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Research on the Selection and Layout Scheme of Main Transformers in the Primary Electrical Design of New Energy Step-Up Stations

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Abstract: This paper focuses on the research of the main transformer selection and layout scheme for new energy step-up substations. From the perspective of engineering design, it analyzes the principles of main transformer selection, key parameters, and their matching with the characteristics of new energy. It also explores the layout methods and optimization strategies. Combined with typical case studies, optimization suggestions are proposed for the design of main transformers in new energy step-up substations. The research shows that rational main transformer selection and scientific layout schemes can better adapt to the characteristics of new energy projects while effectively improving land use efficiency and economic viability. This study can provide technical experience support for the design of new energy projects.

Keywords: New energy step-up substation; Engineering design; Main transformer selection

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1. Introduction

Step-up stations serve as critical interfaces connecting renewable energy to the grid, with their design quality directly impacting system efficiency, safety, and stability. As core equipment, main transformers' selection and layout influence not only power transmission efficiency but also determine overall system reliability and economic performance. Research on transformer selection principles, arrangement methodologies, reliability-economic analysis, and optimization strategies carries significant theoretical and practical value. From an engineering design perspective, this study explores optimized approaches for transformer design, providing empirical and technical support for renewable energy projects while facilitating efficient green energy utilization and advancing sustainable grid development.

2. Overview of the main transformer design of new energy step-up station

2.1. Key aspects of main transformer design

Main transformer design is the core task in renewable energy step-up station design. It primarily involves main transformer equipment selection and layout, while also encompassing other design elements like transformer grounding [1]. This requires comprehensive consideration of the project's actual needs, national standards and codes, industry regulations, as well as the latest advancements in manufacturing and installation techniques. The goal is to ensure the equipment selection and layout are technically and economically sound, enabling stable operation of the system and maximizing economic benefits.

2.2. Functions and characteristics of renewable energy step-up stations

New energy step-up substations (hereinafter referred to as "substations") play a key role in the power system by not only boosting voltage levels but also limiting short-circuit currents, optimizing power quality, controlling grid connection, and providing stability support to the power system [2]. In response to the intermittent and fluctuating characteristics of new energy power generation, substations need to be highly flexible and adaptable, while also meeting the special requirements of local power grids for new energy integration. In terms of layout, modular structures make the system more compact, reduce land occupation, and shorten construction periods, meeting the need for rapid deployment [3]. Overall, new energy step-up substations reflect the characteristics of efficiency, safety, economy, and flexibility in their functionality and design, ensuring the efficient transmission and utilization of new energy electricity.

2.3. Technical standards and specifications for main transformer design in new energy step-up substations

The design of step-up substations must strictly comply with relevant technical standards, specifications, and regulations. This ensures safe, reliable, and efficient operation while aligning advanced technologies with the current state of equipment manufacturing and construction practices [4].

During the design process, the referenced standards, specifications, and regulations include (but are not limited to):

A. Fire Protection Standard for Fossil Fuel Power Plants and Substations GB 50229-2019;
B. Design Specification for Selection of Conductors and Electrical Equipment DL/T 5222-2021;
C. Guide for Selection of Power Transformers GB 17468-2019;
D. Technical Parameters and Requirements for Oil-Immersed Power Transformers GB 6451-2015;
E. Code for Design of Photovoltaic Power Stations GB 50797-2012;
F. Code for Design of Wind Power Farms GB 51096-2015.

3. Selection analysis of main transformer

3.1. Principles and key parameters for main transformer selection

In primary electrical design of step-up stations, main transformer selection must follow principles of safety/reliability, adaptability to renewable generation characteristics, techno-economically sound solutions, and energy efficiency. Key parameters include rated capacity, voltage, short-circuit impedance, cooling method, and efficiency. Focusing on renewable project features, this study prioritizes analysis of rated capacity, short-circuit impedance, and cooling methods. Since efficiency directly impacts system losses and economics, high-efficiency transformers reduce operational costs and enhance renewable utilization [5]. Therefore, rational selection integrating parameters with project realities is undoubtedly significant for ensuring safe and efficient step-up station operation.

3.2. Main transformer capacity analysis

Transformer selection must account for the intermittent and variable nature of renewable energy generation. For PV step-up stations, some regions require transformer capacity ≥ DC capacity. However, actual AC capacity remains significantly lower than transformer capacity – oversized units cause resource waste and increased no-load losses. Designers should optimize capacity using local operational data. Given that well-sited turbines in wind projects exhibit less generation variability and day-night intermittency than solar, along with higher annual operating hours, selecting transformer capacity ≥ total generator capacity aligns with these characteristics. This approach is recommended as standard practice absent specific requirements. Additionally, configurations with fewer high-capacity units offer better economics and streamlined maintenance at equivalent capacities.

3.3. Short-circuit impedance analysis for main transformers

The impedance of the main transformer in new energy step-up substations should be determined according to the access design documents of the system or the opinions of local power authorities. Most of the short-circuit impedances of main transformers in domestic new energy projects are selected as standard impedances. However, with the rapid increase in new energy grid connection capacity in recent years, some regional power grids have requested that the short-circuit impedance of main transformers be designed with specified non-standard impedances. This study mainly analyzes the impact of non-standard impedance main transformers on the design of new energy step-up substations. As the capacity of individual main transformers in new energy step-up substations increases, the grid side may require the short-circuit impedance of the main transformer in new energy projects to be designed to specified non-standard parameters to facilitate protection settings. For example, some areas in Guangdong, based on local grid conditions, require new energy stations with high-capacity 110kV main transformers to use non-standard high impedance (much greater than 16%) to reduce the risk of false operation on the grid side.

Under the same capacity and voltage level, a non-standard design with increased transformer impedance will lead to greater losses. To meet energy-saving requirements, the cooling system needs to be appropriately modified. For transformers using self-cooling, the size of the heat dissipator after modification will increase, and designers should consider the impact of this change on the layout.

A higher impedance also affects the calculation results of short-circuit currents within the step-up substation. An increase in the main transformer impedance not only reduces ground fault current but also decreases the short-circuit current component flowing into the station during an external ground fault at the new energy station, thereby significantly reducing the current entering the ground. For new energy stations sensitive to ground current with high soil resistivity at the station site (2000Ω.m and above), the impact of high impedance should be fully considered during grounding design.

3.4. Analysis of main transformer cooling methods

For current domestic renewable energy projects, main transformers up to 240MVA primarily utilize self-cooling (ONAN) or forced-air cooling (ONAF), with selection requiring comprehensive consideration of environmental conditions, operational costs [6], owner maintenance practices, and national energy efficiency standards. Units below 180MVA are best suited for ONAN cooling to simplify systems, improve energy efficiency, and reduce maintenance burdens.

With recent scaling of renewable facilities, higher-capacity transformers at elevated voltage levels have prompted evaluation of alternative cooling methods. For instance, China's forward-looking research on 500kV distant offshore substations recommends closed-loop water cooling systems. This approach significantly enhances heat dissipation for large-capacity, high-voltage transformers where water access is feasible. Being more compact than air-cooled systems, water cooling also accommodates space-constrained offshore platforms. Note that water cooling demands stringent water quality standards, necessitating inclusion of filtration infrastructure maintenance costs in techno-economic analyses [7].

As critical equipment, transformer reliability directly impacts overall substation safety. Beyond the aforementioned parameters, designers should evaluate manufacturing quality, material selection, and supplier track record. Selecting rigorously tested and validated high-reliability products ensures secure system operation while maximizing cost-effectiveness throughout the lifecycle.

4. Study on layout schemes for step-up station main transformers

4.1. Design principles for main transformer layout

The layout of the main transformer should follow principles of safety, reliability, economy, and ease of maintenance [8]. The main transformer should maintain sufficient fire safety distances from other equipment to meet the fire prevention standards of the substation. Moreover, the layout form should prioritize the forms recommended by typical designs of major power generation groups or power grids, and make necessary optimizations based on the actual situation of new energy projects. The layout of the main transformer should also consider the convenience of maintenance and repair, leaving enough space and passages to ensure that routine inspections and fault handling of the main transformer and its supporting equipment can proceed smoothly. Additionally, for main transformers installed in special environments, the layout should take into account the impact of the special environment on installation, operation, and maintenance. For example, in offshore substations, the main transformer is preferably located in the center of the platform to facilitate control of the center of gravity and structural design. Considering the above principles comprehensively, the rational layout of the main transformer is of great significance for improving the design of new energy step-up substations.

4.2. Analysis of main transformer layout methods

Common layout methods include outdoor, indoor, underground, and containerized layouts, among others. When choosing the layout method for the main transformer, it is necessary to consider the specific circumstances of the project comprehensively, including environmental conditions, land limitations, economic costs, and maintenance requirements, to determine the most suitable plan [9]. The outdoor layout method, with its lower construction investment, shorter construction period, and mature installation and operation experience, fits the needs of new energy step-up substation projects and has become the recommended layout form in the typical design of new energy projects for most power generation groups in China. This paper will focus on discussing this layout method.

To meet the needs of new energy projects for reducing construction periods and saving land, containerized types have been widely applied. The layout coordination between the main transformer and the containerized types (especially the distribution equipment container) has become an important aspect of the main transformer area layout in current new energy step-up substations.

The coordination between the main transformer and the containerized types should meet the following points: A. The layout of the main transformer should comply with compact design requirements; otherwise, the space-saving advantages of the containerized layout cannot be fully utilized. B. The layout of the main transformer should accommodate the installation needs of the main transformer's low-voltage side conductors (or enclosed busbars), the containerized types, and the equipment inside the container. C. The compact layout plan should consider the requirements for the design of the containerized building and public equipment.

4.3. Analysis of the layout of the main transformer

The common layout methods of the main transformer include outdoor, indoor, underground, and containerized types. The selection should take into account the environmental conditions, land occupation restrictions, economic costs, and maintenance requirements [9]. Due to its low construction and installation investment, short construction period, and mature installation and maintenance experience, the outdoor layout meets the needs of new energy step-up substation projects and has become the recommended form in the typical design of new energy projects for most power generation groups in China. This paper focuses on this form. To meet the needs of new energy projects for shortening the construction period and saving land, containerized types are widely used. The layout cooperation between the main transformer and the containerized types (especially the distribution equipment container) is an important part of the main transformer area layout, and it needs to meet the key points such as compact main transformer layout, adaptation to installation requirements, and consideration of the design requirements for containerized types.

4.4. AI-assisted decision making

By integrating artificial intelligence (AI) technology, designers can more quickly access information on theories, technologies, and case studies, and receive relevant analyses and detailed recommendations. Utilizing AI for analysis not only saves time but also reduces the potential for oversights that can occur with manual analysis.

For instance, in the aforementioned case, after adopting a compact layout for the main transformer and the container, the use of leading domestic AI technology analyzed the impact of concentrating the HVAC units of the container on the outer wall away from the main transformer side on the heat dissipation effect of the equipment inside the container (distribution equipment room). This provided a more comprehensive assessment of the related impacts, confirmed the main transformer layout plan, and offered additional suggestions.

It should be noted that in this case, AI technology should currently be used as a decision-support tool rather than replacing designers in making decisions. For example, AI is more efficient in searching for non-specialized information and in analysis speed; however, in terms of detailed analysis in specialized fields, current models still require training. The professional experience of designers should complement AI, guiding it to conduct in-depth analysis in the direction of engineering needs, refining results to achieve optimal decision-making.

Through the application of AI technology, designers can identify and resolve potential layout conflicts and safety hazards in advance, optimize equipment layout plans, reduce engineering costs, formulate the best main transformer layout plan, and ensure the efficient and safe operation of new energy step-up substations.

5. Comprehensive optimization recommendations for primary electrical design of renewable energy step-up stations

5.1. Collaborative optimization of main transformer selection and layout

Transformer selection requires a holistic approach considering capacity, impedance, and cooling methods to ensure seamless integration with renewable energy project requirements. Through coordinated optimization of selection and layout, step-up stations achieve optimal performance-cost balance while securing safe, stable, and efficient system operation.

5.2. Challenges and countermeasures in renewable energy step-up station design

Grid requirements for renewable step-up stations increasingly feature customization and regional specificity. For key parameter selection of main transformers, configurations must effectively address local grid specifications. Designers should proactively communicate to strike a balance between cost-effectiveness and grid compliance [10].

5.3. Future development directions for renewable energy step-up station electrical design

Moving forward, electrical design for renewable step-up stations will evolve toward greater intelligence and efficiency. In intelligentization, advancements in IoT and AI technologies will streamline design decisions and enhance output quality. Additionally, modular and prefabricated design approaches will shorten construction timelines, reduce project costs, and strengthen adaptability to rapid renewable energy growth.

6. Conclusion

Main transformer design in renewable energy step-up stations holds critical importance for system safety and operational efficiency. Transformer selection and layout constitute central aspects of substation design, where scientific selection and cost-benefit analysis enhance equipment compatibility and reliability. Optimized layouts combined with AI-assisted decision-making reduce costs, simplify maintenance, and enhance efficiency. Collaborative optimization strategies tailored to renewable generation characteristics – alongside methodologies addressing design challenges – provide practical guidance for large-scale grid integration. Future substation design will evolve toward intelligentization, sustainability, and digitalization, facilitating energy transition and grid modernization.

Disclosure statement

The author declares no conflict of interest.

References

[1] Abdelhamid Younis E, 2023, Design Methodology for Medium-Frequency Transformer for Solid-State Transformer-Based DC Charging Stations, dissertation, McMaster University.

[2] Rehman A, Imran-Daud M, Haider SK, et al., 2022, Comprehensive Review of Solid State Transformers in the Distribution System: From High Voltage Power Components to the Field Application. Symmetry, 14(10): 2027.

[3] Liu F, 2024, Calculation of Neutral Grounding Method and Grounding Transformer Capacity for Photovoltaic Power Plants, 2024 International Conference on Power, Electrical Engineering, Electronics and Control (PEEEC), IEEE,

311–315.
[4] Alzahrani A, 2023, Energy Management and Optimization of a Standalone Renewable Energy System in Rural Areas of the Najran Province. Sustainability, 15(10): 8020.
[5] Penfield J, Holland M, 2021, Machine Learning Based Online Monitoring of Step-Up Transformer Assets in Electrical Generating Stations, 2021 9th International Conference on Smart Grid (icSmartGrid), IEEE, 32–36.
[6] Varganova AV, Irikhov AS, Utesheva AA, et al., 2024, Comprehensive Structural Reliability Assessment When Choosing Switchgear Circuits for 35–220 kV Step-Up Substations. Energies, 17(7): 1630.
[7] Htay AK, Tun HM, Win LLY, et al., 2024, Analysis of Step Up or Boost Converter Design for Charging Station of Electric Vehicles, International IOT, Electronics and Mechatronics Conference, Springer Nature Singapore, Singapore, 197–204.
[8] Marrapu SHN, Rathinadurai Louis J, 2024, Design and Analysis of Soft-Switching Isolated Step-Up/Down DC–DC Converter for Fuel Cell Vehicles and EV Battery Charging Applications. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 46(1): 17–38.
[9] Thango BA, Jordaan JA, Nnachi AF, 2020, Selection and Rating of the Step-Up Transformer for Renewable Energy Application. SAIEE Africa Research Journal, 111(2): 50–55.
[10] Calil WV, Costa ECM, Salles MBC, 2020, Methodology for Specification of Generator Step-Up Transformers in Photovoltaic Power Plants Based on Real Loading Profile, Doctoral thesis, Polytechnic School of the University of São Paulo.