THE SUMMARY

In the article the existing system of maintenance service and repair of electrotechnical equipment is analyzed. The need of improving repair system is substantiated. The structure of problems on its perfection is considered on the basis of new technology of management by a technical condition of an electric equipment. The simulators of their solutions, based on the use of methods of evaluating the technical state with the aid of the means of diagnostics are resulted.

INTRODUCTION

The technologies of the operation of electrical equipment existing at present are insufficiently effective from the point of view of the guarantee of reliability of the systems of power supply. First of all is an increase in quantity of refusals, increase of charges on maintenance service and repair, growth of number of the repair personnel and the costs connected to it, decrease qualitative and quantity indicators of service services and, as consequence, deterioration of technical and economic parameters of systems of power supply. Effectiveness and reliability of functioning in the systems of power supply depends on its technical state. Operation is accompanied by the change in the technical state, which depends on two processes: the ageing process and development of defects and reduction process. If not to use special measures, then state will continuously deteriorate. In connection with this arises the problem of control of technical state, due to the timely conducting of maintenance and repairing the equipment.

The improvement of operating system is the urgent task, which is consisted in the development of methods and hardware, which ensure control of equipment state, also, in the passage from one system of regular overhaul to repair the next according to technical state. Passage to the new system of repair will require the solution of the entire complex of questions of the organizational and technical nature.

Into the composition of the technical measures, on which depends the maintenance of equipment state, enter the technical operation instructions and rule of the organization of maintenance and repair of the equipment of the systems of power supply. To the most important problems at realization of technical actions concern: development and the introduction of methods and means of state value; determination and the prognostication of serviceability; the determination of the optimum time between overhauls; the selection of rational strategy of conducting maintenance and repair; the selection of strategy of control of the states of the process of operation; planning repair taking into account the technical state.

IMPROVEMENT OF THE SYSTEM OF THE REPAIRS OF ELECTRICAL EQUIPMENT TAKING INTO ACCOUNT THE TECHNICAL STATE

The periodicity of repairs under the actual operating conditions is determined by the normative and actual level of reliability. Simulators, which make it possible to optimize time between overhauls both taking into account for the results of diagnosis and the changes in the indices of serviceability for three strategies: regular overhauls (strategy I), emergency repairs (strategy II), due to the technical state (strategy III). Table 1 resulting expressions for enumerating the optimum periodicity of repairs for three strategies indicated, where Cmwd, Cp, Caer are respectively costs per units for conducting of maintenance works and diagnosis, for preventive and for after-emergency repairs; λb - basic failure rate of equipment; Q(T) - probability of failure; f - probability that the repair is not assigned according to the results of technical diagnostics; T - interval of time, on which is calculated optimum time between overhauls.

Investigated the influence of separate initial data to the periodicity repairs for different types of equipment even three strategies of repair. The models proposed consider the nature of the manifestation of refusals and the results of the diagnosis.

The task of determining the optimum volume of repair is key for preparation and conducting of repair company, planning the need for the repair personnel, the spare parts and the materials. The essence of this task consists in the formation of the enumeration of works on warning of refusals and works, connected with the liquidation of defects and their indicates, that reflect the dynamics of a change of state of equipment. Estimation and recognition is produced in the operational process and in the process of repair.

The algorithm of the determination of the optimum volume of repair, based on the estimation of equipment state is developed. Algorithm includes: determination with the aid of the means of diagnostics of the state of object, the estimation of the values of the worn resource, making the decision about the correspondence to the identified class of the state. Depending on technological and performance attributes the repair is performed by restoring Vrs or replacement Vrp of separate assembly units (elements). The calculation of the volume of repair is carried out in accordance with the formula
\[ V_r = V_{es} + V_{ep} = \gamma \sum_{i} e_{ei} r_{ei} t + \gamma \sum_{j} e_{jp} r_{jp} t, \]

where \( e_{ei} \) and \( e_{jp} \) - specific repair labor expenses respectively to restoration of \( i \)-element and to replacement of \( j \)-element; \( r_{ei} \) and \( r_{jp} \) - the relative values of the worn resource for \( i \)-element and \( j \)-element in time \( t \); \( \gamma \) - the coefficient, which considers the auxiliary operations; \( z_{es}, z_{ep} \) - a quantity of the restorable and replaceable elements.

The selection of the works, which ensure the maintenance of technical state at the necessary level, is achieved on the basis of analysis of indicates change of state and corresponding to them defects.

The procedure of the selection of rational strategy of repairs is based on the comparison of the values of the relation of the objective functions (see Table 1) upon transfer from strategy I to II and III: \( Z_1(T)/Z_2(T) \) and \( Z_1(T)/Z_3(T) \). The purpose of selecting is the determination of the boundary conditions, with which is ensured the effectiveness of the application of strategies II or III in comparison with strategy I. The selection of rational strategy of repairs is achieved on the basis of the analysis of the special system of equations of relation. In this case by coefficient \( \delta \) is considered an actual increase in the defect level of equipment during crew transfer from strategy I to strategy II, and by coefficient \( \delta' \) is considered the actual decrease of defect level upon transfer from strategy I to strategy III. Fig. 1 and 2 depict the functions of the boundary conditions \( Z_1(T)/Z_2(T) = F(\delta) \) and \( Z_1(T)/Z_3(T) = F(\delta') \), which are built for the probabilities of the failures of equipment \( Q(T) = 0,1 \) (fig.1) and \( Q(T) = 0,3 \) (fig.2).

The procedure of the selection of rational strategy of repairs assumes the comparison of the actual value of the coefficient of overpatching of defect level \( \delta \) with the boundary values of the coefficients \( \delta_{bd} \) and \( \delta_{bd}' \), beginning from which is ensured the effectiveness of the application of strategy II or strategy III in comparison with strategy I. In Fig. 1 to point 1 does correspond \( \delta_{bd} \) and to point 2 – \( \delta_{bd}' \). In Fig. 2 to point 1 does correspond \( \delta_{bd} \) and to point 2 – \( \delta_{bd}' \).

It follows from Fig. 1 that if \( \delta_1 < \delta_{bd} \), then strategy I and strategy II are equally rational; if \( \delta_{bd} < \delta_1 < \delta_{bd}' \), then strategy II and strategy III are rational; if \( \delta_1 > \delta_{bd}' \), then strategy I and strategies III are rational.

It follows from Fig. 2 that if \( \delta_1 < \delta_{bd} \), then the application of strategy II and of strategy I are equally expedient; if \( \delta_{bd} < \delta_1 < \delta_{bd}' \), then the application of strategy I is the most rational; if \( \delta_1 > \delta_{bd}' \), then strategy I and strategy III are equally rational.

The expediency of applying strategy I is obtained only in the case, when \( \delta_{bd} < \delta_1 < \delta_{bd}' \) (fig. 2). In other cases it is necessary to examine two competing strategies of the organization of the repairs of the equipment.

A number of the intermediate competing strategy which are taking into account the information on refusals and results of diagnosing with conducting and designation of repair work is offered. It allows to make of the decision by composition of the schedule charts of repairs and to forecast strategy of their further operation taking into account actual state. In this case the process of operation is formalized, and the need for control of it depending on equipment level is quantitatively determined thus. This problem is solved with the aid of the matrix method.

According to this method, strategy of control of the states of the process of operating the group of the equipment of one technological designation is represented by the special matrix of control, the filling with which is determined by the technical level of each unit in the group on the basis of the results of diagnosis. Matrix takes the form:

\[ Y = [y_{ks}], \]

where \( y_{ks} \) - the matrix element of control \( Y \) located in the line with number \( k \) and the column with number \( s \);

<table>
<thead>
<tr>
<th>Strategy of the repair</th>
<th>Objective function of strategy of maintenance and repair</th>
<th>Calculated expressions for determining the optimum time between overhauls</th>
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<tbody>
<tr>
<td>I</td>
<td>[ Z_1 = \frac{C_p Q(T)}{T} + \lambda C_{av}^2 ]</td>
<td>[ T_{opt1} = \frac{\sqrt{C_p Q(T)}}{2\lambda C_{av}}. ]</td>
</tr>
<tr>
<td>II</td>
<td>[ Z_2 = f \frac{C_{med} Q(T)}{T} + (t-1)\lambda C_{av} ]</td>
<td>[ T_{opt2} = \frac{\sqrt{C_{med} Q(T)}}{2\lambda C_{av}}. ]</td>
</tr>
<tr>
<td>III</td>
<td>[ Z_3 = f \frac{C_{med} Q(T)}{T} + (1-f)\frac{C_{med} Q(T)}{T} + \lambda C_{av}^2 - \lambda f C_{av} ]</td>
<td>[ T_{opt3} = \frac{\sqrt{f C_{med} Q(T) + (1-f)C_{med} Q(T)}}{2\lambda C_{av}}. ]</td>
</tr>
</tbody>
</table>
s – the index of the set of operative conditions (S=1 – repairs, S=2 - reserve; S=3 – work). Moreover a quantity of lines is equal to a quantity of equipment in the technological group, and a quantity of columns is equal to a quantity of states of the process of the operation, i.e. S=1, 2, 3 (repairs, reserve, work). Therefore the matrix of control Y does have a size of k × 3. Each element \( y_{ks} \) is Boolean variable, its value showing, in what state of the process of operation from the set \{S\} must find \( k \)- equipment of this group in the dependence on its state. In this case: \( y_{ks}=1 \), if \( k \)- equipment is in state \( S \); \( y_{ks}=0 \), if \( k \)- equipment is not in state \( S \). The matrix of strategy of control Y by its elements \( y_{ks} \) indicates the rule of control of the states of the process of operating \( j \)- group. It gives answer to the question: what equipment from group \( j \) depending on its state and superimposed limitations must be located in the considered planned period in the appropriate state with index \( S \).

Then, the task of the selection of rational strategy of control of the states of the process of operation consists of the determination of such operating instructions, with which the repair first of all is carried out on the equipment, which has lower technical level. Thus, the formation of the schedule charts of maintenance and repair is reduced to obtaining of the priority lists of equipment, which is necessary to carry out repair in planned period in question. The fact for the schedule chart of works on maintenance is characterized that the need is evaluated only according to the value of the actual wear of resource after the previous maintenance.

The latter is determined with the aid of the means of technical diagnostics and are considered real-life environment and operating modes. Let’s formulate three basic regulations, which are accepted with the composition of the schedule chart of the maintenance of power facilities on the basis of the determination of its state using the means of diagnostics.

1. The work to equipment is assigned on maintenance only in case of the actual resource worn by it with the existing working conditions is not less than the normative wear of the resource between two works of this form with the normative conditions;
2. With the composition of the priority list of equipment, which requires conducting maintenance, the criterion of the sequential minimization of the maximum values of the integral index of state is used - the worked out resource;
3. With the composition of the priority list, taken as the schedule chart of maintenance, it is necessary to calculate limitations on the basis of the labor resources, which the power facility for fulfilling the works of this form is arranged.

For the record of the simulator of the procedure of the composition of the schedule chart of works on maintenance let’s accept the following designations of the parameters and concepts:

\( N \) – the total quantity of electrical devices on the power facility; \( m \) – the quantity of groups of electrical devices, obtained by the partition of set \( N \) according to the sign of the technological designation; \( j=1, \ldots, m \) – the ordinal number of the group; \( K_{ij} \) – a quantity of electrical devices in each \( j \)- group; \( i=1, \ldots, k \) – the ordinal number of electrical devices in \( j \)- group; \( [R]_j \) – the normative relative wear of resource of \( j \)- group between two servicing of equipment, in the case of its operation with the normative conditions; \( R_{ij} \) – the relative actual worn resource \( i \)-electrical devices of \( j \)- group, determined with the aid of the specialized control devices and diagnostics, or calculated analytically with the aid of the special algorithms; \( L_0 \) – the quantity of personnel, necessary for conducting the maintenance for the electrical devices, which entered into the comprised schedule chart; \( [L]_v \) – the value of the quantity of the located number of personnel, isolated for conducting the maintenance on the power facility; \( LS_v \) – the list of electrical devices, that requires performing work on the maintenance \( (v=1, \ldots, 6) \). The list \( LS_v \), indicating the following, if \( v \) takes the values:

1 – the list of the equipment, which requires conducting maintenance in \( j \)- group;
2 – the total list of the equipment, which requires conducting maintenance in the system of the power supply;
3 – the priority list of the equipment, which requires conducting maintenance in \( j \)- group;
4 – the total priority list of the equipment, which requires conducting maintenance in the system of the power supply;
5 – the total priority list of the equipment, which requires conducting maintenance, comprised taking into account limitations on the labor resources;
6 – the priority list of the equipment, which requires conducting maintenance for the following planned period.
The formulated basic condition, the adopted designations of the parameters and concepts make it possible to write down the simulator of the formation of the schedule chart of works on maintenance, given in Table 2.

**TABLE 2. SIMULATOR OF THE FORMATION OF THE SCHEDULE CHART OF WORKS ON THE MAINTENANCE**

<table>
<thead>
<tr>
<th>Position of the model</th>
<th>Simulator of the formation of the schedule chart of the maintenance</th>
<th>Result of the fulfillment of conditions of the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$R_j \geq [R_j], j = 1, \ldots, k;\quad LS_1$ and $LS_2$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$R_i \geq R_{i+1}, i = 1, \ldots, k;\quad LS_3$ and $LS_4$</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$L_0 \leq [L_0], \quad LS_5$ and $LS_6$</td>
<td></td>
</tr>
</tbody>
</table>

**REFERENCES**
