Detection of a Faulty Link in the Electric Power Utility Telecommunication Network

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Abstract: This paper presents the original approach for supervision of Electric Power Utility Telecommunication Network function by the analysis of traffic on network links. The specificity of this network is that each connection may be realized using direct link or alternative link in a case of faulty direct link. The traffic level on both links is an indication of direct link incorrect operation. The detector capability is that it discovers pre-alarm state where direct link is faulty and the traffic still may be carried over alternative link. It is proven by examples from praxis that detector has very low-level of detection miss and false pre-alarm appearance. An additional benefit is that detection failure rate decreases when traffic value is increased meaning that detector reliability is higher at more severe traffic conditions.

Keywords: Electric power utility; Telecommunication Network; alternative routing; pre-alarm; detection reliability

1 Introduction

The Electric Power Utility (EPU) Network requires a high degree of reliability. It is considered that the telecommunication network of the EPU must be functional even when there is no electricity, since it has the main function of bringing the network to a proper state. Due to the required high availability, this network is based on several procedures that ensure this property. The first one is the calls alternative routing in the case of telecommunications equipment malfunction. Alternative routing is simply implemented if the network is built in a single layer. A plan where direct and alternative path are distinguished is adopted for such a network. However, this good feature makes it difficult to detect faults in the network because it is designed to get around faults. Therefore, one of the important problems is finding a part of the network that is faulty while the network is still functional due to the alternative routing. This is called pre-alarm detection.

Alternative routing is mechanism, which is implemented in many kinds of networks. It is implementable in directing road traffic [1] in order to minimize traffic influence on the environmental conditions and to improve road network efficiency. Alternate routing is also applicable in wireless sensor networks [2], where it is intended for load balancing and for higher reliability. In its essence, Internet is a huge network where finding alternate paths between network nodes is crucial for data packets sending with satisfactory Quality of Service and the paper [3] deals with the analysis and improvement of protocols to achieve this goal, etc. The main reasons for alternative routing implementation are network performance improvement or overcoming failure on network nodes or links. Artificial intelligence algorithms may be used to improve quality of realized alternative routes [4]. Alternative routing mechanisms for EPU telecommunication networks may be hardly found, so this paper is our original contribution. The EPU telecommunications network had several essential forms for signal transmission in the past. The first network form consisted of single-channel two-way analog transmission paths over power lines. In addition to the failures of these channels, it was also necessary to provide protection against signal collisions on a single-channel connection, [5]. After the introduction of modern transmission systems, the transmission network has become mixed (digital - analog). When choosing channels, digital channels (ISDN and/or IP) were prioritized because they are of better quality and there were more of them. This approach made it possible to detect malfunctions of digital channels by longer seizure of analog (power line carrier – PLC) links [6]. The approach is based on pre-alarm detection, which is the state when only PLC link is operational. Such detection may be realized by software tools [7]. The transmission time of the dialed digit is higher on PLC than on digital links because decadic dialing is used on PLC and this fact may be also used for pre-alarm detection [8].

The aim of this paper is to show that the pre-alarm state in a modern network can be detected by traffic analysis on the links.

Pre-alarm detectors in EPU networks of older techniques are based on the priority seizure of digital lines before analog ones. The second method is based on comparing the transmission rate of dialing signals over the network. Here, we describe a pre-alarm state detector based on the comparison of transmitted telecommunications traffic on the direct and alternate route. This procedure has not been described so far.

The motivation for dealing with this topic comes from the intention to make the EPU telecommunication network highly reliable. The manufacturers of this equipment are faced with a difficult task to ensure a higher level of Quality of Service than in the case of telecommunications equipment for some other purpose.

Section 2 briefly presents the applied modelling in this paper. It defines main elements and variables of the model. The operation of the network nodes and links in normal conditions is described in the Sections 3, and in the case of faulty link

existence in the Section 4. In the Section 5 it is emphasized what are the two states which are analyzed when detector reliability is considered. The first of these states – miss to detect link malfunction is analyzed in the Section 6 and the second state – false pre-alarm in analyzed in the Section 7. Influence of traffic on the probability of false pre-alarm is modelled in the Section 8. At the end, conclusions are in the Section 9.

2 Model, Assumptions and Designations

Analytical modelling is often used to present the behavior of systems in various fields. Aspects concerning the observation process modelling in the framework of cognition processes [9], development of a viscosity model and its application, for the filling process calculation in visco-dampers [10] and modelling possibilities of integrated circuits behavior using active learning principles [11] are just examples of very effective implementation of analytical system models. Besides, nonlinear modeling is used for statistical analysis of medical problems (for example, to monitor, analyze and forecast COVID-19 pandemic [12]), problems in mechanic (for example, the control of piston positioning in pneumatic cylinder [13]) and robotics (for example to estimate robot pose in the framework of its navigation [14]).

A part of the EPU telecommunications network consisting of nodes E, B, C, D and the links between them is considered, Fig. 1. Nodes are points where path selection and calls forwarding (switching) may be performed. The basic rule is that each node should be connected to at least two neighbouring nodes in order to be able to perform alternative routing. Service, i.e. connection requests appear at random instants, and the intensity of these events will be denoted by λ. The length of service, i.e. calls duration is also a random variable with the mean value t_m. These two variables which are designated by λ and t_m are the main ones to describe the model analyzed in this paper. We will assume that the times between calls and the service duration are random variables with an exponential distribution. The value of served traffic on each link (equal to the value of offered traffic) may be determined according direction. The value of this traffic is $A = \lambda \cdot t_m$. It will be considered in this paper that the mean service time is $t_m = 1$, meaning that the numerical values of call intensity and traffic are equal. In the considered model, each dialed number may be sent from each node via main and one alternative link. Connection through the network is built step-by-step. There is a possibility to determine the value of traffic achieved in a previous period on each link for both directions. The operation in the case of a link failure for the requested connection from node X to node Y is determined by a predefined routing table for calls from node X. Traffic from node X to node Y will be denoted as A(X→Y).

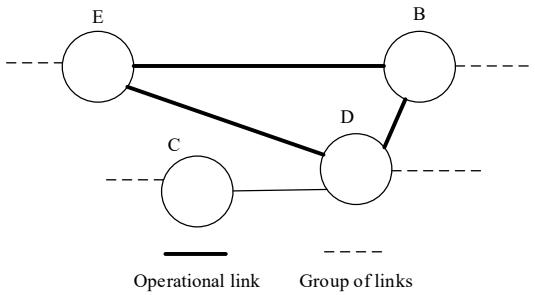

Figure 1
Part of the network, original figure

The model used to calculate the properties of queueing system is a simple model with Poisson processes of request arrival and service (or, in other words, birth-death process). According to Kendall's notation method, this model is marked by M/M/N (M – exponential interarrival time distribution, M – exponential service time distribution, N - the number of parallel serving channels) and the type of service is FIFO (First In First Out). The applied model for analysis in this case is based on classical equations for M/M/N systems.

We distinguish three states in the network. One is the normal, operational state when all elements of the network are correct. The opposite of the normal state is the alarm state, when the network elements are faulty in such a way that connections between individual points in the network are disabled. For this condition, there are strict recommendations on the allowed duration (MTBF, meantime between failures). These recommendations are reduced to a short time of detection and repair of the fault.

The third state is between these two states. It is the state when some connection in the network is faulty but connections can still be established normally. This state is called the pre-alarm state and in this paper we describe the detection of this state. Effective detection of the pre-alarm condition affects the elimination of the alarm condition.

It is important to know the correctness of links operation in each moment of time. A very simple way to achieve this goal is according to only the measurement of traffic on the direct link and the alternative link. There is no need to have spatial hardware components to apply this model of faulty link detection, but the problem is how to reduce the values of link failure detection and false alarm appearance. In this paper we analyze the reliability of detector operation and its dependence on traffic level.

3 Operation in Normal Condition

Operation in the normal condition is illustrated in the Fig. 2. The picture presents the case that the connection should be established from node E to node B. Since all signal paths are operational, the connection is established over a direct link between these nodes.

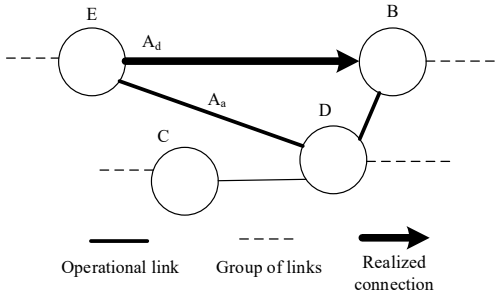

Figure 2
Part of the network with operational links and the connection from E to B, original figure

4 Operation in the Case of Faulty Link

Operation in the case of faulty link is illustrated by an example in the Fig. 3. Due to the failure of the link EB, the call is forwarded from node E to node D and from it to node B, according to the routing table from node E. The connection is made using two links in the regime of alternative routing. It is clear that in this case the traffic on the direct link EB is zero and the traffic from node E on the direct link to node D is increased compared to the value in the operational state of the link EB. In this case, direct traffic E→D and alternative routing traffic E→D→B are performed on this link. We call this state pre-alarm, since the network performs its function, but there are faulty elements. With the failure of one more element (in this case the link ED), the state becomes alarmed because the node E may no longer realize a connection.

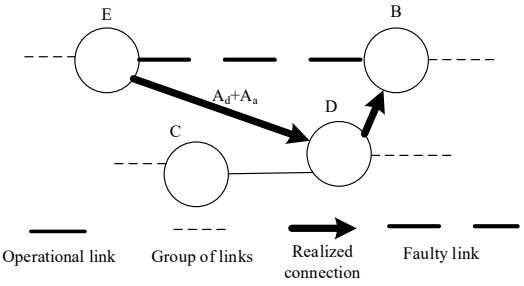

Figure 3
Part of the network with a faulty link and the connection realized using alternative routing, original figure

The basic principle for faulty link detection is that two conditions must be satisfied in the same time:

C1- there is no traffic on the direct link (d) and

C2- the traffic on the link, which is intended for alternative routing of calls intended for the suspected link, A_a, has increased, i.e. it is greater than average traffic in normal/correct operation A_{am}:

i.e. $A_d = 0$ and $A_a > A_{am}$

Since traffic is a random process, the reliability of such a detector must be determined.

5 Detector Reliability

As in [6], it is necessary to analyze the detector indication results in certain situations in the network and determine its accuracy. The two state expectations are: the link is correct – the detector does not respond and the link is incorrect – the detector shows a pre-alarm state. The remaining two states, [6], are two basic errors of the detector: miss (e1) and false pre-alarm (e2):

e1 – link is faulty but detector does not present this (miss) and

e2 – link is correct but detector presents a fault (false pre-alarm)

6 Failure to Detect Link Malfunction (Miss)

The traffic on links E→B (A_d) and E→D, (A_a) will be considered, Fig. 4. The upper part of Fig. 4 presents the traffic on the direct link E→B (A_d), and the lower part presents the traffic on the alternative link, E→D, (A_a). A failure occurs on the direct link at time t_1, i.e. condition U1 is satisfied. The traffic is lower than average on the alternative link in the first test interval (t_2), that is where condition U2 is not met.

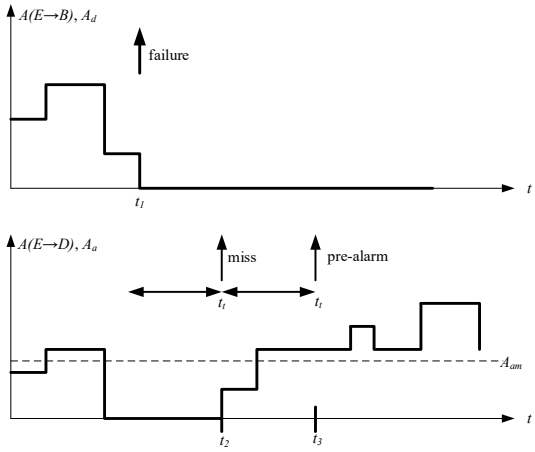

Figure 4
The presentation of the detection miss in the first test interval, original figure

The detector reacts to the loss of traffic on the direct link, t_3, after time t_t. This test time is very important as it should ensure that the detector does not respond to very short traffic interruptions on the direct link in normal operation. In a Poisson process, the zero number of events in the interval t_t is determined by the equation

$$P(0, \lambda, t_t) = e^{-\lambda \cdot t_t} \tag{1}$$

where λ is the call intensity on the link in normal operation. From equation (1), it may be determined for which value of time t_t the probability $P(0, \lambda, t_t)$ represents the failure probability.

Example. Let us consider direct and alternative link where traffic of 10E is offered over both of them in a correct state. The mean service time is, as already stated, equal to unity. Zero traffic on a direct link is required to indicate failure with probability 0.9999. This means that the detector testing time t_t should be long enough so that in the correct state the probability of zero traffic is $P(0, \lambda, t_t) \leq 0.0001$. Equation (1) shows that the test time must be $t_t > 0.921$ i.e approximately equal to the average length of the service time.

A failure occurs when the direct link is faulty and the increased mean traffic value is not detected on the alternative link. This situation may happen due to the randomness of the traffic process. If the detection time is long enough, the traffic increase on the alternative link will be detected. Thus, the property of this detector is similar to the property of the one-step detector presented in [6].

Assume that the direct link is faulty. Traffic from both links, i.e. sum of both traffic is carried out on the alternative link. The probability of zero traffic on a direct link is expressed by equation (1). A miss (in failure detection) will occur if at the same time the traffic on the alternative link does not increase compared to the correct state.

The failure probability can be calculated based on the probability of two events:

- event b1: there is no traffic on the correct direct link in the interval t_t, $P(0,A_d,t_t)$;

- event b2: the number of calls served on the alternative link is $N_p < N_d + N_a$, which is less than the average number of calls generated from $A_d + A_a$ traffic. This probability will be denoted by $P(N_p, A_d + A_a, t_t)$. The miss probability in detecting a pre-alarm is

$$P_{mp} = P(0, A_d, t_t) \cdot P\left(N_p, A_d + A_a, t_t\right) \tag{2}$$

Example. Let us suppose that the traffic on both links is $A_d = 4E$ and $A_a = 4E$, i.e. $A_d + A_a = 8E$ and that testing time is $t_t = 1$. The miss probability obtained in this example is $P_{mp} = 0.00827$, according to the equation (2).

If there is a failure in the pre-alarm detection, and there is still zero traffic on the direct link, the detection continues, Figure 4. The detection of a faulty link can be viewed as a random variable for which the geometric distribution applies. Therefore, the probability P_n of detecting a pre-alarm in the n^{th} testing interval is

$$P_n = {P_{mp}}^{n-1} \cdot \left(1 - P_{mp}\right) \tag{3}$$

From here the mean detection time can be calculated, which is actually the mean number of attempts until a successful outcome when the geometric distribution is applied: $t_g = 1/(1 - P_{mp}) \cdot t_t$. In the previous example, the mean detection time is $t_g = (\frac{1}{0.99173}) \cdot t_{t,}$ i.e. 1.00834 test times.

7 False Pre-alarm

If zero traffic indicates a failure on the direct link, traffic will increase on the alternative link. If zero traffic means no traffic offered to the direct correct link, the traffic on the alternative link will not increase in most cases. If it happens that, due to the traffic process randomness on the links, a zero traffic value occurs on the

direct link and an increased traffic value is detected on the alternative at the same time, there may be the so-called false pre-alarm.

It is necessary to calculate the product of the probabilities of two events in order to determine the probability of a false pre-alarm:

- event d1: there is no traffic on the correct link in the time interval t_t, $P(0,A_d, t_t)$ and

- event d2: the number of calls served on the alternative link is $N_u \geq N_d + N_a$. This number of calls is greater or equal to the number of calls generated from the traffic $A_d + A_a$. The probability of event d2 will be designated as $P(N_u, A_a, t_t)$. The probability of false pre-alarm is now

$$P_{fp} = P(0, A_d, t_t) \cdot P(N_u, A_a, t_t) \tag{4}$$

Figure 5 presents the case of a false pre-alarm if the detection time is t_t. Events d1 and d2 occur in the same time interval. The probability of a false pre-alarm is an indicator of how often this phenomenon can occur at certain traffic values A_d and A_a at direct and alternative link and detection time t_t. It is necessary that there is no traffic on the direct link during the detection time in order that a false alarm occurs. The probability of this event d1 is calculated by equation (1a)

$$P(0, A_d, t_t) = e^{-A_d \cdot t_t} \tag{1a}$$

Traffic A_a is carried out on the alternative link, but due to the randomness of the traffic process, the number of calls equal to (or greater than) the number of calls N_u generated as if both traffics $(A_d + A_a)$ are carried out over this link will appear at the same time,

$$P(N_u, A_a, t_t) \tag{5}$$

The probability (5) presents the sum of probabilities

$$P(N_u, A_a, t_t) = P(N_d{+}N_a, A_a, t_t) + \\ +P(N_d{+}N_a + 1, A_a, t_t) + P(N_d{+}N_a + 2, A_a, t_t) + \cdots \tag{6}$$

or

$$P(N_u, A_a, t_t) = 1 - (P(0, A_a, t_t) + \\ +P(1, A_a, t_t) + \cdots + P(N_d{+}N_a - 1, A_a, t_t)) \tag{7}$$

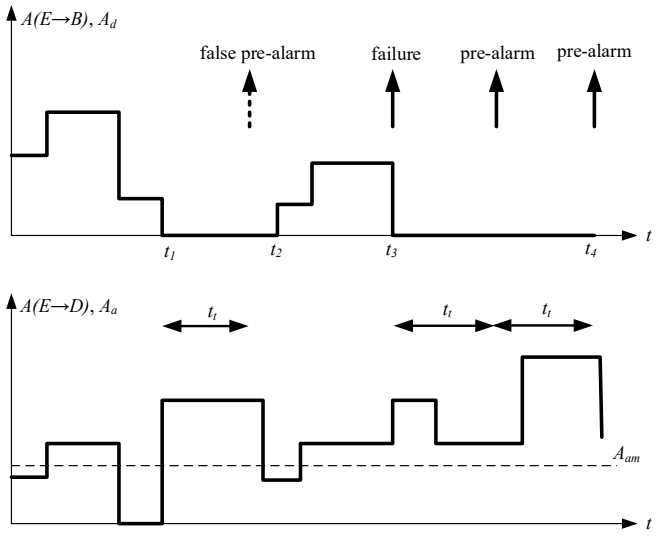

Figure 5
An example of false pre-alarm, original figure

Example. Let us suppose that the traffic offered to both links is equal, $A_d + A_a = 4E + 4E = 8E$.

It follows from these values that the probability of zero traffic on a correct direct link for time interval $t_t = 1$ is $P(0,4,1) = 0.0183$. The probability that $N_u = 8$ or more connections appear on the alternative link in the same period of time is expressed as

$$P(N_u, 4,1) = 1 - \big(P(0,4,1) + P(1,4,1) + \cdots + P(7,4,1)\big) = 0.0527 \tag{8}$$

It follows that the probability of false pre-alarm is in this case $P_{fp} = 0.00096$.

It may be concluded that the probability of false pre-alarm is small even for such a short testing interval $t_t = 1$.

8 Influence of Traffic on the Probability of False Pre-alarm

Figure 6 presents the dependence of the probability of a false pre-alarm on the value of the traffic on the links when the test interval is $t_t = 1$. It may be seen that the value of the probability of a false pre-alarm decreases with the increase in traffic. As traffic increases, the probability of zero traffic on the correct link decreases faster

than the probability of double traffic increases on the alternative link. Accordingly, the product of these probabilities decreases with increasing traffic.

It is clear that a false pre-alarm occurs less often if the traffic is greater since the duration of zero traffic on the correct direct link is shorter.

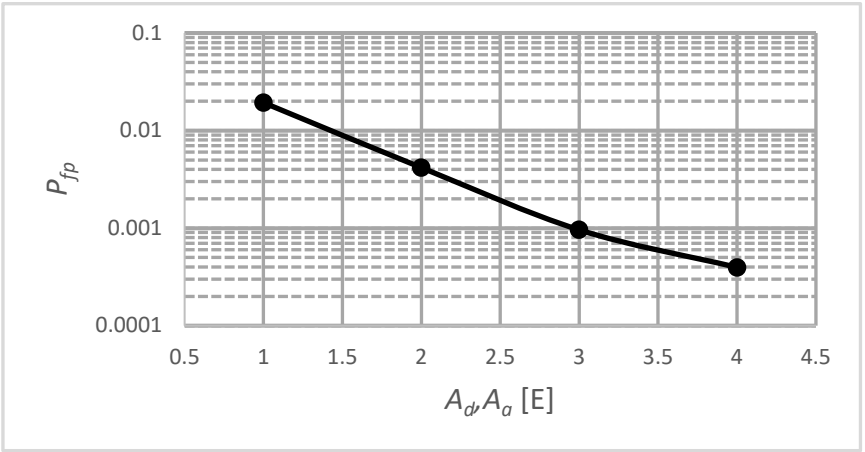

Figure 6
Probability of false pre-alarm P_{fp} as a function of traffic on links for t_i=1, original figure

The parameters of the model are obtained from the project of the links, which specify the type and size of the traffic for which the links are intended. The service time (i.e. the time of testing) is determined from this data.

Performance indices are calculated using probability theory and reliability theory.

The model is validated by comparing the obtained values of probabilities for alarm miss and for false alarm with prescribed MTBF probabilities. Namely, the probability of a network malfunction, i.e. the probability of an alarm, must not be greater than 10^{-6}. For the pre-alarm condition, the regulations are not so strict since the network function is not impaired, so we are satisfied with the probabilities of false alarm and pre-alarm miss whose values do not exceed 10^{-4} - 10^{-5}. Equations (1) – (7) allow the probabilities of the basic unwanted events (miss and false pre-alarm) to be calculated for any traffic values and test times.

The detector testing is simple. The first action when turning on a new detector is to deliberately cause one link to stop operation and check for correctness. In doing so, the test time is set to a value that is 5-10 times higher than the service time. In this way, the probability of a false alarm is reduced to negligible. The detector is always on so that a false alarm, if it occurs, will be lost in the next test step.

Detector function may be illustrated by a diagram in the Fig. 7.

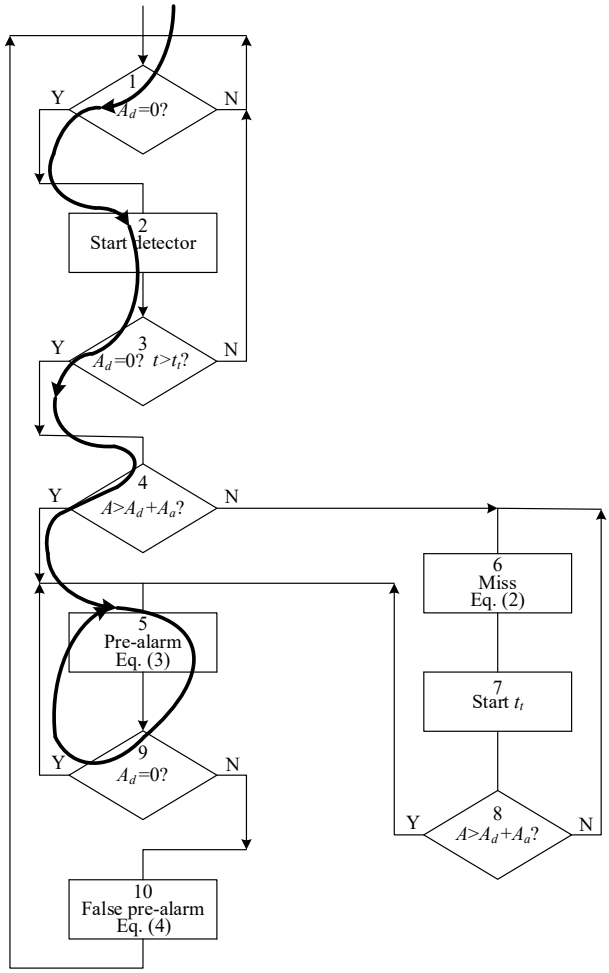

Figure 7
Flowchart of a typical detector function and steps of detection when correct pre-alarm is detected, original figure

Flow-chart in Figure 7 consists of 10 blocks, which are numerated 1-10. It is also designated which equations from the paper text correspond to what block (equation (2) corresponds to the block 6, equation (3) to the block 5 and equation (4) to the block 10). The thicker curved line presents steps of detection when correct pre-alarm state is detected. The detection successively passes through the blocks 1-2-3-4-5-9-5-9-5-9-…, meaning that blocks 5 and 9 are repeated as long as correct pre-alarm exists.

Figure 8 presents typical steps of detection when false pre-alarm is detected. The detection passes through blocks 1-2-3-4-5-9-10-1. As in the block 9 the traffic on the digital link is not A=0, false pre-alarm is stated in the block 10 and detection comes to the beginning in the block 1 again.

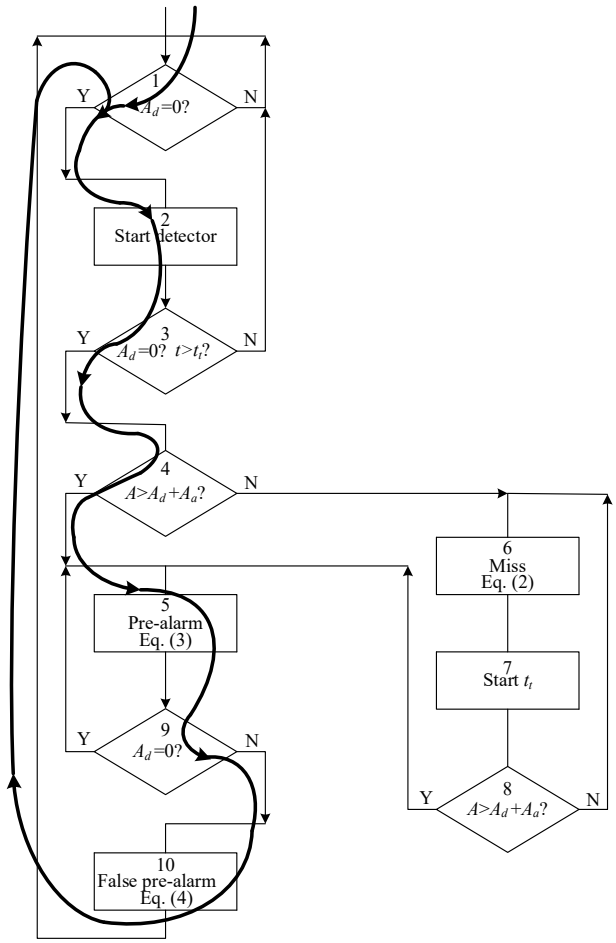

Figure 8
Typical steps of detection when false pre-alarm is detected

Figure 9 presents typical steps of detection when there is a miss of pre-alarm. The detection passes through blocks 1-2-3-4-6-7-8-6-7-8. The loop 6-7-8 is repeated while traffic condition in the block 8 is not fulfilled. When it becomes fulfilled, the detection passes from the block 8 to the block 5 (dashed line in the Figure 9).

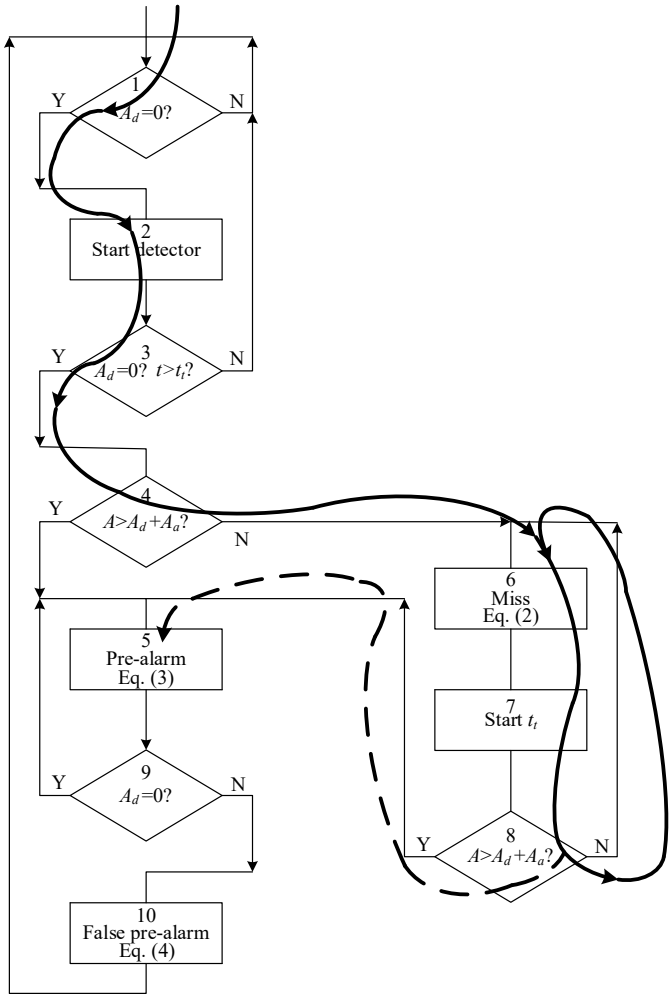

Figure 9
Typical steps of detection when there is pre-alarm detection miss

Conclusions

The paper presents the function principle of the faulty link detector in the telecommunications network of the EPU, i.e. if there is an alternative routing. This type of failure is called a pre-alarm because the network function is maintained during the failure. Link failure detection, i.e. the pre-alarm is based on the monitoring of the existing traffic on the direct and alternative link. In the operation of such a detector, two errors are possible: failure to detect a faulty link and detection of a non-existent fault, i.e. false pre-alarm. It is shown that the probabilities of these events are negligible and "self-correcting".

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