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A3 TRANSMISSION & DISTRIBUTION EQUIPMENT
PS1 Decentralisation of T&D equipment

Development of a 22.9 kV/2,000 A Compact R-SFCL

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SUMMARY

A 22.9 kV/2.0 kA resistive superconducting fault current limiter (R-SFCL) was designed and fabricated focused on compact size, modular design, and efficient operation of cryo-cooling system (CCS). And performance tests, including an electrical insulation test, a temperature-rise test, an impedance test and a fault current limitation test, were successfully passed at LS ELECTRIC's PT&T and KERI, the official certification institute. The R-SFCL is scheduled to be installed on the 22.9kV bus section between two 154/22.9 kV transformers in the Seogochang substation of KEPCO in 2022. In order to prevent the spread of fault current between the interconnected system, the R-SFCL plays a role in limiting the fault current as soon as the fault current occurs.

KEYWORDS

Fault current limiter, FCL, Resistive superconducting fault current limiter, R-SFCL, Power system interconnection, Fault current

I. INTRODUCTION

Recently, problems such as lack of resources, environmental pollution, climate change, etc. caused by the development and use of fossil energy on a large scale have become global issues. As a countermeasure against this, a carbon-neutral policy was established, plans for large-scale expansion and supply of renewable energy and interconnection with existing power grids are increasing. This interconnected operations between power grids may generate a fault current exceeding the rating of the circuit breakers installed in the existing system.
In order to stably interconnect these power grids, it is being positively considered to install a resistive-superconducting fault current limiter (R-SFCL) at the power system interconnection point. In other words, installing SFCL at the power system interconnection point can be a solution to replace all traditional inefficient measures - installing reactors, replacing with circuit breakers that has a large capacity, and increasing % impedance of transformers - that have been used so far.

Item	Specification
Ratings	22.9 kV, 2000 A, 60 Hz
Electrical Insulation	AC 60 kV/min / Lightning Impulse 150 kV BIL
Limited Fault Current	under 15 kA_{peak} (for 1st 1/2 cycle)
	~ 2.2 kA_{rms} (for 0.4 s after 1st 1/2 cycle)
Size	Superconducting Unit : W1.7×D3.0× H3.25 m
	High Speed Impedance Unit :W2.6×D3.0×H3.25 m

Figure 1. Appearance and specifications of a 22.9 kV/2.0 kA R-SFCL

The R-SFCL is an electrical power equipment utilizing changes in physical properties of the superconductor. In usual time, R-SFCL does not give any impacts on power system but when fault current occurs in the power grid, it is activated without relaying signal so that the fault current is immediately limited the initial fault current that cannot be blocked by a circuit breaker. There have been more than 20 developments and field tests of SFCLs in the world [1]. A dozen manufacturers were involved in development of the SFCLs. LS ELECTRIC developed SFCL having the ratings of 22.9 kV and 630 A [2-4], in collaboration with Korea Electric Power Corporation (KEPCO) Research Institute. The SFCL was installed at KEPCO's Icheon substation and successfully performed field testing for two years [5, 6]. Recently, KEPCO is planning a pilot operation of a 22.9kV power grid interconnection by installation of R-SFCL on the 22.9kV bus section between two 154/22.9 kV transformers in the KEPCO's Seogochang substation in 2022, as a first step to respond to changes of the electrical power systems, which has scaled up and complicated further. The R-SFCL here plays a role in limiting the fault current immediately after the fault current occurs, so that the fault current does not affect interconnected power grid. This report describes the specifications, design [7], fabrication, performance tests, and future plans of the 22.9 kV/2.0 kA R-SFCL for power system interconnection.

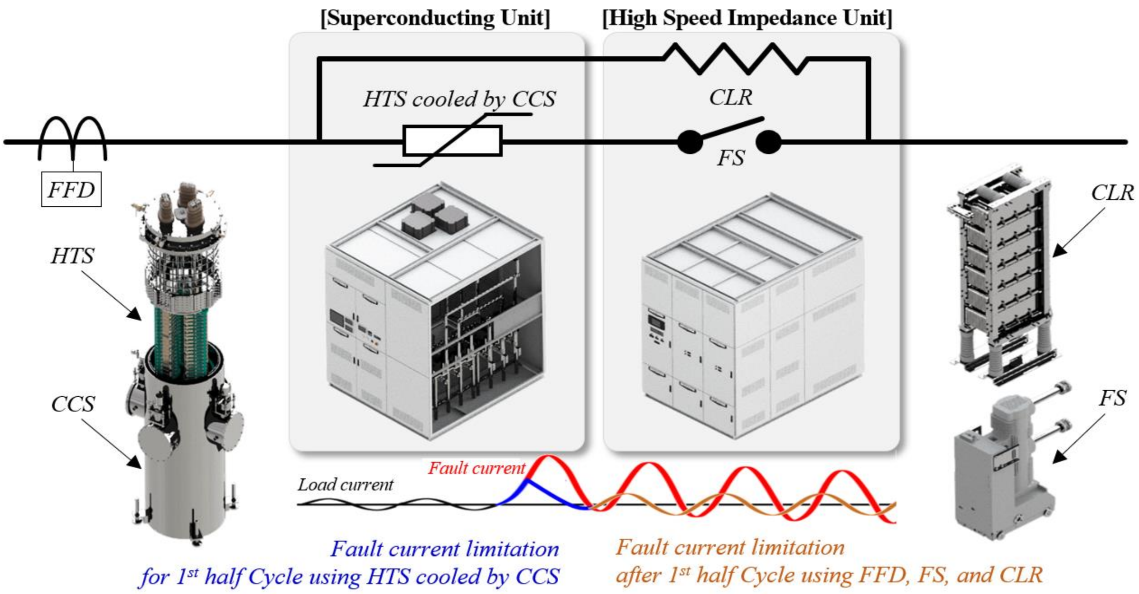

Figure 2. Circuit diagram and configuration of 22.9 kV/2.0 kA R-SFCL

II. SPECIFICATIONS AND DESIGN

The 22.9 kV/2.0 kA R-SFCL was developed with specifications as shown in Figure 1 and designed focused on compact size, modular design, and efficient operation of cryo-cooling system, as shown in Figure 2.

1. Compact and space-independent design

The R-SFCL consists of two detachable cubicle switch boards as shown in Figure 2. One cubicle is the superconducting unit in charge of current limiting for only the 1st half cycle of the fault current. It includes high temperature superconducting (HTS) module and the cryogenic cooling system (CCS). Another is the high speed impedance unit in charge of current limiting after the first half cycle of the fault current. It consists of a fast fault detector (FFD), a fast switch (FS) and a current limiting resistor (CLR). The high speed impedance unit reduces the time that the HTS module limits the fault current, eventually makes the large-capacity R-SFCL compact. Each volume of the cubicle switchboard is W1.7×D3.0×H3.25 m for the superconducting unit excluding junction panel, and W2.6×D3.0×H3.25 m for the high speed impedance unit. And also, each unit can be installed side by side or separately. It can even be installed in a different floor of the substation building. In other words, the R-SFCL is designed in a structure that can be installed in any substation where there is not enough space.

2. Modular design and flexibility

The main components responsible for limiting fault current, the HTS module and the CLR, are modular designed for flexible applications in various fields such as ratings, specifications, and installation conditions. For the HTS module, it is designed to consist of series and parallel combinations of single bifilar coil made by winding 35 m long second generation HTS tape, supplied from SuNAM. Because allowed voltage and critical current of the HTS tape are 75 V/m for 50 ms and 750 A at 77 K, the specifications of the single bifilar coil are 2.6 kV and 500 Arms. In order to meet the ratings of the single-phase HTS module with 13.2 kV and 2.0 kArms, it consists of five sub-modules in series, and each sub-module carries four bifilar coils in parallel. That means, it takes 60 single bifilar coils to build three phases of 22.9 kV/2.0 kA R-SFCL. In case of CLR, the resistance value of 6 Ω is determined in consideration of the protection coordination with conventional relays in the power grid, and the CLR is assembled in a series combination of unit modules with 1 ohm.

3. Efficient operation of CCS

The GM cryocoolers with inverter compressors are applied for efficient partial-load operation of the CCS. The design goal is to maintain three phases of HTS module in a sub-cooled LN2 bath at 77 K and 0.3 MPa. In order to cover the full thermal load at the rated current of 2 kA, four units of GM cooler (Cryomech AL300) are installed evenly around a vertical cryostat, conductively cooling the exterior wall of LN2 container at the height of liquid level. Since the thermal load is strongly dependent on the actual current, the refrigeration capacity of GM coolers is reduced by turning down the inverter frequency of compressors for normal operation with a current level below 2 kA. The frequency can be controlled in a range between 75 Hz (maximum) and 40 Hz (minimum) according to the load current between 2 kA and 1.4 kA. When the current is lower than 1.4 kA, the frequency is set at its minimum (40 Hz) and the on-off operation of electrical heater is applied for usual temperature control.

III. FABRICATION AND PERFORMANCE TEST

As shown in Figure 3, the R-SFCL performance tests to verify the specifications in Figure 1 have been successfully passed at LS Electric's PT&T and KERI, the official certification institute.

An electrical insulation test was passed successfully, two conditions were met: the power frequency withstand voltage test (60kVrms/1 min) and the impulse withstand voltage test (150kVIL). And also, a temperature-rise test and impedance test are passed. In case of a fault current limitation test, the test was conducted only in a single phase, because of a generator capacity. A symmetric and an asymmetric fault current of 25 kA was applied to the R-SFCL for more than 0.4 seconds, and the fault current was limited by the R-SFCL to a level that satisfies the specifications of Figure 1. Figure 4 shows that prospective asymmetric fault current of 25 kArms is limited to the 8 kApeak by HTS module for 1st half cycle and to 2.0 kArms by CLR after 1st half cycle.

(a) Electrical insulation test (b) Fault current limitation test

(c) Temperature-rise test

Figure 3. KERI Performance test photographs

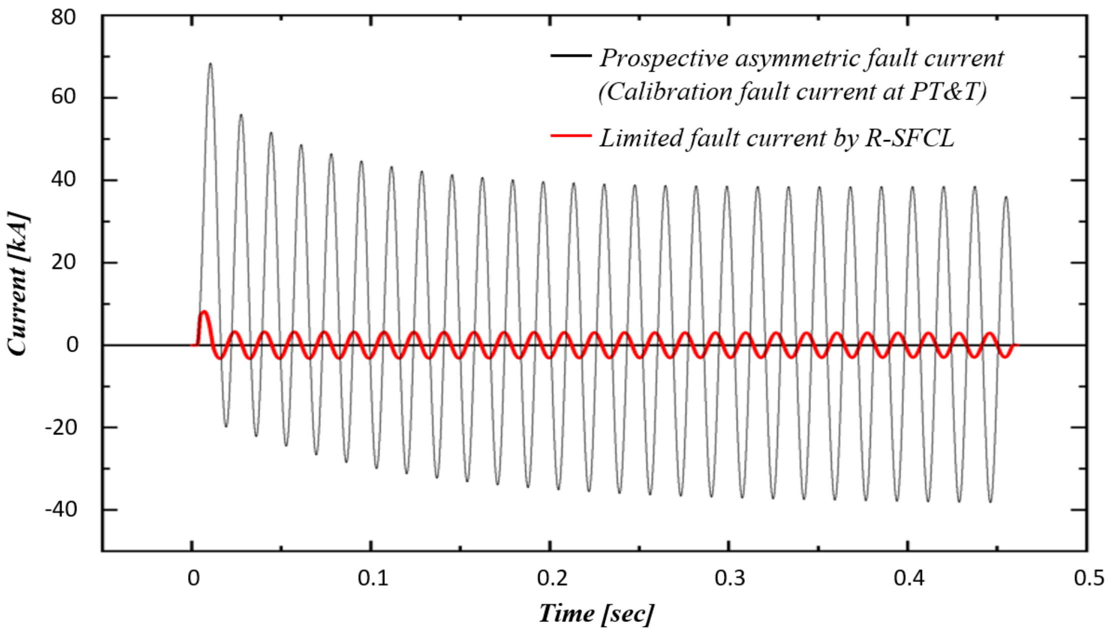

Figure 4. 13.2 kV/25kA Asymmetric fault current limitation test for single phase R-SFCL

IV. Future Activity

From 2022, infrastructure construction for the installation and operation of R-SFCL at KEPCO Seogochang substation is planned. In addition, in order to stably and efficiently operate the parallel operation of the two 154/22.9kV transformers, which are being carried out as KEPCO's first pilot project, it plans to establish a 22.9kV bus connection operation plan (including protection coordination between conventional relays in the power grid) with KEPCO. After installing the R-SFCL at KEPCO's Seogochang substation, the artificial fault current (AFG) test will be conducted to check whether protection coordination between conventional relays is appropriate when the R-SFCL limits the fault current in the real power grid. Here, the AFG is a device that artificially generates fault current and controls the fault current level by adjusting the impedance of the reactor coil in connection with the real grid. After the AFG test in the real-system, a long-term simulated load test that applies a current varying from 100A to 2,000A to R-SFCL using power supply will be conducted for 3 months to evaluate the long-term operational reliability of the CCS. Once the CCS's operational reliability is proven, the pilot operation, which is to operate in interconnected state the 22.9kV bus section between two 154/22.9 kV transformers by applying R-SFCL between transformers, will begin at KEPCO's Seogochang substation in 2023.

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