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Influence of Numbering Scheme on the Efficiency of Failure Detector in Electric Power Utility

***Abstract**. In this paper we consider detector of faulty links in Electric Power Utility network. The detection is based on the prolonged response time of the called party. It is presented how detector efficiency can be increased by suitable directory, or by suitable called numbers of test telephones. The method is illustrated by few numerical examples.*

***Streszczenie.** W artykule opisano detektor błędu w sieci transmisyjnej wykorzystującej sieć zasilającą. Detekcja błędu bazuje na przedłużającym się opóźnieniu odpowiedzi. Metodę zilustrowano przykładami numerycznymi. (**Skuteczność detekcji błędu w sieci transmisyjnej wykorzystującej sieć zasilającą**)*

Keywords: Electric Power Utility, Power line carrier, Failure detector, Pre-alarm state
Słowa kluczowe: EPU, sieć transmisyjna, sieć zasilająca, detekcja błędu

Introduction

Telephone network of Electric Power Utility (EPU), which should have high availability, is designed in one level and it is called non-hierarchical network. The high availability of this network is achieved using all available transmission links, [1], [2], and the possibility of alternate routing of telephone calls, which is the important property of this network. Alternate routing has some problems as the consequence. Besides the possibility of network loop creation, problem of networks with alternate routing is more difficult detection of faulty links between network nodes. The reason is that users establish connections using alternate routes, and the unusable link may be unnoticed. In this short paper we present the method for the detection of faulty link in the mixed EPU network. This mixed network is constituted of exchanges and routers by various suppliers and of links from older technological generations. Faulty link detection on modern links is based on slower dialing over old technology links and on late response from the called party. In this paper it is presented that the numbering scheme can impact the efficiency of faulty link detection.

Faulty link detection principle

Mixed network of EPU consists of telephone exchanges (TE) and transmission systems, which can be IP, ISDN or Power Line Carrier (PLC). The old EPU telephone network was based on the usage of PLC transmission system. In [2] PLC links are called E&M analog (interexchange) lines. PLC is the technics of telephone channel transmission over power cables as a transmission media. Sometimes this transmission is also called voice over high voltage power line. PLCs remain in modern EPU telephone network in order to increase availability. The main characteristics of PLCs is E&M signalling and the transmission of only pulse dialing, [3]. The dialed number is always sent over PLC as decade pulse dialed number regardless of the possibilities of the exchanges connected by this link.

The main feature of ISDN or IP link, that is important for this paper, is that call set-up signalling is performed by message interchange during few tens or hundreds of ms. The main feature of PLCs in EPU telephone network is the implementation of slow E&M signalling with decadic dialing, [3]. That's why transmission of signals, which are necessary for connection set-up over PLC, lasts few seconds.

Let us consider one connection through the mixed telephone network of EPU, and two nodes (TEk and TEk+1) on the connection path, Fig. 1.a) and 1.b). The offered traffic to the link group is designated as *A*. The number of channels on ISDN link, or the maximal number of connections, which can be established on IP link, is *N*.

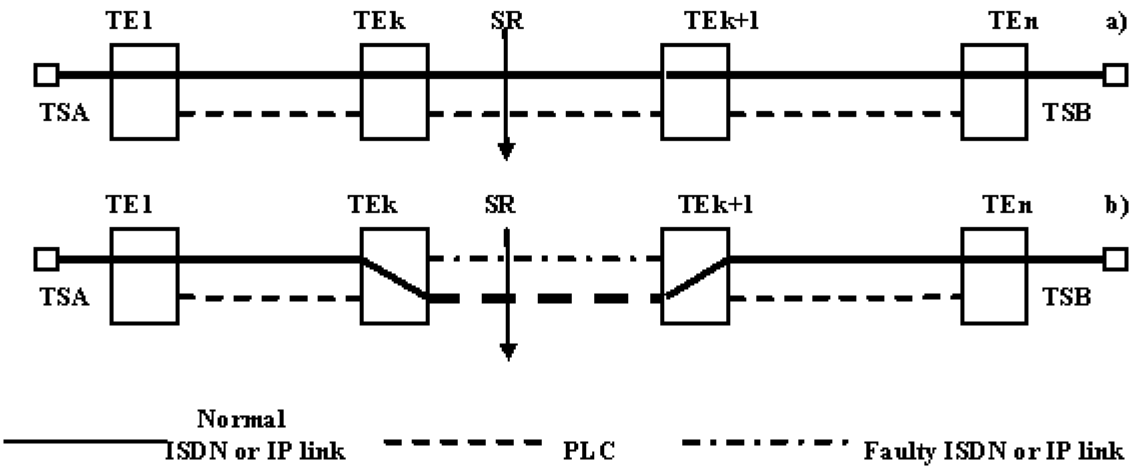

Fig.1. Connection establishment in the mixed EPU network: a) in normal operation; b) in the case of faulty (or occupied) ISDN or IP link

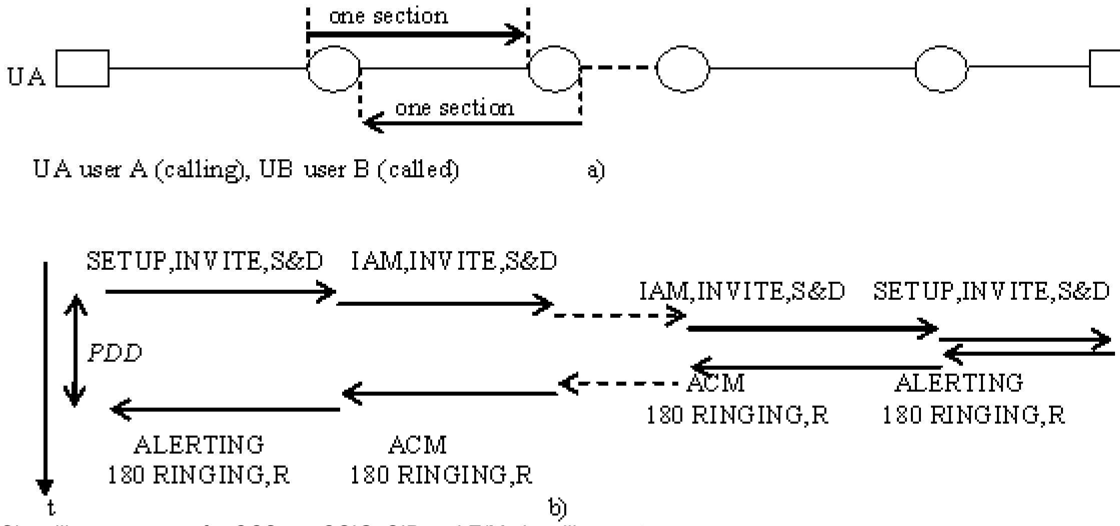

Fig.2. Signalling messages for CCS7 or QSIG, SIP and E/M signalling system

Telephone exchanges TEk and TEk+1 are connected by ISDN or IP link, and from the old network they are still connected by PLC. The connections between exchanges TEk and TEk+1 are established according to the following selection rule (SR): ISDN channel or IP link is selected at first (Fig. 1.a)), and if they are not available, PLC is selected (Fig. 1.b)). This SR is implemented, because connections are established faster and voice connection quality is better on connections over digital links than on connections over PLC.

The normal function (state) is the one when all links between exchanges are correct.
The alarm state is defined as the state when all links between exchanges TEk and TEk+1 are faulty.

The pre-alarm state is defined as the state when connection can not be established by the route of first choice, i.e. by ISDN or IP link, because they are faulty, but can be established by PLC.

Detection of pre-alarm state, i.e. the state when only PLC link is available between two network nodes, is very important. Successful detection of this state decreases probability of alarm state i.e. increases network availability.

Post dialing delay (*PDD*), [4], [5], is defined as time interval from the last dialed digit to the beginning of the answer from the called party, Fig 2. Time interval *PDD* consists of two sums. The first one consists of time intervals for sending signalling messages with called party address between network nodes from calling exchange to called exchange. The second one consists of time intervals for sending acknowledgement messages between the nodes in opposite direction. Signalling messages of signalling system CCS7 or QSIG (SETUP, IAM, ACM, ALERTING), [6], [7], [8], signalling messages of SIP (INVITE, 180 RINGING), [9], and messages of E/M signalling, [10], are presented in Fig. 2.

Let us suppose that five-digit numbering is implemented in network and that probability of transmitting each digit is equal (uniform distribution).

The principle of faulty link detection is very simple. Timer is turned on after sending initial signalling message for connection establishment (SETUP, INVITE, S&D). If the response time from the called party is significantly increased, it can be concluded with great probability that ISDN or IP link is faulty on some route, Fig. 1b). We can call this state detection of pre-alarm.

Let us now consider the real case, when a failure happens only on one route, as in Fig. 1. The difference between the response time in normal function and in the failure state, i.e. in the pre-alarm state is, practically, equal to the difference between needed time to transfer address information between two nodes. In the case of normal function the duration of address information transfer between telephone exchanges TEk and TEk+1 depends on traffic load of signalling resources, and in the case of PLC usage depends on the number of dialing pulses in decadic dialing.

The time of address information transfer between two network nodes (*Ta2*)

The time *Ta2* in the case of digital ISDN and IP links, T_d, is continual random variable. It can be concluded from Refs [11] - [13] that on digital links time interval T_d depends mainly on waiting time for transfer and that exponential distribution can be adopted for the distribution of this time. The greatest value of allowed mean time T_d is 800ms, and the greatest allowed value of time interval for serving 95% of all messages is 1200ms. Cumulative distribution function of time *Ta2* (designated as $F_d(x) = P(T_d \le x)$) in the case of digital ISDN and IP links is presented by solid line in Fig. 3.

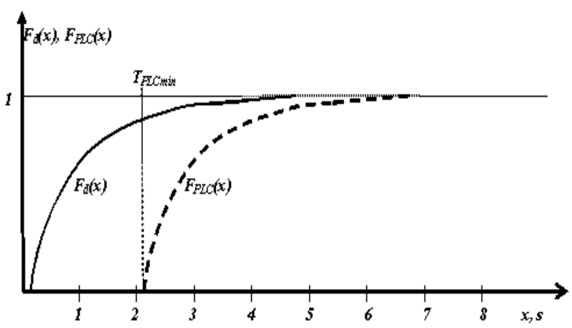

Fig.3. CDF of time for address information sending in the case of digital ISDN and IP and in the case of PLC link

The time *Ta2* for PLC link, T_{PLC}, is random variable which takes discrete values depending on the number of dialing pulses. Example: the numbering is five-digit, i.e. in the network there are more than 10000 users. Then the time of address information sending can be calculated as $T_{PLC'} = 4\cdot t_p + 100\cdot n$ (ms), where t_p is time duration of the pause between digits (350ms), and n is the number of decade pulses, n = 5,6,...49,50. It is necessary to mention that these address information are sent from one exchange to the other and that interdigit time is constant and without human influence. Random variable T_{PLC} takes only discrete values T_{PLC} = 1900, 2000, 2100,…, 6300, 6400 (ms). Cumulative distribution function of random variable T_{PLC}, designated by $F_{PLC}(x) = P(T_{PLC} \le x)$, is stepped function, but it is presented in Fig. 3 (dashed line) as continual line, because the number of steps is 45, i.e. pretty great.

False pre-alarm

The main drawback of the detector, presented in previous section, is false pre-alarm occurrence, i.e. response signal can appear with great delay (great value of *PDD*), although all channels are in function. In this paper we analyze the occurrence of false pre-alarm and the possibility to reduce the probability of false pre-alarm by the implementation of suitable numbering in telephone network of EPU.

Let us consider one connection in EPU network as in Fig. 1. Let us, further, suppose that timer is turned on in the telephone exchange, which originates the call. The timer is turned on in the moment of sending initial signalling message. Let *PDD* be the response time of called exchange and PDD_T the time threshold for waiting of this response. It is supposed that the state is normal if $PDD<PDD_T$. The pre-alarm state is declared if $PDD>PDD_T$. For this paper the following characteristic of pre-alarm characteristic is important: credibility of pre-alarm detector is as greater as PDD_T is greater. I.e., if $PDD_{T1} > PDD_{T2}$ then it is

(1) $$F_d(PDD_{T1}) = P(T_d \le PDD_{T1}) > \\ > F_d(PDD_{T2}) = P(T_d \le PDD_{T2})$$

Probability of pre-alarm detection is greater for greater value of time threshold PDD_T.

It is obvious that time threshold must not be greater than T_{PLCmin}, i.e. it must be $PDD_T < T_{PLCmin}$, Fig. 3. If it is $PDD_T > T_{PLCmin}$, some cases of pre-alarm will not be detected.

False pre-alarm can occur in two cases:

- if telephone traffic is great, so that ISDN or IP links are faultless, but occupied by previous calls, and the next connection is forwarded over PLC, or
- if the signalling traffic between network nodes is great, and the time duration for sending the address information between these nodes is too great. In this case the total time duration for the response of the called party can be $PDD>PDD_T$.

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

(2) $$P_{fpa1} = B = E(A,N)$$

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 false pre-alarm, caused by the too great value of signalling traffic on digital link (probability of false pre-alarm of second kind, P_{fpa2}) can be calculated in the following way. Let us consider the cumulative distribution function of time *Ta2* in the case of ISDN or IP link, Fig. 3. It is obvious that time interval T_d can be greater than T_{PLCmin}. The probability of this event is

(3) $$P_{fpa2} = P(T_d > P_{PLC\min}) = 1 - F_d(P_{PLC\min})$$

Cumulative distribution function of the exponential distribution is

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

where λ is the serving intensity.

It is obvious that probability of false pre-alarm of second kind is

(5) $$P_{fpa2} = e^{-\lambda \cdot PDD_T}$$

The total probability of false pre-alarm is

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

as it is P_{fpa1} << 1 and P_{fpa2}<< 1.

Example 1. Let us consider the primary group of ISDN channels (*N=30*) with the unreally great offered traffic *A=20* Erlang, then it is $P_{fpa1} = 0.00846$. Using the most stringent requirement from the recommendations [11] that the waiting time for 95% calls is less than 1200ms, we can determine the value for λ.

$$F(x) = 1 - e^{-1200 \cdot \lambda} = 0.95 \rightarrow \lambda = 2.5 s^{-1}$$

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

Reduction of the probability of false pre-alarm

The probability of false pre-alarm of the second kind is the main component of the probability of false pre-alarm. That's why it is important to consider the possibility to decrease its value. Let us consider the case when there are 20000 users in the network. The calling numbers of these users are not uniformly distributed from 11111 to 00000, but from 81111 to 90000, i.e. the first digit is always 8 or 9. (Comment: in decade dialing of telephone numbers, "0" is the greatest digit, as it consists of 10 decade pulses). It is clear that the total number of pulses that are sent over PLC will be between 12 and 50, instead of 5 and 50, as in the case of uniform distribution of calling numbers. The value of T_{PLCmin} now increases from 1900ms to 2600ms, and CDF of time *Ta2* ($F_{PLC}(x)$), Fig. 3, is changed as in the Fig. 4. The threshold level (PDD_T) of pre-alarm detection can be increased, and thus, according to inequality (1), the credibility of detection is also increased.

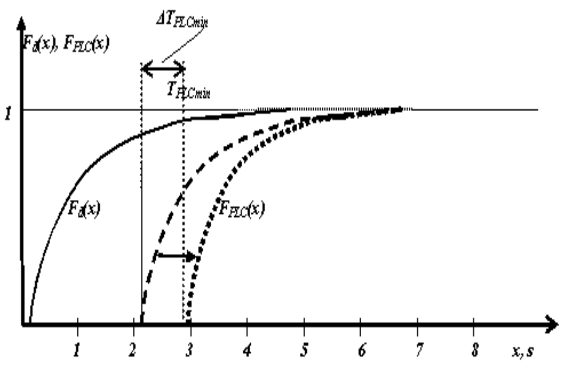

Fig.4. Influence of changing the numbering plan (selecting 8 and 9 for the first digit) on CDF of time *Ta2* for address information transmission

Example 2. Let us now set the detector threshold on the time duration PDD_T=2.5s. The probability of false pre-alarm of the second kind is $P_{fpa2} = 0.00193$, i.e. it is decreased an order of magnitude compared to its value in example 1. The same effect would be achieved if test calls, intended to prove the correct function of the network, were generated from the network center towards telephone users, whose sum of dialing pulses is great.

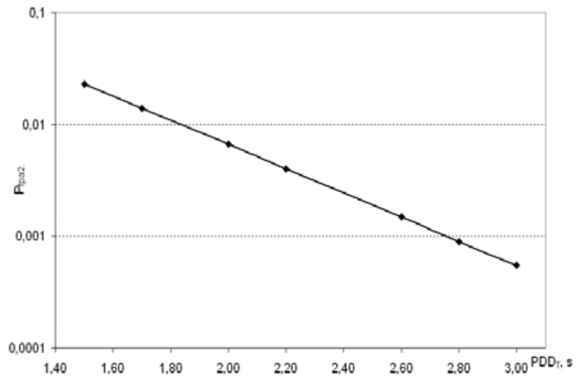

Fig.5. The probability of false pre-alarm in the function of threshold PDD_T

In Fig. 5 we presented the probability of false pre-alarm as the function of the selected threshold of PDD_T for the values calculated in example 2, when it is provided that $PDD_T = T_{PLCmin}$ - *400ms*. The value 400ms is adopted for the safety margin between PDD_T and T_{PLCmin}.

Function of the central detector in EPU network

The central detector of pre-alarm states in EPU network is located in the network center and it generates test calls. Its position and functioning principle are different than the position and the function of local detector, presented in [15] and [16]. (Both detectors described in [15] and [16] are local and based on traffic observations). This private network has limited capacity and the recommendations about PDD that are presented in [17] can be implemented only in the domain of smallest values. It can be easily determined by generating test calls to the users on the network peripheral if the response time indicates the possibility of failure on some link. Dialing the user number with great number of dialing pulses significantly decreases the probability of false alarm. If this time, *PDD*, is considerably greater than the expected time, the route with faulty link can be determined by successively dialing network nodes that are nearer to the network center. The probability of false alarm can be further decreased if the great value of *PDD* is confirmed by double dialing the same telephone number.

Conclusion

The non-hierarchical network has high availability due to the possibility of alternate routing. One imperfection of alternate routing is that it disables fast detection of faulty link between two network nodes, because calls are routed over alternate routes. Detector of faulty links, which uses principle of detecting the difference in response time of called party in the case of digital links and in case of PLC, is simple and cheap. The characteristic of this detector is that detection credibility is increased when the sum of digits of called number is increased. This can be achieved by the choice of suitable directory, or by dialing test telephones with the great sum of digits in the called number.

The detector of faulty links can be also based on considering the retransmission of IAM message (CCS7), [6], SETUP message (QSIG), [7], or SIP message INVITE, [8]. The delay time of a response will depend in those cases on the timers assigned to retransmission buffers and on the number of retransmissions. That's why it will be difficult to determine the probability of false alarm, i.e. detector confidence. And, besides this, the probability of false alarm could not be decreased by the suitable choice of numbering scheme if the detector based on retransmission consideration was implemented.

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