JOURNAL OF NORTHEASTERN UNIVERSITY

Volume 26 Issue 02, 2023 ISSN: 1005-3026 https://dbdxxb.cn/ Original Research Paper

EVALUATION OF THE IMPACT OF FAULT CURRENT LIMITER ON DISTANCE RELAY PROTECTION OF TRANSMISSION LINE

Suhas M. Shembekar[1], Dr. Paresh J.Shah[2], Dr. Krishnakant P.Adhiya[3]

[1]*Electrical Engineering Departmen, S.S.B.T.'s College of Engineering and Technology,* Jalgaon (M.S.), India

[2]*Principal, Shri Balaji Institute of Technology and Management, Betul (M.P.) India*

[3]*Computer Engineering Department, S.S.B.T.'s College of Engineering and Technology,* Jalgaon (M.S.), India

Abstract

The objective of this paper is to determine the impact of the Hybrid superconducting fault current limiter (HSFCL) on transmission lines distance protection for line to ground and line to line fault. The MATLAB software is being used to simulate transmission system with distance relay protection along with Hybrid superconducting fault current limiter (HSFCL). The parameters included in the simulation studies are fault type and fault location. Mostly in context of line to ground and line to line faults, this paper explores the impact of HSFCL on measured impedance at the relaying point. Its installation position, in addition to the degree of constraint, has an impact on the measured impedance. In all situations, the collected research suggests that HSFCL has a negative impact on distance relay performance. The influence of both configurations of Hybrid superconducting fault current limiter (HSFCL) i.e. Resistive and Inductive over distance relay protection for line to ground and line to line faults are to be analyzed and compared.

Keywords: Transmission Line, Distance Protection, Apparent impedance, Fault current limiter, Impedance trajectories.

1. Introduction

The constant increase in electrical energy demand causes an increase in short circuit currents in power networks. This is due to the addition of more generators to the power system, the use of larger cross-section conductors, and the use of double or multi-circuit lines. When short circuit currents increase, higher capacity circuit breakers are required, and the imposed stress on the equipment increases. Several solutions to this problem are presented, including the use of Fault Current Limiters (FCL) to reduce the rated capacity of the circuit breakers and to limit the imposed electrodynamics stress in associated equipment.

In contrast to power system parameters, the imposed impedance due to the presence of FCL may affect the measured impedance even if the fault resistance is zero. In the presence of FCL, conventional distance characteristics are greatly prone to mis-operation in the form of both over-reaching and under-reaching the fault point. As a result, in the presence of FCL, the conventional characteristics may be ineffective. The authors in [1] provides a filter control

Submitted: 28/07/2023 **Accepted**: 25/08/2023

technique to reduce harmonics and a rectification approach for the overcurrent relay using voltage components in order to use SFCL and the concept of DG in a power distribution system. The effects of SFCL installation on DG enlargement in a power system are investigated while keeping the original relay coordination. One of the key solutions regarding interconnected power system and protection is to employ a hybrid type superconducting fault current limiter [2].

The researchers in [3] offers a novel design for a Hybrid Superconducting Fault Current Limiter (Hybrid SFCL), which would be essentially made up of thyristors that are in series with just a superconducting element. The PSCAD/EMTDC programme was used to simulate the Hybrid SFCL throughout this research. The study revealed that the fault current is substantially reduced, and the proposed controller strategy performs very effectively.

The researchers in [4] provide a unique hybrid SFCL with biased magnetic field and 2-stage current limiting characteristics. The short current is limited in this type of SFCL by such a noninductive superconducting coil during the first stage and a dual-split reactor as in second stage. The experimental results showed that such current limiting ratio reaches 89.66%, validating the concept and demonstrating the hybrid SFCL's potential use.

It is suggested in the study [5] to create a power differential-based protection mechanism for appropriate detection and identification of transmission line faults underneath SFCL action. Based on normal load levels, a power differential protection strategy is constructed, and trip characteristics are determined. Simulation experiments on a 220 kV transmission line confirm the efficacy of the power differential technique. Three-phase as well as single line-to-ground faults are examined. In addition, the proposed system was tested for a wide variety of SFCL resistances ranging from 10 to 500Ω. The proposed differential protection mechanism detected faults in all test conditions.

The research [6] proposes a novel remedy for the issue of relaying maloperation that does not necessitate any changes to the relay settings. Furthermore, the results suggest that FCL can be employed as a series compensator to increase power transfer with in transmission system while it is operating normally. This avoids the need to adjust the compensated line's relay settings. As a result, the dual function of improved power transfer and reduced fault current is accomplished.

In the study [7], investigation is done about how SFCLs impact the effectiveness of travelling wave-based protection methods in high-voltage transmission lines. The results demonstrate that the SFCL attenuates the magnitudes of the travelling wave currents and that the pattern of the travelling wave is somewhat altered by the SFCL stray capacitances.

Because to the rapidly developing of the distribution network, these have short lines and many nodes. The standard three-stage current protection technique is difficult to implement and has a long fault elimination time. To address the aforementioned issues, this study [8] discusses the basic design and operation characteristics of superconducting fault current limiter, as well as a new current protection strategy based on it.

The authors in [9] investigate the effects of resistive-type SFCLs on transmission system incremental power frequency relay. The SIMULINK MATLAB programme was used to create and simulate a model of a 220 kV transmission line also with incremental power frequency relay element. Three compensatory techniques for mitigating the detrimental consequences of SFCL integration are developed and compared.

The literature review was studied and analyzed. In the survey, the influences of FCL on transmission line protection for various schemes are to be discussed. As per the previous study, the protection of transmission line gets affected at the time of current to be limited by fault current limiter. The literature survey shows the different types of fault current limiters and their effects on operation of relay for protection of transmission line. But in all these previous work, effect of fault current limiters on distance relay protection of transmission line is not discussed. In this paper the effects of Hybrid Superconducting fault current limiters on distance relay is to be analyzed. The inclusion of FCL in a fault loop will impact the voltage and current signals perceived from the relay point in both steady and fault states. As a result, the apparent impedance observed by that of the distance relay will be influenced. The effect of Hybrid superconducting fault current limiter on impedance computed by distance relay is explored in this work. This effect is studied using the MATLAB software for line to line fault.

The paper is organized as follows: the operation principle and of HSFCL is presented in the next section. The theoretical model of HSFCL is discussed in section 2.2. Section 2.3 provides the simulation studies which are performed in MATLAB software. The results obtained and discussions for Distance relay performance for line to ground and line to line faults for both configurations of HSFCLs are explored in section 3. Finally, the conclusions remarks are given in Section 4.

2. Methodology

2.1 Operating Principle of Hybrid Superconducting Fault Current Limiter (HSFCL)

The terminology Hybrid Superconducting Fault Current Limiter (HSFCL) refers to the method of establishing the limitation function by combining the HTS element with a fast mechanical switch, circuit breaker (CB), as well as power semiconductor switch. The schematic diagram of Hybrid Superconducting Fault Current Limiter (HSFCL) is shown in figure 1.

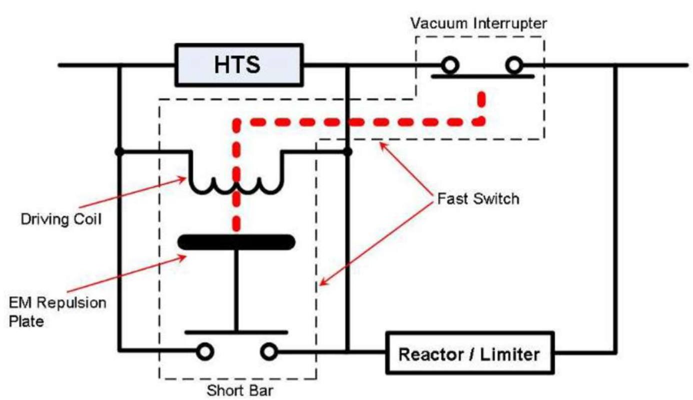

Figure 1. Schematic diagram of Hybrid SFCL Concept [10]

The hybrid SFCL is a technology for limiting fault current within electrical power systems. The most significant advancement seems to be that the superconductor no longer serves as a demarcation for short circuit current, but instead as a sensor for short circuit current and a switch enabling short circuit current to transition toward a Current Limiting Reactor (CLR). Fast switch, current delimiter (current limiting portion), as well as high temperature superconductor (HTS) are the three primary components of hybrid SFCL. That hybrid SFCL's structure combines a fast switch alongside two mechanical switches, a vacuum interrupter (VI), and just a short bar (SB), as well as a driving coil and also an electromagnetic plate (EM) [11]. The fast switch is just a plunger with a switched on either end which commutates the line current when in operation. The driving coil pulls mostly on repulsion plate, causing the plunger to interact and activate the limiting reactor. It's worth noting that such CLP branch (R_{CLP} or X_{CLP}) can indeed be implemented with either a resistive or inductive element. Both types are analyzed in this research using analytical and simulation tests.

2.2 Theoretical Model of Hybrid Superconducting Fault Current Limiter (HSFCL)

The model of HSFCL is explicitly non - linear in nature, related to the working concept of HSFCL. The basic structure for HSFCL is represented in the figure 2. Nonlinear resistance must be employed to represent the behavior of the HTS element. However after quenching, overall resistance of such a superconductor exhibits a nonlinear fluctuation. In different patterns, equation (1) represents a time - dependent concept of the HTS component. R_n and T_F denote the resistance with in quench phase as well as the time constant of such HTS element, respectively. Its quench inception time is indeed known as t_0.

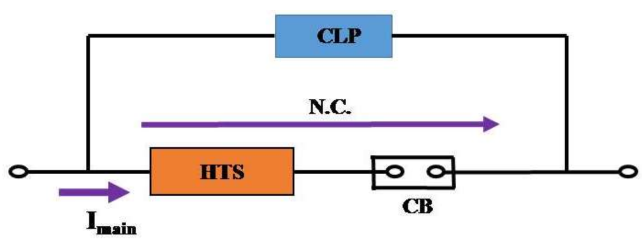

Figure 2. HSFCL concept: the structure of HSFCL

The theoretical expression of the HTS element is required to obtain the HSFCL impedance characteristic in different operating modes. The obtained results reveal that the resistance of the HTS element is time-dependent, as shown in equation (1) [12].

$$R_{HTS}(t)= \begin{cases} \approx 0 & t<t_0 \\ R_n[1-\exp(-(t-t_0)/T_F)]^{1/2} & t\geq t_0 \end{cases} \quad (1)$$

where t_0 is starting time of quench, the coefficients R_n (convergence resistance), T_F(time constant).

The introduced impedance using HSFCL in various modes can be expressed in terms using the preceding equation and indeed the HSFCL operational principle:

$$Z_{HSFCL}=\begin{cases} \approx 0 & t<t_0 \\ \dfrac{R_{HTS}(t)\times Z_{CLP}}{Z_{CLP}+Z_{HTS}(t)} & t_0\leq t<t_1 \\ Z_{CLP} & t\geq t_1 \end{cases} \tag{2}$$

t_1 is first period of recovery modes, Z_{CLP} is impedance of current limiting part and Z_{HTS} is impedance of HTS element.

Indeed, throughout this scenario, its CLP branch plays an important role in reducing fault current, while the HTS element serves as a fault detection sensor for such HSFCL. Equation (2) can so be modified as follows:

$$Z_{HSFCL}=\begin{cases} \approx 0 & t<t_1 \\ Z_{CLP}\ (R_{CLP} \text{ or } X_{CLP}) & t\geq t_1 \end{cases} \tag{3}$$

2.3 Simulation Studies

The power system depicted in Figure 3 is utilized in simulation studies to explore the effects of HSFCL on apparent impedance seen with the distance relay. The HSFCL and case study are modeled using MATLAB software. The apparent impedance is calculated by the relay's measurement units.

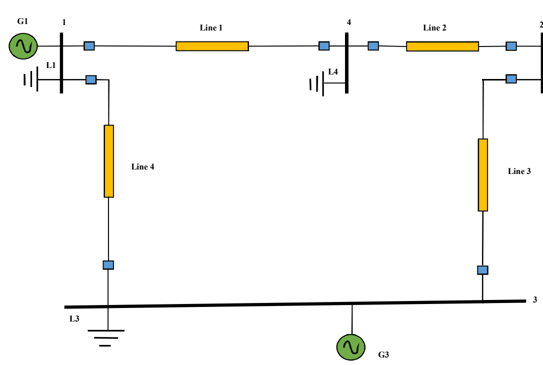

Figure 3. Case Study [13]

3 Result and Discussions

3.1 Waveforms for current and voltage at fault location

Figure 4 and 5 depicts the line current in various conditions due to an under symmetrical fault now at beginning with line 1. According to Figure 5(b) and 5(c), RHSFCL reduces the very first cycle for fault current most effectively than IHSFCL and is capable of rapidly damping the DC component of fault current. The line current during symmetrical fault is found to be 4 kA at main bus without fault current limiter. While by using RHSFCL, the corresponding current reduces to 2 kA. The effect of IHSFCL over short circuit current is that it can be reduced to 2.1 kA as shown in figure. Also it can be shown that installing RHSFCL and IHSFCL modifies the phase of such fault current. Whenever the phase difference among curves is considered, it is discovered that the influence of RHSFCL here on phase relationship is greater than either IHSFCL.

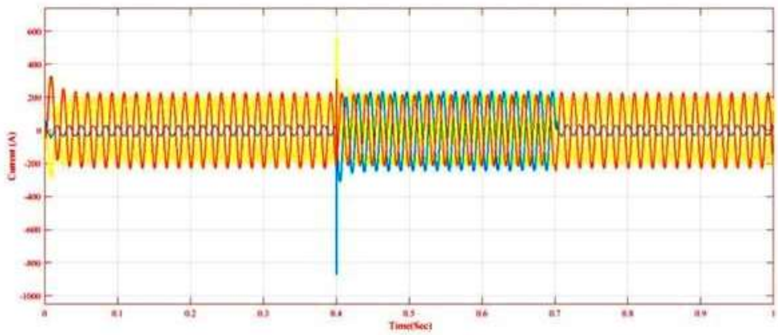

Figure 4-a. Current at fault location

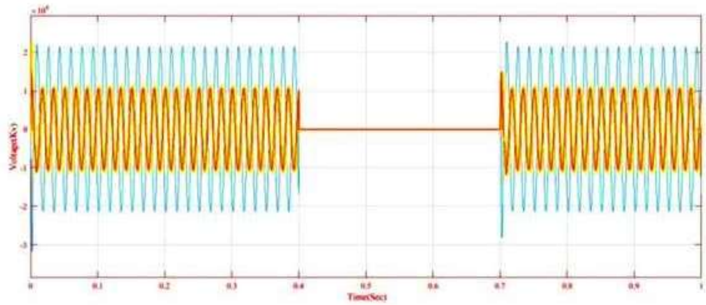

Figure 4-b. Voltage at fault location

Figure 4. Waveforms for current and voltage at fault location

As a result, in this scenario, the influence with RHSFCL on distance relay is correlated mostly to the phase and amplitude of such fault current, while the phase in IHSFCL only has a minimal impact on distance relay.

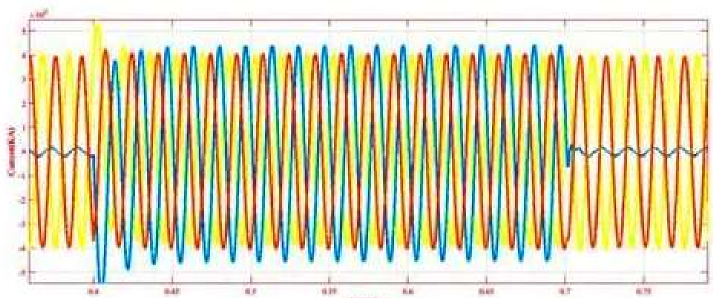

Figure 5-a. Current at main Bus without HSFCL

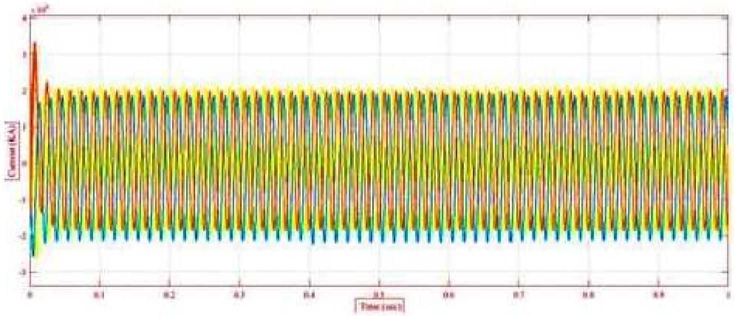

Figure 5-b. Current at main Bus with RHSFCL

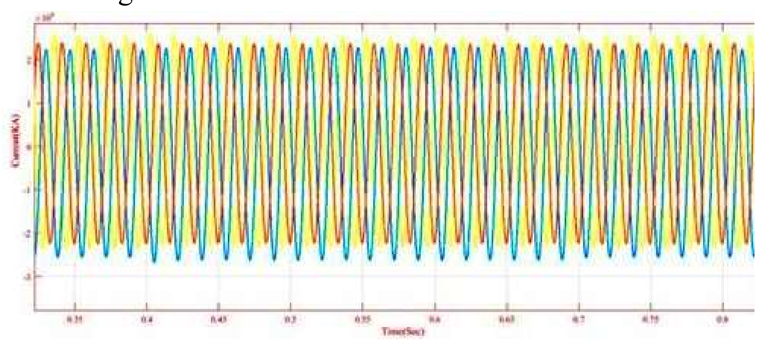

Figure 5-c. Current at main Bus with IHSFCL
Figure 5. Waveforms for current and voltage at main bus

3.2. Distance Relay Performance for Line to ground and Line to line fault

In this section, it must be assumed that the line to ground LG fault happens approximately 60% of line 1 and as such the PT position is at Pt1 as shown in figure 3. With instantaneous protection, the mho characteristic is configured to protect approximately to 80% of the line length. The impedance trajectories of instances are shown in figure 6 without HSFCL, with RHSFCL, and often with IHSFCL.

It is possible to demonstrate that the implementation of RHSFCL or IHSFCL modifies the apparent impedance by analyzing the impedance trajectories depicted in figure 6.

In this context, the overall measured impedance increased in the existence of RHSFCL and IHSFCL; however the relay currently operates efficiently. Whenever an A–G fault arises at 78 and 77 percent of line 1 or greater distance for RHSFCL and IHSFCL, accordingly, the impedance trajectories are entirely outside from mho characteristic, and also the relay is unable to detect the fault. Because the zone 1 reach limit is set to 80 percent of the line length, overall significance of these occurrences is moderate.

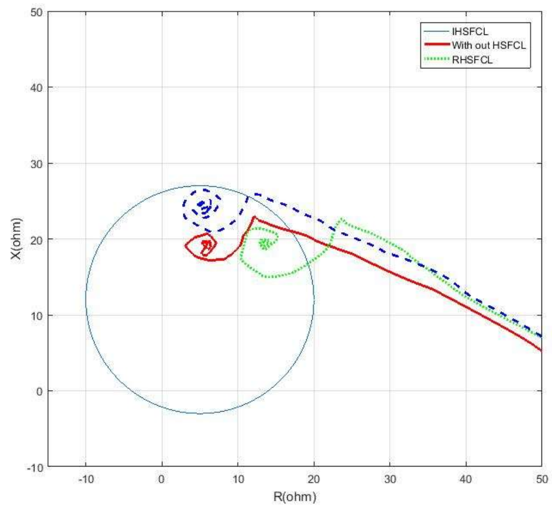

Figure 6. Impedance trajectories with mho characteristics for LG fault

Both types of HSFCL influence apparent resistance and reactance, however the major effect of RHSFCL is dependent on apparent resistance, whereas the main effect of IHSFCL is dependent on apparent reactance.

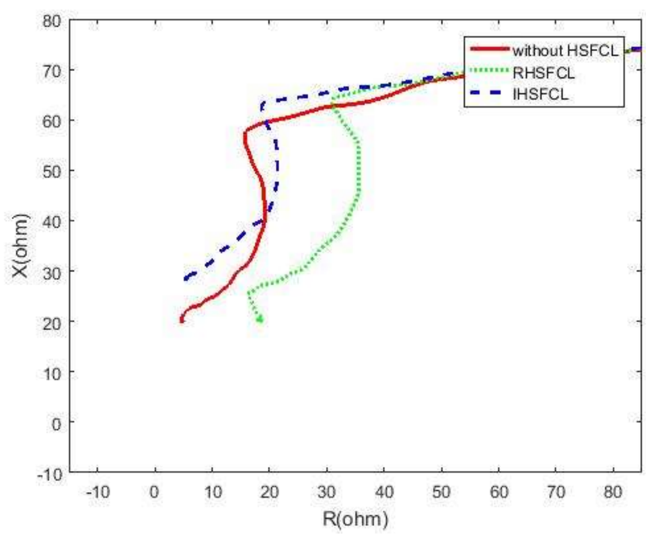

Figure 7. Impedance trajectories for L-L fault

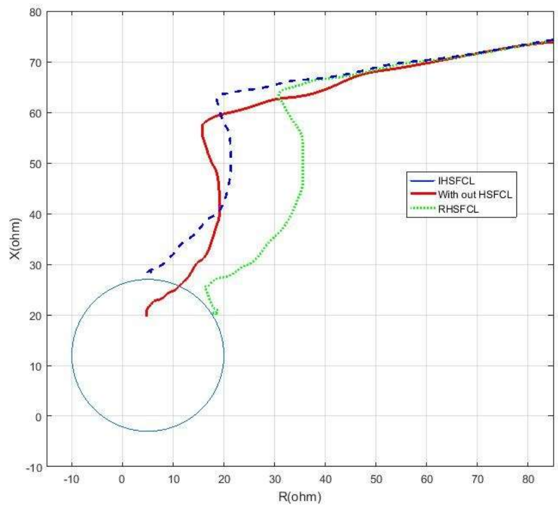

Figure 8. Impedance trajectories with mho characteristics for LL fault

The waveforms also obtained for LL fault by taking the same specification as mentioned for LG fault case. Figure 7 and 8 shows the impedance trajectories for LL fault and Impedance trajectories with mho characteristics respectively. In the mere existence of RHSFCL and IHSFCL, instantaneous protection cannot recognize an L-L fault.

4. Conclusions

The working principles and structures of the Hybrid superconducting fault current limiter (HSFCL) have been elaborated in detail in this paper. In the next part, the effect of HSFCL over distance relay effectiveness was investigated for single line to ground fault using both modes of HSFCL i.e. RHSFCL and IHSFCL. Across all circumstances, the results showed that these SFCLs had a detrimental influence mostly on apparent impedance seen with distance relay. In comparison, the implementation of HSFCL results in significantly underreaching for the single line to ground fault. For line to line fault also the undereaching effect was observed. Comparing measured impedances by distance relay in different cases for PT placed before HSFCL revealed that under-reaching for line-to-line fault is greater than single line to ground one.

5. References

1. Saumen D., Pradip K. Sadhu, and Alok K. Shrivastav, Analysis of over current relay and hybrid filter including the utilization of SFCL in a distribution network with DG, *AIMS Electronics and Electrical Engineering*, 2021:6(1):81–107. doi:10.3934/electreng.2022006
2. Sandeep Ratnadeep Kadam and Mulla A.M., Effects of Distributed Generation and Hybrid Type Superconducting Fault Current Limiter on Power System, *International Journal of Recent Scientific Research*, 2020:13(5): 1166-1169.

doi: http://dx.doi.org/10.24327/ijrsr.2022.1305.0252

3. H.K. Miyamoto , A. T. Queiroz , D.H. N. Dias , B.W. França, F. Sass , G.G. Sotelo, Novel Design of a Hybrid Superconducting Fault Current Limiter with Controlled Solid-State Device, *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, 2021:20(2):334-347.
doi: http://dx.doi.org/10.1590/2179-10742021v20i21029
4. J.Zhu, H.Zhang, P.Chen, Y. Zhao, H.Qin, D.Wei, K. Lu, Experimental investigation of current limiting characteristics for a novel hybrid superconducting fault current limiter (SFCL) with biased magnetic field, *Journal of Physics: Conference Series*, 2020:1-8, doi:10.1088/1742-6596/1559/1/012104
5. D.A. Mansour, E.S. Ahmed, Power Differential Protection for Transmission Lines with Superconducting Fault Current Limiters, *2019 21st International Middle East Power Systems Conference (MEPCON)*, 2019:337-341. doi:10.1109/MEPCON47431.2019.9007982
6. Mohan P. Thakre; Tejal S. Barhate; Prasad S. Jagtap, A Novel Application of a Dual Purpose Active Fault Current Limiter to 400 kV Transmission System, *2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI)*, 2019:837-842. doi:10.1109/ICOEI.2019.8862565
7. H.Lei, J.Geng, B.K. Johnson, Influence of Superconducting Fault Current Limiters on Traveling Wave Based Protection, *IEEE Transactions on Applied Superconductivity*, 2019:29(5):1-5.doi:10.1109/TASC.2019.2898478
8. Y.Chen, J. Gu, X.Yu, T. Lin, Z.Wang, L. Lv, A New Scheme of Level Difference Protection of Distribution Network, *2020 IEEE 3rd International Conference on Automation, Electronics and Electrical Engineering (AUTEEE)*, 2020:227-232. doi:10.1109/AUTEEE50969.2020.9315606
9. Q.Dong, W.T. B. de Sousa, J.Geng, X.Zhang, H.Zhang, B. Shen, Influences of the Resistive SFCL on the Incremental Power Frequency Relay of Transmission Lines, *IEEE Transactions on Applied Superconductivity*, 2019:29(2):1-7. doi:10.1109/TASC.2019.2895926
10. *Technology Watch.* 1017793: "Superconducting Fault Current Limiters", ' (EPRI, Palo Alto, CA, 2009), pp. 4.6-4.8.
11. Eko Nurcahyo, Bambang Prio Hart, Choirul Saleh, The Analysis On Hybrid Superconducting Fault Current Limiter (SFCL) usage to limit short circuit fault current of 20 KV Electric Power Distribution in Sengkaling substation, *Journal of Electrical Engineering, Mechatronic and Computer Science*, 2020; 3(1):33-46. https://doi.org/10.26905/jeemecs.v3i1.3931
12. Mohammad Reza Barzegar-Bafrooei, Asghar Akbari Foroud, Impact of fault resistance and fault distance on fault current reduction ratio of hybrid SFCL, *International Transactions on Electrical Energy Systems*, 2017;1-16. https://doi.org/10.1002/etep.2409
13. Mohammad Reza Barzegar-Bafrooei, Asghar Akbari Foroud, Investigation of the performance of distance relay in the presence of saturated iron core SFCL and diode

bridge type SFCL, *International Transactions on Electrical Energy Systems*, 2018;2736:1-22. https://doi.org/10.1002/etep.2736