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Specialized Software for Computer-Aided Design of Electrical Systems of Vehicles

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Abstract: The study describes the mathematical and software modules of computer-aided design of vehicle electric systems: analysis of modes of electrical systems operation, optimal choice of wire sizes, selection and verification of protective devices.

Key words: Vehicle, computer-aided design, electrical systems, software, wire

INTRODUCTION

Designing of electrical systems of vehicles is currently impossible without use of software products of CAD, CAM, CAE, CALS systems (PLM) technology for the following reasons:

- The number of new models, modifications and complete sets of vehicles constantly increases
- The requirements increase to the quality of project documents and their compliance with international standards and norms this leading to increased number of engineering calculations
- The structure of electrical systems is constantly complicated which leads to increase in the range and complexity of technical drawings
- The volume of routine work of engineer is increased, so the prestige of his work falls
- The intensification of design works occurs with shortage of skilled designers this leads to difficulties in implementation of projects by traditional methods in timely manner, increase of the errors in documentation

The market of information technologies in the design of electrical systems is widely presented by multi-purpose tool systems of computer-aided design: ElectriCS, E3.Series, Catia, Siemens NX, Cimatron, Cimacable, Solid Works and others (Norenkov, 2002). These systems allow us to solve in the single project space the full spectrum of electrical design of modern vehicle, from development of schematic diagrams to formation of bundles and output of all design documentation in electronic form. But most of them are graphical information tools to support the design process. The quality of the design decisions here depends largely on the readiness of personnel ansd expertise. Optimization problems, analysis of quality and reliability of the designed electrical systems are not solved by existing CAD systems. To solve these problems, it is necessary to create algorithms and specialized software that solves the optimization problems.

MATERIALS AND METHODS

The composite structural parts of CAD of electrical systems, reflecting the design problems (Fedorov *et al*., 2015; Tereshchuk *et al*., 2011; Fedorov and Ferenets, 2015) are the following projecting modules: electrical equipment layout, placement of electrical equipment, wiring the electrical circuits, formation and tracing the bundles, analysis of operation modes of electric energy distribution, choice of protection devices, optimization of cross sections of wires, calculation of the balance of electrical energy and other. By present, the Department of Electrical equipment completed by-stage implementation in practice of the following software modules: «Analysis of operation modes of electrical systems of vehicles», «Optimal choice of cross sections of wires», «Selection and testing of protective devices».

Module «Analysis of operation modes of electrical systems of vehicle»: In the course of performing the analysis the following problems are solved:

- Calculation of the currents in the sections of power circuits and voltages in the nodes for normal modes, taking into account the change of current distribution as to the modes of consumption

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- Determination of maximum currents of circuit sections and minimum node voltages of the scheme
- Calculation of the short-circuit current in different places
- Checking as to permissible nominal voltage at the terminals of consumers
- Determination of maximum time off by fuse of the short circuit place

As initial data it is necessary to know the configuration of electrical network. Calculation of currents and voltages for normal and directive modes taking into account the change in the current distribution as to modes of consumption, calculation of currents and voltages for short-circuit modes is carried out by means of method of nodal potentials.

Originally the matrix of nodal conductivities G is formed, covering the whole electricity network of the vehicle. Its elements are the own g_{ii} and mutual g_{ij} conductivities of nodes.

Conductivities g_{ii}, located on the main diagonal of the matrix are equal to the sum of conductivities of sections converging in the node. The values of g_{ij} are equal to conductivity of the section connecting ith and jth or to zero, if there is no connection between nodes. The matrix G is symmetric in relation to the main diagonal, so $g_{ij} = g_{ji}$.

The elements of the main diagonal elements are calculated by summing all elements of line: $g_{ii} = \Sigma g_{ij}$.

Proceeding from the symmetry of the matrix G at the first stage its upper half is formed with simultaneous ranking the nodes and branches according to the following algorithm:

1. In the connections are sought branches having start in the node 1. To these branches as well as to their ends is assigned rank p = 1. To branches are numbered k = 2, 3, ... and to end nodes of these branches the numbers j = 2, 3,...

   In the first line of the matrix formed G are joined conductivity values $g_{12} = g_{1\text{-}2} = g_1$, $g_{13} = g_{1\text{-}3} = g_2$, ... $(g_{1j} = g_{1\text{-}j} = g_k)$
2. For each node n of rank p = 1 are searched outgoing branches. They are assigned the following numbers k and to the end nodes of these branches the numbers j = k

   In the nth line of matrix G are recorded the values: $g_{nj} = g_{n\text{-}j} = g_n$, (j>n)

   The considered at the first steps sections are excluded from further consideration
3. Procedures of step 2 are repeated for nodes n of rank p = 2, 3, ... until will be considered all nodes and sections of calculation scheme.
4. The lower part of the matrix G is completed from the condition: $g_{ij} = g_{ji}$
5. The diagonal elements of G are calculated by the formula: $g_{ii} = \Sigma_{j>i}\, g_{ij}$

The potentials of the nodes of calculation scheme are determined by solving the matrix equation: $G\, U_r = J_r$. Here J_r column matrix of load currents of the r-calculation regime.

Branch currents are calculated by the difference between the voltages at their ends: $I_{(i\text{-}j)r} = (U_{ir}\text{-}U_{jr})\, g_{ij}$. The advantage of nodal analysis lies in its versatility and feasibility of implementation of approach from the general to the particular. In addition when it is used, the routines for solving systems of algebraic equations can be applied.

The short-circuit current is determined by resistance of the circuit between the point of short-circuit and sources. Resistance between these points is determined by adding the resistance areas lying on the shortest path between them. The short-circuit current of ith point is calculated by the formula $I_{SCi}= E/(R_{SCi}+R_S)$ where E is electromotive force of the source; R_{SCi} is resistance of short circuit of ith point and R_S is the source impedance.

Module «Optimal choice of the cross sections of wires»: During the optimal choice of wire sections the following problems were solved:

- Calculation of the currents in the circuit sections of calculation scheme for normal and directive modes taking into account the changes in the current distribution as to the modes of consumption
- Determination of maximum currents of circuit sections for normal and directive regimes
- Checking the wires as to the maximum permissible current
- Checking as to permissible rated voltage at the terminals of consumers
- Checking the protection ability of wires by protection devices

Checking as to permissible current load of wire is carried out according to the condition of $I_{w\,max}<I_p$ where I_{wmax} the maximum current flowing through the wire, under normal and directive modes at all stages of work; I_p permissible current for the given cross-section of the wire. If the condition is not met then the recommendation is given to increase the wire cross-section to the nearest larger one.

Checking the protection ability of the given wire section by the protection device is carried out by using the tables presented in industry standards. For each connection (wire) having a stamp, it is necessary to determine protection apparatus that protects this wire. By brand of the wire, operating conditions, type and rating of protection device the minimum wire size S_{min1} is determined in case of protection by protection device the wire over the entire range of current overloads and S_{min2} in protection by protection device of the wire I_{SC}>2, 5 I_{NA}, where I_{NA}-rated current of the protection device. Provided $S_w \geq S_{min1}$ the wire is protected in all range of overcurrent. Provided $S_{\Pi p} = S_{min2}$ the wire is protected at I_{SC}>2, 5I_{NA}. Otherwise, the wire is not protected by the given protection device.

Checking the selection of wire cross section as to allowable voltage at the terminals of customers allow determining the optimal wire sizes of power supply system of the vehicle taking into account satisfying the requirements of limiting current loads of wires, allowable voltage loss, taking into account the strength factors and multi-mode operation of consumers.

In the base of algorithm of wire cross sections optimization of distribution network the method of dynamic programming is used. The problem of wire cross sections optimization of distribution network is defined as: $\sum_{j=1} m_j(S_j) \rightarrow \min$, for restrictions $\sum_{j=1} n_{ijr} U_{jr}(S_j) \leq \Delta U_{ir}$ for all i = 1,..., N and r = 1, ..., R; $S_{jmin} \leq S_j \leq S_{max}$; $S_j \in \Omega_S$ (j = 1, 2, ..., B) where $m_j(S_j)$-mass, cost or other parameter of the jth site; U_{jr}-voltage drop on the jth site in the rth mode; n_{ijr}-elements of contour matrix (matrix-attachment point-load); ΔU_i-permissible voltage drop from the point of attachment to the ith load; Ω_S-array of standard cross sections of wires.

Module «Selection and testing of protective devices»: During the selection and testing of devices of protection the following problems are solved:

- Calculation of currents in the circuit sections of calculation scheme for normal and directive modes taking into account the changes in the current distribution as to the modes of consumption
- Calculation of the currents in the circuit sections of design scheme for short-circuit modes
- Checking the correct choice of protection devices as to the rated current
- Checking the correct selection of protection device in overloads in case of electric motor loads
- Determining the sequence of triggering of protection devices in the modes of short-circuit and checking the selectivity of protection
- Checking the protection devices for resistance to short-circuit currents

Checking the correctness of the choice of protection devices as to the rated current is carried for the normal mode. Protection devices must be selected taking into account long-term maximum intensity of current in the line, the unevenness of currents distribution in the wires of split. The rated current of protective device of one channel of split line of power network is determined by the equation:

$$I_{NA} = \frac{\alpha \times I_L}{n\text{-}k}$$

Where:

I_{NA} = Rated current of split line of protection device
I_L = Current of line
α = Coefficient of unevenness of current distribution
n = Number of channels of the split line
k = Number of reserve channels

Checking the correctness of the choice of protection devices as to nominal value. For feeders of consumers who do not have starting current, nominal current of protection device is determined on the basis of the conditions: $I_{NA} \geq I_c$, where I_c, operating current of the electrical network.

Checking the protection devices for resistance to short circuit currents is carried out on electrodynamic and switching capacity.

To test the switching capability of the protection device it is necessary to determine the short-circuit current for the set mode I_{SCs}. Switching capacity (breaking capacity) of protection device is sufficient if the condition $I_{SCs} \leq I_{pA}$ where I_{pA} admissible value of the short-circuit current for this protection device.

To test the electrodynamic ability of the protection device it is necessary to determine the short-circuit current for transient mode I_{SCt}. Electrodynamic ability of protection device is sufficient, if the condition $I_{SCt} \leq I_{pA.max}$ where $I_{pA.max}$ allowable maximum value of short-circuit current for the given protection device.

RESULTS AND DISCUSSION

Figure 1 shows the view of the main menu of specialized software on the basis of developed software in Microsoft Access 2007 media: module «Optimal choice of the cross sections of wires of electric systems of vehicles», module «Analysis of operation modes of electric systems of vehicles», module «Selection and testing of protection devices».

The given modules identify and predict operation modes of electrical systems and its components at the stages of design, bench testing and modernization in the calculation of the currents in the sections of power network, calculation of voltage for normal modes, taking into account the changes of current distribution as to the modes of consumption, determination of maximum currents and minimum voltages of electric network sections, calculation of short-circuit current, checking the permissible rated voltage at the terminals of consumers, determination of the maximum time off at the short circuit place by fuse, nchecking the wires as to the maximum permissible current, checking the protection ability of wires by protection devices, checking the proper protective devices as to the rated current, checking the proper protective device in overloads in the case of electric motor loads, determine the sequence of triggering the protection device at short circuit modes, checking the selectivity of protection.

Fig. 1: Modules of specialized software

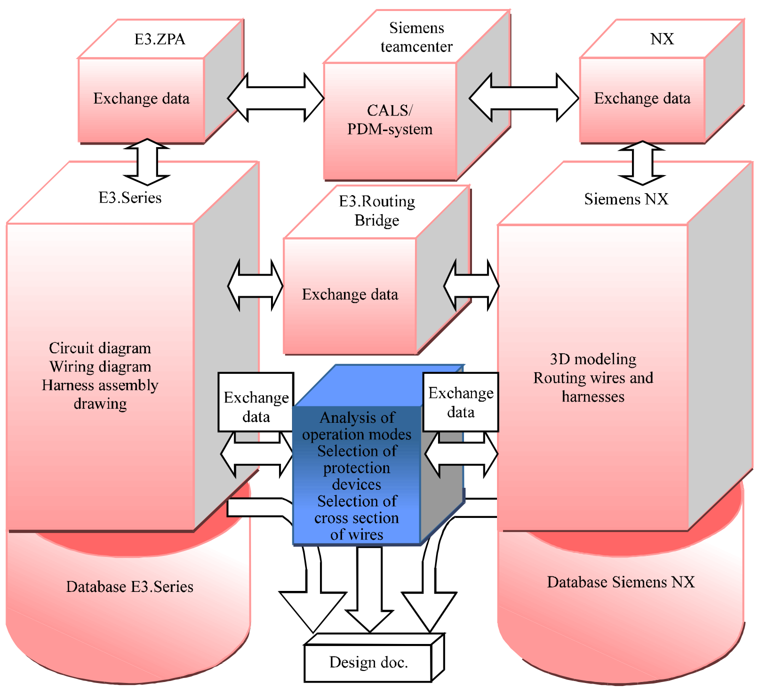

Fig. 2: Computer-aided design electrical systems of vehicle

The developed modules are identified parts of computer-aided design to ensure obtaining the completed design solutions and appropriate design documents. Structural integration of modules in the system is carried out with the help of connections between the components of computer-aided design of electrical complexes of vehicles. Figure 2 is CAD block diagram of vehicle with the existing and new special software. Information interconnection of generated specialized modules with other programs and system database is carried out by means of data exchange programs.

The scheme is based on the analysis of the design process for various types of vehicles, generalization of experience of research works on creation of computer-aided design of electric-technical complexes of vehicles (Tereshchuk *et al*., 2011; Fedorov and Ferenets, 2015).

According to the proposed scheme, the pilot design of electrical systems of trucks was carried out. The developed software modules were studied on a number of modified electrical circuits of trucks under various constraints. As a result, the defects (errors) and recommendations are identified: protection devices, through which the current flows exceeding the nominal; wires in which the current exceeded the permissible value; nonselectivity of triggering of protection devices. Analysis of the results of implementation shows that shortening the terms of design of electrical systems in the modification of truck is about 8.5 h.

CONCLUSION

The introduction of the software in industrial maintenance allowed us to significantly shorten the term of design of electrical systems of vehicles by 8-12% due to reducing the computation time and labor capacity in designing. Also the developed software made it possible to increase the reliability of calculations because of the elimination of mechanical errors of non-automated design, make quick changes in the documents, release engineers from routine work. Thus, it is achieved the early obtaining of practical results, technical and economic effect. Also the willingness of designers to transition from manual design to mastering the interaction skills with specialized software is manifested.

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