

Electrical Engineering in Wartime: Perspectives on Ukraine's Energy Sector

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Abstract—The paper examines the challenges caused by military actions faced by the energy sector and, consequently, their impact on the educational process in higher education institutions, particularly in the teaching of electrical engineering. At the same time, the importance of developing engineering education as one of the key factors for the sustainable recovery of Ukraine's energy sector is emphasized, and possible development trajectories are proposed.

Keywords— energy infrastructure, energy security, power system restoration, electrical engineering education

I. INTRODUCTION

The full-scale Russian invasion of Ukraine began on February 24, 2022, though conflict has persisted since 2014 after Crimea's annexation and fighting in Donbas. The war has caused hundreds of thousands of military casualties and tens of thousands of civilian deaths. As of 2025, Russia occupies about 20% of Ukraine, creating a large-scale humanitarian crisis.

The war in Ukraine has severely damaged energy infrastructure, including nuclear and thermal plants, sharply reducing generation capacity. By mid-2024, about 10 GW of nuclear capacity remained, while thermal and CHP plants operated at roughly 32% of pre-war levels. This increased reliance on nuclear power and imports, underscoring the urgent need to modernize and strengthen energy systems.

The goal of this paper is to analyze the current state of Ukraine's energy infrastructure under wartime conditions and to propose a methodology for teaching of electrical engineering disciplines in higher education institutions.

II. CHALLENGES OF UKRAINE'S ENERGY SECTOR

The full-scale war has led to significant destructive processes across various spheres of life, particularly in critical infrastructure, the energy sector, the economy, and social stability (Table 1). This situation underscores the urgent need for a comprehensive analysis of the current state of the electric power sector and the technical challenges it faces from the perspective of electrical engineering science. This situation has created new challenges for Ukraine's technical education system and highlighted the need to

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ensure access to high-quality education under martial law.

TABLE I. CHALLENGES ARISING FROM WARTIME DESTRUCTION AND INSTABILITY

Category	Challenges	
Infrastructure	Destruction of roads, bridges, and utilities, hindering transportation and communication	Damage to schools, hospitals, and public buildings, limiting essential services
Economic Impact	Collapse of local businesses and industries, leading to unemployment and poverty	Inflation and resource scarcity due to disrupted supply chains
Social Disruption	Displacement of populations, causing refugee crises and loss of community structures	Breakdown of social cohesion, with increased distrust and division
Humanitarian Issues	Food and water shortages, leading to malnutrition and disease outbreaks	Limited access to healthcare, with destroyed medical facilities
Education and Knowledge	Interrupted education, loss of teachers, and destruction of learning materials	Brain drain as skilled professionals flee conflict zones
Environmental Damage	Contaminated water sources and destroyed ecosystems	Long-term land degradation due to explosives and chemical weapons
Psychological Effects	Trauma, PTSD, and mental health crises for civilians and combatants alike	Loss of hope and motivation for future rebuilding efforts
Governance and Security	Weakened institutions, with corruption and lawlessness taking root	Continued violence and instability, making recovery efforts difficult

Consequently, there is a growing demand for the development of new educational disciplines and topics within the field of electrical engineering, including power engineering, electromechanics, and computer science.

As of mid-June 2024, Russian strikes have destroyed a total of 9 gigawatts (GW) of Ukraine's domestic electricity generation capacity. Peak consumption in the winter of 2023 reached 18 GW, meaning that half of Ukraine's generation capacity has been destroyed. Table 2 presents the scale of damage to Ukraine's energy sector infrastructure during the Russian invasion [5].

Thus, the total declared capacity of nuclear power plants amounted to 13,835 MW. During the war, approximately 10 GW (11 units) remained operational [4]. Thermal power

plants (TPPs) and combined heat and power plants (CHPs) had a total capacity of about 17,100 MW before 2022; by April 2023, their effective capacity was reduced to 4.6 GW, a decrease of 68 % compared to the pre-crisis level [6].

TABLE II. DAMAGES OF UKRAINE'S ENERGY SECTOR INFRASTRUCTURE

Station	Type	Location (Region)	Power before war (MW)	Power during the war (MW)
Zaporizhzhia NPP	NPP	Zaporizhzhia	6000	≈ 4000–5000 (reduction: 1–2 units) This NPP is one of 4 NPPs of total 13.8 GW.
Rivne NPP	NPP	Rivne (Varash)	2657	≈ 2000–2657 (3–4 units operating) Total of 4 units: 2,835 MW;
Khmelnyska NPP	NPP	Khmelnyskyi (Netishyn)	2000	≈ 1000–2000 (temporarily stopped units). In 2025 ~4 units operating
South Ukraine NPP	NPP	Mykolaiv	3000	≈ 2000–3000 (2–3 units operating) 3 units total 3,000 MW; 2 units are under operation
Trypilska TPP	TPP	Kyiv	3200	0 (destroyed)
Zmiivska TPP	TPP	Kharkiv	2175	0 (destroyed)
Vuhlehirska TPP	TPP	Donetsk	3600	0 (occupied), under control of Russia since July 2022
Kharkiv CHP-5	CHP	Kharkiv	540	0 (destroyed in in March 2024)
Ladyzhyn TPP	TPP	Vinnitsia	1800	Significantly reduced or 0(destroyed in in March 2024)
Burshtyn TPP	TPP	Ivano-Frankivsk	2300	Significantly reduced or 0
Remaining TPP/CHP (total 17.1 GW before 2022)	TPP/CHP	Across Ukraine	~17,10	~4600 (22 units; – ≈68 %) As of April 2023: 9 stations out of 22 units totaled 4.6 GW

Major TPPs and CHPs experienced significant destruction: some were completely destroyed or occupied, while others were damaged or temporarily shut down. The largest post-World War II catastrophe was at Trypilska TPP, along with Zmiivska TPP, Vuhlehirska TPP, and Kharkiv CHP-5, which were fully taken out of service. These data indicate a substantial reduction in thermal generation and an increased reliance on nuclear power and electricity imports during critical hours of the day.

The implementation of a stepwise approach, integrating microgrids, renewable energy sources, and small modular reactors (SMRs), can play an important role in accelerating the modernization of energy systems. In the context of Ukraine's wartime challenges, microgrids can ensure localized electricity supply for critical facilities during grid disruptions, renewable energy sources such as solar and wind can reduce dependency on damaged thermal power plants, and SMRs can provide flexible, low-carbon baseload generation. Together, these solutions enhance the flexibility, reliability, and resilience of the energy infrastructure, enabling rapid adaptation to both acute crises and long-term reconstruction needs. Key aspects of Ukraine's power sector modernization and expected outcomes after its ending are shown in the Fig.1 and Fig. 2 respectively.

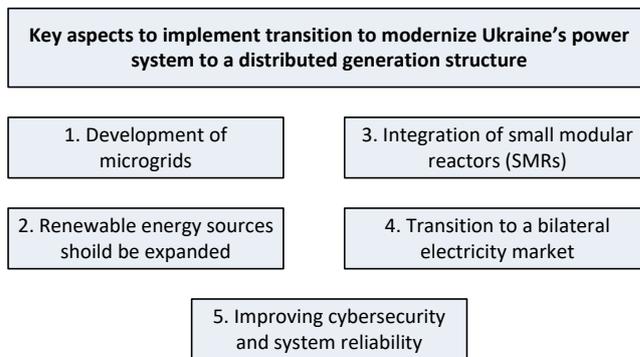


Fig. 1. Aspects of modernization of Ukraine's power system

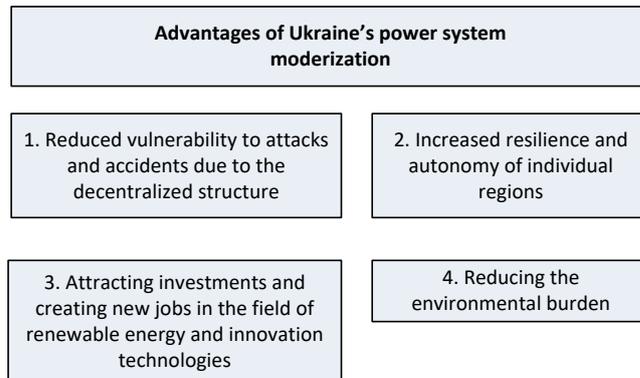


Fig. 2. Expected outcomes for Ukraine

III. THE ROLE OF ELECTRICAL ENGINEERING EDUCATION

In addition to physical destruction, the war has destabilized the education systems complicating the normal functioning of society. Thus, initiatives aimed at adapting infrastructure, ensuring energy security, and maintaining the educational process become particularly critical.

Accordingly, the academic and teaching staff of the Institute of Energy and Control Systems of Lviv Polytechnic National University comprehensively address this challenge to train future engineering specialists. This approach not only provides students with theoretical and methodological knowledge but also equips them with practical experience. Currently, the preparation of a new generation of specialists goes beyond traditional engineering education. The educational process focuses not only on a solid theoretical foundation but also on the development of practical competencies for future engineers. Special attention is given to the integration of modern digital technologies and simulation tools, which fosters systems thinking and the ability to perform comprehensive analyses of electric power processes and facilities.

Moreover, the application of a stepwise approach—combining microgrids, renewable energy sources, and small modular reactors (SMRs)—serves as both a teaching and research framework. By engaging students in the analysis and modeling of such integrated systems, the educational process directly contributes to the modernization of Ukraine's energy infrastructure. Microgrids provide practical examples of localized electricity supply during grid disruptions, renewable sources demonstrate alternatives to damaged thermal plants, and SMRs illustrate flexible, low-

carbon base load generation. This experiential approach equips students with the skills necessary to enhance the flexibility, reliability, and resilience of energy systems under both wartime and peacetime conditions.

In addition to theoretical instruction, students gain hands-on experience through:

- Simulation and Modeling – Essential for training future engineers
- Virtual Simulator of the Power Unit’s Electrical Part – Enhancing practical skills
- Interactive Automated Complex (DAKAR) – Providing immersive learning opportunities

A key part of practical training is using software for mathematical modeling, which deepens understanding of energy system operation. Virtual simulators for a power unit’s electrical system help students develop operational skills for real-world scenarios. Common tools include PowerFactory, ATP/EMTP, PSCAD, SimPowerSystem BlockSet with MATLAB/Simulink, and the Ukrainian-developed interactive complex DAKAR [7]. This program ensures interactive engagement with the learning environment, stimulating students’ cognitive activity and fostering a practice-oriented perspective on professional work in the energy sector.

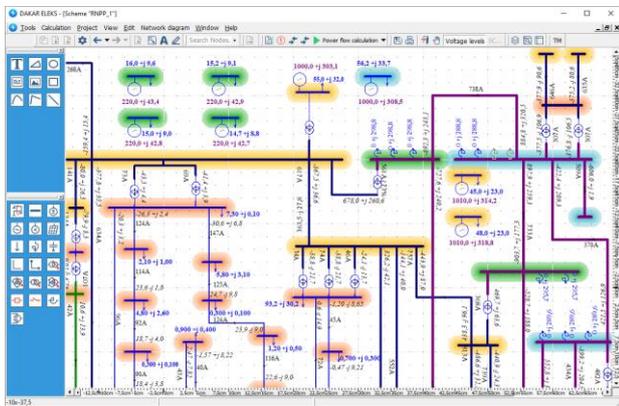


Fig. 3. DAKAR virtual simulator of the electrical part of a power supply system

Figure 3 illustrates a virtual simulator of the electrical part of a power supply system. The system is designed to simulate processes occurring in the electrical part of thermal and nuclear power plant units, taking into account operational parameters, control system dynamics, and typical emergency situations.

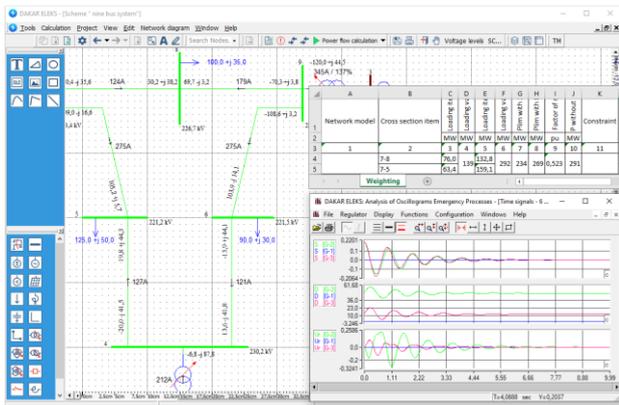


Fig. 4. DAKAR simulation results

The developed model simulates real operating conditions of electrical equipment and provides interactive engagement with a virtual environment. It helps future operators develop professional skills, make prompt decisions in critical situations, and prepare for complex technological conditions. Key scenarios include generator no-load operation, system synchronization, excitation transfer between main and backup units, and other critical events, offering a realistic and interactive training experience.

IV. MODERNIZATION OF ELECTRICAL ENGINEERING COURSES AND NEW FORMS OF LEARNING

Under martial law conditions, when issues of safety, accessibility of educational resources, and stability of the learning process remain uncertain, the implementation of flexible and resilient educational approaches becomes particularly important. Ensuring continuity of the educational process under such circumstances requires adaptive models capable of responding promptly to external challenges while maintaining high levels of student engagement, regardless of the learning format.

Considering the specifics of engineering education, particularly in the field of electrical engineering, where practical and laboratory training plays a crucial role, a combination of online, offline, and hybrid learning forms (Table 3) proves to be an effective solution. This approach not only preserves the quality of educational services under crisis conditions but also develops students’ digital competencies, supports individualized learning, and provides flexibility in shaping educational trajectories.

TABLE III. COMBINATION OF LEARNING FORMS UNDER WARTIME

Online Classes	Offline Classes	Hybrid Approaches	Emergency Adaptations
Live Lectures (Zoom, Teams, Google Meet)	Small Group or Rotational Classes	Blended Learning (Online theory + occasional in-person labs)	Radio or Podcast Lessons
Recorded Video Lectures	Pre-Distributed Materials (Printed notes, USB drives with videos/simulations)	Flipped Classroom (Self-study theory + class discussions/labs)	SMS or Messenger-Based Micro-learning
Virtual Labs & Simulations (MATLAB, Multisim, Proteus)	Local Study Groups	Distributed Hub Model (Small local hubs with generators and internet access)	Offline Apps & Downloads
Learning Platforms (Moodle, Google Classroom)			
Discussion Forums (Discord, Telegram)			

A list of new courses or topics that can serve as valuable additions to the electrical engineering curriculum, adapted to wartime conditions, is presented in Table 4.

TABLE IV. NEW COURSES AS ADDITIONS TO THE ELECTRICAL ENGINEERING CURRICULUM

Category	Proposed Discipline/Topic	Description
Energy Resilience and Crisis Managemen	Resilient Power Systems Design	Designing grids that can withstand attacks and natural disasters.
	Emergency Power	Fast-track repair strategies for

nt	Restoration Techniques	damaged infrastructure.
	Microgrid and Distributed Energy Systems	Creating localized, self-sustaining energy networks.
	Energy Storage and Backup Solutions	Exploring backup systems like batteries, flywheels, and hybrid setups.
Sustainable and Adaptive Technologies	Renewable Energy for Crisis Areas	Using solar, wind, and hydro systems for emergency or off-grid power.
	Portable and Mobile Power Systems	Designing mobile energy units for field use and disaster zones.
	Energy Efficiency in Resource-Constrained Environments	Techniques for optimizing energy use with limited resources.
Cybersecurity and Digital Protection	Cybersecurity for Power Grids	Protecting energy infrastructure from digital threats and cyberattacks.
	SCADA and Remote Monitoring Systems	Monitoring and controlling systems remotely during crises.
	Data-Driven Fault Detection	Using AI and machine learning to predict and prevent system failures.
Field-Ready Skills and Practical Training	Rapid Prototyping and DIY Energy Solutions	Creating improvised energy solutions with available materials.
	Power Electronics for Emergency Applications	Designing and repairing converters, inverters, and transformers on the ground.
	High-Voltage Safety and Damage Assessment	Training on safe handling and post-attack assessment of energy systems.
Policy, Ethics, and International Collaboration	Energy Policy and Humanitarian Law	Understanding legal and ethical aspects of energy systems in conflict zones.
	International Standards for Energy Security	Learning from global best practices and case studies.
	Resilient Community Energy Planning	Designing energy solutions for civilian support during wartime.

The improvement of electrical engineering courses is an essential component in preparing specialists capable of effectively responding to contemporary challenges in the energy sector. Course content is updated to address the need for enhanced readiness to operate under emergency conditions, particularly those related to power outages and risks to critical infrastructure.

Special attention is given to the development of practical skills in restoring electricity supply and ensuring the reliability and stability of power systems during wartime. This approach allows the integration of not only technical aspects into the educational process but also elements of crisis management and energy network resilience, aligning with the current needs of the industry's development.

A. Theoretical questions

1. Which main types of energy facilities are typically targeted or damaged during military operations, and how does such damage affect the reliability of the electricity supply system?
2. What technical and operational requirements are imposed on substation equipment and transmission lines under conditions of increased risk of physical damage?
3. In what ways can the decentralization of the power system and the development of local microgrids enhance system resilience during military conflicts?

B. Practical questions

1. Describe methods for assessing the degree of damage to transformer substation equipment and preparing it for repair.
2. Develop a plan for the restoration of damaged power lines, taking into account the restrictions on access to facilities due to hostilities.
3. What are the requirements for the installation and safe use of generators in cities and critical infrastructure facilities?
4. How are mobile systems for emergency power supply selected and configured?

C. Analyze real-life situations

1. Consider examples of restoration of power supply in Ukraine and around the world after significant damage to power facilities.
2. Analyze the technical measures taken to protect nuclear power plants in wartime.
3. Evaluate how the electricity infrastructure is planned to be protected from the risks of physical damage, cyberattacks, and emergencies.

D. Design and engineering tasks

1. Develop a project to restore power supply for a specific region, taking into account temporary generators and rapidly restored facilities.
 2. Design a microgrid for a small settlement using renewable sources and energy storage systems that can operate independently of the centralized grid.
 3. Develop a power supply scheme for a critical infrastructure facility that includes automatic switching to backup sources when the main supply is disconnected.
- These questions will allow students to understand current challenges and develop practical skills in the context of modern energy engineering realities

V. CONCLUSIONS

The paper provides a strategic framework for the development of Ukraine's energy sector, integrating lessons from damaged and partially restored facilities, and proposes a set of electrical engineering and computer-oriented courses designed to ensure the reliable functioning of power networks during emergency situations. This combined approach of practical education, curriculum modernization, and system-level strategy contributes to the sustainable recovery and long-term resilience of Ukraine's energy infrastructure.

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