The first Italian Superconducting Fault Current Limiter: Results of the field testing experience after one year operation

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The first Italian Superconducting Fault Current Limiter: Results of the field testing experience after one year operation

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Abstract. Ricerca sul Sistema Energetico S.p.A. (RSE) has been gaining a relevant experience in the simulation, design and installation of resistive-type Superconducting Fault Current Limiter (SFCL) devices for more than five years in the framework of a R&D national project funded by the Ricerca di Sistema (RdS). The most recent outcome of this research activity is the installation of a resistive-type BSCCO-based 9 kV / 3.4 MVA SFCL device in a single feeder branch of the Medium Voltage (MV) distribution network managed by A2A Reti Elettriche S.p.A (A2A) in the Milano area. This installation represents the first SFCL successfully installed in Italy. In this paper, we report on the main outcomes after a more than 1-year long steady-state field testing activity. The design of an upgraded device to be installed in the same substation has already been initiated: the new SFCL will allow to protect four different feeders, therefore implying a device upgrade up to 15.6 MVA.

1. Introduction

Superconducting Fault Current Limiter (SFCL) devices enable us to manage the ever-increasing short-circuit currents in distribution grids. For this reason, SFCLs are highly desirable for utilities [1]-[2]-[3]. The historical trend of SFCL designs and applications was already summarized in several works [4]-[5], therefore we hereby focus the attention on the first Italian SFCL device successfully installed in a real distribution grid. This project has been carried-out by Ricerca sul Sistema Energetico S.p.A. (RSE) in the framework of a R&D national project funded by RdS: the main goal of the project is to conceive a first generation (1G) BSCCO-based resistive-type SFCL for Medium Voltage (MV) distribution grids. The main outcome consists in a 9 kV / 3.4 MVA SFCL 3-phase device nowadays permanently installed as a single-feeder fault protection in the S. Dionigi substation (Milan) belonging to A2A Reti Elettriche S.p.A. (A2A), the second largest Italian utility.

The first steps of the project were already summarized [6]-[7]. This paper is aimed at describing the results gathered during the first year of steady-state operation at the S. Dionigi substation.

2. SFCL basic aspects

2.1. SFCL specifications and tests

Table 1 reports on the network requirements characterizing the installation site. According to A2A, the most important specification is that the SFCL device has to guarantee a Limitation Factor (LF) comprised between 1.7 and 2, being LF the ratio between the prospective short-circuit current I_{SC} and

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the limited short-circuit current I_{Lim}. Besides the grid requirements, Table 1 provides also a comparison with the short-circuit tests parameters.

Table 1. Comparison between grid requirements and short-circuit test parameters

Parameter	**A2A Requirements**	**Short-Circuit Test**
Rated voltage V_{nom}	9 kV_{rms}	12 kV_{rms}
Rated current I_{nom}	220 A_{rms}	220 A_{rms}
Prospective short-circuit current I_{SC}	12.3 kA_{rms}	12.3 kA_{rms}
Maximum prospective short-circuit current I_{SCP}	30 kA_p	33.2 kA_p
Ungrounded short-circuit duration t_{fault}	400 ms	300 ms
Limitation factor LF = (I_{SC} / I_{Lim})	1.7 - 2	1.83

All the design details are described in [6]-[7], therefore it is worthwhile here just mentioning that the SFCL device is made of a HTS BSCCO-2223 tape total length of less than 2 km (1880 m) with self-field end-to-end critical current I_C of 180 A at 77 K; in addition, each phase is shunted by an air-core reactor and a closed-circuit Liquid Nitrogen (LN) re-liquefier is used. As described in [6], dielectric and short-circuit tests validated the SFCL readiness for the grid installation.

2.2. SFCL installation
The whole system is composed by several parts. In Figure 1 and Figure 2 are shown, respectively, a picture of the installed SFCL system and a general description of the main SFCL system components. A detailed description of components and of the acquisition system is given in [6]-[7].

Figure 1. SFCL ready for in-field activity

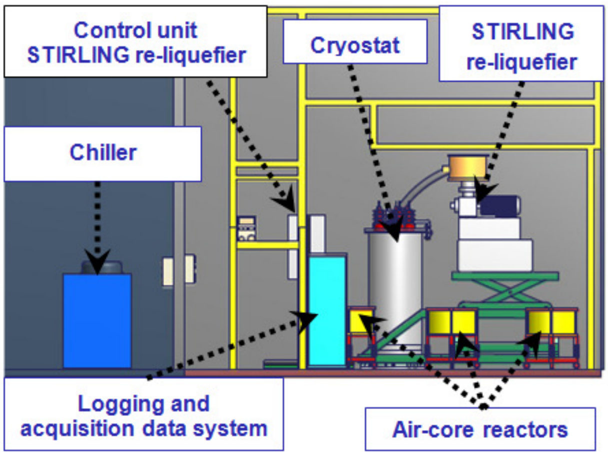


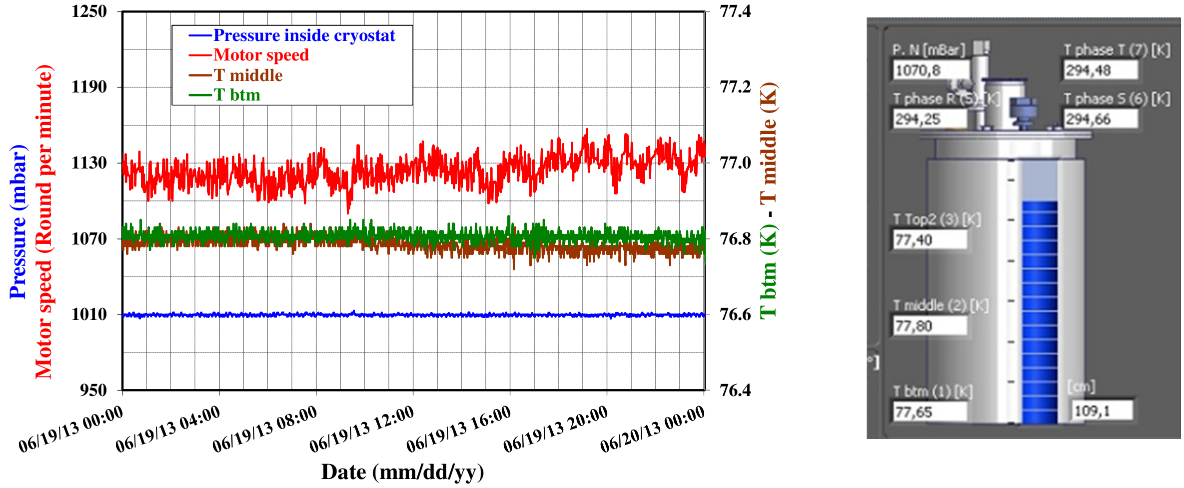
Figure 2. Components description of the installation

3. Field-testing activity of the 9kV/220A SFCL
After having definitely fixed the final connections (Figure 1), the device was officially energized in March 2012, launching a more than one year long in-field testing activity.

The SFCL device worked until the end of June 2013 featuring a 100% availability in the last ten months. At the end of June, the refrigeration system routine maintenance was mandatory due to the achievement of the maximum amount of operation hours foreseen by the manufacturer, therefore the device was switched-off. This temporary outage offered the chance to improve at the same time some features of the acquisition system, hence the SFCL was "re-energized" in the beginning of October 2013 for other six months of in-field testing activity.

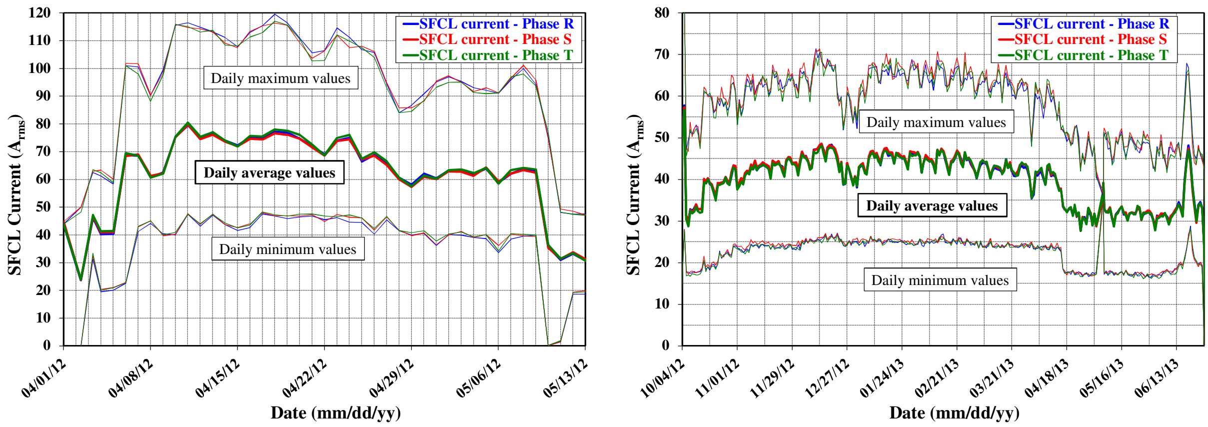
The first preliminary results of the field testing activity were already shown in [7]; here we step forward with the discussion of the most relevant data gathered throughout the whole experimentation. Figure 3(a) is referred to June 2013 and shows the time-behavior throughout 24 hours of both LN pressure and motor speed (i.e. the motor driving the LN re-liquefier), along with the temperature of the

LN bath at two different levels (T_{btm} at the cryostat bottom and T_{middle} at the cryostat medium height), whereas Figure 3(b) provides a graphical representation of the probes position for pressure, temperature and LN level measurement. Figure 4(a) emphasizes the time period from April 2012 to May 13th 2012 characterized by high load conditions (up to 120 A_{rms}) and Figure 4(b) shows the trend of SFCL currents from October 2012 until June 2013.



(a) (b)

Figure 3. (a) Time evolution throughout 24 hours of the motor speed, pressure inside cryostat and liquid nitrogen temperatures at two different levels. (b) Synoptic scheme showing the measurement probes position for pressure, temperature and LN level



(a) (b)

Figure 4. (a) Transport current in the period from April 2012 to May 13th 2012 that corresponds to the condition of higher load; (b) Trend of currents flowing through the SFCL device in a selected period of time (October 2012 - June 2013)

The current level was in agreement with the one A2A foresaw for this first phase of in-field activity and in Figure 5 a zoom of the current level in the third week of June 2013 can be appreciated. One of the most interesting features of the testing activity occurred in January 2013, when an unexpected increase in the LN bath level was noticed. Since the checks on the LN level sensors did not point-out any anomalies, it was assumed that some air could have entered the cryostat, being the pressure inside slightly lower than outside, and could have been liquefied by the refrigeration system. In agreement with this assumption, it was decided to slightly increase the pressure inside the cryostat from 990 mbar, lower than the room pressure and corresponding to a liquid nitrogen temperature of 76.8 K, to 1010 mbar, higher than the room pressure and corresponding to a liquid nitrogen temperature of 77.1 K. In Figure 6 the stabilizing effect of the pressure enhancement on nitrogen level is shown.

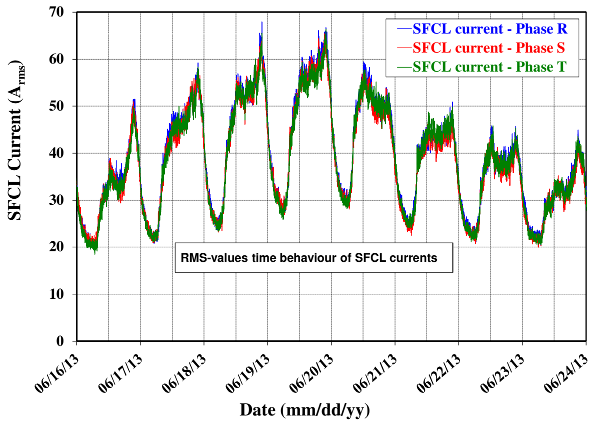


Figure 5. Current RMS-values trend inside the SFCL during the third week of June 2013

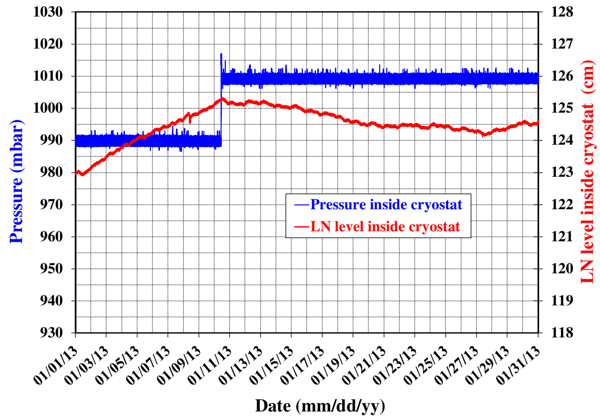


Figure 6. Enhancement in cryostat pressure and effect on liquid nitrogen level

4. Conclusions

The first Italian SFCL device has been installed in a real distribution grid. This project has been carried-out by RSE in the framework of a R&D national project and the result is a resistive-type BSCCO-based 9 kV / 3.4 MVA SFCL installed as a single-feeder fault protection in a A2A substation of the Milan area. The SFCL was commissioned in March 2012, thereby launching a more than one year long field-testing activity. The results gathered in the first phase of field-testing activity confirmed that the SFCL worked as expected in steady-state conditions. After this first success, we will proceed with the analysis of the SFCL behaviour during real fault conditions in the distribution grid; afterwards, the design of the upgraded SFCL (9 kV / 15.6 MVA) to be installed as transformer protection in the same substation has been already initiated. In the upgraded installation, the device will protect 4 feeders where the probability of faults is much higher.

Acknowledgements

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