The resulting equation significantly improved the mathematical description of the process and eliminated some inaccuracies. However, in order to accurately describe all the work being done and their impact on the process as a whole, it is necessary to further decide how it is possible to combine equations (6) and (7). Work in this direction will continue.

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DEVELOPMENT OF A SOFTWARE MODEL OF REDUNDANCY WITH ROTATION FOR A MULTI-CHANNEL VOLTAGE CONVERTER

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Abstract — The paper considers the influence of changes in the load factor when power channels fail in multi-channel voltage converters on the value of their operating time to failure and taking into account the probability of failures (probability of successful switch over) when switching power channels in converters.

Keywords: reliability; dependability; redundancy; diverse redundancy; redundancy with rotation; electrical load factor; probability of successful switch over; multi-channel voltage converters.

INTRODUCTION

In the context of global automation, the task of improving the reliability of computer equipment is becoming more and more urgent. For example, the failure of the power supply system of the information system of a military defense object entails serious material damage, and sometimes can cause a disaster. In practice, the most common method for improving reliability is redundancy [1, 2].

This software model describes a diverse redundancy with rotation of power channels in multi-channel voltage converter (MCVC). Diverse redundancy "N+1+K" refers to a redundancy without restoration, where "N from (N+1)" is an active redundancy with N major elements and 1 hot reserve, the elements of which are reserved with K cold reserves [3, 4].

PROBLEM STATEMENT

In this paper, we consider ways to account for changes in the load factor in the event of failure of power channels (when power channels fail) and the probability of successful switch over in the simulation modeling of MMVC. We also provide an algorithm for recalculating the total operating time of MCVC in connection with the failure of channels during switching [5].

SOLUTION OF THE PROBLEM

When assessing the reliability of a redundant system, the main parameter is the failure rate of its components. The component failure rate is calculated based on the component failure

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rate of its type of radio electronic element [6]. Mathematical models of the failure rate for most types of radio electronic elements have the following form [7]:

$$\lambda_{component} = \lambda_{basic} \times \prod_{i=1}^{n} K_i \,, \tag{1}$$

where λ_{basic} is basic failure rate of element's type (or group), calculated based on the results of tests for reliability and durability for this type; K_i is coefficients that take into account changes in the operational failure rate depending on various factors; n is the number of factors taken into account.

One of the factors affecting the operational failure rate of the radio electrical element is the value (amount) of electrical load, which is characterized by a load factor (K_p) [8]. It is obvious that when power channel fails, the electrical load on the remaining channels increases, which in turn leads to an increase in their operating failure rate [9].

Thus, for the correct calculation of channel operating time [10], it is necessary to recalculate the component failure rate after each failure using the provided formula:

$$\lambda'_{component} = \lambda_{component} \cdot \frac{K'_p}{K_p} \,, \tag{2}$$

where K'_p is a current value of coefficient of electrical load of the channel; $\lambda_{component}$, K_p refer to values of failure rate and the coefficient of electrical load before failure, respectively.

Further, we will discuss in more detail how to calculate the electric load coefficient for various types of redundancy, which are most often used when reserving voltage converters.

1. Active redundancy

By definition, in the active redundancy group (see Fig. 1) all channels are constantly in operation mode [11].

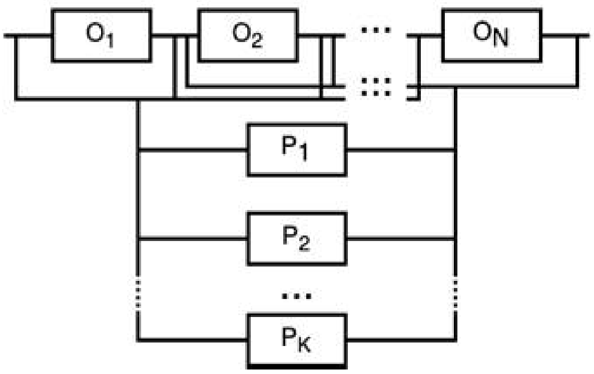

Fig. 1 Reliability block diagram of active redundancy

For an active redundancy, the K_p coefficient is calculated using the following formula:

$$K_p = \frac{N}{N+R} \,, \tag{3}$$

where N refers to number of major elements, R – number of reserves.

Therefore, for each failure, the K_p coefficient of the operable channels will increase until it reaches 1. It follows from (3) that the channel failure rate also increases. The algorithm for taking into account the load factor when calculating the operating time of the active redundancy group is proposed in fig. 2 [12].

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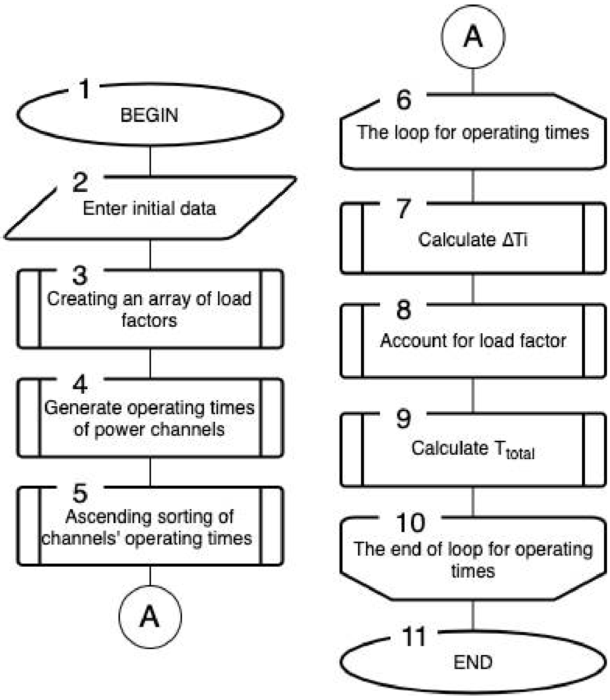

Fig. 2 Algorithm for calculating the operating time of the active redundancy

First, you need to determine the number of major and backup (hot reserves) channels. Let's put them equal to N (main) and R (reserve), respectively (Block 2 in Fig. 2). Then, using the formula (3), an array of load factors (Block 3) is calculated, the values of which are equal to the possible number of failures (the failure criterion of the reserved group) – ($R+1$) [13]. Next, the power channels are generated (Block 4), after which they are sorted in ascending order (Block 5).

The total time taken into account the load changes is calculated in Block 9 using the formula:

$$T_{total} = \frac{T_1}{K_{p(N+R)}} + \frac{\Delta T_2}{K_{p(N+R-1)}} + ... + \Delta T_{R+1}, \quad (4)$$

where ΔT_i is the value of the time interval between $(i-1)$ -th and i-th failures, $K_{p(N+R-i+1)}$ – load factor for ($(N+R-i+1)$ operating channels (it is obvious, that $K_{pN}=1$).

2. Diverse redundancy

For diverse redundancy (see Fig. 3) the cold reserves (R_1 ... R_K) are in standby mode, so they do not affect the K_p coefficient of the working channels, which will remain unchanged until all K channels fail [13] (the K_p coefficient is calculated using the formula (3) for $R=1$).

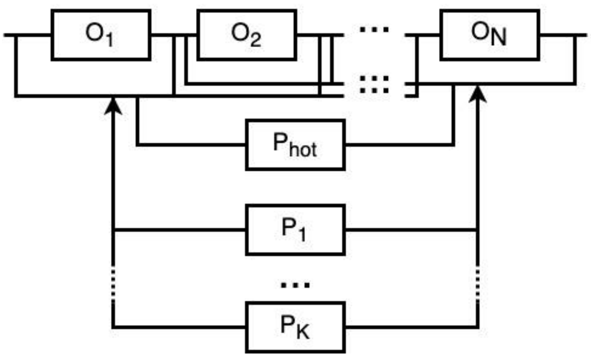

Fig. 3 Reliability block diagram of the diverse redundancy

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After the failure of K channels, the scheme is converted to an active redundancy and the coefficient is also calculated using the formula.

In the framework of the developed program, diverse redundancy with rotation of power channels is considered, so it is necessary to determine the dependence of the K_p coefficient on rotation. During rotation, there is no difference between the main(major) and cold reserve channels, since all channels are in both operation and standby mode for the same time [14]. Therefore, when rotating power channels, the electric load coefficient is calculated using the formula:

$$K_p = \frac{N+1}{N+1+K}. \quad (5)$$

Therefore, K_p increases with each failure until it becomes equal to 1 (similar to an active redundancy).

MCVC in accordance with [15] is the object of multiple cyclic application. In the framework of the developed software model, power channels are considered non-recoverable, that is, they are not subject to restoration during the service life in the event of a failure. Therefore, one of the reliability indicators for power channels according to the classification [15] is $P_{0(on)}$ - the probability of failure-free operation (inclusion).

The probability of a failure- free channel operation is a random variable that obeys the law of uniform distribution. For failure-free calculations, $P_{0(on)}$ take close to 1. Since failure is the opposite of a fail-safe event, the probability of failure is in the range $\left(P_{0(on)};1\right]$. In other words, a failure to switch is an unlikely event [16].

Usually, the number of item switches during redundancy is quite small [17]. For example, for the standby redundancy with N main(major) and K backup elements (see Fig. 1) the number of item switches will be exactly equal to the number of backup items (K). In this case, the probability of switching, as an unlikely event, can be ignored without losing the accuracy of the estimation of the total operating time of the reserved group.

However, when rotating, the number of switches increases greatly. It depends on the number of power channels and the number of full rotation cycles during which the MCVC is expected to operate. The full rotation cycle refers to the length of time during which each of the power channels will be in both standby and operating mode. Note that in this voltage converter model, full rotation cycles can be of any length. The rotation period refers to the length of time between adjacent switches, which is defined as:

$$T_{period} = \frac{T_{full.rotation.cycle}}{N+1+K}, \quad (6)$$

where $T_{full.rotation.cycle}$ refers to value of current full rotation cycle; $N+1+K$ refers to number of working power modules.

Accordingly, for each full rotation cycle, the number of switches for one channel is $m=2$, as defined by the full rotation cycle.

Thus, in general, the number of switches can be quite large. This, in turn, can significantly affect the reliability of the voltage converter [13].

The description of the patent [18] suggests switching channels after 24 hours. For example, consider a converter whose centralized part contains $N=3$ main(major) power channels reserved by one hot reserve and $K=2$ backup channels located in cold reserve. With an estimated service life of 1 year, the number of switches for a single power channel is defined as:

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$$Q_i = m_i \times t, \tag{7}$$

where Q_i is the number of switches for the i-th channel m_i l, refers to the number of switches for the i-th channel in one full rotation cycle and t is the number of full rotation cycles.

According to the formula (7), Q will be equal to 730. Since in this example the values of the full rotation cycles are constant, the formula (7) is converted:

$$Q_i = m_i \times \frac{T_{work}}{T_{full.rotation.cycle}}, \tag{8}$$

where T_{work} is the service life, $T_{full.rotation.cycle}$ refers to the value of the full rotation cycle.

In this case, the total number of switches will be 4380. For comparison, in the standby redundancy with the same number of major and backup switching channels, there will be only 2.

Since the probability of a successful switch over is independent, the probability of a successful switch decreases as the number of switches increases:

$$P_{total} = P_{on1} \times \ldots \times P_{onq}, \tag{9}$$

where q is the number of switches; P_{oni} is the probability of a successful switch over during i-th switch.

Within the limits of the considered values for ensuring the probability of failure-free operation of the MCVC for one year, $P = 0{,}95$ for "absolutely" reliable modules (the probability of failure of the module $P_0 = 0$) the probability of a single switch must be:

$$P_1 = \sqrt[k]{P} = 0{,}99998, \tag{10}$$

where k is the number of switches, P is the probability of failure-free operation of the MCVC for one whole year.

From the calculations given above, it is obvious that taking into account the possibility of failure during switching is necessary for a correct assessment of the voltage converter's reliability.

A special separate module was created for calculating the operating time for channel failures when switching channels [19]. Let's consider in more detail the algorithm for accounting for the probability of successful switch over and the associated recalculation of the converter's operating time.

Due to the fact that to consider the probabilities it is necessary to calculate the number of switches it is done after the initial assessment of operating time.

To correctly identify the power channels that are in operation and standby mode at any time, a matrix of channel transitions is created, in which the rows correspond to the channel numbers, and the columns correspond to the rotation periods.

If two adjacent cells in the i-th row of the matrix are not equal to each other, then at this point in time, the i-th power channel switched (either to the standby mode or to the operating mode state). For each such point in time, an implementation of a random variable is generated that is equal to the probability of a successful switch. If this number is greater than the one specified in technical specifications $P_{0(on)}$), then there is a channel failure in this experiment. Since the failure occurred earlier than the calculated operating time, it is necessary to recalculate the operating time implementations for the remaining channels, as well as the final implementation of the MCVC operating time for the current number of channels.

Recalculation of channel's operating time is performed according to the formula (11), and the final performance — according to the formula (12).

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$$t_i^{'} = t_i - \sum_{j=1}^{n} \left\{ T_{period.j} \times \left[(N+1) + \left(K \times \frac{\lambda_{standby}}{\lambda_{work}} \right) \right] \right\} - T_{period.n+1} \times \left[r_i + \left(w_i \times \frac{\lambda_{standby}}{\lambda_{work}} \right) \right], \quad (11)$$

where $t_i^{'}$ is the new operating time of i-th power channel, t_i is the initial operating time of i-th power channel, n refers to the number of – количество completed full rotation cycles before failure, n + 1, therefore, is a full rotation cycle in which a failure occurred, $T_{period.j}$ is a rotation period in the j-th cycle of full rotation, r_i and w_i are numbers of rotation periods in the n+1 full rotation cycle during which the i-th power channel was in operation and standby modes, respectively, λ_{work} is failure rate in operating mode, $\lambda_{standby}$ – failure rate in standby mode.

$$T = \sum_{j=1}^{n} T_{full.rotation.cycle.j} + T_{period.n+1} \times (r + w), \quad (12)$$

where $T_{full.rotation.cycle.j}$ refers to the value of the j-th full rotation cycle, $(r + w)$ is the number of periods of rotation in n+1 cycle is a full rotation.

If the probability does not exceed the threshold value for any of the switches, then the channel's operating time remains the same.

After determining the MCVC's operating time, its reliability block diagram is reconfigured in accordance with the following rules:

— before failure, the locations of power channels are determined by the transition matrix;

— if a failure occurs, the first backup channel in the queue is connected to the failed channel, which becomes the first of the working channels.

Further, the reconfigured reliability block diagram is considered a new converter with fewer channels and the algorithm for calculating the operating time is repeated until the number of power modules becomes equal to $N+1$.

It is worth noting that the software model provides an event when there was no failure during the entire rotation time. In this case, the probability of switching is also calculated. If there is no failure during switch over, the rotation stops and the reservation method is replaced with regular diverse redundancy.

The block diagram of the software module algorithm described above is shown in Fig. 4.

CONCLUSION

The amount of electrical load is one of the most important factors that affect the failure rate of channels, regardless of the type of redundancy. Thus, in order to create a correct software model for assessing the reliability of the MCVC, it is necessary to take into account the change in the electric load coefficient caused by failures of power channels during operation.

The probability of successful switch over in case of a large number of switches has a significant impact on the operating time. In this regard, to create a correct software model of redundancy with rotation, it is necessary to take into account the probability of successful switch over.

The model used in our program provides for the possibility of failure during the switching and the increase in value of the electric load on the power channels when a failure occurs. This will allow our simulation model of MCVCs to be as close to the actual conditions of their operation as possible. In the future, this will provide an opportunity to determine the optimal full rotation cycle for the specified reliability bock diagram and channel reliability characteristics [20].

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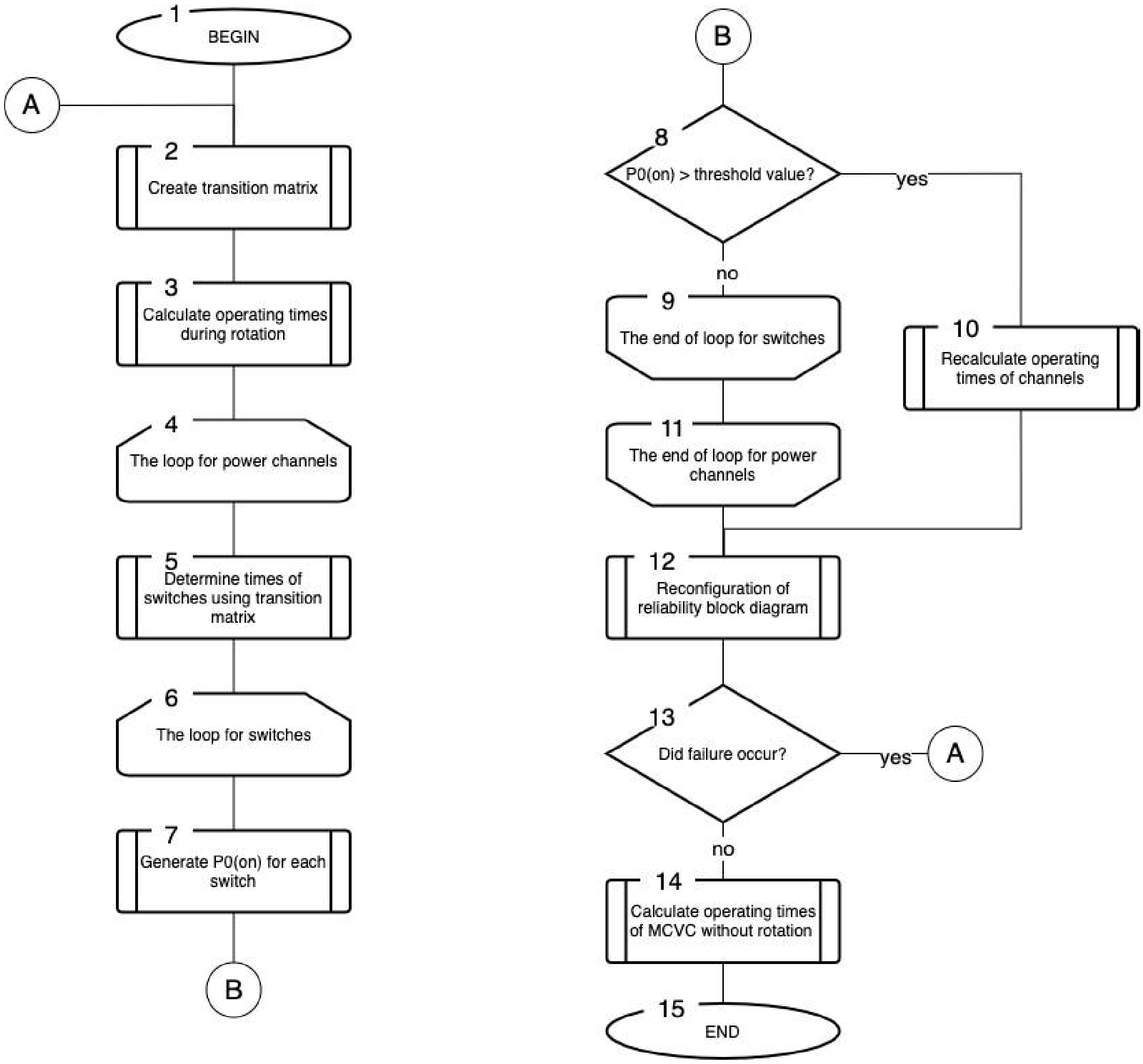

Fig. 4 Block diagram of the algorithm for the operation of the module for calculating the probability of channel failures during switching

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DISTANCE LEARNING METHODS AND TECHNOLOGIES AT AN OIL AND GAS ENTERPRISE

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Annotation—In the context of the increasing role of the innovative factor in the economic growth of Russian companies, the requirements for the qualitative characteristics of personnel and, above all, for their professional qualification level are increasing.

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