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Innovative Grid Technologies for Ukraine Next Winter and Beyond: Four Challenges - Four Actions

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SUSANNE NIES

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Green Deal Ukraïna

Helmholtz-Zentrum Berlin für Materialien und Energie
Albert-Einstein-Str. 16, 12489 Berlin

Contact the authors

greendeal.ua@helmholtz-berlin.de

Content

Executive Summary: Four Challenges, Four Actions

Functioning and functional grids are key for energy security, energy markets and sustainability. And they underpin the ongoing electrification, meaning the rise of electricity in the EU's energy mix from about 24% today to around 60% in 2050.

Building high voltage grids takes on average twelve years in the EU and is very costly to consumers (IEA, 2025). There are technological solutions that can complement, improve, and sometimes even substitute new built grids. Innovative grid technologies, such as Dynamic Line Rating (DLR), power electronics or Battery Energy Storage Systems are mature and available technologies. Digitalisation and AI provide opportunities for the electricity system: backbone of our economies. While innovative grid technologies can be deployed faster and in a more economic and flexible way, their deployment is often prevented by inadequate regulatory frameworks, as well as a lack of an innovation mindset at the level of system operators and government.

How can innovative grid technologies support Ukraine´s transmission and distribution grids in the short-, mid- and long term? Indeed, generation investment is crucial in the light of massive destruction, as much as a more decentralised approach. At once, grid optimisation and grid expansion must be undertaken.

The following three numbers showcase the benefits from IGT, already for the next winter 2025/26:

- At least 500 MW more transfer capacity between Ukraine and neighbouring countries through the installation of SSSC on the Rzeszów-Khmelnytskyi line
- At least 1,530 MW more transfer capacity when using BESS, or even higher when using them combined with SSSC.
- 15-30% more transfer capacity on interconnectors and internally inside Ukraine, through the deployment of DLR.

Taking these steps will last but not least position Ukraine as an early adopter and testbed for innovative solutions.

The challenges faced by the Ukrainian power system since February 2022 are:

Firstly, the emergency challenge. Targeted and continued Russian attacks require emergency operation and fast repair campaigns. Ukraine´s power system is ageing much faster than under peaceful conditions, as it is operated in an extreme way, with fast ramp-ups and downs, stop and goes, stand-still and start again.[1] There are also technical challenges on the power network internally and on several interconnectors. These challenges are called unscheduled flows – or

[1] For a detailed overview on destruction, see the damage reports published by International Energy Charter (2023), Nies & Savytskyi (2024).

loop flows (challenge at the Moldova/Romania side and interconnectors to Ukraine); bottlenecks in the grid, called congestion (inside Ukraine) ; and impedance, meaning the opposition to the flows in a power line that prevent the nominal capacity of the line from being used (affecting the interconnector Poland-Ukraine Rzeszów-Khmelnytskyi). The increasing share of decentralised and small generation requires, in addition, a distributed generation management system at the TSO level.

Secondly, the West-East transfer challenge. The Ukrainian power system has lost its geographical supply-demand balance: instead of supply and demand in respectively East and West, there is now high generation in the West but low in the East. This requires substantial West-East transfers, which the system was not designed for. At the same time, according to discussions with TSOs Ukrenergo, PSE, and ENTSO-E, congestion, impedance and loop-flows in neighbouring countries diminish import- and transfer-capability

Thirdly, supply challenges in Kharkiv and Odesa, the second and third largest cities in Ukraine, are exacerbated by their proximity to war zones, which has caused extensive destruction of major power plants and substations. This challenge is also related to the above-mentioned West-East transfer one.

Fourthly, regulatory dysfunctionalities or delays in implementation pose a challenge to the power grid. From now until 2028,[2] Ukraine needs to implement the EU acquis on energy (Chapter 15), climate (Chapter 27), as well as on energy infrastructure (Chapter 21). If Ukraine wants to join the EU in 2030, the country will need to conclude all negotiations within the next three years, until 2028. There are many trade-offs between the war situation and the EU acquis implementation (such as data transparency or CBAM implementation) that must be properly addressed. Efficient grids require a fit-for-purpose regulatory setting that can be largely ´imported´ through the EU integration process. A fast track towards market coupling will lead to needed price signals also for grid efficiency.

Innovative grid solutions can contribute to addressing all four challenges.

Recommendations

The following four actions must be implemented by Ukrainian network operators, the regulator NEURC, IFIs, and Energy Community, national, regional and EU policymakers, solution providers and European and Ukrainian research centres to unleash the potential of IGT in Ukraine:

Firstly, on the Emergency Challenge:

[2] 2028 in case Ukraine wants to join the EU by 2030. In that case, the country needs to complete all negotiations by 2028.

- **Regional TSOs and Ukrenergo** should address bottlenecks through IGT, such as DLR and FACTS devices with no delay, to be able to ease the missing generation by a maximum of imports, within the margins of the 1.7 GW limit by ENTSO-E.
- **IFIs and other donors** should provide funding and loans for fast solutions and be innovative, such as in the funding of devices belonging to Ukrenergo but
- positioned in a neighbouring country (example Polish-Ukrainian interconnector).

Secondly, on the West-East Transfer challenge

- Beyond needed decentralised Generation **Ukrenergo** should deploy DLR to improve flows in central Ukraine and develop 800 MW battery storage through tenders, as recommended by Expro Consult, over the next 10 years.[3]
- **The Ministry of Energy of Ukraine** should put the needed investments on the agenda of IFIs through G7.
- **Ukrenergo and DSOs** should cooperate on the use of the 110 kV grid to diminish the transfer challenges, using transfer capacities from Romania and Moldova to Ukraine.

Thirdly, the supply of Kharkiv and Odesa

- **TSO, DSO, Regulator, and IFIs** should develop tailor-made solutions for both cities, deploying decentralised generation, developing a next-generation grid including batteries and IGTs. **The Ministry of Energy of Ukraine** should coordinate efforts and develop short-term scenarios, including IGTs, for the use of 110 kV.

Fourthly: Regulatory challenges

- **The Ukrainian Government and Parliament (Rada)** should adopt the Electricity Integration Package with no delay, to establish a framework for distribution system operators, enhance TSO-DSO collaboration, prepare for regional market coupling and improve price signals on the power market.
- **The regulator NEURC** should develop and adopt an efficient NOVA system to support the use of IGT and measure its implementation against a technology overview, such as Technopedia from ENTSO-E/EU DSO Entity.
- **TSOs and DSOs** should develop efficient collaboration on data sharing, IGT deployment and system planning, including within the relevant EU associations ENTSO-E and the EU DSO Entity. This should include developing a vision for the decentralised grid.
- **IFIs** should allow for joint projects, as many IGT are agnostic on which side of the border they are deployed.

[3] Study estimated the need for batteries for Ukrenergo by 800 MW in next ten years (ExPro Consulting, 2024).

List of Abbreviations

AAR Ambient Adjusted Rating

AC: Alternating Current

ADMS: Advanced Distribution System Management

AI: Artificial Intelligence

aFRR: automatic Frequency Restoration Reserve

ATT: Advanced Transmission Technology

BA: Balancing Authority

BEMIP: Baltic Energy Market Interconnection Plan

BESS: Battery Energy Storage Systems

CAIDI: Customer Average Interruption Duration Index

CAISO: California Independent System Operator

CAPEX: Capital Expenditure

CESEC: Central and South-Eastern Europe Energy Connectivity

CHP: Combined Heat and Power

DA: Distribution Automation

DC: Direct Current

DGMS: Distributed Generated Management System

DLR: Dynamic Line Rating

DSO: Distribution System Operator

EBRD: European Bank for Reconstruction and Development

EUDSO: European Distribution System Operator Entity

ENTSO-E: European Network of Transmission System Operators

EPC: Engineering, Procurement, and Construction

FACTS: Flexible Alternating Current Transmission Systems

FCR: Frequency Containment Reserve

FLISR: Fault Location, Isolation, and Service Restoration

GET: Grid Enhancing Technology

GW: Gigawatt

HPP: Hydro Power Plant

HVAC: High Voltage Alternating Current

HVDC: High Voltage Direct Current

IBR: Inverter-Based Resource

IFI: International Financial Institution

IPS: Integrated Power System (IPS/UPS)

FMBC: Flow-Based Market Coupling

kV: Kilovolt

LLM: Large Language Model

mFRR: manual Frequency Restoration Reserve

MW: Megawatt

MWh: Megawatt hour

NEURC: National Energy and Utilities Regulatory Commission

NPP: Nuclear Power Plant

NTC: Net Transfer Capacity

NTO: Network Topology Optimisation

OPEX: Operating Expenditures

PBR: Performance-Based Regulation

PCI: Project of Common Interest

PECI: Projects of Energy Community Interest

PJM: Pennsylvania-Jersey-Massachusetts Interconnection. A regional transmission organisation that operates across 13 U.S. states.

PMI: Project of Mutual Interest

POD: Power Oscillation Damping

PSP: Public Sector Entity

PV: Photovoltaic

RES: Renewable Energy Sources

RR: Replacement Reserve

SAIDI: System Average Interruption Duration Index

SCADA: System Control and Data Acquisition

SSSC: Static Synchronous Series Compensator

T&D: Transmission and Distribution

TPP: Thermal Power Plant

TRL: Technology Readiness Level

TSO: Transmission System Operator

TYNDP: Ten-Year Network Development Plan

UCTE: Union for the Coordination of Transmission of Electricity

UPS: Unified Power System

VPP: Virtual Power Plant

VSC: Voltage Source Converter

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1 Introduction

This paper investigates the use and benefits of innovative grid technologies (IGTs) in the Ukrainian electricity system. It firstly presents the state of the Ukrainian power system, followed by an overview of IGTs. The third section describes the application of such technologies in Ukraine. This research is based on available data and reports, as well as qualitative interviews with the Ukrainian Transmission System Operator (TSO), Ukrenergo, and technology companies.

IGTs are sometimes also called Grid Enhancing Technologies (GET) or Enabling Network Technologies (ENT). They improve the efficiency of power networks and complement new powerlines, sometimes even provide alternatives for them. The Ukrainian use case is particularly interesting as the stress on the power system is extreme and requires fast and deep solutions at affordable costs. What is more, Ukraine is open to trialling new solutions, and is, very much like Estonia, an early adopter of digital technologies. We could, for example, quote the government app Digital State, or Diia. Diia allows access to eleven digital documents (such as passports) and twelve state services (*DIIa*, n.d.). On global innovation indices, Ukraine is ranking high,[4] so that conditions are united for making the country a testbed for next-generation grid solutions. In a grim sense, the war has already turned Ukraine into a *de facto* testbed - for instance, in the areas of cybersecurity, drone usage, and infrastructure resilience, the country must constantly adopt new solutions, learn, test, and improve. Given this, Ukrainian power engineers are sharing their experience with international peers already, such as in the area of resilience of cybersecurity.

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All comments and feedback for this paper are welcome at the Green Deal Ukraïna project. Readers are encouraged to contact greendeal.ua@helmholtz-berlin.de.

[4] See, for example, the Global Innovation Index ranking, where Ukraine was ranked 60th in 2024. (Note: Falling back from place 55 in 2023, due to the war).

2 The Ukrainian Power System State of Play

Ukraine´s energy-intensive industry is historically concentrated in the East. Demand was met through big central power plants: nuclear, hydro, and coal. More than 73% of generation assets and half of the power lines have been damaged or destroyed since the beginning of the full-scale Russian invasion in 2022. It is obvious that rebuilding the generation has to be a priority (Ukrenergo, 2024). Supply losses have been uneven and relate mainly to the East: they include the 6 GW Zaporizhzhia Nuclear Power Plant and equally generators such as the Kakhovka dam with a capacity of 335 MW (GEM, n.d.). Kakhovka also had an important role to play for system stability, reactive power, frequency stability, black start capacity, etc. While industrial production has tremendously decreased due to the war, the supply of major eastern cities has become a challenge and now requires massive West-East transfers. Ukrenergo must operate the grid under reverse-load conditions for which it was never originally designed. Decentralised supply is a no-regrets option, also for the sieged cities, as it is fast and economic to build, and decreases the risk of attacks, that is unevenly higher for big central units.

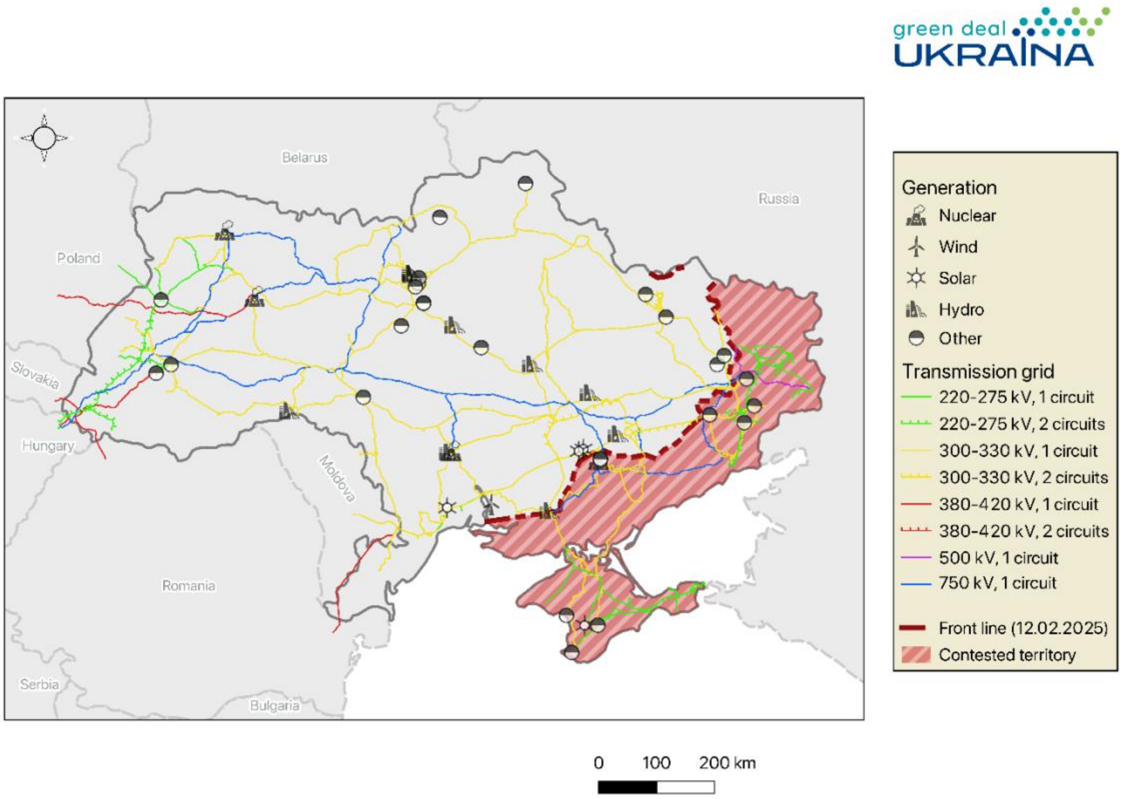
Furthermore, the imports to and exports from neighbouring countries are limited, because of technical constraints or market considerations. The available import capacity has nevertheless not even been used to its full potential – often only 1/3 - while loadshedding under shelling took place.[5]

In the future, Ukraine will need to build a lot more generation, here also decentralise its power system, modernise distribution, repair and replace parts of its prematurely worn-out transmission system and assets due to war.

The National Energy and Climate Plan 2025–2030 (2024), envisions 27% of renewables in overall energy consumption—comprising 33% in heating and cooling, 29% in electricity generation, and 17% in transport. The overall reduction of greenhouse gases (GHGs) (referenced to the 1990 level) is 65%. This is very ambitious, given that the current installed capacity of renewable energy sources (RES) is only 8.2 GW (UkraineInvest, n.d.). As is known, decentralisation comes with tremendous requirements on fit-for-purpose infrastructure; the traditional centralised system will not be able to cope with a decentralised supply without major adaptations and add-ins.

[5] For more details, please see Energy Community Secretariat (2024), as well as GDU (2025).

Figure 1: Power system: Generation and high voltage grid of Ukraine



Source: Green Deal Ukraïna (2025) (generators reflect their sites prior to the war, 2021)

Description of the Power System and its Shift from East to West

Electrification in Ukraine started in the early 20^{th} century, in a very similar way to other industrialised countries. This meant starting in major cities, such as Kyiv and Kharkiv and reaching the countryside only in the 1950s, post-war.[6] The Ukrainian power system developed as a big centralised system, with massive oversupply, heavy industry, and to date remains very centralised. The high-voltage power system in Ukraine has a total length of 19,000 km and includes 103 substations. Before synchronisation, the system featured more than 50 cross-border links. Heritage from Soviet times, Ukraine also operates a high-voltage 750 kV backbone grid, typically related to a huge supply (such as nuclear or coal power plants) or very high industrial demand, bulk long-distance transmission. The legacy

[6] The development was boosted by the Russian template GOELRO (*Gosudarstvennaya komissiya po elektrifikatsii Rossii*): a country-wide electrification plan, which was later expanded across the entire Soviet Union, from 1922.

750 kV links to Poland, Hungary, and Romania, where it has been dismantled except for the one to Hungary. Another Soviet specificity is 330 kV, that does not exist in Western Europe. Typical voltage levels in the EU are 110, 220 or 400 kV, with a tendency to replace 220 kV lines for higher rated 400 kV links, because of increasing electricity consumption.

Until February 2022, Ukraine and Moldova were connected through powerful 4.2 GW links with the post-Soviet IPS/UPS energy system. They synchronised on 16th March, after island test mode. This connection to Russia remains today for the occupied areas of Luhansk and Donetsk, as well as for Crimea.

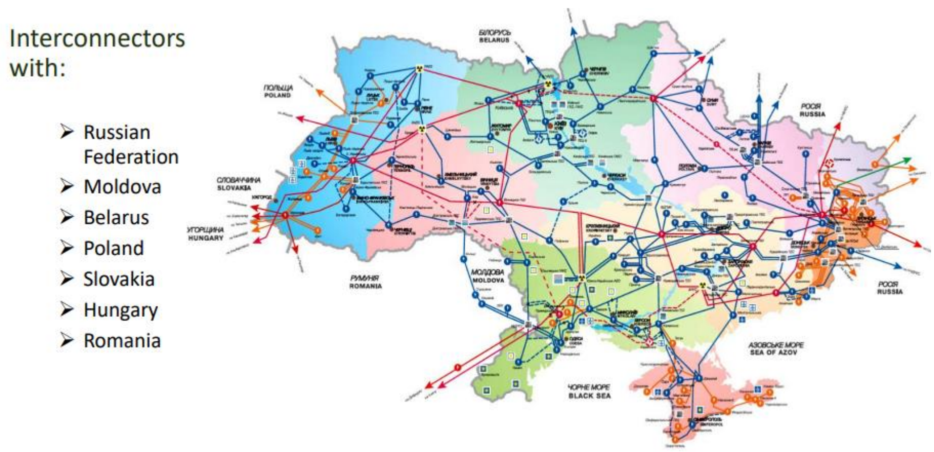
Table 1: State of synchronisation of Ukraine- government-controlled and occupied

Region	Power Grid Synchronisation
Ukraine (government-controlled)	ENTSO-E Grid (since March 16, 2022)
Crimea	IPS/UPS (Russian grid) (via Kerch)
Donetsk & Luhansk (DPR/LPR)	IPS/UPS (Russian grid)
Occupied South (e.g., Kherson, Zaporizhzhia)	IPS/UPS (where occupied)

Source: Green Deal Ukraïna (2025)

IPS/UPS today includes Russia, as well as Belarus, Georgia, and other countries of the former Soviet bloc. On the other hand, even before 2022 some supply islands in Ukraine, such as Burshtyn or Dobrotvir were connected to the ENTSO-E system, but did not form part of the Ukrainian system before synchronisation.

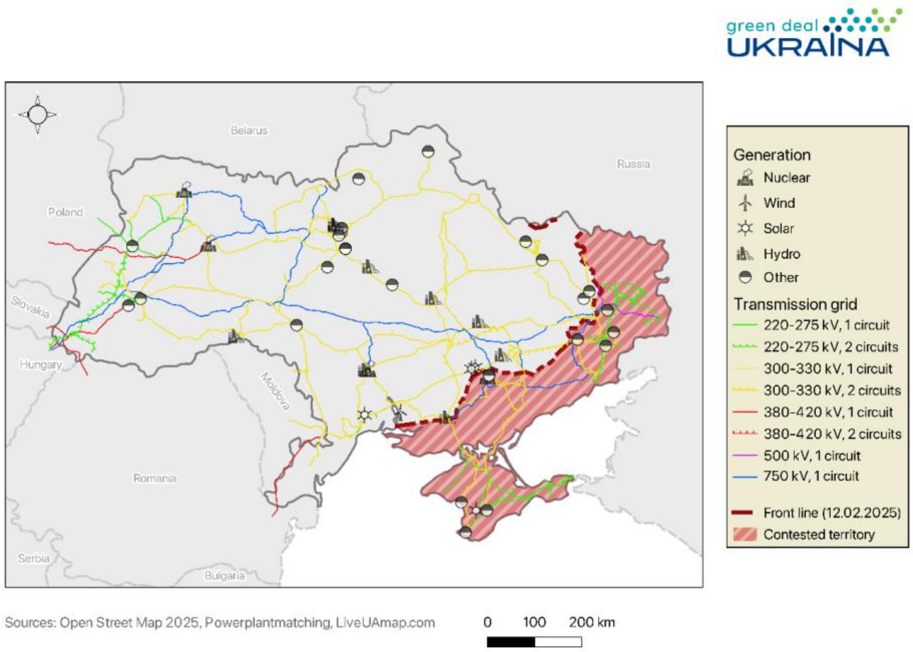
Figure 2: Interconnectors Ukraine to all neighbours, 2018



Source: CIGRE (2018)

Ukraine's electric power system was originally designed for much higher consumption and transfer in all directions. This provided some reserves and redundancy that helped to deal with massive damage from Russian attacks, but now requires a redesign to meet new challenges, including bi-directional trade with EU Member States, decentralisation of generation capacities, and integration of variable renewables.

Figure 3 Grid Map Ukraine, including interconnections, 2025



Source GDU 2025

Infrastructure links are either economic bridges or captivity chains, with roles altered by changing geopolitical and policy environments. On March 16, 2022, the continental European electricity grid and the grids of Ukraine and Moldova became connected and synchronised. Synchronisation implied connecting the large 50 Hertz alternating current (AC) system of continental Europe with the Ukrainian and Moldovan electricity grids.

In the Ukrainian case, synchronisation meant reconnection between Burshtyn Island and the rest of the Ukrainian system, plus additionally connecting Moldova to Romania. The Dobrotvir link did not form part of the synchronisation step.

Synchronisation started with limited import and export windows to protect the Continental European System and to trial the new link first. Since March 2022, the allowed exports and imports have changed multiple times.

Table 2: Allowed export and import capacities based on ENTSO-E announcements 2022-25

Date	Export to Ukraine	Import from Ukraine	Comments
16 March 2022	0 MW	0 MW	Emergency Synchronisation Ukraine-ENTSO-E (Continental Europe) was decided by the EU Commission and the ENTSO-E. In the first two stages of synchronisation, there were no commercial exchanges.
26 April 2022	0 MW	0 MW	Ukraine becomes an ENTSO-E observer member. The first phase of synchronisation trialling was successfully finished.
30 June 2022	-	100 MW	Start of commercial trading through Moldova-Romania.
16 February 2023	700 MW	400 MW	Massive Russian attacks on energy infrastructure from September 2022 to Spring 2023 ended exports from Ukraine.
27 March 2023	850 MW	400 MW	Emergency assistance was agreed upon between the EU and Ukraine.
15 April 2023	1050 MW	400 MW	Start of commercial power exchanges through the rehabilitated Rzeszów- Khmelnytskyi line.
20 June 2023	1200 MW	400 MW	

1 December 2023	1700 MW/h	400 MW/h	The ENTSO-E announces that as of 1 January 2024, Ukrenergo will become the 40th full member of the ENTSO-E.
27 February 2024	1700 MW/h	550 MW/h	
March to December 2024	No change	No change	Massive attacks on Ukraine's energy system started in 2024 on March 22nd, with a major attack on May 8th. and in November 2024. More than 9 GW of thermal capacities lost. Russian energy terrorism continues with now more than 30 attack waves in 2024 alone.
1 December 2024	2100 MW/h	No change	The ENTSO-E announced on 29 October 2024, that it will increase the export capacity limit to Ukraine and Moldova to 2.1 GW. In addition, the capacity limit will be reassessed monthly starting in March 2025.
1 April 2025	1700 MW/h	650MW	Now, capacity is calculated by the ENTSO-E expert group involving the Regional Coordination Center TSC-NET. The exports from Ukraine have increased by 100 MW based on the ENTSO-E expert group decision.

Source: Green Deal Ukraïna (2025), based on information from the ENTSO-E.

Connecting a country at war indeed corresponds to additional risks, especially when exporting to the centre, to continental Europe. Risks are much lower in the case of exports. Every power line has a so-called Net Transfer Capacity (NTC), calculated in hours. TSOs will always avoid using the full NTC, as this disempowers them from applying emergency solutions in case of unforeseen incidents. This is the reason why the ENTSO-E sets limits to allow transfers with Ukraine in both directions.

3 Overview on Innovative Grid Technologies

The very concepts of Innovative Grid Technologies, or Grid Enhancing Technologies have made it in the last years into the vocabulary of power system engineers, policy makers, regulators, and academia.

Innovative grid technologies (IGTs) constitute, together with grid reinforcement or reconductoring as well as the deployment of new grids the three elements of the toolbox of grid operators. All elements are needed, and are chosen, depending on location and system needs.

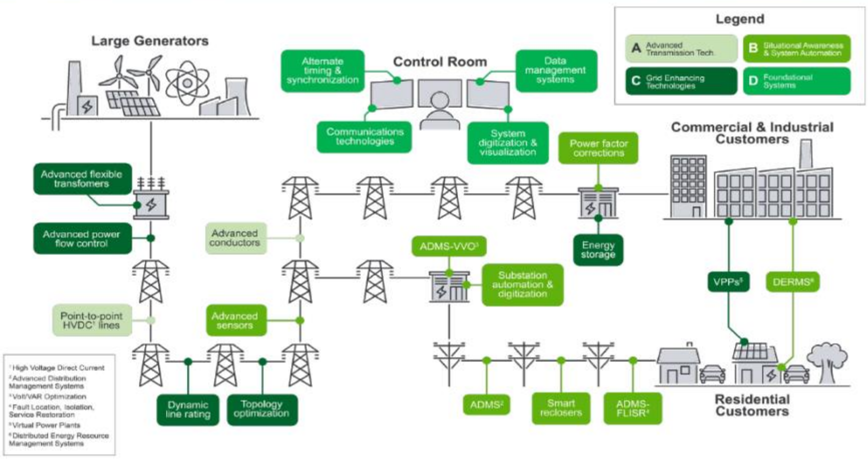
IGTs encompass broadly the following four groups of solutions:

- **Foundational solutions**, such as communication system, data management system, system digitisation and visualisation, alternative timing and synchronisation.
- **Grid Enhancing Technologies (GETs)**, such as Dynamic Line Rating (DLR), Flexible AC Transmission System (FACTS) devices, batteries and storage as network assets, advanced flexible transformers, advanced power flow control, or virtual power plants.
- **Advanced Transmission Technologies (ATTs)**, such as High Voltage Direct Current (HVDC) or also superconductors. These are used to improve bulk transmission across broader regions.
- **Situational awareness and system automation solutions**, such as Advanced Distribution Management Systems (ADMS); Advanced Fault location, Isolation, System Restoration (FLISR); Volt/VAR optimisation; substation automation and digitisation; as well as advanced sensors. These tools are essential for power system security and stability.

This study does not describe the tools in greater detail but refers interested readers to the existing studies or the Technopedia by ENTSO-E/EU DSO entity or respective websites of currENT or WATT.

Figure 4**Error! Reference source not found.** provides an overview of IGTs in the power system, showing where each solution is applied and located.

Figure 4 Overview on IGTs in the power system



Source: Figure 3 (White et al., 2024)IGTs have gained prominence recently, for example, in the Grid Action Plan by the EU, and justified by the fact that the energy transition is very much an electricity uptake, requiring a strong and updated power network, both on distribution and transmission.

The WATT Coalition in the U.S. - short for the Working for Advanced Transmission Technologies - was founded in November 2017 during a workshop at Idaho National Laboratory, bringing together technology firms advocating for grid-enhancing solutions (Tsuchida et al., 2021). Europe followed three years later with the foundation of currENT, short for Enabling Network Technologies, in 2020. It is not surprising that the U.S. was leading the way, as several innovative start-ups on IGTs originated there. The WATT and currENT[7] work hand in hand, with their websites providing up-to-date information on technologies and use cases.

Regulatory forums, such as the Energy Infrastructure Forum (European Commission, n.d.), have seen the topic rise. Regulatory incentives for alternatives to ´more copper in the ground’ form part of the discussion at the national regulators and ACERs level.

Several reports have been published on innovative grid technologies in the last seven years or so, in parallel to the rising insight that solely grid expansion could not solve the electrification paradigm of the energy transition, as it was impossible, given the slow motion of new build- 12 years on average for a new line in Europe (ENTSO-E, 2021), as well as high cost.

The ENTSO-E, the European Network of Transmission System Operators, launched its Technopedia as part of the Research and Innovation workstream in 2018. Technopedia

[7] The author was the founding member and the first board chair of currENT.

encompasses innovative grid technologies, listing them together with use cases and TRL assessments (that are sometimes too conservative). The tool has been recently integrated, in April 2025, into the EU Grid Action Plan, and looks also into collaboration with the European DSO Entity (EU DSO), with the ENTSO-E Technopedia becoming now a TSO/DSO Technopedia (European Commission, 2023).

Table 3 below provides an overview of these reports.

All these reports emphasise the same key message: even though IGTs have reached advanced Technology Readiness Levels, they fail to be deployed internationally at the scale they should be. The reasons are obvious: grid operators, driven by institutional risk aversion and a strong focus on system security, lead to a conservative 'business as usual' approach – ironically ignoring that precisely this approach constitutes a risk to system security.

For this reason, the introduction of the so-called Nova principle is important.

Table 3: Reports, websites, publications on IGTs

Report	Contents
ENTSO-E (2021)	The Technopedia by the ENTSO-E lists, describes, and provides use cases for several grid technologies. It includes TSO and nowadays DSO assumptions on TRL levels, which are sometimes contested by technology providers (ENTSO-E, 2021). The platform became a joint project with the EU DSO in April 2025, as part (Action 7) of the implementation of the EU Grid Action Plan.
currENT Europe Grid Compass (2025)	The Grid Compass by currENT Europe is an interactive tool that shows network performance and grid losses, using publicly available data. Total losses are presented in GWh, measuring the difference between injected energy over energy taken off the grid. A lower GWh indicates a better score with less line losses.
White et al. (2024)	The *Innovative Grid Deployment* Liftoff report is focused on identifying pathways to accelerate the near-term (3-5 years) deployment of key commercially available but underutilised advanced grid technologies and applications on existing rights-of-way transmission and distribution systems.

currENT (2024)	According to this study, IGT can increase the capacity of the existing network by 20-40% by 2040.
Chojkiewicz et al. (2024)	The paper focuses on the integration of renewable energy sources and the corresponding need to increase transmission capacity at speed and scale. The research elaborates on reconductoring and the alternative of advanced conductors, being considered wrongly as niche technology. According to the authors, large-scale reconductoring with advanced composite-core conductors can effectively double transmission capacity, with limited additional permitting.
Siegner et al. (2024)	This brief investigates how the use of IGT could unlock the queue of transmission grids in PJM. It finds that Grid Enhancing Technologies could enable 6.6 GW of solar, wind and storage projects by 2027 in PJM. It also states that GETs are significantly cheaper than default network upgrades. Approximately USD 1 billion would be saved year by year in the PJM area.
Pfeifenberger et al. (2023)	The report highlights how modern HVDC transmission, especially VSC-based systems, offers system operators enhanced grid flexibility, improved interregional optimisation, reduced congestion, and better integration of renewable generation, drawing on successful deployments in Europe and the US (CAISO)
Brunekreeft et al. (2022); Brunekreeft & Meyer (2011)	Expert on innovative grid regulation to incentive the use of technologies and reduce costs for energy transition. Prof. Dr. Gert Brunekreeft – Bremen Energy Research.
White et al. (2024)	This report by the U.S. Department of Energy presents the advantages of virtual power plants for the deeper integration of renewables.
Zogheib (2022)	The implementation of the NOVA principle in Germany: a systematic approach to foster innovation and performance-based solutions in power networks. Best master's thesis of the program (under the supervision of Susanne Nies at TU Berlin)

U.S. Department of Energy (2022)	The U.S. Department of Energy's 2022 report, *Grid Enhancing Technologies: A Case Study on Ratepayer Impact*, evaluates the integration of Dynamic Line Ratings (DLR) and Power Flow Control (PFC) technologies in New York's transmission network. The study demonstrates that deploying these technologies can alleviate grid congestion, reduce renewable energy curtailment, and defer costly infrastructure upgrades, leading to significant cost savings for a ratepayer.
Tsuchida et al. (2021)	The Brattle Group's 2021 report, *Unlocking the Queue with Grid-Enhancing Technologies*, demonstrates that integrating three Grid-Enhancing Technologies (GETs)—Dynamic Line Ratings (DLR), Advanced Power Flow Control (APFC), and Topology Optimization—into the Southwest Power Pool (SPP) grid could enable the integration of 5,200 MW of wind and solar capacity by 2025, more than doubling the amount achievable without these technologies. This approach would result in annual production cost savings of USD 175 million, a payback period of just six months, and a reduction of approximately 3 million tons of carbon emissions per year.
currENT (2021)	The 2021 study *The Benefits of Innovative Grid Technologies*, commissioned by currENT and conducted by Consentec, assesses the potential of three advanced grid technologies—Dynamic Line Rating (DLR), Modular Static Synchronous Series Compensators (M-SSSCs), and superconducting direct current (DC) cables—to alleviate congestion in Europe's transmission networks by 2030. The findings indicate that deploying these technologies could reduce congestion and redispatch costs by over 90% and decrease renewable energy curtailment by 3 TWh annually, highlighting their complementary roles in optimising grid operations.
The World Bank et al. (2024)	The 2024 slide deck, titled "*Ukraine: Energy Storage and Ancillary Services Market Development Support – Role of Smart Grid Technologies in Ukraine*", presented by Ukrenergo, outlines Ukraine's strategic initiatives to enhance grid flexibility and resilience through the integration of smart grid technologies and energy storage systems. The presentation highlights the deployment of Battery Energy Storage Systems (BESS) and Static Synchronous Series

	Compensators (SSSCs) to mitigate low-frequency oscillations, increase export capacity, and support the synchronisation with the European grid, aiming to bolster the country's energy security amidst ongoing challenges

Source: Green Deal Ukraïna (2025)

3.1 The NOVA Principle

The so-called NOVA principle means that the optimisation or the reinforcement of networks should always be considered before building more grids. The principle is enshrined in the regulatory toolbox of the Netherlands, Germany. Countries like Austria, Belgium and Scandinavian countries use similar principles, not calling it NOVA.

While it is very important to have the principle and it is recommended to include it in grid regulation in all countries, it is crucial that the implementation of the principle is enforced. However, the challenge is that the NOVA principle, while it exists in law, is not sufficiently enforced in practice. Today, also in countries with the NOVA principle, the deployment of grid alternatives remains largely a judgement call by grid operators: if they deem that the traditional build out of grids is to be preferred, they will impose their view on the regulator. More transparency, e.g., through stakeholder consultations, as well as justification are needed in the respective grid development plans.[8] It is also obvious that administrative burden and regulatory obstacles will lead to avoidance by operators, rather than adoption and lift-off.

Table 4 The NOVA principle: comparing new built, reinforcement and IGT

	Grid expansion	Grid reinforcement	Innovative grid technologies
Time to deployment	Slow (Transmission 12 years av.)	2-24 months, depending on case	Fast 3 months to 5 years

[8] Prof. Gert Brunekreeft from Bremen University has published several studies and articles on how such regulation could be more efficient so that all options will be considered (Brunekreeft et al., 2022; Brunekreeft & Meyer, 2011).

Costs	High	30-60% cheaper than new lines	Low
Flexibility	No	No	High: Devices can be moved and upscaled (like Lego)

Source: Green Deal Ukraïna (2025)

3.2. The Advantages of IGTs

This section summarises the advantages of IGTs.

The first advantage is costs, which are largely below those of new-built grids. The second advantage is speed of deployment, which is, for example, about three months for Dynamic Line Rating and about six months for FACTS devices.[9] In Ukraine's context, where critical lines are overloaded and new construction faces wartime delays, such rapid relief can be invaluable.

[9] "IGTs can provide some capacity improvements quickly, which can in turn make it easier to schedule outages for the installation of larger projects like reconductoring or new circuits." (currENT, 2024, p. 47)

Table 5: Deployment timelines of IGTs in average

Advanced Grid Technologies and Applications		Initial deployment timeline for a utility (years)			Subsequent deployment timeline
		1-3	4-7	7+	
Bulk system solutions (on existing ROW)	Advanced Conductors				1–3 years
	Point-to-point HVDC				~2–5 years
	Dynamic Line Ratings (DLR)				<3–6 months
	Adv. Power Flow Control (PFC)				<3–6 months
	Topology Optimization				<3–6 months
T&D Capacity Relief solutions	ADMS-VVO				<1 year
	ADMS-DERMS				*Varies based on functions added*
	Energy Storage (as a T&D asset)				<1–2 years
	Virtual Power Plants (VPP)				*Varies based on market and VPP type*
	Power factor correction				<3–6 months
Conventional alternatives	New transmission build				*N/A*
	Utility-scale generation[30,xlix]				*N/A*

Source: Table 4 (White et al., 2024)

Thirdly, such technologies benefit from being combined, which is the case, for example, for FACTS, DLR, and batteries. A report from 2024 lists examples. The case studies indicate that combining multiple IGT upgrades (e.g., advanced conductors + DLR + storage as a transmission asset) can increase the capacity of a given line by up to about 170%. Company collaborations, such as between Operato (DLR) from Slovenia and Smart Wires (FACTS) from the U.S., have emerged as a result.[10]

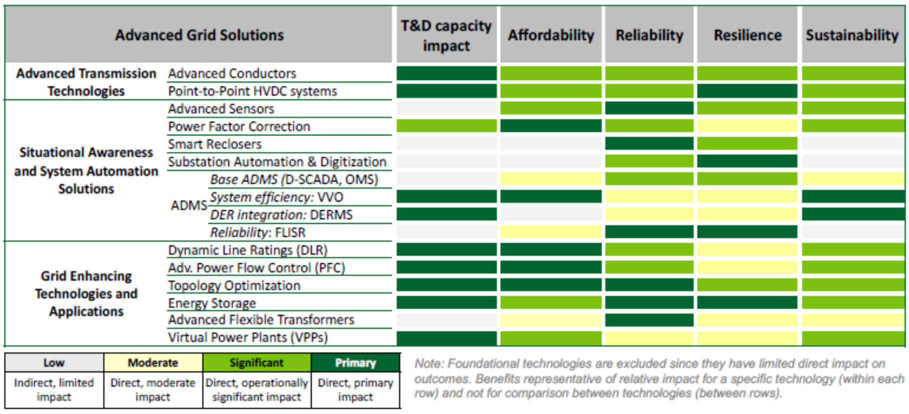
Fourthly, the technologies can be used in a mobile version for several of them, so that temporary solutions can be applied, when needed, for example, during network repairs or restructuring. Grid operators could even have a warehouse of such solutions for temporary deployment.

[10] See the examples on currENT (2024, p.18)

Fifthly, they can be scaled, thus be deployed like Lego: one can start deploying DLR on one line for implementing it after across all existing lines, for example.

Finally, at times where technology adoption is closely related to economic welfare, the trialling and piloting of new, more digital solutions in the grid is a clear competitive advantage for the user and related country. There is a clear advantage in terms of the transmission and distribution capacity impact.

Table 6: IGTs five main value propositions



Source: Figure 7 (White et al., 2024)

4 Technologies in the Ukrainian Power Grid: Used or Intended

The following section describes how grid operators in Ukraine, such as TSO Ukrenergo, but also distribution system operators, are already deploying IGTs, and outlines their further plans. The section also describes the current regulatory framework for IGTs in Ukraine. If only two technologies were applied - SSSC/FACTS devices on the Polish-Ukrainian interconnector, as well as Dynamic Line Rating across the system, the export/import capability could be increased by 500 MW, according to Ukrenergo (2024). If Dynamic Line Rating was applied throughout the main high voltage lines, 15-30% more capacity could be added to the current system transfer capability, without building any new lines.[11]

Ukraine is in the early days of applying IGTs: as generation and grids were, until the war, oversized, overbuilt, energy efficiency was (and is) very low, and the existing system always provided for sufficient alternatives. The war has destroyed more than half of the generation capacities, as well as grids. Ukraine, therefore, must identify quick fixes and build a more sustainable, more flexible, and more secure energy system.

4.1 The Regulatory Framework for a Smarter Grid

The following section describes a rather loose Smart Grid Roadmap for 10 years from now, with very limited legal enforcement, and refers to the EU acquis that Ukraine must implement in the context of accession negotiations.

In May 2024, Ukraine's Ministry of Energy approved a Roadmap for the Development of Smart Grids based on an initial version dating back to October 2022, called the Smart Grid Implementation Concept until 2035. This plan emphasizes automation and digital solutions across all levels of the energy system to create a more balanced and secure network, resilient to military risks. Key objectives include reducing transmission losses by 6 billion kWh annually, the lowering of the System Average Interruption Duration Index (SAIDI) to approximately 100 minutes per year, aligning with the EU average; the implementation of smart technologies, such as microgrids, for restoring facilities damaged by attacks. The plan equally mentions the development of systems for automatic monitoring, control, regulation, protection, and smart electricity metering, as well as the enhancement of cybersecurity measures. The legislation establishes a regulatory framework for smart grid technologies, including microgrids and demand-side management, ensuring alignment with international and European standards. Ukraine has also adopted in July 2024 a ‘Strategy for the Development of Distributed Generation

[11] Average performance of DLR in moderate conditions is 10-15%, and in optimal conditions is 20-30% (ENTSO-E, 2021). White et al. (2024) talk even about 40%.

until 2035,' which includes an operational action plan that highlights the grid requirements (UNN, 2024). The adoption of the Electricity Integration Package, corresponding to key elements of the EU Clean Energy Package[12] is also paramount. Unfortunately, Ukraine is lagging behind in adopting the package.[13] What is more, the EU Action Plan for Grids from 2023, implemented since 2025,[14] will also find its way into Ukrainian legislation through the accession negotiation process.

4.2 Ukrenergo: Deployment and Plans at the TSO Level

Since the war started, Ukrenergo has taken many courageous steps and is highly interested in deploying IGTs. It should be emphasised again that TSOs from the ENTSO-E community and beyond look at the Ukrainian counterpart to learn from their experience, be it on undergrounding, grid protection, cyber security, or grid operation under the most stressful boundary conditions.

The below summarises the state of play and projects with the four fast impact examples Dynamic Line Rating, FACTS devices and batteries, as well as DGMS.

4.2.1 Dynamic Line Rating (DLR)

Depending on the weather, DLR adds 15-30% to the transfer capacity of powerlines. Ukrenergo is at an advanced projecting phase of deploying DLR in internal lines in Ukraine, yet there has been little progress to date. The absence of a NOVA-type principle at the level of the regulator NEURC is also not helpful. The TSO's intention is to deploy DLR especially on the 330 kV[15] lines in Central Ukraine. As those lines form a ring, they will contribute, with DLR, to improve the needed West-East transfers. Several European companies could offer their devices and services, such as the Slovenian company Operato, the Franco-Belgian company Ampacimon, Norwegian Heimdall Power, or Laki Power from Iceland. What is more, Elia Grid International (EGI) has been supporting Ukrenergo in assessing the technical, economic and financial feasibility of DLR technology (EGI, 2023). The European Bank for Reconstruction and Development (EBRD) and also the Energy Community,

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[12] The so-called electricity package is based on the Clean Energy Package (2019) by the EU and foresees electricity market integration by 2027. As of June 2024, it has not yet been adopted in Ukraine.

[13] The Electricity Integration Package has to be adopted at the latest in Q 4/2025, in order to be in line with the Ukraine Facility Requirements.

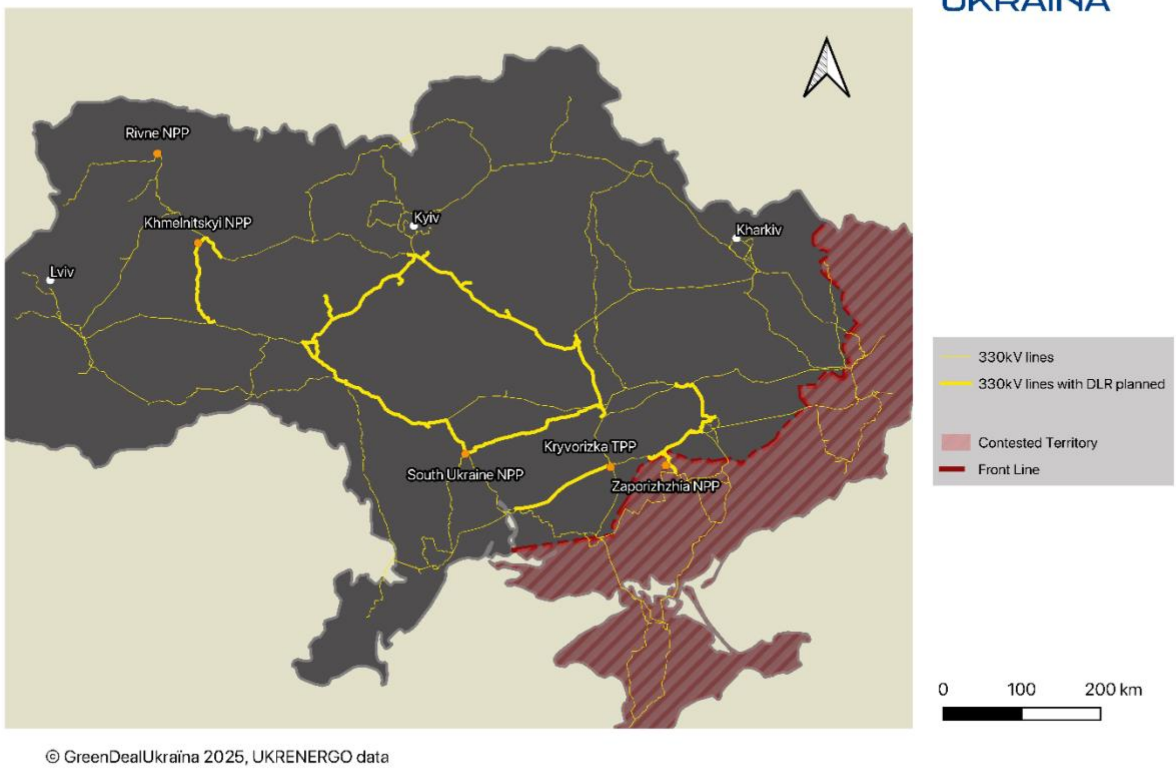
[14] EU Commission: 2023. Grids- the missing link (European Commission, 2023).

[15] 330 kV is a voltage level that is deployed exclusively in former Soviet Union countries, not inside the EU, where 110 kV, 220 kV or 400 kV prevail.

through the Emergency Support Fund, could possibly provide funding for the project. DLR deployment does not need to start with a pilot, but can be deployed immediately, as it has been implemented successfully in many geographies. Nevertheless, Ukrenergo is mentioning a pilot as a start, at the 330 kV overhead line Khmelnytskyi NPP – Shepetivka, and could then be expanded in 2026 towards eight more applications, also on 330 kV.

Given the possibly constrained winter 2025/26, it is strongly recommended to deploy DLR without delay in 2025. It should be emphasized, of course, that no technology deployment or lines can replace generation capacity built up.

Figure 5: Dynamic Line Rating (DLR) projects in Ukraine



Source: Green Deal Ukraïna (2025), based on data from Ukrenergo.

4.2.2 FACTS Devices and the Rzeszów-Khmelnytskyi Project

Implementing the SSSC technology on a single line would add 500 MW to the transfer capacity between Ukraine and neighbouring countries, according to an internal study by PSE, the Polish TSO, as well as by Ukrenergo (Ukrenergo, 2024).

The discussion on implementing so-called Power Flow Control devices in the Ukrainian power network dates to the early 2020s, prior to the war, according to the company. Given the bottlenecks and congestions in the grid, with the forthcoming low-carbon transition, as well as loop flows and line imbalances, short circuit challenges, Ukrenergo appeared to be an early adopter of power electronics. Smart Wires is a company specialising in modular power flow control, and their ´SmartValve´ technology uses power electronic modules to inject variable reactance in series with a transmission line, allowing dynamic control of current. By adjusting line impedance, the devices can shift power flows—for example, pushing more power down the Rzeszów line when needed.

Several possible applications were identified for the ´mini HVDC´ that a so-called SSSC, Static Synchronous Series Compensator, is equivalent to.[16] As in other cases, power electronics are also considered as alternatives to Phase Shifting Devices (PST).

The World Bank is actively promoting the development of innovative technologies in Ukraine, as well as in Central Asia (World Bank Institute, 2024). A study was done on large-scale batteries as well as SSSC in Ukraine. With the full-scale invasion starting in February 2022, the Rzeszów-Khmelnytskyi line was getting back to service. This line was initially designed as a 750 kV line, which, with one exception (Hungary), is not present in the EU and typically exists in the former Soviet Union and its hemisphere. When the interconnector went back into operation, it was evident that downrating the line to 400 kV comes with so-called impedance issues, meaning that only a much more limited amount of power, compared to the technical capacity, could be transferred.

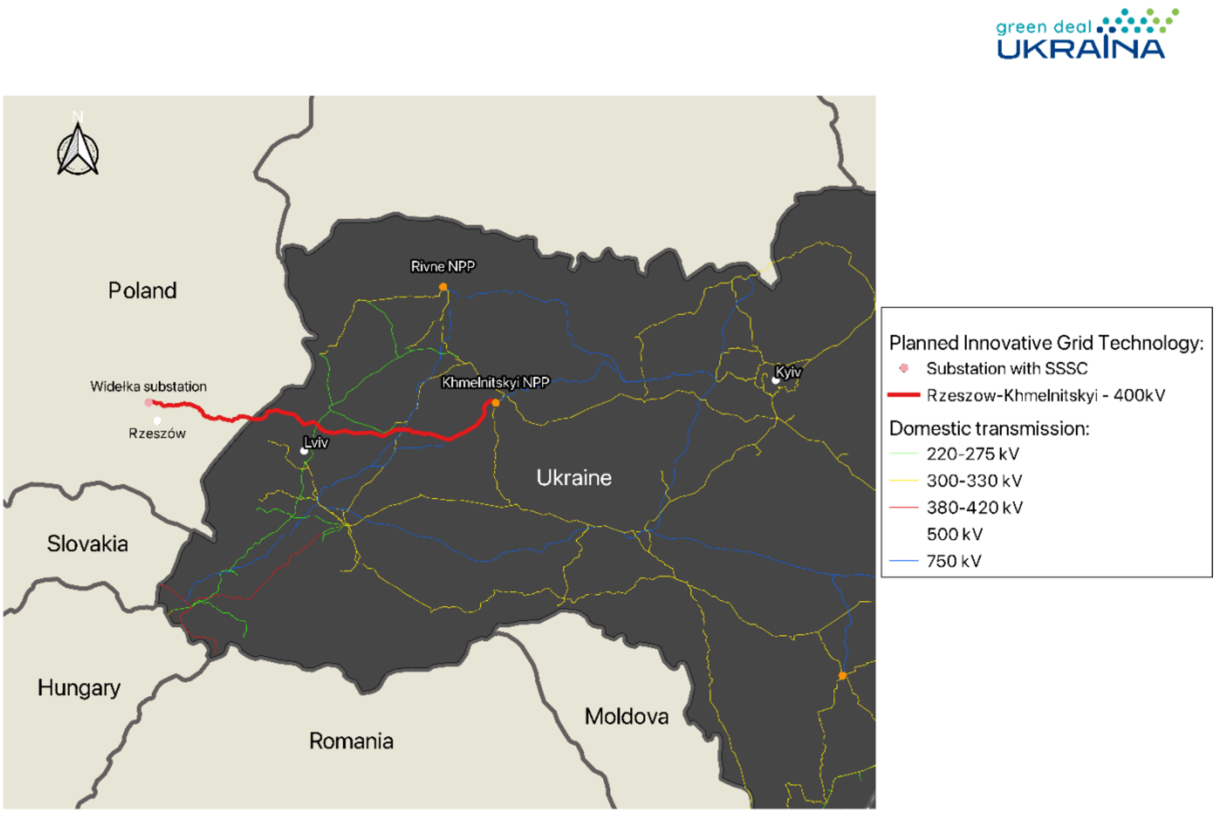
Due to the termination of USAID funding, Ukrenergo and PSE are currently investigating alternative funding sources for this project, which would be very timely for next winter. The deployment of the devices would take only six months, according to Smart Wires.

According to experts from PSE and Ukrenergo, the installation of SSSC would not only improve the profile of the specific Polish-Ukrainian line but also the full profile of interconnection between Ukraine and Poland, Slovakia, Hungary, Romania, and Moldova, thereby contributing to a higher transfer capacity and better stability of the synchronous interconnections.

One innovative funding approach could be to have Ukrenergo own the devices , while the full operational responsibility would be with PSE, given that it is foreseen to install the devices on the Polish side. Since IGTs are often agnostic regarding the location, this could be another regulatory innovation applicable to other technologies.

[16] On the functioning of an SSSC see PSMA Consulting - Power System Studies - Static Synchronous Series Compensator (SSSC) (PSMA Consulting, n.d.).

Figure 6: Planned Static Synchronous Series Compensator (SSSC)



Source: Green Deal Ukraïna (2025)

4.2.3 Battery Energy Storage Systems (BESS)

The deployment of Battery Energy Storage Systems (BESS) would increase the transfer capacity between Ukraine and its neighbours by 1,530 MW, and the combination with FACTS on other locations by even 1,710 MW (Ukrenergo, 2024). According to Article 36 of the Electricity Directive (Directive (EU) 2019/944, 2019) of the Clean Energy Package (2019), the ownership of Battery Energy Storage Systems by regulated grid operators is prohibited, and only exceptionally possible if no market party is responding to a tender on needed system services. In case a network operator owns BESS, the regulator must approve this on a case-by-case basis. The intention behind this law is to decrease battery costs by fostering competition and economies of scale. An example of such an exemption is the German grid booster in the network of Amprion, one of the four German TSOs. Here, BESS was deployed at key nodes which allows the TSO to operate the grid closer to its limits without risking collapse, as the battery instantly responds to hold up voltage and frequency, when a line trips or another incident happens. (Murray, 2024).

As of today, Ukrenergo has installed some batteries that serve as a backup for relay protection panels, the substation's control room, and other internal needs of substations. These batteries do not affect the general operation of the power system in any way.

Ukrenergo does not own any BESS but buys battery services through auctions, providing contracts to private companies for five years. Four special long-term auctions for the purchase of ancillary services have already taken place. They aim to improve businesses in the development of Ukraine's highly flexible generation and further enhance the power system's stability. Through these auctions Ukrenergo purchased 99 MW of Frequency Containment Reserves (FCR) at the auction in August 2024 (expected commissioning in October 2025) and a total of 357 MW of automatic Frequency Restoration Reserve (aFRR) during two auctions in August and December 2024 (with dates of commissioning in October 2025 and January 2026). The fourth auction on 27 May 2025 tendered 550 MW of flexible capacity to be put in operation from December 2026. The first tender was won by the Ukrainian OKKO group, known for its operation of petrol stations across Ukraine, and diversifying its business recently into batteries.[17] DTEK, a company that also owns distribution grids, has announced a USD 140 million investment into BESS to supply ancillary services to Ukrenergo (DTEK, 2024).

Batteries were also discussed already in 2021, before the war, ahead of synchronisation as one solution to power dampening, inter-area frequency oscillation challenges.

One of the results of these studies is the recommended list of countermeasures to increase the damping of low-frequency inter-area oscillations that may occur during synchronous parallel operation of the Ukraine/Moldova and the ENTSO-E CE power systems. Among others, it has been shown that several devices, such as STATCOM, batteries, or FACTS devices can significantly decrease the oscillations. One option was to quickly install a BESS system that can also be adapted to the needs and function in a temporary manner until the end of the war, and ahead of the STATCOM[18] or FACTS deployment.

The previously mentioned presentation by Ukrenergo at KGID in 2024 assessed the effectiveness of Battery Energy Storage Systems (BESS) for frequency oscillation dampening during synchronous operations of Ukraine/Moldova and ENTSO-E, as well as their benefit in combination with FACTS devices such as SSSC. The results of the study

[17] In January, OKKO installed three new ultra-fast chargers.

[18] The STATCOM solution requires clear locations, different from FACTS devices that can be deployed at any location in the grid.

showed that installed capacities of about 66.8 and 80 MW would contribute to an important improvement of the profile. The research found that export capacity would increase through BESS by up to 1,530 MW. The combination of SSSC and BESS would enable export to up to 1,710 MW.

According to Ukrenergo´s forecasts, by 2034-2035, Ukraine will require approximately 800 MW of energy storage capacity to accommodate the active growth of renewables and the decarbonization of the energy mix (Ingrid Capacity, n.d.).

4.2.4 Distributed Generation Management System (DGMS)

Ukrenergo also envisages to install a Distributed Generation Management system as to manage the increasing share of Renewables and decentralised generation in a much more efficient way. DGMS are specialized control and monitoring system used to manage distributed energy resources (DERs)—such as solar panels, wind turbines, small hydro plants, and backup generators—across the electrical grid. Such systems are easy to deploy, are integrated with the SCADA system and can be scaled (Ukrenergo, 2024).

4.3 Use of IGTs – and Batteries- in the DSO Grid

Ukraine has 32 Distribution System Operators (DSOs, one for each of the 24 regions, plus a DSO for Kyiv and some other cities. They emerged because of the unbundling of the former vertically integrated “Oblenergo” companies in 2019 during the market reforms. These DSOs manage the medium- and low-voltage distribution networks in their respective regions.[19] Lvivoblenergo, Vinnytsiaoblenergo, and others are slowly implementing smart grid elements like smart meters, SCADA upgrades, and automation.

Full-scale innovations (like large BESS or digital substations) remain mostly concentrated within DTEK, though replication is beginning, often with donor support. Thus, DTEK Grids announced in June 2023 a EUR 2.4 billion, 10-year project to modernise the power infrastructure in the Kyiv region (DTEK, 2023). The plan includes the installation of 20,000 km of new overhead and underground cables, the construction of 250 substations and 6,000 transformers, as well as the deployment of nearly one million smart meters, and the integration of Digital Twin technology for network modelling. DTEK also intended to facilitate consumer participation through household solar panels and vehicle-to-grid solutions (DTEK, n.d.).[20] DTEK has deployed batteries early on in its distribution system. A

[19] See the forthcoming study on the Ukrainian Distribution Grid by Olha Bondarenko, 2025.

[20] DTEK partnered with Schneider Electric to advance resilient and digital grid infrastructure (DTEK, n.d.).

pilot project was done at Zaporizhzhia Nuclear Power Plant (2021) with Ukraine's first industrial-scale lithium-ion battery energy storage system at the Zaporizhzhia Nuclear Power Plant in Energodar. This system has capacity of 1 MW/2.25 MWh and was certified by the national transmission system operator, Ukrenergo, to provide frequency containment reserve services. The battery demonstrated rapid response capabilities, adjusting from zero to full load in less than 0.6 seconds, significantly faster than traditional power plants. As mentioned, about 200 MW were announced to follow by October 2025 for the forthcoming winter. The storage will hold up to 400 MWh, which is enough to power 600,000 homes for two hours, equivalent to about half of Kyiv's households (DTEK, 2025). The company also collaborates with innovative battery developers such as Fluence Energy. Beyond DTEK, the energy company KNESS from Vinnytsia obtained a EUR 9.6 million loan recently for a pilot battery project (Colthorpe, 2025).

4.4 The Opportunity of the 110 kV Grid

110 kV lines are indeed not an IGT, but a specific type of lines rated at the lowest high voltage level, as from today´s perspective. 110 kV grids are a legacy from the early days of the energy system. The very first high voltage grid of the early 20th century was based on 110 kV, being considered today rather as a toy of TSOs, as the low end of the high voltages.

The use of this abundantly – and wrongly disregarded - existing system is per se innovative, as it allows to address the new needs of a more decentralised power system: connect Renewables, enhance regional and local grids, and enhance security of supply, especially in a country in war like Ukraine, as their destruction is more expensive cynically spoken for the aggressor, than the one of a centralised system. What is more, 110 kV is faster and cheaper to build than 220, 400 or 750 kV grids.

The challenge with 110 kV, probably explains why it has not been used so far, is the fact that ownership is inconsistently held by TSO or DSO or even both (see Table 7 below), depending on the country. As their roles are different, and as interconnectors have to be operated by TSOs according to law, and as the relationship between TSO and DSO is often complex and difficult, the choice was made to disregard the opportunity.

Table 7: Overview on 110kV grid operators across Europe

Country	110 kV Grid Operator(s)	Notes
Austria	TSOs (APG, VUEN)	110 kV lines are part of the transmission network operated by Austrian Power Grid (APG) and Vorarlberger Übertragungsnetz (VUEN).
Belgium	TSO (Elia)	Elia operates the 110 kV grid as part of its transmission network.
Croatia	TSO (HOPS)	Hrvatski operator prijenosnog sustava (HOPS) manages 110 kV lines within the transmission system.
Czech Republic	TSO (ČEPS)	ČEPS operates the 110 kV grid as part of the national transmission system.
Estonia	TSO (Elering)	Elering manages 110 kV lines within the transmission network.
Finland	TSO (Fingrid)	Fingrid operates 110 kV lines as part of the transmission system.
France	TSO (RTE)	Réseau de Transport d'Électricité (RTE) includes 110 kV lines in its transmission operations.
Germany	DSOs and TSOs	In Germany, 110 kV grids are primarily operated by DSOs, but TSOs may also be involved in certain regions.
Greece	TSO (IPTO/ADMIE)	Independent Power Transmission Operator (IPTO/ADMIE) manages 110 kV lines within the transmission network.
Hungary	TSO (MAVIR)	MAVIR operates 110 kV lines as part of the transmission system.

Country	110 kV Grid Operator(s)	Notes
Ireland	TSO (EirGrid)	EirGrid manages 110 kV lines within the transmission network.
Italy	TSO (Terna)	Terna operates 110 kV lines as part of the national transmission system.
Latvia	TSO (AST)	Augstsprieguma Tīkls (AST) operates 110 kV lines leased from Latvenergo.
Lithuania	TSO (Litgrid)	Litgrid manages 110 kV lines within the transmission network.
Netherlands	TSO (TenneT)	TenneT operates 110 kV lines as part of the transmission system.
Poland	TSO (PSE)	Polskie Sieci Elektroenergetyczne (PSE) manages 110 kV lines within the transmission network.
Portugal	TSO (REN)	Rede Eléctrica Nacional (REN) operates 110 kV lines as part of the transmission system.
Slovakia	TSO (SEPS)	Slovenská elektrizačná prenosová sústava (SEPS) manages 110 kV lines within the transmission network.
Slovenia	TSO (ELES)	Elektro-Slovenija (ELES) operates 110 kV lines as part of the transmission system.
Spain	TSO (REE)	Red Eléctrica de España (REE) manages 110 kV lines within the transmission network.
Sweden	TSO (Svenska kraftnät)	Svenska kraftnät operates 110 kV lines as part of the transmission system.

Country	110 kV Grid Operator(s)	Notes
Switzerland	TSO (Swissgrid)	Swissgrid manages 110 kV lines within the transmission network.
Ukraine	TSO (Ukrenergo) and DSOs	In Ukraine, both Ukrenergo and regional DSOs operate 110 kV lines.
United Kingdom	TSOs and DSOs	In the UK, 110 kV lines are operated by both TSOs and DSOs, depending on the region.

Source: Green Deal Ukraïna (2025)

A way forward would be to include the 110 kV grid in the high voltage map as per the ENTSO-E website[21] but also on the national TSO level.

On the regulatory side, efficient collaboration between TSOs and DSOs, as also foreseen since the EU Clean Energy Package, is crucial. The technical challenges of flows on two voltage levels at the same pylon need to be addressed, and some meshing of the 110 kV grid might be useful in addition. The use of IGTs such as FACTS can help address the technical challenges associated with the increased use of 110 kV.

Ukraine has a well-developed network with 11 existing 110 kV lines to Moldova and Transnistria, as well as lines into Romania and Slovakia.

Volodymyr Kudritskyi, the former CEO of Ukrenergo, told the GDU project already in 2024 that the use of the 110 kV grid in Ukraine represented a huge opportunity for security of supply, renewables integration, as well as cross-border flows.

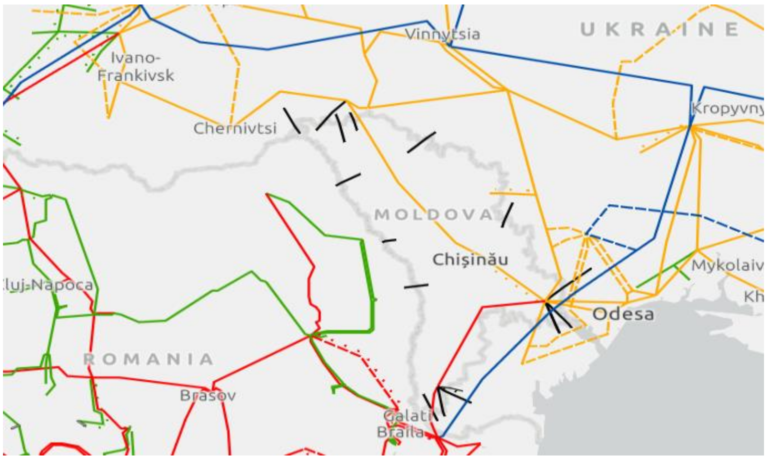
Also, in other countries, 110 kV grids exist in abundance and could be used in a very different way to avoid renewables curtailment, for commissioning new projects, for decentralising the system, and even for cross-border flows. Therefore, Ukraine, here as

[21] Grid Map : the map currently does not list 110 kV. Digital map visualisation should allow for zoom- in zoom out into the densely developed 110 kV network, and enhance projects by private parties to be developed taking advantage of them. A consistent study on the benefits of the 110 kV network for the energy transition should be done at EU level.

well, could become a testbed and innovation driver for a new solution. The already mentioned grid booster by Amprion is developed for the 110 kV level, showing that storage embedded at this voltage level can effectively enhance the higher-voltage grid utilisation by acting as a safety net (Murray, 2024).

In Ukraine, the 110 kV grid is partly operated by Ukrenergo, partly by DSOs, such as DTEK.

Figure 7: 110kV map cross-border lines to neighbouring countries



Source: Green Deal Ukraïna (2025)

The following actions would make Ukraine a frontrunner on 110 kV and allow the country to harvest the low-hanging fruit of more resilience, faster connection of renewables, and decentralisation.

Firstly, Ukraine needs to include the 110 kV network in its network development plan, under a chapter on decentralisation.

Secondly, the cross-border potential of the 110 kV should be used as pilots at the Ukraine-Moldova border, as well as at the Slovakia-Ukraine border, as the legacy grid is extensive here and could support future exports and imports from Romania through Moldova to Ukraine and vice-versa. Later, there is a 110 kV line currently operated at 35 kV, which could provide additional transmission capacity and regional stability at limited cost. More generally, and similarly on the EU level, Ukrenergo and the Ukrainian DSOs need to work hand in hand to establish a customer-oriented approach for a cost-efficient, sustainable and reliable power grid. This DSO consideration is absent from the recently consulted by Ukrenergo Strategy.

4.5 Further Opportunities: Digital Tools- Grid AI

Beyond the four examples of innovative grid operations mentioned here, Ukraine already uses a wide range of digital tools, such as digital substations, with two pilots being deployed in Kharkiv and Kyiv. A digital substation is a digital version of a traditional power substation that uses digital communication, advanced sensors, and automated control systems to monitor, control, and protect the power grid more efficiently and safely. Wide Area Management Systems (WAMS), Renewable Forecast tools, as well as cybersecurity tools, are equally used. Digital Twins are used for planning and stress tests, and are relevant for the integration of ENTSO-E.

Yet, new options such as the offer of companies like the start-up Grid Zero AI (Gridzero.ai, n.d.) or, more generally, the combination of energy and AI could create huge benefits and value (Al-Zu'bi, 2025). AI could also be used to analyse thousands of potential N-1 and N-2 scenarios (like line or plant trips) in near real-time and recommend optimal corrective actions or redispatch strategies to maintain system security.

5 Benefits of Actions

As stated in the executive summary, four actions must be taken to address the power system challenges of Ukraine at the short- and mid-term.

The following three solutions can be implemented very fast and ensure more resilience already for the next winter 2025/26:

- At least 500 MW more transfer capacity between Ukraine and neighbouring countries through the installation of SSSC on the Rzeszów-Khmelnytskyi line
- At least 1,530 MW more transfer capacity when using BESS, or even higher when using them combined with SSSC.
- 15-30% more transfer capacity on interconnectors and internally inside Ukraine, through the deployment of DLR.

Taking these steps will position Ukraine as an early adopter and testbed for innovative solutions.

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