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The Influence of SICSFCL and the Relationship between SICSFCL and Distance Relay Protection of Power Grid

Ji Bin Cui, Yu Wei Sun, Hui Hong, Wei Zhi Gong, Ying Xin, Jian Zhong Wang
Innopower Superconductor Cable Co., Ltd.,
Beijing, China
cjb@innopower.com

Zhi Quan Xiong, Mei Rong Zi, Chang Bin Hu
Yunnan Power Grid Corporation,
Kunming, China
zqxiong@innopower.com

Abstract—**A Saturated Iron Core Superconducting Fault Current Limiter (SICSFCL) provides a powerful fault current limitation in high voltage and high capacity power grid. A 35kV/90MVA SICSFCL was installed in a 35 kV network for live-grid operation, in January 2008 at Puji substation, Kunming, China. With deep research on SICSFCL, the matching problem between SICSFCL and relay protection currently needs to be solved. This paper analyzes the influence that SICSFCL brings to the distance relay protection which is used widely in high voltage power grid, and considering the characteristics of microcomputer-based protection, this paper proposes a new algorithm to eliminate the influence.**

Keywords-fault current limiter; relay protection; superconducting devices

I. INTRODUCTION

As the power system level increasing, the fault current becomes too large for the current breaker to operate correctly. Saturated Iron Core Superconducting Fault Current Limiter (SICSFCL) could limit fault current drastically without influence to the steady status of the power grid. Therefore, SICSFCL is used as the protection device for electric grid. Beijing Innopower Superconductor Cable Company Ltd (referred as Innopower thereafter) has been successfully manufactured a SICSFCL and installed it in Puji Substation, Kunming, China. As the first 35 kV SICSFCL in the world, it has been under operating for three years now. Because of its specific impedance characteristic, SICSFCL will impact the power system's running co-operation. In order to make sure the safety and stability of the device, Innopower's researchers analyzed the relationship between the SICSFCL and the Relay Protection of the power grid. Based on the field experiences, researchers indicated an advisable design plan on how to eliminate the effect that SICSFCL brought to the distance protection on high voltage electric transmission and distribution (T&D) system [4].

II. NON-LINEAR IMPEDANCE OF 35 KV SICSFCL

The intrinsic non-liner characteristic of the iron core causes the SICSFCL to have no permanent impedance under different fault currents [1]. Fig. 1 shows the calculated impedance and limited current of the 35 kV SICSFCL with an increasing fault current. When the fault current is less than 10 kA, the impedance decreases sharply with the increasing fault current [7]. When the fault current is larger than 10 kA, the impedance decreases slowly and approaches 0.4 Ω.

From the limited current curve, it is clear that the larger the fault current, the higher the apparent limitation effect. When the fault current is less than 10 kA, the limitation ratio is about 77 %, while when the fault current is 40 kA, the limitation ration decreases to 56 % [2,6].

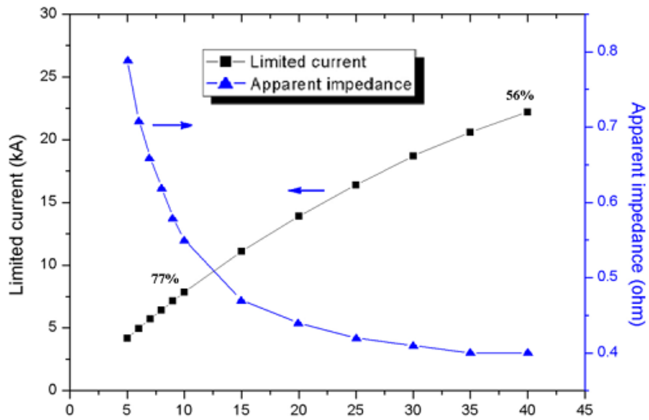

Figure 1. The impedance and limited current of 35 kV SICSCFL vs. varying fault current (kA).

At the shorted fault, because of the concatenation of the SICSFCL and its non-linear impedance feature, the SFCL may impact the relay protection device's correct operation and then the safety operation of the system.

III. THE IMPACT OF THE SICSFCL BRINGS TO DISTANCE PROTECTION

Distance Protection refers to protection measure that the safeguard equipment, on the basis of interval between the fault points and protector to determine the actuation time. The nearer the fault point is, the quicker the response should have been. Thus, the faulty line would be guaranteed cut off accordingly.

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In order to survey the distance, electricity companies are adopting the method of using impedance relay equipment to detect electrolytic impedances between the fault point and protections [5]. Through the generating impedance, they calculate the interval. When a failure happened, SICSFCL could produce high level reactance, the existence of which changed the impedance characteristic of the T&D system. For example, along with the happening or ending of a failure, the alteration of the electric characteristic will change the measurement value of the line impedance, and then influence the distance in-between. In another word, the introduction of the SICSFCL, especially its impedance characteristic, will affect the relay protection in power system.

As for the circuit line with distance protection, the measurement impedances will be influenced by the changing of the SICSFCL's impedances. Under this circumstance, the relay protection and its impedance will have to be reset.

Distance protection's operation time limit character refers to the relationship between the distance protection operation time limit T and the interval L from the protector's installation position to where the short circuit happens. The three stages time-lagprotection is widely used in power system at the moment. There are three operation time limit t1, t2, and t3 response to the movement range, as show in Fig. 2.

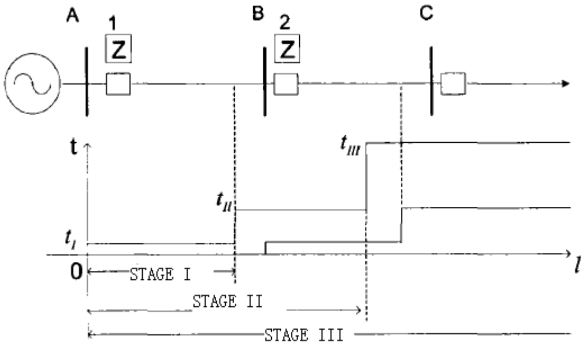

Figure 2. Feature of the distance protection operation time response.

Distance Protection Section I (DPS I) is an instantaneous acting. Its operation time limit t1 only indicates the device's own response time. DPSI's action impedance is set as 80 % - 85 % of the whole line impedance. The distance protection operation time limit t2 is greater than t1. Normally the setting time is 0.5 s. DPSII's action impedance is set to be less than measurement impedance of the terminal shorted fault. DPSIII is the backup protection. Its action impedance time limit t3 is set according to the minimum load impedance which steer by normal operation [4].

Relay Impedance is the core component in distance protection. Normally, it adopts the circular directional relay impedance. Fig. 3 shows the feature before and after the installation of the directional relay impedance. Z_{zd} is the setting impedance. Z_J is the measurement impedance. Z_{SFCL} is the current-limiting impedance of SFCL. Fig. 3(a) shows the conditions that the directional relay impedance needs to be activated (i.e., measurement impedance Z_L is in the circle)

$$\left|Z_J - \frac{1}{2}Z_{zd}\right| \le \left|\frac{1}{2}Z_{zd}\right| \tag{1}$$

After a breakdown, the current-limiting impedance of SFCL will string into the fault circuit then break the intrinsic impedance characteristic. Fig. 3(b) shows that after the installation of SFCL, the measurement impedance Z_J within circle might be come outside it Z'_J. This will further result in the malfunction of the protection because the directional relay impedance will no more detect the failure within the circle [3]. Thus before string the SFCL into the system, there is a need to reset Z_{zd} figure according to the specific parameter. Relay Protection reset amount should be revised to

$$Z'_{zd} = Z_{zd} + Z_{SFCL} \tag{2}$$

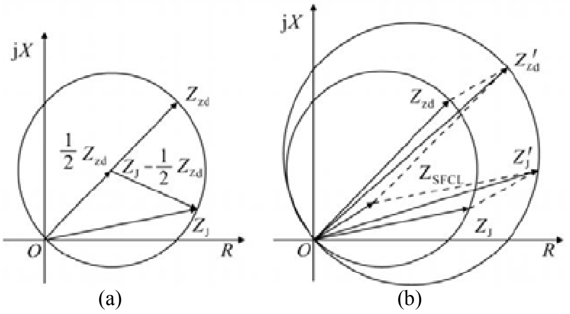

Figure 3. Vector diagram of the directional impedance operation: (a) The original action characteristics; (b) The action characterisitic after reset.

In this way, the measurement impedance Z'_J will fall into the new characteristic circle of the adjusted impedance Z'_{zd}. The relay protection would immediately response to a short cut instead of the malfunction.

The relay protection should be adjusted according to the following formula

$$\begin{aligned} Z'_{zd.I} &= K_{rel}(Z_{L1}) + Z_{SFCL} = K_{rel}(Z_{L1}) + jX_{SFCL} \\ |Z'_{zd.I}| &= \sqrt{(K_{rel}R_{L1})^2 + (K_{rel}X_{L1} + X_{SFCL})^2} \\ \theta &= \tan^{-1}\left(\frac{K_{rel}X_{L1} + X_{SFCL}}{K_{rel}R_{L1}}\right) \end{aligned} \tag{3}$$

In the formula, X_{SFCL} refers to the increased impedance of the SFCL; K is coefficient reliability, value is taken 0.8 ~ 0.85; θ is the adjusting impedance angle.

Based on (3), the impedance characteristic of the reset relay protection is showed in Fig. 4. Both line impedance and the adjusted directional impedance relay are drawn in it.

Via the above analysis, combing with the microcomputer protection feature, merging the SFCL impedance parameters gradingly with the relay protection arithmetic model of power system, through changing several parameters and the algorithm of the relay protection, we could successfully eliminate the influence that SICSFCL brings to the distance protection. Meanwhile, this algorithm has nearly no changing to hardware of the relay protection system which is currently be used by microcomputer embedded system widely. It only needs to modify algorithm. Therefore, it is easy to be implemented.

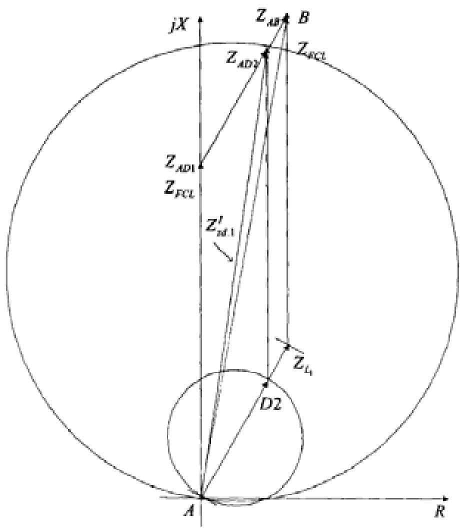

Figure 4. Vector diagram of the directional impedance relay.

IV. THE LIVE-GRID CONNECTION DIAGRAM OF 35 kV SFCL

Yunnan Power Grid Company successfully carried out world's first active kind 35 kV live-grid operation SFCL in Puji Substation. Fig. 5 shows the connecting format. The operational parameters are showed in Table I [8,9].

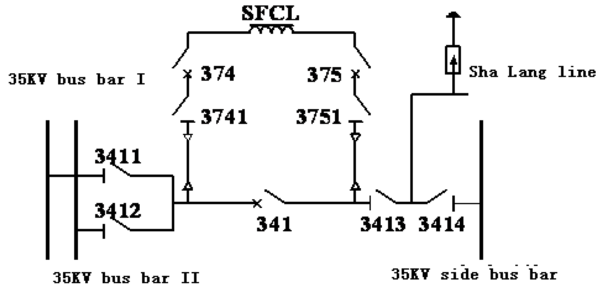

Figure 5. Live-grid connection diagram table of sicsfcl for puji substation.

TABLE I. OPERATION PARAMETER OF SICSFCL

Rated Voltage	35 kV
Rated Current	1200 A
Thermostability Current	20 kA/2 s
Operation Impedance	0.35 Ω
Fault Detecting Time	<1 ms
Response Time	<10 ms
Reset time	<800 ms

When put into operation, both ends of the SFCL breakers turn on, and 35 kV line breaker341 turns off. Therefore, the current will get through SICSFCL. Once de-active the SICSFCL, the 341's turning on causes both ends of the SFCL open. The current will pass by without getting through SICSFCL. If there happens a malfunction, standby power will automatically reset 341 in order to guarantee the sustained stability supplying of the current.

V. THE IMPEDANCE CHARACTERS OF 35 KV SICSFCL

The relay protection calculation parameters are shown in Table II. On the basis of the above method to do the calculation, the maximum effective impedance under the shorted fault condition is 3.5629 Ω, and the minimum value is 0.6064 Ω.

TABLE II. THE RELAY PROTECTION PARAMETERS

Relay Protection Calculation Table	
Line Impedance	4 Ω
The Length	9.96 km
Superconductive Protection Configuration	RCS-9611C/RCS-9647C
The Effective Impedance of SFCL in the Stage 1	0.57 Ω
The Fault Current without SFCL in Stage 1	21.37 kA
The Fault Current Limitation with SFCL in Stage 1	14.66 kA
The Effective Impedance of SFCL in Stage 2	1.06 Ω
The Fault Current without SFCL in Stage 2	7.11 kA
The Fault Current Limitation with SFCL in Stage 2	5.93 kA
The Effective Impedance of SFCL in Stage 3	6.82 Ω
The Fault Current in Stage 3	1.5 kA
The Fault Current Limitation with SFCL in Stage 3	1.35 kA

A. *The Protecting and Setting Principle of Breaker 341*

DPSⅠ is under the maximum pattern, stay away the most critical three phases fault current of the terminal line in order to setting the constant value. The protection action time limit (PATL) is 0 s.

DPSII is set in accordance with the minimum pattern of the line and its sufficient sensitivity. PATL is 0.3 s. DPSIII is set by the maximum stay away load current. PATL is 1.7 s and reclosing unit is placed in service.

B. *The Protection and Setting Principle of Breaker 374, 375*

About the line protection: only breaker 374 configuration line is under protecting. Breaker 375 is used for processing return circuit, observe and control. The principle of Breaker 374 is the same as Breaker 341. The line protection action is only tripping off 374 makes the reclosing unit in service. In order to cooperate with the differential motion protection of the reactor, the time limit for section I is only 0.1 s. During the cable fault of the back end of 375, 374 will trip off the fault to do the protection. As for the front fault, the up level main change 35 kV backup device will trip off the fault.

About the reactor protection: it is installed between breaker 374 and 375. The reactor protection device is put into differential protection (including differential action quick-break) only. The protection movement will trip off breaker

374, 375 without reclosing. Instead, it will active 35 kV SICSFCL's backup power selfdeliver device to reclose 341 in order to recover the power supply.

1) This backup self-deliver device is only useful when SICSFCL is in operating (means breaker 374, 375 switch on), not for any other circumstance.

2) Breaker 374,375 tripped off because of the reactor's protection will enable self-deliver.

3) As for the special connecting wire, this device has one and only one self-deliver pattern.

4) There is no voltage criterion for the backup power.

VI. CONCLUSION

1) There is a common sense about SICSFCL's functions as to improve system's transient state and the dynamic stability; to enhance safety etc. This paper studied the question that how the SFCL and relay protection work together, further provided relay protection parameter setting algorithm. If we adjust the relay protection parameter reasonably according to the characteristic of each different SFCL, we could amplify the application space of SFCL and make it do a better service for power grid.

2) Through 35 kV SICSFCL's live grid operation in Puji Substation, the arithmetic method is proved to be correct and efficient.

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