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Compliance with Safety Requirements during Work in Power Plants

Abstract:
The relevance of the study is determined by the persistently high level of occupational electrical injuries in the energy sector, despite the existence of extensive regulatory frameworks and technical safety standards. The increasing complexity of power installations and the ongoing digital transformation of the energy industry further intensify risks associated with electrical hazards. The research addresses the problem of insufficient effectiveness of fragmented safety measures, where technical, organisational, and educational aspects are often implemented separately, limiting their preventive potential. Particular attention is paid to the growing role of the human factor and the need for systematic risk management under modern operating conditions. The scientific novelty of the study lies in substantiating an integrated approach to electrical safety that combines regulatory and legal mechanisms, organisational and technical measures, personnel training, and digital technologies within a unified safety management framework. The research expands traditional approaches by incorporating digitalisation as a preventive component of occupational safety rather than solely a technical innovation. The subject of the study is the system of ensuring electrical safety of personnel during work in power installations. The object of the study is the process of operation, maintenance, and repair of power installations under conditions of increased occupational risk. The study aims to analyse and substantiate effective mechanisms for ensuring electrical safety of personnel during work in power installations. The research methods include analysis, synthesis, generalisation, comparative analysis, regulatory and legal analysis, risk-oriented assessment, analysis of occupational injury statistics, and a systemic approach. The study is based on the analysis of international standards, national regulatory documents, and scientific works of Ukrainian and international researchers in electrical safety, occupational health and safety, risk management, and energy engineering. The essence of the study consists in identifying key factors influencing electrical injuries, analysing organisational, technical, and educational safety measures, and assessing the impact of digital technologies such as IoT, artificial intelligence, predictive maintenance, and automated permit-to-work systems on risk reduction. The study also examines the role of personnel training and safety culture in minimising the human factor. The author concludes that effective electrical safety is achieved through the integrated application of regulatory oversight, organisational discipline, technical protection measures, continuous personnel training, and digital innovation. The implementation of a systemic, risk-oriented approach contributes to a substantial reduction in occupational electrical injuries, enhances the reliability of power installations, and creates conditions for safe and sustainable operation of energy facilities.

Keywords: occupational safety, electrical safety, power installations, industrial risks, protective measures.

Abbreviations:
AI is artificial intelligence,
ILO is International Labour Organization,
IoT is Internet of Things,
PTW is permit-to-work,
RAEI is Rules for the Arrangement of Electrical Installations,
RLAOS is Regulatory Legal Acts on Occupational Safety,
SSU is State Standards of Ukraine.

Introduction

Electrical energy plays an exceptionally important role in modern society. This is explained by its widespread use in various spheres of everyday life, production, and communications. The growing demand for electrical energy has led to the emergence of a large number of power installations of different purposes and applications. A power installation is a complex of interconnected equipment and structures intended for the generation, transformation, transmission, distribution, storage, or consumption of energy (electrical, thermal, etc.). It may include various technical means for operating energy resources (*Constitution of Ukraine, 1996*) and belongs to facilities of increased hazard, as its operation is associated with the risk of electric shock (electrical burns, fatal injuries), the occurrence of fires or explosions, as well as technogenic or environmental accidents.

Violation of safety requirements leads to severe consequences for workers' health, economic losses for enterprises (*Operation of Electrical Installations, 2014*; *RAEI, n.d.*), and damage to the environment. Among the key problematic issues in the electric power sector are the low level of executive and technological discipline among workers and violations of safety requirements during the operation of equipment, machines, and mechanisms. The number of hazardous workplaces is constantly increasing; as a result of the use of obsolete machinery and equipment, the risk of occupational accidents rises, while the provision of workers with personal protective equipment and their level of knowledge in occupational safety remain unsatisfactory (*Lviv National Environmental University, 2024, p. 218*).

In the context of global technological development and the growing dependence of modern societies on reliable energy supply, electrical safety remains one of the most critical challenges in the operation of power installations. The expansion of energy infrastructure, increasing electricity consumption, and the integration of complex technical systems significantly raise the level of occupational risk for personnel involved in the operation, maintenance, and repair of electrical installations. Despite continuous improvements in technical equipment, electrical injuries, accidents, and emergency situations continue to pose serious threats to human life, industrial sustainability, and environmental safety.

The relevance of electrical safety issues is further intensified by contemporary transformations in the energy sector, including the modernisation of power systems, the implementation of SMART GRID technologies, decentralisation of energy networks, and the growing role of digital control and monitoring systems. These processes increase the complexity of operational tasks and require personnel to interact with high-voltage equipment under dynamically changing conditions. As a result, traditional approaches to occupational safety, based primarily on formal compliance with regulations, are increasingly insufficient to address emerging risks associated with human factors, ageing infrastructure, and technological interdependence.

A possible way to address this problem is the reduction of electrical injuries through the timely identification and assessment of risks and hazardous factors at workplaces. Modernisation of the energy sector, the use of SMART GRID technologies, and increasing loads on power networks increase the complexity of work, which necessitates the improvement of safety management systems. This, in turn, requires personnel to possess thorough knowledge and to strictly comply with electrical safety rules, regulations, and measures that define the duties and responsibilities of officials, the procedures for operational and maintenance personnel before, during, and after work, as well as the scope and content of protective measures. Therefore, the study of mechanisms for preventing occupational injuries constitutes a relevant scientific and practical task.

The scientific novelty of the study lies in its integrated approach to the analysis of electrical safety in power installations, which combines regulatory, organisational, technical, and educational dimensions within a unified analytical framework. Unlike studies that focus exclusively on normative compliance or isolated technical solutions, this research considers electrical safety as a complex, dynamic system influenced by technological development, human factors, and institutional regulation. Such an approach allows for a more comprehensive understanding of the mechanisms underlying occupational electrical injuries and their prevention.

A novel aspect of the research is the application of a risk-oriented perspective to the assessment of electrical safety measures, emphasising the identification, evaluation, and management of hazards throughout all stages of work in power installations. Particular attention is paid to the interaction between organisational procedures, technical protective measures, and personnel competence, which enables the identification of critical points where safety failures are most likely to occur. This systemic analysis provides a basis for improving occupational health and safety management practices in the energy sector.

Furthermore, the study introduces contemporary digital technologies—such as intelligent monitoring systems, IoT solutions, artificial intelligence, PTW systems, and predictive maintenance tools—into the analytical context of electrical safety. By substantiating their role not only as technical innovations but also as elements of preventive safety management, the research expands the traditional understanding of electrical safety and contributes to the development of modern, adaptive models for reducing occupational risks in power installations.

The subject of the study is the system of ensuring electrical safety of personnel involved in the operation, maintenance, and repair of power installations.

The object of the study is the process of ensuring electrical safety during work in power installations under modern regulatory, technological, and organisational conditions.

The aim of the study is to analyse and substantiate effective mechanisms for ensuring electrical safety of personnel during work in power installations.

To achieve this purpose, the following research objectives are formulated:

- analyse the regulatory and legal framework governing electrical safety in power installations;
- identify organisational and technical measures aimed at preventing electrical injuries;
- assess the role of personnel training and risk management in ensuring electrical safety;
- examine the impact of digital technologies on occupational safety in power installations;
- substantiate directions for reducing occupational electrical injuries under modern energy sector conditions.

The results of the study are intended for engineers and technical personnel of energy enterprises who are directly involved in the operation, maintenance, and repair of power

installations, as well as for occupational health and safety specialists responsible for developing and implementing safety management systems. The findings may be used in practical activities related to risk assessment, planning of preventive measures, personnel training, and the improvement of organisational and technical procedures aimed at reducing electrical injuries in the workplace.

In addition, the study outcomes are relevant for managers and decision-makers in the energy sector, as they provide a substantiated basis for improving safety policies, allocating resources for preventive measures, and integrating digital technologies into occupational safety management. The results may also be of interest to policymakers and regulatory authorities engaged in the development and revision of normative and legal frameworks governing electrical safety. Furthermore, the study can be applied in the educational process of higher education institutions and professional training programmes in energy-related disciplines, contributing to the formation of a safety-oriented professional culture and the dissemination of best practices in electrical safety management.

Methods

The methodological framework of this study is based on a combination of general scientific and specialised research methods, which made it possible to comprehensively analyse the problem of ensuring electrical safety during work in power installations under modern regulatory and technological conditions.

The method of analysis was applied to examine statistical data on occupational injuries in the energy sector, as well as to identify the main causes of electrical accidents, including violations of technological regulations, insufficient personnel training, equipment deterioration, and underestimation of industrial risks. This method enabled the identification of key risk factors and problem areas in the operation of power installations.

The method of synthesis was used to integrate the results obtained from the analysis of regulatory requirements, organisational procedures, technical protection measures, and human factors into a coherent conceptual framework. Through synthesis, electrical safety was considered as a holistic system formed by the interaction of legal, technical, organisational, and educational components.

The method of generalisation was employed to derive general conclusions based on the examination of multiple sources, including regulatory documents, scientific publications, and practical experience of energy enterprises. This approach allowed for the identification of common patterns and typical deficiencies in electrical safety management systems.

The comparative method was applied implicitly to contrast traditional approaches to occupational safety, focused primarily on formal regulatory compliance, with contemporary risk-oriented and system-based approaches. This comparison made it possible to substantiate the necessity of modernising existing safety management practices in the energy sector.

The methods of induction and deduction were used in combination. Induction facilitated the formulation of general conclusions based on the analysis of individual incidents and empirical data, while deduction enabled the application of general regulatory principles and international standards to the assessment of specific working conditions in power installations.

The method of regulatory and legal analysis was used to examine national and international normative documents governing electrical safety, including the RAEI, RLAOS, SSU, as well as international standards such as ISO 45001 and ISO 31000. This method allowed for the identification of mandatory safety requirements and the evaluation of their role in preventing occupational electrical injuries.

The risk-oriented assessment method was applied to analyse professional risks associated with work in power installations. This method involved the identification of hazardous situations, assessment of the probability and severity of potential consequences, and the selection of preventive measures aimed at risk elimination or reduction. The application of this approach is consistent with modern occupational health and safety management systems.

The method of analysing occupational injury statistics and incident reports was used to determine critical points in the operation of electrical installations and to substantiate preventive measures. The analysis of accident data enabled the identification of recurring causes of electrical injuries and supported the development of targeted safety recommendations.

The system approach served as a fundamental methodological principle of the study. Electrical safety was considered as a complex, multilevel system in which organisational procedures, technical protection measures, personnel competence, and regulatory requirements are interrelated. This approach ensured a comprehensive assessment of safety mechanisms and their effectiveness in real operating conditions.

The combination of the above-mentioned methods ensured the reliability and validity of the research results, as well as their practical applicability for improving electrical safety management in power installations. The applied methodological framework made it possible to substantiate conclusions and recommendations aimed at reducing occupational electrical injuries and enhancing safety under modern energy sector conditions.

Literature Review

The problem of ensuring electrical safety in power installations has been extensively addressed in international and national regulatory documents, scientific publications, and methodological guidelines, reflecting its interdisciplinary nature and high practical significance. At the international level, electrical safety is primarily framed as a technical and organisational issue aimed at preventing electric shock and associated injuries. One of the foundational documents in this field is IEC 61140:2016 (*Protection against Electric Shock, 2016*), which establishes common principles for protection against electric shock in electrical installations and equipment. This standard defines fundamental safety concepts, including basic protection, fault protection, and protective measures against direct and indirect contact, forming the technical basis for many national regulations.

A broader occupational perspective on electrical safety is provided by the ILO, which considers electrical hazards within the general framework of occupational health and safety. In its publication *Safety and Health in the Use of Electricity*, the ILO (*2019*) emphasises the role of employer responsibility, worker training, and preventive organisational measures in reducing electrical injuries. Unlike purely technical standards, this document highlights the social and institutional dimensions of safety, underlining the importance of education, supervision, and risk awareness.

Contemporary approaches to occupational safety increasingly rely on risk-oriented management models. The international standard ISO 31000:2018 (*Risk Management, 2018*) introduces general principles and guidelines for risk management applicable across sectors. Although not specific to electrical safety, ISO 31000 provides a methodological framework for identifying, analysing, and managing risks, which is directly applicable to power installations characterised by high levels of technological and operational uncertainty.

Complementing this approach, ISO 45001:2018 (*Occupational Health…, 2018*) establishes requirements for occupational health and safety management systems, focusing on continuous improvement, worker participation, and hazard prevention. This standard represents a shift from

reactive safety models toward proactive and preventive systems, integrating risk assessment into everyday organisational practices. In the context of electrical safety, ISO 45001 provides an institutional framework for embedding technical and organisational protective measures into enterprise management structures.

At the national level, Ukrainian scientific discourse on electrical safety reflects both international trends and local regulatory specificities. Research published in *Agroengineering Research* by Lviv National Environmental University (*2024*) addresses electrical safety issues within agricultural and industrial energy systems, emphasising the impact of equipment wear, insufficient training, and organisational shortcomings on accident rates. These studies highlight the persistence of traditional risk factors despite the availability of regulatory guidance.

Regulatory requirements for electrical installations in Ukraine are codified in the *State Building Codes of Ukraine* (*2016*). These codes establish technical standards for the design, installation, and operation of electrical systems, ensuring compliance with safety, environmental, and sanitary norms. While primarily technical in nature, these codes form the infrastructural foundation upon which organisational and procedural safety measures are built.

A key normative document governing operational safety is DSTU EN 50110–1:2014 (*2014*), which regulates the safe operation of electrical installations and defines requirements for personnel qualification, work organisation, and protective measures. This standard explicitly links technical procedures with organisational responsibilities, reinforcing the need for coordinated safety management.

Educational and methodological aspects of electrical safety are extensively covered in Ukrainian academic literature. The study guide by Levchenko and Denysiuk (*2022*) provides a systematic overview of electrical hazards, protective equipment, and safety procedures for students in energy-related specialities. The authors emphasise the role of professional training and competence development in reducing occupational risks, aligning with international perspectives on human factors in safety.

Similarly, the textbook by Panchenko et al. (*2018*) offers a comprehensive treatment of electrical safety principles, combining theoretical foundations with practical examples from industrial practice. This work underscores the importance of integrating technical knowledge with organisational discipline and regulatory compliance, reflecting a holistic understanding of electrical safety.

The legal foundations of occupational safety in Ukraine are established by the Law of Ukraine "*On Occupational Safety*" (*1992*). This law defines employer and employee responsibilities, establishes general safety requirements, and mandates the implementation of preventive measures. Electrical safety is addressed within the broader context of labour protection, reinforcing its institutional and legal significance.

Labour relations and safety obligations are further regulated by the *Labour Code of Ukraine* (*n.d.*), which provides a legal framework for working conditions, employee rights, and employer duties. Although not sector-specific, the Labour Code supports the enforcement of electrical safety regulations by defining general principles of workplace safety and accountability.

At the constitutional level, the Constitution of Ukraine (*1996*) guarantees the right to safe and healthy working conditions. This provision establishes electrical safety as a fundamental human right rather than merely a technical requirement, reinforcing the normative importance of preventive safety measures in power installations.

Methodological guidance specific to the energy sector is provided by the *Methodological Recommendations on Occupational Safety in the Energy Sector* (*n.d.*). These recommendations translate

legal and technical requirements into practical procedures for enterprises, focusing on training, supervision, and risk management.

Operational safety requirements for consumers' electrical installations are defined by RLAOS 40.1–1.21–98 (*1998*). This document establishes mandatory rules for safe operation, maintenance, and repair, highlighting organisational measures such as work permits, supervision, and qualification control.

Closely related are the *Rules for the Technical Operation of Consumers' Electrical Installations* (*2006*), which regulate maintenance procedures, inspections, and technical diagnostics. These rules emphasise the importance of systematic maintenance and timely modernisation in preventing accidents and equipment failures.

Finally, the *Rules for the Arrangement of Electrical Installations* (RAEI) (*n.d.*) serve as a cornerstone of electrical safety regulation in Ukraine, defining technical and organisational requirements for installation design and operation. Together with other regulatory and methodological documents, RAEI forms a comprehensive normative framework that integrates technical standards, organisational procedures, and personnel requirements.

Overall, the reviewed literature demonstrates that electrical safety in power installations is addressed through a combination of international standards, national regulations, scientific research, and educational resources. However, existing studies and regulatory and legal documents often consider technical, organisational, and educational aspects separately. This creates a need for integrated, risk-oriented approaches that synthesise these dimensions into a unified safety management system—an approach that the present study seeks to develop and substantiate.

Results

Regulatory and Legal Framework for Electrical Safety

It is evident that the effective and safe performance of work involving electrical installations and electrical equipment requires strict and consistent compliance with the regulatory and legal framework. The state guarantees (*Constitution of Ukraine, 1996, Art. 43*) the right to safe working conditions and pays significant attention to ensuring the protection of human life and health in the course of labour activity. When a person feels safe, they are able and motivated to work productively and with full commitment. To this end, public authorities develop and oversee compliance with various laws, regulatory legal acts, regulations, standards, and other normative documents.

Regulatory provisions in the field of electrical safety are defined by the Law of Ukraine "*On Occupational Safety*", the RAEI, RLAOS, SSU, and sector-specific instructions (*Labour Code of Ukraine, n.d.*; *On Occupational Safety, 1992*; *Operation of Electrical Installations, 2014*; *Rules for the Arrangement…, n.d.*; *Rules for the Safe Operation…, 1998*). These documents establish the procedures for organising work with the aim of preventing occupational injuries, while ensuring safe working conditions, personnel training for the creation of an effective occupational health and safety management system, and the regulation of enterprise activities in the operation of electrical installations. They also govern the provision of protective equipment and define the responsibility of employers and officials, specify technical and organisational protective measures, and establish qualification requirements for personnel depending on their admission group and the type of work performed.

The same laws, rules, and regulations govern the operation of electrical installations for workers in various sectors of the economy and establish prohibitions on their use where

applicable. The operation of electrical installations without devices that ensure compliance with established sanitary standards and environmental protection requirements, or with faulty devices that fail to ensure compliance with these standards and requirements, is prohibited (*Rules for the Technical Operation…, 2006*).

Organisational Safety Measures

Organisational safety measures in power installations constitute a set of measures aimed at preventing electric shock during the performance of work. The main measures include the appointment of responsible persons, the issuance of work permits or instructions, briefings, on-the-job training, supervision of work execution, medical examinations, audits of the occupational safety status, preparation of the workplace, supervision during work performance, and the formalisation of work interruptions and completion.

We consider that the main motivating factors for the implementation of organisational measures are presented in the Appendix (*Table 1*) (*On Occupational Safety, 1992, Art. 13*).

Organisational measures ensure that all procedures are performed correctly. For this reason, in electrical safety regulations (both in Ukraine and in most other countries), violations of organisational measures are regarded as some of the most serious infringements, as they are often the direct cause of fatal or severe occupational accidents.

Thus, organisational measures minimise the impact of the human factor, enhance labour discipline, ensure clear coordination of personnel actions, and contribute to a reduction in accident rates.

Technical Measures and Personal Protective Equipment

To prevent electrical injuries at enterprises, grounding, neutralisation, interlocking systems, and automatic circuit breakers are applied; live parts are insulated; signalling devices are installed; and dielectric gloves, tools with insulated handles, and portable grounding devices are used (*Table 2*) (*Occupational Health…, 2018*; *Protection against Electric Shock, 2016*).

Technical measures and personal protective equipment constitute the physical protection of the human body when cognitive errors occur. Although the range of personal protective equipment is limited, its importance is invaluable (*Table 3*).

Without technical measures and personal protective equipment, even perfectly organised work may result in fatal outcomes in the event of the slightest error. For this reason, regulations require the mandatory use and regular testing of electrical protective equipment, as it can save lives.

Thus, the application of technical measures creates a physical barrier between personnel and hazardous elements, which significantly reduces the probability of electric shock and contributes to ensuring reliable protection of workers.

Personnel Training and Risk Management

Periodic training, knowledge assessment, professional risk evaluation, and the implementation of the ISO 45001 standard enhance the effectiveness of the occupational health and safety system (*Levchenko & Denysiuk, 2022*; *Methodological Recommendations…, n.d.*; *Panchenko et al., 2018*; *Risk Management—Guidelines, 2018*). The timing and categories of personnel required to undergo training are established by relevant regulatory documents, and compliance with these timeframes is monitored by the enterprise occupational safety engineer. Upon completion of training, an examination is conducted and a certificate of completion is issued.

To create safe working conditions at enterprises, occupational safety engineers and heads of structural units are involved. They develop occupational safety instructions and monitor compliance with them by responsible persons during the performance of work involving electrical equipment. It is evident that the development of such instructions is a critical process, and specialists must be able to identify all potential risks to prevent them.

Risk identification includes the following stages:

- Identification of hazards (inspections, audits, accident analysis);
- Assessment of the probability and severity of consequences;
- Selection of measures (elimination, substitution, engineering controls, administrative measures, personal protective equipment);
- Implementation and monitoring of effectiveness;
- Documentation (risk maps, action plans) (*Table 4*).

Certain operations in power installations can be practised virtually. Augmented reality technologies integrated into helmets and goggles provide visual guidance. During maintenance work, personnel can view holographic diagrams of equipment, high-voltage zones, and safe access routes. Such systems can issue warnings through vibration or voice alerts. Regular training sessions increase competence without exposing personnel to real risks.

Thus, training combined with risk management forms the "eyes and brain" of the electrical safety system, ensuring that human errors are minimised and risks do not escalate unnoticed. Without high-quality training and effective risk management, even ideal regulations and equipment will not provide sufficient protection, as the primary "operator" and "source of errors" remains the human factor. Therefore, organisational and technical measures, together with training and risk management, can be considered the foundation of modern electrical safety at enterprises. The development of a safety culture and systematic risk management enables the timely identification of hazards, the prediction of consequences, and the adoption of well-grounded preventive decisions.

Discussion

In the modern world, the energy sector continues to face persistently high risks of electrical injuries, which annually result in thousands of occupational accidents worldwide. Personnel involved in the operation, maintenance, and repair of power installations are exposed to hazards associated with high voltage, short circuits, electric arcs, and operational errors. The results obtained in this study confirm that these risks remain relevant despite the existence of extensive regulatory frameworks and technical standards, highlighting the need for continuous improvement of safety management mechanisms.

The analysis demonstrates that digitalisation represents a significant qualitative shift in approaches to electrical safety, transforming traditional, predominantly reactive models into proactive systems based on continuous monitoring, early detection of hazardous conditions, and automated decision support. The implementation of digital technologies allows safety management to move beyond post-incident response toward preventive control, which directly corresponds to the risk-oriented principles articulated in international occupational safety standards.

Remote monitoring systems, intelligent sensors, and automated control platforms play a crucial role in reducing the probability of electrical injuries by enabling real-time supervision of operating parameters in power installations. As shown in the study, the ability to detect deviations from normal operating conditions—such as abnormal voltage levels, overheating, or insulation degradation—significantly reduces the likelihood of emergency situations. These

findings substantiate the practical relevance of integrating digital monitoring tools into occupational safety systems.

The use of IoT sensors installed on transformers, power transmission lines, and distribution boards enhances situational awareness and minimises the need for direct human interaction with hazardous equipment. By transmitting real-time data on voltage, current, temperature, and humidity, such systems provide an objective basis for timely intervention. This not only reduces the exposure of personnel to electrical hazards but also supports informed decision-making by operational and maintenance staff.

The application of drones and unmanned aerial vehicles for the inspection of power transmission infrastructure further expands the preventive potential of digital technologies. Thermal imaging and high-resolution visual diagnostics enable the identification of latent defects—such as overheating of insulators or connections—that may not be detected during routine inspections. The integration of these data into analytical platforms allows for the anticipation of potential failures hours or days before their occurrence, thereby reducing the likelihood of emergency interventions under high-risk conditions.

Artificial intelligence systems represent a key element in the transition from descriptive monitoring to predictive safety management. By analysing large volumes of historical and real-time data on equipment behaviour and incident occurrence, machine learning algorithms are capable of identifying hidden patterns and forecasting risk scenarios. The results of this study confirm that AI-based recommendations and personalised action plans enhance personnel preparedness and contribute to more consistent compliance with safety procedures.

The integration of digital work planning tools with PTW systems significantly strengthens organisational control over hazardous operations. Digital permits that clearly specify identified risks, required personal protective equipment, and evacuation routes reduce ambiguity and procedural violations. Automated blocking of unauthorised actions, such as energising equipment during maintenance, addresses one of the most common causes of fatal electrical accidents—human error during coordination of work activities.

Blockchain technology introduces an additional layer of reliability into safety management systems by ensuring the immutability and traceability of records related to inspections, maintenance, and repairs. The possibility of instant verification by auditors and inspectors enhances transparency and accountability, thereby reinforcing organisational discipline and regulatory compliance. This function is particularly relevant in high-risk industries where documentation integrity is critical for accident prevention.

Predictive maintenance enabled by digitalisation further contributes to risk reduction by shifting the focus from scheduled inspections to condition-based interventions. The analysis of vibration, noise, and electrical parameters allows potential failures to be identified before they escalate into emergency situations. As emergency repairs are associated with the highest levels of occupational risk, this approach has direct implications for reducing electrical injuries.

Biometric identification systems controlling access to hazardous zones address the problem of unauthorised or unqualified personnel performing high-risk tasks. Verification of medical clearance and qualification status before granting access ensures compliance with regulatory requirements and reduces the likelihood of accidents caused by insufficient training or health limitations.

At the same time, the findings indicate that digitalisation introduces new challenges that must be critically addressed. High initial investment costs, dependence on digital infrastructure, and the need for continuous system maintenance may limit the feasibility of implementation,

particularly for small and medium-sized enterprises. These constraints underscore the importance of economic justification and phased implementation strategies.

Cybersecurity emerges as a critical issue in the digital transformation of electrical safety systems. The increasing reliance on interconnected digital platforms exposes power installations to cyber threats that may compromise safety functions. The requirement for encryption, secure data transmission, and AI-based intrusion detection systems adds complexity to safety management and necessitates specialised competencies.

Another significant limitation identified in the discussion is the persistence of the human factor. While digital technologies reduce the probability of errors, they do not eliminate the need for qualified personnel capable of interpreting data, responding to alerts, and making responsible decisions. Without adequate training and a strong safety culture, technological solutions may lose effectiveness or even create new risks.

The results of the study therefore emphasise that digitalisation should be regarded not as a substitute for organisational, technical, and educational safety measures, but as a complementary component of an integrated safety management system. The effectiveness of digital tools is maximised only when they are embedded within a coherent regulatory framework and supported by continuous personnel training.

From a broader perspective, the discussion confirms the relevance of a systemic approach to electrical safety, in which regulatory compliance, organisational discipline, technical protection, and digital innovation operate as interconnected elements. Fragmented implementation of individual measures, regardless of their technological sophistication, is insufficient to ensure sustainable risk reduction.

An important implication of the obtained results is the need to adapt regulatory and methodological frameworks to the realities of digitalised energy systems. Existing normative documents often lag behind technological developments, creating gaps between legal requirements and practical safety management. Addressing this discrepancy represents a key challenge for policymakers and regulatory authorities.

Future research should focus on the empirical evaluation of digital safety solutions through pilot projects and longitudinal studies in real operating environments. Comparative analyses of different energy sectors and national contexts may provide valuable insights into the scalability and effectiveness of digitalisation strategies. Additionally, further investigation is required into the interaction between AI-driven decision support systems and human operators, particularly with regard to trust, responsibility, and ethical considerations in safety-critical environments.

Conclusion

Compliance with safety requirements during the performance of work in power installations is a decisive factor in preserving workers' life and health, as well as in ensuring the continuity of production processes. Work involving electrical energy belongs to the category of increased hazard, since even minor violations of established safety rules may result in severe injuries, electrical trauma, burns, fires, or fatal consequences. The conducted research confirms the persistent relevance of electrical safety issues under modern conditions of technological development and increasing operational complexity of energy systems.

The analysis of regulatory documents and operational practices related to power installations demonstrates that the predominant causes of occupational accidents are organisational deficiencies, insufficient supervision, violations of technological discipline, neglect of personal protective equipment, and inadequate personnel training. These findings indicate that technical

protection alone is insufficient and that electrical safety must be addressed as a systemic organisational and managerial task.

The study confirms that effective electrical safety is achieved through the integrated application of organisational and technical measures, including the issuance of work permits, safety briefings, knowledge assessments, the use of interlocking systems, grounding, protective barriers, warning signs, and modern monitoring and control devices. An essential condition for sustainable risk reduction is the use of certified personal and collective protective equipment in combination with continuous supervision and control.

A significant role is played by professional training of personnel, the development of a culture of safe behaviour, the formation of a responsible attitude towards work performance, and the continuous improvement of skills required for action in emergency situations. Regular training and drills contribute to minimising the human factor and increasing readiness to respond to hazardous situations.

Equally important is the implementation of modern monitoring, automation, and remote-control technologies, which reduce the need for direct contact between personnel and hazardous zones. The study demonstrates that digital solutions enhance the reliability of equipment operation and significantly decrease the likelihood of occupational injuries, particularly in high-risk operational scenarios.

The aim of the study—to analyse and substantiate effective mechanisms for ensuring electrical safety of personnel during work in power installations—has been fully achieved. The research has demonstrated that electrical safety under contemporary conditions can only be ensured through the coordinated interaction of regulatory, organisational, technical, educational, and digital measures.

By integrating the analysis of normative and legal frameworks with the assessment of organisational practices, technical protection measures, personnel training, and digital technologies, the study substantiates a comprehensive approach to reducing occupational electrical injuries. This approach is consistent with international risk-oriented safety management principles and responds to current challenges faced by the energy sector.

With regard to the first research objective, the study analysed the regulatory and legal framework governing electrical safety in power installations. It was established that national and international normative documents form a comprehensive system of mandatory requirements that define organisational responsibilities, technical standards, and personnel qualification criteria aimed at preventing electrical injuries.

In addressing the second objective, the research identified key organisational and technical measures for preventing electrical injuries. The results confirm that work permit systems, supervision, technical interlocks, grounding, and protective barriers are fundamental elements of effective safety management, particularly when applied in a coordinated and systematic manner.

The third research objective focused on assessing the role of personnel training and risk management. The study demonstrates that regular training, knowledge assessment, and risk identification significantly reduce the influence of the human factor and enhance personnel readiness to act safely under both normal and emergency conditions.

In fulfilling the fourth objective, the impact of digital technologies on electrical safety was examined. The findings show that digital monitoring systems, IoT sensors, artificial intelligence, predictive maintenance, and automated permit-to-work platforms substantially enhance preventive safety by enabling early detection of hazards and reducing direct human exposure to dangerous environments.

Finally, in relation to the fifth objective, the study substantiated directions for reducing occupational electrical injuries. It was determined that sustainable risk reduction is achieved through the integrated combination of regulatory oversight, responsible management, professional personnel training, technical protection, and the implementation of innovative digital solutions.

Ensuring electrical safety in power installations requires a comprehensive and multidimensional approach that integrates legal regulation, organisational discipline, technical solutions, digital innovation, and continuous personnel training. The implementation of the measures substantiated in this study contributes to a reduction in occupational injuries, an increase in the level of electrical safety, the preservation of human potential, and the formation of a safe working environment.

Further research should focus on the empirical validation of digital safety solutions, the adaptation of international experience to national energy systems, and the development of regulatory models that adequately reflect the realities of digitalised power installations.

Conflict of Interest

The author declares that is no conflict of interest.

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Appendix

Table 1. Reasons for the Importance of Organisational Electrical Safety Measures

№	Reason for Importance	Explanation and Consequences of Non-Compliance
1	The human factor is the primary cause of electrical injuries	According to statistical data, approximately 70–85% of accidents in electrical installations occur as a result of violations of organisational safety measures.
2	Prevention of accidental energisation	In the absence of work permits and warning signs, electrical power may be mistakenly supplied to a team working on a de-energised line.
3	Control of team composition and personnel qualification	Allowing personnel without the appropriate authorisation level or without mandatory safety briefings almost inevitably leads to severe injury or fatal outcomes.
4	Continuous supervision of work activities	Without an assigned supervisor, a worker may unintentionally come into contact with live conductive parts that remain energised.
5	Ability to respond promptly to changing conditions	Work interruptions, changes in weather conditions, or the appearance of unauthorised persons require re-issuance or adjustment of work permits.
6	Significant reduction in injury rates	Enterprises that strictly comply with organisational safety measures demonstrate injury rates that are 3–10 times lower than those with inadequate compliance.
7	Legal requirement	Non-compliance with organisational safety measures constitutes a violation of RLAOS, RAEI, and the Labour Code of Ukraine and may result in administrative fines imposed by the State Labour Service, as well as criminal liability in cases of severe consequences.

Table 2. Reasons for the Importance of Technical and Personal Electrical Safety Measures

№	Reason for Importance	Explanation / Consequences in the Absence of These Measures
	A direct physical barrier between a person and electric current	Organisational measures control the work process, whereas technical measures physically prevent electric current from passing through the human body.
	Protection against human errors and accidental contact	Even in the event of organisational failures (e.g. accidental energisation), residual current devices (RCDs) and grounding systems can save lives.
	Compensation for deficiencies in organisational safety measures	In the absence of warning signs, portable grounding devices or insulating gloves still provide effective protection.
	Reduction of the effects of electric arcs and burns	Dielectric clothing, helmets, and face shields significantly reduce the severity of injuries caused by electric arcs, which are among the most frequent accident scenarios.
	Protection against step and touch voltage during emergencies	Dielectric footwear combined with insulating mats is often the only safe means of leaving a zone affected by emergency grounding.
	Enables work under voltage (live working)	Without essential protective equipment (insulating rods, gloves), such work is prohibited and cannot be performed safely.

	Significant reduction of electrical injury risk	Statistical data indicate that 70–90% of survivals during contact with live voltage are attributable to the use of personal protective equipment and technical safety measures.

Table 3. Personal Protective Equipment

Equipment	Purpose
Dielectric gloves	Hand protection
Safety helmet	Head protection
Insulating rods	Live working

Table 4. Reasons for the Importance of Technical and Personal Electrical Safety Measures

№	Reason for Importance	Explanation of Risk Management
1	Enables early identification of hazards	Instead of reacting to an accident, risk management focuses on prevention, for example by replacing obsolete or deteriorated equipment in advance.
2	Prioritises resources by risk level	Not all areas present the same level of danger; priority is given to critical zones such as explosive, high-voltage, or humid environments.
3	Integrates all safety measures into a unified system	Organisational, technical, and training measures operate together as an integrated system rather than as isolated elements.
4	Reduces the likelihood of severe consequences	Arc-flash risk assessment informs the selection of appropriate protective clothing, reducing injuries to burns instead of fatal electrical shock.
5	Supports compliance with legislative requirements	In Ukraine, risk assessment is a mandatory component of occupational health and safety management systems.
6	Protects company reputation and financial stability	Accidents lead to fines, litigation, downtime, and compensation costs, whereas risk management contributes to cost reduction and economic stability.
7	Establishes safety as a continuous process	Risks evolve due to new equipment, maintenance activities, or external factors; therefore, continuous monitoring and reassessment are required.