Intellectual diagnosis components of electrical equipment in the sphere of transportation

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Abstract. Ensuring the reliability of the electrical equipment in transport means a necessity of its inspection and diagnosis. Frequency convertors are part of this equipment. The article is focused on creation of the optimal logical algorithm for frequency convertors diagnosis. The algorithm determines the most effective knowledge base structure of the diagnostic expert system. The algorithm is developed, the knowledge base structure is constructed in accordance with the proposed algorithm, and the diagnostic expert system used is implemented. Correctness and effectiveness of the expert system functioning are confirmed in practice.

1. Introduction
Ensuring the reliability of the electrical equipment (EE) components in transport is especially relevant today. The EE components in transport include a sophisticated EE of electric drives (ED) [1]. Examples of EE components are frequency-regulated electric drives of pumps and fans as well as the asynchronous traction drive and auxiliary electric drive of locomotive [2].

Industrial frequency convertors (FC) are parts of the EE mentioned above, and their diagnosis is more effective being supported by the diagnostic expert system (ES) [3-5]. Thus, developing a knowledge base (KB) structure for the expert system for diagnosis of frequency convertors is an important and actual task. This paper is dedicated to the development of the optimal logical algorithm for diagnosis of the industrial frequency converters, which can determine the most effective KB structure for the ES intended for diagnosis of this equipment.

2. Structure and characteristics of the object for diagnosis
The functional scheme of industrial FC connection to the electrical network is represented in Figure 1. The scheme shows the basic functional blocks of the system and signals existing in it and uses the following abbreviations: AS – automatic switch; IF – inlet filter; UR – unguided rectifier; RF – ripple filter; AI – autonomous inverter; L – electric load of converter; PU – power unit of control system; CS – control system of converter; CP – control panel; Up – voltage of the power line of alternating current; Uᵢ – converter circuit input voltage; Uₒ – output voltage of autonomous inverter; Uᵦ – output voltage of power unit; Uₛ – output frequency task signal; Iᵢ – electric current of the load.
3. Development of the optimal diagnostic algorithm

To develop the optimal logical algorithm for EE diagnosis a special procedure is proposed. It includes the following stages:

1. FC functional scheme analysis in order to determine whether the functional blocks checks are expediential in different situations;
2. selection of the first check block (top of the algorithm tree);
3. construction of the block nomenclatures for the branches of the algorithm tree;
4. forming the complete arrays of check sequences for the branches;
5. finding the sequences satisfying the optimality criterion;
6. synthesis of the algorithm tree from the obtained components.

The fourth stage is the most complex and time-consuming one of the listed above, it forms a full array of checks sequences. This process can be illustrated by the block diagram shown in Figure 2. The diagram contains the following legend: LACE0 – logical array of the checks execution formed in the case of obtaining the defective output signals; LACE1 – logical array of the checks execution formed in the case of obtaining the proper output signals; SBNB – set of the block nomenclature for the branch; C1 – condition which means that the candidates of the low-order level have been exhausted and the remaining candidates have become unable to form the sequence which would appear to be the equivalent to the nomenclature of the branch without the block corresponding to the component SBNB [i].

**Figure 1.** The functional scheme of industrial FC connection to the electrical network.
In order to implement the procedure represented above for the industrial FC diagnosis, the authors have developed the specialized application *FC_OPTIM*. The structure of its working prototype is shown in Figure 3 that contains the following legend: TC – table of the FC functional blocks characteristics; LACE – logical arrays of the check execution; FACS – full array of check sequences; OA – tree of the optimal logical algorithm for diagnosis of the industrial frequency converters (algorithm output).

**Figure 2.** The block diagram of algorithm.

**Figure 3.** Structure of the application for the optimal diagnostic algorithm development.
Procedure \textit{Start} implements the first stage of the algorithm development. Procedure \textit{Construction} executes the second, third and fourth stages. Procedures \textit{Count} and \textit{Selection} realize the fifth and sixth stages.

Figure 4 shows application FC\textsubscript{OPTIM} output. The procedure \textit{Start} implements the first stage of the algorithm development. The representation of the algorithm tree in the \textit{FC\_OPTIM} output has the following form: the table cell containing the number of block that should be checked when a proper output signal is obtained (left child position) located in the following table row directly under the cell with a number of just checked block (parental position). The cell containing the number of the block that should be checked when a defective signal is obtained (right child position) located in $1, 2, 2^2, \ldots , 2^{n-k}$ cells respectively to the right of the left child position. Here $n$ is a total number of levels of blocks seen as candidates, $k$ is an index of level of parental position under consideration, and the level of the first check block child positions is taken equal to 0).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{Results of \textit{FC\_OPTIM} work.}
\end{figure}

The obtained configuration of the optimal logical algorithm for industrial FCs diagnosis corresponds to the tree of developed by the authors MPT algorithm for FC diagnosis shown in Figure 5.

Figure 5 contains the following legend: circles with the numbers inside mean the elementary checks of functional blocks with corresponding numbers (Figure 1); numbers 1 and 0 represent the results of the block checks (proper and defective output signals respectively); rectangles are the results of diagnosis (number inside the rectangle indicates the number of the defective block).

The MPT algorithm uses the criterion of the first check minimal time and takes into account the technical state characteristics of blocks. In accordance with this algorithm, the first elementary check should have a minimal check time $t(e_i)$. In case of equality of the check times, a check that controls a functional block located nearer to the central section of the diagnosed object functional scheme should be the first. The subsequent checks are selected based on the characteristics of technical states in a descending order of $p(e_i)/t(e_i)$ value.
Figure 5. Tree of the optimal logical algorithm for diagnosis of the industrial frequency convertors.

4. Conclusion
As a result of a detailed analysis of industrial FC structure made in this paper, the configuration of the optimal logical algorithm for FC diagnosis was created. Based on this algorithm and experts’ heuristics, a knowledge base for diagnosis of industrial frequency convertors that are components of frequency-regulated electric drives of pumps, fans, and locomotives is developed. The expert system FC3 used the proposed knowledge base structure is implemented. Correctness and effectiveness of the expert system functioning are confirmed in practice.

References
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