The Method of Selecting Protection Devices in the Automated Design of an Electrical Complex of a Transport Vehicle

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Abstract. The article describes the mathematical and software module of computer-aided design of vehicle electric systems: selection and verification of protective devices. The following problems are solved: calculation of currents in the circuit sections of 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

1. Introduction

The experience of automating the design of various technical devices and systems shows that automation tools have a significant impact on the formulation and solution of design tasks [1].

The problem of choosing protection devices with a manual design method is usually solved as follows. Based on well-known experience and his own intuition, the designer sets the protection devices and wire brands. Then, knowing the voltage at the nodal points and the maximum permissible current loads under the protection conditions, it is enough to simply determine the wire sections and the ratings of the protection devices. In other words, the complete circuit of the electrical complex of the vehicle is decomposed into a set of simple circuits with specified boundary conditions for voltages and currents, which allows us to solve the problem manually [2-4]. This approach can also be implemented in the automated design of the electrical complex of the vehicle. However, the greatest effect is achieved in the computer-aided design system when solving the problem in full, which is not available to an individual designer. The calculation of the complete circuit in the computer-aided design system does not require preliminary setting of nodal voltages and guarantees the optimality of the solutions obtained. It should be noted that the complete calculation of the network dramatically increases the dimension of the problem and the time of its solution [5-7]. However, the use of special methods of equivalence of individual sections of the complete circuit of the electrical complex of the
vehicle allows us to solve the problem in an acceptable time using fairly accurate mathematical models of the electrical network [8-9].

Also, the existing methods of calculating protection devices do not solve all the problems that arise when designing electrical equipment of vehicles. This is due to both the increasing complexity of the electrical equipment of vehicles, and the appearance of a large number of types and ratings of protection devices with new technical capabilities [10-12]. Basically, the following issues are not disclosed: issues of protection of power supply circuits of consumer groups with overload currents; the multi-mode operation of the network is not taken into account; preheating of protection devices with load currents; technological variation of the parameters of protection devices and others. Taking into account the above, it is proposed to develop a methodology for selecting protection devices for electric networks of vehicles that solves the listed tasks. At the same time, we will focus on the hardware and software tools of modern computer-aided design systems [13-16].

2. The method of selecting protection devices

The choice of types and ratings of protection devices largely determines the reliability of operation, safety of operation and weight and size indicators of the vehicle's electrical network [17-19].

When protecting the consumer's power supply circuit with a long-term operation mode without an overload current, the nominal current of the protection device is selected in accordance with the condition:

\[ I_{r,c} = \min_{k \in G} I_k, \quad I_k \in G, \]

where \( I_{r,c} \) – rated current of the protection device;
\( G = \{I_1, \ldots, I_k, \ldots, I_s\} \) – the set of nominal values of the protection device of a given type that satisfy the condition \( \forall I_k \geq I_{p,max} \);
\( I_{p,max} \) – the maximum possible current of the consumer's power supply circuit, taking into account the climatic operating conditions and the quality of the power supply.

To protect the power supply circuits of consumers with a large inrush current, with a long and short-term operation mode, the inertial protection devices must meet the following conditions:

\[ I_{r,c} = \min_{k \in G} I_k, \quad I_k \in G, \]

\[ t_a > t_{\text{start,max}}, \]

where \( t_{\text{start,max}} \) – the time during which the RMS starting current of the consumer reaches the maximum value \( I_{\text{rms, start,max}} \);
\( t_a \) – the shortest response time of the AZ at current \( I_{\text{rms, start,max}} \).

The response time of the protection device largely depends on the ambient temperature and the technological spread of its parameters. Therefore, in the calculations, the shortest response time \( t_a \) is determined by the lower limit of the spread of the ampere-second characteristic corresponding to the maximum ambient temperature in which the protection device is located, taking into account the technological spread of the parameters.

Values \( t_{\text{start,max}} \) and \( I_{\text{rms, start,max}} \) are determined by the curve of the change in the RMS starting current of the consumer over time. The RMS starting current for any given time is determined from the oscillogram of the consumer's starting current.

The value of the RMS starting current for time \( t \) is determined by the formula:
were $I_1, I_2, ..., I_{k_i}$ – arithmetic mean values of the current in the intervals on the section of the curve of change of the starting current of the electric motor;

$k_i$ – the number of intervals into which the time interval is divided $t$.

To protect the power supply circuits of consumers with a repeated short–term or pulse load, the rated current of the inertial protection device must be selected from the conditions:

$$I_{r.c.} = \min_{k=1,q} I_k, I_k \in G_i,$$

$$t_{a1} > (t_i)_{\text{max}} \text{ by } (I_{\text{rms,i}})_{\text{max}},$$

were $G_i = \{I_1, ..., I_k, ..., I_q\}$ – the set of nominal values of the protection device of a given type that satisfy the condition $\forall I_k \geq I_{\text{rms,i}}$;

$I_{\text{rms,i}}$ – the RMS value of the consumer current during the load cycle $t_i$;

$(t_i)_{\text{max}}$ – the time for which the RMS load current reaches the maximum value $(I_{\text{rms,i}})_{\text{max}}$;

$t_{a1}$ – the response time of the protection device when $(I_{\text{rms,i}})_{\text{max}}$.

Values $(t_i)_{\text{max}}$ and $(I_{\text{rms,i}})_{\text{max}}$ are determined by the curve of the change in the RMS value of the load current over time. For the moment of time $t$ ($t \leq t_i$) from the load current waveform can be determined $(I_{\text{rms,i}})_i$ by the formula:

$$I_{\text{rms,i}} = \sqrt{\frac{I_{\text{rms,1}}^2 I_1^2 + I_{\text{rms,2}}^2 I_2^2 + \ldots + I_{\text{rms,k}}^2 I_k^2}{t}},$$

were $I_{\text{rms,1}}, ..., I_{\text{rms,i}}, ..., I_{\text{rms,k}}$ – RMS values of the pulse current;

$t_1, ..., t_i, ..., t_{k_i}$ – pulse duration;

$k_i$ – number of pulses per time $t$.

The values of the currents $I_{\text{rms,i}}$ are determined by the formula (4), were is $k_i$ – the number of equal intervals on the pulse section.

For the special case of a single pulse:

$$I_{\text{rms,i}} = I_{\text{rms,i,max}} \sqrt{\frac{t_i}{t}},$$

were $I_{\text{rms,i,max}}$ – the maximum possible value of the RMS pulse current in the consumer's power supply circuit;

$t_i$ – pulse duration.

When choosing the rated current of fuses in the electric motor power supply circuit in operation, it is recommended that the fuse actuation current for the time $t_{\text{start, max}}$ is at least $2I_{\text{rms,start, max}}$.

The maximum values of the RMS current in the pulse and re–short-term load circuits protected by fuses should also not exceed half of the fuse tripping current for $(t_i)_{\text{max}}$. 
To select the protection device in the power supply chain of a group of consumers, the concept of the circuit operation mode is introduced. The circuit operation modes are understood as a set of possible circuit modes characterized by the immutability of the circuit topology within the mode, and the load modes of consumers that differ in the currents flowing through the protection devices and are characterized by steady-state or quasi-steady-state processes [20].

When protecting the power supply chain of a group of consumers with a long operating mode that do not have overload currents, the protection device is selected according to the condition that takes into account the simultaneity of their operation in different modes:

\[
I_{r.c.} \geq \max_{r \in R} \sum_{p=1}^{n_r} I^{(r)}_{p, \text{max}, i},
\]

were \( n_r \) – the number of simultaneously working consumers in the \( r \) mode;\n
\( R = \{1, \ldots, l\} \) – multiple modes of operation of the consumer group.

To calculate the device for protecting the power supply circuit of a group of consumers, including various types of loads, each mode of operation of the circuit is represented by an oscillogram of the total current consumption. The protection device is selected similarly to the case with a repeated short-term or pulse load, considering this case as more general, according to the condition (5) when \( I_{\text{rms}, i} = \max_{r \in R} I_{\text{rms}, i}^{(r)} \) and checked according to the following condition:

\[
t_{c, i} > t_{c, i}^r, \text{ when } (t_{c, i}^r)_{\text{max}} \leq t_{c, i}^r \leq T^r \text{ and } r \in R,
\]

were \( t_{c, i}^r \) – the response time of the protection device from the RMS value of the total load current of the corresponding mode \( r \) by the curve of its value change for time \( I_i^r \);

\( T^r \) – the time of transition of the consumption process to a steady or quasi-steady process.

Pre-heating of the protection device by load currents can have a significant impact on the time of their operation. This is especially true for protection devices that have an inertial system.

Let the protection device be previously warmed up to a steady temperature by a current \( I_{\text{warm}} \), then, using the heat balance equation, we can write:

\[
t_{\text{resp}} = T \ln \frac{I_2^2 - I_{\text{warm}}^2}{I_2^2 - I_{st}^2},
\]

were \( T \) – heating time constant; \n
\( I_{\text{warm}} \) – preheating current; \n
\( I_{st} \) – critical current (starting current), the response time of the protection device against it is equal to infinity (reference characteristic); \n
\( I \) – the current flowing through the protection device and sufficient for its operation; \n
\( t_{\text{resp}} \) – response time of the protection device.

To simplify, we find such an equivalent current \( I_{eq} \), which causes the same device response time as the current \( I \), but without preheating:

\[
I_{eq} = I_{st} \sqrt{\frac{I_2^2 - I_{\text{warm}}^2}{I_{st}^2 - I_{\text{warm}}^2}}.
\]
Now $I_{rep}$ the current protection device, taking into account the heating current $I_{warm}$ is determined by the available ampere-second characteristics of the software $I_{eq}$.

After the calculation, the protection devices must be checked for: wire protectability; switching ability: the maximum time of disconnecting the short-circuit circuit; selectivity of operation in the presence of several protective devices in the consumer power supply circuit. In addition, among the main requirements for protection devices should be ensuring the protection of consumers themselves.

To determine the necessary protection device with an ampere–second characteristic that provides protection of the electric motor, the characteristics of heating the insulation of the electric motor at various current overloads can be used, the intersection of which with the maximum permissible temperature of heating the insulation $T_{accept,max}$ determines the limiting characteristic of heating the insulation. The relative location of the ampere-second characteristic of the protection device and the maximum heating characteristic of the motor insulation will determine its necessary protection in a given range of current loads.

3. Results and discussion

Fig. 1 shows the view of the main menu of specialized software on the basis of developed software in Microsoft Access 2013 media «Selection and testing of protection devices».

![Figure 1. Module «Selection and testing of protection devices»](image)

The developed module is identified parts of computer-aided design to ensure obtaining the completed design solutions and appropriate design documents. Structural integration of module in the system is carried out with the help of connections between the components of computer-aided design of electrical complexes of vehicles.

According to the proposed scheme, a pilot design of electric systems of vehicles was carried out. The developed software modules were studied on a number of modified electric circuits of trucks under various restrictions. As a result, defects (errors) and recommendations are identified: protection devices through which a current exceeding the rated current flows; wires in which the current has exceeded the permissible value; non-selectivity of the protection devices.

4. Conclusion

The questions of the choice of devices for the protection of electrical networks from the standpoint of problems arising in the design of electrical equipment of vehicles are considered. A method of selecting protection devices has been developed that solves the problems of protecting the power supply circuits of consumer groups that include various types of loads.
The introduction into commercial operation made it possible to significantly reduce the calculation time and labor intensity when designing an electrical complex, increase the reliability of calculations due to the elimination of mechanical errors of non-automated design, promptly make changes to documents, free engineers from routine work. In addition, the use of calculation and design information as input data for programs for obtaining production documentation for the manufacture and control of components of electrical equipment of the vehicle also contributes to the acceleration of the development of the product by industrial production. Thus, a certain economic, technical and social effect is achieved.

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