Using of explosive technologies for development of a compact current-limiting device for operation on 110 kV class systems

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Abstract. This paper considers the possibility of creating on new physical principles a high-speed current-limiting device (CLD) for the networks with voltage of 110 kV, namely, on the basis of the explosive switching elements. The device is designed to limit the steady short-circuit current to acceptable values for the time does not exceed 3 ms at electric power facilities. The paper presents an analysis of the electrical circuit of CLD. The main features of the scheme are: a new high-speed switching element with high regenerating voltage; fusible switching element that enables to limit the overvoltage after sudden breakage of network of the explosive switch; non-inductive resistor with a high heat capacity and a special reactor with operating time less than 1 s. We analyzed the work of the CLD with help of special software PSPICE, which is based on the equivalent circuit of single-phase short circuit to ground in 110 kV network. Analysis of the equivalent circuit operation CLD shows its efficiency and determines the CLD as a perspective direction of the current-limiting devices of new generation.

1. Introduction

The rapid growth of modern metropolis increases as the generated power and the development of modern power supply systems (SmartGrid). It leads to the creation of large interconnected power systems. Possible result is increasing of the maximum value of short-circuit currents (SCC) in electrical network. According to data for 2015 [1] the value of the maximum short-circuit current in the networks of 110 kV (64.3 kA) already exceeds the breaking capacity of available circuit breaker (110 kV) which is capable of shutting down current of 63 kA. Methods for limiting SCC can be divided into two classes:

- Schematic (DC link and network partitioning) is appropriate in a sufficiently large scale network, unlimited lack of space in today's mega-cities.
- The use of short-circuit current limiting devices (CLD) which can be used also for local consumers and separate substations.

There are many schemes of CLD including simple current limiting reactors and complex systems with transformer coupling and power semiconductor elements [2]. Separately, it should be noted the application of high temperature superconductor elements (HTSE) in various versions of current limiters. Superconductivity allows development of devices based on the natural transition of a substance in a normally conducting state when exceeding the set


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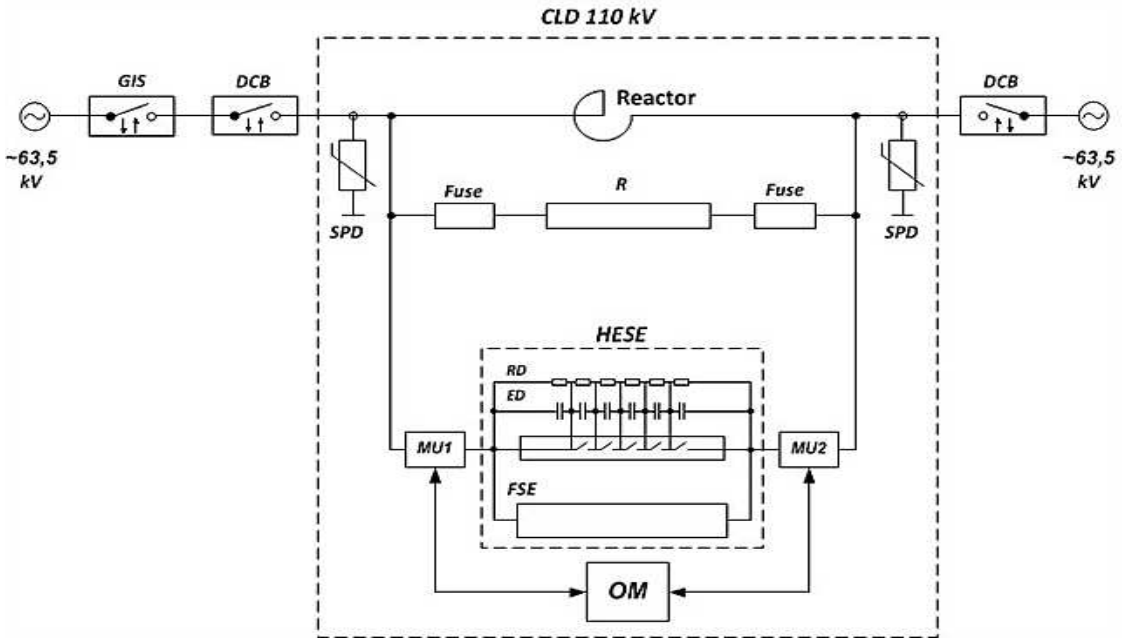


Figure 1. Functional diagram of CLD 110 kV.

current density. However, such systems will be economically feasible only after creating of new generations of HTSE. In our opinion, the use of explosive technologies looks quite promising for building CLD, which are already widely used in international practice, but only in power supply systems in the range of 2.8–38 kV. The examples are the short-circuit current limiters switching type CLiP, manufactured by GW ELECTRIC CO (USA) and the Is-limiter, manufactured by ABB (Switzerland). But for fast CLD working in networks of 110 kV and above, you need to use alternative approaches, as it is necessary to limit the level of the switching voltage of hundreds of kW and damping large of energy (tens of MJ).

2. Current-limiting device for 110 kV networks (CLD 110 kV) based on high-explosive type breakers

To solve the problem mentioned above the original scheme of the CLD 110 kV was developed in JIHT RAS. Figure 1 presents the principal scheme of this device. The functional diagram of CLD 110 kV consists of the following elements:

(i) Two overlapping control system (MU1 and MU2) and one general (OM) for communication with substation automation system.

(ii) The high-voltage explosive switching element (HESE) with fusible switching element (FSE) and additional resistive-capacitive divider (RD and CD).

(iii) The non-inductive resistor with fuse switches.

(iv) Special reactor.

The algorithm of CLD 110 kV operation was described in [3]. When SCC exceeds the set cut-off, two independent control systems give the command to undermine the explosive switch. However, to limit the surge line break with a sharp explosive switch at predetermined SCC must be bridged. This role is performed by fusible switching element. Its parameters are chosen so that it provides a delay of about 1 ms before the transition in current limit mode. Further role of FSE is reduced to a smooth switching of the current in the circuit non-inductive resistor and

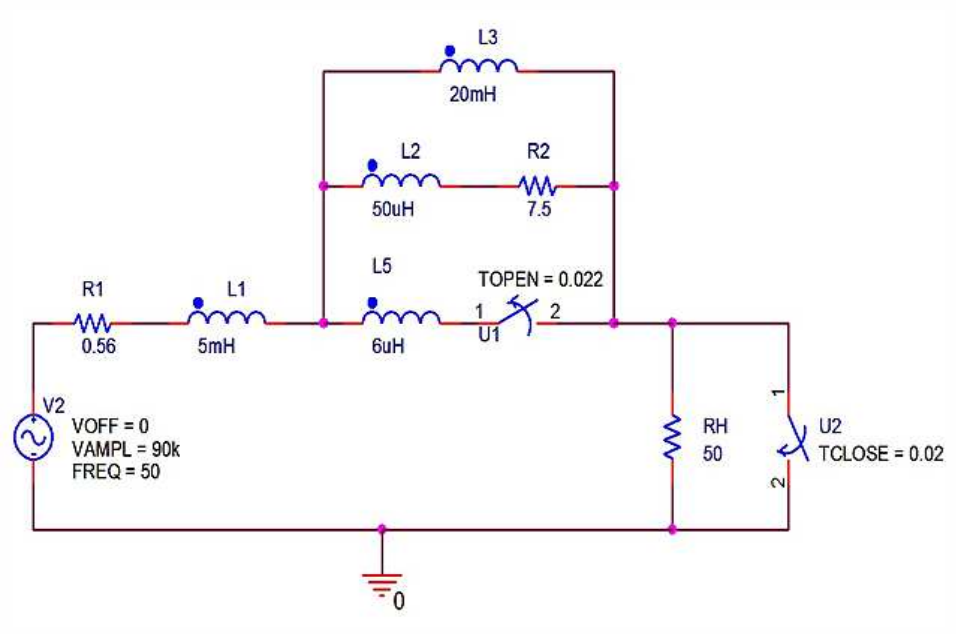


Figure 2. The equivalent circuit diagram of a single-phase short-circuit on the ground in the network of 110 kV.

fuse switches. However, even with a smooth switching of the current in the resistor there is a problem of occurrence of overvoltage on its own inductance. Therefore, there was need to create non-inductive resistor with high thermal capacity [4]. Performed calculations showed that the function of voltage limiter resistor will perform in the self-inductance of not more than 100 μH with the resistance less than 10 Ω. To solve this problem the original design of non-inductive resistor was developed. Designed resistor solves the problem of limiting the voltage and power absorption of the network by an external reactor. The final stage of the current limit is burning fuse switches in the circuit of a resistor and a final switching current in a special reactor.

Special reactor differs significantly from the current limiting reactors which are used directly for the current limit. Firstly, this reactor during normal operation shunted thick explosive switch bus and virtually no effect on the network operation. On the other hand, when the emergency operation can be expected only in the short circuit including the reactor until the regular switching circuit, i.e. the total time of the inclusion of the reactor is no more than 1 s. This fact significantly reduces the requirements for the reactor itself and the depth of the current limit. As a result, it is possible to use reactor with reactive impedance of not less than 10 Ohms without the need to solve problems with the heat sink.

3. The numerical calculation of the various modes of CLD 110 kV

For the analysis of CLD we used special software PSPICE [5], which has an equivalent circuit diagram of a single-phase ground fault in the 110 kV network shown in figure 2.

Since the time lag for the operation of the FSE, the trip circuit current is sufficiently large and ranges from 1 to 1.5 ms, the fault simulation reasonably produce in the early half period of the mains frequency. It is determined that the derivative of the current with the maximum and the delay in the shutdown of the FSE will lead to the maximum value of the surge current faults. Analysis of this scheme operation involves a simple model of fuse breaker, considering that its resistance increases linearly with time from 0.1 mΩ to 300 Ω for the time of 1 ms.

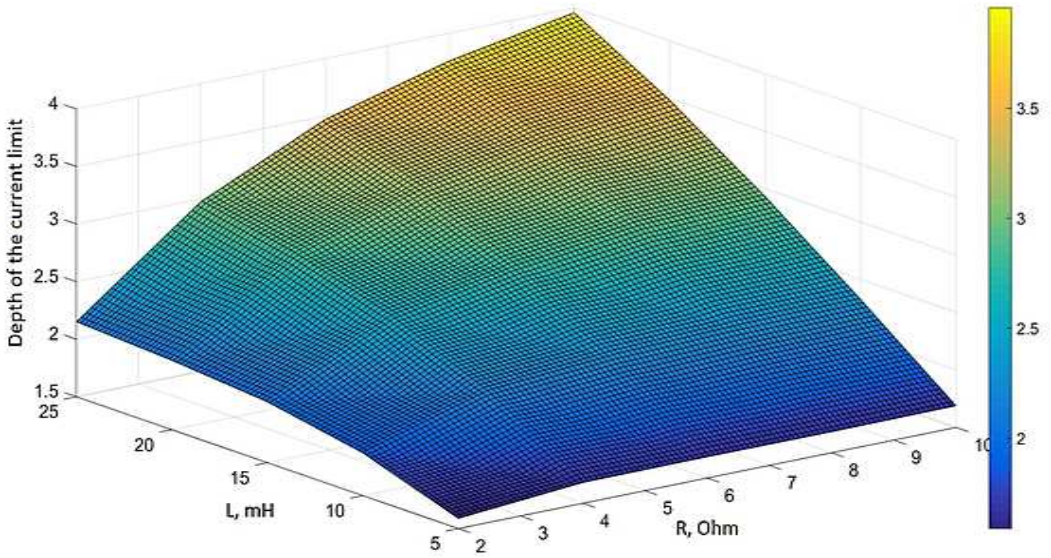


Figure 3. The estimated depth of the current limit depending on the parameters of the CLD 110 kV.

To determine the operating modes of the current from the current-limiting reactor parameters (resistance and inductance) was fulfilled a parametric analysis of the current limit of depth for a short-circuit mode. The depth of the current limit was determined as the ratio of the maximum short-circuit current mode and no current limit and peak current during normal operation CLD 110 kV. Lumped parameters of equivalent circuit CLD 110 kV were ranged within the following limits:

- for shunt resistor R2 = 2, 4, 6, 8, 10 Ohms and L2 = 12, 24, 36, 48, 60 μH, respectively;
- for a reactor (L3 = 5, 10, 15, 20, 25 mH).

Results of parametric analysis are presented in figure 3.

As it can be seen from the above data, the depth of the current limit depends essentially on the inductance of the reactor in the resistances of the shunt resistor 6 Ω or higher, which determines the minimum value of the resistor for current limit effectively. The inductance of current limiting reactor should be chosen taking into account the weight and size and the technical and economic criteria, and, apparently, carried out after selecting the resistance shunt resistor.

Fulfilled analysis allows selecting the following parameters of the circuit: shunt resistor R2 = 7.5 Ω, L2 = 50 μH; the reactor L3 = 20 mH. The results of simulation of CLD 110 kV operation are presented in figure 4.

It follows from data on figure 4 that the use of a resistive-inductive reactor, combined with explosive switching elements fundamentally reduces surge currents and surge voltages compared with the schemes on the basis of purely inductive reactors. Thus, the application of this reactor as a current limiting device is justified and promising in the circuits with a limited current limit time.

Separately it is necessary to consider the effect of parameters of the circuit to the level of overvoltage encountered when using CLD 110 kV (figure 5).

Fulfilled parametric analysis shows that in all the parameters of a selected range of CLD 110 kV surge level is at an acceptable level—up to 70 kV (figure 5), with an operating voltage phase-

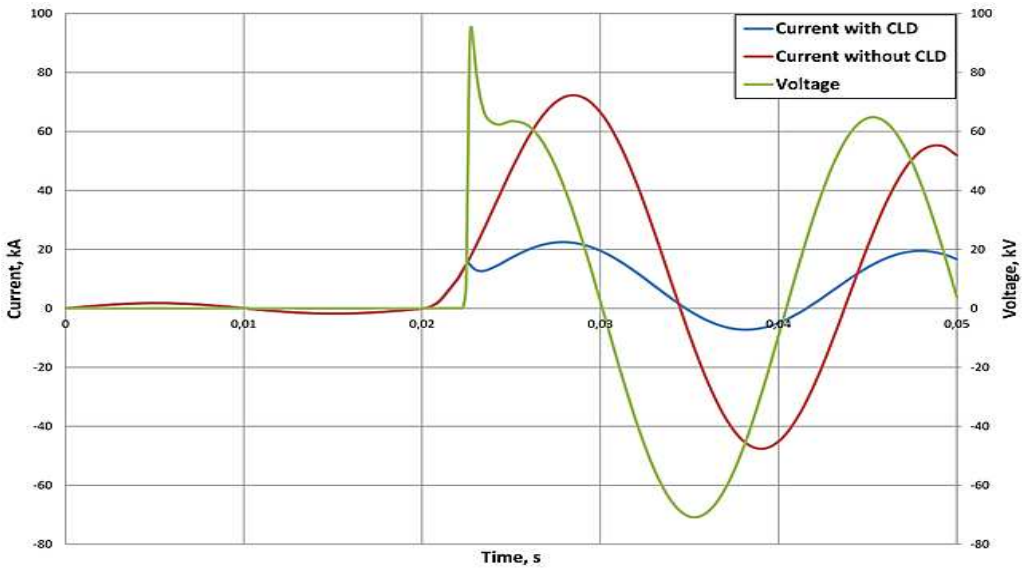


Figure 4. Calculated waveforms of single-phase short-circuit.

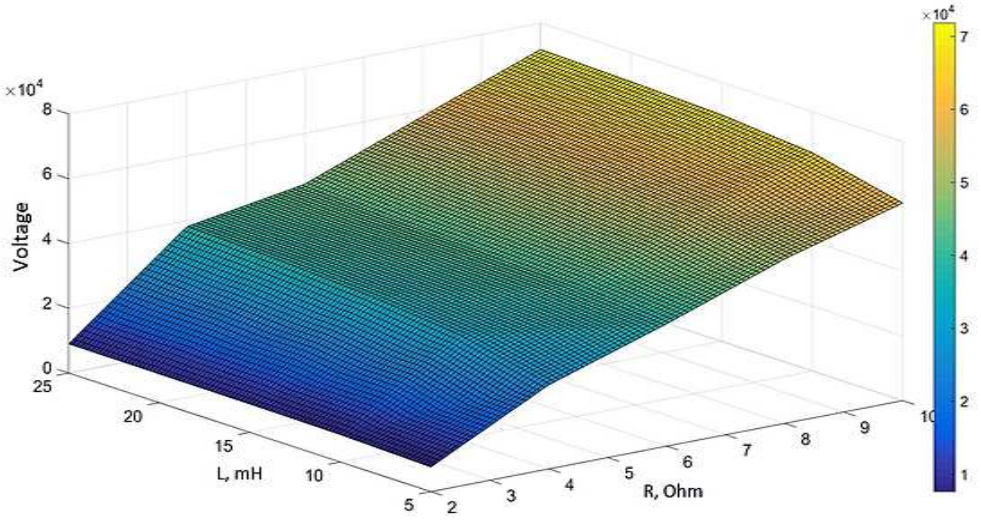


Figure 5. Current levels surge depending on the parameters of CLD 110 kV.

zero to 63.5 kV. Thus, in order to provide a substantial supply of electric strength, explosive switching element must withstand up to 70 kV per unit gap, and in this device at least 5 gaps are required to achieve the desired recovery voltage.

4. Experimental studies of explosive switching element

To confirm the design parameters of the explosive switching element, experimental installation has been designed and constructed to simulate the network reaction on the sudden breakage of the bus conductor (figure 6). Break of the current circuit, which includes an explosive switching element, occurs under the influence of detonation products of condensed explosives which was

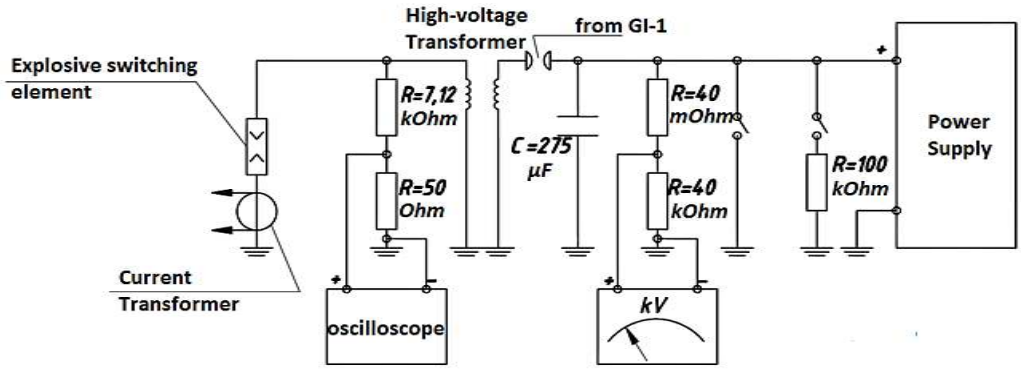


Figure 6. Schematic diagram of the experiment.

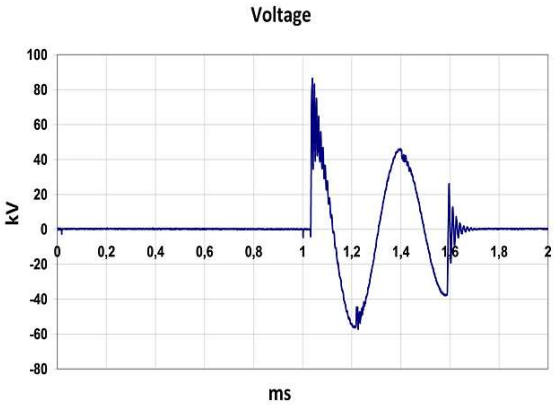


Figure 7. Voltage on the explosive switching element.



Figure 8. The explosive switching element after the experiment.

initiated by electric detonator. Command on the start of undermining comes from an electric pulse generator GI-1. To study the dielectric strength of the insulation gap formed as a result of an explosive rupture of the current element of the switching element at 1 ms after the explosion cutter it was fed a high-voltage pulse with a step-up transformer duration of about 0.6 ms and a maximum amplitude of 70 kV. The high-voltage pulse with step-up transformer duration of about 0.6 ms and maximum amplitude of 70 kV was applied to the insulation gap formed as a result of explosive rupture to study dielectric strength of the gap.

Oscillogram of voltage on explosive switching element is shown in figure 7.

Oscillogram of current is not shown in figure 7 as an electrical breakdown of the gap formed in the explosive switching element, has not occurred, and the current through explosive switching element was absent. Figure 8 demonstrates explosive switching element after the experiment.

5. Conclusion

Numerical analysis of the equivalent circuit operation CLD 110 kV shows its effectiveness and determines the CLD 110 kV as a promising area of current-limiting devices of new generation. CLD 110 kV meets all the requirements, provided for a new class of devices, and can be one of the key components of network security in the future. Suggested current-limiting device is capable of disabling the network in the first half-cycle after the start of short current with substantial

depth of the current limit and a small level surge. It is interesting to further experimental study of the proposed scheme.

Acknowledgments
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