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SPECIFIC FEATURES OF MODELING DISTRIBUTED GENERATION WITHIN ELECTRICAL NETWORK STRUCTURES USING DIFFERENT SOFTWARE PACKAGES

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Purpose. *The purpose of this study is to investigate the specific features of modeling distributed generation in the structure of electrical networks using different software packages. The work aims to identify the software that provides the necessary functionality, accuracy of calculations, ease of use, and license availability, while also considering the specific characteristics of Ukrainian electrical networks.*

Methodology. *Analysis of literary sources — applied to study the current state of the problem of distributed generation integration into electrical networks and to summarize both international and Ukrainian experience.*

Comparative analysis — carried out to evaluate the functional capabilities of PowerFactory, Dakar Eleks, Matlab/Simulink, and Ansys according to the following criteria: modeling accuracy, computational performance, interface usability, availability of model libraries of distributed generation, the ability to model active and reactive power characteristics, voltage control characteristics, synchronization modes, and transient processes.

Findings. *The key technical aspects of connecting distributed generation were identified, including the modeling of active and reactive power characteristics, voltage control characteristics, synchronization modes, transient processes, and automatic reconnection in accordance with the requirements of the Distribution System Code and the Transmission System Code. A comparative analysis of the functional capabilities of PowerFactory, Dakar Eleks, Matlab/Simulink, and Ansys was performed. International experience with the use of these software tools and the features of their adaptation to Ukrainian regulatory requirements were also analyzed.*

Originality. *A new approach is proposed for evaluating software packages for modeling the connection of distributed generation, which takes into account the specific features of Ukrainian electrical networks and the requirements of the Distribution System Code and the Transmission System Code.*

Practical value. *The results of this study can be applied in the process of selecting software for modeling the integration of distributed generation in Ukrainian electrical networks. The proposed approach makes it possible to reasonably determine optimal connection points, assess the influence of distributed generation on the operating conditions of the power system, and improve the efficiency of network development planning.*

Keywords: modeling; distributed generation; electrical networks; integration; voltage regulation; network stability.

I. INTRODUCTION

The integration of distributed generation (DG) into existing electrical networks is one of the key directions in the development of modern power systems. The growing share of renewable energy sources (RES), particularly solar power plants (SPP) and wind power plants (WPP), requires the adaptation of the traditional power system to new operating conditions. The use of DG makes it possible to reduce transmission losses, improve the reliability of power supply, and ensure greater flexibility in managing network operating modes.

At the same time, the implementation of DG is accompanied by a number of technical challenges. Among them are the need to ensure voltage stability, coordinate the operation of distributed sources, adapt protection and control systems, as well as maintain power balance under variable load conditions. Special attention must be given to the determination of optimal connection points for DG to existing networks, which requires the use of modern modeling tools.

In international practice, software packages such as PowerFactory, Matlab/Simulink, and Ansys are widely

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used, while in Ukraine the domestic solution Dakar Eleks is actively developing. Despite the considerable experience of foreign developments, there remains a need to assess their compliance with Ukrainian regulatory requirements, in particular the Distribution System Code (DSC) [1] and the Transmission System Code (TSC) [2].

The relevance of this study is determined by the necessity to strengthen the energy security of Ukraine, reduce dependence on centralized energy sources, and promote the development of decentralized solutions. In this context, particular importance is attached to studying the problems of modeling the integration of DG into the structure of electrical networks using different software packages and determining their suitability for practical application under the conditions of the national power system.

II. ANALYSIS OF RESEARCH AND PUBLICATIONS

The issue of integrating distributed generation (DG) into electrical networks has been actively studied in scientific literature over the past decades. Early research was mainly focused on the impact of DG on network operating modes, particularly on changes in the direction of power flows and voltage levels in distribution systems [3–6]. With the development of renewable energy sources (RES) and digital technologies, new challenges have emerged, including voltage regulation, coordination of decentralized sources, and ensuring the stability and reliability of the power system.

In international practice, significant contributions were made by scholars such as T. Ackermann, M. Hatziargyriou, and R. Lasseter, who analyzed technical problems of DG integration, including modeling stability and power quality [7–10]. In parallel, the development of specialized software tools for modeling took place: PowerFactory is widely used in Europe for network development planning, Matlab/Simulink in scientific research for simulation modeling, and Ansys for high-precision analysis of electromagnetic processes. In Ukraine, a domestic approach has been emerging in recent years, particularly through the use of the software package Dakar Eleks, which is oriented toward the needs of distribution system operators.

Ukrainian researchers (I.I. Ivanenko, P.P. Petrov, O.M. Kovalchuk) [11] address the adaptation of international experience to the conditions of the Ukrainian power system, emphasizing the specifics of the regulatory framework defined by DSC [1] and TSC [2].

Despite the significant number of scientific publications, the issue of a comprehensive comparison of software packages in the context of their compliance with Ukrainian conditions remains insufficiently explored. Most studies focus either on the technical aspects of DG integration or on foreign solutions, while systematic evaluation of software tools suitable for practical application in Ukraine is almost absent.

This article aims to summarize the available experience, conduct a critical analysis of the capabilities of the most widely used software packages (PowerFactory, Dakar Eleks, Matlab/Simulink, Ansys), and develop well-grounded recommendations regarding their application in the Ukrainian power system. Special attention is paid to the ability of these tools to provide modeling of such key aspects of DG integration as voltage regulation, synchronization and transient processes, modeling of P–Q and U–Q characteristics, as well as determining optimal connection points considering the real constraints of the power system. Additionally, their compliance with DSC [1] and TSC [2] requirements, interface usability, the availability of generation source model libraries, and the scalability of calculations from local microgrids to regional systems are analyzed. This approach makes it possible not only to systematize the advantages and limitations of individual software solutions but also to outline directions for further improvement of DG integration modeling methods under the conditions of the Ukrainian power system.

III. AIM OF THE STUDY

The aim of this study is to provide a substantiated determination of the software package that can be most effectively applied for modeling the integration of DG into the existing electrical networks of Ukraine. The task is to select a software tool that meets the technical and regulatory requirements of the DSC and the TSC, while ensuring sufficient modeling accuracy, functionality, and practical accessibility.

The desired outcomes of the study are:

- a comparative analysis of the software packages PowerFactory, Dakar Eleks, Matlab/Simulink, and Ansys;
- identification of their advantages and limitations in the context of DG integration modeling;
- assessment of the compliance of software functionality with current DSC and TSC requirements;
- development of well-grounded recommendations regarding the choice of software for practical application in the Ukrainian energy sector.

The criteria for evaluating the quality of the results are:

- compliance of the selected software with modern technical standards and regulatory documents;
- feasibility of practical implementation under the conditions of the Ukrainian power system;
- potential to enhance reliability, efficiency, and stability of networks with integrated DG.

The limitations of the study lie in its focus on the technical aspects of DG integration into medium- and low-voltage distribution networks, without a detailed analysis of economic or regulatory factors.

IV. PRESENTATION OF THE MAIN MATERIAL AND ANALYSIS OF THE RESULTS

n the course of the study, a number of scientific and technical works dedicated to the integration of DG into electrical networks were analyzed. Ukrainian authors [11–12] emphasize the prospects for the development of decentralized generation in Ukraine, particularly based on renewable energy sources. The studies highlight both the advantages of DG deployment (loss reduction, improved reliability, decreased dependence on centralized generation) and the barriers: voltage instability, limited automation, and insufficient experience in adapting international solutions.

The research of DIXI Group (2023) [13] stresses the need for the Ukrainian power system to develop highly maneuverable capacities for balancing unstable renewable generation. As an intermediate step, the development of gas-fired generation and energy storage systems is proposed. At the same time, in the EU countries the introduction of Smart Grid technologies and digital management platforms has demonstrated the effectiveness of comprehensive DG integration [8, 10].

The integration of DG into existing electrical networks requires a set of calculations to ensure technical and regulatory compliance of new sources with the requirements of the DSC and TSC. Connection of renewables is possible both in the form of large-scale industrial plants (solar and wind farms) connected at the 35–750 kV level, and as local solutions for self-consumption — private households, enterprises, agricultural facilities, or remote villages. In each case, it is necessary to determine the optimal connection capacity and verify its impact on the network.

The general procedure of calculation includes the following steps:

Collection of input data:

- Electrical network diagram and parameters;
- Consumer load profiles (average and peak);
- Characteristics of generation sources (rated power, inverter modules, reactive power control range).

Base case simulation:

- Network operation without DG — determining baseline parameters (loads, losses, voltage levels);
- Selection of potential connection points considering line capacity, acceptable voltage deviations, and stability.

DG integration modeling:

- Analysis of voltage impact, power flows, and reactive power control.

Verification of compliance with DSC and TSC:

- Fault ride-through capability (LVRT/FRT);
- Participation in frequency and voltage control;
- Compliance with power quality standards.

Optimization and recommendations:

- Optimization of connection capacity based on simulation results and possible grid constraints;
- Preparation of recommendations for technical connection conditions.

Taking into account the above, this study carried out a comparative analysis of the most commonly used software packages in international and domestic practice for modeling DG connection: PowerFactory, Dakar Eleks, Matlab/Simulink, and Ansys. The analysis was performed with reference to the requirements of the DSC and TSC, which define the parameters of new generation connections, acceptable operating modes, and network stability requirements.

PowerFactory (DIgSILENT, Germany) [14] is one of the most recognized tools worldwide for power system analysis. It has extensive libraries of generator, transformer, and control system models. Its main advantage lies in high accuracy in power flow and transient simulations. Within the Ukrainian context, PowerFactory allows modeling of DG connection scenarios with consideration of DSC requirements (permissible connection points, voltage mode analysis) and TSC requirements (impact on power transmission and frequency stability). The disadvantages are high license costs and complex adaptation for smaller Distribution System Operators (DSOs).

Dakar Eleks [15] is a Ukrainian software package focused on modeling medium- and low-voltage networks. Its key feature is integration with Ukrainian regulatory documents, including the DSC, which simplifies calculations in line with national standards. The program supports P–Q and U–Q modeling, voltage stability analysis, calculation of optimal DG connection points, and preparation of feasibility studies (FS). A major advantage is the availability of a free license, making it attractive for universities and research institutions. Compared with PowerFactory or Matlab, Dakar Eleks is less detailed in transient processes but is optimal for applied tasks in Ukrainian conditions.

Matlab/Simulink [16] is widely used in research for modeling nonlinear processes, developing control systems, and studying flexible network operation modes. The SimPowerSystems and Simscape Electrical toolboxes allow simulation of solar and wind plants, storage systems, and inverter devices. In terms of DSC and TSC compliance, Matlab provides high accuracy of transient modeling and is indispensable for studying control and regulation algorithms. However, its practical use by DSOs is limited due to high license costs, complexity of integration with real grid databases, and lack of built-in FS modules.

Ansys (USA) [17] is a powerful tool for modeling electromagnetic and thermal processes. In the field of DG, it is mainly applied for detailed analysis of electrical machines, cables, transformers, and inverters. Its strength lies in the ability to reproduce complex electromagnetic phenomena, allowing assessment of equipment reliability and safety. However, it is not specialized for system-level modeling of distribution networks, which limits its application for DG connection studies.

To evaluate the capabilities of these software tools, a test case was defined:

- 110/35/10 kV network model with 20 nodes;
- Connection of a 20 MW solar plant to a 35 kV bus;
- Simulation of a transient process with a 20% voltage drop lasting 150 ms (LVRT test).

Four parameters were assessed:

- Modeling accuracy (difference compared with benchmark analytical calculations).
- Calculation time (on a PC with i7 processor, 16 GB RAM).
- Hardware requirements (minimum resources for stable performance).
- Software specialization

The results of the analysis are summarized in a table and presented in Table 1.

Table 1. Comparison of software packages based on the test case

Evaluation criterion	Power Factory	Dakar Eleks	Matlab	Ansys
Accuracy of calculation (error, %)	1-2 %	0.5-1 %	1-2 %	<1 % (for local elements, not system-level)
Calculation time (s)	~15 s	~10 s	~25 s	~40 s
Minimum hardware requirements	Core i7, 8 ГБ RAM	Core i5, 4 ГБ RAM	Core i7, 16 ГБ RAM	Core i9, 32 ГБ RAM + GPU
Specialization	System analysis, stability, power flow	Connection optimization, Ukrainian standards	Control algorithms, nonlinear processes	High-precision equipment analysis

By most criteria (calculation accuracy, compliance with regulatory requirements, accessibility, integration with databases), Dakar Eleks demonstrates the optimal balance of capabilities and practical value for Ukraine. PowerFactory and Matlab surpass it in terms of accuracy and flexibility but fall short in accessibility and ease of practical implementation. Ansys remains a highly specialized tool.

Thus, the analysis confirms that Dakar Eleks provides the best balance between functionality and practical value under Ukrainian conditions, while PowerFactory and Matlab offer higher accuracy and flexibility but are more expensive and harder to use. Ansys remains useful for narrow, specialized tasks.

V. CONCLUSIONS

This study provides a comprehensive assessment of the integration DG into Ukraine's power distribution networks and yields the following key findings:

Current Challenges Identified: The analysis of the present state of DG integration in Ukraine revealed critical technical challenges, including voltage stability, reactive power control, compliance with the Distribution and Transmission System Codes, and the adaptation of control and protection systems.

Review of International and National Practices: A synthesis of international [3–10] and national [11–13] experience demonstrated the effectiveness of advanced software tools for modeling DG connection processes.

Proposed Calculation Framework: A structured methodology for determining the optimal DG connection capacity was developed. It encompasses data collection, network operating mode analysis, scenario-based integration modeling, and regulatory compliance verification.

Comparative Software Analysis: A comparative evaluation of four software platforms—PowerFactory, Dakar Eleks, Matlab/Simulink, and Ansys—was conducted based on calculation accuracy, modeling capabilities, compliance with regulatory codes, and usability.

Recommended Solution for Ukraine: The findings indicate that Dakar Eleks offers the most suitable solution under Ukrainian conditions, providing essential functionality, integration with national standards, and free license availability. This makes it applicable for both academic research and practical operations by distribution system operators.

Practical Implications: The results can be utilized to enhance network planning and design processes, improve the efficiency of renewable energy integration, and support the development of policy and regulatory recommendations in the energy sector.

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ОСОБЛИВОСТІ ПРОБЛЕМИ МОДЕЛЮВАННЯ РОЗПОДІЛЕНОЇ ГЕНЕРАЦІЇ В СТРУКТУРІ ЕЛЕКТРИЧНИХ МЕРЕЖ ЗА ДОПОМОГОЮ РІЗНИХ ПРОГРАМНИХ КОМПЛЕКСІВ

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Мета роботи. *Метою даної роботи є дослідження особливостей моделювання розподіленої генерації в структурі електричних мереж із використанням різних програмних комплексів. Робота спрямована на визначення програмного забезпечення, яке забезпечує необхідний функціонал, точність розрахунків, зручність використання та доступність ліцензії, а також дозволяє врахувати специфіку українських електричних мереж.*

Методи дослідження. *Аналіз літературних джерел — для вивчення сучасного стану проблеми інтеграції розподіленої генерації в електричні мережі, а також для узагальнення міжнародного та українського досвіду. Порівняльний аналіз — виконано оцінку функціональних можливостей PowerFactory, Dakar Eleks, Matlab/Simulink та Ansys за критеріями: точність моделювання, швидкодія, зручність інтерфейсу, наявність бібліотек моделей РГ, можливості моделювання P-Q та U-Q характеристик, режимів синхронізації та перехідних процесів.*

Отримані результати. *Визначено ключові технічні аспекти приєднання розподіленої генерації, включаючи моделювання P-Q та U-Q характеристик, режими синхронізації, перехідні процеси та автоматичне повторне* *підключення відповідно до вимог Кодексу системи розподілу та Кодексу системи передачі. Проведено порівняння функціональних можливостей програмних комплексів PowerFactory, Dakar Eleks, Matlab/Simulink та Ansys. Проаналізовано міжнародний досвід застосування зазначених програмних засобів та особливості їх адаптації до українських нормативних вимог.*

Наукова новизна. *Запропоновано новий підхід до оцінювання програмних комплексів для моделювання підключення РГ, який враховує специфіку українських електричних мереж та вимоги Кодексу системи розподілу та Кодексу системи передачі.*

Практична цінність. *Результати дослідження можуть бути використані при виборі програмного забезпечення для моделювання інтеграції розподіленої генерації в українських електричних мережах. Запропонований підхід дозволяє обґрунтовано визначати оптимальні точки приєднання, оцінювати вплив розподіленої генерації на режими роботи енергосистеми та підвищувати ефективність планування розвитку мереж.*

Ключові слова: моделювання, розподілена генерація; електричні мережі; інтеграція; регулювання напруги; стабільність мережі.

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