

# Determination of sensitivity for in-process control of cable product insulation

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**Abstract.** This article presents current methods of cable insulation control. The new method which allows to improve reliability of cable insulation control was offered. The cable model with several types of defects was developed by using Comsol Myltiphysics software. Minimal sizes of defects which can be detected by using given in-process control method.

## 1. Introduction

Quality of insulation is one of significant parameters for cable product (continuity, external geometry, isotropy, chemical composition) [1]. This parameter influences operational characteristics and cable quality. The insulation defects lead to cable spoilage because it is cause of noise distorting a useful signal.

Nowadays, cable insulation control is implemented by several ways:

### 1.1. Voltage test

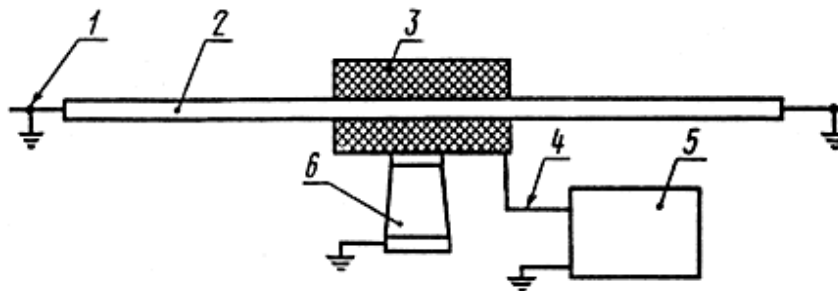
According to the current regulatory documentation [2], there are two categories of high voltage insulation testing: ET-1 and ET-2.

ET-1 category testing is stationary and implemented by immersing hank into a water. Immersed cable is kept under the water during defined time by applying high testing voltage. This method of control makes manufacturing cycle longer and it is also necessary to provide additional technological area in the plant [3]. One more significant disadvantages of water testing is the fact that this cable testing category is carried out in the final stage of technological process. Thus, detected defects are cause of high costs of the company.

The main idea if ET-2 testing is applying of high testing voltage to the surface of cable insulation by the special electrode during technological process while core, armor or shield is grounded. When defect part is in control area breakdown is occurred and it is registrated by automatics of electrospark detector (Figure 1) [1].

In comparison with ET-1 testing ET-2 testing has some advantages. Firstly, electrospark detector for ET-2 testing have significantly smaller size. Then, water medium is not necessary for this kind of testing. Also, ET-2 testing is provided during technological process. It allows to refine technological parameters and prevent mass spoilage [3]. Disadvantage of ET-2 testing is low defect detection sensitivity in comparison with stationary water testing (ET-1).





**Figure 1.** Basic scheme of ET-2 testing: 1 is core; 2 is insulation; 3 is electrode, 4 is high voltage output; 5 is signal processing device; 6 is isolator.

### 1.2. Linear capacitance control

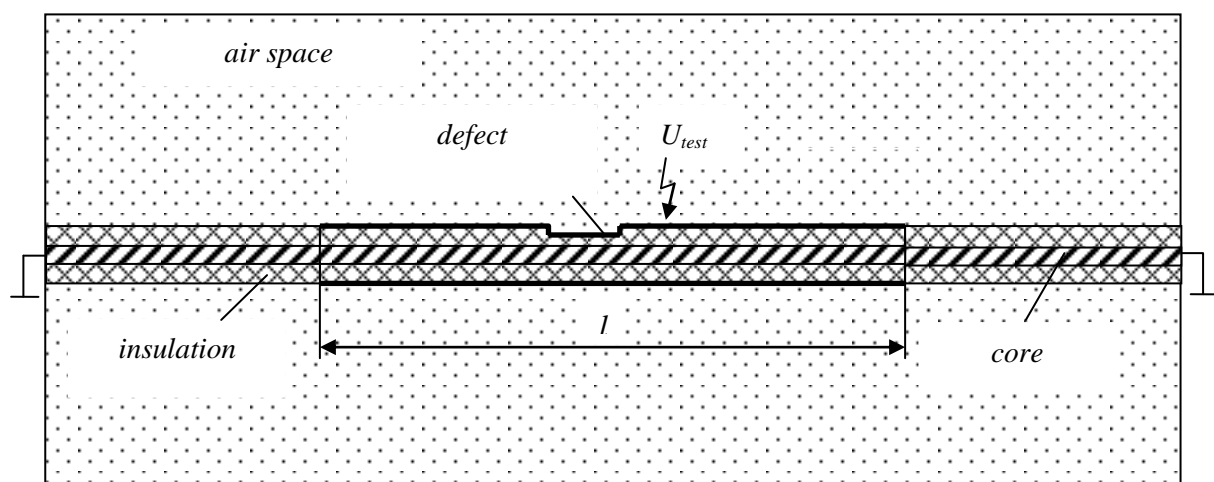
The cylindrical electrode is used to realize this testing method. The cylindrical electrode is immersed under the water of cooling bath for measuring of cable linear capacity. When defect part is in control area linear capacitance of control area is changing in comparison with linear capacitance of defect-free part. Significant advantage of this method is carrying out of in-process control. But there are some disadvantages. Water medium is necessary for this method of control. Additional equipment and maintenance is required for correct work of electrocapacity device.

Take into account disadvantages of present method of control it is offered to explore the electrocapacity method during high voltage technological testing (ET-2) of cable insulation. The aim of this work is determination of minimal defects size which can be detected by this method.

## 2. Mathematical model

To provide this research the mathematical model was developed in Comsol Multiphysics software.

The cable model is presented as two concentric cylinders which have length higher than  $l$  value ( $l$  is the length of cable area with applied high testing voltage). High testing voltage is applied to the cable area surface with  $l$  length. The voltage value ( $U_{test}$ ) was set depending on the insulation thickness [4]. The air space is considered around the cable model (Figure 2).



**Figure 2.** Cable model in COMSOL Multiphysics software

## 3. Defects detection conditions

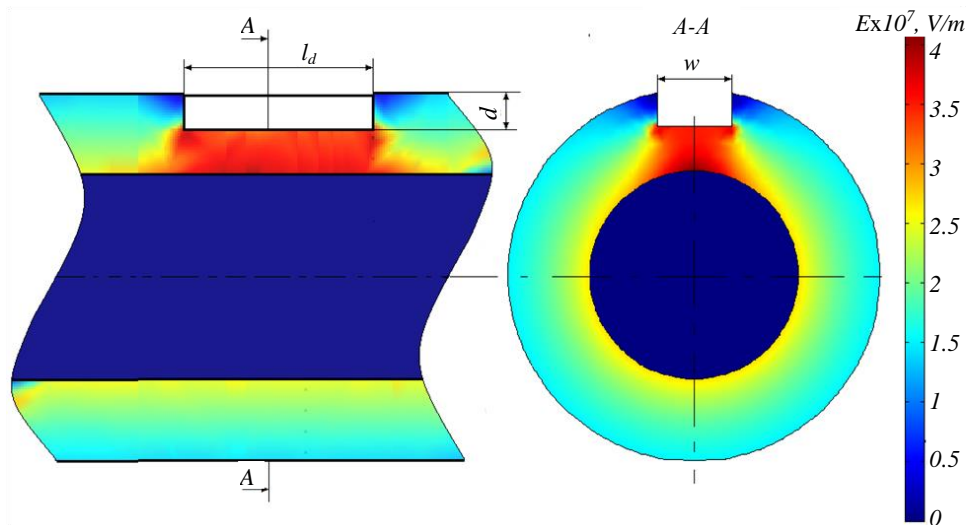
During the capacity changing in-process control measurements it is impossible to detect the defect of any size. Insulation coarseness, horizontal or vertical shifting during moving of the sample through the

measuring device, changing of geometrical parameters, instability of testing voltage lead to deviation of control area cable electrical capacity from defect-free zone value. Consequently, to consider any deviation of electrical capacity as a defect misoperation can take a place. To increase control reliability the deviation is considered as a defect when it is higher than 20% [5, 6].

#### 4. Defects simulation

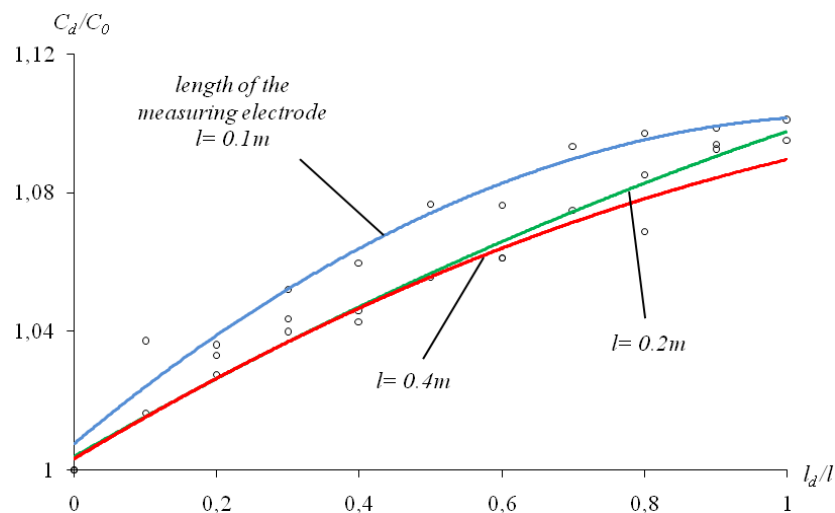
##### 4.1. "Longitudinal cut" type defect

By using given special software "longitudinal cut" type defect was simulated for «NV-3» cable product (Figure 3).



**Figure 3.** "Longitudinal cut" type defect:  $l_d$  is defect length,  $d$  is defect depth,  $w$  is defect width, A-A is cross-section,  $E$  is value of electric field

The dependencies of relative electrical capacity value from relative defect length with several values of  $l$  parameter (length of measuring electrode is 10 cm, 20 cm, 40 cm) are shown below (Figure 4).



**Figure 4.** Dependencies of relative electrical capacity value from relative defect length:  $C_d$  is electrical capacity of control area with defect,  $C_0$  is electrical capacity of defect-free control area,  $l_d$  is defect length,  $l$  is electrode length.

By analyzing obtained dependencies it can be noticed that it has a similar view. As it was written above deviation is considered as a defect when deviation of cable electrical capacity from defect-free zone value is higher than 20%. This defect with constant value of  $d$  and  $w$  parameters lead to deviation less than 20%. Consequently, this kind of defects cannot be registered.

#### 4.2. “Crack” type defect

By using the mathematical calculation minimal size of “crack” type defect which can be detected by in-process control was defined.

For calculation of “crack” type defect electrical capacitance for cable area following formulae was derived:

$$C = 2\pi\epsilon_0\epsilon_r \cdot \left( \frac{l-w}{\ln(R_i/R_c)} + \frac{w}{\ln((2R_i - D_d)/(2 \cdot R_c))} \right),$$

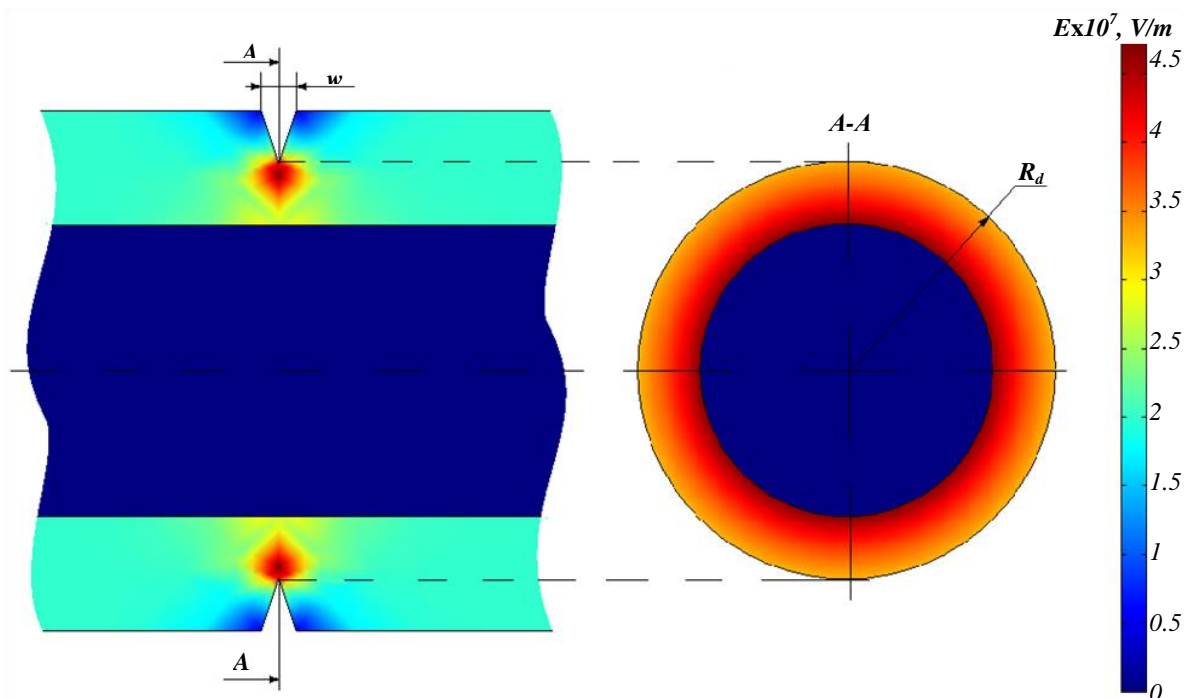
where  $l$  – length of controlled area of the cable (measuring electrode);

$w$  – defect width

$R_i$  – external radius of insulation (defect-free part);

$R_c$  – core radius;

$D_d$  – depth of the defect ( $R_i - R_d$ ) (Figure 5).



**Figure 5.** “Crack”-type defect:  $R_d$  – external insulation radius in defective zone.

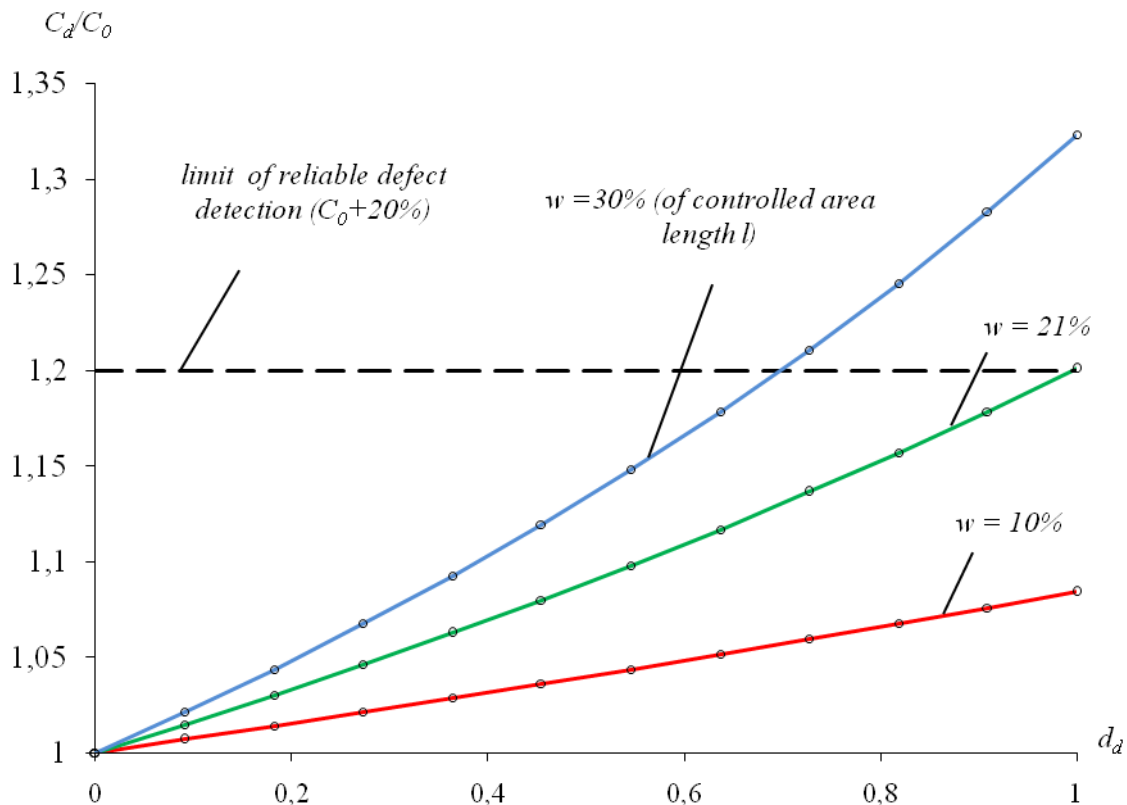
Calculations was provided for NV-3 cable. The characteristics of given cable are:

- core cross-section is  $1.5 \text{ mm}^2$  (diameter of core is 1.4 mm);
- external insulation diameter is 2.5 mm;
- thickness of insulation is 0.55 mm;
- insulation material is PVC.

Length of cable controlled area is 0.1 m.

Dependences of relative electrical capacity of cable area ( $C_d/C_0$ , where  $C_d$  – electrical capacity of defective part,  $C_0$  – electrical capacity of defect-free part) from “crack” type defect dimensions ( $d_d$  is

ration of defect depth to thickness of defect-free insulation) was plotted on the basis of calculations results (Figure 6). It was noticed that in-process control allows to detect cracks which has depth equal to depth of defect-free insulation (relative depth  $d_d=1$ ) with opening width not less than 21% of controlled area length  $l$ . It is also possible to detect defects which have lower depth but higher opening width.



**Figure 6.** Dependence of relative capacity of cable part from size of “crack” type defect.

#### 4.3. Change in external diameter of insulation

By using mathematical calculations minimal deviations of “local changing of external diameter of insulation” type defect (Figure 7) which can be found due to in-process control (with deviations of capacity of controlled area from nominal value higher than 20%) was found.

To find theoretical value of electrical capacity of cable part following formula can be used:

$$C = 2\pi\epsilon_0\epsilon_r \left( \frac{l-l_d}{\ln \frac{R_i}{R_c}} + \frac{l_d}{\ln \frac{R_i + \delta}{R_c}} \right),$$

where

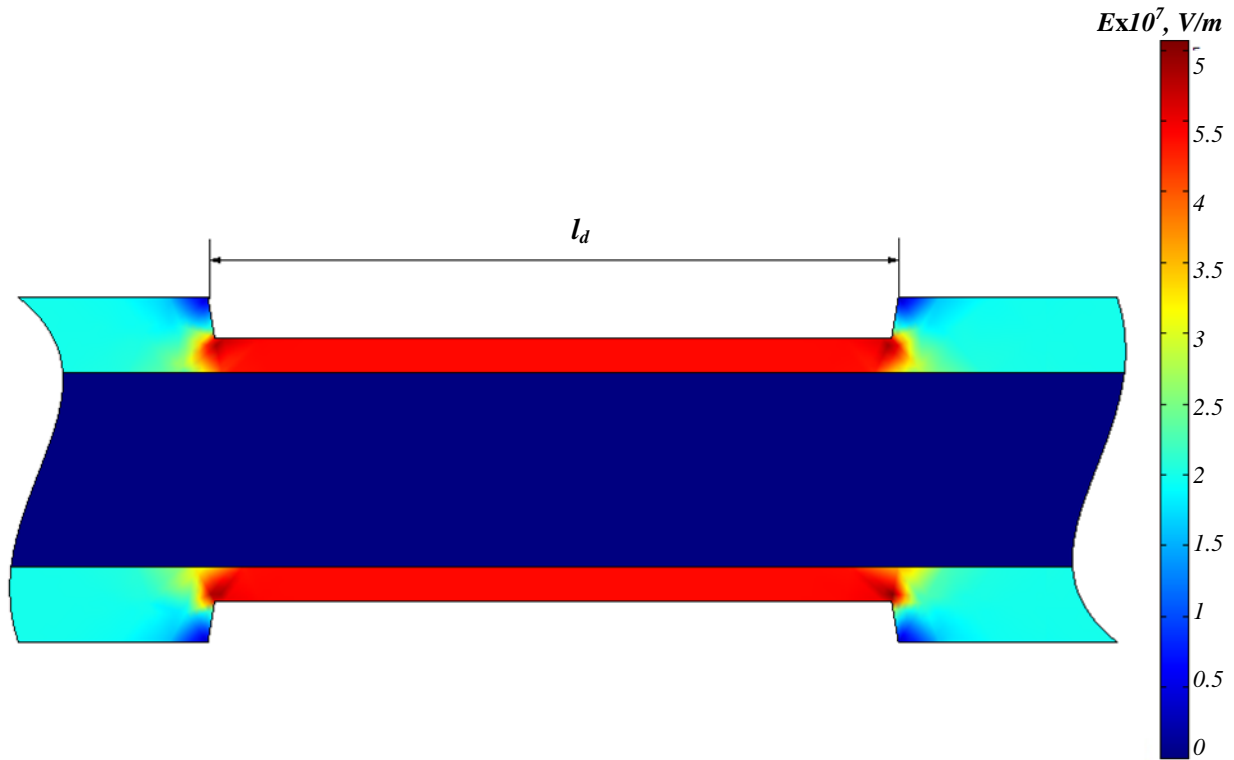
$l$  – length of controlled area of the cable

$l_d$  – length of defective part;

$R_i$  – external radius of insulation (defect-free part);

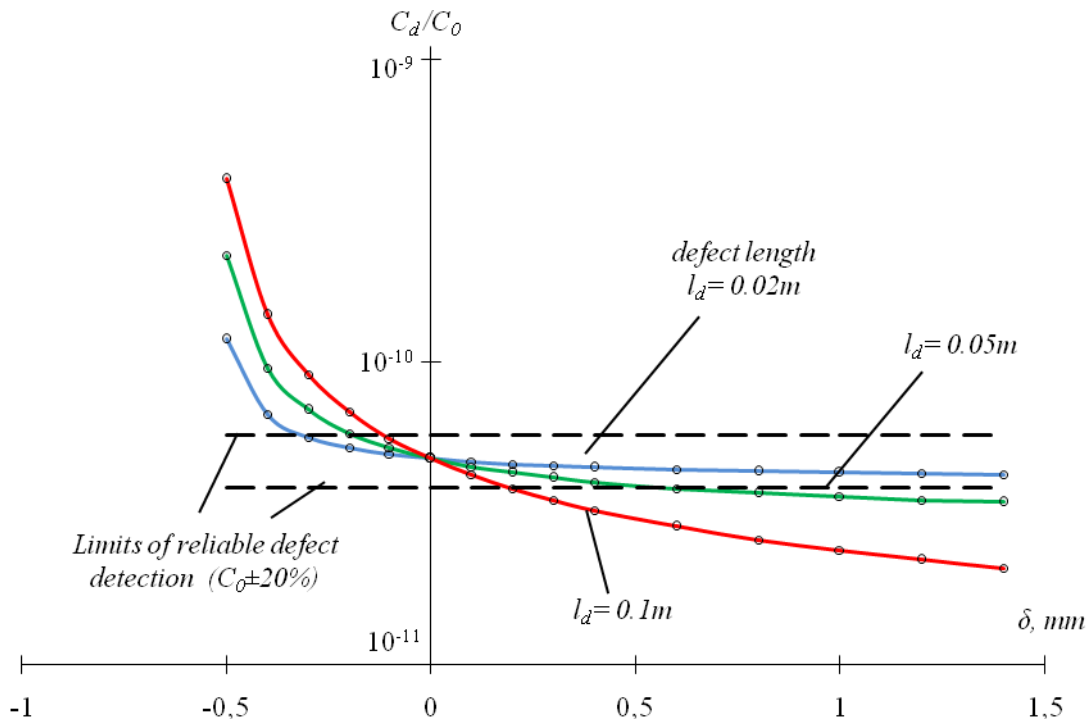
$R_c$  – core radius;

$\delta$  – insulation thickness difference on defective and defect free part.



**Figure 7.** “Local thinning” type defect

Dependences of relative capacity of cable part from deviation of insulation thickness with  $l=10\text{cm}$ ,  $20\text{cm}$ ,  $40\text{cm}$  (Figure 8) were found and plotted. Length of defect was 20%, 50% and 100% for each  $l$



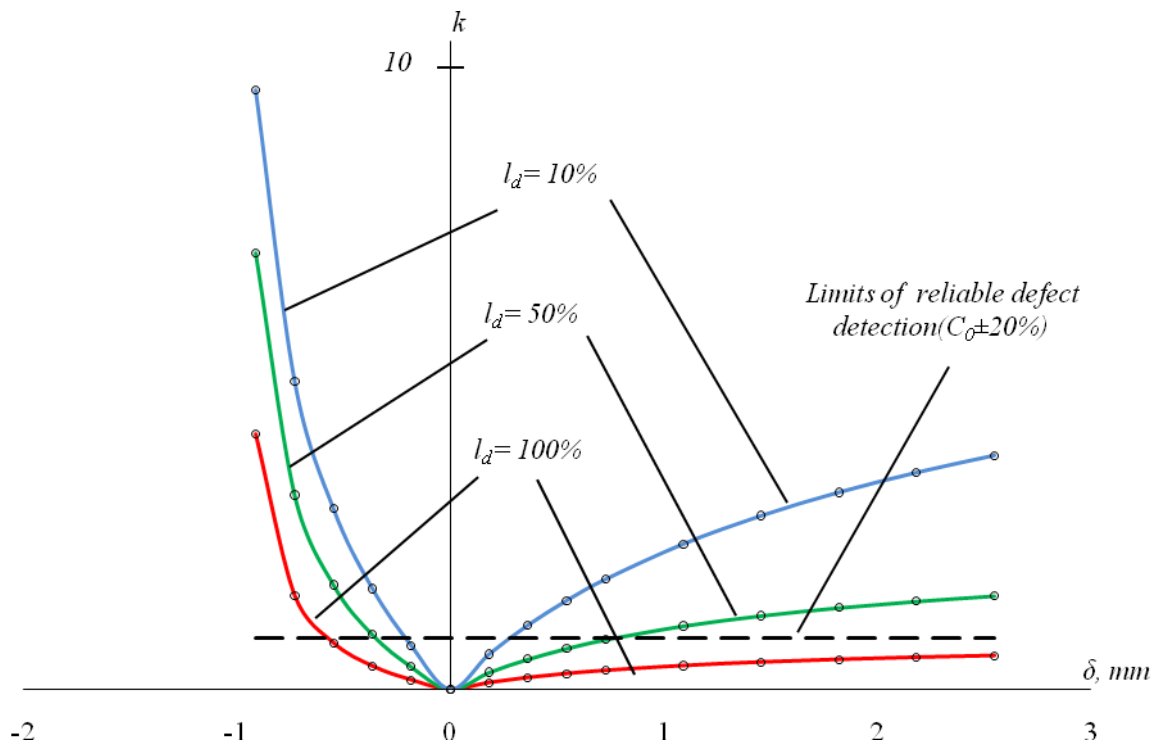
**Figure 8.** Dependences of relative capacity of cable part from deviation of insulation thickness (in the defective part) relatively to defect-free area with  $l=10\text{ cm}$ .

According to plotted figures it was noticed that behavior of dependences for several relative lengths of the defects (10%, 50%, 100%) is similar and sensitivity of the measurements is higher in case of higher relative lengths of the defect. Sensitivity is also improving if insulation thickness is increasing. (Figure 9).

To define capacity variation coefficient in presence of the defect ( $C_d$ ) and without any defect ( $C_0$ ) additional value  $k$  (sensitivity) was added:

$$k = \frac{C_0}{C_d} \text{ for local increasing of external diameter;}$$

$$k = \frac{C_d}{C_0} \text{ for local decreasing of external diameter.}$$



**Figure 9.** Dependences of measurements sensitivity from variation of insulation thickness in the defective area relatively defect free area with  $l_d=10\%$ ,  $50\%$ ,  $100\%$

Thus, it was defined that by changing of cable area electrical capacity it is possible to identify following changes of insulation thickness:

- thickness decrease by 57% and increase by 397% (if defect amounts 20% of controlled area length);
- thickness decrease by 35% and increase by 109 % (if defect amounts 50% of controlled area length);
- thickness decrease by 21% and increase by 36% (if defect amounts 100% of controlled area length).

Based on these results it is possible to conclude that size of defects which can be detected by this method considerably depends from the length of controlled area. Since detection of local variation of external diameter is possible only when defect amounts approximately 100% of controlled area length (reliability of detection is much lower in case of lower defect length) it is possible to change measurements sensitivity by variation of controlled area length.

## 5. Conclusion

In this research special mathematical model was developed. By using this model effect of different defect dimensions on the linear capacity value with different lengths of measuring electrodes was defined as well as ability to detect structural and geometrical defects with offered control method. A simulation of several types of cable insulation defects was provided by using COMSOL Multiphysics software.

By using simulation results it was noted that “longitudinal cut” type defect cannot be detected with given method. In case of “crack” type defect and local variation (increasing or decreasing) of insulation external diameter it is possible to evaluate the defect considering variation of capacity value of controlled area.

## References

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