Creation of a library of images of cable line insulation breakdown for neural network training based on data from the study of wave processes in the digital twin of the cable line

A.A. Yurov¹, A.V. Lukonin¹*, D.E. Srorojenko¹, and D.N. Kuimov¹

¹Don State Technical University, 1, pl. Countries of the Soviets, 344000, Rostov-on-Don, Russia

Abstract. The aim of the work is to create a library of images of cable line insulation breakdown for training a neural network of a functional unit integrated into a high voltage test facility based on data from the study of wave processes in the digital twin of a cable line. The goal is achieved by determining the characteristic properties of the wave process in a cable line when tested with high direct voltage of negative polarity during field experiments and verifying these results on a mathematical model. The calculated data array on the verified model is the main volume of primary information for creating a library of images of insulation breakdown. The most important and significant results are the creation of a library of images of insulation breakdown and the adaptation of the algorithm for approximating input data with images from the neural network library, the integration of artificial intelligence into the process of determining the location of defective insulation at the test stage. The significance of the results is to reduce the methodological and instrumental error in determining the damage zone, since all stages of data collection and analysis are performed by a functional module built into the test unit, in addition, the calculation is performed automatically, which minimizes the role of anthropogenic factors on the result and reduces the requirements for the personnel of the electrical laboratory, the introduction of such equipment will reduce complete the time of elimination of the accident and increase the speed of restoration work on the route of the line.

1 Introduction

Testing of high voltage cable lines allows you to identify defective insulation and determine the distance from the test point to the emergency site [1, 2]. The search for the place of damage is carried out in two stages: the first stage determines the zone of damage with a given error and the second stage determines the place of damage on the cable line route. The integration of artificial intelligence into the process of damage detection will reduce the methodological and instrumental error in determining the damage zone at the first stage and will reduce the total time of accident elimination [3-5].

* Corresponding author: lukonin-av@mail.ru
2 Materials and methods

The analysis of the factors that influence the change in the wave process’s parameters in the cable line is carried out to simulate the transient process in its digital twin [6-8]. For this purpose, the process parameters with the allocation of characteristic zones are determined, shown in Figure 1, including the process of charging the cable line capacity from a high voltage test facility (1) and its discharge as a result of a breakdown of weakened insulation with a wave process in the cable line (2) [9, 10]. The wave process’s parameters in the cable line is a source of information about the nature of damage and the place of its occurrence [11, 12, 13].

Fig. 1. The process of charging the capacity of the cable line in the system "high–voltage test installation - power cable line" at the breakdown of insulation: (1)– the voltage at the output of the installation before the breakdown of insulation; (2) – the wave process in the cable line.

A wave process is formed in the cable line as a result of the breakdown of defective insulation between the cable shell or the core. Conditions for multiple reflections of an electromagnetic wave are created when the resistance at the ends of the line is significantly greater than the wave resistance. The decrease in amplitude and the change in the voltage's shape dependence on time acquires the character of damped oscillations with a period proportional to the cable section’s length from the connection point to the breakdown point.

3 Discussion

The calculated data of the digital twin model are verified by a full–scale experiment in the generalized technological system "test installation - cable line" when testing insulation with a high voltage of negative polarity. Tests on the physical model included the development of a scheme for connecting the cable line to the test installation, closing the "defective core" to the "shell" and to the undamaged core of the cable line when connected to the test installation. Analysis of the experimental results showed that the main parameters of the wave process are the oscillation period and the waveform of the control voltage. The main factors affecting the parameters of the wave process are:

1. The specific parameter of the inductive resistance of the cable line core, its length and the length of the defective section.
2. Insulation parameters, including "core - core " capacitance, " core -shell" capacitance, " core - core " conductivity, " core -shell" conductivity.
3. Voltage of the test unit.
4. The nature of the damage, including " core - shell" or " core - core ".

v = 165 m/μs
Tx = 1,2 us
5. The active resistance of the core and shell of the cable line at its value is more than the wave resistance of the system.

A full-scale experiment allowed us to determine the physics of processes in a cable line during high-voltage tests. The specialized method of calculating the distance to the defective section of the cable line is verified at the control points by the results of the experiment and can be used in the data analysis algorithm when testing the cable line with high direct voltage of negative polarity.

Fig. 2. Fragment of a distributed cable line model.

The model is made by serial connection of three-phase differential elements describing a unified block of a cable line of a certain length (see Figure 3).

Fig. 3. Element of a distributed cable line.

Such a model allows you to set the parameters of the elements in a lowercase form and change them in accordance with the purpose of the study. The form of description of the parameters of the element of a distributed cable line is represented by the following line:

```
.param lx=1 r0cp=0.0335 r0cg=0.038 l0cp=0.0263u c0pp=69n c0pg=1.75n r0pg=500Meg r0pp=500Meg
```

The created model describes the following parameters of the cable line: the length of the cable line section (lx), the specific value of the active resistance (r0cp) and inductive resistance (l0cp) of the cable core, the specific value of the active resistance (r0cg) of the cable shell, the specific value of the capacitance (c0pp) between cable cores, the specific value of the capacitance (c0pg) between cable core and cable shell, the specific conductivity value (r0pp) between cable cores, the specific conductivity value (r0pg) between cable core and cable shell. The parameters taken into account depend on the material and type of insulation, cable cores and shield, and the specific parameters are set relative to the lx
parameter. The model makes it possible to analyze the mutual influence of elements of a
distributed cable line in the study of the transient process that occurs in the cable during
testing with a high direct voltage of negative polarity.

The characteristic points’s calculation of the cable section is confirmed by experimental
data. Figure 4 and figure 5 show two experimental schemes with data from a full-scale
experiment and calculated values on the model.

1. Insulation damage "core-shell", distance - 100 meters, undamaged cores are
grounded

Fig. 4. Scheme for conducting a full-scale experiment (a), the results of a full-scale experiment (b)
and calculation of the cable line model (c) for the "core-shell" closure mode at a distance of 100 m.

2. Insulation damage "core- core ", distance - 100 meters, undamaged cores are
grounded
Fig. 5. Scheme for conducting a full-scale experiment (a), the results of a full-scale experiment (b) and calculation of the cable line model (c) for the "core-core" closure mode at a distance of 100 m.

5 Conclusion

The developed model showed high accuracy in calculating the parameters of the "core-core" and "core-shell" insulation damage. The model is used as a calculation model for creating a library of data for verifying locations insulation damage. The structure of the neural network data presented in Table 1. The image library contains data on emergency processes occurring in cable lines of various lengths, parameters of the core material, insulation, armor and shell.
### Table 1. Parameters of the wave process mask.

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The data for neural network training is presented for each mode as a separate file in the *.txt format. The file content is presented in the fragment below (Figure 6) and is generated automatically by software.

![Time vs. Voltage](image)

**Fig. 6.** Emergency process data.

The data contain the calculated dependence of voltage on time in the first periods of oscillation during a high-frequency damping process. It is superimposed on the time dependence of the breakdown voltage obtained during the test. The artificial intelligence system approximates the input data with the values of the library events and outputs a result about the location of the cable line insulation damage. The reliability of this approach is achieved by a large number of calculated. The research module, which is integrated into a high-voltage test facility, will allow you to quickly and with a high level of reliability identify defective insulation areas [14]. Reducing the time to identify a defective site will reduce the time to eliminate the violation and restore power supply to consumers in a short time.

### References

4. Rajendran, A., Thirumurthy, K.P. Meena, Lecture Notes in Electrical Engineering 598,
12. A.A. Yurov, High-voltage device for registering places of damage to insulation materials of power cable lines by remote means of direct connection to the cable line patent. No. 205414, G01R 31/08, published on 13.07.2021 Byul. № 20
13. Pat. RU. No. 205414, G01R 31/08, published on 13.07.2021 by Issue No. 20. Application No. 2021113790