into DC lines represents an alternative to upgrading the power carrying capability for the existing Rights-of-Way (RoW). The most common reasons favouring DC are power losses, investment cost for the same transmission capacity, long distance water crossing with transmission cables, asynchronous connection, increased power controllability, short-circuit currents, lower visual impact thus lower RoW cost.

[70] CIGRE WG B4.39, “Integration of large-scale wind generation using HVDC and power electronics”, February 2009

[71] D.M.Larruskain, I.Zamora, O.Abarrategui, Z.Aginako, Conversion of AC distribution lines into DC lines to upgrade transmission capacity, Electric Power Systems Research, Vol. 81, Issue 7, 2011, Pages 1341-1348, ISSN 0378-7796, https://doi.org/10.1016/j.epsr.2011.01.020.

Superconductor  	A superconductor is a material that can conduct electricity or transport electrons from one atom to another with no resistance. This means no heat, sound or any other form of energy would be released from the material when it has reached "critical temperature" (Tc), or the temperature at which the material becomes superconductive. Properties of superconductors include: (1) zero electrical resistance (when a superconducting material is cooled below its critical temperature, its electrical resistance reduces to zero), (2) high power density (superconductors can carry significantly higher levels of current and thus are capable of the transmission of higher power levels than copper. As an example, for 1GW a (100kV, 10kA) superconducting cable would be deployed instead of a (500kV, 2kA) copper cable, (3) smaller right of way (as superconducting cables have a smaller cross-section, the right of way required for their installation is much smaller compared to copper cables, (3) lower Cost (for bulk power transmission applications, the cost of a superconducting system is substantially cheaper than conventional technology)

ANNEX B. COMMONLY USED TECHNOLOGIES- FEEBACK FROM TSO

Table B.1 Commonly used technologies –feedback from TSOs

	ENERGINET	EIRGRID	RED ELÉCTRICA DE ESPAÑA	elia	TenneT Taking power further
Dynamic Line Rating	Deployed in critical corridors to monitor underground cables	Only test projects, currently not considered in system planning	Test projects but considered as a solution in the ongoing next NDP, to be considered both in system planning and operation.	Deployed in several lines, considered both in system planning and operation	Deployed in the north part of its grid, considered in system planning
Advanced system operation control devices (deployed and approved for deployment)	Synchronous condensers, Shunt compensators	Power guardian & router (SmartValve)	Phase-shifting transformers, FACTS (STATCOMS, TCCS...), grid booster (*), synchronous condensers (*), modal analysis in real time, advanced controls in HVDC interconnectors (*) Envisaged	Series compensation, Phase-shifting transformers to be deployed by 2022	TCSC, Phase shifting transformers, Synchronous condenser, STATCOM, Grid Booster

Line/voltage upgrades	Not discussed with WindEurope	Deployed pylons' head change	Deployed in limited cases	HTLS, New pylons	Limited use of HTLS, New pylons in the Netherlands
HVDC	Many interconnecti ons, existing & under development	Limited use	Existing (one HVDC VSC between France and Spain, and one between mainland and Balearic Island). Other HVDC envisaged or under-development with advanced controls	Interconnecti on with Great Britain, more to be deployed soon (interconnect ors with the UK and with Germany)	Offshore lines in the Netherlands, 4 onshore lines under development in Germany

Table B.2 Impact and challenges – aggregated feedback from TSOs

	Impact	Challenges
Dynamic Line Rating	- Contradictory feedback: it is considered very successful by certain TSOs while still quite immature by other	- It needs to be deployed with wide area approach - It requires good data communication & reliable long-term forecasting
Advanced system operation control devices	- There is no common view as there is a big diversification of needs in the different cases - Overall, the feedback based on current deployments is very positive	- Miscoordination issues among the different devices need to be considered - Sometimes a review of protection schemes & the addition of new devices might be required - The lack of observability in the distribution grid might not allow to

		fully exploit the potential of the technology - There is a lack of or inadequate incentives for its wide deployment
Line/voltage upgrades	- Overall, the feedback based on current deployments is very positive	- In HTLS projects, there might be noise restriction issues in some cases (when lines become much heavier) - Sometimes new permitting or many civil engineering works (= long outages) are required
HVDC	Overall, the feedback based on current deployments is very positive. VSC technology is preferred (as it can provide also reactive power/voltage control/ride through faults)	Unavailability might be an issue in certain cases Harmonic issues also might arise Interoperability issues between HVDC and wind farm converters might arise In some cases, there is no redundancy (single point failure)