Algorithm for computer-aided design of single-line diagrams of 35-220 kV switchgear with one working busbar system using "ORU CAD"

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Abstract. Designing distribution systems for substations and power plants is a complex process that requires qualification, attention, knowledge of regulatory and technical documentation and takes a lot of time to perform the same type of work. In addition, an integral part of the preparation and delivery of any project is the development of project documentation, including an explanatory note to the project, specifications and, of course, drawings with single-line diagrams, plans, layout schemes, etc. The paper proposes an algorithm for automated design of single-line circuits of open switchgear 35-220 kV with bus bars, implemented in the original software "ORU CAD". The study was carried out with the financial support of the Russian Foundation for Basic Research in the framework of the research project No. 18-37-00115.

Keywords: computer-aided design, single-line diagram, high voltage, switchgear, bus bar circuit, substation, power plant.

Introduction
The development of technology has now led to the automation of not only production processes, but also the automation of design processes and the modeling of objects in various fields of science and industries. Modern computer-aided design systems are fast, multifunctional, and must also ensure human-machine interaction.

In the field of power engineering and electrical engineering, the use of CAD systems is due to the need to carry out the same type, on the one hand, and on the other hand, careful work on the project under development, which must meet the requirements of GOST, Electrical Installation Rules and a large number of other regulatory documents. The use of CAD allows the developer (scientist, designer) to speed up the process of his work on objects of the same type and free his potential for the implementation of new or improved current projects and works.

The existing systems of computer-aided design in the field of electric power engineering and electrical engineering are aimed at solving a large number of problems, the main ones being the design of electrical equipment. So in [1], the authors propose a system that allows the development of documentation in the design and construction of transformers. In [2], with the use of CAD, the problem is solved not of an organizational nature, but of a scientific one - characterization of transformer windings.

The authors in [3-5] proposed to use computer-aided design systems for modeling the designs of electrical machines.
Widespread CAD in the design of electrical networks and power supply systems [6]. In [7], an approach for the automated selection of low-voltage supply systems equipment with the possibility of designing their circuits is described. Article [8] is devoted to CAD, which allows the design of 0.4 kV intrashop distribution networks, taking into account the norms and rules for designing power industry facilities. Computer-aided design systems are used not only to solve complex goals, but also to invest and accelerate the work process in the implementation of private tasks. To calculate the lighting, a large number of CADs [9] have been developed, one of which is the Tracepro system [10], which allows to calculate the lighting taking into account the design features of the luminaires used.

CAD has become widely used to enable the selection and testing of air and cable conductors [11-12]. A number of papers [13-14] are devoted to the design of the placement of power line poles with topological reference to the terrain. Some CAD systems are only aimed at checking overhead power lines for mechanical strength [15], while again solving a particular task.

CAD systems are also used for programming and testing devices for relay protection and automation [16-17]. For modern means of computer-aided design of power generation facilities, it is also possible to take into account the design and construction of power generation facilities [18].

The review of works in the field of computer-aided design of electrical power engineering objects of electrical engineering showed that the existing approaches are focused on solving particular problems related to the simulation of individual equipment and devices, the design of power supply systems.

The authors of this scientific work propose CAD, which allows the design of the electrical part of the switchgear of substations and power stations [19-21], taking into account their feasibility study of the adopted version of the scheme.

**Algorithm mapping switchgear with a single working busbar system**

On stepdown substations with a large number of connections, circuits with busbars are widely used. Such schemes are distinguished by high reliability and good layout. However, the drawing of such single-line diagrams is a sequence of repetitive operations. Automated execution of these operations will significantly simplify the work of the designer.

This paper proposes an algorithm for automated graphic display of 35 kV and above switchgear single-line diagrams in *.cdw format. The proposed algorithm is part of the software “ORU CAD” intended for computer-aided design of downstep substations.

The initial stage of the circuit design is to enter data on the voltage class of the switchgear (U), the number of transformers (T) and power lines (L). Also, according to the results of the operation of the algorithm for the technical and economic comparison of the variants of the scheme [20], the number of the scheme (n) is given. Further, based on the data on the number of power transformers, the number of switchgear sections is determined (s)

\[ s = T. \]  

The next step is to determine the number of power lines in each section.

\[ L_s = \frac{L}{s}. \]  

Considering that with an odd number of sections or transmission lines, the result can be fractional, the algorithm provides for a cycle by the number of sections, in which the number of lines per section is rounded to the nearest smaller integer value on the first pass, and to the next larger one on the rest. The number of transformers is provided one per section. Also the algorithm provides for the connection of a measuring voltage transformer (TV) on each section, i.e. the value of the variable TV equals s. Thus, we obtain the number of connections on each section.
3. \[ C_i = L_i + 3. \] (3)

Then, in the cycle according to the number of connections, each type of connection is drawn on the switchgear, taking into account their number. At the final stage, the connections of the bus-section breaker are drawn. The number of bus-section breakers

\[ CB = s - 1. \] (4)

The algorithm for automated single-line drawing is shown in fig. 1. Table 1 shows the single-line diagrams of individual connections used in the proposed algorithm.

**Table 1.** Connection single-line diagrams

| Connection name       | Single-line diagram |
|-----------------------|--------------------|
| Voltage transformer   | ![Diagram](image)   |
| HVTL                  | ![Diagram](image)   |
| Power transformer     | ![Diagram](image)   |
Bus-section breaker
Figure 1. Algorithm for automated drawing of single-line diagrams in the software "ORU CAD"
After that, the reference numerals of each element is applied in accordance with the standards for the implementation of electrical circuits. For the numbering of elements, their total number in the scheme is determined:

– circuit breakers

\[ N_B = L + T + s - 1; \]  

(5)

– disconnectors

\[ N_D = 2(L + CB) + T + TV; \]  

(6)

– overvoltage limiters for circuits with double-winding transformer

\[ N_{OL} = 2T + TV; \]  

(7)

– overvoltage limiters for circuits with a three-winding transformer or autotransformer

\[ N_{OL} = 3T + TV. \]  

(8)

The number of current transformers is equal to the number of circuit breakers \((N_{TA} = N_B)\).

The result of the implementation of the algorithm proposed by the authors is a single-line switchgear diagram in the * .cdw format, into which one can make changes and additions using a drawing program.

**Conclusion**

The proposed algorithm is designed to automate the process of creating a single-line diagram with one working system of substation busbars with the highest voltage of 35-750 kV. The algorithm is distinguished by its coordination with the requirements of the current design standards, as well as the possibility of making changes to the generated scheme in the drawing program. The proposed algorithm is implemented in the software ORU CAD, which can be used in the work of design engineers of electrical engineering departments of design institutes.

**Acknowledgement**

The reported study was funded by RFBR according to the research project No. 18-37-00115.

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