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Cover: Satellite image of Ukraine on the 24 November 2022, when Ukrenergo and distribution system operators introduced rolling and emergency shutdowns in all regions of Ukraine. We acknowledge the use of imagery from the NASA Worldview application (https://worldview.earthdata.nasa.gov), part of the NASA Earth Observing System Data and Information System (EOSDIS).

Sammanfattning

Rapporten ger en beskrivning av Rysslands attacker mot det ukrainska kraftsystemet, med fokus på vintern 2022-2023. Den redogör för några av de viktigaste konsekvenserna av dessa attacker samt hur Ukraina har agerat för att hantera dessa. Rapporten ger vidare en grundläggande beskrivning av kraftsystemet i Ukraina. Den baseras på öppen information från offentliga aktörer i Ukraina, rapporter och mediebevakning.

Med början i oktober 2022 inledde Ryssland en riktad kampanj mot det ukrainska kraftsystemet, i form av storskaliga attacker med tusentals robotar och drönare. En stor del av kraftsystemet skadades eller förstördes vilket har lett till flera och långvariga strömavbrott för miljontals ukrainare. Ukraina har dock, trots den enorma påfrestningen på hela samhället, återkommande lyckats reparera skadad infrastruktur eller på andra sätt mildrat konsekvenserna av elbortfallet. Landet har på detta sätt undvikit en kollaps av kraftsystemet. Detta har i sin tur bidragit till att möjliggöra fortsatt motstånd mot Rysslands invasion.

Det ukrainska kraftsystemet hade särskilda förutsättningar som underlättade hanteringen av konsekvenserna, såsom överkapacitet i elproduktion och överföring, samt ett decentraliserat kraftsystem. Dessa förutsättningar, tillsammans med ett antal åtgärder som redovisas i denna rapport, har stärkt Ukrainas förmåga att säkra elförsörjning under väpnade angrepp.

Nyckelord: Elförsörjning, elberedskap, Ukraina, väpnat angrepp, robotattacker, drönarattacker

Summary

The report provides a description of Russia's attacks on the Ukrainian power system, focusing on the winter of 2022-2023. It outlines some of the most important consequences of these attacks and measures taken by Ukraine to manage them. It also provides a basic description of the power system in Ukraine. All information in this report comes from open sources, primarily from public actors in Ukraine, reports, and news media coverage.

Starting in October 2022, Russia launched a targeted campaign against the Ukrainian power system in the form of large-scale attacks using thousands of missiles and drones. A large part of the power system was damaged or destroyed, leading to multiple and prolonged power outages. Ukraine has repeatedly managed to repair damaged infrastructure and mitigate the consequences of the power outages, thus avoiding a collapse of the power system. This, in turn, has contributed to enabling continued resistance against Russia's invasion.

Prior to the full-scale war, the Ukrainian power system had particular characteristics, such as overcapacity in production and transmission, and a decentralised power system. These conditions, along with a number of measures detailed in this report, have strengthened Ukraine's ability to secure electricity supply during armed attacks.

Keywords: Power supply, preparedness, Ukraine, armed conflict, missile attack, drone attack

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Executive summary

In this report, we have set out to provide a picture of Russian attacks on the Ukrainian power system, describing the impact they have had, as well as giving an account of the measures taken by Ukrainian authorities in order to mitigate the effects. The report has been compiled using open sources, primarily from social media accounts belonging to Ukrenergo[1] and General Staff of the Armed Forces of Ukraine, as well as reports from organisations, academia and news media outlets. The information was supplemented by two interviews with representatives from authorities with insight into the situation. The report covers the period from the start of the full-scale invasion in February 2022 to the end of the winter in 2023.

Background about the Ukrainian power system

The capacity to produce and distribute electricity largely exceeded Ukraine's needs prior to the Russian invasion.[2] This surplus has gone some way to help cover lost generation, transmission, and distribution capacity due to damaged infrastructure.

On 24th February, 2022, the Ukrainian power system was disconnected from the Russian and Belarusian systems as part of a long-planned test.[3] Later that same morning, Russia launched its illegal full-scale invasion of Ukraine, at a time when the Ukrainian power system was at its most vulnerable. After an urgent request by Ukraine and Moldova for emergency synchronisation, a trial synchronisation with the European Network of Transmission System Operators (ENTSO-E) started only weeks later.

The fact that the Ukrainian power system was originally built during the Soviet era, and designed to be robust and resilient, and to be able to withstand war, has contributed to securing and restoring production and supply.[4] The Soviet heritage has however also been a weakness, as it is likely that Russia has used available information when attacking the power system – a theory put forward by Ukrenergo among others. Another problem stemming from the Soviet heritage is the challenge of sourcing spare parts, as the power system was designed according to Soviet standards and many spare parts are only available in other former Soviet states.[5]

Overview of Russian military strategy

Russian attacks have changed focus several times during the Russo-Ukrainian war. Attacks specifically targeting the power system began on 10th October 2022, where attacks seemed to focus on the destruction of power plants and the transmission infrastructure, thus affecting the power system as a whole. Based on the patterns of attack, with a large number of Russian missiles and drones aimed at power infrastructure and facilities, it is our conclusion that Russia has targeted the power system specifically. The attacks appear

[1] Ukrenergo is the electricity transmission system operator in Ukraine and the sole operator of the country's high-voltage transmission lines.

[2] The Organisation for Economic Cooperation and Development (OECD). Competition Market Study of Ukraine's Electricity Sector. Paris: OECD Publishing, 2023. https://doi.org/10.1787/f28f98ed-en (Accessed 2023-10-27).

[3] Blaustein, A. How Ukraine Unplugged from Russia and Joined Europe's Power Grid with Unprecedented Speed. Scientific American. 2022-03-23. https://www.scientificamerican.com/article/how-ukraine-unplugged-from-russia-and-joined-europes-power-grid-with-unprecedented-speed/(Accessed 2023-10-31).

[4] Jermalavičius, T., Tynkkynen, V., Prokip, A., Egenhofer, C., Righetti, E., Molis, A., Mändmaa, P., Lawrence, T., & Sukhodolia, O. War and energy security. Lessons for the future. Tallinn: International Centre for Defence and Security, 2023. https://icds.ee/en/war-and-energy-security-lessons-for-the-future/ (Accessed 2023-10-13).

[5] Interview. Autumn 2023.

to have been planned with a detailed knowledge of the Ukrainian power system, in order to inflict the most damage possible and cause widespread blackouts.[6]

Russia has employed various tactics to identify or exploit vulnerabilities, evade or overwhelm air defences, inflict maximum damage, and cause severe consequences.These include:

- Targeting specific infrastructure or facilities for the operation of nuclear power plants.
- Attacking the power system in order to disrupt specific operations.
- Destroying critical energy infrastructure when withdrawing from occupied areas.
- Using many different types of missiles in the same attack.
- Attacking during peak load, when the power system have less margin against disruptions.

Extent of Attacks

The number of missiles launched by Russia can be counted in the thousands. According to open information collected from the Facebook accounts of Ukrenergo, the Ukrainian General Staff and Air Force Command of the Ukrainian armed forces, a significant part of the missiles and drones used, targeted the power system. We concur with other analysts, that this underscores the importance of air defence against missiles and drones, but the authors of this report would like to add that this also emphasises the importance of mitigatory measures.

Although Russia has executed numerous cyberattacks against the Ukrainian power system, there have been no reports suggesting that these have had any serious consequences. It is possible (even probable) that any such attacks have simply not been reported in the open sources we have had access to, and that we are unaware of them for that reason. Other potential explanations include that the attacks have been unsophisticated, that Ukraine has a strong cyber defence, that the power system is robust (in the sense that in the case of a cyber-attack, it can be operated manually) or a combination of these factors.[7]

Impact on the energy system

Information collated from a variety of sources (including Ukrenergo) provides a picture of significant damage to Ukraine’s power grid, power stations, and power plant capacities, caused by Russian attacks.

By the end of 2022, available production capacity had decreased by over 60 percent, according to estimates by UNDP and the World Bank.[8] By the end of May 2023, Ukrenergo estimated that 27 GW of installed generation capacity had been lost. In real world terms, this means that millions of Ukrainians have been out of power at some point during the war. According to the above-mentioned UNDP report, the average Ukrainian household experienced five cumulative weeks without power, from October 10 to the end of December 2022.

However, electricity consumption decreased drastically immediately after the invasion, due to a large part of the population leaving the country and businesses and industries

[6] Ukrenergo, “Ракетна атака 11-12 жовтня була спланована за участі російський енергетиків”, Facebook, 2022-10-16. https://www.facebook.com/npcukrenergo/videos/441918591417344/

[7] For a more in-depth discussion on the cyber warfare aspect of the Russo-Ukrainian war, see Per-Erik Nilsson. Unraveling the Myth of Cyberwar - Five Hypotheses on Cyberwarfare in the Russo-Ukrainian War (2014-2023). FOI-R--5513--SE. December 2023.

[8] The United Nations Development Programme and the World Bank. Towards a green transition of the energy sector in Ukraine. Update on the Energy Damage Assessment. UNDP, June 2023. https://www.undp.org/ukraine/publications/towards-green-transition-energy-sector-ukraine (Accessed 2023-11-07). p. 7.

decreasing or shutting down their operations. This has eased the burden on the power system somewhat.

In monetary terms, a study by the Kyiv School of Economics released in June 2023, estimated the cost of the direct damage to Ukraine's power infrastructure at more than $7.2 billion.[9]

Tragically, the attacks have had devastating consequences for energy sector employees performing repair work, leaving a number of them severely injured or killed.

Measures taken to mitigate the impact

Ukrainian authorities have taken several measures in order to mitigate the effects of the attacks and to maintain the power supply. We have divided these measures into seven different categories, as listed below (in no specific order).

- Preparations before the full-scale invasion

For years, Ukraine has been preparing for renewed military aggression, implementing a range of measures to reduce energy dependence on Russia, adopting new legislation to ensure the resilience of critical infrastructure, stockpiling resources and equipment needed to restore damaged infrastructure, and preparing plans for maintaining operations during crises.

- Restoring power supply

We conclude, based on the collected information in this report, that the ability to quickly restore the power supply has greatly relied on the availability of repair personnel, spare parts and equipment, as well as coordination between key actors. Extensive use of backup schemes has also been key to the restoration of the power supply.

The number of repair teams increased during the war, and a system was established enabling coordination and interaction between energy companies, military, and law enforcement units, as well as between different regions.[10] Ukrenergo maintains that this system has allowed for an effective restoration of the power supply, but above all, has helped ensure the safety of repair personnel. The importance of highly qualified engineers and a strategic supply of electrical equipment for a rapid restoration of power systems during emergencies was stressed by ENTSO-E at a General Assembly meeting with the heads of energy system operators of 37 European countries on 30 March 2023.[11]

- Limiting electricity consumption

We have found that Ukraine has used a variety of measures such as shutting down the power supply, implementing efficiency measures to reduce power demand, introducing restrictions on consumption and prioritising supply to the most critical functions.

- Electricity market interventions

Ukraine halted export of electricity to Europe on October 11, 2022, resuming on April 11, 2023. This was done exclusively on the condition that supply of Ukrainian consumers is first priority. Emergency electricity import from Europe has taken place intermittently.

- Supporting citizens with limited access to power

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[9] Kyiv School of Economics. Report on damages and losses to infrastructure from the destruction caused by Russia's military aggression against Ukraine as of June 2023. Kyiv. 2023. https://kse.ua/wp-content/uploads/2023/09/June_Damages_ENG_-Report.pdf (Accessed 2023-12-01). p. 28.

[10] Jermalavičius et al, "War and energy security. Lessons for the future", p. 52.

[11] NPC Ukrenergo, "Криза 70-х років минулого століття зробила", Facebook, 2023-03-30. https://www.facebook.com/vladimir.kudrytskyi/posts/6462152113817765

The initiative ”Unbreakable Points” (where Ukrainian citizens can access basic needs such as power, heat, water and internet access, 24 hours a day) was introduced to support citizens in November 2022.[12] The Ukrainian government also implemented measures to exempt certain goods needed during the colder season from Value Added Tax (VAT) and import duties. A number of financing programmes and support programmes by local municipalities has enabled the increase in purchases of generators.

- International support

Ukraine has received international assistance with funds and equipment to help repair and rebuild the power system. A report from the International Centre for Defence and Security (ICDS) suggests that this has greatly helped Ukraine withstand the large-scale destruction of the power system during the winter season 2022-2023.[13] Assistance has been provided through functions such as EU and NATOs emergency response mechanisms and by bilateral agreements with a number of countries, as well as from energy companies and international financial institutions.

- Additional measures and contributing factors

In addition to the above-mentioned factors, a number of measures, described further in the report, has bolstered Ukrainian resilience. These include:

- The use of renewable energy sources
- Information security measures
- Sectoral crisis management
- Protection of power system facilities
- Strategic communication efforts

Concluding observations

In conclusion, it is our assessment that the extensive Russian attacks have put the actors in the power system under pressure. Preparedness plans have played an important role in Ukraine’s resilience. It also seems that Ukraine has been adaptable and flexible when it comes to using a variety of measures and mitigations, inventing solutions and adopting new regulations. Despite facing relentless attacks from Russia, the Ukrainian power system has exhibited an ability to recover. Through strategic planning, swift response measures, and international support, Ukraine has been able to mitigate the impact of assaults on its critical infrastructure, though not without a significant cost in terms of damaged power infrastructure, hardship, and human lives.

[12] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[13] Jermalavičius et al, “War and energy security. Lessons for the future”, p. 52.

1 Introduction

Since the Russian full-scale invasion of Ukraine on 24th February 2022, Russia has attacked and damaged the Ukrainian power system in various ways. A targeted campaign began in October 2022, using missiles and drones, lasting throughout the winter. This inflicted heavy damage on power production and the transmission and distribution systems. The attacks have caused disruptions in the power supply with serious consequences for Ukrainian society. However, Ukraine has been able to mitigate the consequences by quickly repairing the damage and restoring the power supply, thus avoiding a complete breakdown of the power system.

While it is impossible to ascertain the Russian goals in attacking the power system, attacks probably constitute part of a strategy of attrition, aiming to undermine the Ukrainians' will and ability to defend the country. Other potential reasons include reducing Ukrainian industrial production capacity, including defence production, and forcing Ukraine to use up expensive air defence missiles. It would also serve as a signal to the West that this war is likely to be drawn-out and expensive. Based on these assumptions, and at this stage of the war, Russia has not achieved its strategic goals.

1.1 Objectives

The Swedish transmission system operator Svenska kraftnät (Svk), and the Swedish Energy Agency, who are jointly responsible for securing the power supply in Sweden and developing the preparedness in the Swedish power system, have commissioned this report. It is the first publication in this project and lays the foundation for further analysis.

The purpose of this project is to draw on the Ukrainian experience in managing the impact of Russian attacks on the Ukrainian power system. This includes assessing and analysing how Ukraine has avoided a collapse of the power system through measures aimed at mitigating the loss of power generation and supply. In this way, we hope to contribute to the work on strengthening the preparedness of the Swedish power system and improving the security of power supply during the event of a possible armed attack on Sweden. This report will constitute a basis for discussion and further work in this area, as well as the question of how the West can support Ukraine in maintaining and rebuilding its energy system.

In order to lay the foundation for further analysis, the overall objective of this report is to give an enhanced understanding of the following areas:

- The characteristics of the Ukrainian power system.
- The nature and scope of Russian attacks on the Ukrainian power system from the beginning of the full-scale invasion in February 2022 until May 2023.
- The impact of the attacks (damage on the power system and consequences for the power system and supply).
- How Ukraine mitigated the consequences of the attacks on the power system and ensured power supply.

1.2 Scope and limitations

The main study object of this report is the Ukrainian transmission system and the Ukrainian transmission system operator Ukrenergo. However, since the power system is an integrated system with many parts and actors affected by the attacks, we have deemed it necessary to have a wider perspective. The report thus covers a broader scope and many different aspects. The primary focus is on kinetic attacks, but we briefly address the issue of non-kinetic attacks as well.

This report does not present a complete analysis of the material, but rather lays the foundation for further work at a later stage in this project.

1.3 Disposition

Chapter 1 introduces the background to the study, its objectives, scope and limitations.

Chapter 2 describes the study design and the methods used, and includes discussions on ethics and confidentiality.

Chapter 3 provides a brief description of the Ukrainian power system; the infrastructure, production and consumption, the structure of the electricity market and a short description of the synchronisation of the Ukrainian power system with the European Network of Transmission System Operators (ENTSO-E).

Chapter 4 presents an overview of the kinetic attacks on the power system. This includes descriptions of commonly used weapons, changes in Russian strategy and tactics, scale of the attacks, targets, extent of the damage caused, and the consequences for the power system and supply.

Chapter 5 briefly describes non-kinetic attacks such as cyberattacks and disinformation.

Chapter 6 covers how Ukraine has handled the attacks and how the consequences were mitigated.

Chapter 7 presents observations based on the results of this study.

Appendix A contains a list of complementary written sources with brief descriptions of their content, facilitating further reading.

Appendix B contains a timeline of the attacks and the situation in the Ukrainian power system for the period September 2022 to May 2023. Events that are more recent are also described briefly.

2 Method and study design

Here we present the study design and methods used. First, we set out how the information needs were identified, assessed and structured. Then we describe the process of data collection. A brief discussion of the sources and their credibility follows, along with a description of how the collected data was structured and how it is presented in the report. The chapter ends with discussions about ethical and confidentiality considerations.

2.1 Structuring of information needs

To reach the objectives of the study, the research questions that this report seeks to answer have been developed in conjunction with Svenska Kraftnät and the Swedish Energy Agency. It is the hope of the authors that the results of this study will assist them in formulating measures to increase the security of power supply in Sweden and strengthen preparedness in the Swedish power system.

The process was initiated with a series of workshops with experts, representing the breadth of the operational areas from Svenska Kraftnät. The resulting research questions were then narrowed down and structured into three research areas:

Attacks on the power system.

Kinetic attacks and non-kinetic attacks, Russian tactics, weapons used, magnitude of the attacks, parts of the energy system targeted and areas damaged.

Impact of the attacks.

Damage to infrastructure and facilities, and consequences for the power system and power supply.

Mitigating the impact of attacks.

Management of power supply during and after attacks; how repairs were performed; cooperation, coordination and communication; management, staffing and personnel; electricity market management; protection of infrastructure and facilities; and international support.

To understand the extent of the damage to the power system, the consequences of the attacks, and measures available to Ukraine, a basic understanding of the design and characteristics of the Ukrainian power system is required. Therefore, the study has been guided by the following questions, correlating to the objectives of the study (chapter 1.1) and the research areas:

- How is the Ukrainian power system designed and what are its characteristics?
- What is the nature and scope of the Russian attacks on the Ukrainian power system?
- What were the impacts of the attacks?
- How did Ukraine mitigate the impact of the attacks?

2.2 Data collection and sources

The report is primarily based on open sources such as public information from official entities in Ukraine, reports and news media. The texts were mainly limited to English language sources (though there are some examples of Ukrainian government texts translated by online tools).

We conducted two interviews, one with the Swedish defence attaché in Ukraine, and one with representatives from the Energy Community Secretariat, which is an international organisation bringing together the European Union and its neighbours to create an

integrated pan-European energy market.[14] In the interviews, no sensitive or classified information was requested. Instead, the decision about what information may be shared, rested on the respondents. For the sake of confidentiality, specific statements are not linked to respondents in the report.

Ukrenergo, the transmission system operator in Ukraine, analogous to Svenska Kraftnät, was identified as the most relevant actor to liaise with. Although contact was established with representatives at Ukrenergo, due to the situation in Ukraine, no interviews were held.

The list of research questions that came out of the workshops provided a guide for open source online searches. Further research material was identified by using the snowball search method, which is a way of tracking down related works by using the bibliography or reference list at the end of an article or book as a starting point. The list of questions can be seen as a gross list, from which searches were made and results were analysed (how this was done is described in section 2.4).

Two main sources were identified as being of particular relevance to us:

- The General Staff of the Armed Forces of Ukraine publishes a daily update on the war effort on its Facebook page. This constitutes our main source for information on attacks, number and type of weapons and which parts of Ukraine were targeted in Russian attacks, as well as the amount of missiles and drones destroyed by Ukrainian forces.[15]
- Ukrenergo similarly provides Facebook page updates on the situation in the power system and the power supply, including which parts of the power system have been attacked and what measures have been taken in order to mitigate the consequences of these attacks.[16] We systematically collected information from the Ukrenergo Facebook page, going through every entry from the beginning of September 2022 to the end of May 2023. Information was collected based on the research areas and the interview questions.

As the majority of our information about the events comes from these two sources, and any other sources used as complement have been clearly identified, other researchers should be able to verify and reproduce the results.

2.3 Source limitations

Collecting and verifying information from open sources about Russia's war against Ukraine poses its own challenges. There is much information available about the war. Official Ukrainian institutions and organisations publish a great deal of information regarding the war effort, as part of their strategic communication. National and international news media are present in the area of conflict, and accounts on social media published both by private persons and larger groups have reached a large audience.[17] Together, these sources create a vast information environment that is difficult to navigate.

Much of the information sought is sensitive and most likely classified in Ukraine and we have therefore been unable to access it. Ukraine naturally limits access to sensitive information in order to protect it from being revealed to its adversaries. For security reasons, the Ministry of Energy of Ukraine and Ukrenergo have restricted access to

[14] Energy Community. Who we are. 2024. https://www.energy-community.org/aboutus/whoweare.html (Accessed 2024-04-23).

[15] General Staff of the Armed Forces of Ukraine. https://www.facebook.com/GeneralStaff.ua/

[16] NPC Ukrenergo. https://www.facebook.com/npcukrenergo/

[17] Pär Eriksson, Karl Lallerstedt, Johan Lindgren. Arbete med lärdomar från Ukraina till nytta för det civila försvaret. FOI Memo 8195. 2023. p. 15

information on damage and losses of energy infrastructure facilities as well as operating capacity of power plants.[18]

A large quantity of information is not equivalent with a high quality of information: the message coming from Ukraine is not necessarily complete or correct. Data in information can be hard to verify, information can be biased, and let us not forget that Ukraine chooses which information to publish and which to withhold, for strategic reasons. This renders the picture incomplete and the accuracy and objectivity of the information uncertain.

We have made attempts to corroborate with Ukrenergo if the information obtained from the Ukrenergo Facebook page is correct, complete and accurate, but answers have not been forthcoming.

What we lose by relying on secondary data in open sources rather than first hand data, is completeness and accuracy, or a higher level of detail. There is also the risk of bias, or lack of objectivity, in information from any source. The authors of this report have made the judgement that information from official Ukrainian sources are objectively qualitatively true, although maybe not quantitatively true. Information from news media and reports have also been assessed with these factors in mind. We are of the opinion that, given the circumstances, available information enables us to give a reasonably accurate description of the events and to make certain relevant observations.

A number of observations has been made in the report, helping us understand events and developments. These observations must be seen through the lens of a still ongoing war: it is difficult to draw any substantial conclusions as yet. It may indeed be difficult to do so for a long while, as the information we have access to today may be incomplete. It may be available for a reason. It may be that it is part of a communications strategy, the aim of which is not clear to us at this stage of the war.

Another issue we must have in mind is that the Ukrainian experience is not universal, and so what has worked for Ukraine may not be relevant for other countries. With that caveat, there are still some points that may be of interest for others in strengthening preparedness policy and structures, or simply to understand the situation in the Ukrainian power system better.

2.4 Structuring collected data

When compiling and structuring the data concerning how Ukraine mitigated the impact and consequences of the attacks, a list of categories based on common themes in the data were developed. These categories are:

- Preparations before the start of the war
- Restoring the power supply, i.e. by repairing damaged infrastructure and facilities
- Limiting electricity consumption
- Electricity market interventions.
- Supporting citizens with limited access to power, through different measures.
- International support
- Additional measures and contributing factors
- Rebuilding the power system and preparing for future attacks

[18] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022, NPC Ukrenergo. Facebook. 2023-05-26. https://www.facebook.com/npcukrenergo/posts/635958381906324. , and Jermalavičius et al, “War and energy security. Lessons for the future”, p. 58.

2.5 Ethical considerations

We are cognisant of the need to proceed with respect and care when studying a country at war. We must not allow focusing on numbers and developments to overshadow the fact that the Ukrainian resilience has come at a steep cost in terms of human losses and injuries. In our eagerness to learn from Ukraine, it is essential not to forget how the war has affected the Ukrainian people.

Conducting any form of research during an ongoing conflict presents a myriad of ethical challenges that researchers must grapple with. It is crucial to consider the potential consequences of any findings, including how the information contained in this report may be used to perpetuate further harm.

2.6 Confidentiality considerations

As already stated, this study is primarily based on information collected from open sources, and, to a lesser degree, from two interviews. Much of the information that this report relies on, is published by Ukrainian official entities such as the General Staff of the Armed Forces of Ukraine and Ukrenergo. The Ukrainian government and Ukrenergo have limited the amount of information they release in terms of damage and capacity. However, the type of condensed overview that this report presents, may still be problematic from a confidentiality perspective, although the information is publicly available. We have been careful to keep the information non-specific enough for confidentiality concerns while also attempting to make a relevant contribution to the area. This is not an easy balance.

It is however our considered opinion that the information disclosed does not reveal information or expose vulnerabilities that can be used by the enemy and/or harm or impair the Ukrainian war effort.

When it comes to observations or conclusions based on the collected material, there is also a risk of exposing one’s own vulnerabilities, capabilities or plans. We have therefore been careful not to draw too far-reaching conclusions regarding what Sweden, or other countries for that part, should learn from the Ukrainian experience, or how actors in the power system should prepare in case of an armed attack. That kind of analysis is more appropriately conducted and presented elsewhere.

3 The Ukrainian power system

To better understand how the Ukrainian power system and power supply have been affected by the attacks, and what responses and measures have been available to Ukraine, a basic understanding of the system and its characteristics is required. This chapter presents a brief description of Ukraine's power system and electricity sector (before the Russian invasion in February 2022), as well as the rapid synchronisation of the Ukrainian power system with the European Network of Transmission System Operators (ENTSO-E) in February and March 2022.

3.1 Background and general overview

Large parts of the Ukrainian power system were designed and built during the Soviet era. In order to withstand wartime challenges, the Soviet design was based on survivability, resilience and ease of repair. The power system was dimensioned to be highly robust in terms of power generation and electricity transmission and distribution.[19] It was also dimensioned to energy-intensive industries, both inside and outside of Ukraine. After the country's independence in 1991, there was a sharp decline in industrial production and electricity consumption decreased significantly. Electricity consumption increased and stabilised during the period of economic growth in the early 2000s. After that, global economic crises and Russia's occupation of Crimea and the Donetsk and Luhansk regions in 2014 disrupted economic growth as well as electricity consumption.[20]

Ukraine has one of the largest power systems in Europe, and it should be noted that the capacity to produce and distribute electricity largely exceeded Ukraine's needs prior to the Russian invasion. The installed power production capacity in 2020 was 54.5 GW,[21] while maximum consumption (peak load) was around 25 GW in 2021.[22] For comparison, the countries in Europe with larger production capacities than Ukraine (in 2020), are, Germany (232.8 GW in 2023), France (143.8 GW in 2023), Spain (110.8 GW in 2023), Italy (95.7 GW in 2023),[23] and United Kingdom (76.7 GW in 2022).[24]

The Ukrainian system for transmitting and distributing electricity is extensive, but also meshed, making it decentralised and more robust. However, it is clear to the authors of this report that the power system contains many vulnerable parts that can constitute targets for Russian missiles and drones.

Development since 1991

After the collapse of the Soviet Union in 1991, Ukraine started to build an independent power sector, establishing a wholesale electricity market in 1996, where suppliers and retailers buy electricity from producers. In addition, the electricity production, transmission, distribution, and supply to consumers were operationally separated in 1996.

[19] Jermalavičius et al, "War and energy security. Lessons for the future", p. 42.

[20] OECD. Competition Market Study of Ukraine's Electricity Sector. p. 26.

[21] Forum Energii. Ukraine's Preparations for a Wartime Winter. 2022-09-28. https://www.forum-energii.eu/en/blog/ukraina-zima. (Accessed 2023-11-15).

[22] OECD. Competition Market Study of Ukraine's Electricity Sector. p. 27.

[23] ENTSOE. Statistical Factsheet 2023. Provisional values as of April 2024. https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/Statistics/-Factsheet/entsoe_sfs2023_web.pdf (Accessed 2024-06-12).

[24] UK Department for Energy Security and Net Zero. Digest of UK Energy Statistics DUKES): electricity. Last updated 27 July 2023. https://assets.publishing.service.gov.uk/media/64c23a300c8b960013d1b05e/DUKES_2023_Chapter_5.pdf (Accessed 2024-06-12).

However, the state owned company Energorynok was the only market actor on the wholesale market.[25]

These measures were expected to lead to a higher degree of privatisation, but the process progressed slowly. To increase privatisation and reshape the power sector in line with the European model, considerable structural reforms were introduced (privatisation of coalmines in 1996, followed by Oblenergos in 1998, a market reform in 2002, and further privatisation of Oblenergos from 2011 to 2017).[26] However, these attempts at reform and privatisation of the market were generally regarded as unsuccessful.[27]

In 2011, a reform aimed at aligning the power sector with the European model was initiated and Ukraine officially joined the Energy Community.[28] A new law was adopted in 2013 to liberalise the electricity market, and in 2014, Ukraine signed an agreement to integrate its electricity system with ENTSO-E. To promote liberalisation, a new market model was introduced with the Electricity Market Law in 2017 and institutions responsible for its implementation started preparing legislation.[29]

In 2019, Ukraine switched from single-buyer model to a more competitive power market structure in order to meet the requirements of EU Third Energy Package.[30] The new market model introduced competition in the retail market and included opening of the wholesale market as well as day-ahead, intraday and balancing markets for all market participants.[31] The last part of the new market model, an ancillary service market, began operations in 2020.[32]

Since its independence, Ukraine has made significant efforts towards aligning its electricity market with EU standards. In 2022, according to the Energy Community Secretariat, Ukraine had transposed 64 percent of relevant EU legislation into national law and implemented 68 percent of required power sector legislation. As of 2023, the market design in Ukraine closely resembles those in the EU countries.[33]

3.2 Market actors

Ukraine's electricity market comprises both state-owned and private actors.[34] Below follows a brief description of main participants and actors.

[25] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 22-23

[26] Oblenergos were regional power supply and distribution companies. In 2019 each oblenergo were split into an electricity retailer and a distribution system operator (DSO). Now Oblenergo refers to a DSO. OECD. Competition Market Study of Ukraine's Electricity Sector, p. 34.

[27] OECD. Competition Market Study of Ukraine's Electricity Sector. p. 23

[28] The Energy Community is an international organisation which brings together the European Union and its neighbours to create an integrated pan-European energy market. More information about the organisation may be found here: https://www.energy-community.org/ (Accessed 2023-08-16), European Commission, "Commission welcomes Ukraine in Energy Community". 2010. https://ec.europa.eu/commission/presscorner/detail/en/IP_10_1173 (Accessed 2023-11-17).

[29] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 24.

[30] International Energy Agency. Ukraine Real-Time Electricity Data Explorer. 2022. https://www.iea.org/data-and-statistics/data-tools/ukraine-real-time-electricity-data-explorer (Accessed 2023-08-17).

[31] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 24.

[32] USAID Energy Security Project. How did Ukraine synchronize with the EU's power system, and why is it important for the country's energy security? 2023-03-16. https://energysecurityua.org/news/how-did-ukraine-synchronize-with-the-eu-s-power-system-and-why-is-it-important-for-the-country-s-energy-security/ (Accessed 2023-08-18).

[33] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 33, 44.

[34] International Energy Agency (IEA). Ukraine energy profile. April 2020. https://www.iea.org/reports/ukraine-energy-profile (Accessed 2023-12-07).

Ukrenergo - Transmission system operator in Ukraine

Ukrenergo is a legal entity incorporated as a joint stock company with 100 percent of the shares owned by the state, and falls under the purview of the Ministry of Energy in Ukraine.[35] It operates the national transmission grid (the Integrated Power System of Ukraine) and is responsible for the transmission of electricity from generation facilities to distribution networks. It is the only transmission system operator (TSO) of Ukraine in compliance with EU's Third Energy Package, and was certified by the National Energy and Utilities Regulatory Commission in 2021 as a TSO under the independent system operator (ISO) unbundling model. The certification asserts that Ukrenergo is fully independent from supply and production interests.[36]

The entity also coordinates import and export of electricity, determines the transfer capacity and the mechanism to allocate the transfer. As of 2019, Ukrenergo operates the balancing and ancillary service markets, registers bilateral agreements, and serves as a commercial metering and settlements administrator. It is also responsible for new investment in infrastructure, such as transmission lines and substations, and integrating renewable energy sources.[37] Today, it employs approximately eight thousand people.[38]

Distribution system operators

Distribution system operators (DSO:s) are responsible for delivering and dispatching electricity to end users. DSO:s and power supply companies are largely privately owned by domestic or foreign investors.[39] In Ukraine DSO:s are considered natural monopolies, in line with international practice. The National Energy and Utilities Regulatory Commission, which also issues appropriate licences for distribution, regulates their tariffs.[40] There are 32 DSO:s in Ukraine.[41]

Suppliers and retailers

Suppliers and retailers are economic entities who buy electricity from producers on the wholesale markets, which consist of several submarkets. Suppliers and retailers then resell the electricity to end users at the, often segmented, retail markets.[42]

Some of the other main electricity market actors are listed below.[43]

- Ukrhydroenergo, a state-owned hydropower company managed by the Cabinet of Ministers of Ukraine.
- Energoatom, a state-owned nuclear energy generating company under the management of the Cabinet of Ministers of Ukraine.
- DTEK Group, the largest vertically integrated private holding company in Ukraine, involved in the production, supply and distribution of natural gas and electricity, and coal mining.

[35] Ukrenergo, About us. https://ua.energy/about_us/

[36] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 25, 33-34.

[37] Ibid. p. 34.

[38] NPC Ukrenergo. "Сьогодні «Укренерго» – це майже 8 тисяч висококваліфікованих", Facebook, 2023-04-15. https://www.facebook.com/npcukrenergo/videos/552211853693087/

[39] IEA. Ukraine energy profile. 2020.

[40] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 35.

[41] Ibid. p. 25.

[42] Ibid. p. 22 & 44.

[43] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 25.

- Centrenergo, one of the largest thermal generating companies in Ukraine. The company is state-owned and managed by the State Property Fund.
- Universal service suppliers (USSs), electricity suppliers with a legal obligation to supply residential and small, non-residential consumers at regulated prices. There are 25 regional USSs.
- Ukrinternenergo (supplier of last resort), a state-owned supplier that provides services to consumers in exceptional circumstances.

The Ukrainian government has introduced regulatory measures, known as public service obligations (PSOs), to secure continuous and non-discriminatory supply of electricity, and guarantee minimum levels of quality and service standards. One PSO protects household consumers from high electricity prices by mandating universal service suppliers to supply electricity to household consumers at regulated prices. Another PSO is designed to increase the generation of renewable energy sources (RES), giving RES producers financial advantages.[44]

3.3 Power generation

In Ukraine, nuclear energy is the primary energy source, followed by fossil energy, and renewable energy sources – as seen in figure 1.

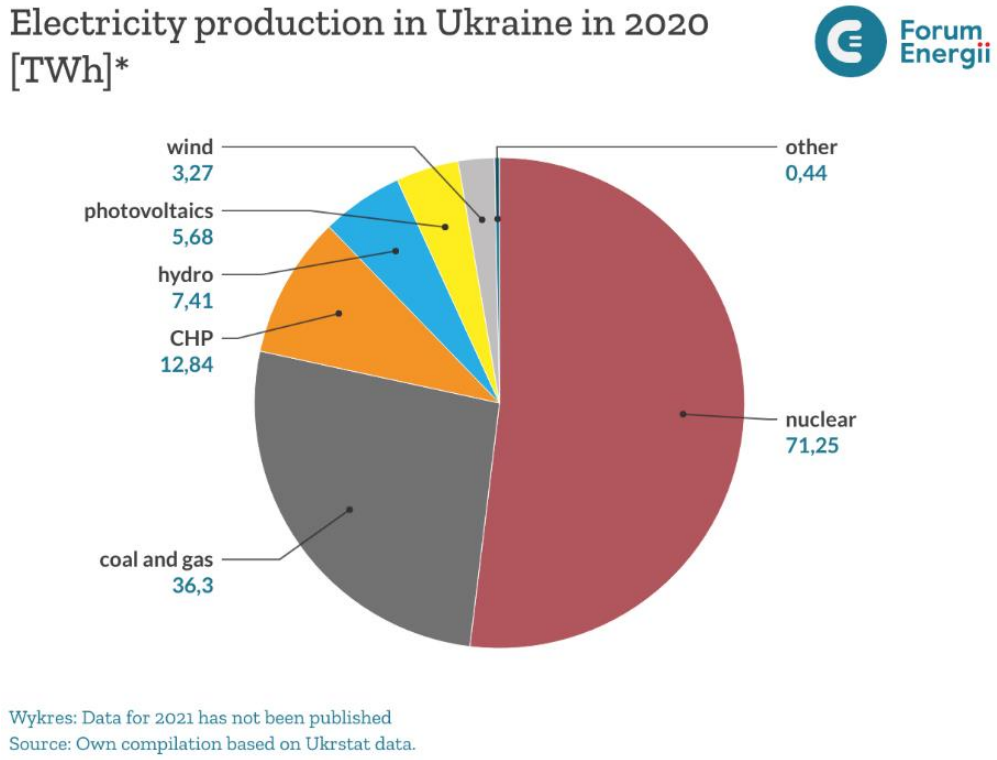

Figure 1. Electricity production in 2020. Photovoltaics is the same as solar power, and CHP stands for Combined Heat and Power. (Published with permission from Forum Energii.)

Source: Forum Energii. Ukraine's Preparations for a Wartime Winter. 2022-09-28. https://www.forum-energii.eu/en/blog/ukraina-zima. (Accessed: 2023-11-15).

Before the outbreak of the full-scale war, there were 17.7 million electricity customers in Ukraine, including 17.2 million households and half a million commercial customers.[45] In

[44] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 61-64.
[45] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

2021, Ukraine produced 143.4 TWh and consumed 124.5 TWh domestically, exported 5.1 TWh and imported 2.7 TWh.[46]

Nuclear power

Ukraine has four nuclear power plants comprising 15 reactors. The total installed capacity is 13.8 GW. In Europe, only France and Russia have larger installed nuclear production capacity.[47] Around 55 percent of Ukraine's electricity production came from nuclear energy in 2021.[48] Ukraine also has Europe's largest nuclear power plant, Zaporizhzhia, with six reactors and a net capacity of 5.7 GW (6 GW gross).[49] The others are the Khmelnytskyi, the Rivne, and the South Ukraine nuclear power plants.

In February 2022, the state-owned nuclear energy generating company Energoatom operated all four nuclear power plants. Of the 15 reactors, 12 were commissioned between 1980 and 1989 and the other between 1995 and 2004.[50]

Thermal power

In addition to nuclear plants, there are also thermal power plants (TPP) and combined heat and power plants (CHP) using coal, oil and, gas. The total installed power capacity of the thermal plants in the beginning of 2022 was 21.5 GW, and 6.1 GW of the combined heat and power plants (excluding plants occupied by Russia before February 24, 2022).[51] The thermal plants are of Soviet design and were commissioned between 1958 and 1977, though most of them were modernised after 2000.[52]

In February 2022, Ukraine had 12 thermal power plants, with capacities ranging between 150 and 800 MW, and three combined heat and power plants, with nine units with a capacity between 100 and 300 MW each.[53] Most of the thermal power plants are located in the eastern and central parts of Ukraine, as seen on the map in figure 2.

[46] WorldData. Energy consumption in Ukraine. 2024. https://www.worlddata.info/europe/ukraine/energy-consumption.php. (Accessed 2023-12-07). The residual is attributed to losses in transmission and transformation, and sometimes other causes.

[47] Forum Energii. Ukraine's Power System: Peace and War. 2022-03-17. https://www.forum-energii.eu/en/blog/system-elektroenergetyczny-ukrainy (Accessed 2023-11-15).

[48] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 29.

[49] IEA. Ukraine energy profile. 2020.

[50] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 29.

[51] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment I. 2022.

[52] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 30.

[53] Ibid.

Figure 2. Overview of power plants in Ukraine (published with permission from Forum Energii).

Source: Forum Energii. Ukraine's Power System: Peace and War. 2022-03-17.

Renewable energy

Ukraine has renewable energy source (RES) generation, consisting mainly of hydro, solar and wind power plants. The major hydro power stations are owned and managed by the state owned company Ukrhydroenergo. In February 2022, there were seven large run-of-river plants (4.6 GW) and two pumped hydro plants (1.2 GW) operating. The majority of the hydro power plants are located along the Dnipro River.[54] While most of the hydro power plants were built during the Soviet era, they were extensively modernised in the 2000s.[55]

There were also more than 1,100 solar installations with a total capacity of 6.4 GW. The capacity of the wind power plants was approximately 1.5 GW in 2021.[56] Most of the solar and wind power plants are located in the south of Ukraine, as seen in figure 2 above.

3.4 Transmission and distribution

The transfer of electricity from power plants and imports to end users, and from power plants to other countries through exports, takes place via the transmission and distribution systems. The transmission system is operated by the state owned Transmission System Operator Ukrenergo, while distribution systems are operated by different Distribution System Operators, called Oblenergos in Ukraine. The Ukrainian transmission system is illustrated in figure 3.

[54] PAX. Risks and impacts from attacks on energy infrastructure in Ukraine. Environment and Conflict Alert Ukraine. December 2022. https://paxforpeace.nl/wp-content/uploads/sites/2/import/2023-01/PAX_Ukraine_energy_infrastructure_FIN.pdf (Accessed 2023-11-07).

[55] OECD. Competition Market Study of Ukraine’s Electricity Sector, p. 31.

[56] Ibid.

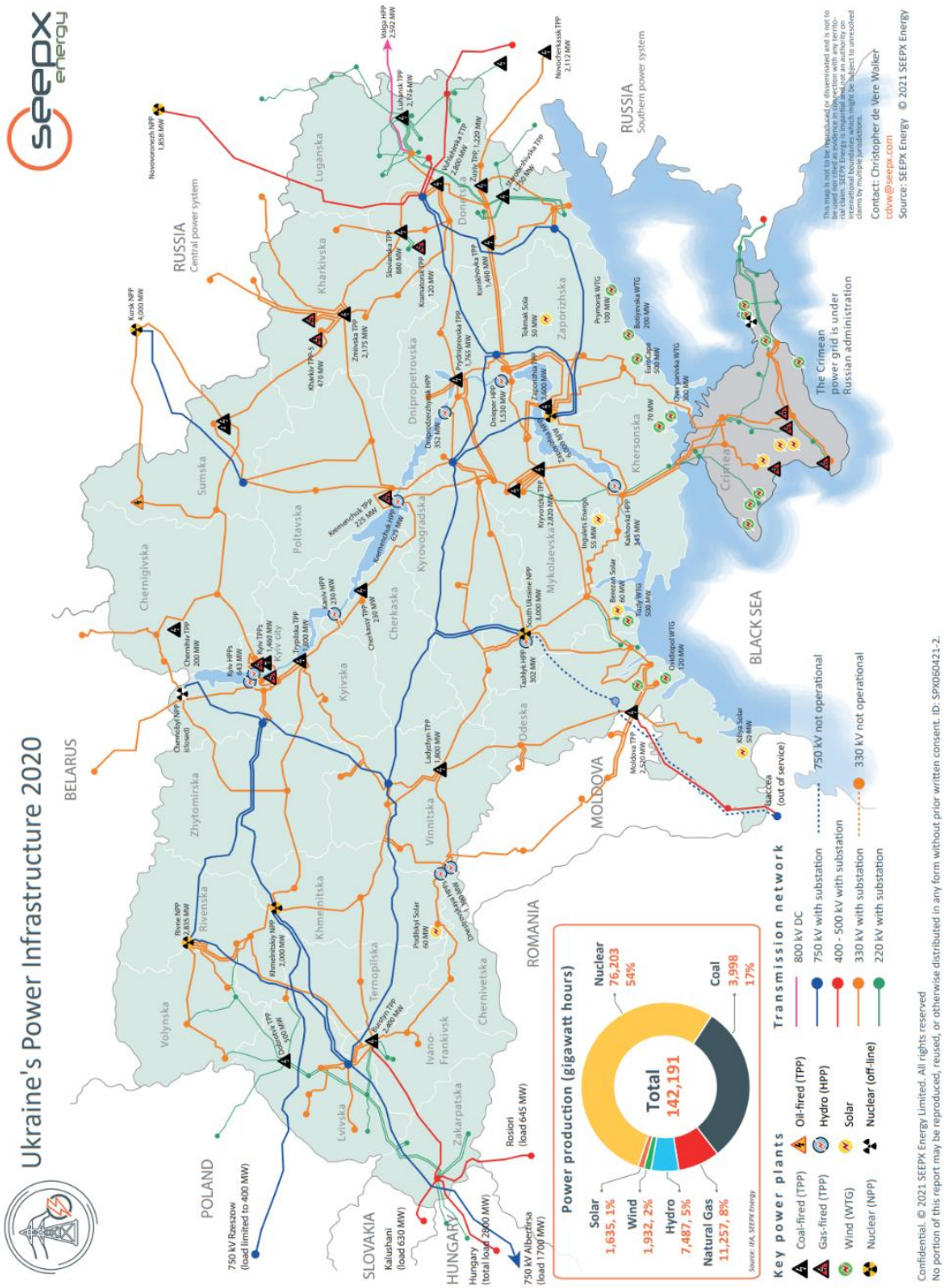

Figure 3. Ukraine's Power Infrastructure (published with permission from SEEPX Energy).

Source: SEEPX Energy, Ukraine's Power Infrastructure, 2020. https://www.seepx.com/_webedit/uploaded-files/All Files/Free Content/MAPS/SPX Ukraine Power Industry Map 2020 eng.pdf (Accessed 2024-05-27).

Transmission

Electricity must be generated in real-time and continually transmitted to users, sometimes over long distances. To avoid large energy losses in long-distance transfers, the electricity is transmitted at high voltages, between 220-750 kV, to high-voltage power substations located near demand centres.[57] 750 kV is used in the transmission systems in former USSR countries, while the most common voltage for transmission systems in Europe is 400 kV. This makes it difficult for Ukraine to source spare parts for the transmission system from Europe.[58]

The total length of the Ukrainian transmission grid is more than 24,000 km.[59] It is meshed, in order to be robust, and prior to the full-scale Russian invasion in 2022, it had a large reserve capacity.[60]

Over the last 25 years, Ukrenergo has built 1,250 km of new high-voltage power lines and five high-voltage substations of 330-750 kV, enabling electricity transfer from power generation facilities to other regions in Ukraine.[61]

As of 16th March 2022, the Ukrainian Power system is synchronised with the Continental European power grid (see chapter 3.5). As of June 2022, Ukraine has the capacity to export electricity commercially to countries within the ENTSO-E.[62]

High-voltage substations

Substations are the nodes in the power system. They reduce voltage, transfer power between networks of different voltage, and monitor the condition in the system. There are approximately 140 substations with a voltage of 110–750 kV in the Ukrainian transmission system.[63]

In an overview of the Ukrainian power system, the Ukrainian online publication Texty noted that the most important, but also the most vulnerable, parts in substations are the transformers.[64] The transformer's task is to convert the high voltage in the transmission network to lower voltages in the distribution network. This is done in several stages, until end users get 220 V in their homes (for industries, the final voltage may be higher). Transformers contain flammable materials, primarily oil for cooling, making them vulnerable to attacks. They are produced by only a few companies in the world, they take a long time to produce, and are expensive.

Substations can be quite large, with a length and width around 100-200 meters. Large substations have to be located under open sky since they need cooling, making them vulnerable to attacks. Smaller substations can be located in buildings or underground, giving them some level of protection.[65]

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[57] IEA. Ukraine energy profile. 2020.

[58] Interview. Autumn 2023.

[59] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 33.

[60] Interview. Autumn 2023.

[61] NPC Ukrenergo. " Народжене у найскладніші часи незалежної України", 2023-04-15. https://www.facebook.com/npcukrenergo/posts/608857921283037

[62] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment I. 2022.

[63] Ibid.

[64] Petro Bodnar & Nadja Kelm. "What's up with the power? How Russia destroys energy infrastructure." Texty. 2022-12-08. https://texty.org.ua/articles/108414/whats-up-with-the-power-how-russia-destroys-energy-infrastructure (Accessed 2023-12-07).

[65] Interview. Autumn 2023.

Distribution

Electricity reaches consumers through various distribution networks, operated by distribution system operators. The total length of the lines in the distribution networks is over 800,000 km.[66] Distribution networks also include around 200,000 low-voltage transformer substations.[67]

3.5 Synchronisation with the European Power System

Synchronisation of the Ukrainian power system with the Continental European Power System has been a goal for Ukraine since the 1990s.[68] The process was initiated in 2006 when Ukraine applied for integration of its power system into ENTSO-E.[69]

The work began in 2017 when Ukraine signed an agreement on the conditions for future interconnection of Ukraine's power system with the power system of continental Europe, with ENTSO-E.[70] As of 2017, Ukrenergo has conducted testing of power units, Ukrenergo staff have received training, and major efforts have been made to prepare for a future synchronisation.[71]

On 24th February 2022, the Ukrainian power system was disconnected from the Russian and Belarusian systems as part of a long planned test.[72] The test, which had to be coordinated with Russia, was originally scheduled for completion in January, but Russia postponed the test until 24th February.[73] The aim of the test, which was a prerequisite for synchronisation with the European power system, was to run the system in island mode for three days in order to confirm its function and resilience.[74]

Later that same morning, Russia launched its illegal full-scale invasion of Ukraine, at a time when the Ukrainian power system was at its most vulnerable.[75] Instead of being a three-day test, the disconnection from the Russian power system became permanent. Only a few weeks later, on March 16, after an urgent request by Ukraine and Moldova for emergency synchronisation, a trial synchronisation with ENTSO-E started.

According to ENTSO-E, the quick completion of the synchronisation process was made possible by previous studies carried out in the project and the adoption of risk mitigation measures.[76]

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[66] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 33.

[67] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment I. 2022.

[68] OECD. Competition Market Study of Ukraine's Electricity Sector, p. 17.

[69] Ukrenergo. Integration with ENTSO-E. 2023. https://ua.energy/european-integration/integration-entso-e/ (Accessed 2023-10-10).

[70] USAID Energy Security Project. How did Ukraine synchronize with the EU's power system, and why is it important for the country's energy security?

[71] DTEK. Maxim Timchenko: synchronizing with ENTSO-E was Ukraine's existential choice. 2023-03-16. https://dtek.com/en/media-center/media-releases/maxim-timchenko-synchronizing-with-entso-e-was-ukraines-existential-choic/?pdf (Accessed 2023-10-12).

[72] Blaustein, "How Ukraine Unplugged from Russia and Joined Europe's Power Grid with Unprecedented Speed. Scientific American".

[73] Interview. Autumn 2023.

[74] USAID Energy Security Project. How did Ukraine synchronize with the EU's power system, and why is it important for the country's energy security?

[75] Ibid.

[76] ENTSO-E. Continental Europe successful synchronisation with Ukraine and Moldova power systems. 2022-03-16. https://www.entsoe.eu/news/2022/03/16/continental-europe-successful-synchronisation-with-ukraine-and-moldova-power-systems/ (Accessed 2023-10-03).

4 Kinetic attacks on the power system

This chapter contains an overview and summary of the Russian missile and drone attacks on the power system in Ukraine, from February 2022 to the summer of 2023. It also addresses the consequences to the power system and the power supply, focusing on the period October 2022 to May 2023.

Due to the large amount of attacks, the situation in the power system and the available power supply is ever changing. This means that presenting a detailed sequence of events would be burdensome to read and absorb. Therefore, we have appended a timeline of the events in the appendix at the end of the report for the reader who wants to immerse him-/herself into the events. Here, the goal is instead to give an overview.

For more detailed information, please see Appendix B, which provides a timeline (based on open information and reports) of the attacks, damage, consequences, and measures taken by Ukraine authorities to restore power.

4.1 Commonly used weapon systems

Russia has used a wide array of weapons in attacks against the Ukrainian power system. These include different types of long-range guided missiles, drones and guided bombs, as well as short-range air defence systems in land attack mode.[77] Attacks with artillery and rocket launcher systems in the Ukrainian frontline regions have occurred almost daily (see Appendix B: Timeline of attacks).

Many different types of land attack cruise missile (LACM) have been employed against Ukraine's power grid.[78] The most prominent are similar in terms of capability, but are launched from different air, sea or ground platforms.[79] These missiles represent a high volume threat, as several thousand such missiles have been used (see chapter 4.3.1).

Semi-ballistic missiles have also been used, often popularly referred to as Iskander (launched from ground platforms) and Kinzhal (launched from air platforms) missiles.[80] These missiles fly in semi-ballistic high speed trajectories. The Russian stock of these missiles is much smaller than for cruise missiles, which normally means that they are reserved for high value targets.[81] It has been suggested that these are considerably harder to intercept and destroy compared to the subsonic cruise missiles mentioned above, however, this is disputed.[82] According to Yurii Ihnat, spokesperson for the Air Force Command of the Armed Forces of Ukraine, the Ukrainian military shot down 25 out of 63

[77] Ian Williams. Putins Missile war, Russia's Strike Campaign in Ukraine. Washington DC: Center for Strategic and International Studies. CSIS. 2023. https://www.csis.org/analysis/putins-missile-war p. 25-32 (Accessed 2023-11-10).

[78] A cruise missile is a guided missile that flies like a fixed-wing aircraft, either at low -altitude trajectory and subsonic speed, or at a higher altitude at supersonic, or even hypersonic, speeds.

[79] The Kalibr family of missiles, Kh-555, Kh-101 and 9M729.

[80] A ballistic missile is a guided missile that flies in a ballistic trajectory, similar to that of a high thrown ball. A semi-ballistic (sometimes also called quasi-ballistic) missile is a category of missile that has a low trajectory and/or is largely ballistic but can perform maneuvers in flight or make unexpected changes in direction and range. 9K720 Iskander is a mobile short-range missile system that can launch a variety of different missiles, both cruise and semi-ballistic missiles. Here we refer to the 9M723 semi-ballistic missile. Kh-47M2 Kinzhal is the air-launched variant of 9M723.

[81] Boyko Nikolov. Why did Russia increase the Iskander-M nuclear missile production? Bulgarian military, 2023-08-19. https://bulgarianmilitary.com/2023/08/19/why-did-russia-increase-the-iskander-m-nuclear-missile-production/ (Accessed 2024-05-22) and The Associated Press. Why would Russia use hypersonic missile to strike Ukraine? 2023-03-10. https://apnews.com/article/ukraine-russia-kinzhal-hypersonic-missiles-e0dc1e20e9dd53528c5381ca5fdee66a (Accessed 2024-05-22).

[82] Alexander H. Montgomery and Amy J. Nelson. Ukraine and the Kinzhal: Don't believe the hypersonic hype. Brookings. 2023-05-23. https://www.brookings.edu/articles/ukraine-and-the-kinzhal-dont-believe-the-hypersonic-hype/ (Accessed 2024-05-17).

Kinzhal hypersonic air-launched ballistic missiles fired by Russian troops since the full-scale invasion started.[83]

All the above-mentioned missiles have similar effects on their targets, as their respective warheads weigh about half a tonne and consists of metal shells filled with high explosives, similar to the outline of conventional artillery shells.[84]

For dedicated land-attack weapons as those described above, guidance to a pre-determined target coordinate is normally accomplished by satellite navigation with the Russian Glonass system, which is similar to the American GPS. If satellite navigation is not jammed, the missile can be expected to hit within around 20 m of the intended target coordinates.[85] It has been argued by Williams (and others) that Russian targeting seems to be plagued by recurring problems with its targeting process, which have lead to entire missile salvos being off target.[86]

The Iranian Shahed 136 one-way attack drone is a low-cost, long-range weapon causing the Ukrainian defence great problems.[87] They are apparently easy to manufacture, resulting in high availability. They are essentially a form of "poor man's cruise missile", as they, similar to the guided missiles described above, are guided by satellite navigation to their target. However, while they show similar precision to the above-mentioned missiles, they perform less well both in terms of speed and in terms of effect. Their low speed make them easier targets for Ukrainian air defences and they can be intercepted and destroyed with anti-aircraft artillery and even small arms fire. Their 50 kg warhead produce an effect more similar to a 155 mm artillery shell than a cruise missile with a 500 kg warhead. However, their great numbers still make them a significant threat and they force Ukrainian air defences to spend expensive and scarce missiles to defend against these cheap and plentiful weapons, according to several sources.[88]

Other weapons that Russia have used are surface to air missiles, such as the 5V55 family of missiles from the S-300 air defence system. They have been used in a secondary land attack mode, with low precision and a limited effect from its 130 kg warhead, which is optimised against air rather than ground targets.[89] In several cases, Russia has also used obsolete supersonic anti-shipping missiles, which have lacked severely in precision but have still provided horrifying effects against built-up areas with their 1,000 kg warheads.[90]

Other weapons that have been reported to routinely cause damage to the Ukrainian power system is artillery. Both artillery shells fired from a gun (howitzer) and rocket artillery are used (see Appendix B: Timeline of attacks). Gun artillery have a much shorter range than the guided missiles discussed above, which is also generally true for rocket artillery. However, rocket launchers can also launch guided missiles with longer range. Abundant artillery can be used to systematically hammer any buildings or installations in range to

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[83] Ukrinform, Air Force spox: 25 Russian Kinzhal missiles intercepted by Ukrainian forces. 2024-01-07. https://www.ukrinform.net/rubric-ato/3810314-air-force-spox-25-russian-kinzhal-missiles-intercepted-by-ukrainian-forces.html (Accessed 2024-05-17).

[84] Experts at the Swedish Defence Research Agency.

[85] Ibid.

[86] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine. p. 17, 24.

[87] In this report we use the common term "drone" for the type of vehicle also known as Unmanned Aerial Vehicle (UAV).

[88] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine. p. 31-32, Thomas Newdick.. Our First Look Inside Russia's Shahed-136 Attack Drone Factory. The Warzone. 2024-03-05. https://www.twz.com/news-features/our-first-look-inside-russias-shahed-136-attack-drone-factory (Accessed 2024-05-20) and Asami Terajima. Explainer: Iran's cheap, effective Shahed drones and how Russia uses them in Ukraine. Kyiv Independent. 2024-04-17. https://kyivindependent.com/explainer-irans-cheap-effective-shahed-drones-and-how-russia-uses-them-in-ukraine/ (Accessed 2024-05-20).

[89] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine. p. 9.

[90] Ibid.

pieces with repeated barrages. High volume more than makes up for limitations in precision and individual shell weight.[91] The Russian army fields a wide array of artillery of different types and calibres. Shell and rocket warhead weights can range from 20 to 250 kg and include cluster munitions.[92]

The effect of individual weapon systems against the Ukrainian power system is difficult to predict, as it depends on a number of factors. For example, if a single point of failure of the system in a given area can be found and destroyed with precision, it may suffice with very few weapons to achieve severe effects against a large part of the system. On the other hand, the system may not be that sensitive, as the selected targets can be hardened, have redundancy or are easy to repair. Some targets may also be difficult to reach with enough weapons if they are well defended. As discussed above, the Russian targeting process has generally been less than optimal, resulting in great weapon expense for comparably modest effects.

The effect of a detonating warhead on power infrastructure and facilities is also hard to predict. The above-mentioned weapons most often carry fragmentation warheads, which upon detonation burst into high velocity fragments that hit and damage parts of the target, affecting its functionality. Another effect of the detonating warhead is the blast wave, but the effects of this in an open environment decreases rapidly with distance from the detonation point. Fragments, however, pose a risk for several hundred meters. At close range, buildings will be vulnerable to the combination of blast and resulting fragments causing significant damage. If the warhead penetrates into the building and detonates inside an enclosed space, the blast will have a significant effect on the amount of resulting structural damage. In discussions with experts at the Swedish Defence Research Agency, it was put forward that a simple rule of thumb may be that a direct hit from a warhead up to 100 kg can be expected to destroy one or several rooms of a concrete building, whereas a 500 kg warhead can be expected to collapse parts and several levels of the same building.[93]

4.2 Russian strategies and tactics

The type of targets for missile and drone attacks has changed during the war, depending on changing Russian strategies to break the Ukrainian resistance.

In this section, we give a short overview of the Russian strategies for missile and drone attacks, starting with the development of the strategy from the start of the war until the summer of 2023, and end with some examples of tactics used in specific attacks.

4.2.1 Changing strategies

Here we present the changes in Russian strategies for missile and drone attacks from the start of the war until the summer of 2023.

The initial phase

It has been suggested that, in the initial phase of the war (from late February to mid-April 2022) the goal of the Russian federation was, most likely, to quickly capture Kyiv, thus causing a collapse of the Zelenskyy government and allowing for the installation of a

[91] For a more detailed discussion about artillery efficacy and doctrines, see: Sam Cranny-Evans. Russia's Artillery War in Ukraine: Challenges and Innovations. RUSI. 2023-08-09. https://www.rusi.org/explore-our-research/publications/commentary/russias-artillery-war-ukraine-challenges-and-innovations (Accessed 2024-05-08).

[92] Cluster munition contains multiple smaller explosive submunitions, which are ejected or released in mid-air over a wide area.

[93] For detailed discussions on this subject, see Geng Sheng Wang. A Method for Simulation of Structural Response of a Full Scale Building Subjected to Air Blast Load, FOI-R--4401--SE. 2017.

puppet regime.[94] This interpretation of the Russian strategy was echoed in a report from CSIS, which described Russian attempts to gain air supremacy by targeting primarily military infrastructure such as airfields and airports (both military and civilian) and on-site stores of aviation fuel.[95] The report goes on to describe how approximately 160 air and missile strikes targeted nearly 10 air bases in the first two days of the invasion. In the following weeks, Russian forces also damaged 70 percent of the high-voltage lines leading to Kyiv.[96]

April- August 2022

The above-mentioned CSIS report charts the time following the initial phase, laying out how the Russian federation changed focus from air bases to other types of targets.[97] Missiles and drones were launched across the whole country, focusing on economic and logistical targets. These included transportation infrastructure such as railways and roads but also the petroleum industry, in order to damage Ukraine's ability to produce fuel. The author of the report concludes that the aim of the attacks was to stop the flow of supplies to the front and transportation of munitions from partnership countries. While the power system was not the primary target, it was often affected by these attacks. For example, power substations received damage during an attack against the railway infrastructure in Lviv.

October 2022 – March 2023

While there were several instances of the power infrastructure receiving damage as a secondary or unintended target, attacks targeting the power system specifically, did not begin until the massive attack on the whole country on 10th October.

The strategy seemingly changed from inflicting local damage to the power networks in the conflict zones, to destruction of power plants and the transmission infrastructure, affecting the whole power system. In order to inflict the most damage possible and cause widespread blackouts, the attacks appear to have been planned with a detailed knowledge of the Ukrainian power system. Ukrenergo representatives have suggested that the attacks on 11th and 12th October were likely planned with the participation of Russian energy workers.[98]

The purpose of the attacks was likely to create hardships for Ukrainian society, especially in the capital area, and thus undermine Ukraine's ability and determination to fight.[99] According to Ukraine's Energy Minister Herman Halushchenko, part of the reason for the attacks is that electricity exports from Ukraine to Europe "helps European countries to

[94] Robert Dalsjö, Russian airpower in Ukraine – Nuisance or Menace? WavellRoom. 2023-05-24. https://wavellroom.com/2023/05/24/russian-airpower-ukraine-nuisance-menace/ (Accessed 2023-11-07) and Jose Miguel Alonso-Trabanco. The Evolution of Russia's Ukraine Strategy. Geopolitical Monitor. 2022-06-30. https://www.geopoliticalmonitor.com/the-evolution-of-russias-ukraine-strategy/ (Accessed 2024-06-03).

[95] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine. p. 5.

[96] NPC Ukrenergo."Сьогодні День Києва", Facebook, 2023-05-28. https://www.facebook.com/npcukrenergo/ 2023-05-28 https://www.facebook.com/npcukrenergo/posts/637150951787067

[97] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine. p. 7-8.

[98] NPC Ukrenergo. "111 ракет за два дні". Facebook, 2022-10-16.https://www.facebook.com/npcukrenergo/videos/441918591417344/

[99] NPC Ukrenergo. "Зруйновані енергоблоки електростанцій", Facebook, 2023-02-22. https://www.facebook.com/-npcukrenergo/posts/575684147933748 and Joshua Yaffa, "The impact of Russian missile strikes on Ukraine's power grid", The New Yorker. 2023-02-20. https://www.newyorker.com/culture/photo-booth/the-impact-of-russian-missile-strikes-on-ukraines-power-grid?fbclid=IwAR3kfpyYXXxZUkOrmcFxF9dKqwuhwf0bmQhSq3qW7VDdahRs9eO9Leesz78 (Accessed 2023-11-06).

save on Russian gas and coal".[100] Thus, impeding the export of electricity from Ukraine to Europe increases the European demand for Russian gas. In an assessment by the Institute for the study of war, it was suggested that the Russian forces attack civilian infrastructure in order to create psychological terror effects.[101]

In an analysis by the Ukrainian publication Texty, it was concluded that most of the strikes against the power system in October were aimed at the northern region of Ukraine. This region is geographically very large, it is where most of the country's major cities (including the capital) are located and it is inhabited by a large part of the Ukrainian population. The authors of the analysis suggest that, due to its size, the region cannot be completely covered by air defence, and due to its geographical location, bordering Russia and Belarus, the approach times of missiles and drones is very short, increasing its vulnerability.[102]

After the initial weeks of attacks in October, missiles and drones were launched on the power system with larger attacks about 1-2 weeks apart. The International Centre for Defence and Security (ICDS) have noted that it was not until Russia secured a supply of cheap, accurate Iranian drones that it was able to pursue a strategy of attacking the power system on a large scale.[103]

In December, Russian attacks started to focus more on power plants (especially combined heat and power plants). Since heat cannot be transmitted long distances, these plants are located closer to, or inside, population centres. This change in tactics also suggests Russia wanted to affect the civilian population by disrupting the heat supply.[104] The attacks against the Ukrainian power system decreased somewhat during the first months of 2023, with a longer break in March.

April-May 2023

In April 2023, Russia once again changed its tactics and started using guided bombs while continuing its regular attacks on the power system. One explanation for this was put forward by the Task Force[105], suggesting that Russia may have had a shortage of long-range missiles after the many attacks on the Ukrainian power system during the winter 2022-2023.[106]

After a quieter period, attacks started again around the end of April. The type of targets were not as predictable as before and an analysis by CSIS, concluded that Russia likely struggled with finding gaps in the air defence. For example, an attack with 34 Iskander and Kinzhal missiles targeting a Patriot battery protecting the airspace over Kyiv seemingly failed, as it was reported that all the missiles were destroyed.[107] According to UK Defence Intelligence, the type of facilities Russia targeted in these strikes might suggest a shift

[100] Alex Hardie. "Russia-Ukraine news. Energy minister: About 30% of Ukraine's energy infrastructure has been hit by Russian missiles since Monday". CNN, 2022-10-11. https://edition.cnn.com/europe/live-news/russia-ukraine-war-news-10-11-22/h_2093c5424cc0e8f0c2b366dd9e147957 (Accessed 2023-12-01).

[101] Karolina Hird, Kateryna Stepanenko, Riley Bailey, and Frederick W. Kagan. "Russian Offensive Campaign Assessment". Institute for the study of war. 2022-10-17. https://www.understandingwar.org/backgrounder/russian-offensive-campaign-assessment-october-17 (Accessed 2023-10-08).

[102] Petro Bodnar, Nadja Kelm. "What's up with the power? How Russia destroys energy infrastructure".

[103] Jermalavičius et al, "War and energy security. Lessons for the future", p. 43.

[104] Interview. Autumn 2023.

[105] "Task Force" refers to the Ukrainian energy sector evaluation and damage assessment, a monthly report from the International Energy Charter, Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force.

[106] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

[107] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine. p. 7-8.

from attacking Ukraine's energy infrastructure to targeting its military, industrial and logistics facilities.[108]

After May 2023, Russia apparently shifted the focus of large-scale kinetic attacks away from the Ukrainian power system. Despite this apparent shift in focus, Russia destroyed the Kakhovka dam on the Dnipro River on June 6, causing massive floods and destruction.[109]

4.2.2 Tactics used in specific attacks

Russia has used a variety of different tactics, presumably in order to try to find or exploit vulnerabilities, thus causing maximum damage.

Launching multiple missiles simultaneously targeting the same power infrastructure facilities

Russia has launched multiple missiles simultaneously targeting the same power infrastructure facilities, likely in order to maximise the possibility for missiles to evade interception by air defence. For example, a damage assessment by the Task Force recounts how the Russian military forces fired seven missiles at one critical substation in the Odesa region.[110]

Attacking at the time of peak consumption

Ukrenergo representatives report that a number of attacks have taken place at the time of peak consumption, when the power system has less margin for lost capacity.[111] This means that remaining capacity might not be able to cover demand.

Targeting specific infrastructure or facilities for the operation of nuclear power plants

Russia has targeted specific infrastructure or facilities for the operation of nuclear power plants, which inhibits power generation at these plants.[112] This increases the deficit in the power system without damaging the actual nuclear power plants. According to one respondent interviewed in the process of compiling this report, damaging nuclear power plants would have put Russia under immense diplomatic pressure, which Russia likely wishes to avoid.[113]

Attacking the power system in order to disrupt specific operations

An example of this was suggested in a report by the Task Force where they speculated that an attack on the power system in the Odesa region with drones on 10th December, was

[108] Ukrainska Pravda. "UK Intelligence assesses Russia's latest missile strikes on Ukraine", 2023-05-03. https://www.pravda.com.ua/eng/news/2023/05/3/7400420/ (Accessed 2023-12-01).

[109] Katerina Sergatskova. Aftermath of the Kakhovka Dam Collapse. Wilson Center. 2023-06-20. https://www.wilsoncenter.org/blog-post/aftermath-kakhovka-dam-collapse (Accessed 2023-12-05).

[110] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[111] NPC Ukrenergo, " Голова правління НЕК "Укренерго", Facebook, 2022-11-15. https://www.facebook.com/npcukrenergo/posts/502712435230920

[112] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[113] Interview. Autumn 2023.

intended to obstruct the work of seaports responsible for Ukrainian grain export within the "grain agreement" framework.[114]

Destroying critical energy infrastructure when withdrawing from occupied areas

It has been reported that Russia has destroyed critical energy infrastructure when withdrawing from occupied areas.[115] While retreating from the districts of the Mykolaiv and Kherson regions, the Russian military forces reportedly destroyed critical energy infrastructure in the region, including a critical transmission substation, two critical autotransformers, three main power transmission lines supplying electricity to the Kherson regions, and damaged renewable energy source facilities.

Using many different types of missiles in the same attack

Many different types of missiles have been used in the same attack, presumably in order to saturate the air defence.[116] This makes it harder to defeat the missiles. For example, in the attacks on 9th March, Russia used a new tactic of launching different types of missiles, including air-based and sea-based missiles. Overall, Russia fired nine different types of cruise and ballistic missiles. The strikes included six Kinzhal missiles that are harder to intercept (see chapter 4.1), as well as anti-ship missiles and air defence missiles. In the pause between the missile waves, Russia also launched at least eight Shahed-136 drones.[117] Of the 81 missiles fired, 47 hit targets, which is a higher ratio than in the previous few months. This higher ratio was likely achieved by using Kinzhal missiles and a higher number of ballistic rather than cruise missiles.[118]

A variant of this tactic has been to launch a series of attacks with an array of different weapons systems. For example, the attack on December 29 started with drone attacks, followed by a massive missile attack, and then several more attacks with air defence missiles (S-300) across Kharkiv region and Mykolaiv region.[119]

Targeting the repair personnel of the power companies performing emergency repairs

The Task Force notes that in addition to targeting the infrastructure and facilities in attacks against the power system, Russia has also attempted to reduce the Ukrainian ability to repair power infrastructure and restore the power supply, by targeting the repair personnel performing emergency repairs.[120]

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[114] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[115] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[116] Andrew E. Kramer. "Russia Blasts Ukrainian Cities, Including Biggest Use of Advanced Missiles", The New York Times. 2023-03-09. https://www.nytimes.com/2023/03/09/world/europe/russia-ukraine-missile-hypersonic.html?searchResultPosition=1 (Accessed 2023-10-20).

[117] Olesia Safronova and Aliaksandr Kudrytski, "Russia Shifts Tactics With Deadly Missile Strikes on Ukraine", Bloomberg. 2023-03-09 https://www.bloomberg.com/news/articles/2023-03-09/ukrainian-cities-hit-by-new-wave-of-russian-missile-attacks?leadSource=uverify%20wall (Accessed 2023-10-16).

[118] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[119] NPC Ukrenergo. "Наслідки десятої терористичної атаки для енергосистеми України", Facebook, 2022-12-29. https://www.facebook.com/npcukrenergo/videos/3702798226617438/

[120] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment X. 2023.

4.3 Overview of attacks

This sections aims at providing an overall picture of the attacks. It is an attempt to establish is a link between the total numbers of missiles and drones that Russia launched, to the extent of damage in the power system. This chain contains uncertainties in each step. The relationship between the total number of missiles and drones launched, and the extent of damage are context specific, and should not be taken as a hard fact. It depends on the attacker's knowledge about the design and vulnerabilities of the power system and the amount of available air defence, as well as how well protected the facilities are (by passive protection). It also depends on the attacker's ability to correctly target their weapons.

This chapter primarily covers the period between October 2022 and May 2023, as this was when the focused large-scale attacks on the power system occurred. The summary includes:

- the number of missiles and drones launched by Russia from the beginning of the war until the summer of 2023
- the number targeting the power system
- description of targets hit

Giving a complete description based on open sources brings with it some difficulty, as sources base their reporting on different periods, and different missile types. It is equally difficult to summarise damage to the power system, as these sources also vary in content and focus. What follows below is an attempt to present the reported numbers and a summary of the overall picture.

4.3.1 Magnitude of total attacks

Based on the numbers reported in a variety of sources, around 2,500 missiles were launched by Russia between the start of the war and June 2022, 1,000 missiles between June and November 2022, and 1,500 missiles between November 2022 and February 2023, adding to the reported total of 5,000. In addition, around 1,000 drones were launched between the start of the war and February 2023, with a majority launched after September 2022.[121]

Our conclusion (based on the above-mentioned sources) is that the intensity in missile attacks decreased during the summer and autumn of 2022, while they focused on the power system in autumn (see chapter 4.2.1). The attacks then intensified once more in November 2022.

An illustration of our summary of the large-scale attacks during the period September 2022 to May 2023 is presented in figure 4.

[121] Maxim Starchak. Missed Targets: the Struggles of Russia's Missile Industry. Centre for European Policy Analysis. 2022-07-22. https://cepa.org/article/missed-targets-the-struggles-of-russias-missile-industry/ (Accessed 2024-05-28) and Igor Kossov, How many missiles does Russia have left? The Kyiv Independent. 2023-01-13. https://kyivindependent.com/how-many-missiles-does-russia-have-left/ (Accessed 2023-10-21), Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine. p. 12, and Ukraine Crisis Media Centre, "How many missiles Russia fired at Ukraine in a year". 2023-02-23. https://uacrisis.org/en/skilky-rosiya-vypustyla-raket-po-ukrayini-za-rik (Accessed 2023-10-28).

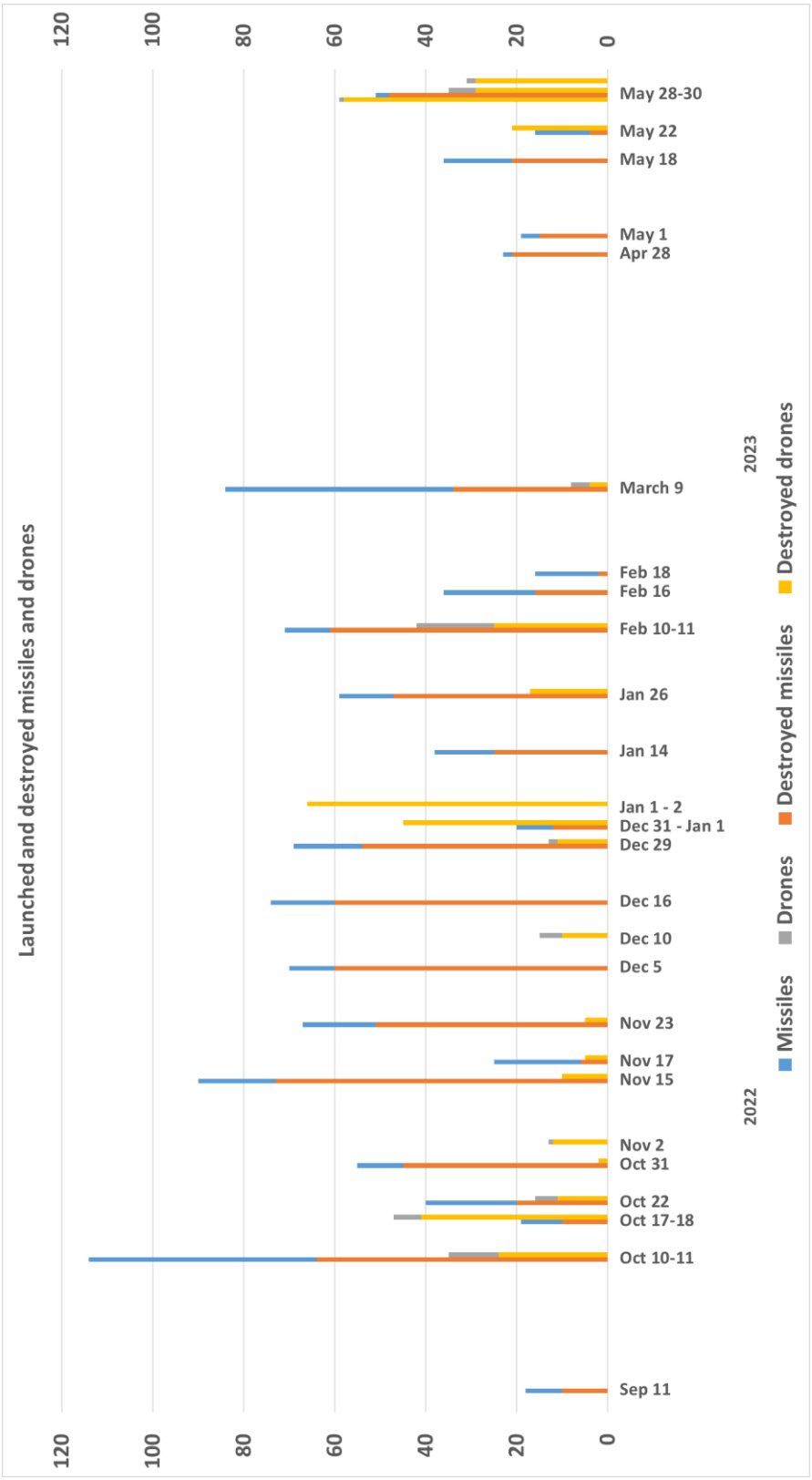

Figure 4. Number of launched and destroyed missiles and drones in the larger attacks between September 2022 and May 2023. Some attacks on consecutive days are grouped together in order to increase visibility. Data from the General Staff of the Armed Forces of Ukraine and the Air Force Command of UA Armed Forces.

Source: Aggregated data from several posts on the Facebook pages of General Staff of the Armed Forces of Ukraine, https://www.facebook.com/GeneralStaff.ua/ and the Air Force Command of the Armed Forces of Ukraine, https://www.facebook.com/kpszsu/.

The comprehensive overview in figure 4 sheds light on the sheer scale of the attacks, how the intensity of the attacks has fluctuated during the assessed period, and the fact that attacks have often recurred within a few days up to around a week, or in around two weeks.

It should be emphasised that the attacks in figure 4 only includes major attacks (defined as those involving at least five missiles or drones). There were approximately 30 of these major attacks between September 2022 and May 2023. The count varies with consecutive-day attacks sometimes considered as one. Our summary indicates a total of 1,144 missiles and 475 drones launched. Of these, 759 missiles (68 percent) and 425 drones (90 percent) were destroyed.

Despite the vulnerability constituted by inadequate air defence systems, highlighted by ICDS, Ukraine's defence capabilities have improved with the introduction of Western systems in late 2022.[122] By winter 2022-2023, Ukraine's Air Force reported that it had intercepted 70-80 percent of Russian cruise missiles, rising to 90 percent by May and June 2023, including drones. Nationally, nearly 80 percent of ballistic missiles were reportedly intercepted, with 100 percent protection in areas equipped with systems like Patriot, with two batteries deployed by June 2023.[123]

We suggest that this development underscores the importance of air defence against missiles and drones but that it also highlights an increasing ability by Ukraine to protect critical infrastructure. With interception rates improving over time, especially in areas equipped with advanced systems like Patriot, Ukraine has seen a marked enhancement of the defence against both cruise and ballistic missiles, providing a crucial layer of protection.

4.3.2 Attacks targeting the power system

This section describes the number of missiles and drones targeting the power system, what parts of the power system that were targeted and the number of hits.

Our summary adds up to a total of 1,619 missiles and drones launched by Russia in the large-scale attacks between September 2022 and May 2023 (see previous section). However, we lack specific data regarding the portion of these attacks directed specifically towards the power system. Determining the precise targets of intercepted or destroyed missiles and drones presents challenges. Assessments by the UNDP and Ukrenergo however suggest that approximately 1,200 missiles and drones targeted the power system and 1,500 targeted the energy infrastructure.[124]

Our summary shows that 385 missiles and 50 drones (435 in total out of 1,619) were not intercepted in the large attacks between September 2022 and May 2023, which means that they could potentially have hit their target. This does not mean that they necessarily *did* hit the intended target. For example, in the attack on 9th March 2023, eight out of the 50 missiles that were not destroyed, missed their target.[125] Some of these 435 missiles and drones most likely hit targets other than the power system, as Russia also targeted military and other civilian facilities in some attacks (see Appendix B: Timeline of attacks).

[122] Jermalavičius et al, "War and energy security. Lessons for the future", p. 43.

[123] Ian Williams. Russia Isn't Going to Run Out of Missiles. Center for strategic & international studies. CSIS. 2023. https://www.csis.org/analysis/russia-isnt-going-run-out-missiles (Accessed 2023-12-01).

[124] The United Nations Development Programme and The World Bank. Ukraine Energy Damage Assessment. Executive Summary. March 2023. p. 4 and NPC Ukrenergo "Найважчий опалювальний сезон в історії української енергосистеми у цифрах", Facebook, 2023-04-08. https://www.facebook.com/npcukrenergo/posts/604550888380407 .

[125] General Staff of the Armed Forces of Ukraine, "Situation update", Facebook. 2023-03-09. https://www.facebook.com/GeneralStaff.ua/posts/545648387748244

In April 2023, Ukrenergo reported that over 250 missiles and drones had hit the power system,[126] and in June 2023, the Task Force reported a similar number of hits on transmission system substations.[127]

On average, each critical power system facility was hit 2.3 times, according to the Task Force[128] and according to Ukrenergo, some substations were attacked 4-5 times.[129]

A large share of these hits occurred between October 2022 and February 2023, with particular intensity of attacks occurring in October.[130] This strengthens the conclusion that, starting in October 2022, Russia targeted the power system to a much greater degree than before.

The attacks in brief:

- In total, Russia launched around 30 large-scale attacks, using missiles and drones, between September 2022 and May 2023.
- The reportedly highest number of missiles used in one attack was on 15 November, 2022 and came to 90. The average number of missiles used per attack came to 43.
- The highest number of drones used in one attack was 59 on 28 May 2023. The average number of drones used per attack was around 20.
- Between 1,200 and 1,500 missiles and drones have targeted the Ukrainian power system.
- Around 250 missiles and drones have hit the power system.

4.4 Damage and consequences

Here we present a general overview of the damage resulting from the Russian attacks and the consequences to the power system and supply from the beginning of the invasion in 2022 until the end of May 2023. Access to information on damage and losses of energy infrastructure facilities, as well as operating capacity of power plants, has been restricted by the Ministry of Energy of Ukraine and Ukrenergo for security reasons.[131] We have therefore been unable to provide a detailed description (including exact numbers) of the damage and the consequences for the Ukrainian power system, power generation and supply for the whole period.

[126] NPC Ukrenergo. “Найважчий опалювальний”, 2023-04-08. https://www.facebook.com/npcukrenergo/posts/604550888380407

[127] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment XI. 2023.

[128] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[129] NPC Ukrenergo, “ ДЕФІЦИТ потужності”, Facebook, 2023-03-04. https://www.facebook.com/npcukrenergo/posts/582903330545163

[130] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[131] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022,
NPC Ukrenergo. “У коментарях на нашій сторінці ви часто зауважуєте”, Facebook, 2023-05-26. https://www.facebook.com/npcukrenergo/posts/635958381906324 and Jermalavičius et al, “War and energy security. Lessons for the future”, p. 58

4.4.1 Damage

The Ukrainian power system suffered massive damage due to Russian attacks during the winter of 2022-2023. Sources estimate that up to 50 percent of Ukraine's power grid received damage[132], 30 percent of Ukraine's power stations were destroyed[133], 40 percent of energy infrastructure were significantly damaged[134], and about 35-40 percent of the installed thermal and combined heat power plant capacities were either damaged or destroyed.[135] A majority of the damage occurred in the autumn of 2022.

Power generation

The Task Force reported that Russian attacks succeeded in damaging 24 power generation facilities, a majority of which were attacked on multiple occasions in the winter 2022-2023.[136] According to Ukrenergo, attacks targeted all power plants in the Eastern region, as well as all thermal and hydroelectric power plants in the whole of Ukraine, causing varying degrees of damage.[137]

In one of two interviews conducted within the framework of this report, one respondent suggested that in the attacks on power plants, the substations near the plants were the main targets. The respondent reasoned that, in comparison to power plants, where larger weapons are required to cause any damage (partially due to the massive concrete walls surrounding the plant), substations are easier to destroy or damage.[138]

Transmission and distribution infrastructure

In April 2023, Ukrenergo reported that since the beginning of the war, 43 percent of the transmission system had been damaged.[139] Two months later, UNDP reported that 42 of 94 critical high voltage transformers had been damaged or destroyed. More than half were hit more than once. The 750 kV high-voltage system used to transmit electricity from nuclear power plants was damaged throughout Ukraine.[140]

According to the respondent referred to above, damage to substations were primarily caused by fragments from warheads detonating in the vicinity, not by direct hits. However, only a few fragments are needed to destroy a transformer. Between ten and twenty hits by fragments might make the transformer impossible to repair.[141]

The distribution system has also suffered countrywide damage. According to the Task Force, by the beginning of January 2023, more than one thousand overhead lines (6-150

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[132] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine. p. 12.

[133] Hugo Bachega and Yaroslav Lukov. Ukraine war: Blackouts in 1,162 towns and villages after Russia strikes. BBC. 2022-10-18. https://www.bbc.com/news/world-europe-63297239 (Accessed 2023-11-17).

[134] PAX. Risks and impacts from attacks on energy infrastructure in Ukraine. Environment and Conflict Alert Ukraine. December 2022.

[135] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022.

[136] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

[137] NPC Ukrenergo. "айважчий опалювальний сезон в історії", Facebook, 2023-04-08. https://www.facebook.com/npcukrenergo/posts/604550888380407 and NPC Ukrenergo, "Найгарячіша ділянка енергетичного фронту", Facebook, 2023-04-06. https://www.facebook.com/npcukrenergo/posts/603488445153318

[138] Interview. Autumn 2023.

[139] NPC Ukrenergo. "айважчий опалювальний сезон в історії", Facebook, 2023-04-08. https://www.facebook.com/npcukrenergo/posts/604550888380407

[140] UNDP and The World Bank. Towards a green transition of the energy sector in Ukraine. Update on the Energy Damage Assessment. June 2023. p. 20.

[141] Interview. Autumn 2023.

kV) and more than eight thousand transformers (6-150 kV) had been damaged or disconnected.[142] 37 distribution substations were damaged between October 2022 and March 2023. Most of the damage occurred in regions located in the combat zone and along the front line.[143] The amount of damage, and the fact that the damaged distribution infrastructure were mostly located near or in the combat zone or the front line, indicate that these attacks were mostly from other weapon systems than long-range missiles and drones, presumably artillery. We assume that this is, at least partly, collateral damage rather than the result of targeted attacks on the power system. However, it cannot be ruled out that the distribution system was specifically targeted and also attacked by long-range weapon systems.

In conclusion, based on the reported numbers, out of 250 hits on the power system (where some object or facilities were hit multiple times) 42 high voltage transformers and 24 power generation facilities were damaged or destroyed. Although we have no specific information on how many missiles and drones hit the transmission power lines, severe damage was reported all over Ukraine.

4.4.2 Consequences for power generation and supply

Russia's invasion in February 2022 has had a considerable impact on Ukraine's power system and supply. In this section of the report, we summarise the consequences for the power generation capacity and supply.

In August 2022, the majority of Ukraine's wind power plants were out of commission, either because they were located in Russian-occupied areas or were damaged. The same was true for some 30 percent of solar and combined heat power plants. The Zaporizhzhia nuclear power plant has been under Russian control since 3rd March 2022, and the power lines from the plant were destroyed in an attempt by Russian forces to re-synchronise the plant with the Russian system. The Kakhovka Hydroelectric power plant was occupied on the first day of the invasion in February 2022.[144]

Power generation

Power generation in the first six months of 2022 is presented in figure 5 (more updated figures have not been available to us due to security restrictions). The decrease in power generation that occurred at the end of February 2022 was mainly due to a decline in nuclear power, but also in coal-fired power generation.[145]

[142] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment X. 2023.

[143] The United Nations Development Programme and The World Bank. Towards a green transition of the energy sector in Ukraine. Update on the Energy Damage Assessment. June 2023, p. 21.

[144] Forum Energii. Ukraine's Preparations for a Wartime Winter.

[145] IAE, Ukraine Real-Time Electricity Data Explorer. 2022. https://www.iea.org/data-and-statistics/data-tools/ukraine-real-time-electricity-data-explorer (Accessed 2023-08-17).

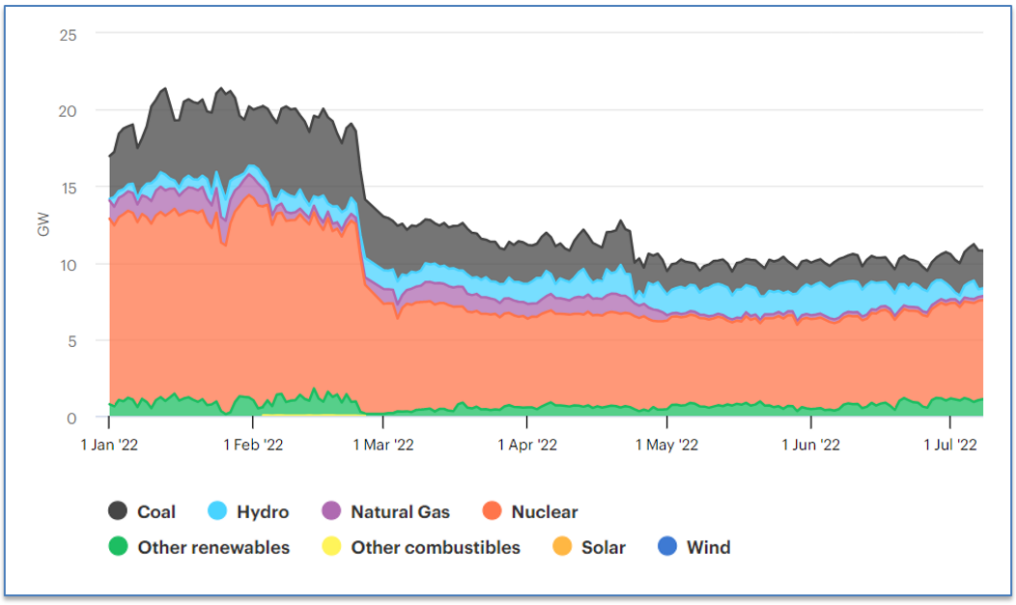

Figure 5. The power generation in Ukraine the first half year 2022.

Source: IAE, Ukraine Real-Time Electricity Data Explorer. 2022. https://www.iea.org/data-and-statistics/data-tools/ukraine-real-time-electricity-data-explorer (Accessed: 2023-08-17).

After the Russian invasion in February 2022, the electricity demand in Ukraine dropped sharply due to reduced activities in business and industry, as well as to the fact that almost 8.2 million people fled the country.[146]

Figure 5 illustrates that the demand decreased drastically at the time of invasion, and kept decreasing slowly until the end of spring, when it stabilised.[147] Power demand fell by as much as a third, from around 15 GW in September 2021 to only about 10 GW a year later.[148]

According to UNDP, available production capacity decreased from 36.0 GW in the beginning of 2022, to 13.9 GW by the end of 2022, a reduction by over 60 percent.[149] The available production capacity increased to 18.3 GW by the end of April 2023, a development that the UNDP report attributes to the high pace of repairs by Ukrainian actors and equipment support from Western partners.[150] At the end of May 2023, Ukrenergo estimated that the total loss of installed generation capacity was around 27 GW.[151]

Ukraine has also lost production capacity due to many power plants being located in areas occupied by Russia. Ukrenergo has calculated that in January 2023 more than 10 GW of basic installed capacity was unavailable to Ukraine because of occupied plants. At the time, most of the wind and solar power plants were located in the occupied territories of

[146] OECD. Competition Market Study of Ukraine's Electricity Sector. June 2023. p. 16.

[147] IEA, Ukraine Real-Time Electricity Data Explorer.

[148] Forum Energii. Ukraine's Preparations for a Wartime Winter.

[149] The United Nations Development Programme and the World Bank. Ukraine Energy Damage Assessment. Executive Summary. UNDP, March 2023. https://www.undp.org/ukraine/publications/ukraine-energy-damage-assessment (Accessed 2023-11-09). p. 4.

[150] UNDP and The World Bank. Towards a green transition of the energy sector in Ukraine. Update on the Energy Damage Assessment. June 2023. p. 6, 12.

[151] NPC Ukrenergo, "У коментарях на нашій сторінці", Facebook, 2023-05-26. https://www.facebook.com/npcukrenergo/posts/635958381906324

the south.[152] This can be compared to the situation in May 2021, when Ukrenergo reported that approximately 4 GW of capacity was lost to the regions occupied by Russia since 2014.[153] 25 percent of transmission substations were located in the territories occupied by Russia before February 24, 2022 and an additional 12 percent were occupied after.[154]

By the end of April 2023, over 90 percent of wind generation, some 75 percent of thermal generation, almost half of the nuclear generation (due to the occupation of Zaporizhzhia NPP), and over 30 percent of solar generation was lost due to damage or occupation.[155]

Power supply

Due to Russian attacks and resulting damage to power production and the transmission and distribution systems, millions of Ukrainians have been without power at some point during the war.

According to a report by the World Bank, the average Ukrainian household experienced five cumulative weeks without power, from 10th October to the end of December 2022.[156] Almost all electricity consumers had been temporarily disconnected from the power supply at some point from the beginning of the war until January 2023.[157]

From the end of October 2022 to the beginning of February 2023, up to 12 million Ukrainians on average were without power during any given hour.[158]

Half of all electricity consumers were disconnected in all regions of Ukraine after the attack on 16th December.[159] On two occasions (23rd November and 5th December), scheduled or emergency shutdowns took place over the whole of Ukraine.[160] The longest reported period with consumer restrictions came to 12 days, between 11th and 23rd October.[161]

[152] NPC Ukrenergo. “СПОЖИВАННЯ електроенергії: прогнозується дещо меншим”, Facebook, 2023-01-18. https://www.facebook.com/npcukrenergo/posts/549760080526155

[153] NPC Ukrenergo. “коментарях на нашій сторінці ви часто зауважуєте”, Facebook, 2023-05-26. https://www.facebook.com/npcukrenergo/posts/635958381906324

[154] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment XI. 2023.

[155] UNDP and The World Bank. Towards a green transition of the energy sector in Ukraine. Update on the Energy Damage Assessment. June 2023. p. 14.

[156] The World Bank, the Government of Ukraine, the European Union, the United Nations. Ukraine - rapid damages and needs assessment. March 2023. https://documents1.worldbank.org/curated/en/099184503212328877/pdf/P1801740d1177f03c0ab180057556615497.pdf (Accessed 2023-09-11). p. 83.

[157] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

[158] NPC Ukrenergo, “Понад три місяці поспіль”, Facebok, 2023-02-23. https://www.facebook.com/npcukrenergo/posts/576589417843221

[159] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[160] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022 and NPC Ukrenergo, “Today, the terrorist country launched the eighth massive missile attack on our energy facilities”, Facebook, 2022-12-05. https://www.facebook.com/npcukrenergo/-posts/517338637101633

[161] NPC Ukrenergo, ”«Укренерго» відновило живлення більшої частини Хмельниччини”, Facebook, 2022-10-23. https://www.facebook.com/npcukrenergo/posts/485281843640646

4.4.3 Other consequences

In addition to the challenges with decreased power generation, damaged infrastructure, and disrupted power supply, the attacks on the power system have had other consequences, some of which are listed below.

- The attacks on the power system and disruption of power supply have affected water pumping and the operation of hospitals and health care facilities, seriously endangering the health and safety of civilians.[162]
- Energy sector employees performing the repair work have been severely injured or killed. By attacking both energy infrastructure and energy sector employees, Russian military forces have been able to reduce Ukraine's ability to efficiently restore the power supply.[163]
- In June 2023, the Kyiv School of Economics estimated the cost of the direct damage to Ukraine's energy infrastructure at more than $8.8 billion. The preliminary estimate of the total amount of damage to infrastructure and facilities for production, transmission and distribution of power is over $7.2 billion. Clearly, the power system was the part of the energy sector hardest hit by the strikes.[164]
- The war significantly affected the financial viability of the energy sector in Ukraine. According to an estimation of the National Bank of Ukraine, the power and utility companies suffered the most. About 90 percent of energy companies will not be able to service their debts due to the inflicted destruction and losses.[165]
- Russia's attacks targeting energy infrastructure and facilities also affected telecommunications and internet connection. For example, the massive attack on 9th March 2023, caused significant disruptions in internet connectivity and access to information in multiple regions of Ukraine.[166]

Damage and consequences in brief:

- Between 30 and 50 percent of different parts of the power system have suffered damage at various times.
- 42 out of 94 critical high voltage transformers have been damaged or destroyed.
- The 750 kV high-voltage network has been damaged throughout Ukraine.
- 37 distribution substations, more than one thousand overhead lines (6-150 kV), and more than eight thousand transformers (6-150 kV) were damaged or disconnected in the distribution system.
- Generation capacity was reduced by over 60 percent by the end of 2022.
- At the end of May 2023, the loss of installed generation capacity was 27 GW.
- The average Ukrainian household experienced five cumulative weeks without power, from 10th October to the end of December 2022.
- Half of all Ukrainian electricity consumers were disconnected from the grid after the attack on 16th December 2022.

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[162] Humans Rights Watch. Ukraine: Russian Attacks on Energy Grid Threaten Civilians. 2022-12-06. https://www.hrw.org/news/2022/12/06/ukraine-russian-attacks-energy-grid-threaten-civilians (Accessed 2023-10-01).

[163] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[164] Kyiv School of Economics. Report on damages and losses to infrastructure from the destruction caused by Russia's military aggression against Ukraine as of June 2023. p. 28.

[165] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[166] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

5 Non-kinetic attacks

This section contains a brief overview of Russian cyber- and disinformation attacks targeting either the Ukrainian power system or the electricity sector. We have found no information indicating acts of physical sabotage against the power system (though this does not preclude that these have taken place). Non-kinetic attacks and influence can also encompass activities involving third parties (such as the EU) that may have indirect effects on Ukrainian electricity supply, in the form of economic support, equipment, etc. These are not included in this report.

5.1 Cyberattacks

There are numerous reports and accounts of cyberattacks in Ukraine having taken place during the war (what is included in the term varies between different reports). Here, we present a few examples of attacks. For a more detailed account and thorough discussion of the subject, see for example the discussion on Russia's impact in terms of cyberwarfare, as presented in the FOI report Unraveling the Myth of Cyberwar - Five Hypotheses on Cyberwarfare in the Russo-Ukrainian War (2014-2023).[167] In this report, the author describes Ukraine as having been subjected to Russian cyber-attacks long before the outbreak of the full-scale war.[168] An example of this is how, in December 2015, a cyberattack on three power substations caused a black-out for 230 000 consumers, and cut power for substation control centres.[169] A year later, another attack left Kyiv without power for about an hour.[170]

In a statement by Deputy Minister of Energy for Digital Development, Digital Transformations and Digitalisation, Farid Safarov, it was reported that Russia has tried to interfere with the work of Ukrainian energy companies, hacking personal client accounts, and interfering with dispatch centres. Safarov stated that, during the first 9 months of the war, more than 1.2 million cyberattacks had been carried out on energy infrastructure facilities.[171]

In a BBC article from April 2022, Viktor Zhora, deputy chairman of the State Service of Special Communications, recounts an attack using malware that targeted one of Ukraine's largest energy companies at the beginning of the invasion of Ukraine. The article goes on to describe how Ukraine cyber authority together with cyber-security companies Eset and Microsoft discovered and neutralised the malware. If the attack had succeeded, it would have caused a blackout for two million people.[172]

There are several other accounts of cyberattacks. For example, ICDS have reported attacks against Energoatom and a distribution system operator and notes that in the attack on the DSO, the industrial control system was targeted.[173] Another report, this time by the Task

[167] Per-Erik Nilsson. Unraveling the Myth of Cyberwar - Five Hypotheses on Cyberwarfare in the Russo-Ukrainian War (2014-2023). FOI-R--5513--SE. December 2023.

[168] Ibid. p. 32.

[169] Kim Zetter. Inside the Cunning, Unprecedented Hack of Ukraine's Power Grid. Wired. 2016-03-03. https://www.wired.com/2016/03/inside-cunning-unprecedented-hack-ukraines-power-grid/ (Accessed 2023-12-03).

[170] Donghui Park, Michael Walstrom. "Cyberattack on Critical Infrastructure: Russia and the Ukrainian Power Grid Attacks". The Henry M. Jackson School of International Studies. 2017-10-11. https://jsis.washington.edu/news/cyberattack-critical-infrastructure-russia-ukrainian-power-grid-attacks/ (Accessed 2023-12-03).

[171] Ministry of Energy of Ukraine, "Since the beginning of the war, more than 1.2 million cyber attacks on the energy sector have been recorded - Farid Safarov", 2022-11-21. https://www.mev.gov.ua/novyna/z-pochatku-viyny-zafiksovano-ponad-12-mln-kiberatak-na-enerhosektor-farid-safarov (Accessed 2023-10-29).

[172] Joe Tidy, "Ukrainian power grid 'lucky' to withstand Russian cyber-attack". BBC. 2022-04-12. https://www.bbc.com/news/technology-61085480 (Accessed 2023-12-05).

[173] Jermalavičius et al, "War and energy security. Lessons for the future", p. 50.

Force, notes that an attack on distribution system operator Lvivoblenergo in December 2022 was only averted due to a timely warning from the Security Service of Ukraine.[174]

The Task Force also asserts that the missile and drone campaign during the winter 2022-2023 against the power system was accompanied by powerful cyberattacks in order to damage the power system. According to the Task Force, Russia carried out more than ten cyberattacks every day between October 25 to November 24.[175] Ukrenergo representatives has confirmed this, and have stated that in-house cybersecurity specialists have repelled hundreds of cyberattack attempts every day.[176]

5.2 Disinformation

Another example of non-kinetic warfare experienced in Ukraine is disinformation, which has also affected the power sector. According to information from Ukrenergo, Russian media distributed a fraudulent letter purporting to be sent from Volodymyr Kudrytskyi, chairman of the management board of Ukrenergo, to the Ministry of Energy (MoE) requesting that the MoE decrease the power supply to some Ukrainian regions in order to resume electricity exports to the EU countries. The Task Force argued that this was an attempt from Russia to establish the narrative that blackouts was due to the priority of export of electricity to Europe, instead of damage caused by Russian attacks.[177] Responding to this, Volodymyr Kudrytskyi stated that "Ukraine does not export electricity to Europe since 11th October. All statements on this topic are either fake or conscious manipulations or a lack of understanding of the physical nature of electricity movement. Because since 11th October, we do not hold auctions on the distribution of access to interstate transmission lines. Without this, export is impossible."[178]

Other examples of disinformation circulated during the winter attacks on the power system, spreading through social media and messaging apps such as Telegram. Some of the disinformation linked to a fake company page.[179] The DTEK group, the largest commercial energy operator in Ukraine, also informed its clients that there were dozens of fake accounts using the company's name on social networks for disinformation and manipulation of public opinion. [180]

5.3 Consequences

Several observers, among them the Polish think tank Government Centre for Security, has claimed that the Russian Federation has long directly targeted Ukraine's cyber infrastructure and critical infrastructure, including government agencies, banks and

[174] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[175] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[176] NPC Ukrenergo, "З перших днів повномасштабного вторгнення спроби атакувати ІТ-системи Укренерго". Facebook, 2023-03-15. https://www.facebook.com/npcukrenergo/posts/590096729825823

[177] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[178] NPC Ukrenergo. "Стан енергосистеми: виклики похолодання і ризики нових атак", Facebook, 2022-12-09. https://www.facebook.com/npcukrenergo/videos/833327977949947/

[179] NPC Ukrenergo "Обережно – фейк!", Facebook, 2022-12-26. https://www.facebook.com/npcukrenergo/posts/534220928746737

[180] DTEK. "About DTEK". 2024. https://dtek.com/en/about/ (Accessed 2024-07-19) and Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

telecommunication providers.[181] Early reports seem to suggest that Russia's cyberattacks against Ukraine since the large-scale invasion in February 2022 have not been as extensive as initially feared.[182] According to ICDS, the attacks appear to have been largely unsophisticated and thus easily defeated.[183] In the above-mentioned report "Unraveling the myth of cyber war", Nilsson describes in more detail how Russian cyber activities, and the impact of these, have changed during different phases of the war. He concludes that few of the recorded cyber operations, if any, seem to have had any impacts resembling kinetic ones, and that the potential strategic value of cyber operations in multidomain operations in 2022 and 2023 is uncertain. He does however emphasise that the massive number of campaigns and operations conducted in 2022 and 2023 are to be considered more than mere "cyber vandalism."[184]

Though it is difficult to verify, as Ukrainian authorities have been careful not to release sensitive information about potential attacks, we have not found reports on disruption of the power supply due to cyberattacks. However, the effects might still be serious (but less obvious to us at this stage and given the available information) as Russian activity in the cyber domain may as yet be undiscovered.[185]

[181] Government Centre for Security. Possible Mitigation Measures Resulting from the Analysis of the Ukrainian Resilience to Hybrid Threats and the Military Aggression. Poland 2023. p. 12-13.

[182] Josephine Wolff, "Why Russia Hasn't Launched Major Cyber Attacks Since the Invasion of Ukraine", Time. 2022-03-02. https://time.com/6153902/russia-major-cyber-attacks-invasion-ukraine/ (Accessed 2023-11-16)

[183] Jermalavičius et al, "War and energy security. Lessons for the future", p. 43.

[184] Per-Erik Nilsson. Unraveling the Myth of Cyberwar - Five Hypotheses on Cyberwarfare in the Russo-Ukrainian War (2014-2023) p. 38, 46, 67.

[185] See for example the discussion in the FOI report Unraveling the Myth of Cyberwar - Five Hypotheses on Cyberwarfare in the Russo-Ukrainian War (2014-2023). Per-Erik Nilsson. FOI-R--5513--SE. December 2023. p. 26.

6 Countermeasures and handling of the consequences

This section contains a summary of the different measures and interventions Ukraine has used to mitigate the consequences of the attacks on the power system. First, we describe how Ukraine prepared for renewed military aggressions, before the full-scale invasion in February 2022. Then we present mitigation measures taken by Ukraine.

We have divided the measures and interventions into seven different categories:

1. Preparations
2. Restoring power supply
3. Limiting electricity consumption
4. Electricity market interventions.
5. Supporting citizens with limited access to power
6. International support
7. Additional measures

These measures are described in more detail in section 6.1 to 6.7. The chapter ends with a description of how Ukraine is rebuilding the power system and preparing for future attacks on the power system.

6.1 Preparations

After the experiences from the annexation of Crimea and the Donbas war in 2014 and 2015, Ukraine has been preparing for renewed military aggression, including increasing preparedness in civil infrastructure, as detailed below. Ukraine has also been implementing a range of measures to reduce energy dependence on Russia.[186]

Ukrenergo, as the TSO, is responsible for a secure power delivery. The electric power industry has to follow operational commands by the TSO in an emergency. The Ministry of Energy is the actor responsible for scenario planning and has, together with Ukrenergo, developed plans and responses for a variety of crises. This work has continued throughout the war, adapting according to developments.[187]

Ukraine adopted new legislation to ensure the resilience of critical infrastructure, The Law on Critical Infrastructure, in 2021. It determines the legal and organisational basis of the creation and functioning of the national system for protection of critical infrastructure.[188] It includes measures to prevent crises and secure continuation of operations during emergencies. The law also established a system for coordination between different response systems and developed requirements for the private sector.[189]

The TSO Ukrenergo, DSO's, and the largest energy companies established alternative control centres, began stockpiling resources and equipment needed to restore damaged infrastructure, and developed plans for the transfer of operations and personnel in case of crisis or attack. These plans were activated a few hours before the invasion in February

[186] Jermalavičius et al, "War and energy security. Lessons for the future", p. 47.

[187] Ibid. p. 57.

[188] CIS Legislation. Law of Ukraine. Of November 16, 2021. No. 1882-IX. About critical infrastructure. https://cis-legislation.com/document.fwx?rgn=136781 (Accessed 2024-01-20).

[189] Jermalavičius et al, "War and energy security. Lessons for the future", p. 56.

2022. They included moving personnel to alternative control centres and establishing communication lines and control of processes.[190]

ICDS have intimated that while plans and teams for repair during crisis and attack were in place at the outbreak of the full-scale war, preparations proved to be insufficient, due to the large scale of the attacks on the power system.[191]

6.1.1 Cyber defence

As noted in chapter 5, the power system was targeted by cyberattacks long before the full-scale invasion in 2022. Between 2015 and 2017, there were multiple attacks on the power system, thus providing Ukraine with a chance to learn and improve cyber security measures.[192] Ukraine has since been working on developing an ability to resist cyberattacks and building a resilient cyber infrastructure.[193]

The Ukrainian regulation outlining the basic principles of cybersecurity is the Law of Ukraine "On the Basic Principles of Cybersecurity of Ukraine". This law, enacted in October 2017, establishes the foundational legal framework for ensuring cybersecurity in Ukraine, defining the basis for protecting the vital interests of the state and citizens, as well as the priorities and objectives of state authorities.[194]

Ukraine has a large IT industry with many professionals contributing to the cyber defence capability.[195] Ukraine's Ministry of Energy has established a network coordinated by two Security Operational Centres (SOCs): one for the power sector, at Ukrenergo, and one for the oil and gas sector, at Naftogaz. ICDS reports how several cyber-attacks against critical energy infrastructure were prevented or repelled in joint efforts from experts in energy and cyber security.[196]

6.2 Restoring the power supply

The capacity to produce and distribute power largely exceeded Ukraine's needs before the Russian invasion. This is likely one of the main reasons for Ukraine having successfully maintained the power supply on an acceptable level, despite massive Russian attacks against the power system.[197] Other measures to restore the power supply are presented below.

6.2.1 Sectoral crisis management

Representatives from the energy sector created a crisis group in September 2022 to manage coordination, preparation of response measures, prioritisation and strengthening the resilience in the energy sector. Final decisions are however still made by the government.[198] ICDS describes a situation where cooperation between national, local and

[190] Jermalavičius et al, "War and energy security. Lessons for the future", p. 52, 58.

[191] Ibid. p. 51.

[192] Park & Walstrom. Cyberattack on Critical Infrastructure: Russia and the Ukrainian Power Grid Attacks.

[193] Per-Erik Nilsson. Unraveling the Myth of Cyberwar - Five Hypotheses on Cyberwarfare in the Russo-Ukrainian War. p. 55

[194] Government Centre for Security. Possible Mitigation Measures Resulting from the Analysis of the Ukrainian Resilience to Hybrid Threats and the Military Aggression. Poland 2023. p. 12.

[195] Interview. Autumn 2023.

[196] Jermalavičius et al, "War and energy security. Lessons for the future", p. 55.

[197] Interview. Autumn 2023.

[198] Roman Svyridovych. "We are creating a headquarters to respond to damage to energy infrastructure". Censor.net. 2022-09-13. URL: https://censor.net/ua/news/3366701/stvoryuyemo_shtab_po_reaguvannyu_na_poshkodjennya-_energetychnoyi_infrastruktury_zelenskyyi (Accessed 2023-12-11).

corporate crisis headquarters enabled balancing the capacity of industry with the demands for energy and power. New, temporary legislation or requirements in order to ease standards and bureaucratic demands, and help facilitate the connection of temporary installations, have been introduced to minimise disruptions and facilitate flexibility and responsiveness.[199]

6.2.2 Repairs

An important factor contributing to Ukraine's ability to repair damages is the increased number of repair personnel employed by Ukrenergo.[200] During the war, the number of repair teams were increased to help restore the function of the power system as quickly as possible.[201]

According to Ukrenergo, there are thousands of specialists in the company with the capacity to conduct repairs.[202] Volodymyr Kudrytskyi, chairman of the management board of Ukrenergo, stated that the fact that repair personnel are employed directly by Ukrenergo is crucial, commenting: "It's impossible to rely on contractors in such extreme conditions."[203]

The professionalism, competence and training of the personnel are key factors in maintaining a functional power system, according to Ukrenergo. There are a number of instructions and several repair schemes for different situations. The members of repair teams know each other, and the competence of other members. Some teams have been practically unchanged for almost 10 years.[204]

The situation in the power system fluctuates, due to almost constant attacks. The same lines and substation are damaged repeatedly.[205] The number of disconnected consumers has to be monitored hour by hour. According to several statements by Ukrenergo, repairs are generally performed in a timely manner. However, we have no means to evaluate what constitutes a timely or "quick" repair. An example of what may be deemed "timely" was reported by Ukrenergo after the attacks on 10th October, when access to power supply was restored almost throughout Ukraine only a day later.[206] Another example came after the attack on 22nd October, when 1.5 million consumers were reconnected within 5-6 hours.[207] There are naturally repairs that may take longer. A substation can require weeks or even months to repair, and requires more spare parts.[208]

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[199] Jermalavičius et al, "War and energy security. Lessons for the future", p. 58.

[200] NPC Ukrenergo, "Україна готується до наступної зими по трьох", Facebook, 2023-04-20. https://www.facebook.com/npcukrenergo/videos/1280187236269442/

[201] Jermalavičius et al, "War and energy security. Lessons for the future", p. 58.

[202] NPC Ukrenergo, "айгарячіша ділянка енергетичного фронту за кількістю уражень сьогодні", Facebook, 2023-04-06. https://www.facebook.com/npcukrenergo/posts/603488445153318

[203] NPC Ukrenergo, "Україна готується до наступної зими по трьох напрямках", Facebook, 2023-04-20. https://www.facebook.com/npcukrenergo/videos/1280187236269442/

[204]NPC Ukrenergo. "Сьогодні День Києва", Facebook, 2023-05-28. https://www.facebook.com/npcukrenergo/posts/637150951787067

[205] Ibid.

[206] NPC Ukrenergo. "ахівцям Укренерго та обленерго", Facebook, 2022-10-11. https://www.facebook.com/npcukrenergo/posts/476066114562219

[207] Natalka Prudka. Yuriy Boyko: Ukraine suffered the largest terrorist attack on the energy industry in world history. Glavcom. 2022-10-24. https://glavcom.ua/interviews/jurij-bojko-ukrajina-zaznala-najbilshoji-u-svitovij-istoriji-teroristichnoji-ataki-na-enerhetiku-884243.html?fbclid=IwAR0SSyLwZHuNONPjc_149MY_bcUtxpyYw-_6Tb6_LmIp0aYBdS-kSdhdenU (Accessed 2023-12-15).

[208] NPC Ukrenergo, "Щосекунди декілька мільйонів українців не мають доступу до електроенергії", Facebook, 2023-02-03. https://www.facebook.com/npcukrenergo/posts/561160359386127

Ukrenergo contend that they have been able to accelerate repair processes without losing quality.[209] In February, the Ukrenergo chairman Kudrytskyi was quoted on the company Facebook page saying that "Recovery is going at a record rate, that no one expected at the beginning of this campaign. We are several times faster than before.".[210] He also stated that they had reached a plateau where there was no further degradation of the system.[211] News outlet Bloomberg further elaborated on this development, reporting that damage can be repaired and capacity regained at the same speed as destruction happens.[212]

Repair teams have quickly been able to reach sites where damage has occurred. One respondent speculated that a contributing factor to this speed may be that Ukrenergo is a state-owned company and the highest management have been able to control and prioritise repairs.[213]

To facilitate the repairs, Ukrainian authorities established a system of interaction between energy companies, military, and law enforcement units. The ICDS report underlines the importance of the coordination between different stakeholders, as well as between different regions, in the effective restoration of power supply.[214] Coordination has been crucial to ensure the security of the repair teams. For instance, close to liberated areas, there are high-voltage lines passing along territories where heavy fighting can break out again, and a second shelling by attacking forces, a so-called "double tap", is a way to hamper the restoration of the damaged infrastructure and slow down the work. Procedures to minimise the risk for the workers are required in these situations.[215] Repair teams need permission from the local military forces before entering an area. It is also important that no information about the damage and location is communicated in the first hour to avoid a second attack.[216]

Before it is possible to assess damage, the area around the attacked facilities need to be checked for mines and unexploded devices. Employees have been killed by detonated mines while repairing the power system.[217] To avoid this, repair teams from Ukrenergo and other energy companies are cooperating with teams from the State Emergency Service of Ukraine, who clear the mines.[218] This takes a long time, which delays repairs.[219] Restoration of power supply to liberated territories has also been hampered by dense

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[209] NPC Ukrenergo "Найгарячіша ділянка енергетичного фронту", Facebook, 2023-04-06. https://www.facebook.com/npcukrenergo/posts/603488445153318

[210] NPC Ukrenergo, "итуація покращилася, особливо в останні дні. Сьогодні", Facebook, 2023-02-14. https://www.facebook.com/npcukrenergo/videos/3462217650687193/

[211] NPC Ukrenergo, "На сьогодні ми досягли плато", Facebook, 2023-02-16. https://www.facebook.com/npcukrenergo/posts/571183825050447

[212] Volodymyr Verbianyi and Olesia Safronova, "Worst Is Over in Russia's War on Ukrainian Energy System, Operator Says". Bloomberg. 2023-02-16. https://www.bloomberg.com/news/articles/2023-02-16/worst-is-over-in-russia-s-war-on-ukrainian-energy-operator-says?sref=57BZtQjJ&fbclid=IwAR3nNpw30qUDO5I3b8wgSME-p5CyEqfrLHxZFwaYAN8A_Rwsb_MoWbSx34o#xj4y7vzkg (Accessed 2023-09-27).

[213] Interview. Autumn 2023.

[214] Jermalavičius et al, "War and energy security. Lessons for the future", p. 53.

[215] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[216] Natalka Prudka. Yuriy Boyko: Ukraine suffered the largest terrorist attack on the energy industry in world history.

[217] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

[218] NPC Ukrenergo, "Ви часто запитуєте, що робимо ми в той час, коли просимо", Facebook, 2022-10-27. https://www.facebook.com/npcukrenergo/videos/1204627850141039/

[219] Marc Santora, "For Ukraine, Keeping the Lights On Is One of the Biggest Battles". New York Times. 2022-11-17. https://www.nytimes.com/2022/11/17/world/europe/ukraine-electricity-water-infrastructure.html?smid=nytcore-ios-share&referringSource=articleShare&fbclid=IwAR3soRpZ85GNxtFJsnMCzZeRe9psmvMzQlL0zMvJ05_Aj0XxIudaQgw1HLM (Accessed 2023-11-29).

mining. In the Kharkiv region, for example, sappers removed more than 1,000 anti-tank and anti-infantry mines under one of the 12 km long distribution lines.[220]

Acquiring equipment and spare parts for repairs is a problem. Since the power system is designed according to Soviet standard, certain replacement equipment is available only from other former Soviet states. One example is high-voltage transformers, of which only a few have been sent to Ukraine.[221] According to Volodymyr Kudrytskyi, the availability of the equipment Ukrenergo accumulated during the renovations of its facilities in previous years, played a key role in repairing power facilities.[222] Ukrenergo has described how replacing damaged equipment has taken thousands of hours of negotiation in 40 countries around the world.[223] Coordination and communication is also fundamental for solving logistical issues. A particularly apt example of this was the transportation of a 1,000-ton transformer, for a distance of 500 km, which took two months. It involved dismantling of the transformer, manually lifting power lines, removing asphalt to increase the height below bridges over the road, and dismantling a fountain at an intersection.[224]

The importance of highly qualified engineers and a strategic supply of electrical equipment for a rapid restoration of power systems during emergencies was stressed by ENTSO-E at a General Assembly meeting with the heads of energy system operators of 37 European countries.[225]

In terms of coordination and communication, the encrypted messaging application Signal is reportedly widely used between different actors or organisations. “The whole war is based on Signal” according to one respondent. This requires that the mobile network is functioning, which it has been for the most part. There are other communication systems for internal use in different organisations. In terms of accessing the internet, Starlink is used frequently, but it is not used to the same extent near the front. The same respondent speculates that this may be due to fears that communications can be traced or tapped.[226]

6.2.3 Backup schemes

When the power grid, transmission and distribution lines and substations are damaged, power is rerouted through other available lines, so-called backup schemes. These schemes have been developed for planned repairs in peacetime but have been used extensively during the war.[227] Oftentimes this means using distribution grids with lower voltage and capacity, resulting in a power supply with a lower maximum capacity. Hence, there is less margin for increasing demand, and the supply is less reliable. If consumption is growing and exceeds the capacity of the backup schemes, power supply has to be shut down for

[220] NPC Ukrenergo,”СИТУАЦІЯ В ЕНЕРГОСИСТЕМІ”, Facebook, 2023-05-17. https://www.facebook.com/npcukrenergo/posts/629757215859774

[221] Interview. Autumn 2023.

[222] NPC Ukrenergo, “Україна готується до наступної зими по трьох напрямках”, Facebook, 2023-04-20. https://www.facebook.com/npcukrenergo/videos/1280187236269442/

[223] NPC Ukrenergo, ”Найважчий опалювальний сезон в історії української енергосистеми у цифрах”, Facebook, 2023-04-08. https://www.facebook.com/npcukrenergo/posts/604550888380407

[224] NPC Ukrenergo. “Два місяці наш новий автотрансформатор (АТ) долав відносно невеликий шлях у 500 кілометрів.” Facebook, 2023-05-06. https://www.facebook.com/npcukrenergo/videos/180496011605914/

[225] NPC Ukrenergo, “Криза 70-х років минулого століття зробила”, Facebook, 2023-03-30. https://www.facebook.com/vladimir.kudrytskyi/posts/6462152113817765

[226] Interview. Autumn 2023. See also discussion in Per-Erik Nilsson. Unraveling the Myth of Cyberwar - Five Hypotheses on Cyberwarfare in the Russo-Ukrainian War, p. 58-59.

[227] Natalka Prudka. Yuriy Boyko: Ukraine suffered the largest terrorist attack on the energy industry in world history.

certain consumers or areas.[228] Such backup schemes have been, on at least one occasion, developed together by representatives from Ukrenergo, the Regional Military administration, and the regional DSO.[229]

6.3 Limiting electricity consumption

In order to decrease the electricity consumption below the capacity of production and transmission, Ukraine has used different interventions and measures. We have grouped these into the following categories:

Emergency shutdowns or disconnections

When demand for electric power outstrips supply in a region (because of either limits in production capacity or limits in transmission capacity), it is possible for the transmission or distribution to be automatically disconnected in order to prevent damage to the system. A dispatcher can also activate such an emergency shutdown when disruptions in the system make such an automatic disconnection highly probable. Ukrenergo prefers using active shutdowns over automatic shutdowns, since when automatic disconnections are triggered, recovery takes longer than when the disconnection is initiated by dispatchers.[230]

Scheduled shutdowns

Scheduled shutdowns, (instead of emergency shutdowns or involuntary blackouts) are used when there are limits in production capacity. They are applied when the power deficit in the power system is reduced to such a level that one out of three consumer groups can be switched off every 4 hours. Scheduled shutdowns are planned and coordinated by military-civilian administrations.[231] Scheduled shutdowns are also necessary during repair work on transmission and distribution systems.[232]

Reducing electricity demand

In order to manage the lower power supply capacity, and avoid shutdowns, Ukrenergo and the Ministry of Energy of Ukraine have requested that consumers save on electricity consumption, especially during peak hours.[233] Households and commercial consumers have voluntarily reduced their electricity consumption during peak hours by 10-20 percent, which has helped avoid additional disconnection of consumers and allowed balancing the power system.[234]

In December 2022, the Government of Ukraine announced an initiative to replace 50 million outdated incandescent light bulbs with new LED lights for residential consumers,

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[228] NPC Ukrenergo, “Як ви вже знаєте, сьогодні 15 жовтня”, Facebook, 2022-10-15. https://www.facebook.com/-npcukrenergo/posts/479237407578423 and NPC Ukrenergo, “Чому у вашій квартирі досі трапляються” Facebook, 2022-11-15. https://www.facebook.com/npcukrenergo/videos/1323431831761055/

[229] NPC Ukrenergo, ” Ліквідація наслідків”, Facebook, 2023-03-09. https://www.facebook.com/npcukrenergo/posts/586436783525151

[230] NPC Ukrenergo, “Consequences of yesterday's rocket attacks”, Facebook, 2022-11-24. https://www.-facebook.com/npcukrenergo/posts/509398604562303

[231] NPC Ukrenergo. ”Інтерв’ю для «Радіо НВ» Володимира Кудрицького, голови правління”, Facebook, 2022-12-06. https://www.facebook.com/npcukrenergo/videos/865094651180678/

[232] NPC Ukrenergo, “The power system is gradually being restored”, Facebook, 2022-11-24. https://www.facebook.com/npcukrenergo/posts/509121591256671

[233] NPC Ukrenergo, “Як ви вже знаєте, сьогодні 15 жовтня”, Facebook, 2022-10-15. https://www.facebook.com/npcukrenergo/posts/479237407578423

[234] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022.

with the financial support of the European Commission. The proposed initiative was expected to reduce the electricity demand by 1 GW or the equivalent of one nuclear reactor's capacity.[235] On 16th January 2023, the replacement program started. At this time, the plan was to replace 35 million light bulbs. Local authorities in six regions started the preparation for the exchange as well as the collection, transportation and disposal of collected incandescent lamps.[236] At the time of writing, we have no information about the outcome of this initiative.

Other measures to reduce the load on the power system and save electricity include the substitution of trolleybuses with motor buses in Kyiv city.[237]

At a General Assembly meeting with the heads of energy system operators of 37 European countries, ENTSO-E stressed the importance of limiting electricity consumption.[238]

Consumption limits

The Government of Ukraine introduced consumption and capacity-limiting schedules in order to ensure balance between production and consumption and to prevent the capacity of the transmission system from being exceeded. The duration of consumption and capacity-limiting schedules varied, but usually lasted between 4-8 hours.[239]

In November 2022, Ukrenergo modified its restriction process, shifting from specifying to regional distributors (DSOs) the quantity of Watts to be restricted, to delineating consumption limits across various regions. Each DSO independently determines the order for shutdowns.[240] To calculate limits for electricity consumption, Ukrenergo receives from each DSO a general forecast of consumption in its region, taking into account migration processes, the relocation of enterprises, actual changes in the overall level and structure of consumption and average monthly temperatures in the region. Ukrenergo, while considering the total possible production in Ukraine, the production in each region and the transmission capacity across Ukraine, calculates the possible consumption limits and the percentage of each area in the total consumption for Ukraine. Ukrenergo then provides the received data to the Ministry of Energy, which analyses and approves, or (if, and when, significant deviations are found) proposes adjustments. After obtaining approved limits, the DSO distributes electricity according to a priority list.[241]

On 7th February 2023, Ukrenergo announced that consumption restrictions would be completely removed countrywide for one day. In this way, Ukrenergo could measure how much electricity each region was consuming with constant access to electricity. This measurement was then used when determining consumption limits for different regions.[242]

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[235] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[236] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[237] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[238] NPC Ukrenergo, Facebook, 2023-03-30. https://www.facebook.com/vladimir.kudrytskyi/posts/6462152113817765

[239] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[240] NPC Ukrenergo, "Станом на 19:00 25 листопада в енергосистемі", Facebook, 2022-11-25. https://www.facebook.com/npcukrenergo/posts/510114997823997

[241] NPC Ukrenergo, "Як визначаються ліміти для різних областей?", Facebook, 2023-02-02. https://www.facebook.com/npcukrenergo/posts/560488339453329

[242] NPC Ukrenergo, "По всій Україні, починаючи з 8 лютого", Facebook, 2023-02-07. https://www.facebook.com/npcukrenergo/posts/564332812402215

On 25th March, Ukrenergo pleaded with the citizens of Ukraine not to join in the "Earth Hour", voicing concerns that an instantaneous decrease in consumption, followed by an instantaneous increase, would damage the power system.[243]

Prioritising supply

When there is a limit on the amount of electricity that can be supplied to a region, electricity is prioritised to critical infrastructure and life support. [244] This includes water supply, treatment facilities, heat, gas distribution networks, communication, hospitals, cleaning facilities and defence companies.[245] The list of prioritised critical infrastructure is determined by local military administrations.[246] Household consumers are gradually connected thereafter.[247]

6.4 Market interventions

Due to the loss in power transmission and production capacity, Ukraine halted export of electricity to Europe on 11th October 2022.[248]

As a result of the attack on 16th December, Ukrenergo announced an emergency in the power system, which suspended all trades on the intraday electricity market.[249] The emergency was introduced exclusively for the electricity market operations, in accordance with the requirements of the Electricity Market Rules. The emergency concluded in the evening the same day.[250]

In December 2022, the wholesale electricity price in Ukraine was 2-2.5 times lower than in Poland and 2-4 times lower than in Hungary, Slovakia, or Romania. Because of the difference in prices, it was estimated that the emergency electricity import from Europe would cost around 800 million EUR during the winter of 2022-2023.[251]

[243] NPC Ukrenergo, "Друзі, будь ласка, не ведіться", Facebook, 2023-03-25. https://www.facebook.com/npcukrenergo/posts/596271565875006

[244] NPC Ukrenergo, «Укренерго» спільно з АТ «Херсонобленерго» та АТ «Миколаївобленерго», Facebook, 2022-11-15. https://www.facebook.com/npcukrenergo/posts/502524571916373

[245] NPC Ukrenergo, "Сьогодні ворог знову завдав масований", Facebook, 2022-12-16. https://www.facebook.com/npcukrenergo/posts/526024339566396

[246] NPC Ukrenergo, "Як визначаються ліміти для різних областей?", Facebook, 2023-02-02. https://www.facebook.com/npcukrenergo/posts/560488339453329

[247] NPC Ukrenergo, "Consequences of yesterday's rocket attacks", Facebook, 2022-11-24. https://www.facebook.com/npcukrenergo/posts/509398604562303

[248] NPC Ukrenergo, "Стан енергосистеми: виклики похолодання і ризики нових атак". Facebook, 2022-12-09. https://www.facebook.com/npcukrenergo/videos/833327977949947/

[249] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[250] NPC Ukrenergo, "Станом на 17 грудня", Facebook, 2022-12-17. https://www.facebook.com/npcukrenergo/posts/526792552822908

[251] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

On 2nd February 2023, Volodymyr Kudrytskyi stated that

> "Although electricity from Europe is more expensive, many Ukrainian industrial consumers are willing to pay this higher price to be able to continue their operation. Ukraine has a considerable technical capacity to import electricity from Europe to Ukraine on already existing interstate power lines. However, Europe wants to increase imports step by step, in order to avoid technical problems for the electricity systems. According to our estimate, imports can be increased by at least 2-2.5 times. This should be able to cover up to 40-50 percent of the deficit."[252]

On 14th February 2023, ENTSO-E increased the technical capacity of the import of electricity to Ukraine to 700 MW at all times, from 700 MW at night and 600 MW at other hours of the day.[253]

On 29th March, the capacity for imports from the Continental Europe zone to Ukraine and Moldova increased from 700 to 850 MW at any hour of the day.[254] Ukrenergo also signed an emergency assistance agreement with 15 system operators of ENTSO-E that allows Ukraine to receive electricity not only from neighbour countries, but also from other EU countries. Emergency assistance is the urgent supply of power from another country at the request of a system operator in case the domestic capacity is not enough to avoid simultaneous shutdown of a large number of consumers.[255]

After a decrease in the intensity of attacks on the power system, and restoration of power transmission and production capacity, Ukraine resumed export on 11th April 2023. First to Moldova,[256] and later to Poland,[257] and Slovakia.[258] Export was resumed exclusively on the condition that supply of Ukrainian consumers is prioritised. Imports still occurred occasionally.[259]

On 18th April 2023, cross-border capacity for import to Ukraine increased to 1,050 MW.[260] By September 2023, allowed import volumes had reached 1,200 MW.[261]

While the technical possibility of importing electricity exists, the commercial possibility is challenging, as there is a significant price difference between the EU and Ukrainian power markets. Ukrainian internal regulations constrain imports when the cost of the imported electricity exceeds Ukraine's price cap. Instead, Ukrenergo has to request technical aid from European countries in order to balance the power system, which is more expensive than commercial imports.[262]

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[252] NPC Ukrenergo, "Електроенергія з Європи дорожча", Facebook, 2023-02-02. https://www.facebook.com/npcukrenergo/videos/939500087215373/

[253] NPC Ukrenergo, "Після перших масованих атак на енергетичну інфраструктуру", Facebook, 2023-02-16. https://www.facebook.com/npcukrenergo/posts/571019168400246.

[254] NPC Ukrenergo, "Ukrenergo and ENTSO-E have expanded their technical capabilities", Facebook, 2023-03-29. https://www.facebook.com/npcukrenergo/posts/598637748971721.

[255] NPC Ukrenergo, "Now Ukraine has the opportunity to receive technical assistance", Facebook, 2023-03-29. https://www.facebook.com/npcukrenergo/posts/598702692298560.

[256] NPC Ukrenergo, "Упродовж минулого тижня виробництво", Facebook, 2023-04-10. https://www.facebook.com/npcukrenergo/posts/605816584920504.

[257] NPC Ukrenergo, "Станом на 12 квітня виробництво", Facebook, 2023-04-12. https://www.facebook.com/npcukrenergo/posts/606986504803512.

[258] NPC Ukrenergo, "Гарна новина до Дня народження Укренерго", Facebook, 2023-04-15. https://www.facebook.com/npcukrenergo/posts/608922361276593.

[259] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

[260] Ibid.

[261] Andrian Prokip. How Will Ukraine's Energy Sector Fare in the Upcoming Winter? Wilson Center. 2023-09-05. https://www.wilsoncenter.org/blog-post/how-will-ukraines-energy-sector-fare-upcoming-winter (Accessed 2023-09-28).

[262] Ibid.

The government approved changes in the regulations of import of electricity during the winter 2022-2023, mitigating the constraints on import due to the high difference in prices between domestic and imported electricity.[263]

Enabling an increase of electricity imports during the winter 2022-2023 (from 700 MW to 1,200 MW) helped stabilise the Ukrainian power system and secured power supply to more consumers. These import levels should be compared to available production capacity by the end of 2022, which came to 13.9 GW.[264]

6.5 Supporting citizens

In November 2022, the Ukrainian government launched the initiative "Unbreakable Points". An Unbreakable point is a place where Ukrainian citizens can access basic needs such as power, heat, water, and internet access, 24 hours a day.[265] The unbreakable points were set up by local municipalities.[266]

In November, the Ukrainian government decided that the import of goods needed during the colder season will be exempted from paying value added tax (VAT) and import duty.[267] "It should simplify and make the supply to Ukraine of generators, batteries, transformers and other similar machinery for power and heat supply cheaper." said President of Ukraine, Volodymyr Zelenskyy in a statement broadcast on the Ukrenergo Facebook page.[268] For example, Starlink terminals and equipment for restoration of energy systems were exempted until May 2023.[269]

According to the Task Force, the demand for power generators in Ukraine increased from about 6 thousand units in January 2022 to 310 thousand units in December 2022. In total, Ukraine imported 669.4 thousand generators in 2022, including 643.8 thousand generators imported by enterprises and 25.5 thousand by households.[270] 86 percent of businesses installed generators or other means of uninterruptible power sources (UPS).[271]

This increase in generators was enabled by different co-financing programmes and support programmes developed by local municipalities. For example, the Kyiv City Council increased the funds for housing maintenance companies by UAH 150 million and provided additional funds to purchase generators, fuel and other consumables in case of emergency.[272] The Lviv municipality refunded 50 percent, and the Kyiv municipality

[263] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[264] UNDP and The World Bank. Towards a green transition of the energy sector in Ukraine. Update on the Energy Damage Assessment. June 2023. p. 12.

[265] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[266] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[267] Ukraine Government Portal. Statement by Prime Minister of Ukraine Denys Shmyhal. 2022-11-08. https://www.kmu.gov.ua/en/news/statement-prime-minister-ukraine-denys-shmyhal-govt-session-8-11-22. (Accessed 2024-05-21).

[268] NPC Ukrenergo, "Уряд ухвалив важливе рішення, яке допомагає пройти зимовий період", Facebook, 2022-11-08. https://www.facebook.com/npcukrenergo/videos/451547320242339/

[269] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[270] Ibid.

[271] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[272] Ibid.

refunded 75 percent of the cost of generators for apartment buildings.[273] Most local authorities implemented similar measures to support Ukrainian citizens and local businesses.[274]

Despite the scheduled and emergency shutdowns and disconnections, thousands of Ukrainian enterprises, small and medium-sized businesses, and public facilities continued to operate using individual generators.[275] The Task Force has calculated that only ten percent of businesses have had to relocate their business or staff due to power outages.[276]

6.6 International support

In a report on war and energy security, ICDS states that international assistance to Ukraine's energy sector has helped Ukraine to withstand the large-scale destruction of the power system during the winter season 2022-2023.[277] While this conclusion seems likely, we have not ventured to make an assessment as to what extent. Assistance has been provided through functions such as EU and NATOs emergency response mechanisms and by bilateral agreements with different countries. Further, various energy companies and international financial institutions have provided assistance throughout the war. Immediately after the attacks on the energy sector started in October, a request was sent to the NATO Crisis Response System and the EU Civil Protection Mechanism. ICDS reported that before the end of October, over 12 countries had responded and offered the required equipment.[278]

In March 2023, Ukraine received a powerful autotransformer from Lithuania. Its transportation was the largest logistical operation ever coordinated by the EU Civil Protection Mechanism. The transformer was installed at a high-voltage substation in the power transmission system.[279]

In April 2023, the Ministry of Energy of Ukraine launched the "AidEnergy" digital platform to effectively coordinate international humanitarian aid related to the restoration of the energy system.[280]

Ukrenergo states that, since the beginning of the full-scale invasion, international partners have provided about 900 million euros to Ukraine in financial support and assistance. 600 million euros of loans and grants has been provided by the governments of European countries for the restoration of infrastructure and facilities. More than 100 million euros in funding comes from international organisations for the purchase of new high-voltage equipment for the transmission system.[281]

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[273] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[274] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[275] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[276] Ibid.

[277] Jermalavičius et al, "War and energy security. Lessons for the future", p. 55.

[278] Ibid.

[279] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[280] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

[281] NPC Ukrenergo, "Весь цивілізований", Facebook, 2023-05-25. https://www.facebook.com/vladimir.kudrytskyi/posts/6646939672005674. .

European partners have also given more than 200 units of various high-voltage equipment for the repair of substations and networks.[282] The Ukraine Energy Support Fund, managed by the Energy Community Secretariat, enables governments, international financial institutions and international organizations as well as corporate donors to provide financial support to the Ukrainian energy sector's efforts to repair damage and keep functioning.[283]

Ukraine has also received support in the form of training programmes. For example, British Armed Forces held a two-week course for Ukrainian professionals, on improving protection of critical infrastructure. See more in chapter 6.8.1.[284]

6.7 Additional measures and contributing factors

There have been numerous other measures and contributing factors helping to secure or restore the power supply, some of which are set out below.

Renewable energy sources

In a report by the Wilson Center, the author contends that renewables have played an important role in securing the power supply during the attacks.[285] In some cases, he suggests, these were the only sources of power when the country experienced massive blackouts after the attacks.

Information security

As noted in chapter 2.3, the Ministry of Energy of Ukraine restricted the dissemination of detailed information on damages and losses of energy infrastructure facilities,[286] and Ukrenergo does not publish data that indicates the available operating capacity of power plants in the power system during the war.[287] According to ICDS, these measures were introduced in order to prevent Russia from gathering intelligence.[288]

In a warning from Ukrenergo, it was suggested that the Russian Federation could draw information from media and social networks in order to identify vulnerabilities and targets for future attacks as well as to adjust strike coordinates post-failure.[289]

Communication with citizens

Many of the measures and interventions mentioned here involve consequences for citizens, or actions or changes in behaviour and expectations by citizens. Clear and timely communication from official bodies and companies is crucial to ensure that consequences

[282] NPC Ukrenergo, "Весь цивілізований", Facebook, 2023-05-25. https://www.facebook.com/vladimir.kudrytskyi/posts/6646939672005674

[283] Energy Community. Ukraine Energy Support Fund. 2024. https://www.energy-community.org/Ukraine/Fund.html (Accessed 2024-04-23).

[284] UK Ministry of Defence. Royal Engineers lead training effort to help Ukraine defend its critical national infrastructure. 2023-10-22. https://www.gov.uk/government/news/royal-engineers-lead-training-effort-to-help-ukraine-defend-its-critical-national-infrastructure (Accessed 2023-11-23).

[285] Andrian Prokip, Ukrainian Energy During the War and Between the Winters. Wilson Center. 2023-05-16. https://www.wilsoncenter.org/blog-post/ukrainian-energy-during-war-and-between-winters (Accessed 2023-09-14).

[286] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022.

[287] NPC Ukrenergo, "У коментарях на нашій сторінці ви часто зауважуєте", Facebook, 2023-05-26. https://www.facebook.com/npcukrenergo/posts/635958381906324

[288] Jermalavičius et al, "War and energy security. Lessons for the future", p. 58.

[289] NPC Ukrenergo "Сьогодні Служба безпеки України", Facebook, 2023-02-09. https://www.facebook.com/npcukrenergo/posts/565758485592981.

are accepted and expectations from citizens are reasonable, while at the same time encouraging desirable changes in behaviour and actions. ICDS have made a similar point, noting that effective and direct communication has played a pivotal role in stabilising the Ukrainian energy system.[290] Ukrenergo's Volodymyr Kudrytskyi, has on several occasions appeared on national television, addressing the situation in the power system, explaining how Ukrenergo is dealing with it, and how citizens can help stabilise the power supply.

6.8 Rebuilding and preparations for the winter 2023-2024

In order to prepare for the winter season 2023-2024, power plants and transmission and distribution infrastructure had to be repaired. In April 2023, Ukrenergo stated that four key components were required to prepare for the coming winter and possible new attacks on the power system: physical protection of power infrastructure, recovery of generation capacity, equipment for repairs, and securing financial means for these measures.[291] In another statement, he also emphasised the need to strengthen air defence, and to increase the availability of specialists who can carry out repairs.[292]

> "We are actively preparing for the next winter and planning how to protect our facilities together with the State Agency for Restoration and Development of Infrastructure of Ukraine. The plan is to significantly enhance the protection of facilities, make substations more impact resistant, and restore generation in hydro and thermal power plants. Also, sufficient amount of equipment for the repair of transmission grids, substations and power plants is necessary, as well as money for repairs."[293]

> "Equipment is ordered and manufactured in preparation for the next heating season, so that we can restore the power supply."[294]

As early as in March 2023, Ukrenergo developed ideas on how to make facilities more resistant to missile attacks. Volodymyr Kudrytskyi underlined the need for "using the latest technologies to make substations more compact and protected either by placing them underground or by some kind of shelter."[295] Later in April 2023, implementation of a program to strengthen passive protection at the most critical objects began.[296] (See chapter 6.8.1.) It was hoped that, in addition to these preparations, the numerous generators that households, industries, and utilities purchased during the winter of 2022-23, would help Ukrainians during shutdowns and restrictions in the upcoming winter.[297]

In the spring of 2023, a massive repair and maintenance campaign started. According to a statement by Ukrainian Prime Minister Denys Shmyhal, 62 percent of damaged thermal power plant's units had been repaired and maintained, as well as 68 percent of hydropower plants and 80 percent of transmission power lines. The repair work continued as long as

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[290] Jermalavičius et al, "War and energy security. Lessons for the future", p. 52.

[291] NPC Ukrenergo, "Для того, щоб країна могла підготуватися", Facebook, 2023-04-01. https://www.facebook.com/npcukrenergo/videos/1343914356454939/

[292] NPC Ukrenergo, "Україна готується до наступної", Facebook, 2023-04-20. https://www.facebook.com/npcukrenergo/videos/1280187236269442.

[293] NPC Ukrenergo, "Для того, щоб країна могла підготуватися", Facebook, 2023-04-01. https://www.facebook.com/npcukrenergo/videos/1343914356454939/

[294] NPC Ukrenergo, "Україна готується до наступної", Facebook, 2023-04-20. https://www.facebook.com/npcukrenergo/videos/1280187236269442.

[295] NPC Ukrenergo, "Цього року, використовуючи фінансові ресурси", Facebook, 2023-03-13. https://www.facebook.com/npcukrenergo/videos/1163350587716994/.

[296] NPC Ukrenergo, "Україна готується до наступної", Facebook, 2023-04-20. https://www.facebook.com/npcukrenergo/videos/1280187236269442.

[297] Prokip, How Will Ukraine's Energy Sector Fare in the Upcoming Winter?

the weather permitted.[298] Ukraine aimed to restore as many power blocks as possible before the beginning of the autumn-winter period, but in a video on Ukrenergo's Facebook page, Volodymyr Kudrytskyi cautioned that the complete restoration of the power system would take several years.[299]

Because of the extensive damage to, and Russian occupation of, several large power plants (among them the Zaporizhzhia NPP), it was clear that Ukraine would have less available capacity than usual in the summer of 2023. Therefore, during the repair and maintenance campaign, Ukraine would have to activate all the reserves in the power system to avoid interruptions, mainly thermal power plants. It was also deemed likely that imports of electricity from Europe would be required.[300] Several power units would need to be taken out of commission for repairs, and it was hoped that hydroelectric power plants and renewable energy sources would compensate this interruption.[301]

However, since the scale of the damage was so great and there was a lack of funds, it was not possible to make all the required repairs before the start of the winter 2023-24. Not all facilities would reach full function and, over the upcoming winter, it was estimated that Ukraine would have less excess capacity over peak demand, compared to the start of the war in February 2022.[302]

During the summer of 2023, Ukraine was stockpiling resources, on some occasions across the border in neighbouring countries.[303] They had also secured the option for urgent orders should it be required.[304]

Ukraine is today making moves towards a further decentralised energy system. In this regard, energy security and the development towards a sustainable energy system works hand-in-hand. At a General Assembly meeting of ENTSO-E, German minister for Economy and Energy, Robert Gabek, noted that together with further integration of the energy systems in Europe, these developments would increase the opportunities for electricity trade and would contribute to Europe's energy security.[305]

6.8.1 Protection of power system facilities

Ukraine has identified 200 objects or facilities as part of its critical infrastructure. These include energy facilities, infrastructure (e.g. like bridges), and strategic industries i.e. industries critical for the war (defence industry). One of the respondents interviewed in this project states that of these three categories, energy facilities is the highest prioritised.[306]

International support can take more forms than financial donations. For example, Ukrainian civilian professionals received training in the UK on how to protect critical

[298] Ukrainska Pravda, "Over 50% of nuclear power units repaired in Ukraine", 2023-08-13. https://www.pravda.com.ua/eng/news/2023/08/13/7415404/ (Accessed 2023-11-15).

[299] NPC Ukrenergo, "Значний відсоток", Facebook, 2023-05-04. https://www.facebook.com/npcukrenergo/videos/230614066243565/

[300] Ibid.

[301] NPC Ukrenergo, "Станом на сьогодні", Facebook, 2023-04-26. https://www.facebook.com/npcukrenergo/posts/616273253874837

[302] Prokip, How Will Ukraine's Energy Sector Fare in the Upcoming Winter?

[303] Aura Sabadus, Ukraine Bolsters Energy Defenses for the Coming Storm, The Centre for European Policy Analysis. 2023-11-07. https://cepa.org/article/ukraine-bolsters-energy-defenses-for-the-coming-storm/ (Accessed 2023-11-08).

[304] Roman Olearchyk, "Ukraine braced for attacks on its power grid as winter draws in", Financial Times. 2023-11-02. https://www.ft.com/content/aea600e6-2c19-42ab-ad13-5c6507c00579 (Accessed 2023-11-17).

[305] NPC Ukrenergo, "Бажання і стратегічні плани", Facebook, 2023-04-03. https://www.facebook.com/npcukrenergo/posts/601693971999432

[306] Interview. Autumn 2023.

infrastructure from armed attacks. They were instructed in how to identify critical infrastructure, impacts of different weapons and how to protect critical infrastructure during a two-week course given by British Army Royal Engineer specialists.[307]

Ukraine tested and improved fortifications during the attacks in the winter 2022-2023. The protection of energy infrastructure facilities is coordinated with the General Staff and the State Emergency Service, according to the State Agency for Reconstruction and Infrastructure Development of Ukraine. Protection is provided on three levels.[308]

- The first level of protection is the use of gabions, cylinder cages filled with rocks, and big-bags, industrial containers made of flexible material that can be filled with sand. This protects from the fragments and debris of drones and missiles. In November 2023, the Agency for Reconstruction had protected 90 objects in 21 regions.[309]
- The second level is construction of concrete structures around facilities. This protects against drones. This started in March 2023. 22 substations and 63 transformers in 14 regions are protected as of November 2023.[310]
- The third level is protection against direct hits by missiles. 22 substations in 14 regions are protected, in November 2023. Ukrenergo formulated tasks for design and construction, according to the Agency for Reconstruction press service.[311]

While it is difficult to assess the efficacy of these measures, Ukraine's prime minister Denys Shmyhal has stated that the passive protection works "in 80 to 90 percent of cases", especially against drones that veer off course or whose debris falls on to critical infrastructure after being intercepted.[312] Sandbags and cage roofs are used to protect smaller targets that can be taken out in a single strike and trigger a massive blackout, and infrastructure that does not require ventilation has been moved underground, according to the article. In the article, Shmyhal is reported as saying that Ukraine has also taken steps to further decentralise its grid, making damage in one location less likely to affect other regions.[313]

According to one of our respondents, 340 km of gabions would be needed to protect facilities in Ukraine, which would cost around $40 million. The problem is the scarcity of gabions, both in and outside of Ukraine. For example, if every gabion in the United Kingdom were to be used, they would be sufficient for just around half the need in Ukraine.[314]

In a report from the Wilson Center, it was stated that, at the beginning of autumn 2023, the Ukrainian air defence was stronger than in had been in the previous winter, and suggested that this was due to international support.[315] Ukraine Prime Minister Denys Shmyhal has expressed the need for more air defence systems, as well as ammunition.[316] Oleksandr Kharchenko, managing director of the Kyiv-based Energy Industry Research Centre has

[307] UK Ministry of Defence. Royal Engineers lead training effort to help Ukraine defend its critical national infrastructure. 2023-10-22.

[308] Liliana Oleniak, "Ukraine's energy facilities receive three protection levels: Details revealed". RBC-Ukraine. 2023-11-20. https://newsukraine.rbc.ua/news/ukraine-s-energy-facilities-receive-three-1700483039.html (Accessed 2023-11-25).

[309] Ibid.

[310] We have not been able to assess the number as of 2024.

[311] Ibid.

[312] Olearchyk. "Ukraine braced for attacks on its power grid as winter draws in."

[313] Ibid.

[314] Interview. Autumn 2023.

[315] Prokip, How Will Ukraine's Energy Sector Fare in the Upcoming Winter?

[316] Olearchyk. "Ukraine braced for attacks on its power grid as winter draws in."

however noted that it would not be possible to cover all the territory of Ukraine with air defences, since there are more than 100 substations and high-voltage transmission stations scattered all over the country.[317]

Ukraine has developed around 3,000 light air defence teams, consisting of a vehicle, personnel, a man-portable air defence system (MANPADS) and a machine gun with up to 30 mm calibre. The team is connected to a sensor and information system which can detect incoming threats with position and direction, and relay this information to the team, which then tries to intercept and destroy the threat. These air defence teams are primarily expected to protect against drones.[318] According to one of our respondents, Ukraine would need around 1,000 additional teams.

[317] Olearchyk. "Ukraine braced for attacks on its power grid as winter draws in."

[318] General Staff of the Armed Forces of Ukraine, "Meet Ukraine´s mobile air defense unit", Facebook, 2023-02-11. https://www.facebook.com/GeneralStaff.ua/videos/719696163084940/ and Interview, autumn 2023.

7 Observations and conclusions

It is the hope of the authors that this report will play a part in a wider discussion on how to ensure energy security in times of conflict and war. There are very few aspects of modern society that can continue unaffected by disruptions in power supply: from the operations of hospitals to food production and safety, heating and communications. They all depend on stable access to power. The issues discussed in this report are therefore of the utmost importance to address.

The question of how NATO, the European Union, and other countries should support Ukraine in maintaining and developing its power system is best managed in separate closed forums or studies. It is our hope that this report can contribute to that discussion.

This report takes its starting point in three facts:

- **The Ukrainian power system has faced massive attacks from Russian forces.** During the winter 2022-2023, Russia was aiming a large number of missiles and drones against power infrastructure and facilities.
- **The power system has sustained significant damage.** The attacks resulted in extensive damage and destruction with serious consequences for the power supply. Again, the details of this damage is not known, as Ukrainian authorities (for security reasons) have restricted this information. However, available information shows that Ukraine have suffered from extensive power outages throughout the war.
- **The power system still works.** Available information shows that power is still available, albeit with frequent interruptions. At times, power is even exported to other countries.

It is possible that the attacks on the power system have not had the effect Russia may have wished or even expected. However, when we, as observers at a safe distance, see the scale of the attacks and the damage and destruction, we can only assume that it must have been a tremendous challenge for the actors in the Ukrainian power system. Despite this, Ukraine has continuously managed to repair facilities, restore the power supply and mitigated the consequences of power outages.

These are the facts. The questions this report has attempted to answer are “what?” and “how?”. *What* has happened, and *how* has Ukraine handled Russian attacks on their power system?

There are certain pre-existing conditions that have contributed to shape the way in which Ukraine has responded to Russian attacks on the power system. The conditions for the power system entail both strengths and weaknesses. Some of these conditions are specific to Ukraine and are not replicable across the board. This means that some specific observations might not be relevant for actors in other countries, Any lessons we learn from Ukraine must therefore be adapted to suit.

The conclusions we are able to draw at this point, centre on what likely contributed to Ukraine’s management and mitigation of the consequences of the attacks on the power system. These conclusions may change in the future as more information comes to light. The Ukrainian experience during the war will probably be the subject of analysis for many years to come. With that said, there are some conclusions that may be drawn.

The information we have collected in this study indicates that Ukraine has been both adaptable and flexible in terms of managing the effects of the attacks. Below, we list some of the measures and conditions we believe are key to Ukraine’s ability to maintain a functioning power system, securing the power supply, and mitigating the effect of power outages, when these occur. Additionally we discuss what actors can do in other countries to prepare for armed attacks on their power systems.

7.1 Repairs

Electricity has been restored after each attack (at various speeds, depending on the situation), which indicates that Ukraine has been able to repair and replace equipment in the power system to restore power supply. According to information from Ukrainian entities, this ability depends on the availability of skilled and trained repair personnel, engineers and dispatchers, equipment for repairs, and the ability to coordinate with other actors. Some of these measures may be indicative of flexible and innovative approaches, but many are also simply about experienced and well-organised teams performing their duties well.

Personnel

Having experienced repair teams that have worked together for a long time is one of the keys to efficiently performing repairs. How to ensure the availability of trained repair personnel, including questions such as staff training and internal knowledge transfer, is an important issue for actors in the power system. Having directly employed instead of contracted personnel for critical functions is a question that needs careful considerations.

An issue which we have not touched upon in the report, but is nevertheless important, is the maintenance of "regular" human resources functions, such as training, promotion, and recruitment. In order to keep a robust workforce, these are all essential functions.

Routines

Ukrenergo has underlined their ability to utilise already developed backup schemes as a crucial part of their resilience. The backup schemes were used to connect or reroute power supply, bypassing damaged power lines, sometimes using lines with a lower voltage, and avoiding bottlenecks due to unavailable production or transmission capacity. Such backup schemes are most likely already developed in advance by actors in the power system, but it is important that personnel are trained to implement them and that experiences are documented, evaluated and shared on an operational level. It is also helpful to synchronise these routines and efforts with other actors.

Equipment

Cooperation and coordination within the power sector to source and provide spare parts, equipment and personnel across regions have also greatly facilitated repairs. This has been particularly useful, as sourcing parts have been a challenge due to the fact that some parts can only be acquired from former Soviet countries. Here, the way in which Ukraine has stockpiled used spare parts highlights the need for storage solutions and management. The issue of storage and cooperation also raises the question of what level of standardisation of certain products and tools is required: how many varieties of tools and spare parts can be stored? It may also be necessary to investigate which requirements may be lowered, or put aside, during emergencies in order to facilitate the use of other equipment.

Cooperation

Cooperation and coordination between actors in the power system, the military forces, law enforcement and the state emergency service has enabled efficient prioritisation of repairs and supply, mine and unexploded ordnance removal, and the safety and protection of repair workers during repairs. They face the same issues that are facing other parts of Ukrainian society, where personnel have to be in close contact with mine clearance operators and bomb disposal teams before being able to perform their own duties. One way of ensuring that this runs as smoothly as possible is to conduct joint exercises. This kind of cooperation requires constant communication on all levels, which also underscores the need for common communication solutions setting out who to contact, when, and how. How do we communicate; which communication solution should be used and how should

that choice be prioritised; is it security in terms of encryption, or availability and ease of use?

7.2 Power system structure

The overcapacity and level of decentralisation and redundancy in the Ukrainian power system makes it more resilient in terms of maintaining power supply, by allowing using alternative supply routes and temporary schemes, and relying on local power production. Having overcapacity in the power system, or in any critical function for society, is an obvious, yet costly solution to achieve redundancy and preparedness for emergency situations or armed attacks. However, developing a power system in this regard might not be viable in the short term, as investments in power system infrastructure are long-term projects. Balancing the benefit against cost and time of implementation between different measures to increase robustness, resilience and preparedness is a crucial task for responsible actors.

7.3 Limiting consumption

Ukraine has managed to reduce electricity consumption by efficiency measures and spread consumption more evenly during day and night, in order to decrease peak consumption and ease the burden on the power system. This has helped to reduce the risk of unplanned blackouts. Likewise, Ukraine has used different kinds of disconnections, such as scheduled shutdowns, in order to stabilise the power system, again reducing the risk of unplanned blackouts. Disconnection routines should be set in place. It is also necessary to identify which consumer groups that can be disconnected from the power supply without major consequences.

7.4 Communication

Clear communication in crises is crucial. The government, power industry and official entities have communicated extensively with citizens, informing them about the situation in the power system and supply, how they work to resolve interruptions in power supply, and what citizens and businesses can do to help. This has been important in conjunction with the above-mentioned scheduled shutdowns, but above all, it has been crucial as a way of countering disinformation from Russian sources, addressing claims that power cuts are a result of Ukraine exporting electricity, rather than Russian attacks.

7.5 Legal provisions

Ukraine has adopted new regulations to facilitate electricity import and mitigate the constraints on import (due to the high difference in prices between domestic and imported electricity), and ease standards to enable temporary installations. The relevant actors should identify laws and regulations that might need to be adapted to wartime conditions.

7.6 International cooperation

Early on, Ukraine developed functions to coordinate requesting and receiving international support. The efficiency of this process has been important to enable receiving much needed supplies from abroad. ENTSO-E and Ukraine have taken measures in order to increase the amount of electricity that can be imported to Ukraine, and enabling emergency import from more countries. Ukraine has received international support with financing, equipment, and training. This has strengthened Ukraine’s ability to repair and replace power infrastructure and secure power supply.

7.7 Passive defence measures

Ukraine has used passive protection for power infrastructure and facilities, using gabions, big bags and concrete structures, which has decreased the damages inflicted by attacks. Knowledge-transfer from other countries and actors with experience of these types of measures (such as British engineering corps) appears to have been useful. A lesson that we can learn from the Ukrainian situation is the importance of preparing an inventory of available tools (such as gabions) and creating a list of prioritised infrastructure together with other actors.

7.8 Active defence measures

Air defence systems have been crucial in protecting the power system, as well as other critical infrastructure, military installations and troops, and the population. Systems donated by western countries seem to have bolstered Ukraine's ability to counter aerial attacks. Ukraine has also developed light mobile air defence teams in order to increase the protection against air attacks, mainly from drones. An important issue to determine is what level of protection the power system can expect from military air defence systems, and what responsibility falls on the actors in the power system. For example, do they have the authority to use their own active defence measures against drones?

7.9 Logistics

Logistics matter: the transportation of power system equipment can be demanding, take a long time, and require extensive coordination. This issue is equally relevant during peacetime, and is of great importance in other types of crises, including natural disasters. The question of logistics also apply in many other areas, not the least for the supply of fuel, and specifically for reserve power generators, which have been used extensively in Ukraine. Planning and solving logistical issues requires a foundation of cooperation between actors and within the organisation itself.

7.10 What is next?

Today, Ukraine is aiming to make the energy system more decentralised in order to increase its resilience. In addition to this development, the role played by renewable energy (such as water, wind and solar) in the war should be further investigated, especially in relation to the transition towards a sustainable energy system and the European Green Deal. European politicians have noted that, together with further integration of the energy systems in Europe, these developments increase the opportunities for electricity trade and contributes to Europe's energy security.

The war in Ukraine has had significant effects on the energy situation in the rest of Europe, where some countries previously relied heavily on Russian exports, contributing to a serious European energy crisis. This emphasises how energy transition, energy security, and security policy go hand in hand.

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Appendix

A. Additional written sources

As explained in section 1.2, this report covers a large scope and many different aspects, which has necessitated the use of complementary written sources. Here we list these sources chronologically and briefly describe their content, facilitating further reading.

The report from PAX, *Risks and impacts from attacks on energy infrastructure in Ukraine. Environment and Conflict Alert Ukraine*, published in December 2022, covers attacks on energy infrastructure during the period February to November 2022, and analyses the impacts of the attacks.[319] It also presents a case study of the attacks on the Zaporizhzhia Nuclear Power Plant and the power supply to the plant.

The *Ukrainian energy sector evaluation and damage assessment* is a monthly report from the International Energy Charter, Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force.[320] The work is funded by the European Commission. The reports cover the period from the invasion in February 2022, to June 2023, published from August 2022 to June 2023. The reports also cover damage, as well as demand and supply in all energy sectors. In this report, these sources are referred to as the "Task Force".

The International Centre for Defence and Security (ICDS) report *War and energy security. Lessons for the future* from May 2023, analyses the events during the war and draws lessons from Ukraine's response related to critical energy infrastructure and resilience in the energy sector.[321]

The report *Putin's Missile war, Russia's Strike Campaign in Ukraine* by Ian Williams from the Centre for Strategic and International Studies (CSIS), describes Russia's missile attacks against Ukraine.[322] The report also analyses shifts in tactics, Russian performance, and the weapons used in the attacks.

The two reports Ukraine Energy Damage Assessment – Executive Summary[323] and the update Towards a green transition of the energy sector in Ukraine – Update on the Energy Damage Assessment[324] are published by United Nations Development Programme (UNDP) together with The World Bank. They include information on damage and losses to energy infrastructure and what is needed to restore energy supply in Ukraine. The update from June 2023 includes recommendations for immediate response aligned with mid-term energy sector priorities.

In June 2023, the OECD published the *Competition Market Study of Ukraine's Electricity Sector*.[325] It contains a description of the electricity market in Ukraine and the regulatory framework, and an assessment of the wholesale and the retail market.

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[319] PAX. Risks and impacts from attacks on energy infrastructure in Ukraine. Environment and Conflict Alert Ukraine. December 2022.

[320] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment (I – XI). 2022-2023

[321] Jermalavičius et al, "War and energy security. Lessons for the future".

[322] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine.

[323] The United Nations Development Programme and The World Bank. Ukraine Energy Damage Assessment. Executive Summary. March 2023.

[324] The United Nations Development Programme and The World Bank. Towards a green transition of the energy sector in Ukraine. Update on the Energy Damage Assessment. July 2023.

[325] OECD. Competition Market Study of Ukraine's Electricity Sector.

The Kyiv school of Economics (KSE) published the Report on damages and losses to infrastructure from the destruction caused by Russia's military aggression against Ukraine as of June 2023, with support from the United States Agency for International Development (USAID).[326] It presents an assessment of the damage and losses to Ukraine's economy caused by Russia's military aggression. The report covers the period from February 2022 to June 2023.

The International Atomic Energy Agency (IAEA) follows the situation regarding the nuclear power plants and nuclear safety in Ukraine and publishes weekly updates on the situation online as well as regular reports.[327]

B. Timeline of attacks and the situation in the Ukrainian power system

The information in this timeline comes from a variety of official sources, primarily Facebook accounts from Ukrenergo, the Ukrainian Air Force Command and the Ukrainian General Staff. Terms and calculations vary depending on the source, and the information may therefore vary or overlap somewhat. We have taken the information as given, and have not attempted to analyse or interpret it in any way.

February-August 2022

Up until the end of August 2022, after half a year of full-scale war, Russia had occupied or damaged about 35 percent of the country's installed power capacity, thousands of km of electric, gas and heat networks, thousands of transformers, compressor stations and heating points. Electricity and natural gas consumption decreased by 30-35 percent compared to 2021.[328]

More than 7.5 million consumers had been cut off from the power supply at some point since February 2022, but supply had also been restored to over 7 million. 1,299 settlements remained without power, affecting 738,000 consumers.[329]

11 September

Attacks

The first major disruption to the Ukrainian power supply was on 11th September. Russia launched 18 missiles and 39 air strikes on military and civilian objects. Ukraine air defence was able to shoot down one X-59 guided missile, four Kalibr-type sea-based guided missiles and five X-101 air-based guided missiles and destroy one Orlan-10 drone.[330]

[326] Kyiv School of Economics. Report on damages and losses to infrastructure from the destruction caused by Russia's military aggression against Ukraine as of June 2023.

[327] International Atomic Energy Agency. Nuclear Safety, Security and Safeguards in Ukraine.

[328] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment I. 2022.

[329] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment II. 2022.

[330] General Staff of the Armed Forces of Ukraine. Facebook, 2022-09-12. https://www.facebook.com/GeneralStaff.ua/posts/406565444989873

Consequences

Following the attack on the thermal power plant in Kharkiv, power was partially cut off in several parts of eastern Ukraine.[331] According to Ukrenergo, artillery attacks in the northeastern region of Ukraine damaged the transmission power grid and caused fires.[332]

The Kharkivska combined heat and power plant (CHP-5), Zmiivska thermal power plant and three high-voltage substations were damaged, which resulted in power disconnection of more than a million consumers in Poltava, Dnipropetrovsk, Kharkiv, Sumy and Donetsk regions.[333]

Measures

Power was distributed to consumers from backup power lines.[334] Emergency repairs of the damage to the transmission power grid caused by artillery began the next day.[335] In only a few hours power supply was restored to all the affected regions, including Kharkiv", according to chairman of the management board of Ukrenergo Volodymyr Kudrytskyi.[336]

17-19 September

Consequences

The Slovianska Thermal Power Plant (0.8 GW) was heavily damaged by shelling on 17 September,[337] as well as the Pivdennoukrainska (South Ukraine) nuclear power plant, the second largest Ukrainian nuclear plant, on 19th September.[338]

Measures

On the 19th of September, Ukrenergo stated that in the previous week nine main power transmission lines of both 750 kV and 330 kV in the east and south of Ukraine had been repaired. Equipment at two 330 kV and 750 kV substations, damaged by missiles, and many wire damages and breaks, had been repaired. Repair work was ongoing at two other 330 kV substations. The repairs ensured power supply to more than 5 million customers in the east and south of Ukraine.[339]

22 September

A statement from Ukrenergo confirmed that the seasonal increase in electricity demand had begun, but that there was no lack of power. Export of electricity to Europe continued unabated. However, the number of thermal power plants undergoing emergency repairs increased at a high rate.[340]

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[331] General Staff of the Armed Forces of Ukraine. Facebook, 2022-09-12. https://www.facebook.com/GeneralStaff.ua/posts/406565444989873

[332] NPC Ukrenergo. Facebook, 2022-09-11. https://www.facebook.com/npcukrenergo/posts/451346737034157

[333] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment II. 2022.

[334] NPC Ukrenergo. Facebook, 2022-09-11. https://www.facebook.com/npcukrenergo/posts/451346737034157

[335] NPC Ukrenergo. Facebook, 2022-09-12. https://www.facebook.com/npcukrenergo/posts/451839680318196

[336] NPC Ukrenergo. Facebook, 2022-09-12. https://www.facebook.com/npcukrenergo/videos/391087796359606/ and Abené Clayton, Joanna Walters, Richard Luscombe, Vivian Ho, Martin Belam and Martin Farrer. Ukraine claims Russian military command has stopped sending new units into country – as it happened. The Guardian. 2022-09-13. https://www.theguardian.com/world/live/2022/sep/12/russia-ukraine-war-zelenskiy-accuses-kremlin-of-terrorist-attacks-on-kharkiv-power-supply-live-updates?page=with:block-631edaf88f0804237ace7342 (Accessed 2023-10-02).

[337] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment II. 2022.

[338] Ibid.

[339] NPC Ukrenergo. Facebook, 2022-09-19. https://www.facebook.com/npcukrenergo/posts/456828826485948

[340] NPC Ukrenergo. Facebook, 2022-09-22. https://www.facebook.com/npcukrenergo/posts/459091406259690

24 September

An assessment of the current situation showed that Russia occupied or had damaged about 40 percent of the country's installed power capacity. Over 30 overhead lines and 10 substations with a voltage of 220–750 kV were at this point damaged or disconnected. More than 1,200 overhead lines (6-150 kV) and more than 8 thousand transformers (6-150 kV) were damaged or disconnected due to continuous shelling and hostilities. At the time, the power supply had already been restored to over seven million consumers. As of 24th September 2022, about 1,299 settlements in Ukraine remained without power (completely or partially), covering about 738,000 consumers.[341]

Measures

On the 26th of September, Ukrenergo were still working on repairs on substations in the eastern region hit by missiles on the 11 September. The damage was assessed, destroyed equipment removed and rebuilding of control facilities was under way.[342]

October 2022

October saw some of the most significant damage to the electricity system due to Russian attacks. The attacks destroyed or damaged a large part of the Ukrainian power system and cut the power supply for millions of Ukrainians. Because of the damage, the Ukrainian Government decided to halt electricity export to the European Union (EU) on 11th October 2022.[343]

10-11 October

Attacks

10th October: Russia launched 84 missiles and 24 drones. Cruise, ballistic, and anti-aircraft guided missiles were used. 13 of the drones were Iranian Shahed-136.[344] According to a statement by President Zelenskyy, of the 84 missiles and 24 drones Russia fired, Ukrainian forces shot down 43 missiles and 13 drones.[345] Ukrainian media reported that 70 targets were hit, including 29 critical infrastructure facilities.[346]

11th October: Russia again launched a missile attack using almost thirty Kh-101 and Kh-55 cruise missiles, carried out seven airstrikes and about twenty-five rocket artillery attacks. Russia also launched attacks using Shahed-136 drones. 21 cruise missiles and 11 drones were destroyed.[347]

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[341] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment II. 2022.

[342] NPC Ukrenergo. Facebook, 2022-09-26. https://www.facebook.com/npcukrenergo/posts/462294055939425

[343] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022, and Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[344] General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-10.https://www.facebook.com/GeneralStaff.ua/posts/430261882620229

[345] Adam Schreck, Hanna Arhirova. Russia unleashes biggest attacks in Ukraine in months. *AP News*. 2022-10-11. https://apnews.com/article/russia-ukraine-kyiv-government-and-politics-8f625861590b9e0dd336dabc0880ac8c (Accessed 2023-10-02).

[346] Kateryna Stepanenko, George Barros, Riley Bailey, Angela Howard, and Frederick W. Kagan. *Russian Offensive Campaign Assessment*, 2022. Institute for the Study of War. https://www.understandingwar.org/backgrounder/russian-offensive-campaign-assessment-october-10 (Accessed 2023-10-02).

[347] General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-11. https://www.facebook.com/GeneralStaff.ua/posts/431184305861320

Consequences

According to Ukraine's Energy Minister Herman Halushchenko, Russian missiles hit around 30 percent of the energy infrastructure in Ukraine. This was the "first time from the beginning of the war" that Russia has "dramatically targeted" energy infrastructure, Minister Halushchenko said in a statement to CNN.[348] After the attack, there were more than 4 million disconnected consumers.[349]

Three of DTEK's thermal power plants were damaged. In Lviv, energy facilities were damaged causing a shutdown.[350] In Kharkiv, the power grid was damaged and power was cut off in some areas.[351]

Measures

Access to the power supply was restored to almost all consumers within 12-24 hours. However, due to the significant losses in generation capacity and damages to the network infrastructure, the Ukrainian energy system was forced to switch to saving mode.[352] Ukrenergo introduced a schedule of emergency consumer shutdowns in the regions of Kyiv, Chernihiv, Cherkasy and Zhytomyr.[353]

Power supply was restored on 11th October to most of the territory of Ukraine, according to Ukrenergo. The power supply was restored in the western regions and almost completely in the Kharkiv region. Restoration work continued in the Kyiv region and the central regions.[354]

The damage to the power system resulted in the decision of the Ukrainian Government to stop electricity export to the European Union on 11th October 2022. It was however seen as a temporary measure, and the intention was to resume the export as soon as the restoration work was completed and the power system could generate a surplus.[355]

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[348] Kathleen Magramo, Sana Noor Haq, Ed Upright, Adrienne Vogt and Aditi Sangal. October 11, 2022 Russia-Ukraine news. *CNN*. 2022-10-12. https://edition.cnn.com/europe/live-news/russia-ukraine-war-news-10-11-22/h_2093c5424cc0e8f0c2b366dd9e147957 (Accessed 2023-10-17).

[349] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022.

[350] Iryna Znas. In Lviv, the occupiers hit energy facilitites, there is no electricity in part of the city. *ZN.UA*. 2022-10-10, https://zn.ua/ukr/UKRAINE/u-lvovi-okupanti-vdarili-po-enerhetichnikh-objektakh.html (Accessed 2023-10-05).

[351] Ukrinform. There is no electricity or water in Kharkiv after the shelling. 2022-10-10. https://www.ukrinform.ua/rubric-regions/3589824-u-harkovi-pisla-obstrilu-nemae-elektriki-ta-vodi.html (Accessed 2023-10-05).

[352] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022.

[353] NPC Ukrenergo. Facebook, 2022-10-10. https://www.facebook.com/npcukrenergo/posts/475133271322170

[354] NPC Ukrenergo. Facebook, 2022-10-11. https://www.facebook.com/npcukrenergo/posts/476066114562219

[355] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022, and Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

12-18 October

Attacks

Between the 12th and 17th of October, missiles and drones struck 405 locations across the country, including 45 power stations, representing approximately 30 percent of power stations across Ukraine.[356] On 17th October, Russia launched 9 missile and 39 air strikes and carried out about 30 rocket artillery attacks. Cruise, aviation and anti-aircraft guided missiles were used.[357] Five missiles and 25 Shahed-136 drones were destroyed.[358] Another thermal power plant was attacked on 17th October, and two additional attacks occurred on 18th October at DTEK Energy enterprises.[359]

On the morning of 18th October, the General Staff stated that over the past 24 hours, Russia launched 10 missile and 58 air strikes, and launched up to 60 rocket artillery attacks. Cruise, aviation and anti-aircraft guided missiles were used. In addition, 43 Shahed-136 drones were launched, 38 of which were shot down by Ukraine.[360] Five Shahed-136 drones struck infrastructure in the Shevchenkivskyi district of Kyiv, including the Ukrenergo building.[361] Later the same day, Russia launched 9 missile and 10 air strikes and carried out more than 10 rocket artillery attacks. Cruise, aviation and anti-aircraft guided missiles were used. In addition, in one of the directions, Russia launched 4 Shahed-136 drones, 3 of which were shot down. Air defence units shot down 5 cruise missiles.[362] Energy facilities in the Kyiv, Kharkiv, Dnipro, Zhytomyr, Sumy, Zaporizhzhia, Dnipropetrovsk, and Donetsk regions were hit.[363]

On 19th October, Russia launched four missiles, eleven air strikes, and more than ten attacks from artillery systems on civilian infrastructure in Kyiv, Chernihiv, Vinnytsia, Ivano-Frankivsk, Donetsk, Dnipropetrovsk, Zaporizhzhia, and Mykolaiv regions. During the night, the occupiers also attacked Uman, Cherkasy region, and Kobleve, Mykolaiv region, with five Shahed-136 drones. All of them were successfully shot down by the Defence Forces of Ukraine. In total, air defence units shot down four cruise missiles and thirteen Shahed-136 drones.[364]

Consequences

Energy infrastructure in the central and northern regions of Ukraine were damaged,[365] and missiles and drones caused severe damage to energy infrastructure in Kyiv city and the

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[356] Williams. Putin's Missile war, Russia's Strike Campaign in Ukraine, and Megan Specia & Andrew E. Kramer, Russian Barrage Targets Power, Water and Heat for Ukraine's Civilians. New York Times. 2022-10-18. https://www.nytimes.com/2022/10/18/world/europe/ukraine-russia-blackout-water.html (Accessed 2023-10-09).

[357] General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-17. https://www.facebook.com/GeneralStaff.ua/posts/436226505357100

[358] Air Force Command of UA Armed Forces. Facebook, 2022-10-17. https://www.facebook.com/kpszsu/posts/483815427119744 and https://www.facebook.com/kpszsu/-posts/484277627073524, and General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-17. https://www.facebook.com/GeneralStaff.ua/posts/436226505357100

[359] Aaron Larson. Ukraine Grid Operator Issues Call for Help, Needs Equipment to Keep Lights On. Power. 2022-10-18. https://www.powermag.com/ukraine-grid-operator-issues-call-for-help-needs-equipment-to-keep-lights-on/ Accessed 2023-10-09

[360] General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-18. https://www.facebook.com/-GeneralStaff.ua/posts/436622915317459

[361] Karolina Hird et al, Russian Offensive Campaign Assessment.

[362] General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-18. https://www.facebook.com/-GeneralStaff.ua/posts/437016778611406

[363] PAX. Risks and impacts from attacks on energy infrastructure in Ukraine. Environment and Conflict Alert Ukraine. December 2022.

[364] General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-19. https://www.facebook.com/-GeneralStaff.ua/posts/437766375203113

[365] NPC Ukrenergo. Facebook, 2022-10-17. https://www.facebook.com/npcukrenergo/posts/480699454098885

Kyiv region.[366] DTEK reported that more than 30 percent of Ukraine's energy system has been damaged as a result of shelling by the Russian army.[367] Several of DTEK's power facilities were attacked by Russian forces. 40 percent of energy infrastructure was significantly damaged. Around half of the thermal power generation capacity, 4 GW, was damaged.[368]

President Volodymyr Zelenskyy confirmed in a statement that 30 percent of Ukraine's power stations had been destroyed between the 10th and 18th of October.[369]

Measures

Ukrenergo started applying restriction schedules for consumers of various categories, population and industrial consumers throughout the country.[370]

On 20th October, due to increased electricity consumption, temporary controlled restrictions on consumption was introduced in the regions of Kharkiv, Sumy and Poltava.[371]

Other

Minister of Energy, German Galushchenko, told Reuters in an interview on 21st October that Ukraine may need electricity imports to get through the winter after attacks that had struck 30-40 percent of power infrastructure.[372]

22 – 30 October

Attacks

On 22nd October, Russia launched 40 missiles and 16 Shahed-136 drones. Ukraine managed to shoot down 20 missiles and 11 drones.[373] Russian military forces also used drones to attack the transmission system operator's dispatching centre, aiming to destroy the command and control centre of the Ukrainian power system.[374]

Consequences

Energy and critical infrastructure facilities in the regions of Volyn, Rivne, Kharkiv, Khmelnytskyi, Kirovohrad, Cherkasy, Zaporizhzhia, Odesa, and Mykolaiv were hit by attacks.[375]

A statement by Ukrenergo noted that "the scale of the damage is comparable or may exceed the consequences of the attack on October 10–12". Power supply restrictions were enforced in the regions of Kyiv, Chernihiv, Cherkasy, Zhytomyr, Sumy, Kharkiv, Poltava, Dnipropetrovsk, Zaporizhzhia and Kirovograd.[376] The missile strikes cut off power for 1.5

[366] PAX. Risks and impacts from attacks on energy infrastructure in Ukraine. Environment and Conflict Alert Ukraine. December 2022.

[367] Larson. Ukraine Grid Operator Issues Call for Help, Needs Equipment to Keep Lights On.

[368] Hunder, At least half of Ukraine's thermal power capacity hit by Russian strikes

[369] Bachega & Lukov. Ukraine war: Blackouts in 1,162 towns and villages after Russia strikes.

[370] PAX. Risks and impacts from attacks on energy infrastructure in Ukraine. Environment and Conflict Alert Ukraine. December 2022.

[371] NPC Ukrenergo. Facebook, 2022-10-20. https://www.facebook.com/npcukrenergo/posts/483099630525534

[372] Hunder, At least half of Ukraine's thermal power capacity hit by Russian strikes

[373] General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-22. https://www.facebook.com/-GeneralStaff.ua/posts/440182781628139

[374] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022.

[375] General Staff of the Armed Forces of Ukraine, Facebook, 2022-10-22. https://www.facebook.com/-GeneralStaff.ua/posts/440182781628139

[376] NPC Ukrenergo. Facebook, 2022-10-22. https://www.facebook.com/npcukrenergo/posts/484444530391044

million Ukrainians according to Kyrylo Tymoshenko, deputy head of Zelenskyy's administration.[377]

As of 24th October, about 35-40 percent of the installed thermal power and combined heat and power capacities in Ukraine were either damaged or completely destroyed. The power transmission and distribution networks were also heavily damaged, resulting in complete or rolling shutdowns in almost all Ukrainian regions. Between October 10-24, about 5 million consumers were temporarily disconnected from the power supply.[378]

Measures

Consumer restrictions were applied for 12 days between 11th and 23rd October on the city of Kyiv and the regions of Kyiv, Chernihiv, Cherkasy and Zhytomyr.[379]

From 27th October, in order to prevent shutdowns in the capital and central regions, Ukrenergo introduced unprecedented emergency restrictions: the use of long-term power shutdowns without a schedule.[380]

Starting on the 28th of October, many cities and districts applied scheduled stabilization shutdowns. About 4 million Ukrainians came under these restrictions in the city of Kyiv and the regions of Kyiv, Zhytomyr, Poltava, Rivne, Kharkiv, Chernihiv, Sumy, Cherkasy and Kirovograd. It was also noted that emergency shutdowns may be required in other regions.[381]

On 30th October, President Zelenskyy released a statement saying, "There were no emergency shutdowns throughout the day today. Power supply capacity has been restored after the week-long Russian strikes, but the generation deficit persists".[382]

31 October

Attacks

Russia carried out up to 10 airstrikes and launched more than 20 attacks from rocket artillery systems. In addition, the infrastructure in the regions of Kyiv, Poltava, Zaporizhzhia, Kharkiv, Cherkasy, Chernivtsi and other regions suffered attacks. Russia launched 55 missiles against military and civilian infrastructure facilities, 45 of which were shot down by Ukrainian forces. Ukrainian air defence units also shot down two drones.[383]

Consequences

Equipment of the transmission network was damaged in several regions.[384] This included transmission system substations, large hydropower, pumped storage and thermal power plants. As a result of the attack, 18 energy facilities in 10 regions of Ukraine were damaged.[385]

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[377] Roman Olearchyk. Russia ramps up missile strikes on Ukraine's energy infrastructure. Financial Times. 2022-10-22. https://www.ft.com/content/00433ac0-d6b4-41fe-b36c-f465cf53067c (Accessed 2023-10-16).

[378] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment III. 2022.

[379] NPC Ukrenergo. Facebook, 2022-10-23. https://www.facebook.com/npcukrenergo/posts/485281843640646

[380] PAX. Risks and impacts from attacks on energy infrastructure in Ukraine. Environment and Conflict Alert Ukraine. December 2022.

[381] NPC Ukrenergo. Facebook, 2022-10-28. https://www.facebook.com/npcukrenergo/videos/2050495841803574/

[382] NPC Ukrenergo. Facebook, 2022-10-30. https://www.facebook.com/npcukrenergo/videos/486684193493698/

[383] General Staff of the Armed Forces of Ukraine. Facebook, 2022-10-31 https://www.facebook.com/-GeneralStaff.ua/posts/447346027578481

[384] NPC Ukrenergo. Facebook, 2022-10-31. https://www.facebook.com/npcukrenergo/posts/491704406331723

[385] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

Measures

After the attack on 31st October, Ukrenergo provided distribution network operators coverage for the application of emergency shutdowns for industrial and residential consumers in all regions of Ukraine.[386]

November 2022

As of the beginning of November, more than 40 overhead lines in the transmission system and more than 20 substations with a voltage of 220–750 kV were damaged or disconnected due to continuous attacks and hostilities.[387] Power supply capacity had been restored by October 30, but generation deficits remained into the next month.

Around 4.5 million consumers were temporarily disconnected after the attack on 2nd November and later attacks (15 November) left 10 million consumers without power. On 23rd November, further Russian attacks forced scheduled and emergency shutdowns across Ukraine.

2 – 13 November

Attacks

On the night between 1st and 2nd November, Russian forces attacked Ukrainian infrastructure facilities from the eastern direction with missiles and 13 Shahed-136 drones, of which 12 were destroyed by air defences in the eastern and central regions of the country.[388]

Over 15 settlements were targeted, among them Kremenchuk in the Poltava region, Vuhledar and Vodyane in the Donetsk region, and the city of Smila in the Cherkasy region.[389] Further attacks were carried out on 11 November.[390]

Consequences

The attacks seriously damaged one of Ukrenergo's key facilities.[391] The facility, which provided energy supply of the entire right coast of the Kherson region and a large part of the Mykolaiv region, was practically destroyed. Two autotransformers, each weighing 250 tons, were destroyed.[392]

Measures

In the beginning of November, scheduled restrictions continued to apply in different areas in Ukraine. About 4.5 million consumers were temporarily disconnected from consumption under emergency and stabilization schedules on November 3.[393] Consumption restrictions were required, as the colder weather led to an increase in energy consumption, which in turn was expected to lead to increased loads on equipment and power shortages in the energy system.[394]

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[386] NPC Ukrenergo. Facebook, 2022-10-31. https://www.facebook.com/npcukrenergo/posts/491704406331723

[387] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[388] Air Force Command of UA Armed Forces. Facebook, 2022-11-02. https://www.facebook.com/kpszsu/posts/496484855852801

[389] General Staff of the Armed Forces of Ukraine. Facebook, 2022-11-02. https://www.facebook.com/GeneralStaff.ua/posts/448875490758868

[390] NPC Ukrenergo. Facebook, 2022-11-11. https://www.facebook.com/npcukrenergo/posts/499500935552070

[391] NPC Ukrenergo. Facebook, 2022-11-13. https://www.facebook.com/npcukrenergo/videos/518428210171481/

[392] NPC Ukrenergo. Facebook, 2022-11-14. https://www.facebook.com/npcukrenergo/posts/501996231969207

[393] NPC Ukrenergo. Facebook, 2022-11-03. https://www.facebook.com/npcukrenergo/videos/870904757610330/

[394] NPC Ukrenergo. Facebook, 2022-11-08. https://www.facebook.com/npcukrenergo/posts/497324475769716

After the attack on 11th November, emergency shutdowns were applied in Kyiv city and the regions of Kyiv, Chernihiv, Cherkasy, and Zhytomyr. This was required in order to maintain the stable operation of the energy system. At night and in the morning, emergency shutdowns were applied in the regions of Sumy, Kharkiv and Poltava. The situation in the energy system was subject to change, especially during the evening peak consumption. In all other regions of Ukraine, scheduled shutdowns continued to operate.[395]

15 November

The largest attack on the power system up to this date.

Attack

Around 14:30 on 15th November, Russia hit the territory of Ukraine with missiles from air and sea platforms. In total, over 90 missiles were launched: about 70 missiles from the northern Caspian Sea and from Volgodonsk (Rostov region), and about 20 Kalibr missiles from the Black Sea. In addition, 10 drones were used in the attack. According to the General Staff's preliminary data, 73 missiles were destroyed as well as all 10 drones.[396]

Ukrenergo reported that over 100 missiles and drones were launched across the territory of Ukraine.[397]

Consequences

The attack damaged 15 energy facilities, including thermal power plants and transmission substations, as well as thousands of kilometres of high-voltage power lines. This infrastructure was essential for power generation and transmission from the western regions to the east. About 10 million consumers were left without power. Many cities had problems with heating and cold and hot water supply.[398] The attack was carried out at peak consumption time, likely so that it would be more difficult for the power system to cope with the workload.[399] Western Ukraine as well as the central and northeastern regions were hit the hardest.[400]

Measures

The attack affected the operation of two nuclear power plants in the West of Ukraine. As a result, both nuclear power plants were disconnected from the grid. Due to damage caused to the power transmission lines, both operating reactors of Khmelnytska were stopped, and the plant was forced to switch to emergency diesel generators. Rivnenska NPP lost connection with one of its 750 kV power transmission lines. As a result, the plant reduced its operation capacity, and one of its four reactors was automatically shut down.[401]

Emergency outage schedules were used to stabilise Ukrenergo's energy system, according to Volodymyr Kudrytskyi.[402]

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[395] NPC Ukrenergo. Facebook, 2022-11-11. https://www.facebook.com/npcukrenergo/posts/499433668892130

[396] General Staff of the Armed Forces of Ukraine. Facebook, 2022-11-15. https://www.facebook.com/GeneralStaff.ua/posts/459001113079639

[397] NPC Ukrenergo. Facebook, 2022-11-15. https://www.facebook.com/npcukrenergo/posts/502712435230920

[398] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[399] NPC Ukrenergo. Facebook, 2022-11-15. https://www.facebook.com/npcukrenergo/posts/502712435230920

[400] NPC Ukrenergo. Facebook, 2022-11-15. https://www.facebook.com/npcukrenergo/videos/671030104419803/

[401] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[402] NPC Ukrenergo Facebook, 2022-11-15. https://www.facebook.com/npcukrenergo/videos/671030104419803

Nine repair teams from different regions of Ukraine were involved in the restoration of trensmission networks. Work began immediately after clearing the area of mines.[403]

Ukrenergo, together with Khersonoblenergo and Mykolaivoblenergo developed a backup power scheme of Kherson region and began its implementation on 15th November.[404]

On 16th November, hourly outages and emergency outages were applied throughout Ukraine.[405] Ukrenergo stated that more than 1000 specialists worked 24/7 to restore the energy system.[406]

Other

Due to the attack on one of the power transmission lines transporting electricity to Moldova, the cross-border line was automatically disconnected. This led to massive power outages in Moldova.[407]

17 – 19 November

Attacks

On 17th November, Russia carried out five air strikes and 25 missile strikes, and carried out more than 10 attacks from rocket artillery systems. The attacks targeted civilian infrastructure objects in Dnipro and Odesa, Balakliya in the Kharkiv region, Vilniansk in the Zaporizhzhia region, Nikopol in the Dnipropetrovsk region, and Ochakiv in the Mykolaiv region. The Defence Forces shot down two cruise missiles, two guided air missiles and five Shahed-136 drones.[408] According to the Air Force command, the attack consisted of 18 missiles and five Shahed-136 drones. Six missiles were destroyed and all five drones.[409] On 19th November, Russia shelled the Zaporizhzhia NPP site and damaged its equipment. The IAEA experts reported 12 explosions at the plant site and the adjacent territory of the plant.[410]

Measures

On the 17th November, electricity was restored to about 70 percent of customers in the central region and high voltage lines for connection in the western and Dnieper regions were prepared. In the liberated Kherson region, repair teams of Ukrenergo together with sappers examined high-voltage lines.[411]

On 20th November, Ukrenergo stated that they had managed to stabilise the situation in the power system after the last mass attack on 15th November. Only scheduled (rather than emergency) shutdowns occurred during the weekend. The volume of restrictions on electricity consumption was slightly higher than normal. This was related to an increase in

[403] NPC Ukrenergo. Facebook, 2022-11-15. https://www.facebook.com/npcukrenergo/posts/502524571916373

[404] Ibid.

[405] NPC Ukrenergo. Facebook, 2022-11-16. https://www.facebook.com/npcukrenergo/posts/503059421862888

[406] NPC Ukrenergo. Facebook, 2022-11-17. https://www.facebook.com/npcukrenergo/posts/504214761747354

[407] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[408] General Staff of the Armed Forces of Ukraine. Facebook, 2022-11-17. https://www.facebook.com/GeneralStaff.ua/posts/460662889580128

[409] Air Force Command of UA Armed Forces. Facebook, 2022-11-17. https://www.facebook.com/kpszsu/posts/507891618045458

[410] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[411] NPC Ukrenergo. https://www.facebook.com/npcukrenergo/ 2022-11-17. https://www.facebook.com/npcukrenergo/posts/504214761747354

consumption typical for the beginning of the working week, according to Volodymyr Kudrytskyi.[412]

23 – 30 November

Attacks

On 23rd November, Russia launched 67 missiles, of which 51 were shot down by the Defence Forces of Ukraine. Five Lancet drones were also shot down. In Kyiv, 20 of the 30 missiles launched were destroyed.[413]

Consequences

Residential buildings and combined heat and power plants, thermal power plants and substations in the city of Kyiv and in the regions of Kyiv, Vinnytsia, Lviv and Zaporizhzhia were hit.[414] There were also reports about hydropower plants being hit.[415]

Also, due to a decrease in power system frequency, emergency protection was activated at Rivnenska, Pivdenoukrainska and Khmelnytska nuclear power plants. As a result, all nuclear power plants were automatically disconnected.[416]

On 24th November, more than 40 overhead lines and more than 20 substations with a voltage of 220–750 kV were damaged or disconnected due to continuous attacks and hostilities.[417]

Measures

The attack resulted in emergency outages in multiple Ukrainian regions and interruptions in heating and cold and hot water supply. In response to the critical energy infrastructure damage, Ukrenergo and distribution system operators introduced rolling and emergency shutdowns in all regions of Ukraine.[418] Dispatchers and engineers of Ukrenergo worked on reconnecting the attacked regions with backup schemes. Ukrenergo repair crews assessed the scale of damage and went about repairing the damage wherever it was possible.[419]

By the evening of the 24th of November, measures had been taken to enable power producers to cover more than 50 percent of the country's consumption needs. Most thermal and hydroelectric power plants were working, and all nuclear power plants, with the exception of the occupied Zaporizhzhia NPP, gradually gained capacity. Still, the consequences of the attack the day before were felt in all regions of Ukraine. Disconnections were triggered automatically and, typically, recovery takes longer when this happens, rather than when the outage is manually initiated by dispatchers.[420]

As of 24th November, between six to seven million consumers remained without power (entirely or partially) due to hostilities or consumption and capacity-limiting schedules.

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[412] NPC Ukrenergo. Facebook, 2022-11-20. https://www.facebook.com/npcukrenergo/videos/661607555602070/

[413] General Staff of the Armed Forces of Ukraine. Facebook, 2022-11-23. https://www.facebook.com/GeneralStaff.ua/posts/465372582442492

[414] General Staff of the Armed Forces of Ukraine. Facebook, 2022-11-23. https://www.facebook.com/GeneralStaff.ua/posts/465311169115300

[415] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[416] Ibid.

[417] Ibid.

[418] Ibid.

[419] NPC Ukrenergo. Facebook, 2022-11-23. https://www.facebook.com/npcukrenergo/posts/508735121295318

[420] NPC Ukrenergo. Facebook, 2022-11-24. https://www.facebook.com/npcukrenergo/posts/509398604562303

Ukrainian TSO and DSO's restored power supply where possible, but regular attacks by Russian troops made this difficult.[421]

As of 26th November, another nuclear unit was back in operation. Thus, power producers could cover about 75 percent of consumption needs. Throughout the territory of Ukraine there continued to be a regime of consumption restriction.[422]

For the rest of November, the power deficit was around 30 percent, although the power generation gradually increased. Consumption continued to grow due to worsening weather conditions and there were several emergency shutdowns at power plants.[423]

Other

Ukrenergo changed the process of restrictions. Previously, Ukrenergo decided how much each DSO should restrict power consumption, whereas in the new process, DSO:s were given a max consumption level that must not be exceeded. DSO:s independently determined consumer shutdown queues.[424]

The attack on 23rd November also affected the cross-border interconnection, leading to massive power outages in Moldova.[425]

December 2022

During the first 9 months of the war, Ukrenergo specialists carried out emergency work and partially restored power to 45 substations of different voltage classes, constituting 88 percent of all damaged objects. Emergency repair work was carried out and 52 of 87 high-voltage power lines were restored, equalling tens of thousands of kilometers. A considerable number of energy facilities, substations and power lines suffered repeated damage after emergency recovery work.[426]

Emergency shutdowns were in effect in all regions after an attack on 5th December.

On 16th December, attacks led to disconnections for 50 percent of consumers, with power restored to 6 million the next day. Information from the UN indicated that 50 percent of Ukraine's power grid were assessed as damaged by mid-December and by 26th December, about 9 million people were still without power. Consumption restrictions were lifted for New Year's Eve.

As many power units were under repair, the system was forced to rely on coal and hydropower.

[421] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[422] NPC Ukrenergo. Facebook, 2022-11-26. https://www.facebook.com/npcukrenergo/posts/510550207780476

[423] NPC Ukrenergo. Facebook, 2022-11-28 https://www.facebook.com/npcukrenergo/posts/511906380978192, NPC Ukrenergo. Facebook, 2022-11-29. https://www.facebook.com/npcukrenergo/posts/512613567574140, and NPC Ukrenergo. Facebook, 2022-11-30. https://www.facebook.com/npcukrenergo/posts/513296240839206

[424] NPC Ukrenergo. Facebook, 2022-11-25. https://www.facebook.com/npcukrenergo/videos/444534377879880/ and https://www.facebook.com/npcukrenergo/posts/510114997823997

[425] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IV. 2022.

[426] NPC Ukrenergo Facebook, 2022-12-02. https://www.facebook.com/npcukrenergo/videos/684891186487954/

5 – 9 December

Attacks

On 5th December, Russia launched a massive missile attack on civilian infrastructure throughout the territory of Ukraine. Of the over 70 missiles that Russia launched on the territory of Ukraine, 60 or more were shot down.[427]

Consequences

Power generation and transmission facilities in the regions of Kyiv, Vinnytsia, and Odesa were hit.[428] The attack caused considerable damage to both power plants and substations.[429] Due to the attack, certain power plants were not able to operate at full capacity for some time.[430]

Measures

In order to maintain a balance between power production and consumption, emergency shutdowns were introduced in all regions of Ukraine. Repair teams from Ukrenergo and regional power companies and producers began emergency recovery procedures of power facilities in Odesa and other regions. Ukrenergo dispatchers and engineers worked on powering the affected regions using backup schemes. Where possible, consumers were reconnected. In combination with colder weather in the coming days, this increased the shortage of power in the system.[431]

The regions of Odesa and Kyiv were the most affected. A few days were required to restore power production to the level it had been at prior to the missile attack on 5 December. All regions were given limits for electricity consumption. In some regions, the limits of consumption were exceeded, and so emergency disconnections were applied.[432]

Other

For a few days in December, weather conditions (snow and rain causing wiring freezing) negatively affected the condition of high-voltage and distribution networks and complicated repair work. There was a significant deficit in the Kyiv region.[433]

10 – 15 December

Attacks

On 10th December, Russia attacked the energy infrastructure facilities in the Odesa and Mykolaiv regions with supposedly Shahed-136 drones. Ukrainian defence forces intercepted ten out of fifteen drones.[434]

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[427] General Staff of the Armed Forces of Ukraine. Facebook, 2022-12-05. https://www.facebook.com/GeneralStaff.ua/posts/474347281545022 and NPC Ukrenergo. Facebook, 2022-12-05. https://www.facebook.com/npcukrenergo/posts/517338637101633

[428] General Staff of the Armed Forces of Ukraine. Facebook, 2022-12-05. https://www.facebook.com/GeneralStaff.ua/posts/474347281545022

[429] NPC Ukrenergo. Facebook, 2022-12-05. https://www.facebook.com/npcukrenergo/videos/638335588027414/

[430] NPC Ukrenergo. Facebook, 2022-12-05. https://www.facebook.com/npcukrenergo/posts/517338637101633

[431] Ibid.

[432] NPC Ukrenergo. Facebook, 2022-12-06. https://www.facebook.com/npcukrenergo/posts/517861173716046

[433] NPC Ukrenergo. Facebook, 2022-12-09. https://www.facebook.com/npcukrenergo/posts/519990030169827

[434] General Staff of the Armed Forces of Ukraine. Facebook, 2022-12-10. https://www.facebook.com/GeneralStaff.ua/posts/478628261116924

Consequences

The drones not shot down by Ukrainian forces, damaged the power transmission system. As a result, all consumers in the city of Odesa (over 1.5 million people) were disconnected from the power supply.[435]

On 14th December, there was a significant power shortage. Power plants suffering constant damage due to almost daily shelling exacerbated the already difficult situation in the eastern parts of Ukraine. Repair work slowed down due to the threat to repair staff.[436]

Measures

Due to a significant power deficit in the energy system throughout Ukraine, consumption restrictions were applied.[437]

In liberated regions, power was restored to some areas, some of which had remained without power since the beginning of the full-scale invasion.[438]

Another nuclear unit went into operation on 13th December, mitigating the power deficit in the system.[439]

In some areas, limits on consumption were exceeded, requiring emergency shutdowns.[440]

Other

On 13th December, worsening weather conditions across the country (strong winds, frost, wet snow, freezing wires) negatively affected the condition of high-voltage and distribution networks, significantly complicating the work of repair crews.[441]

16 – 26 December

On 16th December, Russia launched a massive attack on the civil infrastructure in Ukraine. According to the General Staff, Russia fired four guided air missiles and 70 cruise missiles, of which 60 were shot down.[442]

Consequences

As a result of the strikes, several energy infrastructure facilities and residential buildings were hit in the regions of Zhytomyr, Kyiv, Kharkiv, Dnipropetrovsk, and Zaporizhzhia.[443]

The main targets were thermal power plants, hydropower plants and transmission system substations with voltage of 330-750 kV. About 50 percent of electricity consumers were disconnected in all regions of Ukraine. The attack also caused significant heat, cold and hot water supply interruptions. Disruptions to the power supply also effected consumers in Moldova.[444]

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[435] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[436] NPC Ukrenergo. Facebook, 2022-12-14. https://www.facebook.com/npcukrenergo/posts/524194893082674

[437] NPC Ukrenergo. Facebook, 2022-12-10. https://www.facebook.com/npcukrenergo/videos/5741560545938492/

[438] NPC Ukrenergo. Facebook, 2022-12-13. https://www.facebook.com/npcukrenergo/posts/523304046505092

[439] NPC Ukrenergo. Facebook, 2022-12-13. https://www.facebook.com/npcukrenergo/videos/922771279129531/

[440] NPC Ukrenergo. Facebook, 2022-12-15. https://www.facebook.com/npcukrenergo/posts/525062236329273

[441] NPC Ukrenergo. Facebook, 2022-12-13. https://www.facebook.com/npcukrenergo/posts/523304046505092

[442] General Staff of the Armed Forces of Ukraine. Facebook, 2022-12-16. https://www.facebook.com/GeneralStaff.ua/posts/484003610579389

[443] Ibid.

[444] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

Measures

Ukrenergo announced a power system emergency. Following the announcement, all trades on the intraday electricity market were suspended.[445] The emergency mode, which was introduced exclusively for the electricity market operations, ended on 16th December at 19:15.[446] Power supply to almost 6 million consumers was restored the next day.[447]

18th December: all power units of the nuclear plants operating in the controlled territory resumed operation. The deficit, due to the drop in temperatures, was significant. There were also restrictions on networks due to damage.[448]

19th December: drone attacks and shelling created a difficult situation is in the central, eastern and Dnipro regions. Emergency shutdowns were introduced in the regions of Sumy, Kharkiv, Poltava, Dnipropetrovsk, Zaporizhzhia, Kirovograd, Zhytomyr, Chernihiv, Cherkasy and Kyiv as well as the city of Kyiv. Power supply to critical infrastructure was prioritised.[449]

20th December: less than half of the consumption needs in Kyiv were provided, with critical infrastructure prioritised.[450]

22nd December: Power was partially restored to 78 percent of damaged high-voltage substations and 62 percent of power lines.[451]

On the morning of 22nd December, there was a significant power deficit in the energy system. There were some restrictions in the power transmission system caused by damage to transmission networks. Consumption limits were provided to all areas. The central region of Kyiv and the frontline regions in the east and south of the country were the hardest hit by power shortages. One more nuclear power plant unit was also reconnected to the network.[452]

On 26th December, it was noted that 9 million people were disconnected in different regions of Ukraine.[453]

29 – 30 December

Attacks

The attacks on 29th December consisted of a series of attacks, starting at night with drones, followed by a massive missile attack in the morning, and then several more attacks with anti-aircraft systems across the Kharkiv and Mykolaiv regions.[454]

[445] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[446] NPC Ukrenergo. Facebook, 2022-12-17. https://www.facebook.com/npcukrenergo/posts/526792552822908

[447] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[448] NPC Ukrenergo. Facebook, 2022-12-18. https://www.facebook.com/npcukrenergo/videos/469888865317606/

[449] NPC Ukrenergo. Facebook, 2022-12-19. https://www.facebook.com/npcukrenergo/posts/528325646002932

[450] NPC Ukrenergo. Facebook, 2022-12-20. https://www.facebook.com/npcukrenergo/posts/529193849249445

[451] NPC Ukrenergo. Facebook, 2022-12-22. https://www.facebook.com/npcukrenergo/videos/932694454378164/

[452] NPC Ukrenergo. Facebook, 2022-12-22. https://www.facebook.com/npcukrenergo/posts/530769502425213

[453] NPC Ukrenergo. Facebook, 2022-12-26. https://www.facebook.com/npcukrenergo/videos/467622472203077/

[454] NPC Ukrenergo. Facebook, 2022-12-29. https://www.facebook.com/npcukrenergo/videos/3702798226617438/

In the early hours of 29th December, Russia struck Kharkiv's energy infrastructure with 13 Shahed-136 drones. The time was likely chosen in order to avoid drone interception and cause maximum damage. Eleven of the 13 drones were shot down.[455]

In the morning, Russia launched a massive missile attack on the whole territory of Ukraine. Air and sea-based cruise missiles and S-300 anti-aircraft missiles were launched at energy and civil infrastructure facilities in the eastern, central, western and southern regions of Ukraine. According to the General Staff of Ukraine, 69 missiles were launched, of which 54 were destroyed by Ukrainian defence forces. Later in the day, there were 10 missile strikes, 23 air strikes, and 14 rocket artillery strikes at the positions of troops and populated areas along the front line.[456]

According to the Task Force, Russian military forces launched 70 missiles in total, 58 of which were intercepted by Ukrainian defence forces.[457]

Consequences

The attacks caused significant damage to the network and some power plants and damaged energy infrastructure facilities in the regions of Kharkiv, Kyiv, Odesa and Ivano-Frankivsk, resulting in the disconnection of about one million consumers in those regions.[458]

Measures

Much of the generating capacity in the system was quickly restored, but due to significant damage, there were limitations in power supply to the regions of Kharkiv, Kyiv, Odesa, Mykolaiv, Kherson and Lviv. Repair crews from Ukrenergo were quickly on site to work on the restoration of networks.[459]

On 30th December, the power deficit in the energy system had returned to the same level as it was prior to the attack. The attack had significantly smaller impact on the operation of the energy system than in previous attacks. However, the situation in the southern and eastern regions remained difficult. Consumption limits remained in all areas.[460]

It should be noted that the damage inflicted by the Russians on 29-30 December, had a significantly lower impact on the energy system compared to the previous nine attacks. The Task Force suggested that this was due to the efficient work of the Ukrainian defence forces.[461]

31 December 2022

Attacks

On New Years Eve, between 12:40 and 14:30, a total of about 20 missiles were launched. Several of them did not reach Ukraine and fell on the territory of the Russian federation. Ukraine destroyed 12 cruise missiles in the regions of Kyiv, Zhytomyr and Khmelnytskyi

[455] General Staff of the Armed Forces of Ukraine. Facebook, 2022-12-29. https://www.facebook.com/GeneralStaff.ua/posts/494217079558042

[456] General Staff of the Armed Forces of Ukraine. Facebook, 2022-12-29. https://www.facebook.com/GeneralStaff.ua/posts/494713089508441

[457] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[458] NPC Ukrenergo. Facebook, 2022-12-29. https://www.facebook.com/npcukrenergo/videos/3702798226617438/ and Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[459] NPC Ukrenergo. Facebook, 2022-12-29. https://www.facebook.com/npcukrenergo/videos/3702798226617438/

[460] NPC Ukrenergo. Facebook, 2022-12-30. https://www.facebook.com/npcukrenergo/posts/536878731814290

[461] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

and in the city of Kyiv, an Orlan-10 drone was shot down.[462] Later in the night Russia launched 45 Shahed-136 drones. All drones were shot down.[463] According to the Task Force, the attack targeted energy infrastructure facilities in Kyiv.[464]

Measures

On New Years Eve, Ukrainian transmission system operators halted consumption restrictions for residential consumers in all regions of Ukraine for the duration of the festivities, despite the emergency in the energy system and the missile attack that very day. This was made was possible by limitations imposed on industry consumption for the same period.[465]

In December, many power units of thermal power plants and combined heat and power plants were under emergency repair or could not operate due to damage to the power grid, which significantly reduced the ability to transmit electricity to consumers. Due to the temporary disconnection of nuclear power plants from the grid, Ukraine increased the power generation by coal-fired thermal power plants and hydropower plants. The latter used water stored in reservoirs for emergencies.[466]

The average Ukrainian household experienced five cumulative weeks without power, from 10th October to the end of December 2022.[467]

January 2023

Power deficit remained at 20-30 percent, with continuing emergency measures in place. Import of electricity began. From 21st December 2022 to 24th January 2023, almost all electricity consumers had been temporarily disconnected from the power supply at some point.[468] It resulted in the continuation of emergency measures, i.e. rolling shutdowns and restrictions on electricity consumption for industrial consumers and households.

1-10 January

Attacks

On New Year's Day, Russia carried out 35 airstrikes, including Shahed-136 drones, all of which were shot down, according to the General Staff.[469]

[462] General Staff of the Armed Forces of Ukraine. Facebook, 2022-12-31. https://www.facebook.com/GeneralStaff.ua/posts/496154006031016

[463] General Staff of the Armed Forces of Ukraine. Facebook, 2023-01-01. https://www.facebook.com/GeneralStaff.ua/posts/496671452645938 and NPC Ukrenergo. Facebook, 2023-01-01. https://www.facebook.com/npcukrenergo/posts/538454334990063

[464] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[465] NPC Ukrenergo. Facebook, 2022-12-31. https://www.facebook.com/vladimir.kudrytskyi/posts/6176633692369610 and Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[466] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment V. 2022.

[467] The World Bank, the Government of Ukraine, the European Union, the United Nations. Ukraine - rapid damages and needs assessment.

[468] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

[469] General Staff of the Armed Forces of Ukraine. Facebook, 2023-01-01. https://www.facebook.com/GeneralStaff.ua/posts/497066729273077

On the night between the 1st and 2nd of January, Russia carried out a strike with 39 Shahed-136 drones. All of which were shot down, again according to the General Staff.[470]

On 2nd January, Russia launched missiles and 28 air strikes. 27 Shahed-136 drones were launched against civilian infrastructure. All were shot down.[471] According to the Task Force, the attack on January 2 was again launched during the night, probably to avoid interception and thus cause maximum damage.[472]

Consequences

Attacks on 2nd January targeted energy infrastructure facilities in the city of Kyiv. This had a significant negative impact on the power supply in that same area. Emergency shutdowns were introduced and a large number of consumers remained without heat supply.[473]

Other

On 2nd January, Ukrenergo stated that the situation in the energy system was fully under control. Warm weather contributed to reduced consumption and the need for daytime restrictions decreased.[474]

From 4th January, due to colder weather, daytime consumption limits were again required in order to balance the power system in all regions of Ukraine. At night time, power generation was deemed adequate.[475]

On 10th January, electricity consumption in Ukraine increased due to low temperatures, reinforced by strong winds in most regions, as well as increased consumption by industry and businesses. As a result, the power deficit increased, including at nighttime. To ensure balance in the energy system, consumption limits were applied for a full 24 hours. In the areas where the limits were exceeded, emergency shutdowns were applied. In some regions, adverse weather conditions (gusty winds) caused damage to the distribution networks.[476]

14 – 24 January

Attacks

On 14th January, Russia launched a total of 3 air strikes and about 50 missile strikes according to the General Staff. Kyiv was attacked by anti-aircraft missiles (S-400/S-300) from the north, in the morning. This was followed by a total of about 28 cruise missiles of various types and five guided aircraft missiles, targeting critical infrastructure.

The General Staff stated that of these, Ukrainian forces destroyed 18 cruise missiles and three guided aircraft missiles.[477]

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[470] General Staff of the Armed Forces of Ukraine. Facebook, 2023-01-02. https://www.facebook.com/GeneralStaff.ua/posts/497432822569801

[471] General Staff of the Armed Forces of Ukraine. Facebook, 2023-01-02. https://www.facebook.com/GeneralStaff.ua/posts/497771375869279

[472] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[473] Ibid.

[474] NPC Ukrenergo. Facebook, 2023-01-02. https://www.facebook.com/npcukrenergo/posts/539111064924390 and NPC Ukrenergo. Facebook, 2023-01-03. https://www.facebook.com/npcukrenergo/posts/539763751525788

[475] NPC Ukrenergo. Facebook, 2023-01-04. https://www.facebook.com/npcukrenergo/posts/540445758124254

[476] NPC Ukrenergo. Facebook, 2023-01-10. https://www.facebook.com/npcukrenergo/posts/544255437743286

[477] General Staff of the Armed Forces of Ukraine. Facebook, 2023-01-14. https://www.facebook.com/GeneralStaff.ua/posts/506677118312038

Information released by the Air Force command, stated that 25 out of 38 missiles were destroyed by Ukrainian forces.[478]

Consequences

Energy facilities in six regions were damaged: Kharkiv, Lviv, Ivano-Frankivsk, Zaporizhzhia, Vinnitsia and Kyiv. Two thermal power plants were attacked, one of which completely suspended the power production due to the destruction of its turbine and other units. The attack led to reductions in power generation and an increased deficit in the power system.[479] According to Ukrenergo, several thermal power units were significantly damaged.[480]

Measures

Ukrenergo reduced consumption limits for all DSOs in Ukraine. New emergency outages were introduced in many regions.[481] Limits were exceeded in 11 areas, where emergency disconnections were applied as a result.[482]

On 17th January, there was a significant power deficit in the power system, especially during the morning and evening consumption peaks. Due to exceeded limits, emergency blackouts were applied in Kharkiv, Donetsk, Dnipropetrovsk, Kyiv, Zaporizhzhia and Kirovograd.[483]

On 24th January, while power production increased slightly, the power deficit was significant. By restoring a 330 kV line, the reliability of power supply of one of the power plants in the southeast of the country increased.[484]

Other

Adverse weather conditions (gusty winds, freezing wires) in the central regions led to local outages in the distribution networks.[485]

26 – 30 January

Attacks

On 26th January, Russia carried out 37 air strikes, of which 17 were Shahed-136 drones. All the drones were shot down. Later on, 59 missiles were launched, 47 of which were destroyed. There were also 53 attacks from rocket artillery. Ukrainian forces shot down three reconnaissance drones during the day.[486] In addition to drones and long-range missiles, there were short-range missile strikes (using S-300 anti-aircraft missile systems) on critical infrastructure facilities in the Zaporizhzhia region.[487]

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[478] Air Force Command of UA Armed Forces. Facebook, 2023-01-14. https://www.facebook.com/kpszsu/posts/551326907035262

[479] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[480] NPC Ukrenergo. Facebook, 2023-01-18. https://www.facebook.com/npcukrenergo/posts/549760080526155

[481] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VI. 2023.

[482] NPC Ukrenergo. Facebook, 2023-01-14. https://www.facebook.com/npcukrenergo/posts/547068310795332

[483] NPC Ukrenergo. Facebook, 2023-01-17. https://www.facebook.com/npcukrenergo/posts/549025663932930

[484] NPC Ukrenergo. Facebook, 2023-01-24. https://www.facebook.com/npcukrenergo/posts/553759910126172

[485] NPC Ukrenergo. Facebook, 2023-01-17. https://www.facebook.com/npcukrenergo/posts/549025663932930

[486] General Staff of the Armed Forces of Ukraine. Facebook, 2023-01-26. https://www.facebook.com/GeneralStaff.ua/posts/515049824141434

[487] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

Consequences

Energy infrastructure facilities were simultaneously targeted in different regions of Ukraine. Critical energy infrastructure facilities in Kyiv, Odesa and other regions were damaged. Powerful explosions occurred outside of the Zaporizhzhia nuclear power plant causing a significant threat to the plant.[488] The deficit in Ukraine's power system reached 5 GW which was equal to the total installed capacity of two NPPs, i.e. Khmelnytska (2 GW) and Pivdennoukrainska (South Ukraine, 3 GW). Worst hit by emergency power outages were the Kyiv, Odesa and Dnipropetrovsk regions.[489]

Measures

Emergency shutdowns were introduced throughout Ukraine during the attack, as the deficit in the system was significant. Consumption limits were set in all areas.[490] Later the same day, Volodymyr Kudrytskyi stated that: "At the moment we have already stabilised the situation in the energy system. The biggest problems remain only in the Odesa region. Critical infrastructure is repaired there and we are working together with the DSO to reconnect and provide power to consumers. In other regions of the country, the situation is already stabilised. We switched to scheduled restrictions. Several main substations were affected today."[491]

The extensive damage caused delays to the restoration of power in the Odesa region. Emergency shutdowns therefore continued in that region.[492] On 30th January, the deficit in the energy system was significant. Several power units were taken out for repair over the weekend.[493]

Other

As a result of the massive attacks and the damage to the power system, the Ukrainian Government decided to start electricity import from January 2023.[494]

February 2023

From the end of October to the beginning of February, an average of 12 million Ukrainians per hour remained without light.[495]

In the beginning of February, the generating capacity in the system was enough to cover about 80 percent of consumer needs. Generation loss was compensated by taking one of the power plant units back in commission and increasing power production by hydroelectric plants and network restrictions were only applied in the Odesa region.[496] Ukrenergo repair crews restored functionality of key equipment in substations in eastern and southern regions.[497]

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[488] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[489] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[490] NPC Ukrenergo. Facebook, 2023-01-26. https://www.facebook.com/npcukrenergo/posts/555310623304434

[491] NPC Ukrenergo. Facebook, 2023-01-26. https://www.facebook.com/npcukrenergo/videos/845811073155831/

[492] NPC Ukrenergo. Facebook, 2023-01-28. https://www.facebook.com/npcukrenergo/posts/556704883165008

[493] NPC Ukrenergo. Facebook, 2023-01-30. https://www.facebook.com/npcukrenergo/posts/558180859684077

[494] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[495] NPC Ukrenergo. Facebook, 2023-02-23. https://www.facebook.com/npcukrenergo/posts/576589417843221

[496] NPC Ukrenergo. Facebook, 2023-02-02. https://www.facebook.com/npcukrenergo/posts/560378862797610

[497] NPC Ukrenergo. Facebook, 2023-02-03. https://www.facebook.com/npcukrenergo/posts/561128456055984

4 – 9 February

In several missile attacks, Russia seemed to deliberately target the entire high-voltage infrastructure in the Odesa region. All high-voltage substations in the region were significantly affected and there was extensive damage.[498]

On 4th February, two large-scale accidents occurred at the high-voltage substation in the Odesa region. As a result of the accident, the whole city of Odesa and parts of the Odesa region (about 500,000 consumers) were completely disconnected from the power supply.[499]

Measures

Together with Odesa Regional Military Administration and the DSO, Ukrenergo specialists developed backup schemes for bringing power back to Odesa and surrounding areas.[500]

On 5th February, energy supply to over 200,000 consumers were restored in the Odesa region. Ukrenergo focused on one particular facility, with five emergency crews working 24/7. This measure restored power supply to Odesa and the Odesa district.[501]

On 7th February, electricity was imported. The amount of power produced was still insufficient to cover the full consumption.[502]

On 9th February, the situation significantly improved and increasing volumes of electricity were provided to Odesa and the Odesa district, as repairs were completed faster than expected.[503]

Electricity consumption remained high, due to colder weather.[504]

10 – 14 February

Attacks

Russia launched over 100 missiles during another missile attack, lasting from 21:50 on 9th February to 12:00 on 10th February. According to the Ukrainian General Staff, the attacks consisted of 29 anti-aircraft guided missiles (S-300) and 71 air and sea-based cruise missiles, of which 61 were destroyed by Ukrainian forces. There were also 20 attacks from rocket artillery and five Shahed-136 drones were reportedly shot down.[505]

According to the Task Force, Russia used 35 short-range missiles (S-300). The Task Force stated that this was the largest number of this type of missiles launched during a single attack since the beginning of Russia's full-scale invasion on 24th February 2022. In

[498] NPC Ukrenergo. Facebook, 2023-02-04. https://www.facebook.com/npcukrenergo/posts/561906009311562

[499] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023, and NPC Ukrenergo. Facebook, 2023-02-05 https://www.facebook.com/npcukrenergo/posts/562744512561045

[500] NPC Ukrenergo. Facebook, 2023-02-04. https://www.facebook.com/npcukrenergo/posts/561918502643646

[501] NPC Ukrenergo. Facebook, 2023-02-05. https://www.facebook.com/npcukrenergo/posts/562744512561045

[502] NPC Ukrenergo. Facebook, 2023-02-07. https://www.facebook.com/npcukrenergo/posts/564179522417544

[503] NPC Ukrenergo. Facebook, 2023-02-09. https://www.facebook.com/npcukrenergo/videos/914035339792548/

[504] NPC Ukrenergo. Facebook, 2023-02-09. https://www.facebook.com/npcukrenergo/posts/565712928930870

[505] Air Force Command of UA Armed Forces. Facebook, from 2023-02-10. https://www.facebook.com/kpszsu/posts/570698085098144 and General Staff of the Armed Forces of Ukraine. Facebook, 2023-02-10. https://www.facebook.com/GeneralStaff.ua/posts/527026892943727

addition to the massive missile and drone attack, there was heavy shelling by Russia on the regions located near the frontline.[506]

In the evening of 10th February 2023, Russia attacked critical infrastructure in several regions. Ukraine intercepted 20 Shahed-136 drones.[507]

On 11th February, there were 17 drone attacks in the southern and southeast regions. Thermal power plants and objects in the transmission system were targeted.[508]

Consequences

Eastern, western and southern regions of Ukraine were hit.[509] Some hydropower capacities, at least four thermal power plants (two of them were targeted again on the evening of 10th February), and high-voltage infrastructure facilities in six regions were damaged.[510]

As a result of shellings, energy infrastructure facilities were damaged in the Zaporizhzhia, Dnipropetrovsk and Kharkiv regions. In the Kharkiv region, the attack resulted in the disconnection of about 150 thousand consumers from the power grid.[511]

Measures

Emergency shutdowns were applied. Network restrictions were already in effect in Khmel Xnič region and continued in Odesa and Kyiv. The deficit in the energy system was significant.[512]

Backup schemes were used to quickly restore consumer access to power after the attack on 11th February. Emergency shutdowns were applied in Kharkiv. As consumption increased, emergency shutdowns were used in Khmelnytsky, Zhytomyr, Kyiv region and Kyiv city.[513]

Two out of three operating Ukrainian nuclear power plants, Rivnenska and Pivdennoukrainska (South Ukraine), reduced power output as a precautionary measure due to the attack on energy infrastructure. The instability in the power grid due to the massive attack also caused an emergency shutdown of one of the Khmelnytska nuclear power plant reactor units.[514]

On 12th February, two nuclear power units were in use. There was no power shortage and consumption limits were not exceeded.[515] In Odesa, the power supply was almost completely restored. Only small consumption restrictions still applied in the city and the Odesa district.[516]

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[506] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[507] Air Force Command of UA Armed Forces. Facebook, 2023-02-11. https://www.facebook.com/kpszsu/posts/571301551704464

[508] NPC Ukrenergo. Facebook, 2023-02-11. https://www.facebook.com/npcukrenergo/posts/567243905444439

[509] NPC Ukrenergo. Facebook, 2023-02-10. https://www.facebook.com/npcukrenergo/posts/566561792179317

[510] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[511] Ibid.

[512] NPC Ukrenergo. Facebook, 2023-02-10. https://www.facebook.com/npcukrenergo/posts/566561792179317 and Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[513] NPC Ukrenergo. Facebook, 2023-02-11. https://www.facebook.com/npcukrenergo/posts/567243905444439

[514] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[515] NPC Ukrenergo. Facebook, 2023-02-12. https://www.facebook.com/npcukrenergo/posts/567944805374349

[516] NPC Ukrenergo. Facebook, 2023-02-12. https://www.facebook.com/npcukrenergo/videos/849990156105548/

On 13th February, there was no power deficit in the energy system. Additional power units at several thermal power plants increased the power production in the energy system. Repairs of the grid were prioritised in order to eliminate bottlenecks.[517]

Other
Due to rising water levels, hydroelectric stations were in extensive use. Increasing daylight and clear weather also contributed to generation from renewable energy. Import of electricity from Slovakia continued.[518]

On 14th February, the European Energy Association ENTSO-E decided to increase the technical capacity of the import of electricity to Ukraine to 700 MW at any time. Previously, the maximum possible import from Europe was 700 MW at night and 600 MW in daytime.[519]

16 February

Attacks
Defence forces shot down 16 out of 36 missiles launched in an attack against Ukraine. There were also 12 air strikes and more than 10 rocket artillery attacks, killing and wounding civilians.[520]

Consequences
The attack targeted Ukrainian energy infrastructure. Multiple missiles hit Kremenchuk and Drohobych oil refinery plants although both plants were out of commission at that time. In addition to the large refineries and other energy facilities, the attack also targeted mini refineries, of which one (in the Kyrovograd region) was damaged.[521]

Other
On 16th February, all types of power plants in the energy system were in operation, with thermal and hydro power generation providing coverage during peak consumption periods in the morning and evening hours. The import of electricity declined as power supply in the country stabilised.[522]

18 – 28 February

Attacks
On 18th February, Russia launched 16 missile strikes, focusing on the civilian infrastructure of the city of Khmelnytskyi and Ukrains`k of the Donetsk region. In these attacks, Russian forces also carried out four air strikes and more than 30 rocket artillery attacks.

[517] NPC Ukrenergo. Facebook, 2023-02-13. https://www.facebook.com/npcukrenergo/posts/568711941964302

[518] NPC Ukrenergo. Facebook, 2023-02-13. https://www.facebook.com/npcukrenergo/posts/568711941964302

[519] NPC Ukrenergo. Facebook, 2023-02-16. https://www.facebook.com/npcukrenergo/posts/571019168400246

[520] General Staff of the Armed Forces of Ukraine. Facebook, 2023-02-16 https://www.facebook.com/GeneralStaff.ua/posts/531546495825100

[521] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[522] NPC Ukrenergo. Facebook, 2023-02-16. https://www.facebook.com/npcukrenergo/posts/571024265066403

Ukrainian defence forces destroyed two of the Kalibr cruise missiles.[523] Two long-range missiles flew over the Pivdennoukrainska (South Ukraine) nuclear power plant (3GW), constituting a threat to the safe operation.[524]

On 21st February, Russian forces attacked energy infrastructure facilities in the Kherson region. As a result, multiple towns and settlements in the Kherson region were disconnected from the power supply.[525]

On the morning of 28th February, there was 86 shelling attacks in the Kherson region.[526]

Measures

Ukrenergo applied preventive disconnections to minimise the possible consequences of the attack on 18th February. After the attack, the power plants returned to normal, with capacity enough to cover the consumption fully. However, network restrictions caused by significant damage were still in effect in Odesa. Therefore, to avoid equipment overload, hourly shutdown schedules applied. In the Kyiv region, consumption restrictions applied certain hours, due to network restrictions.[527]

On 23rd February, power had returned to the whole of Ukraine. The high pace of repairs and equipment support from Western partners allowed for quick restoration of power and enabled workers to stabilise the energy system.[528]

On 26th February, restrictions in transmission networks were removed in the Odesa region, but scheduled shutdowns continued.[529]

Shelling on the morning on 28th February, left 26,000 consumers disconnected from the power supply in the Kherson region.[530]

In Kharkiv and Sumy regions, there was damage to distribution networks and disruption of settlements. All energy facilities that were previously damaged underwent repairs to restore their functionality and increase the reliability of power supply.[531]

Other

Due to favorable weather conditions and the gradual increase of daylight, the operation of renewable power plants increased, partly participating in the coverage of the morning peak consumption. Electricity imports were insignificant and approaching zero levels as a result of the stabilization of power supply in the country.[532]

On 27th February, an accident occurred at a high-voltage line in the Odesa region. As a result, the city of Odesa and the whole region were temporarily disconnected from the power supply.[533] According to Ukrenergo this was due to increased consumption, which

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[523] General Staff of the Armed Forces of Ukraine. Facebook, 2023-02-18. https://www.facebook.com/GeneralStaff.ua/posts/532950652351351

[524] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VII. 2023.

[525] Ibid.

[526] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[527] NPC Ukrenergo. Facebook, 2023-02-18. https://www.facebook.com/npcukrenergo/posts/572551538247009

[528] NPC Ukrenergo. Facebook, 2023-02-23. https://www.facebook.com/npcukrenergo/posts/576589417843221

[529] NPC Ukrenergo. Facebook, 2023-02-26. https://www.facebook.com/npcukrenergo/posts/578697430965753

[530] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[531] NPC Ukrenergo. Facebook, 2023-02-28. https://www.facebook.com/npcukrenergo/posts/580309680804528

[532] NPC Ukrenergo. Facebook, 2023-02-20. https://www.facebook.com/npcukrenergo/posts/574031851432311

[533] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

the damaged network was unable to handle. There was an emergency shutdown of certain elements of the transmission system in the region. Repair crews quickly began working to eliminate damage and restore energy supply.[534] Power was restored by temporary schemes the same evening.[535]

March 2023

In March 2023, Russia increased its military formations at Zaporizhzhia nuclear power plant, interfered with the plant's heating and power supply systems, constructed unauthorised structures on the plant's territory and stole equipment. Further increasing the risk of the situation, the plant faced a shortage of professional personnel as a result of the Russian occupation and repercussions against workers who refused to sign contracts with pro Kremlin organisations.[536]

Ukrenergo decreased the number of updates on the power system to three per week.[537]

1 – 8 March

Attacks

The 1st of March saw massive shelling in many regions.

Consequences

Power supply restrictions were introduced in Kharkiv, Poltava, and Sumy regions. High-voltage power lines were damaged in the Sumy region.[538]

On 3rd March, there were no network restrictions in the Ukrenergo networks. In Donetsk, there was damage in the networks of the distribution system.[539]

Measures

Repair work on power facilities in the Odesa region started on Sunday 5th March in order to increase the power reliability.[540] From 7th March, no restrictions were planned in Odesa.[541]

9 – 30 March

On 9th March, The General Staff reported that Russian forces launched a total of 84 missiles of various types. 34 missiles were destroyed by Ukrainian forces, another 8 did not hit their targets. Russia launched 12 air strikes. 8 Shahed-136 drones, half of which were shot down, were also used.[542]

The Task Force reported that there had been a change in the Russian tactic, with Russia using different types of missiles, i.e. air-based and sea-based missiles, including cruise

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[534] NPC Ukrenergo. Facebook, 2023-02-27. https://www.facebook.com/npcukrenergo/posts/579576057544557

[535] NPC Ukrenergo. Facebook, 2023-02-28. https://www.facebook.com/npcukrenergo/posts/580309680804528

[536] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[537] NPC Ukrenergo. Facebook, 2023-03-06. https://www.facebook.com/npcukrenergo/posts/584167783752051

[538] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[539] NPC Ukrenergo. Facebook, 2023-03-03. https://www.facebook.com/npcukrenergo/posts/582217913947038

[540] NPC Ukrenergo. Facebook, 2023-03-04. https://www.facebook.com/npcukrenergo/posts/582903330545163

[541] NPC Ukrenergo. Facebook, 2023-03-05. https://www.facebook.com/npcukrenergo/posts/583509427151220

[542] General Staff of the Armed Forces of Ukraine. Facebook, 2023-03-09. https://www.facebook.com/GeneralStaff.ua/posts/545648387748244

missiles Kh- 22 and Kh-47 ”Kinzhal”. In the pause between the missile waves, Russia also launched at least 8 drones.[543]

Russian military forces launched near daily attacks on the energy infrastructure facilities in the frontline regions, using artillery and rocket launcher systems, thus causing shutdowns and restrictions.[544]

Consequences

Simultaneous attacks targeted energy infrastructure facilities in ten Ukrainian regions. Three thermal power plants were damaged, as well as a number of substations. The last overhead line supplying power to Zaporizhzhia nuclear power plant was damaged.[545]

Measures

All nuclear power plants were forced to reduce their power generation and the government of Ukraine introduced new restrictions preventively in all regions to reduce risks. As a result of shellings, Zaporizhzhia nuclear power plant worked on diesel generators for several hours. Restrictions were applied in Zhytomyr, Kharkiv and Odesa regions.[546] The energy supply of the Zaporizhzhia nuclear power plant was restored later the same day.[547]

On 10th March, some consumers in Zhytomyr and Kharkiv were still left without power due to damage and scheduled shutdowns. The critical infrastructure of these cities worked mainly from autonomous power sources. Consumption was covered by existing power production.[548]

On 11th March, power returned to all consumers of the Zhytomyr region. Hourly shutdown schedules continued to operate in the morning and evening hours of peak consumption. In Kharkiv, the energy supply of critical infrastructure and household consumers had also been restored. Unfortunately, due to network restrictions there were stabilization outages in some areas in Kyiv. Power supply was fully restored in Odesa and the Odesa region, but hourly outages continued when the load increased during peak hours.[549]

Due to the consequences of shelling, restrictions in certain areas of the Dnipropetrovsk and Mykolaiv regions remained. At 17:00 the same day, network restrictions, and stabilisation shutdowns were lifted in Kyiv.[550]

Following attacks on 9th March, there were restrictions on consumption due to damaged networks, mainly in Zhytomyr, Kharkiv and Kyiv, which continued for the rest of the month. Emergency shutdowns were also used when consumption increased above manageable levels. In the rest of Ukraine, there were no general restrictions.

On 30th March, restrictions on the main networks for the city of Kyiv as well as the region of Kyiv were lifted after completed restoration work on one of the energy facilities.[551]

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[543] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023.

[544] Ibid.

[545] Ibid. and NPC Ukrenergo. Facebook, 2023-03-09. https://www.facebook.com/npcukrenergo/videos/214839174435250/

[546] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment VIII. 2023, and NPC Ukrenergo. Facebook, 2023-03-09. https://www.facebook.com/npcukrenergo/posts/586124236889739

[547] NPC Ukrenergo. Facebook, 2023-03-09. https://www.facebook.com/npcukrenergo/posts/586305093538320

[548] NPC Ukrenergo. Facebook, 2023-03-10. https://www.facebook.com/npcukrenergo/posts/586847866817376

[549] NPC Ukrenergo. Facebook, 2023-03-11. https://www.facebook.com/npcukrenergo/posts/587464510089045

[550] Ibid.

[551] NPC Ukrenergo. Facebook, 2023-03-30. https://www.facebook.com/npcukrenergo/posts/599156545586508

Other
On 27th March, Ukrenergo and ENTSO-E increased the technical possibility of importing electricity from the Continental Europe zone to Ukraine and Moldova from 700 to 850 MW at any hour of the day.[552]

Due to adverse weather conditions, restrictions were introduced in west and southern Ukraine on 28th March, in most of central Ukraine on 29th March, and in Northern Ukraine on 30th March.[553]

April 2023

In April, over 10 GW of installed generation capacity was under Russian control and thus unavailable to the Ukrainian energy system. This included the Zaporizhzhia nuclear power plant, as well as a number of thermal power plants and most wind and solar power plants.[554] Russia continued to increase their military presence at the Zaporizhzhia plant. On 21st April 2023, the IAEA once again raised concerns related to the protection of the plant. IAEA Director General Rafael Mariano Grossi stated that:"At a time of growing speculation about military offensives and counter-offensives in the region, it is more important than ever to agree that a nuclear power plant should never be attacked, nor used to launch attacks from".[555]

Ukraine continued importing small volumes of electricity as well as started exporting electricity to European countries.

At the end of April, the annual repair of power plants began. This is a long-standing routine, in order to prepare for the winter period. Hydroelectric power plants and renewable energy sources normally compensate for the repair of power units.[556]

1-12 April

Consequences
One of the thermal power plants stopped generating power due to Russian attacks on the power system. Detailed information on the damage was restricted.[557]

Measures
2nd April: repair crews of Ukrenergo completed emergency restoration work on the power system of the central region. All consumption restrictions imposed in the regions of Kyiv, Zhytomyr and Kharkiv (due to damage to equipment from the missile attack on 9th March) were lifted. There were no restrictions in the transmission networks in other regions either.[558]

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[552] NPC Ukrenergo. Facebook, 2023-03-29. https://www.facebook.com/npcukrenergo/posts/598637748971721

[553] NPC Ukrenergo. Facebook, 2023-03-28. https://www.facebook.com/npcukrenergo/posts/597943092374520, NPC Ukrenergo. Facebook, 2023-03-29. https://www.facebook.com/npcukrenergo/posts/598501518985344 and NPC Ukrenergo. Facebook, 2023-03-30. https://www.facebook.com/npcukrenergo/posts/599156545586508

[554] NPC Ukrenergo. https://www.facebook.com/npcukrenergo/ 2023-04-20. https://www.facebook.com/npcukrenergo/videos/1280187236269442/

[555]Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023, and International Atomic Energy Agency. Update 153 – IAEA Director General Statement on Situation in Ukraine. https://www.iaea.org/newsCentre/pressreleases/update-153-iaea-director-general-statement-on-situation-in-ukraine

[556] NPC Ukrenergo. Facebook, 2023-04-26. https://www.facebook.com/npcukrenergo/posts/616273253874837

[557] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment IX. 2023.

[558] NPC Ukrenergo. Facebook, 2023-04-02. https://www.facebook.com/npcukrenergo/posts/600964238739072

3rd April: the power supply was limited in regions along the frontline, where there was constant Russian shelling, resulting in damage to power grids.[559]

5th April: Ukrenergo asked consumers to consume electricity sparingly, including, whenever possible, distributing the use of powerful devices evenly throughout the day.[560]

12th April: Five main lines were restored and the equipment of nine substations of different voltage classes were partially restored.[561]

17th April: The situation with faltering energy supply along the front line continued. Due to damage to the networks by Russian shelling, power supply in Kherson was temporarily disrupted. Energy workers quickly restored power.[562]

Other

11th April: Ukraine starts exporting electricity again.[563]

On 12th April, power production fully met consumer needs and electricity was exported to Moldova (30-95 MW in different hours), and to Poland (up to 75 MW in different hours). Hydroelectric power generation covered peak consumption in the morning and evening. During some periods, the share of hydroelectric power in the production was about 20 percent, replacing part of heat generation. To avoid large-scale flooding of settlements along the rivers, controlled water discharges were carried out at Ukrhydroenergo hydroelectric stations.[564]

28 April

Attacks

Russia launched a total of 23 X-101 and X-555 cruise missiles targeting the cities of Uman (Cherkasy region), Dnipro, and Ukrainka (Kyiv region). Ukrainian forces destroyed 21 cruise missiles and 2 drones.[565]

Consequences

One of the generation facilities and its equipment was damaged in the Donetsk region.[566] The morning attack on 28th April did not damage the energy infrastructure and did not lead to the necessity of consumption restrictions. However, the situation in eastern Ukraine remained difficult, where energy infrastructure had received damage.[567]

Measures

As of 28th April, the power production was sufficient to cover consumption. Hydropower plants continued to work, not only to cover consumption peaks in the morning and evening, but also throughout the day.[568]

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[559] NPC Ukrenergo. Facebook, 2023-04-03. https://www.facebook.com/npcukrenergo/posts/601549742013855

[560] NPC Ukrenergo. Facebook, 2023-04-05. https://www.facebook.com/npcukrenergo/posts/602786401890189

[561] NPC Ukrenergo. Facebook, 2023-04-12. https://www.facebook.com/npcukrenergo/posts/606986504803512

[562] NPC Ukrenergo. Facebook, 2023-04-17. https://www.facebook.com/npcukrenergo/posts/610127304489432

[563] NPC Ukrenergo. Facebook, 2023-04-10. https://www.facebook.com/npcukrenergo/posts/605816584920504

[564] NPC Ukrenergo. Facebook, 2023-04-14. https://www.facebook.com/npcukrenergo/posts/608221538013342

[565] General Staff of the Armed Forces of Ukraine. Facebook, 2023-04-28. https://www.facebook.com/GeneralStaff.ua/posts/575309818115434

[566] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment X. 2023.

[567] NPC Ukrenergo. Facebook, 2023-04-28. https://www.facebook.com/npcukrenergo/posts/617483643753798

[568] NPC Ukrenergo. Facebook, 2023-04-28. https://www.facebook.com/npcukrenergo/posts/617483643753798

Other

In April 2023, Ukrenergo published the preliminary estimates of the company's damage and losses in the Kharkiv, Donetsk and Lugansk regions as a result of the Russian aggression.[569]

May 2023

Power distribution networks suffered severe damage affecting multiple regions. The desynchronisation of the energy system in late May affected some 2 million consumers. Technical issues caused shutdowns, but power was restored quickly.

In an analysis by UK Defence Intelligence, it was noted that the Russian missile strikes on Ukraine that took place on 28th April and 1st May were the first such attacks since 9th March. The report by UK Defence Intelligence noted that a smaller number of missiles was used in both strikes than in previous missile strikes, which "is likely due to Russian attempts to rebuild its air-launched cruise missile stockpiles". "The observed types of facilities damaged by the Russian strikes indicates a possible shift away from targeting Ukraine's electrical power network. Both recent strikes were likely focused on Ukraine's military, industrial and logistical infrastructure," according to the report.[570]

1 May

Attacks

On 1st of May, there were 19 missile strikes, 13 air strikes and 13 launched rounds from rocket artillery. Russia deployed Tu-95 and Tu-160 strategic bombers to launch Kh-101 and Kh-555 missiles.[571] Ukraine destroyed 15 cruise missiles of the Kh-101 and Kh-555 types.[572]

Consequences

According to Ukrenergo, the attack did not damage the power transmission system and did not lead to the necessity of consumption restrictions.[573] However, the attack caused significant damage to the power distribution networks. As a result of the attack, a part of Dnipro city and the Dnipropetrovsk region were disconnected from the power supply. More than 18,000 consumers in Kherson city and its region were also disconnected due to multiple shellings.[574]

18 May

Attacks

Russia carried out 36 missiles and 23 air strikes, as well as about 30 shellings across the positions of troops and settlements. Ukraine destroyed 21 missiles and seven

[569] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment X. 2023.

[570] Ukrainska Pravda. UK Intelligence assesses Russia's latest missile strikes on Ukraine, and Ministry of Defence. Intelligence Update. Twitter. 2023-04-29. https://twitter.com/DefenceHQ/status/1652188434184695812/photo/1

[571] Ukrainska Pravda. UK Intelligence assesses Russia's latest missile strikes on Ukraine.

[572] General Staff of the Armed Forces of Ukraine. Facebook, 2023-05-01. https://www.facebook.com/GeneralStaff.ua/posts/577201281259621

[573] NPC Ukrenergo. Facebook, 2023-05-01. https://www.facebook.com/npcukrenergo/posts/619509466884549

[574] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment X. 2023.

reconnaissance aircraft of different types.[575] The attack targeted the entire Ukrainian territory, and energy facilities were damaged.[576]

Consequences

The transmission network was not damaged but shelling caused damage to the distribution systems, especially in Khmelnytskyi. In the border and frontier territories, energy supply in the regions of Kherson, Mykolaiv, Kharkiv, Donetsk and Zaporizhzhia was disrupted due to intense shelling.[577]

Other

The power production was sufficient to cover consumption. At night and day hours, when the energy system had excess capacity and reduced consumption, export to Moldova and Poland continued.[578]

22 May

Attacks

Russia launched another massive missile and air strike attack against the civilian and critical infrastructure of Ukraine. This included the use of 21 missiles on the cities of Dnipro, Zaporizhzhia and populated areas of the Kharkiv region, using four Kh-101/Kh-555 air-launched cruise missiles (which were all destroyed), five Kh-22 cruise missiles, two Iskander-M ballistic missiles, five S-300 anti-aircraft guided missiles and four "others". Russia also carried out 42 airstrikes which included the use of 21 Shahed 136 drones. All drones were destroyed. There were also about 50 rocket artillery attacks on Ukrainian settlements and Ukrainian defence forces.[579]

Consequences

In the attack on 22nd May, the power grid was damaged in several regions. Twenty-four settlements in the Dnipropetrovsk region were disconnected from the power supply due to damage to 330-750 kV high-voltage lines, leading to the shutdown of one of the powerful power plants in the region. More than 246,000 consumers were also disconnected in the Zaporizhzhia region as a result of damage to the power system and substations.[580]

Measures

Due to damage to the last high-voltage line, Zaporizhzhia nuclear power plant was disconnected from the power system and ran on diesel generators. This was the seventh time since the beginning of the war.[581] Ukrenergo restored the power to the nuclear plant.

Despite the attack, the produced power was sufficient to meet the needs of consumers. Energy companies restored energy supply to consumers under backup schemes.[582]

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[575] General Staff of the Armed Forces of Ukraine. Facebook, 2023-05-18. https://www.facebook.com/GeneralStaff.ua/posts/588486633464419

[576] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment X. 2023.

[577] NPC Ukrenergo. Facebook, 2023-05-18. https://www.facebook.com/npcukrenergo/posts/630417749127054

[578] Ibid.

[579] General Staff of the Armed Forces of Ukraine. Facebook, 2023-05-22. https://www.facebook.com/GeneralStaff.ua/posts/591217346524681

[580] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment X. 2023, and NPC Ukrenergo. Facebook, 2023-05-22. https://www.facebook.com/npcukrenergo/posts/633193952182767

[581] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment X. 2023.

[582] NPC Ukrenergo. Facebook, 2023-05-22. https://www.facebook.com/npcukrenergo/posts/633193952182767

Other

Export of electricity to Moldova and Poland continued.[583]

28 May

Russia launched a total of 97 air strikes, including 59 Shahed-136 drones. 58 of these were intercepted. There were also 39 rocket artillery attacks at the positions of Ukrainian troops and various settlements.[584] The attack did not cause any damage to the power transmission system, according to Ukrenergo.[585]

29 May

Russia attacked military objects and critical infrastructure objects with up to 40 missiles and 38 drones. 36 missiles and 30 drones were destroyed. Later the same day Russia launched 11 Iskander missiles on Ukraine. All missiles were destroyed.[586] Ukrenergo reported no new damage.[587]

30 May

Attacks

Russia carried out another massive airstrike on the territory of Ukraine, in particular, on Kyiv, using 31 Shahed-136 drones, of which 29 were destroyed. There was some damage to the infrastructure. Russian forces launched 44 air strikes and one missile strike and launched about 20 rocket artillery attacks on Ukrainian settlements and Ukrainian defence forces.[588]

Consequences

The Ukrainian energy system was desynchronised due to an emergency related to the massive attack, according to the Task Force. In total, almost 2 million consumers were cut off from the power supply in many regions.[589] According to Ukrenergo, several high voltage lines were accidentally disconnected, resulting in a number of consumers being disconnected. The shutdowns occurred due to technical reasons and were not related to the lack of power in the system.[590]

Measures

All five Ukrainian hydropower plants and pumped storage plants worked at full capacity to maintain the frequency and balance of the power system.[591]

Later the same day power was restored to consumers.[592]

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[583] NPC Ukrenergo. Facebook, 2023-05-22. https://www.facebook.com/npcukrenergo/posts/633193952182767

[584] General Staff of the Armed Forces of Ukraine. Facebook, 2023-05-29. https://www.facebook.com/GeneralStaff.ua/posts/595078956138520

[585] NPC Ukrenergo. Facebook, 2023-05-28. https://www.facebook.com/npcukrenergo/posts/637095675125928

[586] General Staff of the Armed Forces of Ukraine. Facebook, 2023-05-29. https://www.facebook.com/GeneralStaff.ua/posts/595391232773959

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[589] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment XI. 2023.

[590] NPC Ukrenergo. Facebook, 2023-05-30. https://www.facebook.com/npcukrenergo/posts/638523308316498

[591] Cooperation for Restoring the Ukrainian Energy Infrastructure project Task Force. International Energy Charter. Ukrainian energy sector evaluation and damage assessment XI. 2023.

[592] NPC Ukrenergo. Facebook, 2023-05-30. https://www.facebook.com/npcukrenergo/posts/638618564973639

June – December 2023

After May 2023, Russia apparently shifted the focus of large-scale kinetic attacks away from the Ukrainian power system. However, Russia destroyed the Kakhovka dam on the Dnipro River on 6th June, causing massive floods and destruction.[593]

In September, an attack damaged objects in the western and central regions. Consumers in Rivne and Zhytomyr regions were disconnected from the power supply**.** Emergency restoration work began immediately after the alarm was lifted.[594]

In December 2023, Russian forces targeted Ukrainian electricity infrastructure in various regions. The attacks resulted in significant damage to key components of the infrastructure, including high-voltage lines and thermal power plants. Emergency restoration efforts were initiated promptly to address the damage and minimise disruptions to consumers.[595]

Update: attacks in 2024

In 2024, Russia has again intensified its attacks on Ukraine's energy infrastructure, leading to devastating consequences. These attacks have become a destructive pattern, affecting cities and towns across Ukraine. What follows below is a brief overview of the attacks against the Ukrainian power infrastructure in the first quarter of 2024.

In 2024, Russian forces have systematically targeted energy facilities, disrupting electricity and water supply for millions of people. More than two dozen energy facilities have been destroyed or damaged, including the Dnipro Hydroelectric Power Plant, which was directly targeted.[596]

Russian attacks targeted the Zaporizhzhia Nuclear Power Plant directly, raising concerns about a major nuclear accident. The International Atomic Energy Agency (IAEA) called for an immediate cessation of such attacks. The situation remains critical.[597]

January

In January 2024, Russian attacks on the Ukrainian electricity infrastructure escalated, with multiple instances of missile strikes targeting critical energy facilities. These attacks caused widespread damage, including disruptions to transmission lines and substations, leading to significant disruptions in power supply for hundreds of thousands of consumers across various regions. Emergency restoration works were initiated promptly following each attack.[598]

February

In February 2024, Russian attacks on the Ukrainian electricity infrastructure were marked by a series of coordinated drone strikes and missile attacks across southern and central regions. These attacks targeted key energy facilities, including substations and transmission lines, resulting in widespread damage and disruptions to power supply for

[593] Wilson Center. Aftermath of the Kakhovka Dam Collapse.

[594] NPC Ukrenergo. Facebook, 2023-09-21. https://www.facebook.com/npcukrenergo/posts/722056429963185

[595] NPC Ukrenergo. Facebook, 2023-12-29. https://www.facebook.com/npcukrenergo/posts/783962777105883

[596] United Nations. Russian attacks 'a daily destructive pattern' in Ukraine, Security Council hears. 2024-04-11. https://news.un.org/en/story/2024/04/1148446

[597] Ibid.

[598] NPC Ukrenergo. Facebook, 2024-01-02. https://www.facebook.com/npcukrenergo/posts/786450560190438, NPC Ukrenergo. Facebook, 2024-01-08. https://www.facebook.com/npcukrenergo/posts/790087083160119 and NPC Ukrenergo. Facebook, 2024-01-30. https://www.facebook.com/npcukrenergo/posts/804392491729578

both industrial and residential consumers. The attacks posed challenges to Ukraine's energy system, necessitating emergency restoration efforts by Ukrainian energy workers and military forces.[599]

March

In March 2024, Russian attacks on the Ukrainian electricity infrastructure reached a critical point, constituting a significant escalation in both scale and intensity. The attacks included a combination of rocket strikes and drone attacks targeting vital energy facilities such as substations and power lines across multiple regions of Ukraine. These assaults resulted in extensive damage to the infrastructure, leading to widespread power outages affecting numerous residential and industrial consumers. Ukrainian authorities, alongside energy workers and military personnel, responded with emergency restoration efforts aimed at minimising disruptions and restoring power supply to affected areas.[600]

The rocket strike on 22nd March became the largest attack on the energy infrastructure of Ukraine since the beginning of the full-scale phase of the war. "This attack was particularly dangerous because the enemy combined different attack means, kamikaze drones, ballistic and winged missiles," said Volodymyr Kudrytskyi, in a comment to the international news organisation Associated Press. He explained that "the Russians tried to destroy every significant power facility that powers the city of Kharkiv", leaving at least 700,000 people without electricity. Several hundred thousands of consumers were left without electricity in other regions.[601]

[599] NPC Ukrenergo. Facebook, 2024-02-02. https://www.facebook.com/npcukrenergo/posts/806330204869140, https://www.facebook.com/npcukrenergo/posts/806405228194971 and NPC Ukrenergo. Facebook, 2024-02-07. https://www.facebook.com/npcukrenergo/posts/809737777861716

[600] NPC Ukrenergo. Facebook, 2024-03-21. https://www.facebook.com/npcukrenergo/posts/837059278462899

[601] NPC Ukrenergo. Facebook, 2024-03-23. https://www.facebook.com/npcukrenergo/posts/838526461649514

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