B4 DC systems & power electronics
PS 1/ HVDC systems and their applications

Method for detecting of faulted section in cable-overhead HVDC line

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It is well known that the most frequent type of damage in the DC cable-overhead transmission lines is short-term insulation flashover in the overhead section, caused by lightning or another type of insulation damage. To eliminate such damage, it is enough to provide a reclosing dead time of damaged line. In the event of damage in the cable section caused by insulation breakdown, the entire line should be tripped off without automatic reclosing. At the same time output signals of line protection should not be generated in case of fault on the rectifier or inverter and in adjacent AC systems.

A review of existing protection methods showed that in the absence of measuring sensors at the junction of the cable and overhead sections of the line, the currently known protection algorithms for cable-overhead DC transmission lines are not able to determine the faulted section.

For example, commonly in case of a pole to ground short circuit, the protection system initiates a transmission line trip signal with or without automatic re-closing regardless of type of damaged section.

The paper describes the line protection algorithm, which is able to make the difference between transmission line short circuits from faults at the converter substations accompanied by a voltage reduction, and to detect the damaged section (cable or overhead) with subsequent protection action.

The proposed algorithm is based on the analysis of the transient voltage signal from a measuring device installed at the line termination (in this case at the rectifier converter side) (Fig. 1).

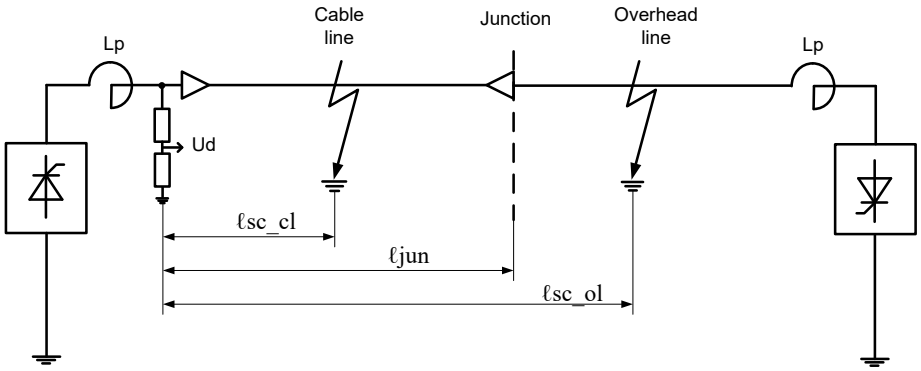

Fig.1. Fault locations on cable and overhead sections

When short circuit occurs in the cable section, the recorded signal will be determined by the natural frequency of the line, corresponding to the total propagation and reflection cycle of waves (Fig. 2).

If short circuits occur in the overhead section, the analyzed signal will be a superposition of processes occurring when the wave is repeatedly refracted at the junction of two sections and its multiple reflection from the junction point, linear reactor and short circuit points (Fig.3).

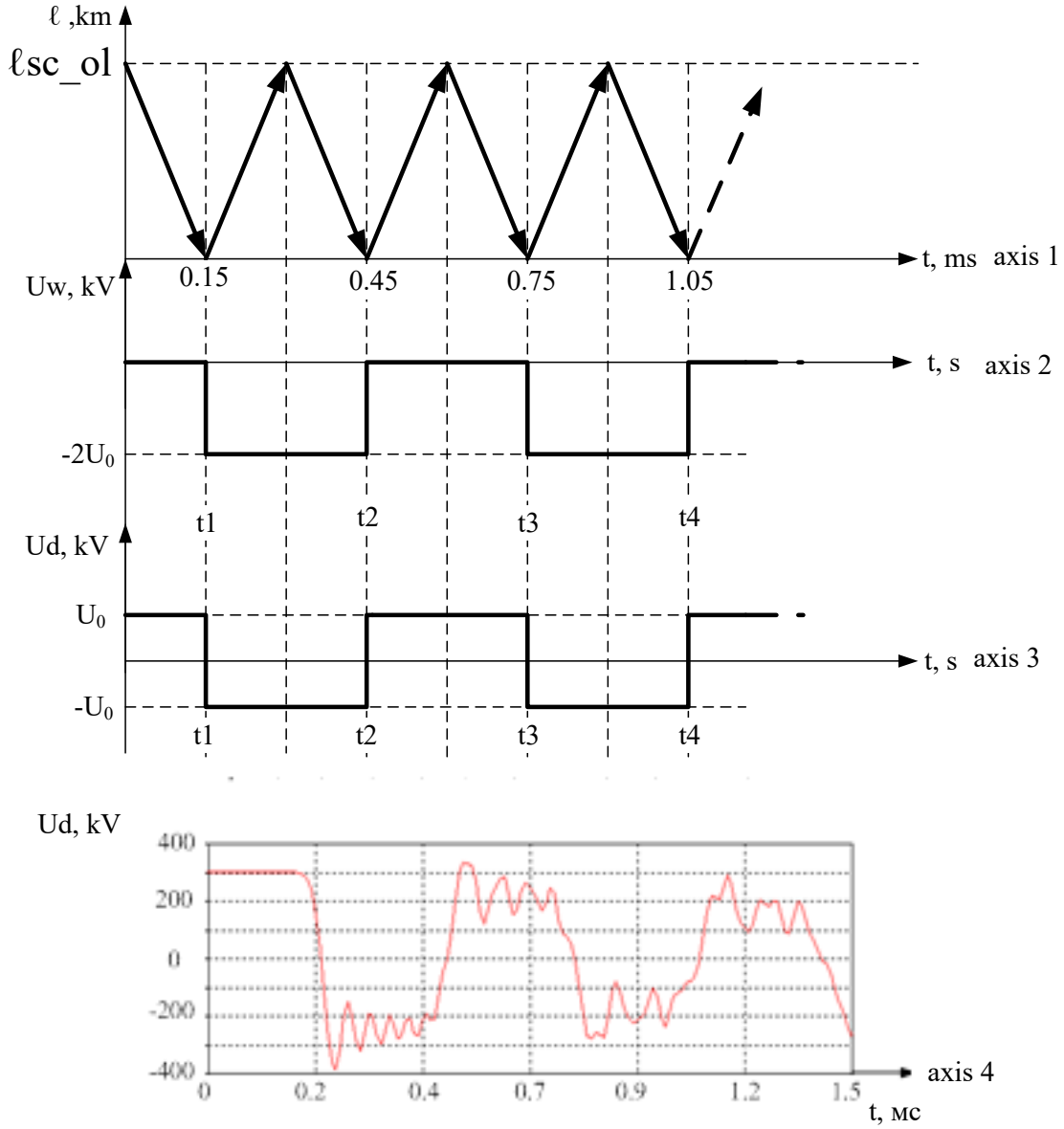

Fig.2. The direct and reflected voltage waves (axis 1), the change of voltage wave Uw at the line sending end (axis 2) and the line sending end voltage (axis 3) during a short circuit in the middle of the cable section (obtained with use of analytic expressions) and DC voltage Ud (axis 4) at the line sending end when short circuit in the middle of the cable section (obtained with use of simulation)

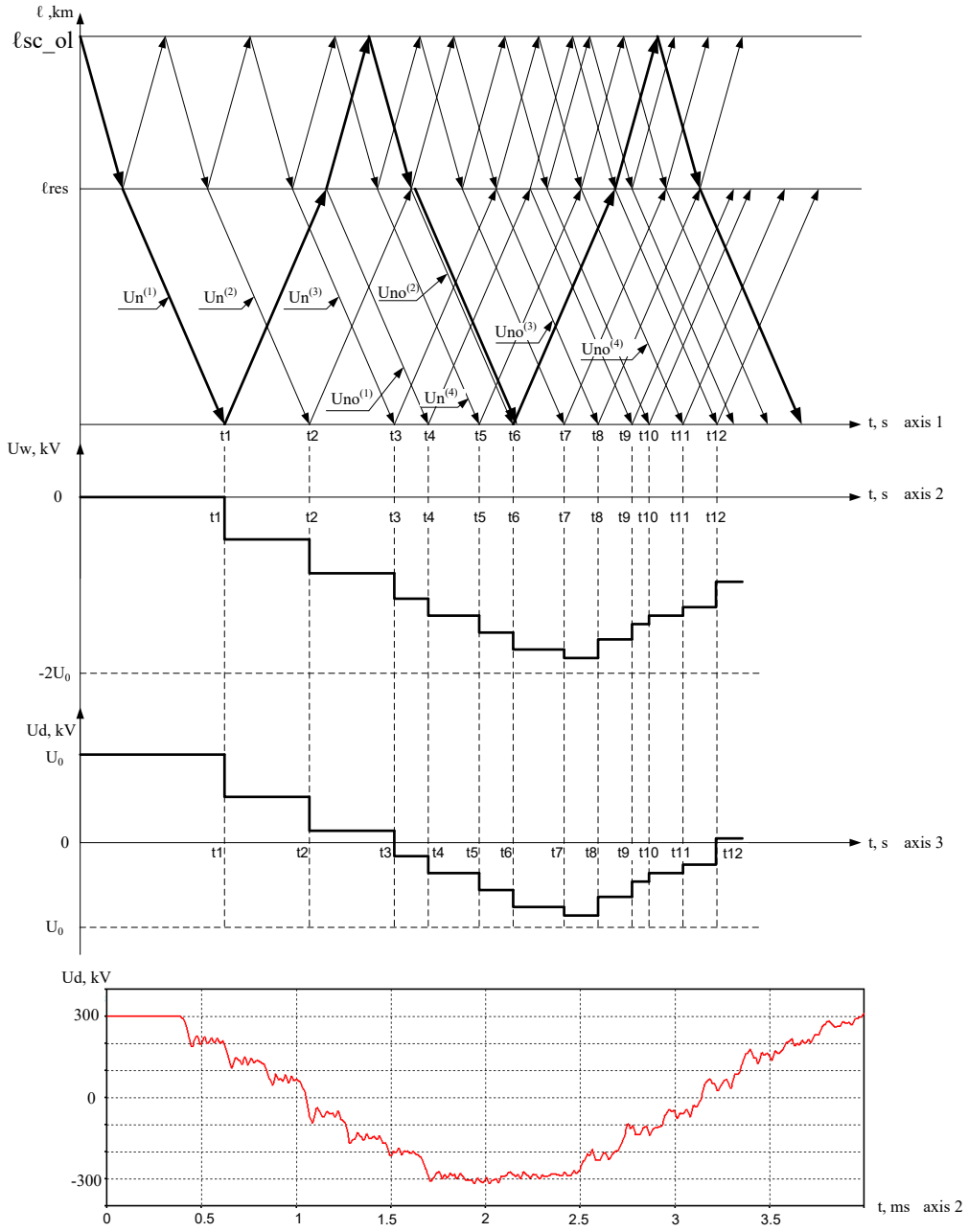

Fig.3. The direct and reflected voltage waves (axis 1), change of voltage wave Uw at the line sending end (axis 2) and the line sending end voltage (axis 3) during a short circuit in the middle of the overhead line (obtained with use of analytic expressions) and DC voltage Ud (axis 4) at the line sending end when short circuit in the middle of the overhead section (obtained with use of simulation)

The measured frequency of zero-crossings of the recorded voltage Ud at the instants t1, ..., t5 and the comparison of the obtained values with the reference value will allow to identify the faulted section and generate the proper tripping signal.

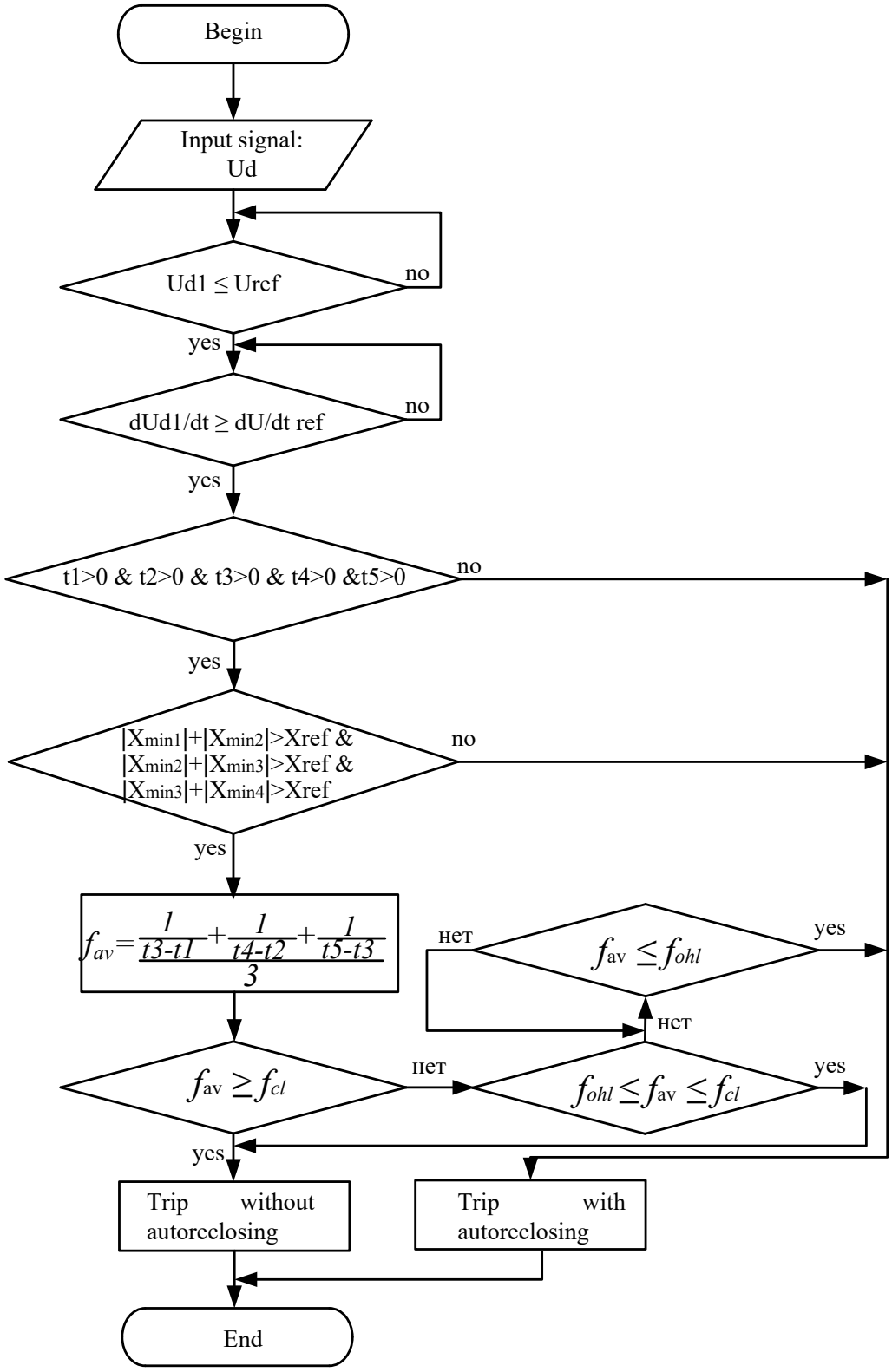

Fig.4. Algorithm for the detecting of faulted section on cable-overhead DC line

Studies of the operation of the developed line protection algorithm with use of mathematical model of a three-terminal HVDC transmission showed its effectiveness in the case of short circuits in different sections of the line. Figure 5 shows the initiation of a tripping signal without automatic reclosing on line transmission in the simulation of a short circuit in the cable section.

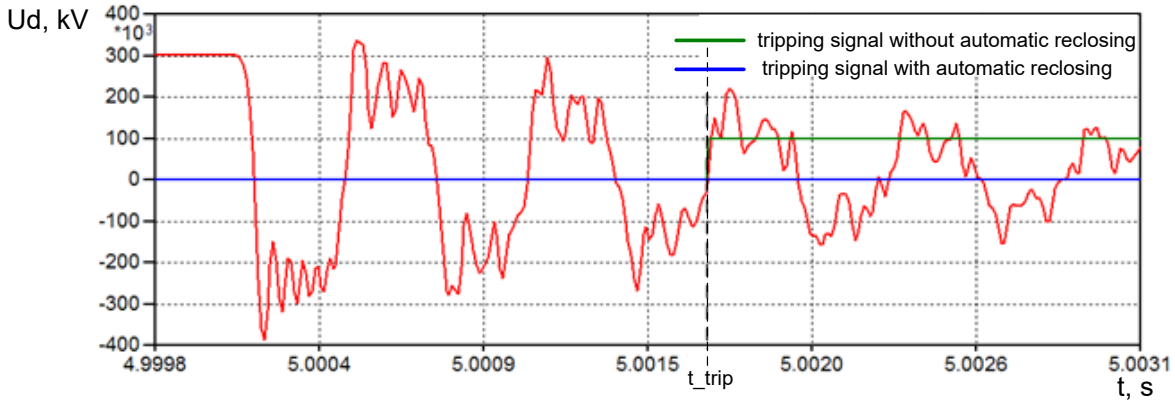

Fig. 5. Locating the fault in the middle of the cable section and initiation of a tripping signal without automatic reclosing on line transmission.

Figure 6 shows the initiation of a tripping signal with automatic reclosing on line transmission in the simulation of a short circuit in the overhead section.

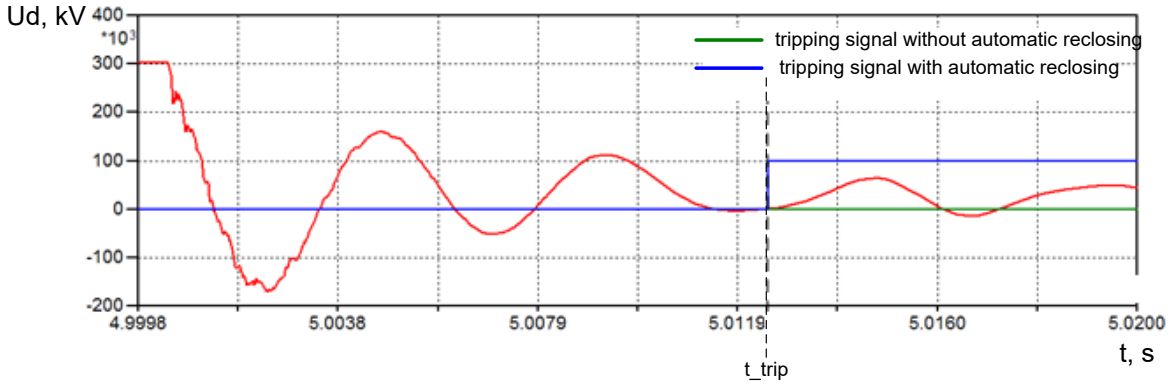

Fig. 6. Locating the fault in the middle of the overhead line section and initiation of a tripping signal with automatic reclosing on line transmission.

The proposed line protection algorithm is able to detect the faulted section in case of short circuits at various points of the non-uniform line and at the values of transition resistance at the short circuit point up to 50 Ohms. At the same time, the insensitivity zone of protection system in the vicinity of the junction between the cable and overhead sections for the mathematical model of DC transmission is 50 m to both sides from the junction of the sections. The proposed algorithm has a excessive operation tune-out in case of faults at the converter stations, accompanied by a decrease in voltage.
The developed protection can also be applied on a uniform HVDC transmission line in addition to conventional line protections, since any element of the power system

must be protected by at least two protections based on a different principle of operation.
The advantage of this method is the ability to perform a less costly modernization of an existing digital control and protection system by introducing an algorithm for detecting of faulted section in cable-overhead HVDC line under condition that there is no measuring equipment at the junction of cable and overhead sections.