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Faculty of ELECTRICAL ENGINEERING
Doctoral School of ELECTRICAL ENGINEERING

RESEARCH ON INCREASING EFFICIENCY OF DEFECT DIAGNOSE IN CABLE ELECTRIC LINES

SUMMARY

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CONTENT OF THE PHD THESIS

Key words: ***dielectric, insulation fault, degradation factors, sterile water, fault identification, reliability, probability of failure, location methods, self-laboratory defectoscopy, logical schemas.***

INTRODUCTION

1. THEME PRESENT INTEREST

The continuous development of urban areas and the expansion of industrial zones have generated in recent years an increasing trend of transition from overhead and cable power lines and at the same time there have been a number of problems related to the normal operation of power cables. regarding the supply of domestic and industrial consumers.

Ensuring continuity in the supply of electricity to large industrial consumers and the use of the fastest possible methods for detecting and repairing defects in power cables, have required extensive research on increasing operational safety, thorough investigation of the causes of defects and the production of the best possible diagnostic equipment. Therefore, research on the efficiency of fault diagnosis in cable power lines is a current field of great interest, both for electricity generation and distribution companies and for large electricity cable manufacturers..

2. PHD OBJECTIVES AND STRUCTURE

In the process of pre-localization and location of defects in power cables, several destructive or non-destructive methods, classical or specific, are used. Measurement errors can be significant and only adequate training and experience in the interpretation of measurements by operating personnel can lead to the identification of the defect quickly, accurately and without material loss.

On the power cables in operation there are several internal and external factors that lead to the degradation and aging of electrical insulation, ultimately causing it to break through. Partial discharges, as well as the appearance of electrical and water arborescences, are causes that lead in most cases to the appearance of defects in electrical cables.

Knowledge of the electromagnetic phenomena that manifest around the cables traversed by electric current, the notions related to the polarization and breakdown of dielectrics in the electric field, are essential in making quick decisions regarding the operations to be undertaken to locate and repair the fault. consumers of electricity in the shortest time.

A rich specialized bibliography was used to carry out the work, as well as the personal practical results obtained in the activity of detecting defects in the electricity cables..

The objectives of the PhD thesis are:

- Analysis of the degradation mechanisms and their effects on the insulation of electricity cables, developing solutions to reduce the failure rate and increase the operational safety of electricity distribution networks.
- Analysis of the insulation behaviour of electricity cables to various environmental factors, in areas with high acidity.
- Monitoring of the electrical parameters of the power cables and estimating the lifespan based on the measurements performed.
- Improvement of the current diagnostic methods and combining them in more difficult situations of fault detection, to reduce measurement errors and the time allocated to the identification and repair of the cable for re-commissioning as soon as possible.
- Investigation of real situations of pre-location and location of defects in electricity cables and development of solutions based on personal results or information obtained from those involved in the process of defectoscopy.

SYNTHESIS OF THE PHD THESIS CHAPTERS

The doctoral thesis is structured in five chapters, of which the first two are theoretical, followed by chapters three and four of a practical (applied) nature and chapter five, where the conclusions and personal contributions resulting from the research are presented..

Chapter 1- aims to clarify the notions regarding the polarization of dielectrics in the electric field, defines the notion of dielectric strength, electric moment, electric polarization vector, the notion of electric discharge, types of electric discharges that may occur in the structure of the dielectric. Also, emphasis was placed on defining the phenomena of breakdown, contouring, the study being done mainly for materials with solid insulation.

The property of the dielectric to polarize under the action of the electric field weakens the value of its total insulation resistance, concluding that there is in fact no

perfect insulator that does not allow electricity to pass through it at all.

The electrical insulation of the equipment in operation is subject to electrical, thermal, mechanical, and environmental stresses, which trigger the degradation process until the dielectric penetrates. The piercing phenomenon is characterized by melting or evaporation of the electrical insulating material. If for the gas dielectric the breakdown can be reversible, in the case of the solid dielectric the breakdown is irreversible, requiring intervention to replace the affected part of the insulation [1], [2], [3], [7].

It was concluded that in the structure of solid electrical insulating materials there are cavities (vacuoles) resulting from technological processes. In these gas-filled vacuoles, under the action of the electric field, partial discharges take place due to the collisions of the field-accelerated charge carriers and which spread around the vacuole, causing changes in the intensity of the electric field. These ionization and recombination processes weaken the electrical insulating properties of the dielectric [20], [21].

In practice, the breakdown phenomenon is preceded by a pre-discharge, in which the avalanche of electrons moves towards the electrodes generating a conduction current, and the electric discharge phase that leads in time to the breakdown. In most cases, the electric discharge is manifested only on a small portion of the dielectric (Fig.1), a situation in which the expression "partial discharge" is frequently used..

Fig.1. Irreversible partial discharge followed by breakdown of a medium voltage cable [16]

In terms of humidity, the amount of water that enters the dielectric gives rise to channels called water arborescences, which form defects near or on the surface of insulation and generate areas with very high electrical permittivity, with ionic concentration [7], [17], [18]. The amount of moisture absorbed, worsens the dielectric properties, and has mechanical effects on the tensile strength and elongation at break of the insulating material. At the same time, under the action of the electric field, the polar water molecules rotate, generating dielectric losses due to mechanical work.

An example of a water arborescences is presented in Fig.2.

Fig.2 . Effect of water arborescences on the surface of the dielectric [16]

Solid electrical insulating materials are subjected to variable temperature regimes in operation that generally influence the life of the dielectric, an increase in temperature above normal (for example at short circuit or overload) triggers a series of reactions that eventually lead to breakdown.

Sudden changes in temperature combined with changes in ambient temperature cause expansion and contraction of the insulation. If the operating temperature is higher than normal, it causes premature aging, a process called thermal aging [2], [8], [10]. Considering this aspect, electrical insulating materials are manufactured at a maximum permissible insulation temperature value as high as possible, to ensure the best possible dielectric strength of the electrical installations in the structure of which they are part.

At the same time, heating the insulation causes energy losses that significantly reduce the life of the dielectric.

Any breakdown of an electrical nature is followed by a thermal one, so it is difficult to separate the two types of breakdowns. Fig.3 shows an example of breakdown (combined) of the insulation of a medium voltage cable, having the effect of melting the material under the influence of heat released by the Joule effect.

Fig.3. Insulation breakdown in the terminal head area [16]

In conclusion, the insulation of electrical equipment in operation can be affected by several factors of an electrical, thermal, mechanical, chemical nature, which lead to the loss of electrical insulating properties and to shorten the life of the dielectric. This is because in practice there is no perfect insulator that does not allow electricity to pass through it at all, so the aim is not to eliminate power losses, but to reduce them.

At the same time, the electric charges are deposited on the walls of the cavities filled with gas existing in the solid dielectric and are scattered around them, generating deformations of the electric field.

Following the partial discharges, a series of ionization and recombination processes take place, which modify the electrical insulating properties of the dielectric.

Chapter 2 - presents a general description of the main constructive elements of electricity cables, analyses the types of defects, and causes of failure and conducts research on the phenomenon of electrical insulation degradation, by simulating in the laboratory the operating conditions. The failure mechanisms are highlighted and some defective assembly situations that have been the cause of frequent failures are described.

The main constructive elements of power cables are:

- conductors.
- insulation.
- screen.
- coat or sheath.
- protective coatings.

Insulation is the most important element on which the safety of electrical cables depends. From a constructive point of view, it consists of one or more layers of insulating material arranged around the conductors.

The most used dielectric materials are the following [3],[4]:

- Polyvinyl chloride (PVC).
- Polyethylene (PE).
- Cross-linked polyethylene (PER).
- Electrical insulating oil.
- Insulating gases (SF6).
- Rubber.

To even out the electric field around the insulation and to attenuate the influence of external electromagnetic fields, the shielding of the cables is done by applying a screen consisting of a coating of metallic paper, wire or metal strip, arranged over one or more insulating conductors. Also, the screen has the role of ensuring the passage of capacitive and fault currents to earth in emergency situations, thus allowing the reduction of the thickness of the insulation layer of each conductor.

At the same time, shielding ensures better cooling as well as increasing the charging capacity of the power cable [28], [29]. [30].

In use installations, the shields of the power cables are connected to earth through their ends. Grounding protects the cable from low and high frequency disturbing oscillations. To prevent the flow of current through the screen, in operation it is ensured that the earthing circuit is as short as possible, the screen is uninterrupted along the entire length of the cable, and the earthing contacts are firm. (Fig.4).

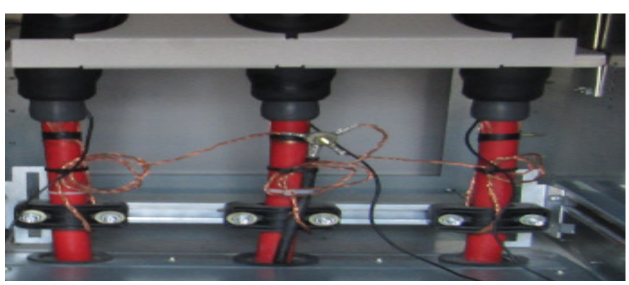


Fig.4. Connecting the copper shields to the metal housing of the medium voltage cell [16]

The cable sheath consists of a sheath made of lead, aluminium or plastic and a non-metallic outer sheath, both of which provide protection against external factors such as moisture or chemicals in the environment in which the cable is laid.

Plastic jackets are the most used due to lower and faster manufacturing processes. For example, sheaths made of polyvinyl chloride or cross-linked polyethylene, in combination with those made of lead or aluminium, are present in most electrical cable insulation systems currently produced.

The specific electrical parameters of the power cables are: ohmic resistance, inductive reactance, capacitive susceptibility, conductance [32], [33].

From the point of view of dielectric losses, the conductance is directly influenced by the losses due to the dielectric (leakage) conduction currents, the hysteresis phenomenon, or the ionization phenomenon from the existing cavities in the dielectric material. The conductance value is determined by measuring the dielectric loss factor, respectively a.

Practically, the measurement of electric cables is almost impossible, especially for long lengths, due to the large capacity proportional to their length and which generate capacitive currents that exceed the allowable limit of the capacitive current of the measuring bridge [33].

Apparent service capacity (susceptibility) is an important electrical parameter in the normal operation of power cables in operation. Any power line is defined by a service capacity that represents the sum of the earth's parasitic capacitances (Cp) and the mutual capacities (Cm) between phases. The equivalent scheme of the three-phase power line with the representation of capacities is presented in Fig.5.

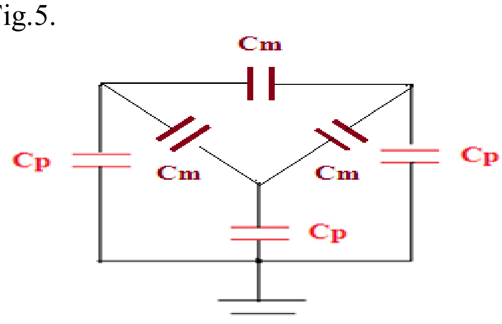


Fig.5. Equivalent diagram of the three-phase power line [43]

Prior to commissioning (PIF) but also during operation, the power cables are subjected to tests and measurements.

The main steps taken before switching on are the following: Checking the continuity and identifying the phases, measuring the insulation resistance, testing the insulation with increased voltage.

The most important parameter in ensuring the functionality and continuity in operation of electricity cables is the insulation resistance. The measurement of this electrical parameter is performed with the help of an analogue or digital megohmmeter, at voltages established by the regulations in force, depending on the value of the nominal voltage of the respective cable.

The high voltage test is a necessary but not mandatory condition, especially in the case of long-term electrical cables in operation (aged insulation), especially in the case of MT and IT cables, when the insulation resistance values are not adequate.

It should be noted that any voltage applied to the cable, higher than the nominal value, leads to premature aging of the insulation, shortening the service life.

In order to investigate the mechanisms of degradation of the electrical insulation of the electric power cables in operation, in the laboratory measurements were performed at predetermined time intervals on samples of cables with PVC insulation, XLPE.

In the experimental study, the cable sample was introduced into a rigid PVC tube, filled with an electrolyte solution that includes a series of chemical compounds in order to simulate the environmental conditions in operation.

A monopolar cable was chosen for testing, with the following characteristics: type NA2XSY; Uo / Un = 12/20 kV; section 185 mm2; compacted aluminium conductor and copper wire screen. The cable, with a length of 4 m, was inserted in the tub in such a way that its two ends are located outside it at a height of more than 30 cm from the ends, to avoid the bypass phenomenon.

The first stage aimed at testing the cable at voltages higher than the nominal one and monitoring the conduction currents, the insulation resistance, and the electrolyte temperature at 24 h intervals. The tested cable was tested for direct current electric fields, where the leakage current values are relatively low compared to those resulting from alternating current electric fields, considering the protection of the test equipment during monitoring.

In the second stage, the same cable sample was tested for a period of time in the absence of supply voltage, being subjected only to the corrosive action of the electrolyte in the installation tank, and in the following time intervals it was refuelled at different voltage values. insulation. The principle diagram of the experimental electrical insulation test installation that has been developed is presented in Fig.6.

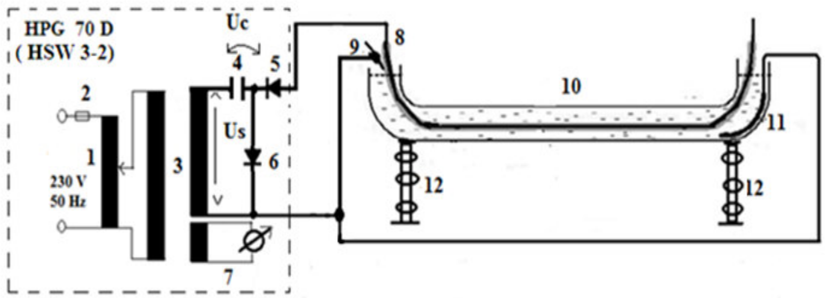


Fig.6. Experimental test installation with increased voltage in direct current: 1- Autotransformer for voltage regulation; 2- Safety protection of the installation; 3- Voltage transformer; 4- Coupling capacitor; 5.6 - Rectification and multiplication diodes; 7- Tertiary measuring winding; 8- Main conductor; 9- Cable screen; 10- PVC tub; 11- Graphite counter electrode; 12-Isolator IT

Following the experimental research, the following conclusions were obtained:

- Under operating conditions at voltages close to the rated value (Uo / Un = 12 / 20kV), the conduction current flowing through the insulation determines a normal heating, maintaining the insulation at a positive temperature, in principle higher in relation to the temperature in the tank of the installation. The electrolyte absorption, in this case, is low.

- During the time when the supply voltage has high values in relation to the nominal voltage of the cable sample, the insulation enters a process of continuous degradation due to heating, losing its electrical insulating properties and generating a rapid decrease in value. insulation resistance.

- In the absence of supply voltage, the internal temperature of the cable decreases with the temperature of the electrolyte in the tank, and the process of degradation of insulation is accentuated, because the insulation absorbs more electrolyte from the tank, causing significant decreases in insulation resistance. When re-energizing, the cable insulation broke through the voltage value of 42kV (Fig.7).

Based on these considerations, it is recommended to avoid situations in which unused power cables are left unpowered for long periods of time. In this case, since no conduction current flows through the insulation, the insulation contracts and allows water and corrosive agents to penetrate inside the cable, especially in the sleeves or terminal ends. This phenomenon occurs mainly in periods of low temperatures and high humidity.

At the same time, the use of electricity cables at voltages other than the nominal ones should be avoided, because it accelerates the aging process of the insulation and causes the premature appearance of the dielectric breakdown phenomenon.

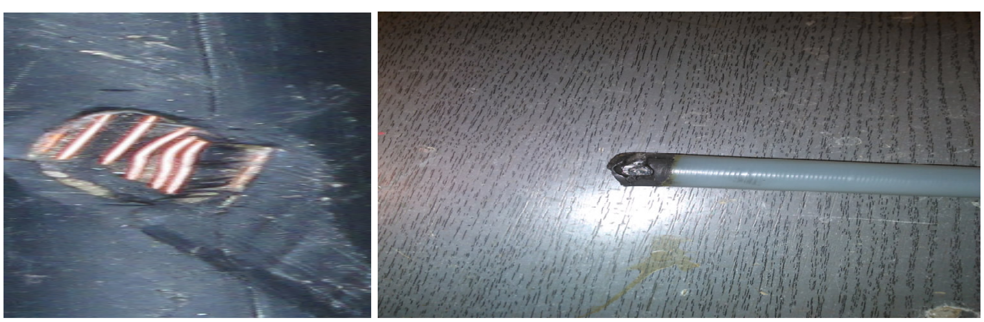
The results of the measurements during the experimental study are presented in Tab.1, Tab.2.

Tab.1. The values of the quantities measured constantly in the first stage of the experimental study

Time interval		U_{meas} [kVcc]	I_c [μA]	$R_{ins.}$ [GΩ]	$T_{electroyite}$ [ºC]
Commissioning test	15"	72,0	2,0	277,0	20,0
I	24 h	62,2	16,8	156,0	47,8
II	48 h	54,8	26,5	94,6	38,0
III	72 h	46,5	45,0	86,8	32,4
IV	96 h	32,9	34,5	46,5	28,5
V	120 h	24,0	40,0	28,2	24,5
VI	144 h	23,8	42,3	27,9	23,7
VII	168 h	23,4	41,8	27,4	23,2

Tab.2. The values of the quantities measured constantly in the second stage of the experimental study

Time intervals		U_a [kVcc]	I_c [μA]	$R_{ins.}$ [GΩ]	$T_{electroyite}$ [ºC]
-	-	-	-	29,4	20,0
I	24 h	-	-	12,5	18,7
II	48 h	-	-	6,5	19,2
III	72 h	-	-	4,8	20,8
IV	96 h	-	-	3,4	21,2
V	120 h	-	-	1,4	21,4
Repowering					
I	24 h	12	690,5	0,8	19,8
II	48 h	20	1450,0	0,4	25,0
III	72 h	30	2480,0	0,1	28,0
IV	-	42	→ breakdown		



a b

Fig.7. View of the insulation breakdown location :a) after removing the outer coating. b) after removing the semi-conducting layer

The following types of faults occur in cable networks:

- Defects caused by insulation breakage resulting in the grounding of one between phases, two or three phases.
- Defects caused by short-circuiting of two or three phases due to insulation breakage among them.
- Defects caused by the interruption of one, two or three phases with or without earthing.
- Partial downloads.

- Sheath defects.
- Mixed defects, by the simultaneous appearance of different defects.

The causes that lead to the aging and puncture of the dielectric are multiple starting from defects resulting from the manufacturing process, defects caused during laying electrical power cables in operation, electrical faults (overvoltages, overcurrents) that lead to heating of the electrical cable above the temperature limit allowed by the manufacturer.

Accidental breakage of the insulation may also occur because of subsequent work along the routes when mechanized or non-mechanized excavations are carried out without the contractor being informed in advance of the existence of cable sections in the work area.

In theory, the electric cable should be considered as a network with four terminals (quadripole) consisting of two gates (Fig.8), each gate representing a pair of terminals accessible from the outside [56]. Starting from this representation, it is considered that each conductor is defined by an ohmic resistance R and an inductor L series arranged longitudinally respectively a conductance G and a capacitance C as input quantities and arranged transversely. These input quantities are theoretically equal and of opposite direction (compared to quadripole) with the output quantities R1, L1, G1, C1.

When the proportionality of these sizes changes, the electrical insulating properties degrade, and the electrical cable is damaged..

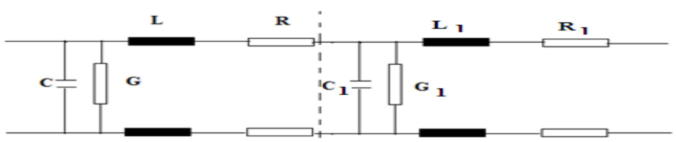


Fig.8. Equivalent circuit for a network with four terminals [56]

In the case of power cables, the probability of failure is very high, given the stresses they are subjected to during operation. Therefore, it is very important to know both the methods and means for identifying defects and the probability of failure.

In mining regions, research in the field of pollution has shown a higher degree of pollution, primarily because of poor management of waste from exploitation.

A polluting element is tailings, with a major impact on the environment, as acidic waters, and toxic substances (as main tailings results) directly affect the insulation systems of power cables.

Tailings represent an acidic solid that in combination with water forms a highly corrosive liquid solution. When the electrolytic substance reaches the laying area of the power cables and comes into contact with their outer surface, it causes faster insulation damage over time, negatively affecting the properties of electrical insulating materials that are part of the electrical insulation system. Defects occur as a result of the breakdown of electrical insulation due to the breakdown of corrosive substances through the polymeric protective layer of the electrical cable [54], [66]. Degradation caused by the acidic environment was also found in the case of electrical equipment and installations, as well as the surfaces of plastic pipes used in water supply.

Measurements were made on the pH of the water in the vicinity of the cable routes in the Moldova Nouă area, which indicated a high acidity near the industrial areas as well as the mining and former mining areas. Deposits of tailings (tailings industrial sand) were identified in this area. At the same time, the whitish appearance of the water sample collected from this area confirmed the existence of the tailings in diluted form, in the acid concentration of the water.

The corrosive substance formed by water with tailings acted aggressively on the insulation of the cables, especially in the area of the sleeves, affecting their operation (Fig.9).

a b c

Fig.9.a),b). Identification of the sleeve defect on the solidified tailings portion c) The insulating (decomposed) portion of the heat-shrinkable sleeve resulting from the acid effect.

The examination concluded that polyethylene (PE) is the most affected by the acidic environment, having a low chemical resistance to corrosive acids, while the insulation of HEPR (ethylene propylene rubber) and PVC (polyvinyl chloride) have a higher chemical resistance. high, protecting the electric cable from the effect of acid water.

As measures to limit or prevent incidents in the acid environment, we can list the use of special sleeves with PTFE (polytetrafluoroethylene) insulation, due to the excellent chemical resistance to corrosive substances and the design of cable routes to bypass areas with high acidity, decisions that are established following an AMDE analysis (*Analysis of Fault Modes and Fault Effects).*

Chapter 3 **-** analyses a series of mathematical models for predicting defects, simultaneously with AMDE analysis.

In the case of electricity cables, the forecasting of defects is currently made based on existing mathematical models in the literature, which consider the phenomena of mechanical, electrical, thermal, and environmental, which require the power lines in operation. Mathematical models evaluate the performance of electrical cables by investigating the number of accidental outages.

Particular emphasis is placed on the study of reliability which is based on probability theory [59], [60], but at the same time takes into account the data from the history of events, in the monitored time interval. The reliability study involves the systematic evaluation of reliability indicators, the elimination of the causes of failure and the reduction of the probability of other defects.

The analysis of failure modes and their effects (AMDE), aims to identify the causes of defects from the design phase of products, through a management program to ensure reliability [72], [73]. The activities of recognition, analysis and evaluation of defects are performed by a team of specialists, coordinated by a moderator, who knows the operating conditions and ways of failure. Because AMDE is achieved through joint action, it involves a huge amount of work that also involves significant errors. These disadvantages have led to research in order to automate AMDE processes by using software applications, which allow quick access to information stored in a database, also called knowledge base. The results of AMDE are essential in the rapid decision-making, to avoid further failures being developed a series of recommendations and a plan for their implementation.

In operation, for certain systems, the distribution of failure times is not suitable for any of the distributions. For example, in the case of power cables, there are cases where the defects occur because of degradation (wear) over time. In such situations, the Weibull distribution law, the most widely used distribution in reliability engineering, is used [72], [74].

To estimate the maximum operating time between two successive faults, simulations were performed for four separate circuits of existing electrical cables in operation, using the EasyFit analysis and simulation software, designed by Mathware Technologies.

The program is designed based on an algorithm for estimating the parameters entered in the calculation, by analysing the probability data and selecting automatically or manually the distribution that best fits the data entered [79]. The operating times between faults were the input parameters based on which the calculations of the reliability functions were performed. Data on the number of events, the causes of failure, the values of insulation resistances and conduction currents, as well as the periods of good operation between faults, were collected on the basis of test reports issued after detecting and repairing defects, existing in the register during maintenance work on medium and low voltage power lines [16].

At the same time, for continuous functions, the cumulative distribution function F (x) can be calculated and vice versa on the characteristic probability interval x(P) ϵ [0,1].

The **''Inverse CDF''** funciton performs inverse probability estimates by calculating the random variable x for a given probability value P.

More than 55 continuous and discrete distributions are used, based on which the probabilities of failure were calculated for each of the four cases, obtaining concrete results.

The first analysed case study is uderground power line (*UPL) 20 kV Lugoj*, Timiș county, positioned between *PT 5094–PT 5095*, with an approximate length of 450 m.

In the first stage, the periods of good operation were calculated:

1. The 20.07.2015 - 07.10.2015 interval = 79 days
2. The 07.10.2015 - 19.06.2016 interval = 256 days
3. The 19.06.2016 - 22.06.2016 interval = 3 days
4. The 22.06.2016 - 09.08.2016 interval = 48 days
5. The 09.08.2016 - 20.08.2016 interval = 11 days
6. The 20.08.2016 - 23.02.2017 interval = 187 days

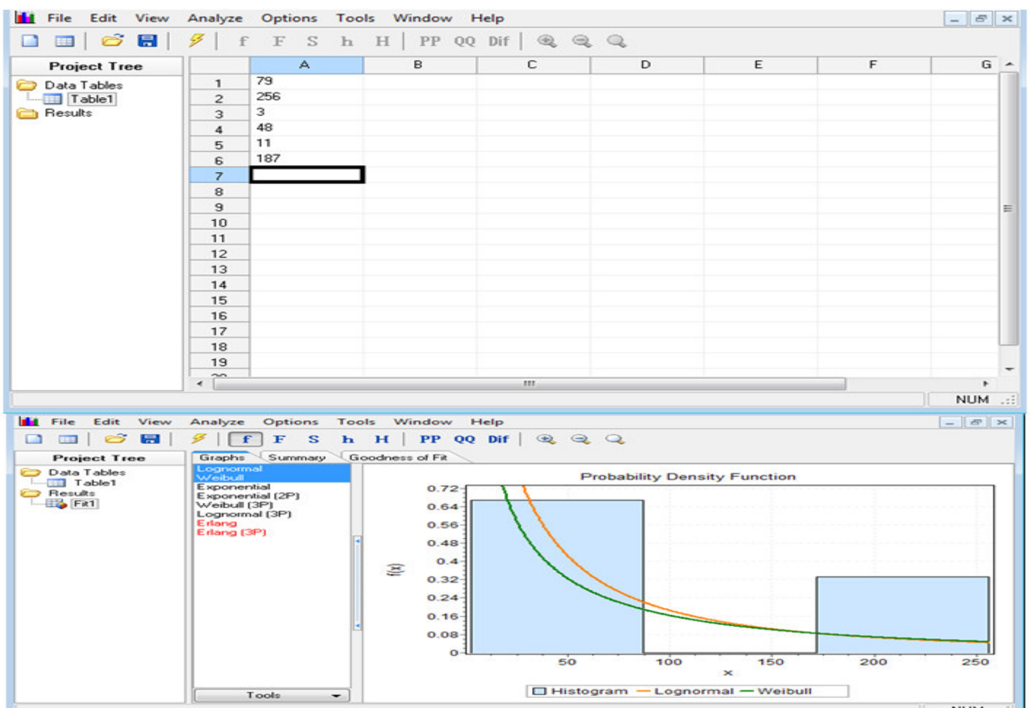


Fig.10. Data entry and manual selection of the best distribution

For a more suggestive interpretation, the values obtained were considered by rounding.

The values of the probability functions for operating times of 100, 200, 300 days were calculated. For operating days of 100 days, the probability of failure is 70%, a relatively high value given the short time interval.

Also, over longer time intervals, the probability of failure increases substantially to 0.88 (88%), for a service life of 300 days, while the probability of good operation S (x) is of 0.11 (11%).

For a reverse estimate of 95%, the maximum service life between two faults is 543 days.

The percentage values calculated automatically are presented in Fig.11.

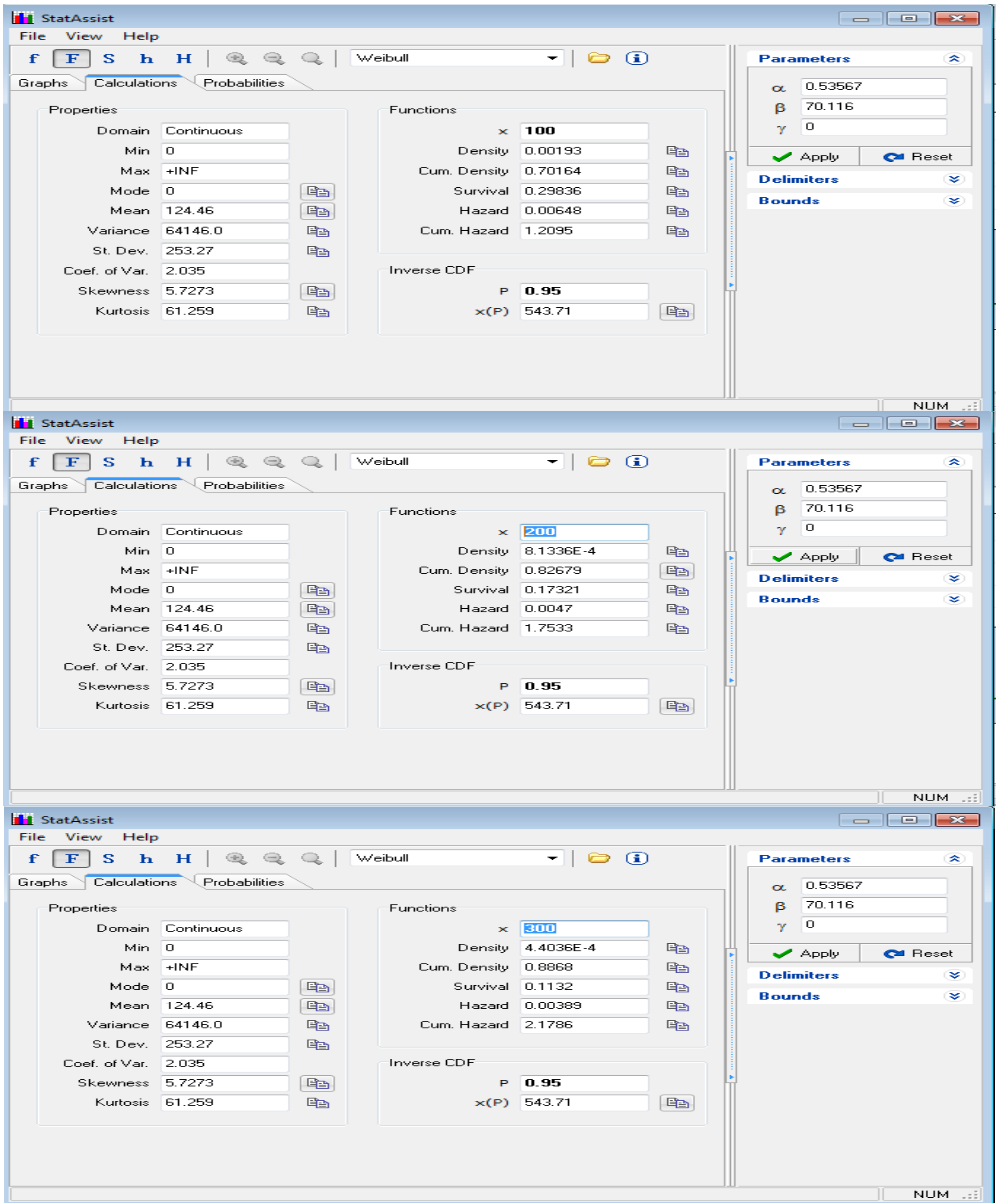


Fig.11. Percentage values calculated for intervals of 100, 200, 300 days

The second case analysed is 20 kV overhead power line(OPL) belonging to Ponor OHL, Oravița area, Caraș-Severin county. The twisted MT cable is laid aerially over approximately 5950 m, between the posts with separators 81-166.

Fig.12 shows the values of the probability function variable, calculated for operating intervals of 200, 400 and 800 days.

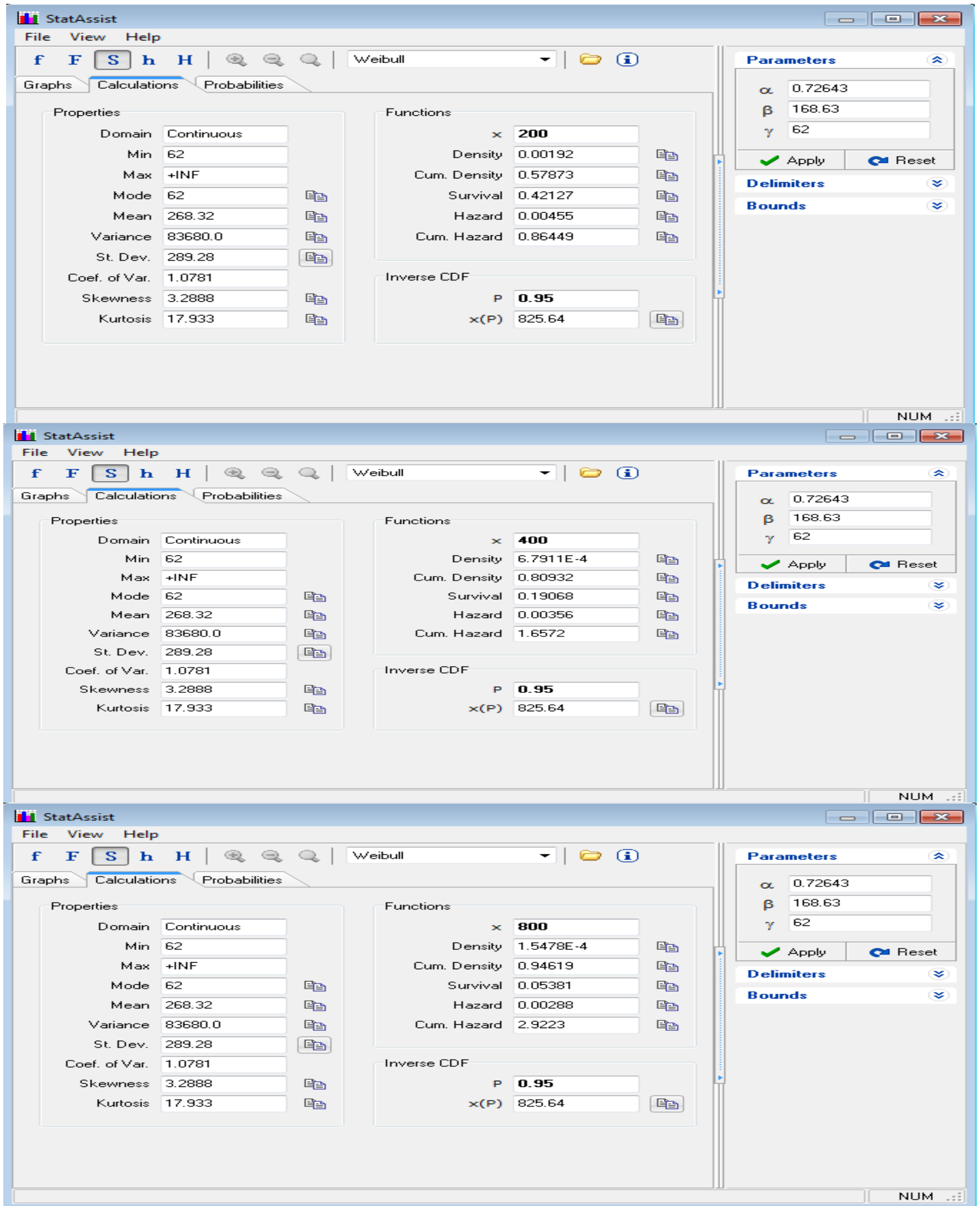


Fig.12. Calculated values of the probability functions for 200, 400, 800-day operating intervals and the inverse CDF function

Thus, over a period of operation of 200 days, the probability of failure of the power cable is 0.579 (57.9%) and the probability of survival (operation without failure) is 0.421 (42.1%), a relatively good probability given the complexity of the factors influencing the normal operation of the cables in operation.

During the operating periods of 400 and 800 days, respectively, the probability of failure increases continuously reaching the value of 0.947 (94.7%) and the reliability function decreases to the value of 0.053 (5.3%).

Calculating the inverse of the function F (x) for a probability estimate of 95%, we conclude that the maximum duration of good operation between defects is 825 days.

Next, one analysed the circuits belonging to *UPL 6 kV Bârzava Reşiţa*, Caraş-Severin county *(Station 110 /20/6 kV Bârzava(Reşiţa) - PT 4029)* and *UEL 20kV(PT 5005-PT 5095),* belonging to the Lugoj distribution network, Timiş county, obtaining the following results:

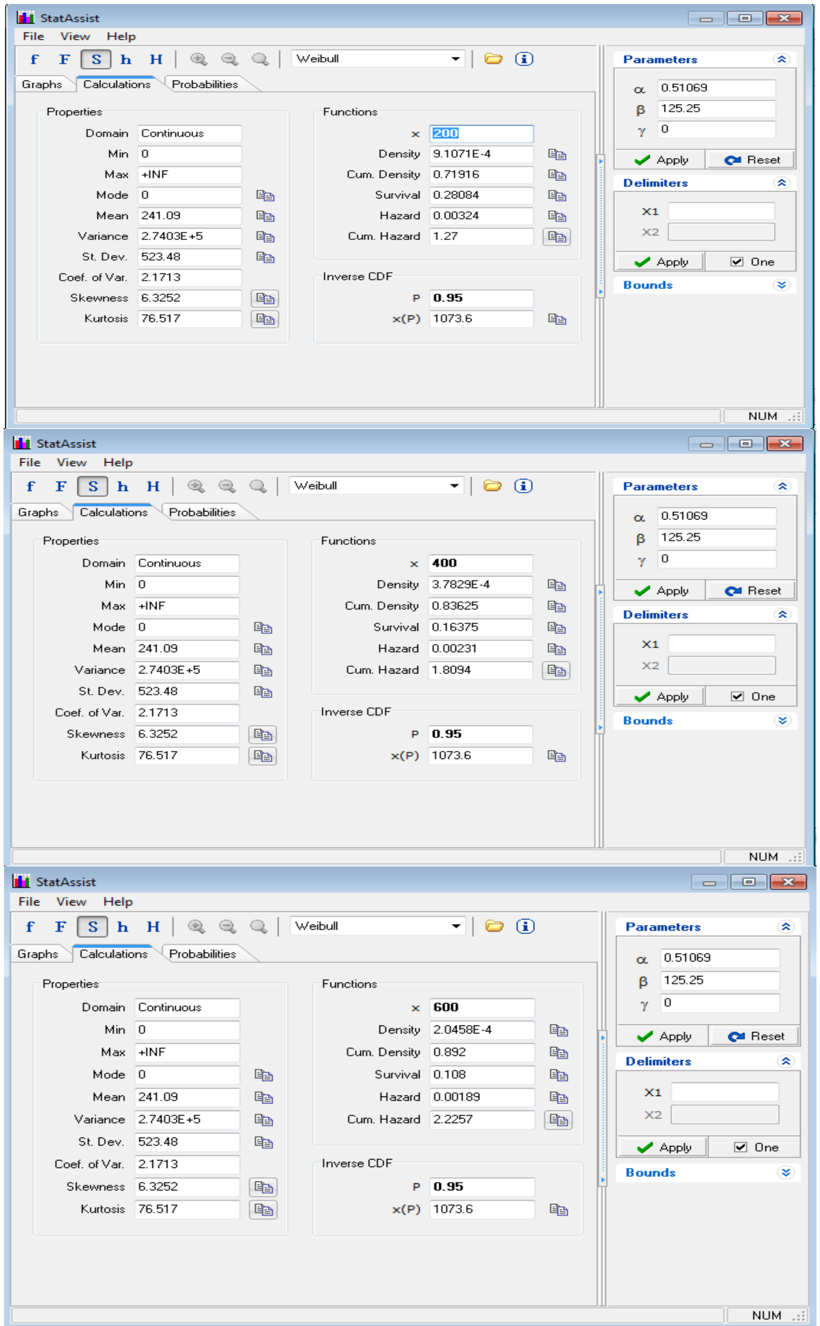


Fig.13. *UPL 6 kV Bârzava* - Percentage values for durations of 200,400,600 days

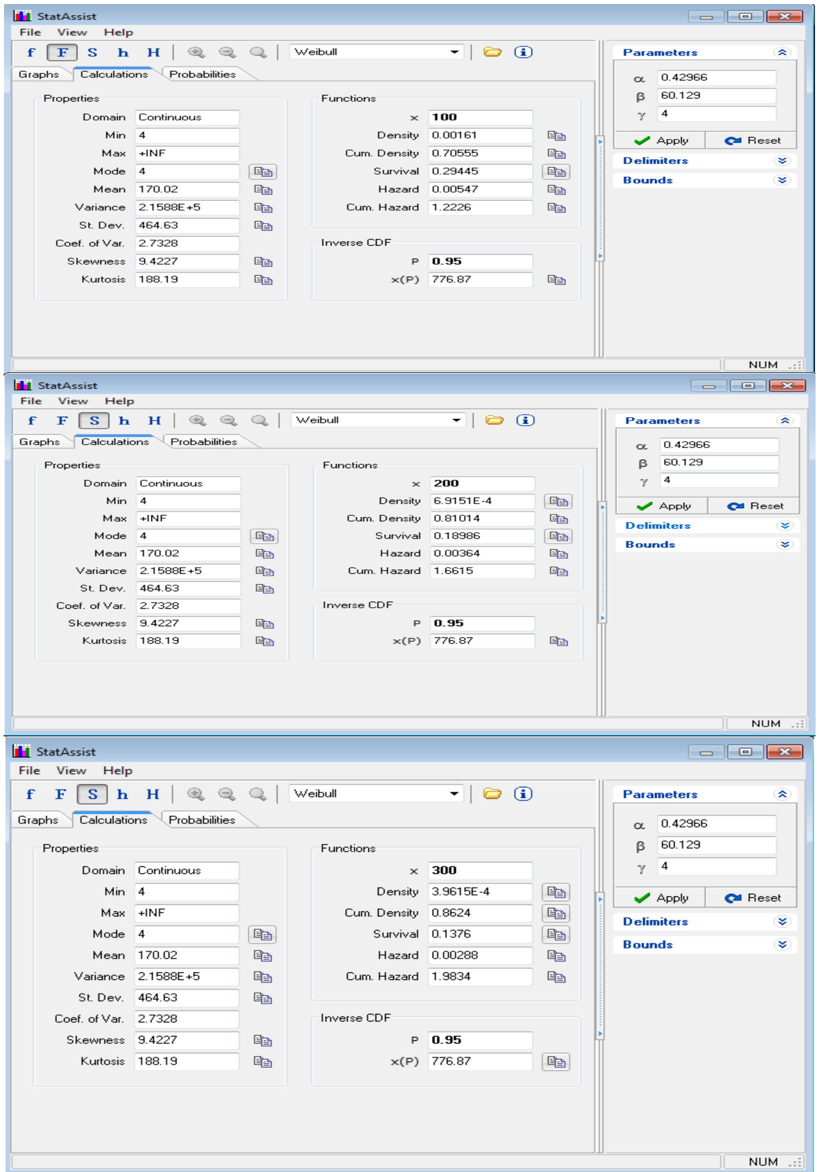


Fig.14. *UPL 20kV(PT 5005-PT 5095)*. Percentage values of probability functions and the value " Inverse CDF"

It should be noted that the same calculation method was performed for all four cases, this time using, as input parameters, the values of the conduction currents flowing through the insulation.

For an objective evaluation of the results obtained from the use of the software for prediction and simulation of defects, the situation of the incidents following the prediction was evaluated [16], concluding the following:

1. For *UPL 12/20kV(PT 5094-PT 5095)Lugoj*, a probability of 70-88% failure was calculated for 100, 200, 300 days, a high percentage compared to the short time intervals for which the prediction was made. In contrast, the predictive value of the conduction current did not exceed the usual values for cables in operation.

The cable operated without interruption between 23.02.2017-09.09.2017 (198 days), failing for 200 days, for which the forecast probability of failure was 83%.

2. For *OPL 12/20kV Ponor-Marila*, the probability of failure for a period of 400 and 800 days was 80 - 94.7%. The inverse of the function F (x) indicated a maximum service life of 825 days, and the probability that the values of the conduction currents will exceed the normal threshold, 3%.

The cable operated without incident during 24.03.2015-24.06.2017 (824 days), according to the test bulletins issued during the last two resumption interventions. The measured values of the insulation resistances after the last repair, recorded an average percentage decrease of 83% in relation to the values measured at the beginning of the interval, indicating a continuous process of degradation.

3. For *UPL 6kV(PT 4029-ST.Bîrzava) Reșița*, the calculated probability of failure
for 200, 400 days was in the range of 72-84%. The operation duration between the last two failures was 314 days, no other incidents were reported between 11.11.2016-20.09.2017.

The predictive value of the conduction current (1400 μA) exceeds the usual values, indicating low reliability, high failure rate.

4. For *UPL 12/20kV(PT 5005-PT5095)Lugoj*, the cable worked normally between 16.09.2016-14.09.2017 (364 days). And in this case, the predictive value of the conduction current (> 1500μA) indicates a high failure rate, being calculated a probability of failure of 86%, for a service life> 300 days.

We conclude that the incidents that took place after the analysis and prediction process for the 4 analysed cases, occurred over time with probability of failure.
> 80%, with the lowest prediction error.

The most frequent cases of failure were those due to the errors of execution of the sleeves and the terminal ends, but also because of some operations by joining by sleeve two circuits of cables of different types and sections.

At the same time, in the *OPL Ponor* case, the defects occurred due to the spare loops near the support poles, which were not properly anchored to avoid their collision with the poles, under the action of the wind. It was recommended to use the clamps on the stainless steel carrier wire to secure the cable in place, and if the sleeve is made in the OHL shaft (between the posts), the loop resulting from the joint must be as small as possible and the sleeve more many conductors (when applicable) in the same place must be made in steps.

So as to conclude, estimating the maximum service life between two faults using an analysis and simulation software program is an effective method of monitoring electrical parameters that define the state of insulation during the operation of the electrical cable, and indicates when to perform corrective maintenance in order to reduce the number. incidents and increase the service life of the cable in operation.

Chapter 4 **–** details the operation of the equipment that is part of the classic auto laboratory of defectoscopy and describes how to use and how to select the equipment, depending on the particularities of each type of defect. The operation of the defectoscopy system is shown, such as the control and control block with connection and protection role of the modules and the IT equipment consisting of the control unit, the lifting transformer, the rectifier diode and the coupling capacitor, positioned in the compartment behind the autolab. .

The identification methods used and presented are the following: the relative pulse method, the absolute induction method, and the acoustic method (mobile digiphone use).

At the same time, the operation of the digital reflectometer made on the principle of the pulse reflected in the cable is presented, a pulse that will be reflected from the fault place with a certain speed, of known value. Based on the time difference between the sent pulse and the reflected pulse, the reflectometer automatically calculates the distance to the fault location.

The measurement results are displayed on an illuminated screen, where the reflectograms of the two pulses can be viewed, and the point of separation between them determines the place of the defect (Fig.15).

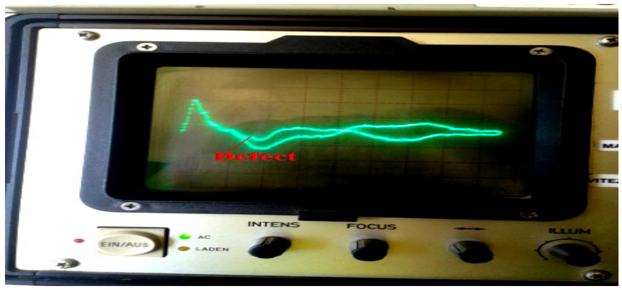


Fig.15 . Example of a fault reflectogram

To accurately identify the faults, the operation of the audio frequency generator is described, which consists in generating a known frequency current and receiving the signal created by the electromagnetic field around the conductor by means of a portable audio frequency receiver, tuned to that frequency.

Currently, the most widely used method of fault identification is the reflected arc method (ARM), in which the reflectometer is used in combination with a shock wave generator, whose high voltage pulse sent to the cable generates a resistance electric arc. low at the fault location, which makes it possible to determine the distance by the reflectometer.

It is a relative method that does not directly lead to the detection of the defect, but which significantly restricts its search area, greatly reducing the time allocated to the defectoscopy process.

The operations of pre-localization and location of defects in the power cables that are the subject of the case studies presented, were performed using two different models of three-phase modular self-laboratories, one Seba Dynatronic and the other Hagenuk, both equipped by SebaKMT .

The chapter analyses five case presentations based on which several logical schemes have been established to identify defects developed for more delicate situations, as well as an algorithm for using the equipment specific to the autoscope of electrical cables, following as much as possible the use of methods for detecting non-destructive defects, which do not cause a premature weakening of the electrical insulation or which cause additional defects in the cable.

The first case presented is that of locating the fault in a low voltage electrical cable, of the *ACYY 3x70+35* mm^2 type, with a length of approximately 320 meters, which supplies electricity to one of the buildings of the zoo in Reșița, Caras-Severin County.

The cable is laid underground in a PVC tube. This positioning method is a special problem in the defectoscopy process because the noise generated by the electric arc at the fault site propagates through the tube on both sides of the fault over long distances, being very difficult to locate the fault location.

It was noticed in this case that the sound produced by the discharge is intercepted with the same intensity on a length of about 20 m on either side of the fault pre-location, and the electromagnetic signal is almost non-existent along the entire length of the cable due to the existence of water. inside the tube, which has the property of absorbing electromagnetic waves.

For the exact location of the defect, a drilling was made in the pre-location area to be able to visually observe the way the cable was laid underground. After the excavation, it was found that there were several sections of parallel cables, two of them being laid in a rigid PVC tube. As the noise produced by the discharge came from the area of the rigid tubes, to identify the defective section, the two PVC tubes were drilled one by one and the digiPhone microphone was placed on the hole, in order to intercept the acoustic signal with the highest intensity (Fig.16).

a b c

Fig.16. a) Visualization of the laying of the cables after the excavation; b), c) Identification of the defect after removing the portion of PVC pipe from the defect area

After the gradual elimination of water through the crack, the search was resumed only in the direction with the most intense acoustic signal, the locator now intercepting the corresponding electromagnetic signal. The search operation continued until the fault was located.

In conclusion, it was found that in the case of cables laid in protective tubes or pipes, the probability of damage is higher than in the case of those laid directly in the ground due to infiltrations that penetrate inside and keep the cable long-term in high humidity conditions. , the defect in this case is almost impossible to detect by usual methods, due to the propagation of the acoustic signal over long distances on either side of the fault site, but also the property of the water of absorption of electromagnetic waves.

The defect identification algorithm, proposed for cables laid in protective tubes or pipes, is presented in Fig.17.

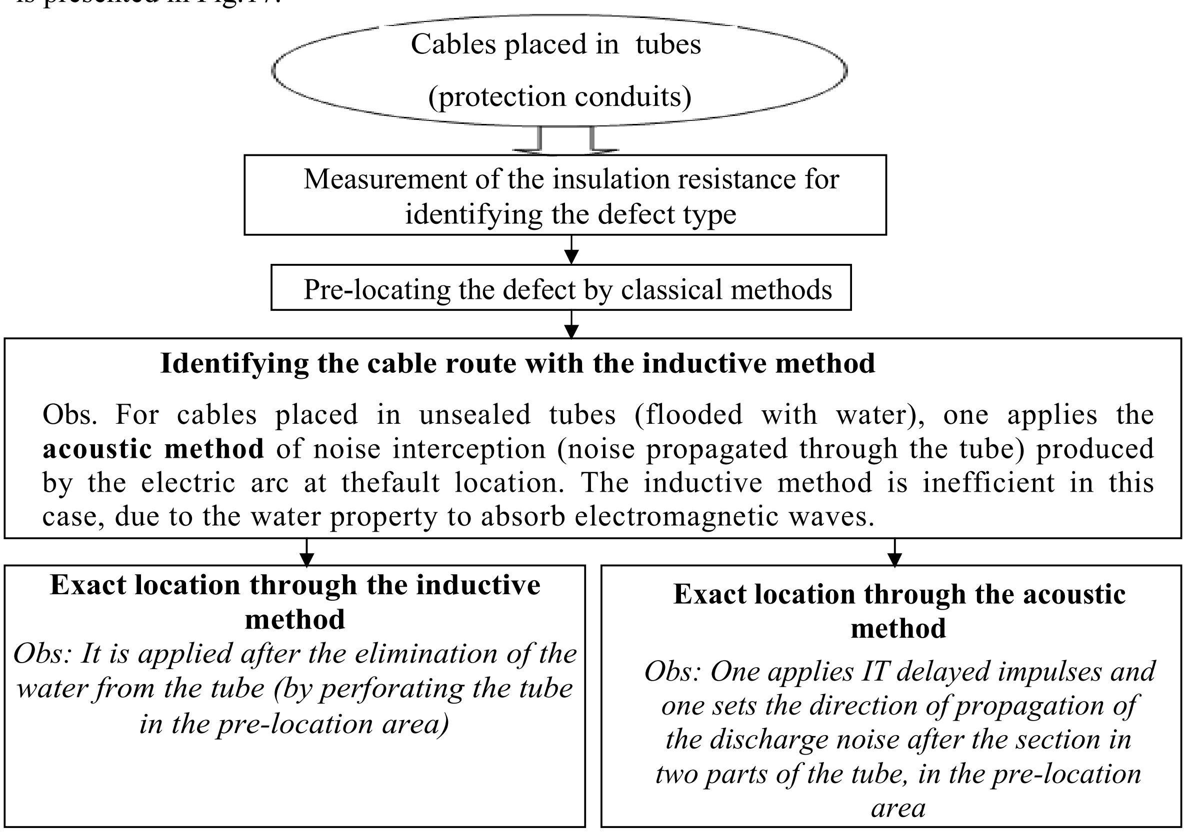


Fig.17. Logical schema of faults identification in cables placed in protection tubes

Detecting defects in low voltage cables is difficult not only due to the current way of laying in flexible or rigid PVC pipes, but also due to incorrect sleeves.

In most cases, for low voltage cables, most of the time the executors do not consider it important to restore the continuity of the steel reinforcement or the screens on the sleeve portion, thus generating an interruption but also an insulation from the ground. Considering the connection mode of the fault location installation which refers to the zero potential of the earth, we can deduce that in case of a phase-screen short-circuit fault (metal armature) isolated, the generation of electric arc at the fault location is impossible.

This problem was encountered when locating the fault at 0.4 kV SLE, with an approximate length of 50 meters, type *CYABY 3x150+70* supplying from *PTZ 6023* a block of flats in Caransebeş, Caraş-Severin County.

After checking the continuity of the steel reinforcement using a multimeter (buzzer mode), it was noticed that there is no continuity from one end of the cable to the other, and the insulation resistance measured between the earth potential and the reinforcement indicated a high insulation value. the two points.

Following this finding, it was concluded that it is necessary to restore the continuity of the metal reinforcement, at least on the cable section to the defect, in order to generate the electric arc between the defective conductor and the metal reinforcement, grounded.

It was decided to identify the sleeves on the cable path, based on the probability that the armature interruptions will be in front of them.

The identification was performed using the generator and the audio frequency receiver, by injecting an audio frequency signal between two of the cable conductors, shorted between them at the other end of the cable. The electromagnetic field remained homogeneous until it changed in the sleeve due to the different position and the greater distance that the conductors have between them inside the sleeve, determining a maximum signal above it.

The excavation was performed next to the only sleeve identified on the cable section (Fig.18) and the outer sheath was sectioned to restore the continuity of the metal reinforcement, by mounting a tinned braid.

Fig.18. Installation of tinned braid with fixing rings for reinforcement transfer; Installation of the heat-shrinkable zipper sleeve

After finishing the work, the connected shock wave generator started to generate discharges, and the intense noise produced by the discharge was intercepted directly on the surface, without using the digiPhone device.

From this case we concluded how important is the continuity of the metal reinforcement or the screen in the process of identifying defects, for certain situations.

However, there are also cases in which the detection of the defect in the low voltage cable is complicated precisely due to the metal reinforcement or the screen, which in certain conditions makes difficult the operations of detecting the defect, generating delays and material losses.

An eloquent example is the detection of the defect in *UPL 0,4 kV*, posed at about 120 meters between the transformer station *PTZ 4038* and a block of flats, in Reșița locality, Caraș-Severin county. The cable is of the type *ACYABY 3x150+70 mm*^{2}.

After identifying the route and generating the IT discharges on the defective R phase, the pre-located area was moved, intercepting in the headphones a medium-intensity acoustic signal propagating over long distances, from one end of the cable to the other, as if the defect existed on the entire length of the cable.

The inductive method was also used but without result because the intensity of the electromagnetic field was kept constant throughout the cable route, the changes being imperceptible.

The solution for noise attenuation was to disconnect the metal armature of the cable from the ground potential at both ends of the cable, and generate the electric arc at the fault location between the positive potential of the defective main conductor and the negative potential of the ground, without the active involvement of the metal armature. .

The shock wave generator was restarted and it was observed that the noise produced by the metal armature due to the vibrations caused by the electric arc at the fault site, and which was heard along the cable path, attenuated to a negligible value, which allowed to distinguish the area with the intensity of the most intense acoustic signal, respectively the place of defect.

After the excavation, the outer sheath of the cable was sectioned to visualize the defect and it was concluded that the noise of the sheath was produced by the vibration of the metal reinforcement, under the action of the electric arc created between the defective conductor (potential high) and the reinforcement (potential zero). which also produced a cavity in the steel strip of the reinforcement (Fig.19).

Fig.19. The point of insulation breakdown between the conductor and the metal reinforcement; The portion of the steel strip in which the electric arc generated the vibration phenomenon of the metal reinforcement.

In conclusion, the detachment of the metal reinforcement from the earthing belt determined the attenuation of the mantle noise by changing the resistance of the defect, this time the electric arc being established between the defective conductor and the ground, the metal reinforcement being insulated from the ground.

The detection of defects in medium and high voltage cables has several distinct features. Although the stages of the defectoscopy process are the same as in the case of low voltage cables, problems of locating the defects often occur due to the long laying distances, sometimes kilometers. At the same time, if in the case of low voltage cables, their connection to the mains voltage is made by a direct connection or by means of "cable slippers", the connection of MT and IT cables in substations and substations is made through the terminal ends.

An interesting case is the one encountered at *UPL 20 kV Câlnic-Mociur*, in Reșița, with an approximate length of 360 meters, which ensures the connection between two overhead power lines by means of line dividers, mounted on poles (no. 48-50).

After disconnecting the terminal ends from the terminals of the line separators, the insulation resistances of the cables to the grounded copper screens were measured. Measurements were made from the pole with number 48 and indicated a short circuit defect (155 kΩ) with respect to earth (phase T), the R and S phases having normal values (14/22 GΩ). Using the ARM pre-localization method, two measurements were performed, the first by comparing the defective T-phase reflectogram with itself, and the second by comparing the T-phase reflectogram with the stored reflectrogram of one of the other R, S phases. The obtained results are presented in Fig.20.

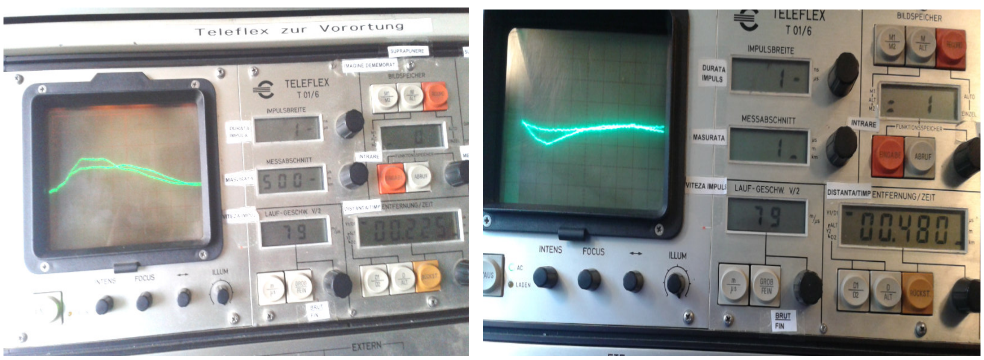


Fig.20. Comparison of the reflectogram: a) T phase with itself; b) T phase with R phase reflectogram

The two different results determined the extension of the search portion, starting from the first pre-location area and moving to the opposite end of the cable, following the two signals, electromagnetic and acoustic of the mobile receiver. The defect was identified at approximately 276 m from the measuring end of the cable.

Fig.21. Visualization of the sleeve defect after the excavation

The cable was sectioned in the sleeve area for sleeve and the insulation resistances of the two resulting sections were measured, finding that on the starting section to the opposite end, respectively to the pole number 50, there is another defect.

The measurement of the pre-location distance after the execution of the sleeve, indicated the defect at the opposite end, at the terminal end of the cable.

The movement was performed to investigate the condition of the end heads at the pole with the opposite separator, but visually no defect could be found. Following the generation of pulses with the shock wave generator, a weak sound was intercepted in the terminal head, a so-called "rattle", based on which the presence of the defect could not be confirmed.

To continue the defect detection process, we looked for a way to change the resistance of the defect, initially measured (<1 kΩ), to a value that would allow the formation of the electric arc. It was decided to disconnect the screen at both ends of the cable from the ground potential and measure the insulation resistance to the ground potential.

The megohmmeter indicated the value of 2.5 kΩ. For this value, the IT pulses managed to generate an electric arc, the defect being identified inside the terminal head (Fig.22).

Fig.22.a) Detaching the copper shields from the earthing belt of the OHL pole and identifying the terminal head defect; b) Removing the outer shell and overviewing the defect.

In conclusion, in order to change the resistance of the defect, in practice a series of fireworks can be made to create the conditions for the application of the usual methods of defect detection, avoiding, as much as possible, the accidental breakdown of the insulation by destructive methods.

Therefore, a verified method of transforming the resistance of the defect, consists in the intervention on the screen or the metallic reinforcement of the cable, to put or insulate from the ground. Due to the position of the screen (between the core and the ground), in most cases of failure, the value of the fault resistance is directly influenced by the value of the resistance of the screen (metal reinforcement) to the potential of the earth. Restoring the continuity of the screen and grounding it determines, in case of a short circuit fault, the transformation of the fault resistance into values that allow the location of the fault. The methods used during the defect identification operations are presented in Fig.23.

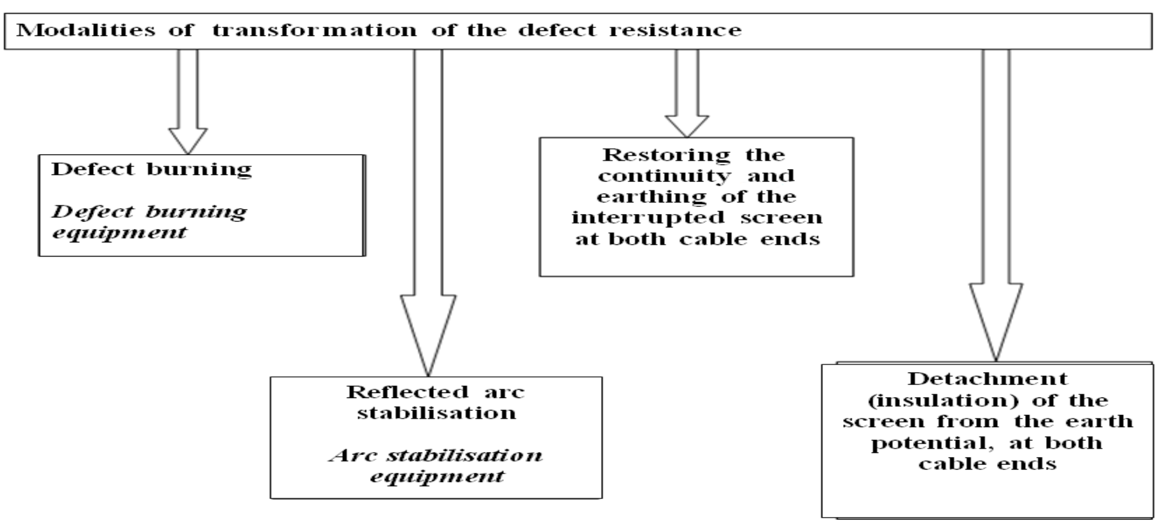


Fig.23. Ways to transform the value of the fault resistance

In operation, sections of cables with a duration of decades in operation are often encountered, whose physical wear and tear has determined the degradation of the insulation and implicitly the modification of the mechano-electrical parameters. It is also increasingly common to replace only sections of the used cable section with a new cable or to perform sleeve work between sections of cables with different insulation and / or different sections, for example, cables with PE / XLPE insulation with those with HIU oil insulation, having different electrical parameters.

It will be presented how to detect the defect in the 20 kV UPL, which ensures the connection of the MT cell from *PTZ 5072 at LEA 20 kV no.1 IURT* from Lugoj locality, Timiș county, with an approximate length of 620 meters. The cable consists of two sections with different insulation, respectively cable type A2XS (F) 2Y 3x1x150 combined with ACHPB 3x150 (oil insulated cable), the latter having an age of about 30 years in operation.

After performing the insulation resistance measurements, it was concluded that there was a short-circuit fault with low resistance (<2 kΩ) on the T phase to ground, which could have been identified by using the IT pulse pre-location and location method, using the wave generator. shock SWG. Although this method is most often used, in this case it was not used because the high voltage pulses could have been destructive for the cable portions with a higher degree of insulation aging, and the inductive method was chosen, with signal of audio frequency. The defect reflectogram is shown in Fig. 24.

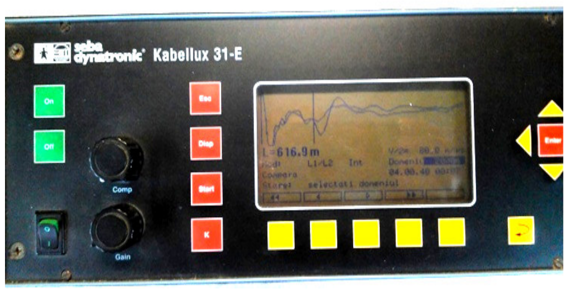


Fig.24. Pre-localization reflectograms

Next, we proceeded to the exact identification of the defect using the audio frequency receiver set to the frequency of 8.44 kHz, making the movement in the pre-located area on the cable route. Due to the different impedances of the sections that complete the cable circuit from one end to the other, electromagnetic fields of variable intensities were intercepted, which alternated with maximum and minimum levels along the entire length of the cable. As it was not possible to establish exactly a restricted portion with a maximum signal level, which would have indicated the location of the defect, the places where the signal suddenly changed from maximum to minimum and vice versa along the entire cable route were marked and the decision was made. inject a signal from the opposite end of the cable as well, by moving the defectoscopy autolab. The same operation was performed to mark the places with sudden increases and decreases of signal, after which the results were compared by their overlap, emphasizing the route close to the pre-location area, given by the reflectogram.

According to the results, a significant maximum-minimum variation of the signal was recorded at about 610 m from the transformation point, at about 10 m from the OHL pole.

The excavation was carried out in the indicated place and a defect of piercing of the sleeve was discovered on a section of cable with oil insulation Fig.25.

a b

Fig.25 . a) Identification of the breakdown point in the cast iron jacket; b) Cable sleeve using two transition sleeves from HIU cable to three cables monopolar cables with XLPE insulation.

We conclude that the process of identifying defects is a complex one and requires experience from authorized personnel in making the best decisions in choosing the methods specific to each case, requiring theoretical and practical knowledge in the fields of electrical engineering and energy.

By correlating the technical data of the diagnostic equipment provided by the manufacturer with the data obtained during the pre-location and fault location operations, a logic diagram was designed (Fig.26) describing the operating algorithm of the defectoscopy installation, for the main types of defects encountered in operation: serial defects and parallel defects.

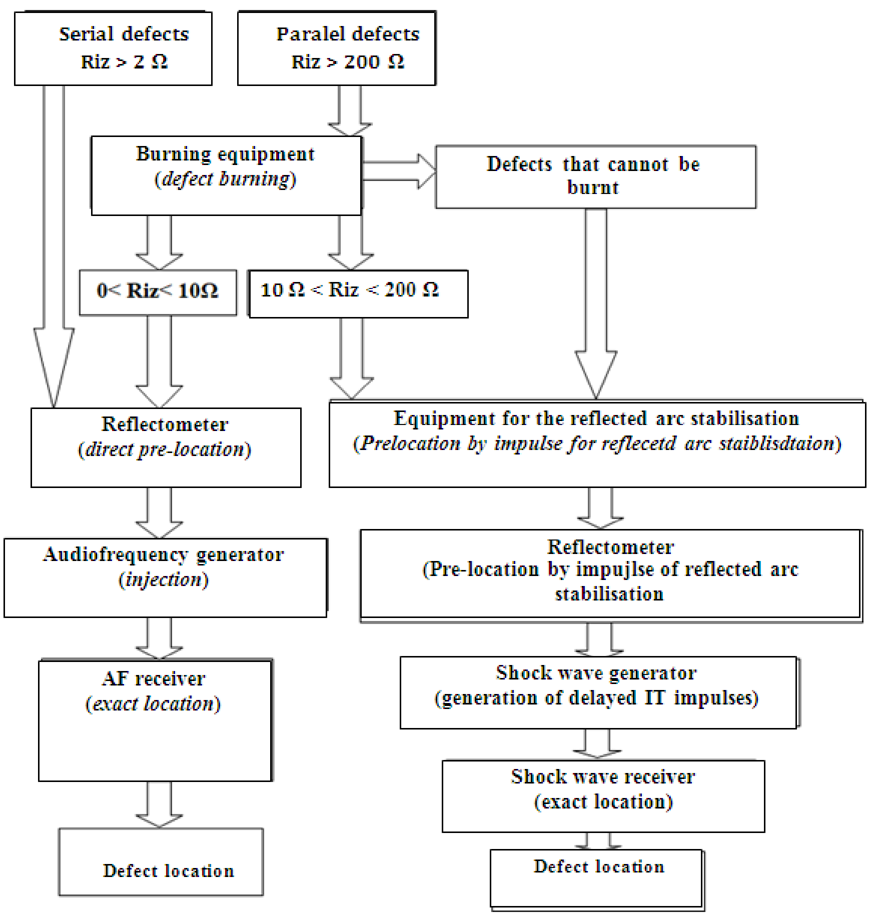


Fig.26. Logical schema of the use of the autoscope installation of the defectoscopy

Monitoring the measured values of insulation resistance to defect during defectoscopy operations, it was concluded that for serial defects with insulation resistance <2Ω, the prelocalization of the defect can be done directly, using the pulse (JT) transmitted by the cable reflectometer, without use of the shock wave generator. The exact location is achieved, in this case, by the inductive method which consists in injecting an AF current into the cable, from an AF generator, and locating the fault by tracking the signal using the mobile AF receiver.

For parallel faults, with insulation resistance> 200 Ω, the combustion equipment of the fault is used, after which, depending on the resulting value of the insulation resistance, either direct pre-localization or pre-localization with IT pulses from the wave generator is used of shock.

We concluded that there are also situations in which burning the defect is impossible or requires a very long waiting time interval. In this case, the electric arc stabilization equipment is used, which in combination with the shock wave generator, can generate electric arc at the fault location, the noise produced by the discharge can be intercepted on the surface by means of the mobile sound interception equipment (digiphone).

Chapter 5 - summarizes the general conclusions and personal contributions obtained from the research carried out on the efficiency of the diagnosis of defects in power cables, capitalizing on the studied literature and experimental results obtained in the activity of pre-location and location of defects in power cables.

Frequent malfunctions of power lines in operation certify that there is currently no perfect insulator that does not allow electricity to pass through it, so there is no emphasis on completely avoiding power leaks, but on reducing them.

In the experimental study, a laboratory installation consisting of a tank (rigid PVC tube arranged horizontally) filled with an electrolytic solution like that of acid rain, and a test equipment with continuous high voltage, HPG type was performed. 70 D.

A cable sample was immersed in the acid solution and positioned so that its ends remained insulated from the tank fixed on ceramic insulators, with the main conductor insulated from the grounded copper shield.

In the chemical composition of the electrolytic substance were used two chemical compounds with strong corrosive effect, commonly found in polluted areas: sulfuric acid (H2SO4) and nitric acid (HNO_3).

The measurements performed during the experimental test showed significant changes in dielectric parameters due to demands from simulated environmental factors (water, chemicals, temperature). They influenced the dielectric strength of the insulation causing energy losses by increasing the value of the conduction current, in relation to the values at the beginning of the test.

In the first stage of the test, it was concluded that the value of the insulation resistance decreases in proportion to the supply voltage gradient of the tested cable sample. For accidental situations that can occur high (overvoltage, overcurrent, overload), the cable heats up and although it gives off some of the heat to the outside environment, the value of the insulation resistance decreases as the temperature of the cable increases.

During the testing of the cable sample in the absence of supply voltage, the results showed that the cable insulation is strongly affected by the acidic environment, caused by the electrolyte in the tank. Under these conditions, the cable can no longer maintain a constant temperature in the absence of conduction current, and becomes more vulnerable to the chemical agent.

After the completion of the experimental study stage and the comparison of results, it was noted that the electrolyte acted most aggressively on the insulation during the time when the cable was de-energized, which caused, when re-energized, the insulation broke.

Correlating the results obtained in the laboratory with the situations encountered in the field, it was recommended to keep the power lines permanently under voltage (hot reserve), even if they are not used continuously in the supply of electricity consumers. In this way, the phenomenon of premature aging of the insulation can be avoided, and implicitly the damage of the cable when it is re-energized.

In operation, it has been observed that for OHLs that use twisted cable, the installation of spare loops on the twisted conductor for joints requires electrical insulation and causes an acceleration of the process of degradation and aging. Because the sleeves are made mainly near the support poles, there have been situations in which the spare loops have not been properly anchored to avoid collision with the poles (under the action of the wind), causing incidents.

During the identification of the defects, errors were made in the execution of the sleeves, which allowed water to penetrate inside the cable. It is extremely important that all accessories are installed correctly, in low humidity conditions and by qualified and authorized personnel.

In order to highlight the state of insulation degradation, reliability calculations were performed based on mathematical models, using a software analysis and simulation program, for different existing cable circuits in operation, having as reference data the durations of good operation between two faults, as well as the values of the conduction currents measured during the incidents. The percentage values of the failure function and of the reliability function over certain time intervals indicated in most cases a high probability of failure, over relatively short time intervals.

From the monitoring of subsequent incidents history, it was concluded that the predicted failures for all four cases analysed occurred after time intervals for which the probability of failure was> 80%.

Research has also been done on how the tailings-contaminated environment acts on the polyethylene insulation of the joint sleeves. The investigation of the cause and the way of producing the defects for these situations, showed that the chemical resistance of polyethylene is much lower compared to that of ethylopropylene rubber or polyvinyl chloride from which the cable insulation is made, as evidenced by the polyethylene coating of its sleeve. effectively dissolved in acidic water, becoming a gelatinous mass, while the insulation of the cable on either side of the joint sleeve did not degrade.

The replacement of the existing sleeves with special sleeves with PTFE insulation solved the problem of defects, the PTFE insulation proving to be the most stable to the action of corrosive agents in areas polluted with tailings.

The measurements performed on the occasion of the re-commissioning of the electric cables after removing the defects, indicate that 80% of the network of cable power lines in the territory of Caraş-Severin county and Lugoj locality (Timiş) have a high degree of wear and are no longer safe. in operation.

To understand the phenomena that cause premature aging and dielectric breakdown, research has been conducted to identify the main factors that act on the insulation of power cables in operation, by applying the method AMDE (Analysis of Failure Modes and Effects). The analysis was possible after collecting data and synthesizing information obtained from maintenance work on low and medium voltage cables in Caraş-Severin and Timiş counties, during 2012-2018.

Regarding the process of pre-location and location of defects, logical schemes have been developed for the use of self-defective laboratory equipment, as well as fault identification algorithms for more special cases, such as for cables laid in protective tubes or sections. of cables of different sections and types, with a high degree of wear in operation.

From the point of view of the transformation of the defect resistance, a new method was proposed, apart from the usual methods, which verified its usefulness, namely, the modification of the defect resistance, so as to have values that allow pre-localization and localization.

The results of the research obtained in the thesis, in order to avoid the occurrence of defects and to increase operational safety, were implemented for cable lines laid overhead

(OPL-UPL) and for those laid underground (UPL) in Caraş-Severin County and the locality of Lugoj (Timiș). They formed the basis of several scientific papers published during the elaboration of the PhD thesis.

Some of the future research directions would be the improvement of diagnose methods, in order to solve the problems related to the impossibility of using them in certain defect conditions, as well as the development of theoretical and practical research to choose the most appropriate identification solution. of the nature of the defect.

Also the elaboration of an expert software system, in the form of a distinct module implemented in the installation of the autoscope of defectoscopy, which to analyse and recommend automatically the algorithm of using the methods of defect detection, for each case, would ensure a substantial improvement. of the diagnosis of faults in the power lines in the cable.

SELECTIVE BIBLIOGRAPHY

[3] *Radu Zlatian*, Electric insulation (in original in Romanian), Aius Publishing House, Craiova, 2013.
[4] *E. Ivan, A. G. Husu,M. I. Olariu*, Materials used in electrical engineering (in original in Romanian), Publishing House Bibliotheca, Târgoviște, 2009.
[7] *P.V. Notingher,L. M. Dumitran*, Electrotechnical materials (in original in Romanian), Matrixrom Publishing House, Bucharest, 2015.
[16]*** *EEI-Electroechipament Industrial Reșița* - Execution of maintenance works at the facilities medium and low voltage disconnected-MT-JT area, Caras-Severin county - Timiș county, 2013-2018 (in original in Romanian).
[20] *Mircea Gușă,* Electrical discharges in the insulation of high voltage installations - Teaching materials (in original in Romanian), Technical University" Gheorghe Asachi" Iași, 2015.
[21] *Laurențiu Marius Dumitran,* Electrical insulation systems (in original in Romanian), Printech Publishing House, Bucharest , 2008.
[28] *** *www.imsaproiect.ro*, The advantages of Raychem heat-shrinkable products (in original in Romanian).
[29] ****Tyco Electronics Raychem GmbH,* Accessories for power cable, 2008/2009 catalogue (in original in Romanian).
[30] *Cristina Sărăcin*, Electrical installations (in original in Romanian), Matrixrom Publishing House, 2009.
[31] *Lucian Ciobanu*, Low voltage electrical installations. Elements of audit and domotics (in original in Romanian), Publishing House Matrixrom 2004.
[32] *G. Basarab, G.Darie, S.Gal, D.Olovinaru,* Power stations and networks (in original in Romanian), Romanian Academy Publishing House, Bucharest 2005.
[33] *Maria Vintan*, Production, transmission, and distribution of electricity (in original in Romanian), Matrixrom Publishing House, Bucharest 2009.
[49] *Maria Lazăr,* "Research on the stability and ecological reconstruction of lands affected by mining" (in original in Romanian), Habilitation Thesis, University of Petroșani, 2016.
[54] *N. Butoi, A. Lucchian, A. Caramitru, S.Mitrea, T. Rus*, " Influence of biological factors on the durability and operational safety of electrical and energy equipment and installations" (in original in Romanian), Electrotehnica, Electronica, Automatica (EEA) Journal, 2017, vol. 65 (1), pp. 72-80.
[59] *Lucian Ciobanu*, Reliability, diagnose and calibration elements (in original in Romanian), Publishing House of the Technical University "Gh. Asachi" Iasi, 2015.
[60] *C.Mihai, S.Abagiu, L.Zoiţanu,* Interconnections between reliability, maintenance and availability" (in original in Romanian), Proceedings of „National Conference and Energetics Exhibition, SIER 2009", pp. 606-613, Sinaia, Romania, 2009.

[66] *A. Savin, I. Barnoaiea, C. Buzdugan*, ”Aspects regarding the physical analysis of the tailings dumps in the Calimani Mountains” (in original in Romanian), Annals of the University” Ştefan Cel Mare” Suceava , 2007.
[72]*** *C.N Transelectrica S.A*, NTE 005/06/00 - Normative regarding the methods and elements for calculating the safety in the operation of energy installations (in original in Romanian).
[73] *Titu I. Băjenescu*, Reliability of technical systems (in original in Romanian), Publishing Matrixrom House , Bucharest , 2006.
[74] *C. Homan, C. Csuzi, I. Lingvay, C. Lingvay*, “Reliability of medium voltage power installations. Studies on the evolution of incidents on the electricity distribution network Cluj-Napoca” (in original in Romanian), in EEA, vol. 57/2009, nr. 1, p. 31.
[79]***https://*www.mathwave.com*, EasyFit Profesional 5.6.- Analysis and simulation software, Mathwave Technologies.