CENTRALIZED DETECTION OF PRE-ALARM STATE IN TELEPHONE NETWORK OF ELECTRIC POWER UTILITY

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Abstract. *In this paper we consider the mixed telephone network of electric power utility consisting of IP, ISDN and Power Line Carrier links. Very important demand in the network is high availability. The central detector of IP and ISDN link failure (pre-alarm) is presented. The detector function is based on the prolonged response time of the network in the case of IP and ISDN link failure. We define undesirable events in the detector operation: false pre-alarm and miss detection, and we derive the expressions for their probability calculation. It is indicated that centralization of this detector is merit, which facilitates testing of the whole network from one location.*

Key words: *centralized detector, electric power utility, mixed telephone network, pre-alarm state*

1. INTRODUCTION

The main demand for the telephone network of electric power utility (EPU) is very high availability and all possible resources are used to achieve that. In order to realize the main demand, different technologies (optical cables, metal cables, radio) and non-hierarchical network architecture (alternate routing) are used in the EPU telephone network. Using of different technologies increases the availability [1], [2], but the problem is the conversion of different signalling systems (CAS, ISDN, IP) and speech signal forms (analog, digital, packet) in signalling and media gateways.

In this paper we present how the mixed network of EPU, which uses new and old techniques, (besides the problem of interworking), can use different signalling systems, i.e. different duration of post-dialling delay for monitoring the proper operation of the parts of mixed network. Different methods can be used to detect faulty link in the telephone network of EPU. A few approaches based on telephone traffic characteristics are presented in [3-8].

This paper deals with a novel method of finding faulty ISDN or IP link (link of the first choice) by measuring post-dialling delay to the beginning of the ring-back tone. The method implementation is based on the fact that there are one or more links of the second choice (Power Line Carrier (PLC) links) with considerably slower dialling speed than the links of the first choice. If there is a fault in some part of the network, the slower link will be activated on that part of the network and the dialling speed will be decreased. By proper choice of dialling numbers, it is possible to detect the network section with faulty links of the first choice. The main advantage of the method is that the testing for the whole EPU telephone network can be realized from one, central place. The testing can be realized manually, without any equipment, only by adequately choosing subscriber dialling numbers, or using relatively simple equipment to generate dialling. The contribution of the paper is that it develops the method for testing and that it calculates the main characteristics of the system: the miss probability and the probability of false pre-alarm.

2. Model, Designations and Assumptions

The mixed network of EPU consists of telephone exchanges (TE) and transmission systems, which can be IP, ISDN and PLC systems. The old network was based on PLCs. (PLC is the technique of telephone channel creating by the use of high voltage power lines. Sometimes this transmission is called voice over high voltage power line. PLCs exist in new mixed network in order to increase availability. In [2] PLCs are referred E&M analog lines.) The main characteristics of PLCs in EPU telephone network are the use of slow E&M signalling with pulse digit transfer, [9], and lower quality of speech signal transfer.

Let us consider the connection through the mixed EPU telephone network, (see Fig. 1.a)). From this connection let us consider only two nodes on the connection route, (see Fig. 1.b)) and (Fig. 1.c)). The offered traffic to the group of links is designated as A. The number of channels on the ISDN link, or the greatest number of connections using IP link is N.

Telephone exchanges TEk and TEk+1 are connected by ISDN or IP link and from the earlier network are still connected by PLC. The connections between exchanges TEk and TEk+1 are established by the selection rule (SR) such that first ISDN channels (see Fig. 1.b)) or IP link (see Fig. 1.c)) are selected, and if they are not available, PLC is selected. This SR results from the faster connection establishment and the better speech signal quality when digital connections are used then when PLCs are used. (It is clear that selections in different directions on ISDN links will be in such a way that collision probability will be minimized).

Normal operation (state) is the state when all links between exchanges are faultless.

The alarm state is the state when it is not possible to establish the connection between exchanges TEk and TEk+1 because all links between exchanges are faulty.

Pre-alarm state is defined as the state when it is not possible to establish the connection by the route of first choice, i.e. by the ISDN or IP link, because these links are faulty. The connection can be established using PLC. It is important that some connections can be established in this state, for example dispatcher connections.

Post-dialling delay (PDD, or post selection delay) is defined as the time interval from the last dialled digit until the start of the called side answer, i.e. until the beginning of the

ringing (busy) tone. Let us suppose that 5-digit numbering plan is used in the network and that the transfer of all digits is equally probable (uniform distribution).

The aim of this paper is to present the operation of pre-alarm state detector (the state when ISDN or IP links are faulty). The operation of this detector is based on the difference in PDD values in the case of using digital links and PLCs.
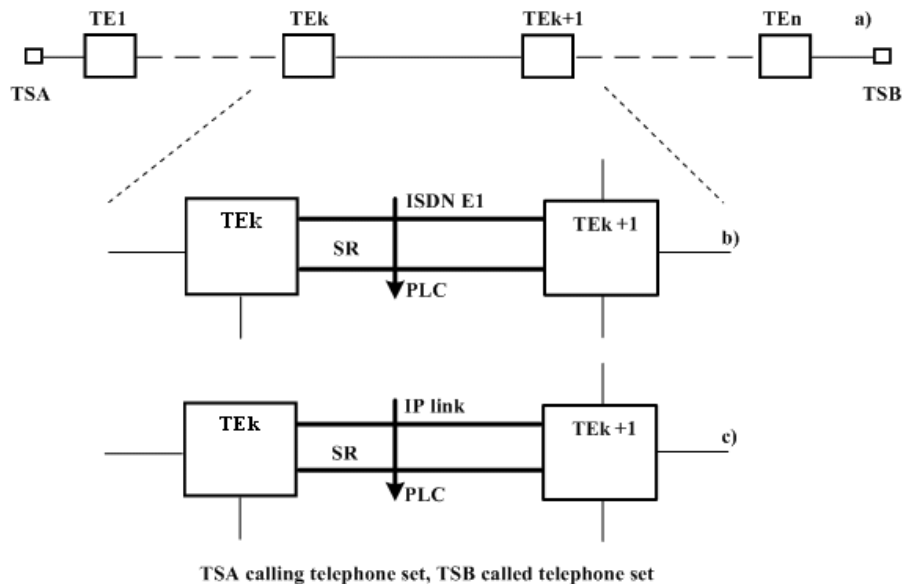

TSA calling telephone set, TSB called telephone set

Fig. 1 Model of connection through mixed EPU network

The main components of PDD are the time intervals used for processing and sending the information about dialled number between adjacent network nodes. That's why it is necessary to know the characteristics of transferring time intervals between nodes in the case of digital links and PLCs.

3. TIME DELAY OF SUCCESSFUL TRANSFER OF ADDRESS INFORMATION (DIALLED NUMBER) BETWEEN EXCHANGES

The time of successful transfer of signalling information about the dialled number between the network nodes is the most important component of PDD. This time depends on the signalling type, transmission method, traffic load of the links and nodes. That's why it is random variable. In order to satisfy the main request that PDD has sufficiently short duration, the recommendations about the allowed duration of transfer of signalling information (concerning the dialled number) between network nodes are introduced. These recommendations are different for different techniques.

3.1. ISDN technique

Recommendations for the greatest allowed time of exchange operation are presented in [10], sections 2.3 (*Delay probability – non-ISDN or nixed (ISDN – non-ISDN) environment*) and 2.4 (*Delay probability – ISDN environment*). Among all recommended values, we shall select the most stringent ones (the longest time intervals), which deal with ISDN technique, the message carrying address information and en-bloc signalling (en-bloc signalling means that signalling transmission on one link starts when complete address information from the previous link is collected in the node preceding the considered link). These greatest allowed time intervals are defined in the following sections of [10]:

2.3.2.3   Local exchange call request delay,
2.3.3.2.3 Exchange call set-up delay for originating outgoing traffic connections,
2.4.3.1   Call set up delay,
2.4.5   Incoming call indication sending delay

which recommend that the longest allowed mean time for the activity of one route section and one network node is 600ms (load A) and 800ms (load B). The longest recommended time for the activity in the case of 95% connections is 800ms (load A) and 1200ms (load B).

The reason for taking the longest time intervals from [10] is that in that case is most probable to make an error (i.e. to replace dialling using ISDN or IP link by dialling using PLC link or vice versa), thus making one of two possible false detections in decision algorithm (false pre-alarm or miss detection).

In [11] for cross-office transfer time for signalling CCS No 7 messages in the most difficult conditions (complex message content – processing intensive and increased load 30%), the longest mean time (450ms) and the longest time for forwarding at least 95% messages (900ms) is recommended. The probability distribution of time necessary for forwarding the address information is exponential, and its main component is the waiting time on the (signalling) processor service, [12]. In [12] it is indicated that the time of processor service can be constant or exponentially distributed. Here we suppose that signalling processor service time is distributed according to exponential distribution. There are two reasons for this: the first one is that the service time of signalling processor for different messages is different, and the second one is that the results for exponential distribution are more reliable (conservative, on the safe side). The probability density function of the time duration needed for the address signalling message transfer across ISDN link is presented by the function $f(t)$ (see Fig. 2). It is clear that in this case t is continuous random variable. The mean value of this time is signed as t_{mISDN}.

3.2. IP technique

The parts of telephone network, which are realized using IP techniques, use SIP for connection setup [13]. The address information for connection setup exists in message (method) INVITE, and after sending message INVITE, an acknowledgement using some of the provisional or final responses from the groups 1XX or 2XX is expected. The message INVITE also can be transmitted using unreliable protocol (UDP), and in this case preventive retransmission must be used. In [13] it is stated that the first retransmission is sent after 500ms. Let us suppose that in private network, as is the case of EPU network, the time interval of 500ms is enough to receive the response on 95% INVITE requests. We can suppose that for address transmission between two network nodes using IP techniques the

same recommendations are valid as for transmission time across ISDN link. The only (positive) difference is that in this case the time intervals are shorter.

As the conclusion, it can be said that the longest allowed time for address information transfer between two network nodes of digital links is that which is valid for 95% of all connections with traffic load B, i.e. 1200ms.

3.3. PLC

In this technique the dialled digits are forwarded in pulse form without acknowledgement. That's why we shall consider that address information transfer between exchanges is finished after the selected number is completely transmitted. The time of address information transfer between exchanges in IP or ISDN technique depends on processor load and link load (i.e. signalling equipment load), and doesn't depend on signalling message duration. On the contrary, in the case of PLC the time for address information transfer between exchanges depends on signalling information transfer, i.e. on the number of dial pulses.

The time for address information transfer using PLC link is random variable, which has discrete values.

Example 1: if we use 5-digit numbering plan, i.e. there are more than 10000 users in the network, then the time for address information transfer can be calculated as $t_{PLC} = 4 \cdot t_p + 100 \cdot n$ (ms), where t_p is interdigit pause (350ms), and n is the number of dial pulses, $n = 5,6,...49,50$.

Probability distribution of this time duration is presented symbolically and signed as $p(t)$ (see Fig. 2). The values of time distribution $p(t)$ for the five-digit numbering and PLC link have discrete values (see Fig. 3) (every fifth value presented bold). It is obvious that this is discrete random variable and that the probability has values different than 0 only for the values $t = 1400 + 100 \cdot n$ (ms), where n is integer, i.e. only for values $t = 1900, 2000, 2100,...., 6300, 6400$ (ms).
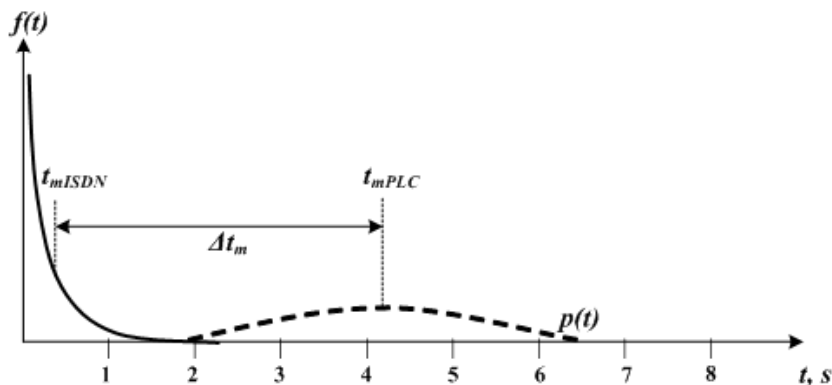

Fig. 2 Probability density function (full line) in the case of ISDN link and probability distribution (dashed line) of address information transfer time in the case of PLC link
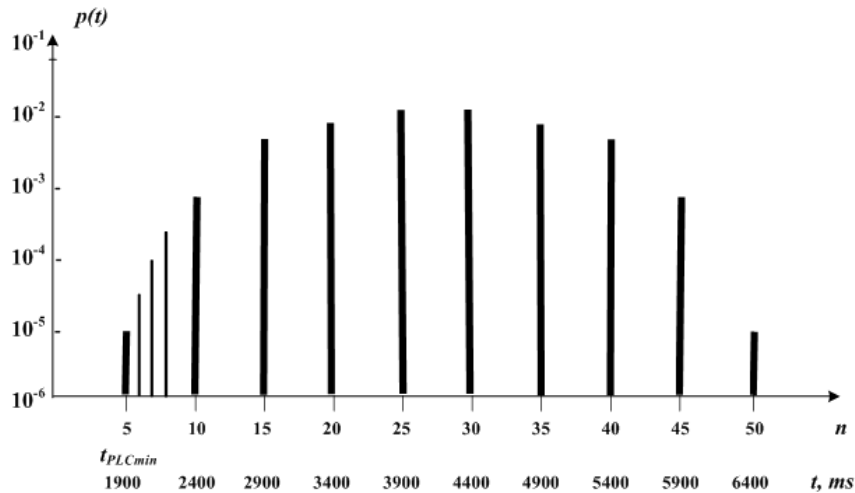
Fig. 3 Probability distribution of the time for digit transfer on PLC link for 5-digit numbering plan

Value t_{mPLC} is the mean value of time needed for address information transfer over PLC link (see Fig. 2).

The main conclusion of this section is that time of address information transfer between two adjacent nodes of EPU network differs in the case of ISDN or IP link (t_{ISDN}) and PLC link (t_{PLC}) for several seconds. In the case of 5-digit numbering plan, the mean value of this difference Δt_m is about 4s (see Fig. 2.).

4. BASIC IDEA FOR PRE-ALARM STATE DETECTOR

Main idea of the detector is that it generates test telephone calls in the network and compares PDD with the usual values and, in the case of a great difference, declares pre-alarm state.

The difference in the time delay of address information transfer on the link (Δt), which is in pre-alarm state, is transferred on the total PDD time.

Let us present the main idea of the detector (see Fig. 4) and (Fig. 5).

In normal state, i.e. when all ISDN or IP links are correct, these links are used for the whole connection setup (see Fig. 4.a)). When there is one faulty ISDN (IP) link on one section of call route, it is replaced by PLC (see Fig. 4.b)). (The established connection is presented by bold line).

The time values of PDD are different in the case of correct and faulty section on the call route (see Fig.5). The moment of test signal sending is signed as t_d (see Fig. 5). The time interval from signal sending till receiving the answer from the called side, in the case of all ISDN and IP links are correct on the trace towards the called user (see Fig. 4.a), is signed as PDD_1 (see Fig. 5). The response time from the receiving side if some ISDN or IP link is faulty (see Fig. 4.b), is signed as PDD_2 (see Fig. 5). Time interval PDD_T is

chosen in advance as the threshold time value. If $PDD > PDD_T$, the pre-alarm state is declared. The guard interval is $PDD_T - PDD_1$.
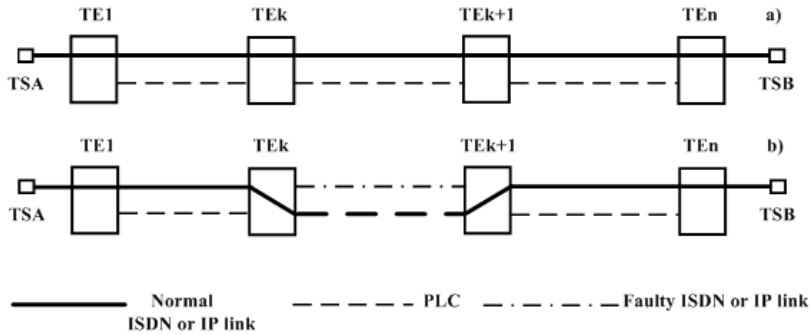
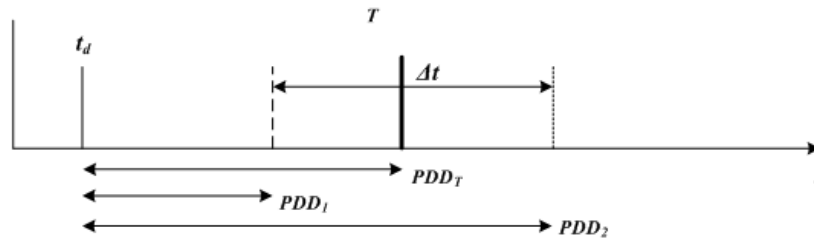**Fig. 4** Basics of pre-alarm state detector

Fig. 5 The PDD values in the case of correct and faulty section on the call route

As is the detector function based on random variables analysis, two undesired consequences are also possible: the false pre-alarm and the miss detection. The false pre-alarm is the phenomenon that all links are correct, and the detector declares the pre-alarm state. The detector miss is the reverse situation: the failure on ISDN or IP link exists, but the detector does not detect it.

The false pre-alarm is possible in the case of increased traffic load when all links are correct, and the connection is realized by PLC.

The miss in pre-alarm state detection is possible in the case that the value of PDD_T is chosen to be too high.

5. CALCULATION OF PROBABILITY FOR FALSE PRE-ALARM AND FOR MISS DETECTION

Let us consider two network nodes in EPU network (see Fig. 1). These two nodes belong to one connection (see Fig. 4). The central detector of pre-alarm state is turned on and for this case the threshold value for the answer time delay of the called side (PDD_T) is defined, (see Fig. 5). The pre-alarm state is declared if $PDD > PDD_T$. The false pre-alarm can occur in two cases:

- if the telephone traffic is high and ISDN or IP link is faultless, but busy by previous calls, and the next call is served by PLC;
- if the signalling traffic between network nodes, which form the connection, is great, the time for address information sending is too great and the total time until the answer from the called side becomes $PDD>PDD_T$.

The probability of false pre-alarm, caused by the great traffic, i.e. the probability of false pre-alarm of the first kind is, obviously:

$$P_{fpa1} = B = E(A,N) \tag{1}$$

where $E(A,N)$ is the well known Erlang loss formula in the group of N channels with the offered traffic A, [14].

The probability of the false pre-alarm, caused by the too great signalling traffic (probability of false pre-alarm of the second kind) can be calculated in the following way: let us consider the distribution of the time for address information sending between network nodes on ISDN or IP link. In the subsection III.1. it was pointed that this distribution is negative exponential, (see Fig. 6).
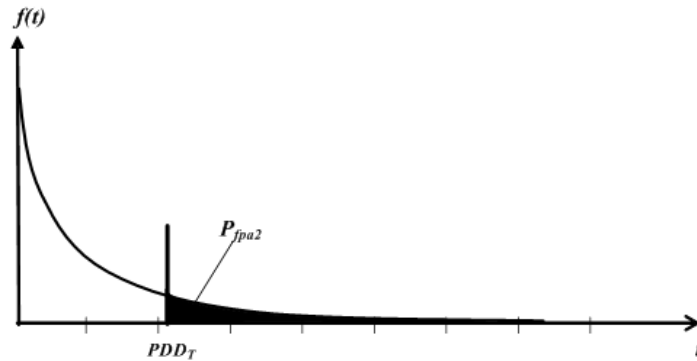

Fig. 6 Distribution of the time for address information sending between network nodes

The probability density function of exponential distribution is

$$f(x) = \lambda \cdot e^{-\lambda \cdot x}, x \geq 0 \tag{2}$$

while the cumulative distribution function, i.e. the probability that $t \leq x$ (in other words $P(t \leq x) = F(x)$), is:

$$F(x) = 1 - e^{-\lambda \cdot x} \tag{3}$$

The probability of false pre-alarm of second kind (see Fig. 6) can be expressed as:

$$P_{fpa2} = P(t > PDD_T) = 1 - F(PDD_T) \tag{4}$$

The total probability of false pre-alarm is:

$$P_{fpa} = 1 - (1 - P_{fpa1}) \cdot (1 - P_{fpa2}) \approx P_{fpa1} + P_{fpa2} \tag{5}$$

because $P_{fpa1} \ll 1$ and $P_{fpa2} \ll 1$.

Example 2: Let us consider the primary group of ISDN channels ($N = 30$) with the offered load of 20E, then is $P_{fpa1} = 0.00846$.

Using the most stringent requirement from the subsection III.1. that the waiting time for 95% calls must be less than 1200ms, we find the value of λ:

$$F(1200) = 1 - e^{-1200 \cdot \lambda} = 0.95 \longrightarrow \lambda = 2.5 s^{-1} \tag{6}$$

Taking the value $PDD_T = 1.5s$, we have $P_{fpa2} = 0.0235$. The total probability of false pre-alarm in this example is $P_{fpa} = 0.032$.

There is no possibility for miss detection ($P_{miss} = 0$) if it is possible to define the value of time threshold (for address information sending when ISDN (IP) links are faultless) on the smaller value than it is the minimum time of address information sending over PLC. In that case there is no overlapping of possible time intervals: time interval of address information sending when all ISDN (IP) links are faultless is surely shorter than time interval of address information sending over PLC. But, the situation changes when these time intervals are overlapping. It means that the probability of miss detection exists if the value of time threshold (PDD_T) is greater than the lower limit for transmission time of address information over PLC (t_{PLCmin}), $PDD_T > t_{PLCmin}$, (see Fig. 3). In this case, if the value of PDD is $t_{PLCmin} < PDD < PDD_T$, the pre-alarm state will not be detected. Therefore, the miss probability P_{miss} is equal to the probability that the time of address information sending over PLC is less than PDD_T:

$$P_{miss} = P(t_{PLC} < PDD_T) \tag{7}$$

Example 3: If the 5-digit numbering plan is used in EPU network, and the threshold value is $PGG_T = 2.25s$, then $P_{miss} = p(1.9s) + p(2s) + p(2.1s) + p(2.2s) = 0.00056$ (see Fig. 3).

6. CHARACTERISTICS OF FALSE PRE-ALARM PROBABILITY AND MISS PROBABILITY

The probability of false pre-alarm of the first kind, P_{fpa1}, is equal to the loss probability in the Erlang group of channels, and, obviously, depends on the offered traffic.

Example 4: if the offered traffic in primary group of ISDN channels ($N=30$) is increased from 20E to 26E, then P_{fpa1} is increased from 0.00846 to 0.06661, i.e. about 8 times. Decrease of this probability can be achieved by double testing, and if both tests indicate pre-alarm state, the probability of false pre-alarm of the first kind in this example falls to 0.0044.

The probability of the false pre-alarm of the second kind, P_{fpa2}, is inversely dependent of the defined threshold PDD_T.

Example 5: if PDD_T is increased from 1.5s to 2s in Example 2, P_{fpa2} is decreased from 0.0235 to 0.0067.

The probability of the false pre-alarm of the second kind can be decreased by increasing the value of the threshold PDD_T. After some value, increasing of the threshold PDD_T can lead to the detector miss in pre-alarm detection, as it is mentioned in section V.

The probability of the false pre-alarm of the second kind depends also on the numbering plan. In fact, dialling the telephone number with great number of dial pulses provides the possibility to put the threshold PDD_T on the higher value, and so the value P_{fpa2} is decreased.

Example 6: let us consider dialling the number 11111, and the detector threshold is $PDD_T =$ 1.9s. In this case is $P_{miss} = 0$, and $P_{fpa2} = 0.00865$. If we dial the number 11199, the detector threshold can be increased to 3.5s, and, in this case, $P_{miss} = 0$ and $P_{fpa2} = 0.000158$.

We can avoid detector miss (by the choice $PDD_T < t_{PLCmin}$, (see Fig. 3), but if we want to completely decrease P_{fpa2}, then by increasing detector threshold $PDD_T > t_{PLCmin}$, we can come to the situation when is $P_{miss} > 0$.

7. HOW CENTRAL DETECTOR FUNCTIONS IN EPU NETWORK

Central detector contains the numbering plan of the whole EPU network. In the situation when all links are correct it generates test calls (directed towards test ports) and determines the standard value of PDD (PDD_1) for each node in the network (see Fig. 5). These data are memorized in detector for comparison with later measured values of PDD. Besides, according to the dialled number and the standard value of PDD, the threshold PDD_T is determined for each network node. The testing is performed in such a way that the ports of farthest nodes are called first. If $PDD<PDD_T$, testing passes to next far network node. If it is $PDD>PDD_T$ for distant node, it is necessary to determine on which route section the pre-alarm state exists (see Fig. 7). Let us suppose that we dial subscriber number of TSD in the exchange TED (far network node) from telephone TSA in the exchange TEA, where centralized detector is situated. The response time differs from the standard value more than it is allowed according to the threshold. It means that on some of the route sections TEA – TEB, TEB – TEC, TEC – TED pre-alarm state appeared. Standard values for the PDD exist for the connections TSA – TSC and TSA – TSB. It is possible to detect the route section on which pre-alarm state appeared by successively dialling telephone numbers TSC and TSB. If the fault exists on the link between TEB and TEC, the PDD value when dialling TSC will be greater than the pre-defined threshold and the PDD value when dialling TSB will be smaller than the pre-defined threshold.

Flow-chart of the detector algorithm is presented in Fig.8. In this flow-chart m is the number of directions, which have to be tested, i is the direction, which is instantaneously tested, n_i is the number of nodes in the direction i, and j is the node, which is instantaneously tested in the direction i. $DN_{i,j}$ is the testing dial number in node determined by i and j.

As it is already pointed, testing of direction i starts from the last node in the direction ($j = n_i$). Test number is dialled ($DN_{last\ i,j}$) and if PDD is less then PDD_T for node i,j ($PDD_{Ti,j}$), testing is finished for direction i. If it is not the last direction to be tested ($i < m$), testing is continued on the next direction ($i = i + 1$). If all directions are tested, it is started again from the first direction.

In the case that test PDD<$PDD_{Ti,j}$ is not satisfied for the last node in direction i, testing is continued with the previous node ($j = j - 1$). Test number is dialled for that node ($DN_{i,j}$), and if the condition PDD<$PDD_{Ti,j}$ is now satisfied, faulty ISDN or IP link is detected (evidence: i,j). If the condition PDD<$PDD_{Ti,j}$ is not satisfied, testing must be continued for the previous node in the direction.

This method for faulty link detection is implemented in the EPU telephone network. Its development is initiated by the college from EPU, who intuitively used dialling of test telephone numbers in various nodes of EPU telephone network to determine whether there is some fault in the network. As the result of this paper, we fulfilled method of detection, based it theoretically and initiated development of equipment (software) for automatic testing and detection of faulty link.
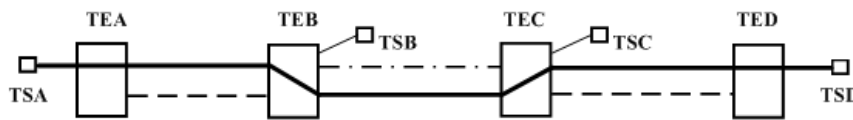

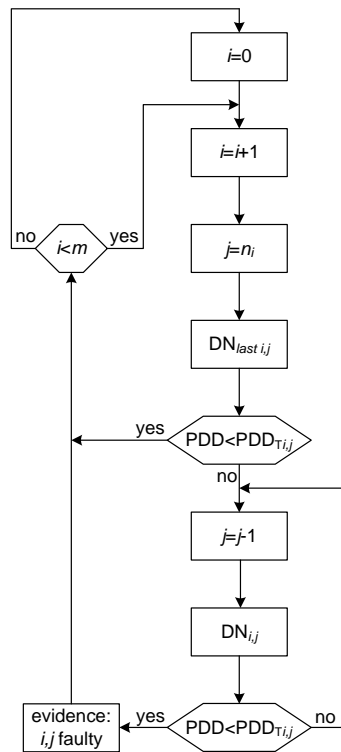**Fig. 7** Connection in the network with pre-alarm state on one route section

Fig. 8 Flow-chart of the algorithm of detector functioning

8. Conclusion

The function of the central detector of pre-alarm state in telephone network of EPU, i.e. faulty ISDN and IP links, is based on the different response time in the case of faulty and correct digital links. The great advantage of the detector is that all links can be tested from one point. The condition for this testing is that PLC links in the network are correct, which is checked separately. In the case of the incorrectness on all links, (alarm state), the connection could be realized using alternate digital links. In this case the called side response would be fast enough and the failure would not be detected.

The probability of false pre-alarm can be decreased by the choice of suitable numbering plan, because the difference in the response time of the called side when PLC and digital links are used depends on the number of dialling pulses in the called number.

The mean time from the failure to its detection equals half the time interval of validation.

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