https://www.sworldjournal.com/index.php/swj/article/view/swj35-01-023
DOI: 10.30888/2663-5712.2026-35-01-023

INTERDISCIPLINARY RISK ANALYSIS: ENSURING THE RELIABILITY OF THE POWER SYSTEM WITH HIGH RESEARCH AND DEVELOPMENT INFILTRATION THROUGH A RAPID RESPONSE METHODOLOGY

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Abstract. *The sustainability of the energy sector requires the implementation of a synergistic comprehensive approach that combines the implementation of technological innovations, effective management and a risk management system. Against the background of the intensification of the infiltration of renewable energy sources in the national energy system, there is a need to integrate innovative approaches to rapid response. Modern open modular digital platforms and electricity storage systems, intelligent multi-agent control systems, Internet of Things technologies and digital financial instruments allow not only to proactively respond to risks, but also contribute to increasing the reliability of the energy system. The study highlights the importance of smart power supply networks (Smart Grid), which actively involve information and communication technologies for more effective power supply management, flexible energy system management, and rapid response to potential risks.*

Keywords: *power system, sustainability, risks, renewable energy sources, smart grids (Smart Grid), modular platforms, infiltration, digitalization.*

Introduction

The destruction of Ukraine's energy infrastructure by Russia's military intervention has led to significant losses in capacity: 78% of thermal power plants, 44% of nuclear power capacity, 75% of wind power capacity, and more than 20% of solar power capacity were lost in the first year of the invasion. The strategy for maintaining energy sustainability to support the national energy system must be based on diversifying supply sources, stimulating the development of alternative energy, and public-private partnerships in the industry. In addition, a special role is assigned to risk prevention and the integration of rapid response methods in the context of high penetration of renewable energy sources, i.e., an increase in their share in the overall energy balance with the gradual replacement of fossil fuels.

Literature Review

The subject matter of the article is one of the hot topics in contemporary scientific discourse. In particular, scientists S. Stepanenko et al. [1], F. Medvid [2], R. Bayindir et al. [3] are investigating the interrelationships between economic growth, social responsibility, and energy diversification, while M. Tuballa, M. Abundo [4], A. Khotyan, V. Rosen [5], M. De Rosa et al. [6] are developing a concept for the development of energy systems that are adaptive and resilient to current challenges. General approaches to the development of alternative energy in crisis conditions are presented in publications by A. Sutrisno et al. [7], R. Thaler, V. Hofmann [8], R. Østergaard et al. [9], which focus on the role of institutional support, consideration of the regional specifics of alternative sources, and stimulation of the investment process.

An analysis of current research in the field highlights the relevance of creating national synchronization standards for small power generation sources, which will minimize risks in the field of energy supply, combine energy from different sources, and increase the reliability and efficiency of the power supply system, especially in conditions of distributed generation. It is evident that the issue is interdisciplinary in nature and requires further research into specific aspects.

The purpose of the study is to conduct a comprehensive analysis of modern approaches to risk prevention and energy system stability support in the context of high penetration of renewable energy sources using rapid response techniques.

Research Results

Energy systems are currently undergoing a series of transformations in their operational work due to the rapid growth in the number of renewable energy sources. It is clear that not only control systems need to be upgraded, but also aspects of operational robotization, automatic load distribution, and prevention of related risks.

Innovative power distribution control systems and Smart Grid intelligent technology platforms offer new opportunities to ensure the reliability of the power system, as they enable power companies to “smooth out” electricity demand at times of peak load, minimize the need for additional investment, and prevent key risks [10]. Thus, the priority aspects of the new technological paradigm in the energy sector, given the high penetration of renewable sources, are currently positioned as follows intelligent multi-agent control systems, open modular digital platforms and electricity storage systems, Internet of Things technologies (actuators, digital sensors, etc.); digital financial technologies (smart contracts, blockchain, etc.) (Fig. 1).

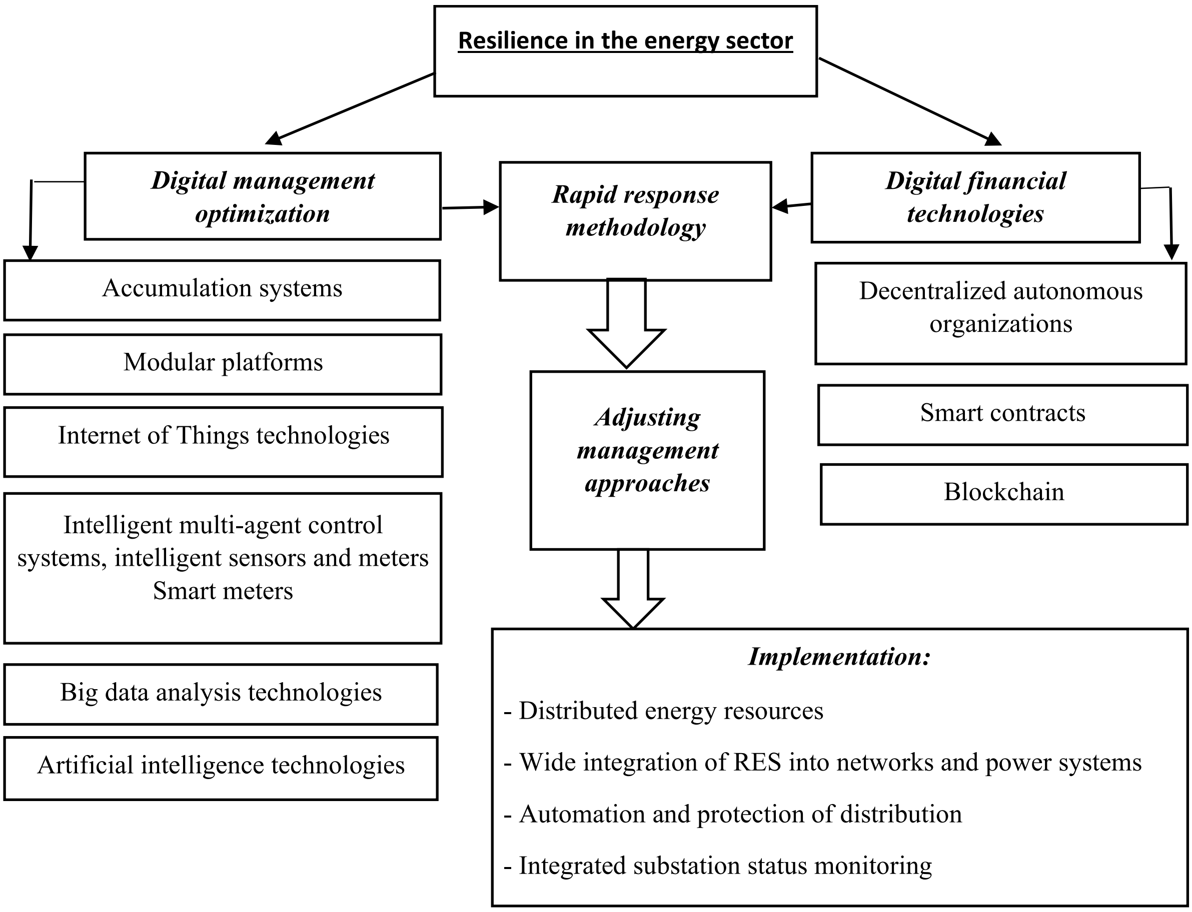

Figure 1 - Algorithm for ensuring power system stability with high penetration of renewable energy sources

Source: author's development

At the beginning of 2022, the installed capacity of renewable energy in Ukraine reached 10 GW. The prolonged war caused a significant drop in the share of RES in total electricity production (Fig. 2): from 13.4% in 2022 to 5-6% as of 2024 [11].

The Smart Grid is currently positioned as a relevant concept for electrical networks, actively utilizing information and communication technologies for more efficient power supply management, using digital technologies for data collection and exchange, which allows for more flexible and efficient power system management, respond quickly to accidents, reduce production costs, and increase consumer engagement. Smart Grid involves the use of smart meters, automation of load management by automatically switching consumers to more favorable tariffs or reducing the load during peak hours, as well as the development of energy storage systems and reduction of environmental impact [12].

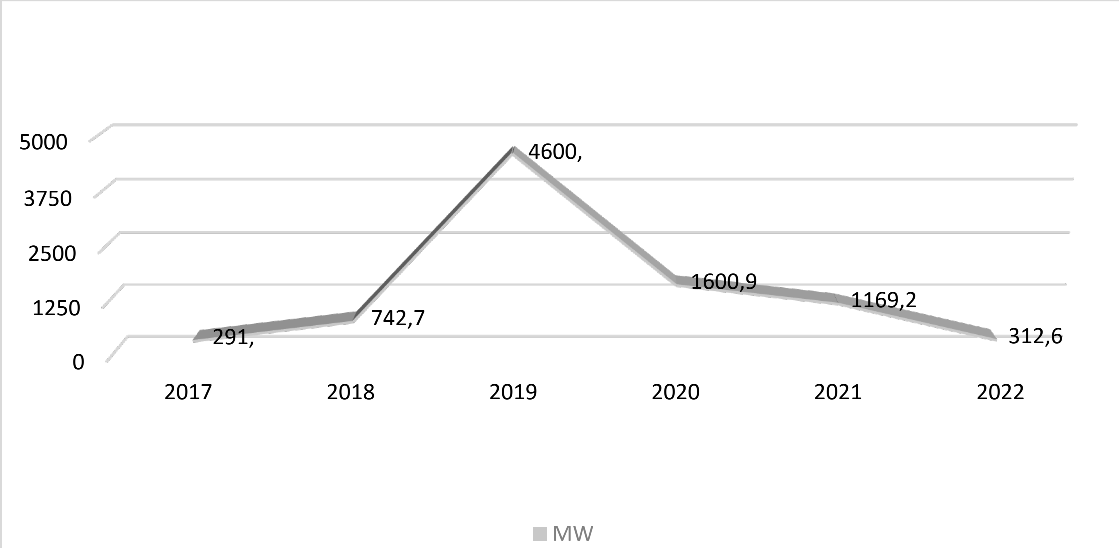

Figure 2 - Dynamics of renewable energy capacity in Ukraine, MW.

Source: systematized by the author based on [11]

A separate problem is potential frequency fluctuations due to network overload. Today, it seems necessary to develop a special frequency synchronization standard that will allow maintaining the set base frequency even without major power plants, in order to prevent the problem of rolling blackouts without the possibility of forming autonomous areas [13]. Correcting the situation at the standard level will ensure the accuracy and reliability of the system, uninterrupted operation of systems even in the presence of interference, as well as flexibility in the context of adaptation to different requirements and conditions, and interoperability (different systems can interact effectively with each other using a single synchronization standard).

Intelligent switching systems are positioned as effective modern solutions for managing and optimizing the switching (connection) of various devices or networks, managing power distribution, optimizing load, and improving the reliability of power supply [7]. Smart switching systems can analyze traffic and network performance data to ensure optimal data routing and minimize delays; they can automatically configure and reconfigure the network depending on needs and conditions; they use analytics to detect anomalies and problems in the network, block threats, and predict future needs.

Unlike traditional systems, where energy is transmitted in only one direction, a smart power grid provides two-way communication and control at all levels, from the electricity producer to the end consumers. Smart switching is currently being implemented in the context of the high-voltage side, but it seems necessary to further expand it to the low-voltage side and the consumer side, using the same protocols [14].

An innovative solution within the rapid response system with high-RES penetration is positioned as electricity distribution management. Its functions include optimisation of network assets, minimisation of peak demand, and ensuring reliable and efficient electricity supply. Since modular electricity distribution management system platforms enable dispatchers to monitor the status of all assets in real time, information about distributed energy sources and smart metering infrastructure becomes available in a single interface format for more meaningful risk analysis [15].

New features of industry platforms (such as Oracle Utilities Network Management System) include a mobile interface that allows dispatchers to communicate quickly with field repair crews, as well as security features that alert dispatchers to risks. Complete monitoring of the distribution network is carried out using distributed sensors, smart metering infrastructure, a dispatching and data collection system (SCADA), a geographic information system (GIS), and other end devices on a single platform [2, 6].

Thus, modern rapid response systems with high-RES penetration include approaches to electricity generation and distribution management that enable energy companies not only to manage effectively, but also to detect, warn, or eliminate network malfunctions in a timely manner before an emergency situation arises, implement global monitoring systems and integrated network management system elements.

We can observe the assimilation of three key market segments: resilient and flexible networks, consumer services, and intelligent distributed energy. The Smart Grid concept should be viewed as an innovative approach to rapid response systems, an integrated, reliable power system that combines energy generation, distribution, and end consumption based on innovative approaches to monitoring, communication, analysis, and dynamic control [4, 10].

The implementation of the Smart Grid concept is impossible without transforming approaches to management and institutional support for the industry, physically upgrading generating and network equipment, and stimulating economic interaction from the local to the national level. The proposed approach will enable a qualitative transformation of the reliability of energy supply with high-RES penetration by increasing the levels of digitalization, automation, and intelligence at all levels of market operations management systems and power system functioning.

Conclusions and Prospects for Further Research

Improvements in distribution network management systems, integrated emergency shutdown management systems, and Smart Grid intelligent technology platforms offer new opportunities for ensuring the reliability of the power system, including the elimination of power supply interruptions and the coordination of peak load times, the prevention of risks to ensure increased fault tolerance, the reduction of peak loads on the system, the optimization of network assets, and the formation of a modular and flexible platform for an integrated network and secure infrastructure. Decentralized energy management systems allow for the most effective control and monitoring of the power of all electricity generators, ensuring a rapid response to challenges in conditions of high infiltration of renewable energy sources.

A promising area for future research is the development of practical implementation of “smart” platforms for managing a rapid response system in a complex energy environment where renewable energy is actively developing, which will be of particular importance during the post-war reconstruction of Ukraine.

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