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DEVELOPMENT OF CURRENT LIMITING DEVICE FOR SHORT AND AUTONOMOUS NETWORKS

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Abstract. In this paper, the problem of tripping of high values of short-circuit currents in medium-voltage networks will be considered. Disconnection of short-circuit currents which can reach 100–300 kA in short networks is difficult task for modern switching equipment due to the impossibility of damping the electric arc generated by such currents, and due to strong thermal and electrodynamic effects on elements of the switching device. Solution based on active current limiting reactor will be presented.

Keywords: current limiting, short circuit, arcless commutation, arc extinction.

1. Introduction and problem defining

Short circuits have a chance of occurrence in any network types. To protect network and equipment from the destructive effects of high short circuit current the principle of fast disconnection of the fault place from the power source is commonly used. Among all types of electrical networks we would like here to consider short and autonomous networks and consider the features of short circuit disconnection process in such networks. When we are talking about common long lines and short circuit protection on it, we can find that modern commercially available switching units are able to operate with currents up to 63 kA for 220–550 kV and 27.5 kA for 35 kV [1–4].

In short networks the transmission line impedance is negligibly small, which becomes a reason for the occurrence of high value short-circuit currents. Short circuit current that occurs in short and autonomous network may exceed mentioned limits several times [5, 6] and reach 100–300 kA for example, in field of marine construction. For present day, disabling such high currents is a very difficult task due to high electrodynamic force, acted to the contacts, and high temperatures, caused by the electrical arc burning. In addition, quenching of the electric arc at currents of the order of 100 amperes and above will require a significant complication and increase in the cost of the circuit-breaker design, increasing the mass and dimensions of the arc extinguishing chamber and its cooling system.

One of the effective solutions in the question of short circuit protection in such low-impedance networks is the design and operating of the device which could limit the short-circuit current down to the values which can be switched off by commercially available circuit breakers. In that case it becomes possible to decrease the arc current and use more simple and small arc extinguishing chamber.

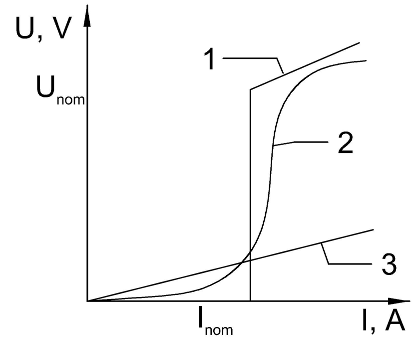

Figure 1. The volt-ampere characteristics of current limiting devices. 1 - ideal characteristics; 2 - non-linear characteristics; 3 - linear characteristics.

The task of limiting of short circuit currents and facilitating of the switching of emergency mode networks of class 110 kV and above is currently trivial. The electrotechnical industry has extensive experience and the theory of designing and creating current-limiting devices for networks of such stress classes. Nevertheless, the permissible continuous current for power lines does not exceed 1 kA. In connection with this, passive current-limiting reactors are the most widely used to date. Passive reactors have relativity simple design and low price and high reliability. Fig. 1 shows the volt-ampere characteristics of different reactor types. The passive reactors usually have linear or close to linear characteristics (shown on figure as curves “1” and “2” respectively)[7].

Autonomous and short networks, especially designed for special use purposes, operate at voltages not exceeding 35 kV. Accordingly, the rated operating current can reach 30 kA in such networks [5, 6]. Under these conditions it is impossible to use passive current-limiting reactors actively used at voltages of 110–220 kV because of their linear volt-ampere characteristics [8] and high energy losses in normal oper-

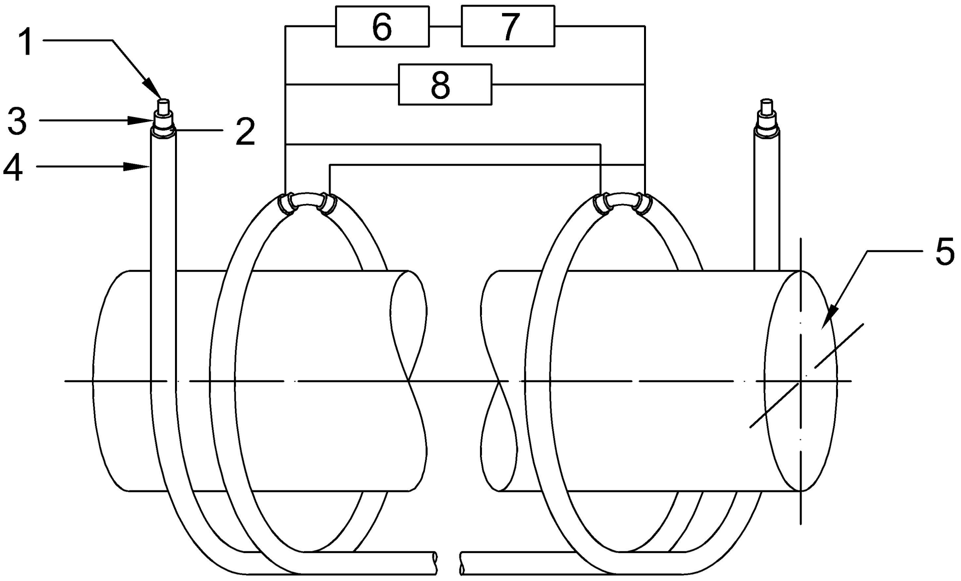

Figure 2. The sketch draw of the coaxial cable transformer-based current limiting device. 1 - cable core; 2 - cable shield; 3 - insulation between the primary and secondary windings; 4 - External cable insulation; 5 - the core; 6 - the battery of capacitors; 7 - active losses in the capacitor branch; 8 - semiconductor switch.

ating mode. In case of high nominal currents, it is necessary to provide very low impedance during the nominal currents range with its sharp increase when the current increases up to short circuit value. The volt-ampere characteristics of such device should have a view of ideal current-limiter curve with zero normal state impedance, which shown on fig. 1 under the label “3” or close to that.

As was mentioned earlier, different types of current-limiters was developed for high voltage application, but due to economical and practical reasons did not go into mass production. Considering the knowledge background and currently invented principles, it was found that the use of active current limiting reactor, instead of passive, can provide a desired volt-ampere characteristics. The working principle and design of active reactor for the class of 110 kV was described in [8, 9]. The principle may be successfully applied for the medium voltage networks and the desired level of current limiting may be reached. The basic idea of the principle will be given in further parts of the paper. The computer simulation model of the active reactor, designed taking into account the specifics of the operation modes of autonomous and high-current networks was created and tested. Simulation results are presented and described in corresponding section.

2. The current limiting device design and simulation

As a current-limiting device for networks with high short-circuit currents, we can use the active current limiting reactor. The reactor is built on the principle of coaxial cable transformer [8, 9], made from the conventional coaxial cable (figure 2). The transformer’s primary winding is a current-carrying core, while the secondary winding is a shield of coaxial cable, which divided to several sections and joined in parallel. The circuit diagram of the current limiting device is shown on figure 3.

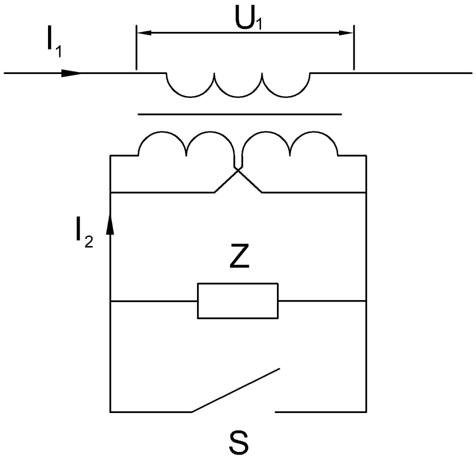

Figure 3. The coaxial cable transformer-based current limiting device circuit diagram.

Regardless of the splitting of the secondary winding, the working principle of the current limiting device is following. In normal operation, when the current in the cable is nominal, the current flows through the cable core, which is the primary winding. The secondary winding is short-circuited by a semiconductor switch and does not actually affect the current in normal operation.

As known, the transformer's short-circuit voltage usually does not exceed 10 percent from its nominal voltage [10], thus, we can find the impedance of the system in normal operation state. Total impedance of the transformer in short-circuited state can be found using the equation 1.

$$Z_{\mathrm{nom}} = \frac{U_{\mathrm{n}} \times 0.1}{I_{\mathrm{n}}} \tag{1}$$

Considering, for instance, a 35 kV nominal voltage network, with steady state operating current of 30 kA, we can find that full current limiting reactor impedance in regular operation state will not exceed the value of 0.17 Ω. Such impedance is comparable with the linear portion of the cable.

In the magnetic system of the device there is practically no flow, since the entire magnetic flux is concentrated inside the cable. The secondary winding sections are connected in parallel for obtaining the required transformation ratio. Splitting the screen into sections gives the option to reduce the voltage on the transistor module and makes possible to use only one transistor key, which greatly simplifies the electronic switch construction. A control semiconductor device (for example, based on IGBT - transistors) is connected to the screen clamps and a capacitor bank.

In case of a short circuit, a trip signal based on the current derivative is applied to the semiconductor switch. Thus, a capacitor is turned on in the secondary winding and the total resistance of the cable transformer increases. In dependence on the required level of limited current, different impedance capacitors may be used. The secondary winding impedance Z_{s} can be found as

$$Z_{\mathrm{s}} = \frac{1}{C \times \omega} + R; \tag{2}$$

total impedance of current limiter referred to the primary winding Z_{p}, can be calculated as

$$Z_{\mathrm{p}} = k^2 \times Z_{\mathrm{s}} \tag{3}$$

where ω is angular frequency, k is transformer's turns ratio, R and C are resistance and capacitance of the capacitor bank respectively.

Taking as an example a condenser battery with a capacity of 400 µF and circuit resistance of 0.05 Ω, we obtain the impedance Z_{p} equal to 175 Ω.

In case of smaller capacitance installed, the limited short-circuit current may be much lower than nominal current. In such case the coaxial cable transformer operates at the mode close to open-circuit mode.

The given principle was modelled using Matlab Simulink environment for the case of autonomous network short circuit protection. For the simulation it was chosen the 35 kV low-impedance alternating current network, which consists of the power source, the active load and current limiting device. The circuit breaker in examined system is not modelled since the aim of the research is to limit the current. The nominal operating current of the modelled system is 0.7 kA (1 kA amplitude value), and the unstitched short circuit current is tends to 115 kA. The current limiting device under the simulation was built according to the principle shown on fig. 3 and basically consists of the cable transformer, where secondary winding is divided by 8 sections. The active resistance of the reactor is determined by the length of the cable and the specific active resistance and the inductance parameters was found using the equation 4 as it was described in [8, 11].

$$L = \mu_0 \omega^2 \frac{\pi}{4} \frac{D}{0.44} k_1 k_2 \tag{4}$$

where D is the core diameter, k_1 and k_2 - Kuhler coefficients, which depends on the geometrics [8, 11]. In section 3 the simulation results are shown and described.

3. Results discussion

Figure 4 shows the protected line current vs. time dependence for the process of short circuit current being limited. In the simulation it was assumed that the moment of the short circuit occurs at 0.095 seconds after the start of the observation. Also it was assumed that current sensors and the semiconductor switch control device has the response time of 0.001 s. It means that after the time of 1 ms after the moment of the short circuit, the impedance of the active reactor will be increased. On figure 4 one can see the normal operating mode from 0 to 0.095 s with the current amplitude value of 1 kA; at the period 0.095–0.096 s we can see uncontrolled current raise up to 2.3 kA peak; after the moment of 0.096 s the current becomes limited by the active reactor and the steady-state short circuit current is set at a value of 65 A. At this point the task of the current limiting device is performed and further shutdown is performed by the circuit-breaker.

Presented example was tested for the case of using the cable transformer with ratio k=8. Such winding ratio, especially with high impedance Z_2, allows to reduce the short circuit currents very effective, down to values when the switching arc may be extinguished by itself. In the case where there is no need for strong limitation of the short-circuit currents it is possible to use smaller winding factor transformer and disconnect the short circuit by conventional circuit breaker, operates with common short circuit currents.

Figure 5 presents the current vs. time dependence for the secondary circuit's capacitor current. As we can see, there is no current in capacitor during the normal operation state. When the current limiting

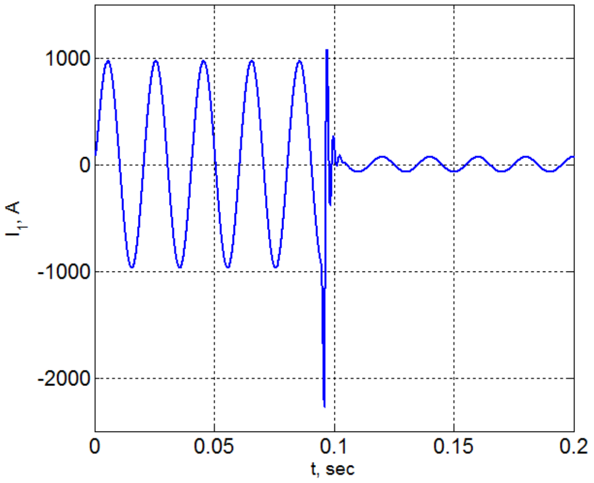

Figure 4. The cable core current waveform at the moment of occurrence of a short circuit and the current-limiting device reacting.

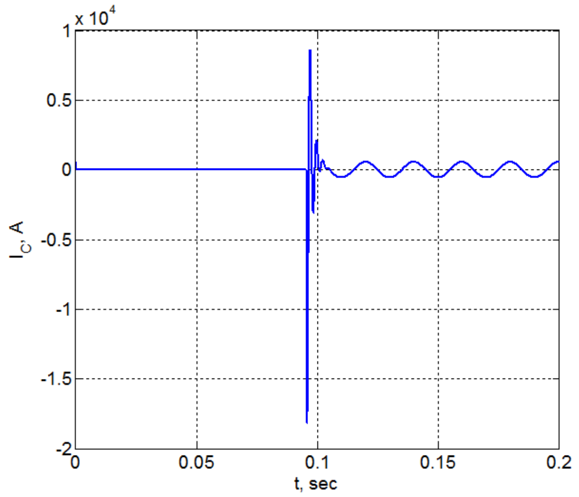

Figure 5. The cable core current waveform at the moment of occurrence of a short circuit and the current-limiting device reacting (secondary circuit's capacitor current).

function is switched on, the steady-state current becomes at the level of 500 A amplitude value, with transient peak value of 18 kA.

4. Conclusion

As we can see from figure 4, the short-circuit current limited by the active current-limiting reactor can be even lower than normal operation current. The degree of decreasing depends on the impedance, which may vary by setting different capacitance placed in secondary winding and different transformer's winding factor. In presented model it was used the 400 µF capacitor, which is commercially available and does not ask for extra large volume to be placed. Depending on the circuit breaker, installed in series with the current limiter, the capacitance and transformation ratio may vary until the value at which the short-circuit current is close to the breaking capacity of the circuit-breaker but does not exceed it. Thus, a compromise between capacitor's size, cable transformer design and short circuit current value can be found. Possibility of such significant current reducing makes it possible to greatly reduce the arc or carry out arcless commutation, which has the great development potential in the field of shipbuilding, submarine construction, oil platforms building, mining industry, can increase reliability and time response for civil and special energy systems. The obtained theoretical and simulation results will be utilized during the design of full-size full-voltage working prototype. The form-factor and size of the device designed for general application can be limited only by the transportation issues and the size of regular truck load. The 35kV device designed for the shock current up to 300 kA can be implemented by the coil radius of about 1 m, the length of which is not going to exceed 4 m.

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