The device for monitoring the insulation breakdown zone of power cable lines in distribution networks with isolated neutral system during high-voltage diagnostic

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Abstract. The article considers an electrical device designed for diagnostic work in distribution networks of 6-10 kV, namely, the determination of damage zones in case of failure of insulating materials of cable lines during high-voltage diagnostics with a rectified voltage of negative polarity. The novelty of the developed device is its ability to connect directly to a high-voltage cable line without additional matching devices. The device is capable of detecting damage zones in lines up to 10 km remotely with an error of up to 0.2% of the cable length. The prefix allows you to fix any variants of damage to single-phase and three-phase cable lines with high transient resistance at the site of damage without the operation of "burning" insulation, which significantly reduces the time of repair work at the controlled facility.

1 Introduction

The analysis of a power distribution networks with isolated neutral system evaluates the electric mains' insulation as the most damageable elements of a network [1]. Therefore, the tasks of monitoring, residual life analysis, power supply reliability, development and appliance of new devices [2-4] and monitoring systems are considered as up-to-date [5-6]. Nowadays, for the majority of electric grid companies the tasks of high-voltage test [7-9;14] and accident localization of breakdown (failure) of cable lines' insulation [10-13] are divided into separate work directions. However, the variety of applied devices complicates the overall maintenance leading to time increasing of repair and recovery activities including the human factor. The relevancy of appliance and implementation of unified approach on planning, management and carrying out the repair and recovery activities is ensured by technical policy of integrated power grid [16]. The described task could be solved with development of new monitoring devices being able to combine several features or to form systems of monitoring via unity of different equipment of electrical engineering [18].

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2 Materials and methods

The developed device (attachment) for accident localization of breakdowned (failure) cable lines' insulation is an addition to high-voltage power source. Proposed attachment is connected in parallel to engineering test facility and cable line. The described connection forms the integrated monitoring system, which allows to record the wave form of processes automatically. It serves in estimation of a range before the breakdown zone of insulation in cable line with no need to change the monitoring's schematic. The accident zone of a cable line is determined via method of electron oscillation discharge. This method is suitable for all kinds of damage with high rate of local transition resistance – non-sustained disruptive discharge. The developed device is connected to high-voltage engineering test facility of examined cable line with no additional connection devices [15].

So, a computer model of a three-phased cable line 10kV was developed to test the proposed device (Figure 1 shows the example of a cable line's computer modelled section). The model is performed in a distributed appearance. It considers the mutual induction between the wire and insulation material. Also, all of the cable elements are linear (including the armored layer, which operates in a range of relevant permeability). Additionally, the wave forms were studied in the state of monitoring with a further results' evaluation on a real sample of a cable line (Figure 2 shows the results contest of a simulation for some kind of insulation breakdown).

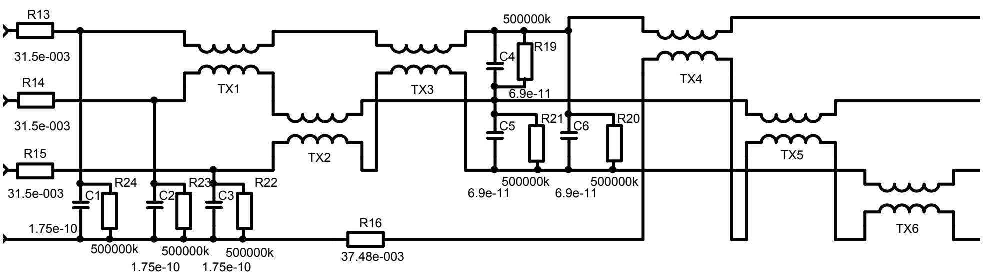

Fig. 1. Sample of a computer model for a power cable line.

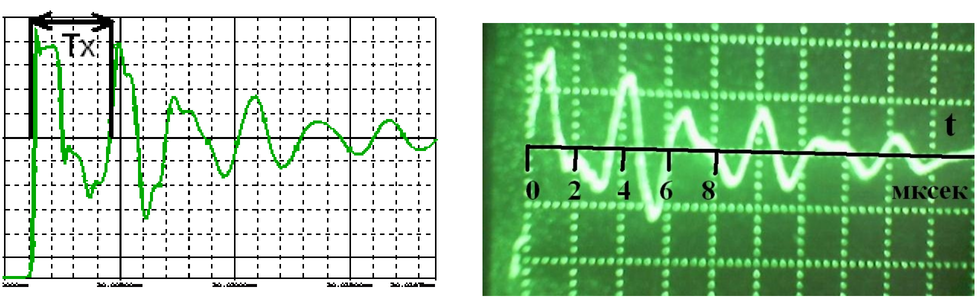

Fig. 2. Estimated cable line's wave form in terms of model (left) and examination (right, oscilloscope C8-17) in case of insulation failure during the high-voltage test.

The proposed attachment allows to determine the breakdown zone of cable line's insulation of electrical main in any combination of phases and enclosure being damaged in conditions of a high rate of local transition resistance without the state of insulation being burned down due to developed algorithm for an integrated controller. The distance to the zone of insulation's breakdown *lnp* is calculated according to free oscillation period in a cable line. A cable line is closed from one side and opened from the other. So, this period is calculated as a transit time of electromagnetic field (*tnp*) multiplied by 4:

$$T = 4 \cdot t_{пр} \tag{1}$$

With a knowledge of the first period *Tx* (Figure 2) and speed of electromagnetic field being equal to *υ=160-165* m/mks, the following equation shows the distance to the zone of insulation failure:

$$\ell np = tnp \cdot \upsilon = (Tx/4) \cdot \upsilon \tag{2}$$

Nowadays, there is no domestic alternative to proposed high-voltage device. Current analogues have low output voltage of probing sign. Moreover, they are inefficient in case of high-resistivity damage. Additional high-voltage power sources and reflection-coefficient meter are necessary to solve these issues. However, such devices are unable to operate without conditioners [17].

3 Results and Discussion

The following results were achieved via registered invention [19] shown on Figure 3, where 7 – high-voltage source, 8 – the attachment for accident localization of breakdown (failure) cable lines' insulation, including the elements: 1- high-voltage valid compliance unit (9 – decoupling high-voltage capacitor, 10 and 11 – potentiometer-type voltage divider, 12 and 13 – high-voltage tracking resistors); 2 – blocks for electromagnetic field calculation (3 – a-d converter, 4 – controller, 5 – liquid-crystal display, 6 – power supply unit) .

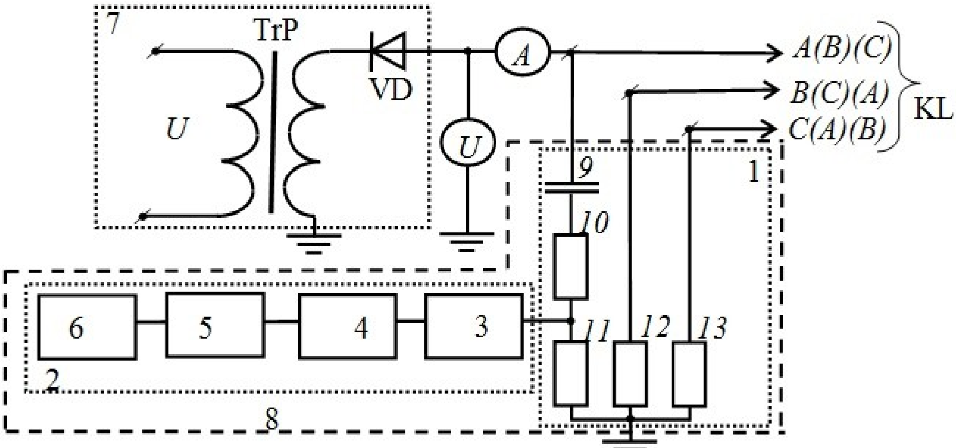

Fig. 3. Overview diagram system structure of the attachment for accident localization of cable lines' insulation breakdown (failure).

The power supply unit (6) allows the proposed device to operate both from 220 V, 50 Hz and from DC voltage source - battery unit 12 V. The decoupling high-vltage capacitor (9) sets a break between the device (8) and a cable line during high-voltage test till breakdown and wave forms in cable line as a result of insulation breakdown. Resistors 12, 13 are used for time response conditioning in cable line with line-to-line breakdowns.

The preparatory tests were handled via standard-voltage generator (sin-wave and square-wave) on a frequency of 4 kHz – 200 kHz due to the shutdown of high-voltage device during high-voltage test in case of cable's insulation breakdown. Whereas the cable line is a RF voltage generator (the frequency depends on failure distance). So, the aim of the proposed attachment is to record the frequency of wave form in a cable line in accordance with failure distance. Figure 4 shows the reflectogram of wave form being recorded by developed device. The generator E-100 simulates the insulation failure "wire-enclosure" in a power cable line with a 198 m distance from cable terminals. The frequency of wave from equals to 200 kHz with a period of Tx=4.8 ms.

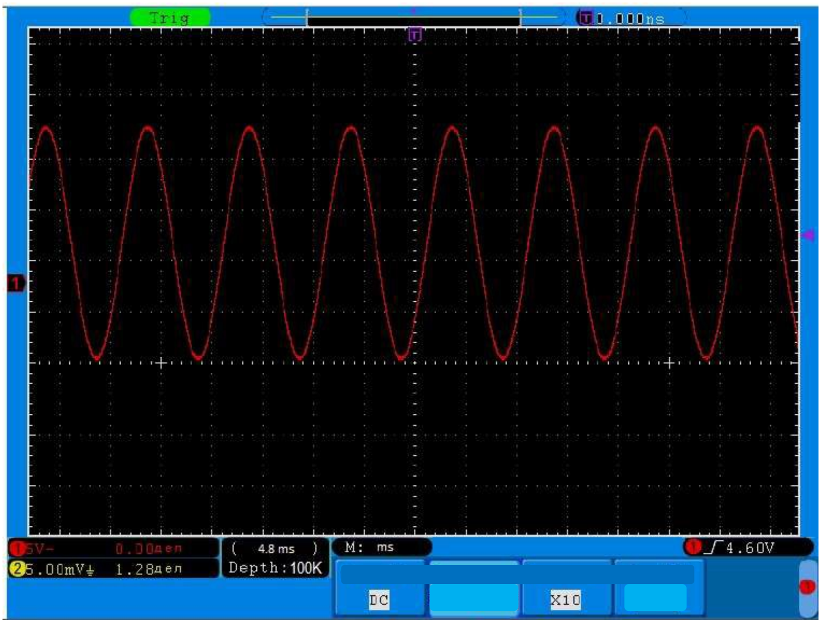

Fig. 4. The wave process in a cable line during an insulation breakdown.

The developed device doubles the data of transient analysis for operator in two formats. They are: the distance to the calculated zone of insulation breakdown and an oscillograph for the results' validation. The attachment is connected in parallel to technological system "high-voltage source – power cable line". Figure 5 shows an example of the following connection.

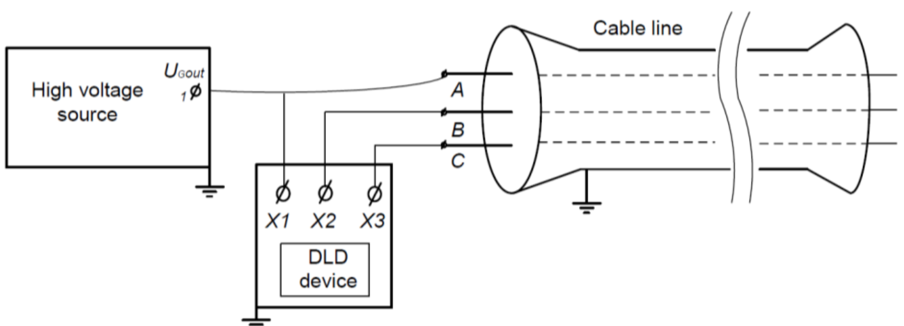

Fig. 5. Schematic of the attachment for accident localization of breakdown of (failure) cable lines' insulation in monitoring state.

The appearance of the attachment for accident localization of breakdown of (failure) cable lines' insulation is shown on figure 6. The research and development of the device were held in order with contract No. 3606GC1/60530 for grant of "Innovation Promotion Fund" in association with OOO "Research and Production Enterprise "Energocom" company.

Fig. 6. The device's appearance.

The main technical parameters of the device are presented in Table 1.

Table 1. Main device parameters.

No.	Parameter	Value
1	measured distance	From 50 to 10000 m
2	direct connection to the CL	6-20 kV
3	power consumption	No more than 50 watts
4	device power supply	100-240 V
5	device power supply	12 V
6	protection class of the device with the lid closed	IP 54
7	continuous operation	At least 8 hours
8	mass	Does not exceed 10 kg
9	device dimensions	456x363x181

The attachment for accident localization of breakdown of (failure) cable lines' insulation should be connected to a power cable line in a state of shutdown in order to schematic on Figure 3. Free wires on the ending terminals of a cable line should be opened and unconnected to the current-using equipment.

The tested wire of a cable line is connected to high-voltage source of unidirectional voltage with negative polarity and high-voltage input terminal of the device X1. The least two terminals are connected to the device of breakdown zone (in case of three-phase cable monitoring) X2-X3. The enclosure of a cable line is grounded. The tested wire is connected to the high-voltage source and terminal X1 of the device in case of one-phase cable. The terminals X2-X3 should be opened. The high-voltage source increases the testing voltage continuously (with a rate of not more than 1.5-2 kV/s). The device records the electromagnetic field automatically in case of insulation breakdown (Figure 4). Whereas, the hardware-software complex determines the zone of accident. Therefore, the time of servicing is decreased and insulation could not be "burned down". The main features are decribed on Table 2.

Table 2. The main features of the device.

No.	Function	Note
1	Intelligent detection of cable line insulation damage locations	Wave methods
2	Determination of phase-to-phase damages with high transient resistance	Swimming breakdown
3	Fixing the breakdown of insulation in the cable line of the live conductor on the cable sheath	Swimming breakdown
4	Fixing damage to the protective shells of the cable	-

4 Conclusion

The developed attachment for automatic localization of breakdown zone of cable line's insulation allows to record the high-voltage reflectogram with no need to use additional connection devices. Moreover, the proposed device monitors all types of power cable line's breakdown with high-voltage transition resistance. The distant method of checking the failure eliminates the burning state of cable line's insulation due to integrated controller with studied algorithm.

The following engineering proposal gives us:

- Significant decrease in the time of all monitoring complex of a cable line.
- The decrease in space for testing site via device connection to the distribution network during experiments (essential for close spaces).
- More sufficient use of energy (an economic effect from decreasing the time of current-using equipment being shut down).
- The decrease in risk of service errors during monitoring of breakdown due to unified schematics of experiments.
- Additional increase in device's mobility due to the battery unit.
- Energy efficiency due to elimination of time- and power-consuming state of cable line's insulation being burned down.

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