A model experiment of current limiting characteristics of superconducting fault current limiter in the demand side with distributed generator

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Abstract. Superconducting Fault Current Limiters (SCFCLs) are expected to improve both reliability and stability of power systems. Specifications of SCFCLs, such as trigger current level, recovery characteristic and impedance must be considered precisely in introducing SCFCLs to a power system. In this paper, current limiting characteristics of SCFCL in the demand side, (that is, a customer who has distributed generators and loads), is studied and demonstrated experimentally by use of a small 18kVA synchronous test generator with a test three-phase SCFCL unit of a transformer type and an artificial transmission line. In general, a current limiting reactor of normal conductor is installed in order to reduce the large fault current from the generator, however, it also decreases the maximum output power of the generator to the grid. The current limiting tests were carried out by replacing the reactor with the SCFCL. It was experimentally confirmed that SCFCLs can suppress the fault current considerably and can improve the transient stability at a certain fault without reducing the steady state stability margin.

1. Introduction

Recently, the distributed generators (DGs) are introduced to the load system side. The fault current will increase with installation of DGs. Fault current limiting devices may be necessary especially in case that the DG is a synchronous generator. Usually a limiting reactor is set in series to the DG as a fault current limiting device. It reduces the fault current from the DG to the grid at the fault condition. However, it also reduces the maximum generator power which can be transmitted to the grid in steady state operation because of the terminal voltage drop due to the series impedance of the reactor. Superconducting fault current limiter (SCFCL) has low impedance in the steady state and switches to be high impedance at the fault. It can reduce the over-current and also keep the transmittable generator power. Many types of the SCFCL have been studied, for instances, [1]-[3], but there are little discussions on the functions of the SCFCL in the power system with distributed generators. In the previous papers, the authors carried out the demonstration test of three phase SCFCLs in the laboratory scale power system simulator [4],[5]. Excellent features of the SCFCLs were confirmed experimentally in the current limiting function, in the power system transient stability improvement and in the repetitive operation.
In this paper, the functions and the effects of a SCFCL to protect DGs were studied experimentally by use of a small 18kVA synchronous test generator with a test three-phase SCFCL unit of a transformer type [3]. The SCFCL is installed instead of the current limiting reactor. It is expected that since the impedance of the SCFCL in the waiting mode is small, it has a small influence on the steady state stability. And it turns to be large immediately at the fault and the large transient currents of the armature and the field windings of the generator are reduced compared with those without SCFCL.

2. Experimental system

![Diagram](image1)

Figure 1 Assumed demand side system with distributed synchronous generator and SCFCL at incoming feeder.

![Diagram](image2)

Figure 2 One unit of 3-phase SCFCL of transformer type and an experimental system for demonstration of the SCFCL in the demand side with distributed generator (DG). The inductance of primary coil of SCFCL is 3.82 mH, that of secondary coil is 0.69 mH and the mutual inductance is 1.43 mH, leakage inductance is 0.454 mH.

In this experiment, as shown in Figure 1, we assumed that a fault occurs in a feeder to demand side with a distributed generator, and investigated the characteristics of SCFCL installed at the feeder, such as protection of the distributed generator and loads and reduction of short-circuit capacity. Figure 2 shows an experimental system corresponding to the system shown in Figure 1. A synchronous generator (18.26 kVA, 200V ratings) and a load (0 kW ~ 3.0kW) are connected to an infinite bus through reactors (line models). The field current of the generator is supplied by a constant voltage source and set 19.2 A. Three ramp-loads that consist of plural light bulbs (200W per each) connected in parallel are used for the three-phase load. The reactors La, Lb and Lt simulate distribution lines and a transformer, respectively. By closing a switch Sw1, three-line grounded fault is simulated. A switch Sw2 is closed after the fault clear to shunt the fault current and to make the SCFCL recover to the waiting mode. The SCFCL was replaced by the reactor of 0.32mH or the short circuit line for the stability tests.
3. Experimental results and discussion

3.1. Current limiting tests

The generator output and the load were set 3.0 kW and 1.5 kW, respectively. It was confirmed that every unit of three-phase SCFCL turned into the current limiting mode as soon as the current of the fault reached the trigger current level at the simulated fault. Figure 3 (a), (b) and (c) show one of the experimental results at the three-line grounded fault with and without SCFCL, and with reactor, respectively. The field current of generator, U-phase of the generator voltage, the current, the line to line voltage of the load and the fault current of U-phase are listed from top to bottom.

While the peak of the fault current reached 590.8 A without SCFCL, it was suppressed to 307.8 A with SCFCL. It means that the SCFCL in the incoming feeder reduces the short-circuit capacity that increased because of introduction of the DG. The peak of the field current reached 120.0 A without SCFCL was suppressed to 46.3 A by SCFCL. While the peak of the generator current reached 430.2 A without SCFCL, it was suppressed to 140.2 A with SCFCL. The function of the SCFCL in the incoming feeder to protect the DG from the over current at the fault was demonstrated.

At the same time, the voltage of load was kept more than 80 Vrms with SCFCL. The power to the load during the fault dropped almost 0kW. On the other hand, it was kept to some level with SCFCL.

3.2. Steady state stability test

If the reactor whose impedance is same as that of the SCFCL in current limiting mode is installed in incoming feeder, the same current limiting characteristics as the SCFCL are expected at the fault. The
reactor of 3.2 mH was set instead of the SCFCL whose current limiting impedance is 1.2 Ohm (3.8mH inductive). As is shown in Figure 3 (c), almost the same current limiting characteristics as those of the SCFCL were confirmed.

Next, the steady state stability test was carried out with SCFCL or the reactor or neither of them. The generator output was increased gradually keeping the field current constant (19.2A). The terminal voltage of the generator decreases as the output increases for every case as shown in Figure 5. However, since the generator angle is larger with the reactor than that in other cases for the same output, the generator reactive power is also larger and the terminal voltage drop is larger. There was no stable operating point with more than 5kW output in case of the reactor and the generator stepped out, while it can supply 7kW in both cases of the SCFCL and the short-cut. It was confirmed that the SCFCL can reduce the fault current without decreasing the maximum output power and the power system stability margin.

4. Conclusion
Experimental study for investigation of the current limiting characteristics of SCFCL installed in incoming feeder to demand side was carried out. The following results were obtained.

- The SCFCL turns into the current limiting mode immediately after the fault current reaches the trigger current, and suppresses the fault current effectively.
- The distributed generator is successfully protected from the over current at the fault by the SCFCL.
- Power supply to the load continues to a certain extent during the fault by use of the SCFCL.
- It was confirmed that the SCFCL can reduce the fault current without decreasing maximum output power of the generator and the stability margin

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