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Application of Electrical Industry Standards to Superconducting Fault Current Limiters

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***Abstract* - Superconducting fault current limiters (SFCLs) are a novel type of electrical equipment designed for protection of high-voltage (10 kV and higher) power grids. At present around 20 SFCLs are installed worldwide. All these SFCLs have custom design and are specifically tailored to installation site specifics. This may limit widespread application of this technology since each new SFCL installation requires different design, and as a result - multiple approvals from numerous parties (utilities, government, etc.) which is labor-intensive and time-consuming processes. To reduce the efforts required for equipment approval electrical industry developed an extensive system of standards, and thus it is necessary to explore the possibility to create an SFCL which complies with existing standards. This article examines the existing regulations for the closest to SFCL equipment – current limiting reactors (CLRs), deduces the possibility of applying these regulations to existing SFCLs, provides requirements which SFCLs are yet to satisfy and, finally, estimates the basic technical specifications of SFCL which should comply with all the requirements studied.**

***Index Terms* - fault current, fault current limiter, superconductor, short-circuit current**

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I. INTRODUCTION

Recent commercial availability of second-generation high temperature superconductors (2G HTS) [1] enabled production of new type of electrical equipment – superconducting fault current limiters (SFCLs). This equipment is designed to protect electrical grids by reducing in-grid electrical current during faults [2]. Up to date several SFCLs were successfully produced, tested and put into in-grid operation [3, 4, 10], with the highest power-rated 220 kV SFCL in Moscow, Russia being in daily operation up to present day [5]. Several high-voltage SFCL devices are being developed, including 160 kV SFCL in China [6] and 380 kV in Europe [7].

All of the listed SFCLs are custom-build devices, specifically tailored to installation site specifics. This approach may simplify some technical requirements to SFCL (such as fault current magnitude and duration values) but limits installation opportunities (not all substations can accept installation of custom SFCLs). It also increases SFCL onsite engineering and construction expenses. As a result, widespread application of SFCL technology may be hindered.

To simplify engineering and construction of electrical equipment power grid industry provides extensive system of standards. Designing SFCLs using available standards as a reference is a valid approach to make integration of the technology into existing power grids easier.

The standards for SFCL devices are scarcely present. General rules for SFCL specifications and testing are provided in IEEE C37.302-2015 [8]. Being a relatively new standard, it provides limited data regarding the specifics of tests, making SFCL customer decide the properties of SFCL by themselves, developing their own specifications which results in fore mentioned costly and complex custom solutions.

The closest devices to SFCLs by its properties and purpose are current limiting reactors (CLRs). CLR provides constant (same during fault and during normal load) impedance, thus limiting fault currents in adjacent grid. As CLR impedance is constant, its in-grid utilization has its shortcomings such as power losses and power quality issues. SFCL lacks such drawbacks, providing reduced resistance during normal operation and increased – during faults [9]. As a result, direct economic comparison between CLR and SFCL is difficult since CLRs may be impossible to install with required impedance or in acceptable quantities. For example, in 2011 [11] it was shown installation of CLRs in comparable with SFCL quantities results in reduced grid stability since CLRs have high resistance constantly. CLRs in large quantities or resistance block power transmission sometimes rendering their massive usage in city grids impossible. Consequently, economic comparison between SFCL and switchgear is preferable for some highly loaded city grids. Since the technical scope of SFCL application is broader than CLR it is reasonable to access SFCL as an improved CLR, with specifications that exceed CLR requirements.

CLRs have a broad regulatory base. General requirements to CLRs are given in IEC 60076-6 (Power transformers - part 6: reactors). Regional standards (for example PAO Rosseti organization standard 56947007-29.180.04165-2014) may provide even more details regarding equipment ratings, testing details and other requirements. However, several ratings (such as thermal current withstand time) are notably stricter for CLR compared to existing SFCL devices. Verification whether these CLR-specific requirements can be met by SFCL is required while still meeting SFCL-specific standards such as IEEE C37.302-2015.

This paper provides comparison between several SFCL and CLR standards for 110 kV and 220 kV

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voltage class (Table I). These voltage classes are chosen since 110 and 220 kV grids are mostly affected with high fault current levels to authors knowledge and most countries use voltages in 110-220 kV range for power transmission. The table lines correspond to requirements listed in the standards. Column F proposes best to date values for existing in-grid SFCL devices. Column G compares requirements from columns C-E with values in table F, stating possibility to meet the requirements with the following status:

1. complies - existing SFCLs comply with requirement,
2. possible - compliance is not demonstrated on full-scale, but expected to be possible,
3. not applicable – requirement cannot be applied to SFCL.

In case no existing device provides the required value, we provided our estimations based on experiments or calculations (described below in results).

TABLE I.
List of Standards for CLR Comparing With Best to Date SFCL Devices.

A	B	C	D	E	F	G
№	**Requirement**	**IEEE C37.302-2015**	**IEC 60076-6**	**PAO Rosseti 56947007-29.180.04.165**	**Best to date in-grid SFCL**	**Compliance**
1.	Rated voltage	Not specified		110 kV 220 kV	220 kV [5]	Complies
2.	Maximum rated voltage	Not specified		126 kV 252 kV	252 kV [5]	
3.	AC withstand voltage	Test required		200 kV 395 kV	440 kV [5]	
4.	BIL test voltage	Test required		480 kV 950 kV	950 kV [5]	
5.	Rated continuous current (RCC)	Not specified		250; 400; 630; 1000; 1600; 2000; 2500; 4000 A	Up to 2300 A [3,5]	
6.	Rated short-time current (RTC)	Test required		1.2 RCC 60 min 1.3 RCC 45 min 1.4 RCC 32 min 1.5 RCC 18 min 1.6 RCC 5 min	1.6 RCC 0.4 s [5]	Possible. Described in sec. 3.1
7.	Rated short-circuit duration (RSD)	Not specified	2 sec	3 sec	400 ms [5]	Possible. Described in sec. 3.2
8.	Rated short-circuit impedance[1] (RSI)	Not specified			40 Ohm [5] 6.6 Ohm [12]	Possible. Described in sec. 3.3
9.	Rated continuous impedance (RCI)	Not specified			<0.1 Ohm [5]	
10.	Rated thermal short-circuit current (RSC)	Test required		$\frac{U}{\sqrt{3}(Z_{SFCL}+\frac{U^2}{S_{SC}})}$ [2]	1.2 kA [5]	Possible. Described in sec. 3.4
11.	Rated mechanical short-circuit current	Not specified	2.55 RSC	2.55 RSC	5.8 RSC [5]	
12.	Recovery under load	Test required	Not specified		Not presented	Possible. Described in sec. 3.5
13.	Interval between fault conditions	Not specified	At least 6 h	Allowed after auto reclosing	47 sec [5]	
14.	Temperature rise at RCC	Not specified	According to IEC 60076-7	60°C 80°C	<75°C for 220 kV [5]	Complies
15.	Partial discharge	Test required	Not specified		Test successfully passed [5]	
16.	Electromagnetic compatibility	Test required	Not specified		Test successfully passed [5]	Complies

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17.	RCI tolerance	Not specified		<15%		<10% [5]	
18.	Coupling factor	Not specified		0.4-0.6		-	Not applicable
19.	Temperature due to RSC and rated short-time current loading	Not specified	According to IEC 60076-5:2006	180°C copper	250°C copper	-	

[1] after 50 ms (typical time of switchgear operation) under SC due to manufacturing constraints is proposed.

[2] Formula description: U – rated voltage, Z_{SFCL} – SFCL impedance in the end of RSD, S_{SC} - short circuit power: 25000 MV·A for 220 kV, 15000 MV·A for 110 kV.

Several requirements from standards are not applicable strictly for SFCL (marked “Not applicable” in column “G”):

1. Coupling factor (line 18) is not applicable for SFCL due to SFCL single phase construction.
2. Temperature due to RSC and rated short-time current loading (line 19) are applicable for current leads only which are tested by producer according separate standard. For example, current leads for 220 kV SFCL [5] are tested according regional standard GOST 55187 which includes temperature rise tests.

There are fundamentally two types of SFCLs based on the type of load introduced into the network during a short circuit: resistive and inductive. Resistive SFCL construction and operation principles are thoroughly described in [2], [13].

The work examines in detail the requirements for CLR devices, for which resistive SFCL technology has not yet reached the required values (marked “Possible” in column “G”) and proposes technical specifications for resistive SFCL which may fulfill these requirements. Other SFCL types may be designed to fulfill the requirements listed, but this work focuses on resistive type of SFCL where the authors have most experience with.

II. MATERIALS AND METHODS

SFCL specifications provided in this article are based on test results made on samples listed in Table II. Samples were made using S-innovations 12 mm 2G HTS wire (wire critical current being in range of 450-600 A) laminated with varied amount of stainless steel (0.2 – 12 mm) to provide different thermal stability (400 – 3000 ms) and enable recovery under load since higher amount of stainless steel results in increased thermal withstand ratings and faster recovery time. 40 mm width allows to combine several 12mm HTS wire to reach higher critical current while providing sufficient thermal exchange with liquid nitrogen medium to enable thermal withstand and recovery. Module and SFCL phase critical currents are specific requirement of customer. We propose less critical current to meet all standard requirements.

Model samples were tested using proprietary SuperOx test bench with electrical scheme on Fig. 1B. Test bench consists of three electrical circuits: switch K1 turns on short-circuit currents (duration is up 1 minute with 20 ms gap), switchers K2 and K3 change electrical scheme to nominal mode with short-time current and rated continuous current (duration up to hours). Test bench allows to combine short-circuit test with nominal mode without pause between these modes which allows to simulate recovery under load in a real network after removing a short-circuit. Sample critical current measurements were employed before and after the test to ensure the sample endured test stresses safely.

TABLE II.
List of HTS Samples

№	**Name**	**Length, m**	**Thickness, mm**	**Width, mm**	**Total HTS length, m**	**Critical current, A**
1	Model	0.2-0.275	12	40	0.8-1.1	2000
2	Module	200	0.2	40	1000	3000
3	SFCL phase	1800	0.2	40	9000	3000

Modules and complete SFCL phases were tested at specialized test facilities with test conditions provided in Table III. Conditions for short-circuit tests and short-time current test are described in standards mentioned in Table I.

No standard describes requirements for recovery under load test. According to the Line 12 Table I SFCL should be able to fully recover its original properties after short-circuit and without breaking a power line, thus recovering under load. SFCL recovery can be defined as an SFCL state when SFCL impedance decreases lower than rated continuous impedance (0.1 Ohm) after short-circuit current. In that operation mode, SFCL will gradually release heat energy accumulated during the short-circuit into surrounding cryogenic medium and still pass though rated continuous current. The higher SFCL impedance is, the bigger amount of heat is released.

Obviously, this test should simulate the worst conditions of SFCL operation after fault: rated short-circuit duration – 3 s, rated continuous current – 1000 A. This conditions are simulated using electrical scheme on Fig. 1B with experimental conditions in Table III Line 3. The sample is deemed recovered when its resistance is lower than rated continuous impedance (0.1 Ohm).

TABLE III.
List of Test Conditions

№	Test	Sample	Electrical scheme	U	I, kA	R, mOhm	L, mH	Time	Test facility
1	Short-circuit test	SFCL phase	Fig.1A	52 kV	15	150	11	80 ms	KERI[1]
		Module	Fig.1A	7 kV	5	130	5	400 ms	Domestic facility
		Model sample	Fig.1B	16 V	I1=5.8	R1=2	6	3 s	SuperOx test bench
2	Short-time current	Model sample	Fig.1B	16 V	I2=1.6	R1+R2=2.008	6	1 h	SuperOx test bench
3	Recovery under load	Model sample	Fig.1B	16 V	I1=5.8 I3=1,1	R1=2 R1+R3=2.012	6	3 s 700 s	SuperOx test bench

[1] KERI - Korea Electrotechnology Research Institute

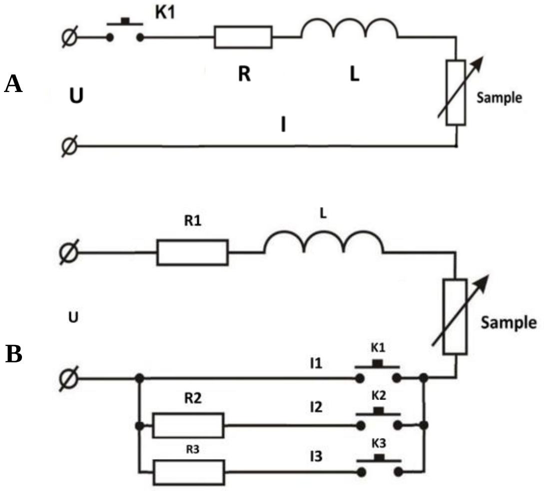

Fig. 1. Electrical schemes for module and SFCL phase samples (A), for model sample (B)

Results of model sample short-circuit tests are intended to scale up to propose full-scale SFCL phase (110-220 kV) SFCL properties. For example, 220 kV SFCL described in [5] consists of 9 modules with equal 2G HTS length and uniform resistance across the length of the wire. These 9 modules each as well as full-scale SFCL phase were tested with short-circuit test (Table I Line 1). The comparison between module samples (local test facility) and full-scale SFCL phase tests (in KERI test lab [5]) is given in Fig.2. Module impedance (multiplied 9 times) coincides with full-scale SFCL phase with the coefficient R^2=0.9903, confirming possibility of upscaling model tests.

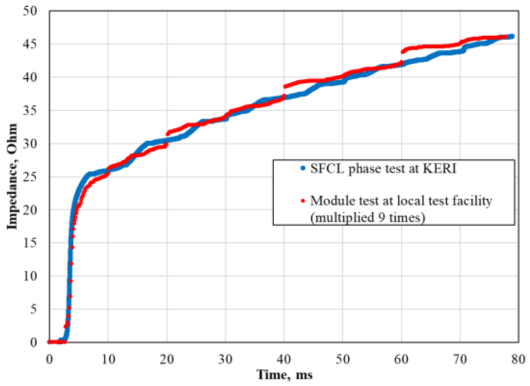

Fig. 2. Impedance comparison between full-scale SFCL phase and module sample (scaled up to full phase)

III. RESULTS

At the moment, there is no SFCL (being developed or commissioning in grid) that meets all CLR standard requirements. Below we discuss in detail each standard provision where the required values are possible to meet (according Table I):

- Line 6 – rated short-time current – described in sec. 3.1 of present article,
- Line 7 – rated short-circuit duration – described in sec. 3.2,
- Lines 8-9 – rated impedance (short-circuit and continuous) - described in sec. 3.3,
- Lines 10-11 rated short-circuit current (thermal and mechanical) - described in sec. 3.4,
- Lines 12-13 – recovery under load and interval between fault conditions - described in sec. 3.5.

3.1. Rated short-time current

Rated short-time current is a current above rated current that devices should be able to withstand during specific time period without taking any damage and after that being able to return to nominal state. Standard requires devices to comply 4 different test conditions (see Line 6 Table I). For SFCL this requirement can be interpreted as SFCL should stay in nominal mode (without quench and current limiting) during short-time current since prolonged, several-minute, quench may result in SFCL resistance buildup, excessive SFCL cooling system load or other complications. Other words, rated short-time current has to be less or equal critical current (Ic) in magnitude values, because 2G HTS under current less critical current does not exceed heat (due to zero resistivity) and cannot be damaged. Sufficient critical current of SFCL can be reached by increasing number of HTS in parallel. This dependence can be provided by the following formula:

$$n \ge \frac{RTC}{Ic} = 1.6 \cdot \frac{RCC}{Ic} \qquad (1)$$

n – number of HTS in parallel,
Ic – minimum critical current,
RTC – rated short-time current,
RCC – rated continuous current.

According to the formula (1) total HTS amount in parallel for model sample is at least 1.6*1000A/450A=4 tapes. Such model sample passed

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rated short-time current test (Table III Line 2) without any resistance rise and critical current reduction (no quench, no transition in current-limiting state), confirming critical current of model sample is enough to meet standard requirement and complete SFCL can be constructed using similar to model sample wire composition (number of parallel HTS tapes and stainless steel stabilization).

3.2. Rated short-circuit duration

SFCLs should withstand short-circuit current during 3 seconds, which is 5-7 times longer than the best to date SFCL [5] (according to Table I Line 7). Increasing short-circuit duration leads to HTS temperature rise that may cause critical current degradation.

It is possible to characterize HTS temperature by comparing resistance (R) of sample in the end of short-circuit test with sample resistance at room temperature (RRT) – above its critical temperature 2G HTS resistance is related to material temperature.

Short-circuit test was provided on model sample with varied total HTS length (0.8-1.1 m), results are given on Fig. 3. Samples which were heated up to 1.2RRT (0.23-0.275 m) are not damaged (no critical current degradation). Sample with 0.2 m length is damaged with critical current decrease more than 30%. The manufacturer may guarantees spread of resistance across the length no more than 10% [5]. Therefore, HTS heating threshold should be reduced up to 1.1RRT to prevent local overheating and damaging of the full-size device because of critical current degradation.

The sample with 0.25 m length and with heating up to 1.1RRT is used for further calculations. Further reduction of the stabilization thickness (reduction of the conductor cross-section) is inappropriate, since its reduction will lead to the sample overheating with critical current deterioration.

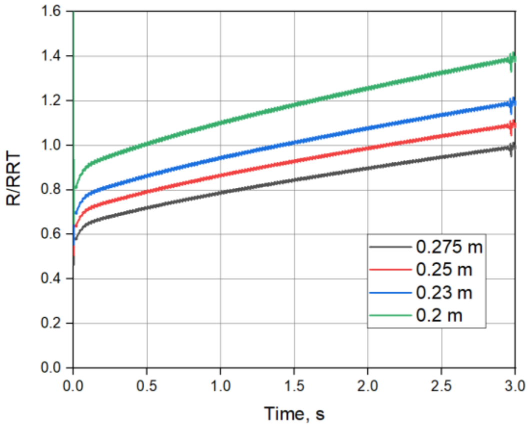

Fig. 3. R/RRT time dependence for model sample during short-circuit test

3.3. Rated impedance (continuous and short-circuit)

Standards (Line 7-8 Table I) do not describe numeric requirements for device impedance (continuous and short-circuit). However, CLR has constant operating impedance and its specific value is selected based on grid analysis. SFCL by design has variable resistance, differing between in nominal operation mode (with impedance close to zero) and during faults (with impedance close to grid load value) [2]. Thus for SFCL specification it is necessary to describe both continuous (nominal mode) and short-circuit impedances.

Continuous impedance in nominal mode in 220kV SFCL project [5] is less than 0.01 Ohm which is practically negligible (busbar impedance of this SFCL is 10 times bigger - around 0.1 Ohm). Thus, value of 0.1 Ohm in nominal mode can be proposed as a standard value for resistive SFCLs for 110-220 kV grid (note that lower or higher voltage class SFCL resistance should be scaled proportionally).

Short-circuit impedance is used for grid fault current calculations (other words, switchgear capacity determination). To describe SFCL performance in these calculations we propose to define short-circuit impedance as SFCL impedance at 50 ms after fault with rated grid voltage (fault resistance is zero). Proposed time is typical time of switchgear disclosure, while fault resistance at zero provides maximum fault current level (and maximum load of SFCL and switchgear, ensuring SFCL will provide sufficient impedance during fault).

Since SFCL short-circuit impedance is not specified in any standard we propose to estimate 220 kV SFCL starting from reasonable cryostat (HTS vessel) size to have some SFCL size and impedance reference. Cryostat producers may propose cryostat length around 9 meters and diameter of 2.5 m. These constraints limit HTS total amount inside. According to sec. 3.2 it is necessary to use 4 HTS in parallel, taking into account electrical strength requirements is necessary to provide insulating gap between cryostat and HTS which limits diameter of HTS part by 1400 mm roughly. In this case module inside HTS part (module consists of 52 pieces of stainless steel laminated HTS) should have dimensions 950 x 931 x 40 mm with total HTS length of 200 m (Fig. 4A). 152 modules may be placed in the SFCL phase longitudinally (possible cross section is given in Fig. 4B). As a result, SFCL phase should consist of 30 km HTS (proposed HTS part placement in the cryostat is in Fig. 4C).

Having short-circuit test on model sample it is possible to scale up this to a complete SFCL with 30 km of HTS inside. Model sample impedance after 50 ms was measured as 0.22 mOhm/m (Fig. 5A). Thus, 220 kV SFCL phase rated short-circuit impedance is evaluated by multiplying up to 30 km sample impedance which is 6.6 Ohm. This value can be easily change in order to SFCL installation location by varying HTS length used for exact SFCL.

For onsite engineering reasons it is important to note auxiliaries around 120-180 kW per 3 phase SFCL should be provided to ensure sufficient cooling and other vital operations of SFCL with abovementioned cryostat size. Post-fault current operation of the cryogenic system should also be studied to ensure absence of overheating. However existing SFCL designs use large volume of liquid nitrogen in SFCL (more than 10 tons per phase) and the temperature change after fault is barely noticeable [5] and, consequently, does not affect SFCL performance in general.

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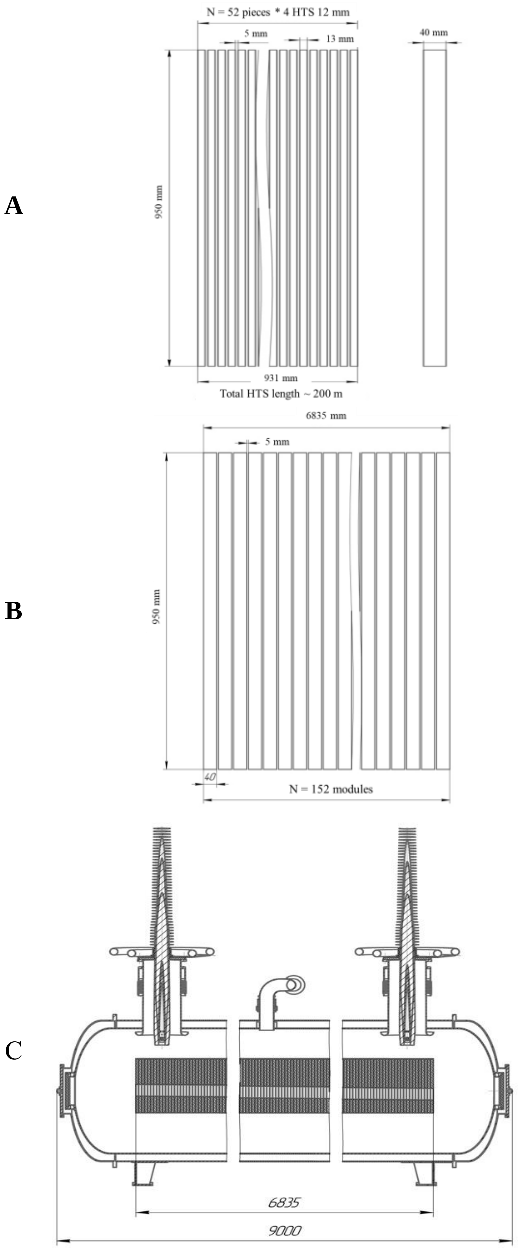

Fig. 4. Principle construction of HTS module (A), 152 modules in series (B), modules placement in a cryostat

3.4. Rated short-circuit current (thermal and mechanical)

Standard requirements describe rated thermal and mechanical short-circuit currents in formulas (Table I Line 10-11). Rated thermal short-circuit current depends on SFCL impedance in the end of short-circuit test (Z_{SFCL}). This value is determined from short-circuit test of model sample (Fig. 5B) and is equal 0.35 mOhm/m or 10.5 Ohm for full SFCL phase (multiplied up to HTS length 30 km, which proposed in sec. 3.3). Thus, according the formula rated thermal short-circuit current is $\frac{220}{\sqrt{3}(10.5+\frac{220^2}{25000})} = 10.2$ kA. Rated thermal short-circuit current during model sample test is equal 10.3 kA (Fig.5C) that complies standard requirement.

Rated mechanical short-circuit current depends on rated thermal short-circuit current and is equal to 10.2=2.55*26 kA (according Table I Line 11). During the short-circuit test short-circuit current equal 18 kA was observed (peak current value in fig. 5C) due to limited test available power at our domestic facility. This value is lower standard requirement, but mechanical short-circuit current relates more to full phase mechanical construction than short sample test. CLR are designed and comply to standards, so there are no fundamental restrictions to design SFCL this appropriate mechanical strength. Thus, provided HTS length and cross section is deemed enough to meet the standard requirements, but the complete SFCL definitely should be tested by full mechanical short-circuit current test (26 kA for 6.6 Ohm, 220 kV SFCL) to ensure proper design of all mechanical components.

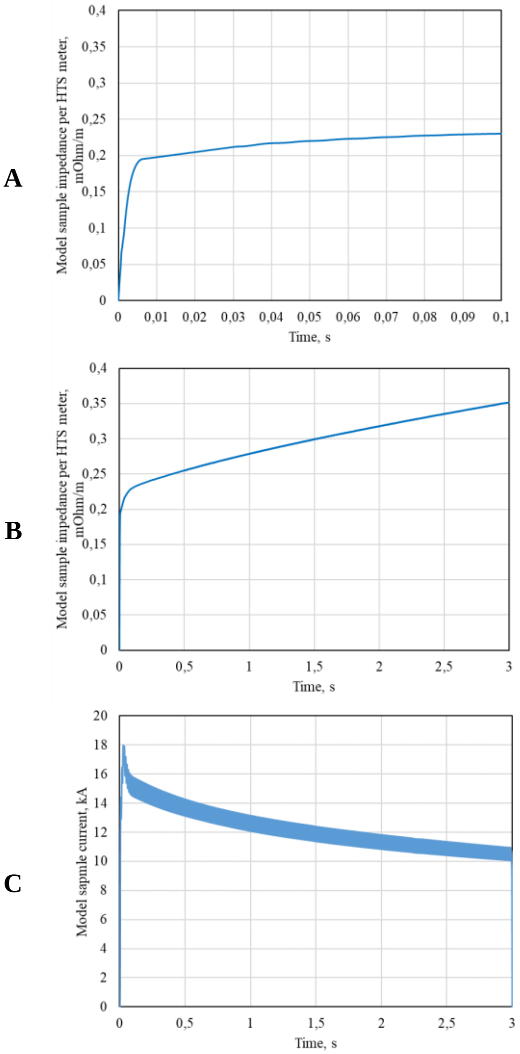

Fig. 5. Model sample resistance vs. short-circuit duration 0-0,1 sec (the graph is smoothed due to high noise level) (A) 0-3 sec (B), RMS current through model sample vs. short-circuit duration (C)

3.5. Recovery under load and interval between fault conditions

Recover under load is provided on model sample (electrical scheme is given on Fig.1B). Sample was heated up to 1.1RRT (proposed maximum SFCL load during fault) simulating 3 s load. After heating continuous current 1.1 kA was conducted through the sample. Sample impedance reached zero (because

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impedance is measured on HTS directly without contribution of current leads) within 11 minutes without critical current degradation (Fig. 6). Thus, the selected HTS total length is sufficient to provide SFCL recovery. Mentioned recovery time (11 minutes) should be taken into account for in-grid SFCL studies during onsite engineering. However, since SFCL phase resistance (6.6 Ohm) is more than 20 times lower than the consumer load impedance (Fig.7). SFCL recovery should not significantly affect grid performance (specifically, voltage levels) throughout recovery. That makes us conclude mentioned recovery time is acceptable.

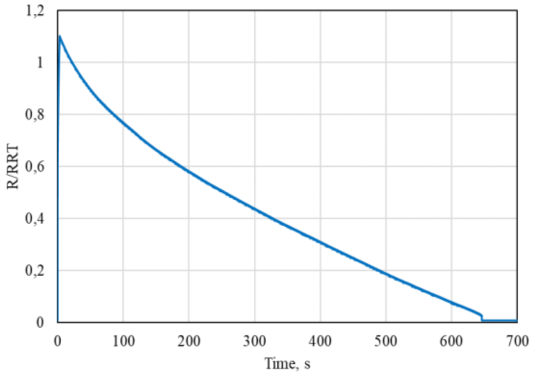

Fig. 6. SFCL phase impedance vs time for single fault

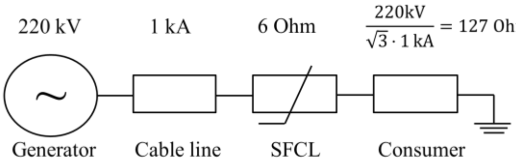

Fig. 7. Electrical scheme provided SFCL installation

If a power line has automatic circuit recloser (ACR) installed, repeated short circuits during reclose attempts are possible and SFCL should be able to withstand them, as stated by the standard (Table I Line 13). Since SFCL proposed recovery time is 11 minutes (Fig. 6) ACR reclosure attempts are highly likely during that time (typical auto reclosing cycle is 0.3-3.0-30 s). In that case device won't be able to fully recover and will start increasing its resistance similarly to short-circuit situation (see Fig. 8).

Such repeated faults were simulated using SFCL thermal model [14]. It has been observed that SFCL recovery after repeated short circuits is possible provided the total duration of all repeated short circuits during the recovery time does not exceed 3 s (equal rated short-circuit duration described in sec. 3.2). If this value is exceeded, SFCL must be turned off in order to avoid device damaging.

This SFCL operation feature be taken into account during engineering of SFCL implementation into specific grid since different network structures may not allow SFCL disconnection during repeated short circuits. A sophisticated algorithm of SFCL protection may be used in this case to ensure continuous power transmission which should be described in a separate paper.

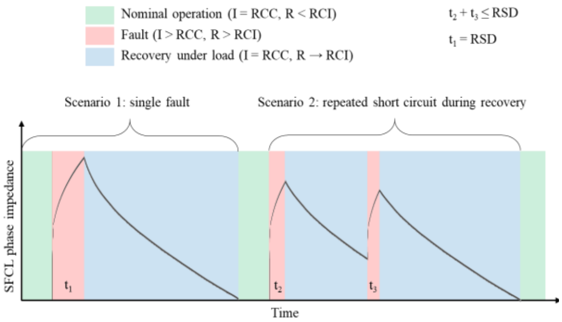

Fig. 8. Concept of allowable interval between fault conditions for SFCL

IV. DISCUSSION

Up to date no in-grid SFCL fully meets both SFCL and CLR industry standards (Table I). Thermal fault-current duration (Table I Line 7) and recovery under load (Table I Line 12) are the most challenging factors for SFCL meet the existing industry standard. On the other hand, as described in sections 3.2 and 3.5 it is possible to meet all of the required standards. The specifications for 110-220 kV SFCL which complies with the CLR industry standards are summarized in Table IV and can be used for grid studies, preliminary onsite engineering and economy estimations.

TABLE IV.
Estimations for SFCLs Meeting the Standard Requirements.

№	Specification	Unit	Value		Justification
1.	Rated voltage	kV	110	220	Standards requirements
2.	Rated continuous current	kA	1000	1000	Standards requirements
3.	Construction	Single/ Triple-phase	Single phase		No standard requirements – single phase is chosen as most simple solution
4.	Total 2G HTS usage per 3 phase	kA*m	6 750	40 500	Depends on short-time current (sec. 3.1), short-circuit impedance (sec. 3.3), recovery under load (sec. 3.5)

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5.	Rated continuous impedance	Ohm (active)	0.1	0.1	No standard requirements – value proposed based on Mnevniki SFCL commissioning
6.	Rated short-circuit impedance	Ohm (active)	3.3	6.6	Comparable to reactors (described in sec. 3.3)
7.	Single phase dimensions (without cryogenic system)	LxWxH, m	6x2.9x6.7	9x2.9x6.7	Depends on voltage class requirements, (sec. 3.3)
8.	Single phase mass	ton	33	62	Preliminary estimation from total HTS amount and cryostat dimensions (sec. 3.3)
9.	Auxiliaries (cryogenic cooling system and other subsystems power consumption)	kW @ 77K	120 – 180		Cryostat and cryogenic system provider recommendation for 9 m cryostat

V. CONCLUSION

The existing utilities industry standards for current limiting devices were analyzed with specifications meeting all listed standards proposed. While no one of the existing SFCLs do not fully meet all the standards, this paper indicates production of resistive SFCL meeting the listed requirements is possible. The paper also provides specifications (resistance, size, weight, auxiliary loads) that such “standard-compliant” SFCL may have for further engineering and economical evaluations.

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