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Coordination of overcurrent protection relays in networks with superconducting fault current limiters

W. Rebizant [a,*], K. Solak [a], B. Brusilowicz [a], G. Benysek [b], A. Kempski [b], J. Rusiński [b]

[a] The Faculty of Electrical Engineering, Wroclaw University of Science and Technology, Wyb. Wyspiańskiego 27, 50-370 Wroclaw, Poland
[b] The Faculty of Computer Science, Electrical Engineering and Automatics, University of Zielona Góra, ul. Licealna 9, 65-417 Zielona Góra, Poland

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ABSTRACT

The paper concerns coordination of overcurrent (OC) protection relays in power networks with superconducting fault current limiters (SFCL). At the beginning, information about designed SFCL and conditions that ensure overcurrent protection coordination are presented. Next, settings of the overcurrent relays were determined for a sample network with SFCL model installed. The considered HV/MV power system was modeled in the ATP/EMTP software and the effects of OC relays coordination was analyzed. At the end, conclusions from conducted studies and resulting guidelines for protection coordination are provided.

1. Introduction

The growing importance of distributed electricity generation, as a result of the rapid development of renewable energy sources, in many cases may cause a need to increase the transmission capacity of the medium voltage (MV) power grid [1,2]. Direct connection of a new energy source to the MV grid increases short-circuit power at the point of common coupling (PCC), which may cause risks for the existing technical infrastructure of the electric power network due to the impact of thermal and dynamic effects caused by increased values of short-circuit currents. This may be sufficient reason for the refusal to give permission for the connection of a new generation unit to the grid, or it may necessitate additional investments in the modernization of the MV line supplied from the substation. An alternative to the modernization of power system is to limit the maximum values of expected short-circuit currents [3–6]. Limiting of short-circuit currents consists in the artificial increase of the short-circuit impedance. An application serving this purpose is the limiter, which contains a fast fuse (so called Is-limiter), whose operation causes a long power interruption and requires maintenance service intervention [3,6].

Short-circuit impedance can also be increased by using current limiting reactors, which are connected in series with the protected circuit [4,5]. The main disadvantage of this solution is a voltage drop in normal operating state of the power system and increased risk of overvoltages generated as short-circuit currents are switched-off.

In recent years, in several countries, some research and technical work have led to development of the construction of more effective superconducting fault current limiters (SFCL) [7–10]. The impedance of an SFCL is practically equal to zero in the superconducting state and increases rapidly after leaving the superconducting state (quench), when the short-circuit current exceeds certain critical value [11].

The main advantage of these solutions, irrespective of the construction, is the ability to return to the superconducting state in a relatively short time after disappearance of a short-circuit without the need for maintenance service intervention.

Zero impedance of the SFCL in the superconducting state permits the exploitation of the possibilities which are created by an increased short-circuit power (improved voltage quality and reliability of the power), while the SFCL impedance after exiting the superconducting state permits the realization of the main aim - limiting the value of the maximum short circuit current. Therefore, settings of preventive protections, responsive to frequency or voltage changes (if voltage sag is not related to the appearance of short circuit), do not need to be changed. However, under fault conditions, the exit from the superconducting state of the SFCL is an irreversible phenomenon as long as short-circuit conditions persist. Since too long short-circuit duration can lead to damage of the

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* Corresponding author.
E-mail addresses: waldemar.rebizant@pwr.edu.pl (W. Rebizant), krzysztof.solak@pwr.edu.pl (K. Solak), bartosz.brusilowicz@pwr.edu.pl (B. Brusilowicz), g.benysek@iee.uz.zgora.pl (G. Benysek), a.kempski@iee.uz.zgora.pl (A. Kempski), j.rusinski@iee.uz.zgora.pl (J. Rusiński).

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superconducting circuit of the SFCL, thus consequently short-circuit currents must usually be switched-off by substation circuit breakers. Therefore, the application of an SFCL requires close correlation between the critical current of the SFCL and overcurrent settings of the protection devices, so that the SFCL reacts only to short-circuit currents with values exceeding the short-time withstand currents of the network infrastructure elements (nearby short-circuits), while maintaining as large as possible functionality of the system protection.

Application of an SFCL may have positive impact on operation of power systems. SFCL can improve voltage quality by reducing voltage dips [12], can be used to protect synchronization of generators with a power system [13] or to protect generators against consequences of faults [14].

The protection devices should protect components of a power system to which they have been designed, however, often they are also aimed at providing backup in some network configurations. Such a case often occurs when power line sections are protected. Proper setting of protection devices guarantees that every fault will be switched off, despite the failure of one of the protection relays. An SFCL installed in a specific power system node may affect operation of not only protection device installed at the same node but also operation of all following devices. For this reason, presence of an SFCL should be taken into account while setting all devices in order to ensure coordination of operation between them. In literature, coordination of overcurrent protections with dependent time characteristics can be found [15–20]. However, for protection devices installed in distribution networks independent time characteristics are quite frequently used. In this paper, studies of coordination between overcurrent protections with such characteristics applied in the network with an SFCL are presented.

2. Superconducting fault current limiter

The model of SFCL that was investigated in the simulative way is based on the structure described in [9,10]. This is an induction limiter which has two superconducting windings in parallel connection with the copper winding. The scheme of the SFCL is shown in Fig. 1.

In the superconducting state the SFCL has a structure analogous to a transformer with the primary superconducting winding connected in series with the protected circuit and the secondary winding shorted. Superconducting windings HTS1 and HTS2 are wound together, therefore they are characterized by practically identical parameters and a good magnetic coupling. The task of the secondary winding HTS2 is to compensate the inductance of the primary winding. Thanks to this the SFCL in the superconducting state is characterized by practically zero impedance and the superconducting circuit works as an air compensated reactor through which load current flows [21]. Another advantage is also the lightweight coreless construction, which could have important meaning in the implementation of SFCLs in existing substations.

Some electrical and construction parameters of the considered SFCL have been specified in the papers [9,10]. Based on this and additional experimental studies of superconducting tape properties the full set of parameters necessary to build the simulation model has been determined.

Nowadays the superconducting circuits of the SFCL system are built with high temperature superconducting tapes (HTS). These tapes are characterized by two basic limit parameters: the critical temperature T_C and the critical current I_C (the current at which the superconductor quenches). Fig. 2a shows a view of the test stand used for investigation on the properties of superconducting materials, and Fig. 2b shows a sample of testing tape with a length of 10 cm. This is the tape SF-12100 produced by SuperPower company.

The HTS tape resistance as a function of temperature is shown in Fig. 3. After exceeding the temperature $T_C = 90$ K this material is quenched and the resistance of the HTS changes in practically step mode and increases with temperature. This allows estimation

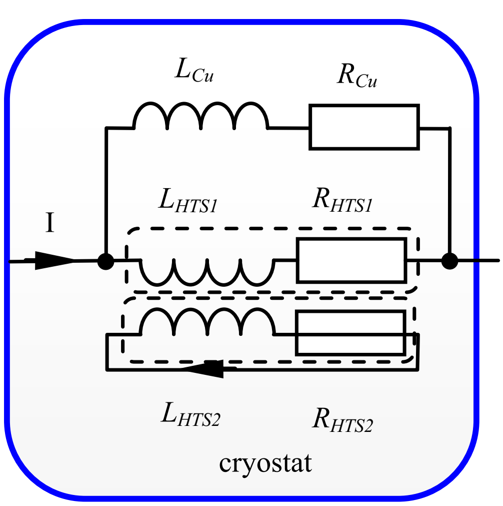

Fig. 1. Superconducting fault current limiter.

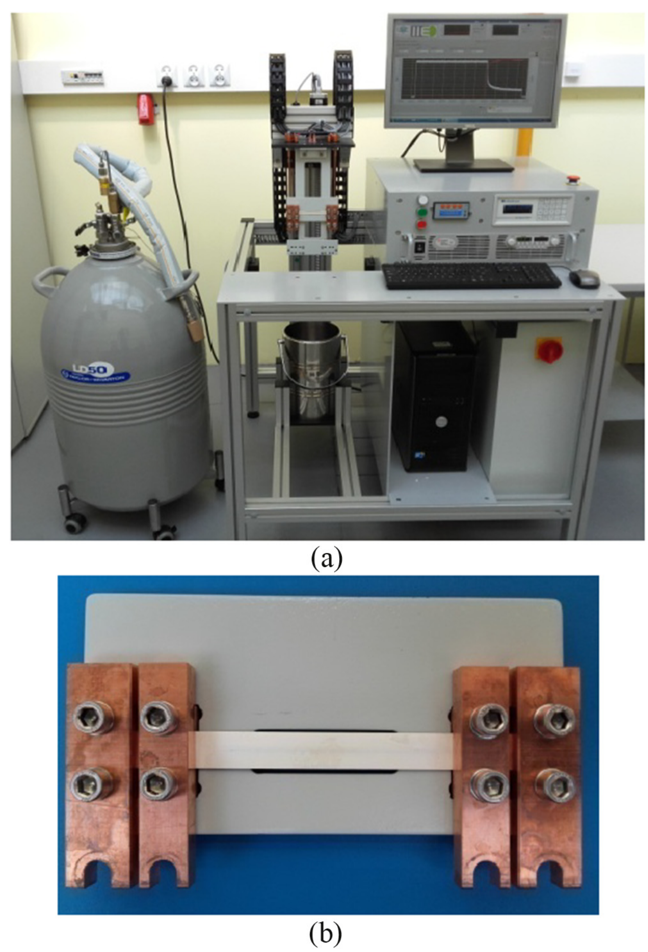

Fig. 2. Testbed to investigate the properties of superconducting tape: (a) testbed layout, (b) sample of the tested tape.