Ukraine’s Electric Grid During The Russian Invasion
March 17, 2022

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Research Analyst: Tabor French

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Agenda

- Executive Summary
- Transmission, Control, and Synchronization
- Generation Plants and Energy Sources
- Grid Disruptions During the Russian Invasion
- Indicators of Ukrainian Infrastructure Status
- Summary Observations
Executive Summary

- Ukraine Has a Modern, Interconnected, and Synchronized Electric Grid with a System Frequency of 50 Hz
  - High Voltage Transmission Lines with Transformer Substations
  - Transmission System Operator & Regional Distribution Providers
  - Regulated Wholesale Electricity Market
  - Like All Relay-Protected Grids, Susceptible to Cascading Collapse
  - Synchronized on March 16 with ENTSO-E (Western Europe Grid)

- Ukrainian Grid Has Wide Diversity of Energy Sources
  - Nuclear, Coal, Natural Gas, Hydroelectric, and Renewables

- Continued Electric Reliability During Invasion

- Few Attacks on Generation Plants and Substations
  - Interruption of Cross-Border Natural Gas Pipelines a Disincentive

- If War Persists, Nuclear Safety & Fossil Fuel Supply Issues
Transmission, Control, and Synchronization
High Voltage Transmission Lines in Ukraine

Source: energydata.info
Ukraine's Electric Grid During The Russian Invasion

Ukrenergo Transmission Control Room

Source: Flickriver.com
Ukraine's Electric Grid During The Russian Invasion

Ukrenergo Video Dated March 2, 2022

Source: YouTube
Foundation for Resilient Societies

Ukraine’s Electric Grid During The Russian Invasion

Frequency Map of European Electric Grids

Source: FNET by the University of Tennessee
Ukraine Grid Synchronized with ENTSO-E on March 16
Generation Plants and Energy Sources
Ukraine’s Electric Grid During The Russian Invasion

Ukraine Generation Capacity By Energy Source
56 GW in 2020

- Nuclear 24%
- Coal 43%
- Natural gas 9%
- Hydro 8%
- Wind 3%
- Solar PV 13%
- Other 0%

Ukraine Electricity Generation by Energy Source
143,400 GWh in 2020

- Nuclear 53%
- Coal 30%
- Natural gas 8%
- Solar PV 1%
- Wind 1%
- Hydro 5%
- Other 2%

Source: IEA, Global Energy Monitor, GlobalData, U.S. EIA, Resilient Societies Estimates
Ukraine Generation Capacity Factors by Energy Source—2020

- Nuclear: 64%
- Coal: 21%
- Natural gas: 25%
- Hydro: 19%
- Wind: 16%
- Solar PV: 3%

Source: IEA, Global Energy Monitor, GlobalData, U.S. EIA, Resilient Societies Estimates
Ukraine Fossil Fuel Sources

Coal
- 45% of coal supply is imported
- Of imported coal, 70% is from Russia
- Russia stopped coal deliveries in November 2021
- Deliveries from South Africa & U.S. in December-January
- On February 28, DTEK estimated 15-20 days of coal reserves

Natural Gas
- 30% of natural gas is imported, mainly from “Western Europe”
- Massive natural gas storage facilities of 31 billion cubic meters

Refined Petroleum
- 70% supplied from Belarus and Russian refineries
- Kremenchug, west of Karkiv, is sole operating Ukrainian refinery
- Petroleum storage capacity is a Ukraine state secret

Ukraine’s Coal-Fired Generation Plants

Coal supplies from Poland
- Railway capacity up to 100 thousand tonnes per month
- 15 mines

Coal supplies from Russia
- Railway capacity more than 1 mln tonnes per month
- 83 mines

Source: Euromaidan Press
December 24 “Energy War” Article in Euromaiden Press

Amid Russian energy war, government denies expert warnings that Ukraine may face electricity and heating cuts

Rivne nuclear power plant. Ukrainian nuclear power plants have reached record power generation amid Russian energy war.

About the Source
Bohdan Ben

Bohdan Ben is a researcher in the field of social and ethical philosophy and in the field of local governance. He was among the winners of the program “Youth will change Ukraine” organized by Bohdan Hawrylyshyn Foundation. Together with his friends, he began the implementation of the project “In the land of Hope” which aims to...
Ukraine’s Electric Grid During The Russian Invasion

Ukraine’s Nuclear Power Plants

Source: Business Insider, IAEA
Ukraine’s Nuclear Power Plants

- 15 Nuclear Reactors at 4 Plant Locations—13.1 GW
  - 6 Reactors Operating on March 16; Approximately 5 GW
- Soviet-Designed Water-Water Energetic Reactors (VVER)
- Steel and Concrete Containment for Reactors
- Zirconium-Clad Rods Used for Reactors Fuel
  - Fuel Currently Supplied by Russia, Two Year Inventory
  - Pending Transition to Westinghouse Fuel
- Plants Have Spent Fuel Pools Not in Containment
- Spent Fuel Pools Require Electric Power for Cooling
- When Water Boils Off from Spent Fuel Pools, Zirconium Fires and Radioactive Plumes Can Result
- Without Water for Radiation Shielding, Spent Fuel Pools Are Highly Radioactive and Cannot Be Approached
Ukraine’s Natural Gas/Fuel Oil Generation Plants

Source: Global Energy Monitor, Google Maps, Resilient Societies Analysis
European Union & Ukraine Gas Storage

Total capacity: 142.4 bcm

Source: Naftogas Group
Ukraine’s Electric Grid During The Russian Invasion

Ukraine’s Hydropower Plants

Source: Global Energy Monitor, Google Maps, Resilient Societies Analysis
Energy-Resilient Generation Capacity in Ukraine—March 17

Source: Global Energy Monitor, IEA, Wikipedia, NY Times, Resilient Societies Analysis
### Energy-Resilient Generation Capacity in Regions Controlled By Government of Ukraine—March 17

<table>
<thead>
<tr>
<th>Rank</th>
<th>Plant Name</th>
<th>Energy Source</th>
<th>Capacity (GW)</th>
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<tbody>
<tr>
<td>1</td>
<td>South Ukraine</td>
<td>Nuclear</td>
<td>2,850</td>
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<td>2</td>
<td>Rivne</td>
<td>Nuclear</td>
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<td>3</td>
<td>Burshtyn power station</td>
<td>Coal</td>
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<td>4</td>
<td>Khmelnitski</td>
<td>Nuclear</td>
<td>1,900</td>
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<td>5</td>
<td>Dnieper HPP</td>
<td>Hydro</td>
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<td>Trypilska power station</td>
<td>Coal</td>
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<td>7</td>
<td>Ladyzhyn power station</td>
<td>Coal</td>
<td>1,200</td>
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<td>8</td>
<td>Kyiv CHP-5 power station</td>
<td>Natural Gas/Fuel Oil</td>
<td>800</td>
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<td>9</td>
<td>Dniester HPP</td>
<td>Hydro</td>
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<td>10</td>
<td>Kremenchug HPP</td>
<td>Hydro</td>
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<td>Trypilska power station</td>
<td>Natural Gas/Fuel Oil</td>
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<td>Dobrotvir power station</td>
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<td>Kaniv HPP</td>
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<td>14</td>
<td>Kyiv CHP-6 power station</td>
<td>Natural Gas/Fuel Oil</td>
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<td>15</td>
<td>Kyiv HPP</td>
<td>Hydro</td>
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<td>16</td>
<td>Middle Dnieper HPP</td>
<td>Hydro</td>
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<td>17</td>
<td>Kalush power station</td>
<td>Coal</td>
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<td>18</td>
<td>Cherkasy power station</td>
<td>Coal</td>
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<td>19</td>
<td>Darnytska power station</td>
<td>Coal</td>
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**Total Capacity: 19,077**

**Evening Peak Load on March 6, 2022:** 13,700

Source: IEA, Global Energy Monitor, Wikipedia, DiXi Group, Resilient Societies Analysis
Grid Disruptions During the Russian Invasion
Russian Advances Blackout Sumy & Mariupol on March 3
Attack on Zaporizhzhia Nuclear Power Plant on March 3
Interdependence of GazProm and UkrTransGas Pipelines
Indicators of Ukrainian Infrastructure Status
Ukraine Electric Grid Outages on March 17

Welcome! This is an ongoing project created to track, record, and aggregate power outages across Ukraine. Find out more on our About page. Click on an oblast to see more information. Data is updated site wide approximately every ten minutes.

Helpful Definitions:
- Oblasts are the same as a state or province
- Raions are the same as a county or region
- Oblenergo means electric distribution utility

Oblasts

<table>
<thead>
<tr>
<th>Oblast</th>
<th>Outages</th>
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<td>Donetsk</td>
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<td>Kyiv</td>
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<td>Kherson</td>
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<td>Dnipropetrovsk</td>
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<td>Chernivtsi</td>
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<td>Kirovohrad</td>
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<td>Odessa</td>
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<td>Rivne</td>
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<td>Ternopil</td>
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<td>Vinnytsia</td>
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<td>Volyn</td>
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<td>Zakarpattia</td>
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<td>Zaporizhzha</td>
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Last Updated: 3/17/2022, 09:14:59 AM
DTEK Donetsk Grids has returned electricity to almost 5,000 families in the Donetsk region

On March 9, DTEK Donetsk Grids repair crews fully or partially restored electricity for 4,900 thousand families living in 13 cities and villages of Maryinskyi, Dobropillyi, Konstantynivski, Oleksandrivski, and Yasynuvata districts. Emergency repair works in the region will continue as soon as the company’s specialists are able to perform them safely.

As of March 10, DTEK Donetsk Grids repair crews restored electricity to the villages: Solodke, Stepove, Slavne, Uspenivka, Annivka, Boholavlenka, Ostrivske, Katerynivka, Kostiantynivka, Illinka, Antonivka, Yelyzavetivka, Yakovlivka, Mykhailivka, Lvivka, Dmytrivka.

In total, the DTEK crew restored electricity for 4,900 thousand families in 5 districts of the region.

Residents of 148 settlements in the Donetsk region are left without electricity. The most difficult situation remains in Mariupol, where due to regular shelling and the inability to repair power grids, more than 200,000 families remain in the city without electricity. The situation is complicated by active hostilities in the city, which had no break for more than a week.

DTEK Donetsk Grids is continuously working and doing everything possible to promptly restore electricity supply to settlements affected by the fighting. The company cooperates with the Armed Forces of Ukraine to gain safe access to places with damaged power lines.
IODA Monitoring of Ukrainian Internet Traffic

Source: https://ioda.inetintel.cc.gatech.edu/country/UA
FlightRadar24 Ground Stations on March 17

Source: https://www.flightradar24.com
Summary Observations

■ Russia’s Attack on Ukraine Unprecedented in Modern Era
  – Besieged Country with Wide-Area, Synchronized Electric Grid
  – Nuclear Power Sector Supplied Over 50% of Electricity
  – Telecommunications Interdependent with Electric Grid
  – Cross-Border Natural Gas Pipelines Also Interdependent

■ Not Yet The Society-Wide “Total War” of World War II
  – Few Attacks on Electric Grid and Continued Reliable Operation

■ Russian Incentives To Preserve Grid Infrastructure
  – Continued Transmission of Russian Gas to European Customers
  – Prevention of Cascading Grid Collapse and Risky Blackstart
  – Avoided Long Lead-time Replacement of Critical Grid Components
  – Averted Humanitarian Disaster in Country of 44 Million