Research on Assembly Automation Technology of New Prefabricated Transformer

Peifeng Pan, Zhiyi Yang, Longda Li, Xiaoying Zhu*, Tao Wu
State Grid Zhejiang Yinzhou District Power Supply Company, Ningbo 315100, China

*Corresponding author e-mail: 106749850@qq.com

Abstract. The technical field of transformers discussed in the paper relates to the production of lead wires, especially a factory-made prefabricated transformer with a new lead wire; its transformer includes a transformer main body and a new transformer lead wire connected to the main body of the transformer. The transformer lead wire includes a transformer lead wire, and a copper-aluminium terminal, a heat shrinkable tube, a composite insulator, a grounding test ring, a lightning arrester lead assembly, and a C-clamp are arranged in order from one end to the other end. The design of the new type lead wire transformer assembly can completely realize the factory prefabrication of the transformer lead wire, the manufacturing process is simple, and the construction time on site can be greatly reduced and the construction efficiency can be improved.

1. Introduction
With the gradual improvement of the high-voltage and ultra-high-voltage systems of the State Grid, backbone transmission lines of "three verticals, three horizontals" and "three intersections and four straights" have been formed, providing a solid backing for reliable power supply in the central and eastern regions and coastal areas. However, at present, the construction of urban and rural distribution networks in China is still at a relatively low level. In 2014, State Grid Corporation put forward the goal of achieving "two transformations" and creating "a world-class power grid and an international first-class enterprise", with an emphasis on "strengthening the construction of urban distribution networks." To promote the work requirements of intelligent grid ". The distribution transformer and its station area are the main equipment of the low-voltage distribution network. Its installation, construction, operation, stability and reliability directly affect the economic benefits and user experience of the entire power system. With the promotion of intelligent distribution integrated station area, State Grid Corporation announced the typical design of distribution network project (2016 version) to promote the standardization of distribution network construction, including 10kV integrated on-column substation and distribution complete sets of equipment The volume provides detailed solutions for the construction of integrated distribution areas in distribution networks. However, in the current construction of the power distribution station area, most of the structural accessories need to be manufactured and installed on site, resulting in a long construction time in the station area, a large amount of on-site work, and a serious waste of materials. In the process of wire production, especially the wiring of the transformer, it includes key processes such as wire
interception, bending, stripping, C-clamp installation, and insulator installation. The process is complex and time-consuming, requiring a lot of manpower and resources.

Based on this background, in view of the problems of low construction standardization, low on-site processing and installation efficiency and difficult civilized construction management in the installation process of distribution network bench-type transformers, the factory-made prefabricated bench-type transformer lead wires are proposed. Design standards, the machine replaces the manual, pre-fabricated the transformer lead wires in the installation company's factory in advance, innovative research and development to achieve automated wire feeding, cutting and end stripping, copper nose crimping of the lead wire, middle stripping, bending and assembly of the arrester, Grounding flat iron punching and spraying, wedge wire clip crimping and other complete automation equipment. Improve the construction efficiency and construction technology of Ningbo Power Grid's distribution network project [1].

2. Current transformer assembly status
At present, China's power development has entered the stage of large power grids, large generating units, high voltages, and high automation, which has put forward higher requirements for the safe and stable operation and safety management of power grids. The continuous operation of large-capacity, ultra-high voltage, AC-DC hybrid, and long-distance transmission projects has significantly increased the complexity of the power system, and it is crucial to strengthen the safety management of the power system and improve the stable operation level. Judging from the management process and construction status of the distribution network project of State Grid Corporation of China, the main existing problems in the distribution network project are:

(1) The construction is arbitrary and the standardization is not high. It is mainly reflected in the production and installation process, especially the randomness of the connection line direction and curvature, which is directly related to the installation skill level of the construction personnel.

(2) Material intensification and civilized construction management are difficult to implement in place. It is mainly reflected in the large randomness of the construction cutting, the accumulation of more residual materials, the construction site with more sporadic materials and tools, and the piles are messy.

(3) There are many on-site installation and production processes, and the work efficiency is not high. It is mainly reflected in the large number of machinery and facilities required for installation and production on the construction site. In addition, the poor construction site environment, low work efficiency, and difficult to control the operation time.

In view of the problems of low standardization of construction, low efficiency of on-site processing and installation, and difficult management of civilized construction in the process of distribution network engineering, the factory prefabricated bench-type transformer lead wires are proposed. Install the pre-fabricated transformer lead wires in the factory of the company in advance, innovatively develop and realize automatic wire feeding, cutting and stripping of the ends, copper nose crimping of the lead wires, middle stripping, bending and assembly of the arrester, grounding flat iron punching and spray, A full set of automation equipment such as wedge wire clamp crimping, improve the construction efficiency and construction technology of the Ningbo power grid distribution network project [2].

3. Basic content and innovation of the project
The project revolves around the research on the key technology of bench-type transformer lead wiring assembly automation. There are three parts. One is to study the integrated equipment of automatic wire feeding, precise cutting and automatic stripping of the terminal. The automatic equipment can automatically feed the wire and accurately break the wire, and at the same time realize the stripping of the cable end and realize the integrated control; the second is to study the wedge wire clamp crimping equipment based on the hydraulic control, which can quickly crimp the steel wire to the wedge wire In the clamp, the tightness and efficiency are obviously improved; the third is to study the automatic
equipment for fast bending cables and steel strands, which can realize automatic bending of the wires, and the bending radius is consistent with the porcelain bottle. Content one is expected to complete the development of integrated equipment for automatic wire feeding, precision cutting and automatic stripping of the ends. Content two is expected to complete the development of research on hydraulically controlled wedge wire clamp crimping equipment. Content three is expected to complete the development of a set of automatic equipment for fast bending cables and steel strands. Some research results are shown in Figure 1.

Figure 1. Field picture of wedge wire clamp device and punching device

The design is closely combined with the distribution network factory construction and the assembly delivery concept to minimize on-site construction time. The theoretical problem comes from engineering practice, and the research results will be applied to practice to guide the development of practical technology. The innovation of this design mainly lies in:

3.1. Can effectively shorten the construction period.
The use of factory assembly line standardization operations can effectively improve the production and assembly efficiency, standardize the production and installation process, and shorten the prefabrication time compared with on-site production; by arranging the prefabrication in advance, the prefabrication is no longer a critical path work, which shortens the construction Critical path; semi-finished product modular prefabricated assembly delivery management, greatly reducing the workload of aerial work, reducing the workload on the construction site and the difficulty of aerial work, shortening the aerial work time, on-site operation time, and planned power outage; no on-site material is available, which is conducive to policy Treatment, reducing unplanned downtime, thereby shortening the construction period [3].

3.2. The quality control of the whole process can be strengthened.
The factory assembly requirements are designed according to the requirements of the 2016 edition of the distribution network, and use the standard materials of the State Grid Corporation to form an inverse mechanism for the previous process, which can successfully implement the factory-based "PDCA" quality control system, effectively improving the quality of the project and Standardization of construction technology.

3.3. It can strengthen the intrinsic safety management of the project.
After factory assembly, the workload of high-altitude lifting and installation is correspondingly reduced, the difficulty of working at height is reduced, and the intrinsic safety of the project is greatly improved.

3.4. Can effectively promote the intensive management of materials.
Through factory prefabrication, there is no blanking and residual material recovery work on site, and no sporadic materials are stacked. The utilization rate of materials has increased, the protection of
finished products has been strengthened, and the level of intensive management of materials has been strengthened.

3.5. Improve the level of civilized construction on site.
After the factory assembly is delivered, the number of sporadic equipment materials and machinery facilities that need to be delivered to the site is greatly reduced, the site work difficulty is reduced, the construction site is free of materials, the site management is more orderly and clearer, and the level of civilized construction is effectively improved [4].

4. Experimental analysis

4.1. Experimental principle
The boosting principle of the integrated test device is shown in Figure 1. The medium voltage tap is set in the test transformer, and the reactive power compensation reactor is connected to compensate the capacitive reactive component of the voltage transformer in the tested GIS (the equivalent circuit is parallel resonance), which can effectively improve the test with medium voltage compensation. The input power factor of the transformer reduces the input power capacity (ie increases the Q value of the system).

Figure 2. Boosting principle of integrated test device

The equivalent circuit of this device is a power frequency parallel resonant circuit, and $U_1/U_2 = N$ is the transformation ratio of the test transformer. The voltage value of the high-voltage primary circuit is only related to the input voltage of the test transformer and the transformation ratio of the test transformer, and there is no need to worry about the situation of insufficient boost during series resonance. When the adjustable reactor fully compensates the capacitance of the tested voltage transformer, the loop resonates, and the inductance and capacitance satisfy the formula (1), namely:

$$\omega \times \left( \frac{L_1' \times L_2 \times L_3 \times L_4}{L_1' + L_2 + L_3 + L_4} \right) = \frac{1}{\omega \times C_i}$$

(1)

In the formula: $L_1'$ is the equivalent inductance of $L_1$ converted to the primary side. The quality factor is shown in equation (2):
The value of Q is related to the impedance of the test variable output winding, the impedance of the adjustable inductor, the equivalent impedance of the standard voltage transformer, the equivalent impedance of the tested voltage transformer, and the wiring resistance. It can be deduced from this that the input capacity of the system is the primary test capacity divided by the Q value without considering the small influence of the input impedance and leakage reactance of the test variable. The larger the Q value, the smaller the input capacity requirement, and the relationship between the input power capacity and series resonance is the same. According to the above principle, the design parameters of each component are as follows [5].

Secondary winding output voltage: The high voltage output from the test transformer is used to connect the standard voltage transformer and the high-voltage primary side of the tested voltage transformer. Input winding: match the output of the voltage regulator, connect the output of the voltage regulator to 0-420 V. The input capacity matches the voltage regulator to 40 kV, which should be less than this capacity in actual use. The parameters of the test transformer are shown in Table 1.

| Serial number | variable | Numerical value | unit |
|---------------|----------|-----------------|------|
| 1             | $U_{n0}$ | 350             | kV   |
| 2             | $I_{n0}$ | 0.77            | A    |
| 3             | $U_{l0}$ | 0-400           | V    |
| 4             | $I_{l0}$ | 100             | A    |
| 5             | $U_{m0}$ | 4 000           | V    |
| 6             | $I_{m0}$ | 67.4            | A    |
| 7             | $P_{n0}$ | 269.5           | kV   |
| 8             | $P_{l0}$ | 40              | kV   |
| 9             | $P_{m0}$ | 269.5           | kV   |
| 10            | $T_{no}$ | <5%             |      |
| 11            | $f$      | 50              | Hz   |
| 12            | $K$      | ≤85             | K    |

In Table 1: $U_{n0}$ is the rated high-voltage output winding output voltage; $I_{n0}$ is the rated high-voltage output winding output current; $U_{l0}$ is the rated low-voltage input winding input voltage; $I_{l0}$ is the rated low-voltage input winding input current; $U_{m0}$ is the rated medium-voltage compensation winding output voltage; $I_{m0}$ is the rated medium-voltage compensation winding output current; $P_{n0}$ is the rated high-voltage winding capacity; $P_{l0}$ is the rated low-voltage winding capacity; $P_{m0}$ is the rated medium-voltage winding capacity; $T_{no}$ is the output waveform distortion rate; $f$ is the rated frequency; $K$ is the temperature rise [6].
4.2. Experimental design
The SVPWM pulse width modulation signal is output to the interlock circuit through the ARM. The interlock circuit performs logic processing on the signal and transmits it to the IGBT driver chip EXB841. When EXB841 fails or detects that the IGBT collector current I is too large, the fifth pin will send a fault signal to the ARM through the isolation light hazard. The ARM outputs a protection signal after receiving the fault information, and the IGBT gate potential is driven by the drive circuit Pulled down to -5V, which turns off the IGBT. The DC bus voltage and current signals are transmitted to the ARM chip for analysis and processing after passing through the sampling circuit and the Hall sensor, respectively. If over-voltage or over-current occurs, ARM will issue a corresponding fault signal after receiving the signal, so that the system can suspend work or shut down the system completely. Due to the large fluctuations of the grid voltage under the influence of the external environment, the rectified DC bus voltage is not stable. When the DC voltage is too high or too low, the inverter output voltage waveform will also change accordingly. In order to ensure that the system works within a safe range, it is necessary to monitor the DC bus voltage and deal with the overvoltage phenomenon. In addition, the DC bus current is also a factor that cannot be ignored; when the circuit is short-circuited or the load is too large, the DC bus current will rise sharply. By detecting the bus current, the working status of the system can be monitored and corresponding protection actions can be performed. The monitoring of the bus voltage can be achieved by the method of voltage divider sampling. The sampling circuit is shown in Figure 3:

![Figure 3. DC bus voltage sampling circuit](image)

5. Design of transformer assembly automation platform

5.1. System requirements
The oil-immersed distribution transformer system designed in this paper needs to complete three functions, namely the optimized design function, the parameterized drawing function and the virtual assembly function. The requirements of the transformer design process for the two parts may be independent, but from the perspective of efficiency, the integration of these three parts of the system will speed up the design speed and shorten the calculation time of the serial design of the transformer, while the complete software system can also ensure the transformer The accuracy and reliability of structural data, so the system needs to strengthen the connection between them on the basis of completing the three parts of the design independently, and establish an integrated structure. The following is a demand analysis of these three parts of the system:

For the optimized design system of oil-immersed distribution transformers, first, good data input and output functions are required, in which the data input part needs to cover a wider range of transformer models as much as possible, and as much data as possible can be adjusted, such as connection group The choice, the choice of the transformer core structure, the choice of the winding of the transformer winding, etc., all of these should increase the dimensions of the data selection range as
much as possible. Secondly, a comparison interface for transformer optimal design schemes should be provided. The optimized design of oil-immersed distribution transformers usually obtains a lot of results. Usually, users need to set the weight ratio of key performance parameters, and the system will screen all schemes according to the weights. Sort to determine the optimal solution, but such a system does not have the flexibility, and sometimes the design process needs to be screened in some relatively good schemes. Third, the reliability of the system is required to be high. In addition to the accidental collapse of the control system, the accuracy of the transformer optimal design scheme should be verified through a large number of experiments. Any error in any parameter may cause major problems in the performance of the transformer. Fourth, the system is required to have expandable functions, and there are large differences between different series of transformers. The usual design method is to include one or several series of transformers, which will be gradually expanded in the future. The connection between data objects can be divided into three kinds of one-to-one, one-to-many, and many-to-many. As shown in Figure 4, it is a RE diagram of the platform system.

![RE diagram of the platform system](image)

**Figure 4.** RE diagram of the platform system

5.2. *System development plan*

The modularization of software is to divide the program into multiple independently named and independently accessed sub-ranges. The modularization of software solves some important problems in the development process of large programs, that is, if only one module is used to develop the entire program, the software is difficult to be understand that later maintenance work is also very difficult. The modularity of the program enables a large program to be managed by human intelligence, simplifying the process of adding or deleting a function in the system. However, as the number of module divisions increases, the development cost of software will also fluctuate. Figure 5 is a function curve of the number of module divisions and development costs. M represents the lowest cost interval [7].

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Figure 5. Cost and number of modules

Compared with the complicated direct development method, the secondary development method of this system based on the mature software platform is relatively simple in the division of software modules. From a functional perspective, this system only needs to develop three major functional modules, namely the electromagnetic optimization design module, Parametric modelling module and automated assembly module. In order to make the development process clearer, for each module, it needs to be further divided by considering the software function implementation method and data flow direction. For the optimization design part of the oil-immersed distribution transformer, there are input and output interfaces, calculations and Optimize program, data and solution storage functions; for parametric modelling, you need to consider input and output data, solution reading interface, database connection and other functions; automated assembly system needs to complete two functions, namely automatic assembly of standard parts and parts Automatic assembly. According to the coordinate diagram of module division and cost, too many or too few module divisions will increase the development cost. The system needs to control the number of modules in the M interval as much as possible on the basis of balancing various functions.

In software engineering, the hierarchical diagram is designed to explain the hierarchical structure of the system. A rectangular box in the hierarchical diagram represents a module. The connection between the boxes mainly represents the calling relationship between the modules. The hierarchical diagram is analysed by According to the requirements, the modules are divided to make the software function structure clearer and the development process easier to plan. For more complex systems, if multiple people are required to participate in the development, the hierarchy chart will assist in the division of work among members by considering the development difficulty of the hierarchy chart and each module, can make the division of developers more reasonable. Hierarchical diagrams can also be expanded according to different development requirements to guide the structural design of the system. Software system development is a top-down process. In the development process, the function branches are gradually refined from the requirements. Using a hierarchy chart to guide software development is essentially an exploration of the top-down development process. Figure 6 is a hierarchical diagram of the development and use of the system, which is mainly designed according to the system data flow and module division. The top layer represents the main control module of the computer-aided system of the oil-immersed distribution transformer. It calls the function modules of the lower layer to complete the entire content of the oil-immersed distribution transformer design; each module of the second layer completes one of the oil-immersed distribution transformer design. The main steps, such as the transformer part parametric modelling system, can complete the modelling of the main parts of the transformer; the third layer is a detailed functional module, and each module can be subdivided as needed, for example, the part parametric modelling branch can be divided into iron cores, Iron core clamps, fuel tanks, etc [8].
6. Conclusion
During the installation of the lead wire of the bench-type transformer, it is necessary to cut and bend the raw cable. After the cut cable is completed, a double wire clamp is provided between the two cables to achieve the fixation of the two cables after bending. In the traditional operation, an operator intercepts the cable of the set length by visual inspection or tape measurement, and another operator cuts the cable with a wire cutter, and the cut cable merges a cable by manual bending into two strands of cable, and the double wire clamp is clamped on the two strands of cable. Due to the extremely high hardness of the cable itself, the manual bending method greatly tests the operator's arm strength. The above operation method not only causes serious waste of materials during site construction. The construction process standards are not uniform, and it seriously affects the orderly advancement of distribution network standardization work.

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