FAULT LOCATION IN POWER TRANSMISSION LINES

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The theory of wave propagation in power transmission lines (PTLs), whose basic principles were worked out by O. Heaviside, is widely used in the high-voltage electrical engineering with the purpose to protect PTLs against surges.

It should be noted that this theory was elaborated about 15 years ago mainly due to the efforts of US electrical engineers who studied overloads in high-voltage facilities.

The emergence and propagation of waves along PTLs are known [1] to be governed by the Kirchhoff law and to satisfy both a system of differential equations for PTLs and the energy conservation law. So, the issues pertaining to wave processes in PTLs can be elaborated for any practical applications.

The wave reflections at transition points, which are commonly used to reduce the wave-front steepness giving rise to surges, can also be used as an indicator that helps to detect the position of asymmetry points or inhomogeneities in PTLs.

The aim of this study is to develop a technique and to construct a device enabling fast and accurate fault detection in PTLs on the basis of the phenomenon of wave reflection from faulty points. To this end, we presumably used a cathode-ray oscilloscope, which allowed us to observe simultaneously all the faulty points on its screen and to reveal the nature of these faults (breakage, short-circuit, current leakage, etc.).

It is worth noting that other researchers attempted to use such an oscilloscope for this particular purpose as long ago as in 1929 [2] and 1931 [3]. However, although those studies are rather long-standing, none of the readily available manuals includes any reference to the relevant technique.

Our domestic literature on the measurements of electrical networks and cables [4] contains no description of a device or technique based on the wave reflection principle.

Scheme and Principles of Device Operation

To construct a device for fault detection in PTLs, we had to use the equipment capable of producing periodic short DC pulses as well as a cathode-ray oscilloscope with a fast and pulse-synchronized sweep.

The operation involving the line fault location and the determination of the distance to the faulty point was as follows.

The oscilloscope integrated with a short-pulse generator is connected either directly to the PTL to be tested, if the line is currentless, or through coupling capacitors in the case of the alive line.

The pulses fed into the line are recorded on the oscilloscope screen at the beginning of its sweep, whereas the pulses that are partially or entirely reflected from the points characterized by a drastic deviation from symmetry or electric homogeneity are recorded at a certain distance along the sweep.

With the sweep rate given, the distance to the faulty point is found by measuring the inter-pulse spacing. The pulse duration and the oscilloscope sweep rate are determined by the PTL length and the required accuracy of distance measurements. For PTLs about 1 km long, the use of a pulse with the duration $\tau \simeq 10^{-7}$ s and the sweep rate $\upsilon \simeq 3\times10^{6}$ cm/s allows the distance to the faulty point to be measured to an accuracy of ±15 m.

For 30–50-km PTLs, the sweep rate should be reduced by a factor of 30 to 50, so that the direct pulse and the pulse reflected from any point of the line can fit the oscilloscope screen.

Figure 1 shows the scheme of the device developed by the author and designed to produce dc pulses which have a duration from 10^{-5} to 10^{-7} s at a peak voltage of about 500 V and which are synchronous with the voltage pulses for the oscilloscope sweep. This scheme can be used to test the PTLs with length from 100 m to 100 km.

Figure 2 presents schematically the variations of the voltages and current strengths in various scheme components, including the generation of pulses with a

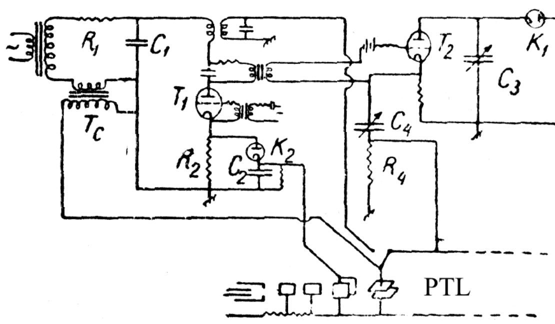

Fig. 1

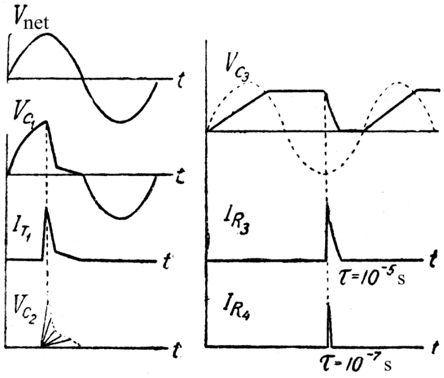

Fig. 2

duration of 10^{-7} s and the linearly varying sweep voltage.

The charging current of capacitor C_4 produces needle-like voltage pulses across resistor R_4, the pulse amplitude being several hundreds of volts and the pulse duration being $\sim 10^{-7}$ s. These are the pulses fed into the PTL to be tested.

The voltage rising linearly across capacitor C_2 (the sweep voltage) ensures the pulse-synchronized and uniform motion of the spot across the screen at any constant speed between 10^4 and 10^7 cm/s.

Figure 3,*a* shows the motion of the oscilloscope spot during one period of the alternating current. The thin horizontal line *AB* corresponds to the linearly rising voltage across capacitor C_2.

The voltage rise rate and, hence, the sweep rate are controlled by the filament current of kenotron K_2.

Bold curve BCDA corresponds to the alternating current flowing through transformer T_c, whose secondary winding is connected to the oscilloscope through a radio choke and serves to shift the spot from point *B* to the initial point *A* along curve *BCDA*. The dashed circle indicates the boundaries of the oscilloscope screen.

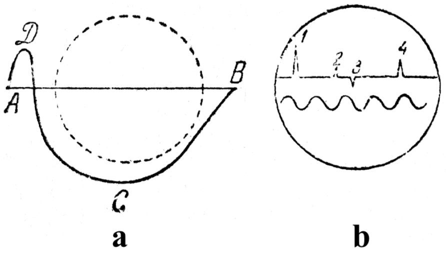

Fig. 3

Figure 3,*b* illustrates the oscilloscope screen with an exemplary image of the direct pulse (1) and the pulses (2,3,4) reflected from different faulty PTL points. The distances to the faulty points were counted off using the sinusoid of the time contour graduated in meters or kilometers (the curve below the pulses in Fig. 3,*b*). The synchronism and the total stability of the images displayed on the screen are achieved automatically, because the whole system is activated at one push by the ignition of thyratron T_1.

Experimental Results

The device manufactured according to the scheme shown in Fig. 1 (see Figs. 4,*a* and 4,*b*) was tested on an experimental 1800-m two-conductor line and a high-voltage line about 5 km long.

The experimental line was made of a 1-mm copper conductor and consisted of eight separate parallel 225-m segments. The ends of these segments were connected to the device, so that man-made faults could be produced at any PTL point, with the consequences observed on the oscilloscope screen.

Figures 5,*a*,*b*,*c*,*d*,*e* show the oscillograms obtained under different faulty conditions.

The device was tested on a high-voltage PTL at the fifth substation of the local energy supply department (Kharkovenergo).

A three-phase overhead line about 5 km long was grounded at its end. The following faults were made at a distance of about 1 km from the beginning of the line: two conductors were shorted out, and a bare conductor, whose end touched the frozen soil at the base of the line mast, was cast on the third conductor.

The grounding at the PTL end and the other faults were clearly discernible on the oscilloscope screen.

The distances to the fault point and to the grounding site were equal to 1160 and 4880 m, respectively, according to the measurements made with our device.

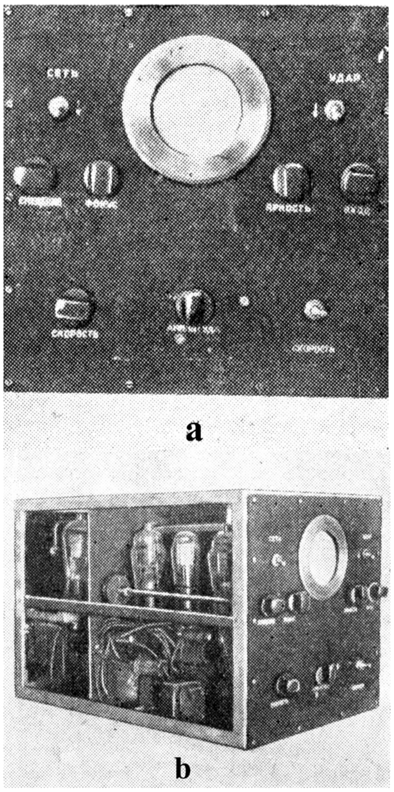

Fig. 4

The true distances (measured by the Kharkovenergo staff) were equal to 1140 and 4950 m, respectively.

By varying the sweep rate, we could observe subsequent reflections (besides the first one) up to the seventh reflection.

The amplitude of the seventh reflection was about 2–3 mm, which was equivalent to the detection of the PTL grounding at a distance of about 35 km.

With regard for the fact that the output resistance of a generator R_4 (which served as the load for reflected pulses, see Fig. 1) was approximately equal to 1000 Ω, the pulse reflection factor being about 0.5, the device operation distance was estimated at 50 km for an initial amplitude of about 120 V. The transmitted signal amplitude could be increased by several times. Thus, the device does allow one to test PTLs of length 100 km (and even longer ones).

Conclusion

We developed a device which allows one to (i) test PTLs of length from 100 m to 100 km; (ii) locate faults and reveal their nature (breakage, short circuit, grounding, current leakage); (iii) determine the distances to faulty points with an accuracy of ±15 m for the lines shorter than 5 km and ±100 m for the lines up to 100 km long.

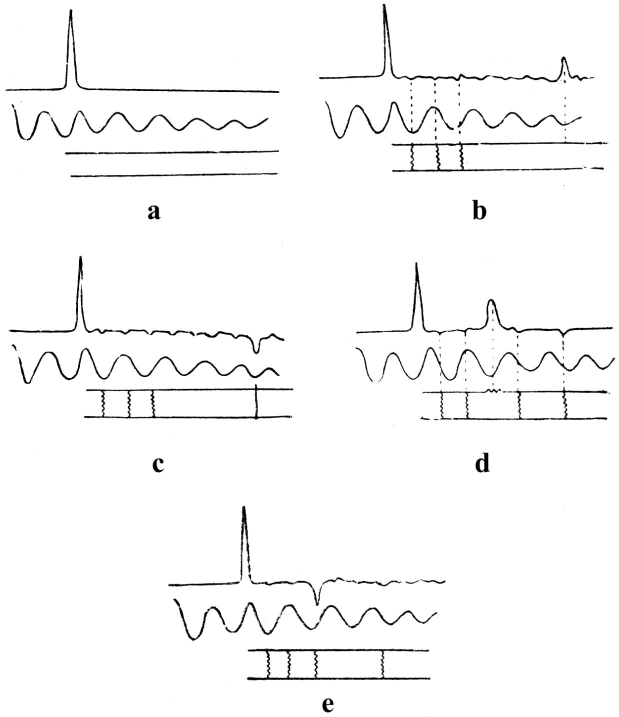

Fig. 5

The time required to examine the entire PTL on the oscilloscope screen, to locate faults, to reveal their nature, and to measure distances is no more than 5–10 min.

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His researches dealt with microwave physics, new methods of millimeter radiowave generation, and quantum electronics. In 1939, in collaboration with colleagues, he constructed a magnetron-based three-coordinate radar station operating in the decimeter wave range. Together with his co-workers, he constructed a series of magnetron generators and developed the methods of digital image processing.

A.Ya. Usikov was the Lenin's Prize (1960) and State's Prize of Ukraine (1981) winner. The Institute of Radiophysics and Electronics of the NASU was named after him.