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Performance analysis of a Superconducting Fault Current Limiter in a power distribution substation

Antonio Colmenar-Santos*, J.M. Pecharromán-Lázaro, Carlos de Palacio Rodríguez, Eduardo Collado-Fernández

Department of Control System, Electronics, and Electrical Engineering, UNED, Juan del Rosal, 12, Ciudad Universitaria, 28040 Madrid, Spain

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ABSTRACT

All substations that make up an electric energy distribution system are vulnerable to unwanted voltage or current surges, with negative implications for the affected facilities. The consequence are economic losses for the companies which operate them as well as interruption of energy delivery. This paper presents the implementation of an advanced fault current limiting device based on second generation superconducting. The purpose of the system is to avoid the negative effects of network incidents. The research analyses the performance under the conventional operating conditions of a distribution substation in Spain. The results show a reduction of peak short-circuit currents, low operating losses and the correct operation of substation with interconnected busbars. The implemented system not only prevents economic losses due to the destruction or shortening of useful life of the equipment, but also increases the quality of energy supply to customers. The conclusion from the economic analysis is that the benefit-to-cost ratio of the technology would be positive with the estimated series-produced price for the system of 100000 €.

1. Introduction

All the specialist literature agrees that in the medium- and long-term future, the energy sector will suffer major technological changes. The massive introduction of renewable energy, distributed generation and smart grids allows the growth of small electric power systems with islanding capabilities. The introduction of new technological equipment with more demanding electronic components, in terms of power quality, and advanced digital instrumentation, requires a more demanding supply to consumers. This will be an excellent opportunity to further explore the weaknesses identified in legislation and standardisation, as well as the financial instruments needed to address the technology challenges. Having been one of the limitations, power interruptions are introduced into the network, when disturbances occur within these systems. To avoid these interruptions, a system has been designed (a more detailed description will be provided later). The technology aims to provide electrical energy with a little or practically no resistance (a property known as superconductivity) [1] with the consequence that electrical energy losses will be practically zero.

The system implemented is developed within the initiative of a European project, ECCOFLOW [2] and represents the latest research into superconductor technology applied to electrical networks [3]. Its main objective is to develop a current limiter based on second-generation high-temperature superconducting (HTS) cables [4] (Fig. 1), and all of which will now be abbreviated as SFCL. The ultimate goal is to integrate these systems into the substations of the electric distribution networks. The research on this advanced SFCL device operating on real distribution conditions is novel and complements the previous research.

Through the installation of the SFCL, the aim is to improve the operation, stability, quality of the supply and efficiency [5] of the electrical networks without the need to construct additional substations or new infrastructure.

The project's main objective is to observe the behaviour and analyse the results in the medium- and long-term. Additionally, the system was adjusted in order to achieve the optimal operation. Besides, it is acceptable that this prototype, mainly due to its high initial investment cost, cannot have a short-term economic depreciation.

The ultimate goal of the SFCL system is none other than to ensure proper operation and achieve the objectives specified by the distribution company. The quality of supply is expected to increase, as it is affected by the various incidents [6] which may occur in

Abbreviations: SFCL, Superconducting Fault Current Limiter; HTS, high temperature superconducting; YBCO, yttrium oxide, barium and copper; TIEPI, time equivalent installed power interruption; EDS, supplying energy left; HV, high voltage; MV, medium voltage; AC, alternating current.

* Corresponding author. Tel.: +34 913 987 788; fax: +34 913 986 028.
E-mail address: acolmenar@ieec.uned.es (A. Colmenar-Santos).

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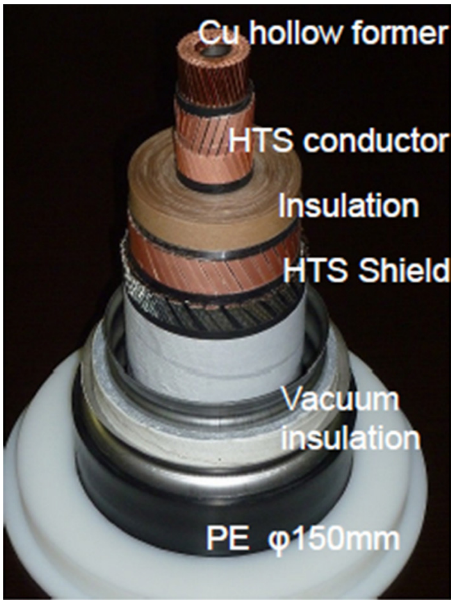

Fig. 1. Cross-section of a high-temperature superconducting cable (HTS).

medium-voltage networks and substations. Moreover, another consequence and result of the SFCL installation is that energy losses are minimised. Therefore, there are greater savings in costs for companies which have such a system installed.

It is important to note that, prior to its installation, a thorough analysis has been conducted to determine the ideal location for the installation of such a system with SFCL technology. It was an important part of the project, and researched together with the distribution company specialist staff. The primary objective of the analysis was the improvement of the quality of supply and the reduction of relevant negative incidents in HV/MV substations.

Before the installation process, the dimensions of the whole SFCL installation were taken into account. The feasibility was verified, since the minimum space required by the size of the SFCL installation is relatively small (below 100 m^2 as can be seen in Fig. 2) with respect to the available land within the conventional medium-voltage substation in which it was installed.

The weight of the SFCL installation is also insignificant, as basic foundation and ground levelling are sufficient to support the weight of all components.

An overview of the design of the SFCL system is shown in Fig. 3. This corresponds to the design process and the real installation.

Fig. 2. Location of the SFCL installation within the substation.

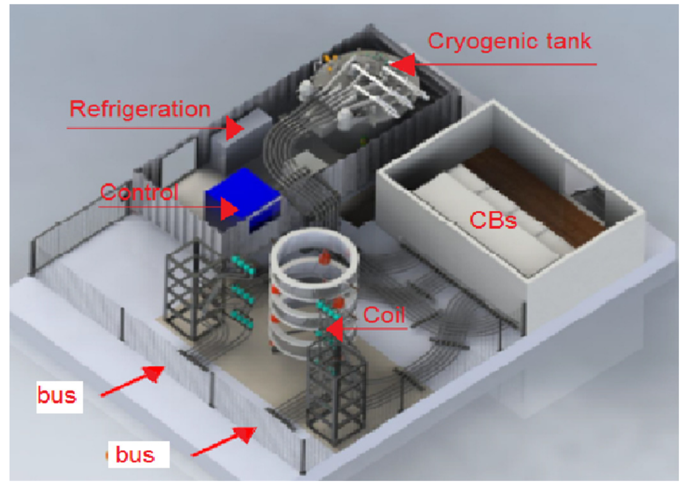

Fig. 3. Design of the overall SFCL system installed.

It shows all devices part of the installation, which will later be described in detail.

The SFCL in this project is arranged as medium-voltage longitudinal coupling busbars in a distribution network substation (Fig. 4), which are in turn electrically fed by two processors working in parallel [7].

The descriptions and details of each of the components that make up the whole SFCL are found in Section 2. Reference is also made to the original and final specifications required by the distribution company. Other relevant information about the components is also described therein. In Section 3, the main advantages and disadvantages are listed together. Finally, in Section 4, the economic investment of the project and the results as an experimental prototype model for experimentation and analysis are stated and justified.

2. Description of the SFCL installation components

The various components of the SFCL installation have been manufactured [8] taking into account the electrical parameters for installation required and specified by the distribution company (Fig. 5). These values have been supplied to the manufacturers to be taken into consideration when designing the different components so that the SFCL device can be seamlessly integrated into the

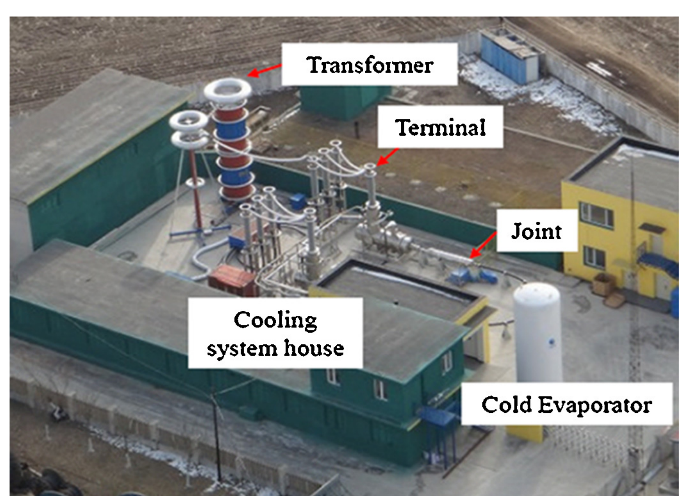

Fig. 4. Basic diagram of the SFCL device installation.