Design algorithm for a transport power supply device

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Abstract. The article considers the synthesis of an algorithm for designing traction substations for electric transport, which takes into account such a complex issue as the reconstruction of existing traction substations. In addition, special attention is paid to the issues of deployment of traction substations when increasing power supply or extending existing lines, for example, urban transport.

1. Introduction
Energy supply is one of the main production processes of electric transport as a complex system, whose functions depend on the efficiency of its management. At the same time, the electric grid is a rather expensive component, therefore it is important to optimize investments in it. The power supply design cost for large facilities can be 15%-25% of the construction and installation costs; therefore, state and commercial structures create engineering centers and design institutes capable of using expensive computing systems and networks to automate the design process introducing CAD. Designing manually with a computer, it is impossible to calculate a large number of design options. Computers with high performance, large amounts of random access memory, cybernetic decision-making methods in combination with methods for finding an optimum made it possible to solve a number of optimization design problems. This allowed us to reduce the time and improve the quality of projects. Thus, the development of computer technology and its periphery made it possible to use a new method of computer-aided design (CAD).

2. Results and discussion
At present, CAD is a designer's toolkit, which includes technical, mathematical, linguistic, software, information, methodological and organizational support. It is designed to automate the design of facilities at all life cycle stages - from the issuance of technical specifications to the transfer of the project to the manufacturer. Technical decisions are made in the mode of a dialogue between the designer and the computer based on mathematical modeling of design objects. This increases the accuracy and eliminates errors in calculations, ensures the best option, and speeds up the preparation of project documents. CAD goals and objectives can vary depending on the purpose of the design object and its complexity.

The computer-aided design has a number of advantages over the manual method: the use of new design methods, namely, mathematical modeling, optimization methods, decision-making methods, complex, but more accurate calculation error design models, the preparation of better design docu-
ments, the ability to analyze large design solutions and increase the productivity of designers and the quality of projects.

How to improve the design speed?

Previously, this was achieved by using standard projects by linking them to specific conditions (climatic zone, customer's technical requirements, possible amounts of funding, etc.). Currently, manufacturing plants offer original databases on their products. Using them with other design tools, you can reduce the time for creating a project without performing working drawings or layouts of switchgear chambers. Consider the design algorithm for a traction or transformer substation.

Step 1. Let us draw up a structural diagram of the facility based on the customer's technical assignment (e.g., a substation service). The block diagram is shown in Fig. 1.

![Block diagram of the traction substation](image)

**Figure 1.** Block diagram of the traction substation

Step 2. We select the prototype of the traction substation single-line diagram from the well-known typical, reusable projects and other sources (e.g., those already existing in the industry). It will be specified after calculating the power of the substation traction unit (iteration).
Step 3. For a given type of substation, taking into account the requirements of the technical task (for example, the type of cooling, placement conditions, fire safety, etc.), several types of converters that differ in nominal parameters ($P_{dn}$, $I_{dn}$) were selected. Using formulas (1), their number was determined depending on the design mode: according to the maximum mode - formulas (1a)

$$N_{11} = \frac{I_{pm}}{K_{ovl} \cdot I_{dn}} + D, \quad N_{12} = \frac{P_{dn}}{K_{ovl} \cdot P_{dn}} + D,$$

according to the effective mode – formula (1b)

$$N_{13} = \frac{I_{en} \cdot K_{ov}}{K_{ovl} \cdot I_{dn}} + D,$$

where $I_{dn}$, $I_{en}$, $I_{am}$, $P_{dn}$ – nominal, effective, maximum currents and the corresponding power of the traction substation;

$K_{ov}$ – the overload coefficient, for a 10-second maximum, taken equal to 2, and for an average daily load mode taken equal to 1.1 ... 1.2;

$K_{ovl}$ - the coefficient of daily load unevenness determined for the average substation current $I_{am}$.

In the range of 300-2000 A, the coefficient of daily non-uniformity is in the range of 1.12 ... 1.28;

$D$ - part of a number that rounds the result to the nearest higher integer value $N_i$.

The highest value s is taken from the values $N_{11} ... N_{13}$. The final choice of the option is made taking into account the selected structural scheme and results of the economic comparison of the options.
The choice of the economic option of the traction substation is made at the minimum of the estimated reduced annual costs, $D_i$:

$$D_i = C_i + E_i K_i,$$

where $D_i$ - estimated costs of the i-th option;
$C_i$ – annual operating costs of the i-th option;
$K_i$ – capital investment of the i-th option;
$E_i$ – standard efficiency factor, taken equal to 0.1 ... 0.15 / year.

Annual operating costs $C_i$ are calculated using the formula

$$C_i = \Delta A_{ri} P_e + C_{pi} + q K_i,$$

where $\Delta A_{ri}$ – annual electricity losses (kWh) in transformers and converters of the i-th option;
$P_e$ – the price of electricity, (rub / kWh), equal to the electricity tariff for electrified vehicles (0.6-1.5) 102 rub / kWh;
$C_{pi}$ – annual costs of maintaining the i-th option (salary of maintenance personnel, cost of materials, spare parts and tools for preventive inspections and maintenance);
$q$– annual depreciation deductions equal to 0.065.

Determination of energy losses in converting units of traction substations.

Annual electricity losses under operating conditions are

$$\Delta A_{ri} = \sum_{k} \Delta P_k \cdot t_k$$

The power losses $\Delta P$ for time $T$ are losses of steel of the traction transformer, power of rectifier's auxiliary needs, copper of the transformer, and SPP:

$$\Delta P = P_{st} \frac{I_{ol}^2}{I_{di}} + U_F \frac{a}{s} I_{le} \cdot 10^{-3} + P_{no} + P_{n}.$$

In formulas (4) and (5)

$n$ – the number of converting units installed at the traction substation;
$P_{st}$ – total losses of steel of the converter transformer and equalizing reactor, equal to no-load losses, kW;
$P_{on}$ – auxiliary power of the rectifier (fans, control circuits, etc.), kW;
$P_e$ – total losses of copper of the transformer and reactor equal to short-circuit losses, kW;
$s$ and $a$ – the number of serial and parallel connected NGNs;
$U_F$ – voltage drop across SPP, V, with a forward current flow;
$I_{ol}$ – average value of load current for time $T$, A;
$I_{le}$ – effective value of load current for time $T$, A;
$I_{d}$ – rectifier rated current, A;
$T$ – operating time of the k-th unit during the year, h;
$\Delta P_k$ – power losses of k units installed at the substation, kW.

Under operating conditions, real graphs of loads of an operating traction or transformer substation, a mine, a transport system and other objects can be built for a long period (2-5 years) using the methods of probability theory and mathematical statistics. As a result of an analysis of the load curves, dependencies and correlation coefficients can be obtained. They can be used to calculate total energy losses at the traction or transformer substation. In the draft design, you can use typical graphs.

Step 4. In recent years, a number of companies have been offering ready-made modular substation devices. Focusing on one of the Russian firms, based on the calculations and the refined TP scheme, the number of modules required can be determined and a photo-plan of the projected traction substation can be prepared.
Figure 3. Photo-plan of the substation: 1 - inputs from the regional substation RP-110 kV; 2 - converter transformers; 3 - power transformers and substation lighting; 4 - silicon rectifiers, 5 - RU 380/220 V; 6 - RU of rectified current; 7 - service module (control panel); 8 - 10 kV switchgear

All detailed design documents will be provided by the manufacturer. The designer must prepare only the working documentation for the layout, cable channels, ground loops and lightning protection. Road slabs or sleeper-rail sections of the required length can be used as foundations.

3. Conclusion
The design algorithm can be used for reconstructing or extending existing lines, or building transformer substations while increasing the power supply.

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