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New Digraph Models for Diagnosis of Electric Cables

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Introduction

Monitoring and memorizing the actual life of cables is a hard task, therefore we propose an effective evaluation method for the duty cycles characterized or approximated by medium of event phases, phases of faults or over-loads. The number and the duration of the emergency situations (overloads, insulation break-down, etc.) are taken statistically into account (IEC rules) or are fixed in advance for an allowable average time per year over the life of the cable (ICEA frame-work) [1÷4]. The supervisory control literature provides few indications how to implement the generated abstract supervisory control model in real applications [5÷7]. The faults that may occur in these cable networks are: insulation faults (one or many wires have short circuits to the ground, or among each others); continuity faults (one or many other wires are interrupted); mixed faults (faults that presume interruption of wires and also short circuits) [8, 9].

This paper is organized as follows: the second section describes the customary reliability indicators for cable networks. The third section proposes a digraph model for evaluating the reliability of railway control systems cable networks. A new algorithm for optimal reliability evaluation of cable network is introduced in the fourth section by an example on railway control systems. Finally, we end the paper with some conclusions in the last section.

Reliability indicators for cable networks

Compared to other technical devices, the cables are different because of the magnitude of the report between their length and their diameter. For instance, the power cables operational life time assume that the admissible operating temperature T_a is established for each cable insulating material as "the maximum temperature that the conductor withstands over a prolonged time period without serious demerit" [4]. The Arrhenius model of thermal aging of insulating materials provides the following equation, which allows us to determine the conventional life time $C_L(T)$ of the electrical cables [8, 9]:

$$\ln C_L(T) = \alpha + \frac{\beta}{T+273}, \qquad (1)$$

where the parameters α and β have different values for each kind of insulated cables. One may find out [9] that for low voltage cables $C_L(T)$ are equal to about 20 years, equivalent to 175,200 hours. Conductor ampacity, given in the Allowable Ampacities Tables [4]:

$$I = \sqrt{\frac{T-(T_0+\Delta T_\Delta)}{RDC\cdot(1+YC)\cdot RCA}}, \qquad (2)$$

where ΔT_Δ is the dielectric loss temperature rise; *RDC* is the DC resistance of the conductor at the temperature *T*; *RCA* is the effective thermal resistance between the conductor and surrounding ambient and *YC* is the component AC resistance resulting from skin effect and proximity effect.

In practice, the allowable value of the ampacity shall be reduced by the adjustment factors, i.e. temperature demerit factor and grouping factor [5]. Other specific reliability indicators for cable networks are the following ones [8, 9]:

a) The failure density:

$$D = \frac{100\cdot n}{t\cdot L}\left[failure/100\ km\cdot year\right], \qquad (3)$$

where *n* is the sum of failures; *t* is the time interval [*years*]; *L* is the length of the cable network [*km*].

b) The mean time between failures (MTBF):

$$m = \frac{\sum_{i=1}^{n} t_i}{n}[hours] \qquad (4)$$

where t_i is the time interval of proper functioning [*hours*]; *n* is the number of faults.

One may estimate the MTBF by using the following equation:

$$m = \frac{8760 - D\cdot t_R}{D}[hours], \qquad (5)$$

where *D* is given by relation (3); t_R is the mean time to repair; and 8760 is the numbers of *hours* in a *year*.

c) The mean time to provisional repair characterizes the cases when one replaces, in an electrical cable, some conductors that have poor insulated resistance related to other conductors which have better insulated resistance:

$$m_P = \frac{8760 - D \cdot t_{RP}}{D}[hours]. \quad (6)$$

d) Mean time to definitive repair:

$$m_D = \frac{8760 - D \cdot t_{RD}}{D}[hours]. \quad (7)$$

e) The failure installment:

$$d = \frac{1}{m}[hours^{-1}]. \quad (8)$$

We have the provisional failure installment:

$$d_P = \frac{1}{m_P}[hours^{-1}]. \quad (9)$$

where m_P is from (6), and the final failure installment is:

$$d_D = \frac{1}{m_D}[hours^{-1}]. \quad (10)$$

f) The reliability function *R(t).*

For the cable networks we have the following distributions of the time between failures (TBF): for the symmetric cables the distributions of the TBF is exponential; for optical fiber cables the distributions of the TBF is Weibull. We notice that for the failure installments given by (9) and (10) we have respectively the following reliability functions:

$$R_P(t) = e^{-d_P \cdot t}, \quad (11)$$

$$R_D(t) = e^{-d_D \cdot t}. \quad (12)$$

From practice we have that:

$$R_P(t) \geq R_D(t). \quad (13)$$

For reversible system Electro Dynamic Centralized Railways (EDCR) and Automatic Block Line (ABL) cable networks the cable systems are connected in large networks that display three possible states: proper functioning, short circuit wires defect and interruption wires defect.

The EDCR cable networks reliability evaluation using the fluency graphs

A system's reliability graph is a fluency graph that reflects the system structure in terms of how the function or dysfunction state of an element allows the other elements to fulfill their function in the system. The transmittance of the reliability graph is equal with the element reliability that represents it. The global reliability is determined like the graph's equivalent transmittance in-out, which can be computed in various ways. We will propose an algorithm that consists in the decomposing of the system's reliability graph in a number of graphs that contains all the possible directions between the entrance (IN) and the output (OUT) nodes:

a) Finding all the targeted direct ways (between IN and OUT). Computing the S_0 sum of their reliabilities; this sum will be considered non-negative;

b) Finding all the targeted graphs between IN and OUT that contains a single loop. Computing the S_1 sum of their reliabilities; this sum will be considered negative;

c) Finding all the targeted graphs between IN and OUT with two loops. Computing the S_2 sum of their reliabilities; this sum will be non-negative;

d) Steps b) and c) are repeated considering graphs with a large number of loops, until it reaches graphs with maximum number of loops. We compute the probability of functioning of the system; this sum will be negative if the graphs contain an odd number of loops and non-negative for an even number of loops. The reliability function is:

$$F_S = S_0 - S_1 + S_2 - S_3 + \ldots. \quad (14)$$

Example: An EDCR station cable network represented in Fig.1, where: F_A is the reliability of the supply cables output, section X (SI 1-3, SI 5, etc.); F_B is the reliability of the supply cables output, section Y (SI 10, SI6, etc.); F_C is the reliability of the signal cables input, section X, connected in DSX; F_D is the reliability of the signal cables input, section Y, connected in DSY; F_E is the reliability of the interconnection control center cables (CP).

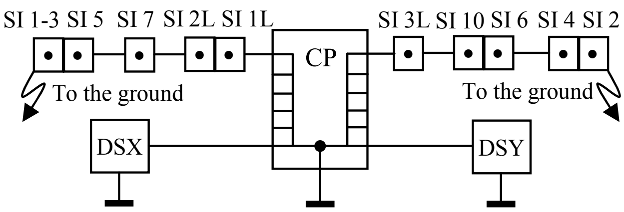

Fig. 1. Example of EDCR station cables network

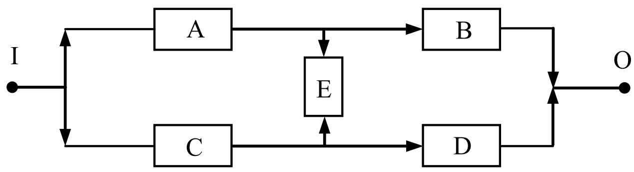

Fig. 2. The reliability graph for the cables network from Fig. 1

The reliability graph of the system with an indecomposable reliability structure given in Fig. 2 can be emphasized in four direct paths (Fig. 3), five targeted graphs with a loop (Fig. 4) and two targeted graphs each with two loops (Fig. 5).

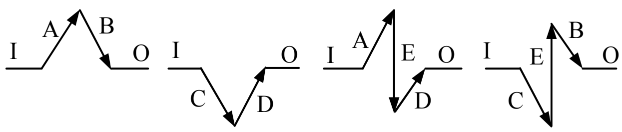

Fig. 3. The reliability graph's decomposition in direct paths

From Fig. 3, we have:

$$S_0 = F_A F_B + F_C F_D + F_A F_D F_E + F_B F_C F_E. \quad (15)$$

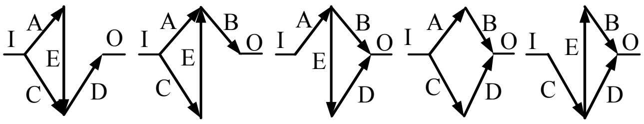

Fig. 4. The reliability graph decomposition in targeted graphs with one loop

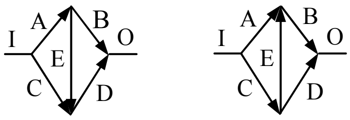

Fig. 5. The reliability graph decomposition in targeted graphs with two loops

From Fig. 4, we have:

$$S_1 = F_A F_B F_D F_E + F_A F_B F_C F_D + F_A F_C F_D F_E + + F_A F_B F_C F_E + F_B F_C F_D F_E . \quad (16)$$

From Fig. 5, we have:

$$S_2 = 2 F_A F_B F_C F_D F_E . \quad (17)$$

The systems reliability is computed using relation (14). For a complex cable network, the usage of the computer becomes imperative, based on searching the paths in a graph.

Methods for optimizing the evaluation of network railway remotes cable reliability

In the previous chapter we have proposed a new digraph model for calculating the cable network availability. Next, we will try to determine also the type of failures which is possible to appear after the last performed maintenance. For this we remind the main elements that compose the railway remote cable network: cables, cable distributors, pickets of two types: the extension of a cable route (pickets plug), and wiring in the installation at one cable end (destination pickets). We will represent the EDCR station cable network with a graph where the nodes symbolize the distributors and pickets and the graph arches represent the EDCR cables. We will calculate which of the graph's nodes have the lower insulation resistance and which of the cable network distributor or picket will break down first. Next, we will compute for each network cable distributors the insulation resistance of the adjacent pickets for calculating the partial reliabilities of the EDCR network cable. To determine the cable with the minimum reliability from the proper system cables to an EDCR station, we will model the station cable network with the graph described above, where the arch weight represents the insulation resistance of the cables. In this graph we will consider as a source node the cable distributor from the relays room Command Point (CP), and the final node will be given by the destination picket. We propose [9] an algorithm that reduces substantially the necessary computation memory related to a station.

The model of network cable reliability for an EDCR station is represented in Fig. 6, where X represents one of the station's entrance signal-terminal, CP_X and CP_Y represents the distributors from the CP according to the X and Y station's terminals, Y represents the other station signal-terminal. The graph's arches weights represented in Fig. 6 are the following:

$$c_{x1} = \left(f_{x1} + f_{x2} + ... + f_{xn} \right) / n , \quad (18)$$

where c_{x1} represents the medium switch cables reliability from the X terminal; f_{xi} represents the *"i"* cable reliability, with $i = 1, \ldots, n$; where n is the number of switch cables for the X terminal.

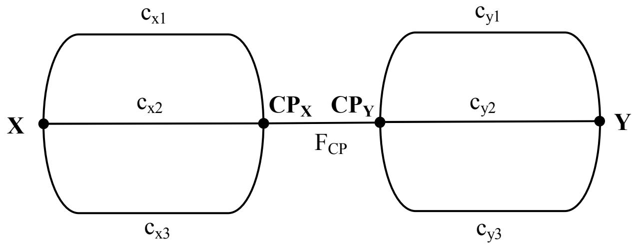

Fig. 6. Representation of the cable system's reliability from EDCR station

$$c_{x2} = \left(a_{x1} + a_{x2} + ... + a_{xm} \right) / m , \quad (19)$$

where c_{x2} represents the medium cable reliability from the X terminal; a_{xi} represents the *"i"* cable reliability, with $i = 1, \ldots, m$; where m is the number of cables for X terminal.

$$c_{x3} = \left(b_{x1} + b_{x2} + ... + b_{xp} \right) / p , \quad (20)$$

where c_{x3} represents the signal cables medium reliability from the X terminal; b_{xi} represents the *"i"* cable reliability, with $i = 1, \ldots, p;$ where p is the number of cables for the station X terminal.

$$c_{y1} = \left(d_{y1} + d_{y2} + ... + d_{yr} \right) / r , \quad (21)$$

where c_{y1} represents the medium switch cables reliability from the Y terminal; d_{yi} represents the *"i"* cable reliability, with $i = 1, \ldots, r$; where r is the number of switch cables for the Y terminal.

$$c_{y2} = \left(e_{y1} + e_{y2} + ... + e_{yq} \right) / q , \quad (22)$$

where c_{y2} represents the medium cable reliability from the Y terminal; e_{yi} represents the *"i"* cable reliability, with $i = 1, \ldots, q$; where q is the number of cables for the Y terminal.

$$c_{y3} = \left(g_{y1} + g_{y2} + ... + g_{yw} \right) / w , \quad (23)$$

where c_{y3} represents the signal cables medium reliability from the Y station terminal; g_{yi} represents the *"i"* cable reliability, with $i = 1, \ldots, w$; where w is the number of cables for the station Y terminal.

In Fig. 6 the information flux circles through a bidirectional cable (from the relays room to the train installation and backward), and doesn't explain anymore the representation with orientated or fluency graphs. The network cables reliability from an EDCR station, regardless to the station size, is given by the formula:

$$F_S = F_X \cdot F_{PC} \cdot F_Y , \quad (24)$$

where $F_{X\,(Y)}$ represents the network cable reliability from the station $X\,(Y)$ terminal; F_{PC} represents CP's reliability.

From Fig. 6 we have:

$$S_{0X} = c_{x1} + c_{x2} + c_{x3}, \tag{25}$$

where S_{0X} represents the graphs cost (reliability) sum between node X and PC_X with no loops.

S_{1X} represents the graphs cost sum between node X and PC_X with one loop. The graphs that contain a single loop are given by the "1" elements placed above the main diagonal from the M_{X1} array:

$$M_{X1} = \begin{matrix} & c_{x1} & c_{x2} & c_{x3} \\ c_{x1} & 0 & 1 & 1 \\ c_{x2} & 1 & 0 & 1 \\ c_{x3} & 1 & 1 & 0 \end{matrix}. \tag{26}$$

It results that:

$$S_{1X} = c_{x1} \cdot c_{x2} + c_{x1} \cdot c_{x3} + c_{x2} \cdot c_{x3}. \tag{27}$$

The graphs that contain two loops are given by the "1" elements placed above the main diagonally of M_{X2} array:

$$M_{X2} = \begin{matrix} & c_{x(1,2)} & c_{x(1,3)} & c_{x(2,3)} \\ c_{x(1,2)} & 0 & 1 & 1 \\ c_{x(1,3)} & 1 & 0 & 1 \\ c_{x(2,3)} & 1 & 1 & 0 \end{matrix}. \tag{28}$$

It results that:

$$S_{2X} = c_{x1}^2 \cdot c_{x2} \cdot c_{x3} + c_{x1} \cdot c_{x2}^2 \cdot c_{x3} + c_{x1} \cdot c_{x2} \cdot c_{x3}^2, \tag{29}$$

where S_{2X} represents the graphs cost (reliability) sum between node X and PC_X with two loops.

S_{3X} represents the three loops graphs cost sum of node X and PC_X., and from Fig. 6, we have:

$$S_{3X} = c_{x1} \cdot c_{x2} \cdot c_{x2} \cdot c_{x3} \cdot c_{x1} \cdot c_{x3} = c_{x1}^2 \cdot c_{x2}^2 \cdot c_{x3}^2 \tag{30}$$

$$F_Y = S_{0Y} - S_{1Y} + S_{2Y} - S_{3Y} \tag{31}$$

Conclusion

This paper proposes a systematic approach to model the failure detection framework in order to ensure a proper maintenance for the electric cables. Monitoring and memorizing the actual life of electrical cables should be possible to define an equivalent power cable ampacity, based on the allowable cable life loss. Our approach will allow an operation preventive control for the evaluation of different load duties and memorize the actual stage of the circuits. Future work will focus on the implementation of these models in the Petri nets framework in order to perform advanced simulations.

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This paper proposes a new systematic approach to model the electric cables failure detection, in order to design a supervisory system which prevents human errors. To demonstrate this, we apply it to railway electric cable systems.Ill. 6, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

Ц. Цюфудеан, Ц. Филоте, А. Ларионеску. Применение новых диграфических моделей для диагностики электрических кабелей // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – С. 65–68.

Описывается новая диграфическая модель для определения отказа кабелей связи, которим позволяет исключить ошибки операторов. Модель экспериментально проверена в системах электрокабелей, применяя сообщения в железнодорожных путей. Ил. 6, библ 9 (на английском языке; рефераты на английском, русском и литовском яз.).

C. Ciufudean, C. Filote, A. Larionescu. Naujų digrafų modelių taikymas elektros kabelių diagnostikoje // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 6(94). – P. 65–68.

Pateiktas elektros kabelių gedimų nustatymo modelis, kuriuo siekiama sukurti priežiūros sistemą padedančią išvengti žmogiškųjų klaidų. Modelis eksperimentiškai patikrintas geležinkelio elektros kabelių sistemose. Il. 6, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).