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Євген Гончаров, к.т.н., доц.
Національний технічний університет «Харківський політехнічний інститут», Україна

ОСОБЛИВОСТІ РОБОТИ ЕЛЕКТРОМАГНІТНОГО ОБМЕЖУВАЧА СТРУМУ КОРОТКОГО ЗАМИКАННЯ

Розглянуто конструкція, принципи роботи електромагнітного обмежувача струму короткого замикання індуктивного типу. Проаналізовано особливості роботи електромагнітного обмежувача струму короткого замикання у номінальному режимі та короткого замикання.

Ключові слова: обмежувач струму короткого замикання, індуктивність, магнітне поле, магнітопровід.

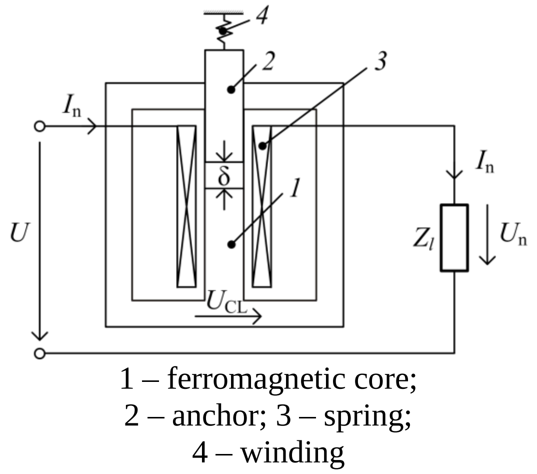
Evgen Goncharov

OPERATION FEATURES OF ELECTROMAGNETIC SHORT-CIRCUIT CURRENT LIMITER

The design, operation principles of electromagnetic short-circuit current limiter of inductive type are considered. The peculiarities of the operation of electromagnetic short-circuit current limiter in the nominal and short-circuit mode are analyzed.

Keywords: short-circuit current limiter, inductance, magnetic field, ferromagnetic core.

The electric power industry increases the power consumption, therefore, it is characterized by an increase in the generation of electricity, which is the cause of the emergence of ultrahigh voltage classes, the development and creation of new energy complexes of high power. Various devices, including such as fuses, switches, relays, current limiting reactors, and various current limiting devices that limit the current to a certain value, are used to protect electric power and consumers from short-circuit currents. This ensures an increase in the efficiency and lifetime of electrical equipment. In addition, the protection of transmission lines is one of the defining parameters when choosing the equipment of substations [1].



1 – ferromagnetic core;
2 – anchor; 3 – spring;
4 – winding

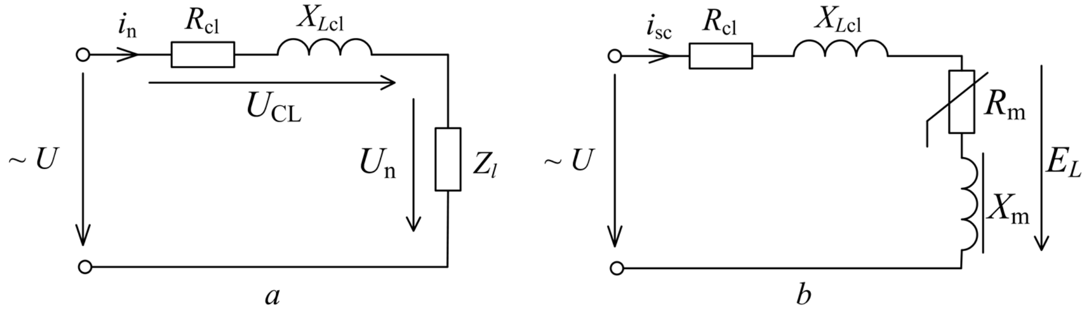
Fig. 1. Constructive scheme EM SCCL

Consider the electromagnetic short-circuit current limiter (EM SCCL) of the inductive type, which is given in Fig. 1. The design scheme of the EM SCCL contains a ferromagnetic core 1 with an average rode of which is placed winding 3, connected in series up to the load Z_l, with a moving anchor 2 attracted by a spring 4 [2]. It is connected in series with the load and in the nominal mode of operation the load current I_n passes through it, which is determined by the nominal voltage U_n and the full load impedance Z_l (Fig. 2, *a*).

Transient process is distributed: 1. from the initial current i_{n0} to the moment of anchor is attracted to the core of current limiter; 2. from the moment of anchor is attracted to the core to the power supply of electric grid is switched off [3].

Under normal operation, the load current flows through the winding 3 and the load Z_l. Given that the voltage drop across the current limiter does not exceed 3-5% of the u_n, and the nature of the voltage drop is almost inductive, it can be assumed that $i_n = u_n / Z_l$.

In the case of short-circuit, the current for a short time increases sharply, the anchor is attracted to the core and closes the magnetic circuit, the winding inductance increases by an order of magnitude. Thus, at the moment of a sudden short-circuit t_{sc} (Fig. 2, *b*), the initial conditions are as follows: $u_n = U_{nm} \sin(\omega t_{sc} + \psi_u)$; $i_{n0} = I_{nm} \sin(\omega t_{sc} + \psi_u - \varphi_l)$, where $I_{nm} = U_{nm} / Z_l$, ψ_u – initial phase of short-circuit, φ_l – power factor of load.



a – until a short-circuit occurs; *b* – in the event of a short-circuit

Fig. 2. Equivalent scheme of replacing the current limiter in the electric circuit

An increase in the inductance of the current limiter winding, in turn, leads to a change in the time constant and the full resistance of the current limiter.

In the event of short-circuit an electromagnetic current limiter can be represented by an

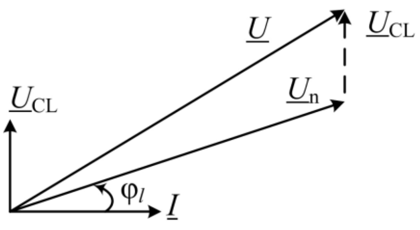


Fig. 3. Vector diagram of the electric circuits with EM SCCL at nominal mode

equivalent substitution circuit (Fig. 2, *b*). Parameters of the circuit of substitution: R_{cl} – active resistance of the winding of the current limiter; X_{Lcl} – inductive resistance to replace the inductive action of the dissipation magnetic flux Φ_d of the current limiter; R_m – active resistance to replace the magnetic losses of power in the steel core of the current limiter; X_m – inductive resistance to replace the inductive action of the main magnetic flux Φ.

Let's consider how the voltage drop U_{CL} on the current limiter reduces the load voltage U_n in relation to the voltage of the electrical network U. If we neglect the resistance of the current limiter winding, this reduces the impedance to almost purely inductive. That is, the

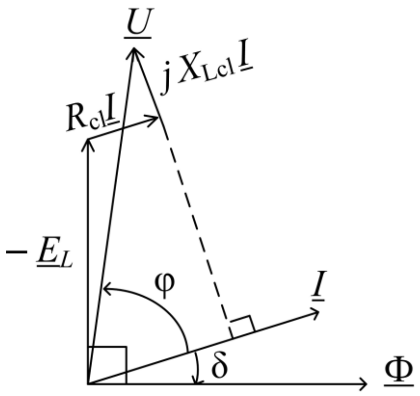


Fig. 4. Vector diagram of the electric circuits with EM SCCL at current limiting mode

$X_{\text{Lcl}} >> R_{\text{cl}}$ voltage on the current limiter $U_{CL} = I\sqrt{R_{\text{cl}}^2 + X_{L\text{cl}}^2}$ outstrips current I by almost 90° (Fig. 3).

From the vector diagram we obtain: $\underline{U} = \underline{U}_{\text{n}} + \underline{U}_{\text{CL}} = \underline{U}_{\text{n}} + k_{\text{cl}}\underline{U}_{\text{n}}$, where k_{cl} – coefficient, which correlates the voltage drop on the current limiter with the load voltage U_{n}.

According to the vector diagram:

$$U_{\text{n}} = \frac{U}{\sqrt{\left(k_{\text{cl}} + \sqrt{1 - \cos\varphi_l^2}\right) + \cos\varphi_l^2}},$$

where $\cos\varphi_l$ – power factor of load.

From the moment of the short-circuit current in the electric grid and the anchor is attracted to the core, due to the hysteresis, the induction and current are shifted to one another at the angle of magnetization δ, and the voltage and current at the angle $\varphi = \frac{\pi}{2} - \delta$, which is shown on the vector diagram (Fig. 4).

The voltage is spent not only to overcome the self-induction E_{L}, but also to overcome the active resistance of the winding of the current limiter R_{cl} and the inductive X_{Lcl} (from the dissipation magnetic flux) resistance in accordance with the second law of Kirchhoff: $\underline{U} = -\underline{E}_L + R_{\text{cl}}\,\underline{I} + jX_{\text{Lcl}}\underline{I} = \underline{U}_{\text{n}} + \underline{Z}\,\underline{I}$, where $E = 4{,}44\,f\,w\Phi_m$; R_{cl} – active resistance of the winding; $X_{\text{Lc1}} = \omega L_{\text{c1}}$ – inductive dissipation magnetic flux resistance; $\underline{Z} = R_{\text{cl}} + jX_{\text{Lc1}}$ – complex resistance of the coil of the electromagnetic current limiter.

Thus, at an active load of the electric grid, the voltage drop on the current limiter, at nominal parameters, does not significantly affect the voltage decrease on the load. The voltage on the electromagnetic inductive current limiter should be limited to $0{,}05 \cdot U_{\text{n}}$, which is possible with appropriate design parameters of the current limiter.

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