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Designing the Fault-Detection and Troubleshooting Tests For the Troubleshooting Target Flowchart

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Abstract. This paper covers the matter of troubleshooting in urban electric transport and electrical equipment. The solution to this issue requires transferring the qualitative determination of the health of the equipment to some quantitative basis. The formalization of qualitative definitions is a prerequisite for constructing formal (computable) troubleshooting algorithms.

Continuous systems of railway automation, telemetry and communications have features that allow their preference to be given to logic models. The use of logic models is associated with tolerance-based test methods, which are described by the conclusion about the equipment health is based on the evaluation of signal values at reference points (values of test parameters). The parameter test results in this case are reduced to the following estimates: “within tolerance - out of tolerance”, “satisfactorily - not satisfactorily”, in other words, to estimates of the two-digit type (zero or one) [1-3]. Hence, logic models and various logic methods appear to be useful in such cases.

At the first stage of building the logic model in the system, individual functional elements are distinguished whose inputs and outputs are available for measurement.

At the second stage of building the model, a flowchart of the system as a troubleshooting target is designed to show all selected elements and the connections between them.

The troubleshooting target flowchart (Fig. 1) consists of eight elements: *E1 – E8,* has four external input actions: x_1 – z_4, and produces four output responses: y_5, y_6, y_7, y_8. Each element produces its own output response y_i, while the output responses of the elements *E5, E6, E7, E8* match the output responses of the flowchart. Let us accept that x_i=1 and y_i=1, if *i*-th input action or output response of the *j*-th element is valid; otherwise x_i = 0 and y_i = 0.

We restrict ourselves to the case of considering only single faults, so the system has nine states:

S_0=11111111, S_1=01111111, S_2=10111111,
S_3=11011111, S_4=11101111, S_5=11110111,
S_6=11111011, S_7=11111101, S_8=11111110.

When handling the logic model, it is assumed that the input of the troubleshooting target receives a single input action, determined by the permissible values of all input signals.

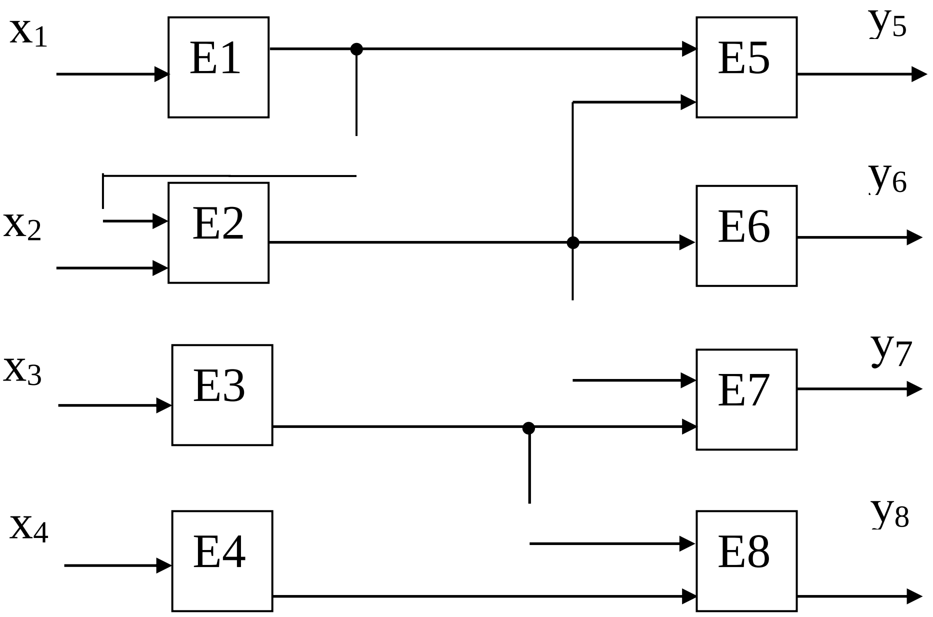

Fig. 1 The Troubleshooting Target Flowchart

Therefore, possible simple tests differ only in the reference points to measure. In this event, the purpose of buiding a troubleshooting algorithm is reduced to choosing reference points sufficient to solve a specific troubleshooting problem [4-6]. In practice, a large number of tests cannot be performed, since there is no access to the outputs of some elements; it is impossible to connect directly to the outputs of several elements, etc.

In the case in hand, it is as if only those tests are possible that consist in measuring the response at the output of one of the system elements, and the outputs of all elements are available for measurement. Let us denote the simple test as π_i - this is the response control at the output of the i-th element ($i \in \{1, 2, ..., 7\}$).

Table 1 lists fault functions compiled for the system (see Fig. 1).

Table 1

Test	Test result R for the system in state								
	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
π_1	1	0	1	1	1	1	1	1	1
π_2	1	0	0	1	1	1	1	1	1
π_3	1	1	1	0	1	1	1	1	1
π_4	1	1	1	1	0	1	1	1	1
π_5	1	0	0	1	1	0	1	1	1
π_6	1	0	0	1	1	1	0	1	1
π_7	1	0	0	0	1	1	1	0	1
π_8	1	1	1	0	0	1	1	1	0

When the system is in the healthy condition (state S_0), the outputs of all elements have valid signal values [7]. Failure of any element causes an invalid signal value at its output and at the outputs of all associated elements.

This fault functions table contains all the data necessary for designing the fault-detection and troubleshooting tests [7,8]. Each table column sets a function defined on a set of tests. The function is equal to one if the test is satisfactory. Let F be the function of the healthy item; f_i is the function of the i-th state of the faulty item or the function of the i-th fault. For example:

$$F = \pi_1 \vee \pi_2 \vee \pi_3 \vee \pi_4 \vee \pi_5 \vee \pi_6 \vee \pi_7 \vee \pi_8,$$

$$f_1 = \pi_3 \vee \pi_4 \vee \pi_8, \qquad f_2 = \pi_1 \vee \pi_3 \vee \pi_4 \vee \pi_8,$$

$$f_3 = \pi_1 \vee \pi_2 \vee \pi_4 \vee \pi_5 \vee \pi_6, \qquad f_4 = \pi_1 \vee \pi_2 \vee \pi_3 \vee \pi_5 \vee \pi_6 \vee \pi_7,$$

$$f_5 = \pi_1 \vee \pi_2 \vee \pi_3 \vee \pi_6 \vee \pi_7 \vee \pi_8,$$

$$f_6 = \pi_1 \square\square\square_2 \square\square\square_3 \square\square\square_4 \vee \pi_5 \vee \pi_7 \vee \pi_8, \qquad f_7 = \pi_1 \square\square\square_2 \square\square\square_3 \square\square\square_4 \square\square\square_5 \square\square\square_6 \vee \pi_8,$$

$$f_8 = \pi_1 \square\square\square_2 \square\square\square_3 \square\square\square_4 \square\square\square_5 \square\square\square_6 \vee \pi_7$$

When designing the test T_{fd} for each fault, the fault-detection function is calculated:

$$\varphi_i = F \oplus f_i . \qquad (1)$$

The function $\varphi_i = 1$ only on those tests where the test results are different for healthy conditions and for a condition containing the i-th fault [9, 10]. In other words, it combines those tests on which the i-th fault is detected.

Fault-detection test

$$T_{fd} = \varphi_1 \varphi_2, \ldots, \varphi_n, \qquad (2)$$

where n is the number of faults.

In this case, n = 8.

In order to find φ_i, let us sum up the obtained values according to formula (1) to have:

$$\varphi_1 = \pi_1 \vee \pi_2 \vee \pi_5 \vee \pi_6 \vee \pi_7, \quad \varphi_2 = \pi_2 \vee \pi_5 \vee \pi_6 \vee \pi_7,$$

$$\varphi_3 = \pi_3 \vee \pi_7 \vee \pi_8, \qquad \varphi_4 = \pi_4 \vee \pi_8,$$

$$\varphi_5 = \pi_5, \quad \varphi_6 = \pi_6, \quad \varphi_7 = \pi_7, \quad \varphi_8 = \pi_8$$

Then

$$T_{fd} = \varphi_1 \varphi_2 \varphi_3 \varphi_4 \varphi_5 \varphi_6 \varphi_7 \varphi_8 =$$

$$= (\pi_1 \vee \pi_2 \vee \pi_5 \vee \pi_6 \vee \pi_7)(\pi_2 \vee \pi_5 \vee \pi_6 \vee \pi_7)(\pi_3 \vee \pi_7 \vee \pi_8)(\pi_4 \vee \pi_8)\pi_5\pi_6\pi_7\pi_8 \qquad (3)$$

The equation (2) can be simplified based on the absorption law, which is described by the following equalities:

$$a(a \vee b) = aa \vee ab = a \vee ab = a(1 \vee b) = a \times 1 = a,$$

$$(a \vee b)(a \vee b \vee c) = a \vee b,$$

or in the general case

$$(G_1 \vee G_2)(G_1 \vee G_3) = G_1, \qquad (4)$$

where G_1, G_2, G_3 are any logic functions.

Using the actions:

$$\begin{aligned}
&1)\left(\pi_6\right)\times\left(\pi_6+\pi_7\right)=\pi_6\times\pi_6+\pi_6\times\pi_7=\pi_6\times(1+\pi_7)=\pi_6\\
&2)\left(\pi_6\right)\times\left(\pi_6+\pi_8\right)=\pi_6\times\pi_6+\pi_6\times\pi_8=\pi_6\times(1+\pi_8)=\pi_6\\
&3)\left(\pi_6\right)\times\left(\pi_4+\pi_6\right)=\pi_6\times\pi_4+\pi_6\times\pi_6=\pi_6\times(1+\pi_4)=\pi_6\\
&4)\left(\pi_1+\pi_5\right)\times\left(\pi_1+\pi_5\right)=\pi_1+\pi_5\\
&5)\left(\pi_1+\pi_5\right)\times\left(\pi_1+\pi_2+\pi_5\right)=\pi_1\times\left(\pi_1+\pi_2+\pi_5\right)+\pi_5\times\left(\pi_1+\pi_2+\pi_5\right)=\pi_1\times(1+\pi_2+\pi_5)+\pi_5\times\left(1+\pi_2+\pi_5\right)=\\
&=\pi_1+\pi_5
\end{aligned} \tag{5}$$

results in 2 fault-detection tests:

$$\begin{aligned}
T_{\Pi 1}&=\pi_6\times\pi_1\\
T_{\Pi 2}&=\pi_6\times\pi_5
\end{aligned} \tag{6}$$

It follows from the equation that the complete testing of the system requires just to simultaneously apply the permissible signals to the external inputs of elements 1 and 6 or 6 and 5 and measure the response at the output [11, 12, 13]. If the system is healthy, then the output of the element will be a valid signal, if it is faulty, then the output of the element will be an invalid signal.

In general, it is enough to verify all its external outputs to test the healthy condition of the equipent item [14, 15, 16]. However, the logic model and the fault functions table allow one to find such a minimal set of checks that will not include the external outputs of the object, which are also the inputs of the model blocks [17,18].

A troubleshooting test of Tt is designed at the time of solving the problem of detection of a faulty element. For each pair of faults (with numbers i and j), a discriminating function is calculated:

$$\varphi_{i,j} = f_i \oplus f_j \tag{7}$$

The discriminating function obtained by equation (7) is equal to one only in those tests where the test results are different for the conditions with the i-th fault and for the conditions with the j-th fault. In other words, it combines those tests on which the i-th and j-th faults differ from each other.

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