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Superconducting Fault Current Limiter

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Abstract

The need for power demand has been ever increasing due to numerous day-to-day causes. With increase in power demand, the fault levels witness a general rise. The superconducting fault current limiters have been seen as a much needed power device to limit the fault current in the electrical power system. This paper presents the undeniable usage of the superconducting fault current limiters (SFCLs) in large fault current limitation. In li ne to this, this paper also analyses its usefulness as compared to the conventional methods of fault limitation. It reviews the different techniques involved in current limitation through SFCL. It also discusses the basic operation of SFCL by exploiting the change in the behaviour of a superconductor under different conditions. This paper also includes the fault control mechanism of SFCL, their characteristics and their main region of application. An overview of challenges to the usage of SFCL in power circuitry and its future prospects in the existing world is provided.

Keywords

Current Limiting; Fault Current; High Temperature Superconductor; Power Transmission Grid.

I. Introduction

The need for power demand has been ever increasing due to numerous day-to-day causes. With increase in power demand, the fault levels witness a general rise. The short circuit faults are the most destructive ones among the uncountable faults occurring in power systems. These short-circuit faults can even cause current over 20 times the rated current.

The consequences of inevitable fault current in ele ctrical network usually mean thennal or mechanical stress for the affected equipment. Protection relays interrupt the normal power tlow. The results are voltage interruption and other power quality problems to the end-users. Power equipment is normally dimensioned for the tremendous stress under fault conditions. The maximal short-circuit current is one of the most important dimensioning parameter and it is directIy Iinked to the price of the equipment. The downsizing of the existing equipment, such as transformers, lines, bus-bars and circuit-breakers is possible by decreasing the maximal fault current [1]. At present there exist no conventional devices to limit peak short-circuit currents in high voltage power systems [2]-[3].

Some devices are used to reduce the fault current levels in transmission and distribution systems while they remain "electrically invisible" under nominal conditions. That is, the role of such devices comes into play only during faulty conditions. Such types of devices, called fault current limiters or FCLs, have significant potential in alleviating power system stresses in locations where fault current levels are supposed to rise beyond the capacity of an existing circuit breakers. Traditionally, the power transmission and distribution systems contain circuit breakers for disconnecting the power when a fault occurs. But for maximum reliability; they want to interrupt every possible faulty portion of network [4]. That is, all the circuit breakers, even the smallest ones, should be able to disconnect huge fault currents. This paper has been organized in eleven sections.

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The need of a fault current limiter in electric power generation and transmission has been discussed in Section 11. Section III gives a brief overview of a superconducting fault current limiter (SFCL). Section IV discusses the operation of SFCL by exploiting the properties of a superconductor. The two major types of SFCL, resistive and inductive, Section V shows the applications of SFCLs to various locations in a power grid. Advantages of SFCL are pointed out in section VI discusses the challenges to be achieved yet. Future prospects and Conclusion, presents the references.

II. SUPER-CONDUCTOR

An element, inter-metallic alloy or compound that will conduct electricity without resistance below a certain temperature. The Dutch Physicist Heike Kamerlingh Onnes of Leiden University was the first person to observe superconductivity in mercury [5-7]. The Fig 2.1 shows the arrangement of SFCL

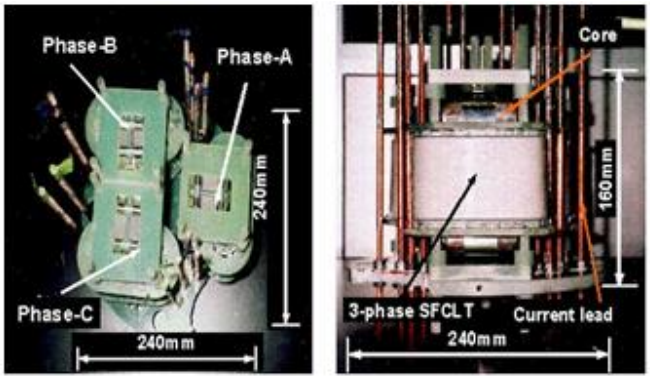

Fig 1 Arrangement of SFCL

Types of Superconductors:

1. Low Temperature Superconductor (LTS)
2. High temperature Superconductors (HTS)

LTS are the substances that lose all resistivity close to 4K , a temperature attainable only by liquid helium. HTS are the substances that lose all resistance below temperature attainable only by liquid nitrogen at 77k.

Meissner Effect:

The Meissner effect is the expulsion of the magnetic field from a superconductor during its transition to the superconducting state. The German physicists Walther Meissner and Robert Ochsenfeld discovered the phenomenon in 1933 by measuring the magnetic field distribution outside superconducting tin and lead samples. The magnetic flux is conserved by the superconductor, when the interior field decreased the external field is increased.

III. FAULT CURRENT LIMITER

A Fault Current Limiter (FCL) is a device which limits the prospective fault current when a fault occurs. Generally fault current limiters are superconducting fault current limiter. A fault current limiter (FCL) limits the amount of current flowing through the system and allows for the continual, uninterrupted operation of the electrical system, similar to the way of surge protectors limit damaging currents to house- hold devices.

A. IDEAL FAULT CURRENT LIMITER

An Ideal fault current limiter should posses following properties:- Invisible during normal system operation i.e insert zero impedance in the system when there is no fault in the system. Insert large impedance when fault occur in the system. Operate within the first cycle of the fault current. It should have short time recovery i.e. it return to its normal operation within short interval after limiting the value of the fault current. It should operate and return back to its normal state automatically. Capable of repeated system operation and should have long life. It should not affect relay coordination [8-10]. It should be of small size and cost effective. The traditional devices, used for fault current limitation, are: Fuses are simple, reliable and they are usually used in low voltage and in middle voltage distribution grids. The main disadvantages are the single-use and the manually replacement of the fuses; Circuit-breakers are commonly used, reliable protective devices.

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The circuit- breakers for high current interrupting capabilities are expensive and have huge dimensions. They require periodical maintenance and have limited number of operation cycles; Air-core reactor and transformers with increased leakage reactance increase the impedance of distribution network and consequently limit the short-circuit currents; System reconfiguration and bus-splitting.

B. FAULT-CURRENT PROBLEM

Electric power system designers often face faultcurrent problems when expanding existing buses . Larger transformers result in higher fault-duty levels , forcing the replacement of existing bus work and switchgear not rated for the new fault duty. Alternatively , the existing bus can be broken and served by two or more smaller transformers . Another alternative is use of a single , large , highimpedance transformer , resulting in degraded voltage regulation for all the customers on the bus [11-13] . The classic tradeoff between fault control , bus capacity , and system stiffness has persisted for decades . Fig 3.1 shows the compact arrangement of transmission lines which leads for fault in the power system.

Fig 2.Compact Arrangement Of Transmission Lines

Other common system changes can result in a fault control problem:

- In some areas, such as the United States , additional generation from co generators and independent power producers (IPPs) raises the fault duty throughout a system.
- Older but still operational equipment gradually becomes underrated through system growth ; some equipment , such as transformers in underground vaults or cables, can be very expensive to replace.
- Customers request parallel services that enhance the reliability of their supply but raise : the fault duty.

C. NEED OF FCLS

The need for FCLs is driven by rising system fault current levels as energy demand increases and more distributed generation and clean energy sources , such as wind and solar, are added to an already overburdened system. Currently, explosive fault-limiting fuses are utilized to limit fault current, but they require a service call to replace the fuse after it blows and they are only available for voltages below 35 kV. Series reactors are also used but they have constant high reactive losses, are bulky, and contribute to grid voltage drops. FCLs overcome these weaknesses . Additionally, rising fault current levels increase the need for larger and often costly high impedance transformers . However, in contrast to these transformers , FCLs operate with little to no impedance during normal operation which allows for a more stable system. FCLs are supporting technology in the smart grid. The main purpose of the installation of FCL into the distribution system is to suppress the fault current. The FCL is series element which has very small impedance during a normal operation [12-14]. If the fault occurs the FCL increases its impedance and so prevents over-current stress which results as damaging, degradation, mechanical forces, extra heating of electrical equipment.

The main requirements to the FCLs are :

- To be able to withstand distribution and transmission voltage and currents;
- To have low impedance, low voltage drop and low power loss at normal operation;

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- To have large impedance in fault conditions;
- To have a very short time recovery and to limit the fault current before the first peak;
- To properly respond to any fault magnitude and/or phase combinations;
- To withstand the fault conditions for a sufficient time;
- To have a high temperature rise endurance;
- To have a high reliability and long life;
- To have fully automated operation and fast recovery to normal state after fault removal;
- To have a low cost and low volume.

The pyrotechnic FCL (so called explosion faults limiting fuses, Is-limiters) takes special place. Is-limiters are consist of an ultra fast acting switch for nominal loads connected in parallel to a heavy duty fuse. A small explosive charge is used to open the main current path if the fault occurs. The current is transferred to the fuse and its magnitude is limited.

IV. NEED OF FAULT CURRENT LIMITER

The traditional devices, used for fault current limitation, are:

- Fuses are simple, reliable and they are usually used in low voltage and in middle voltage distribution grids. The main disadvantages are the single-use and the manual replacement of the fuses.
- Circuit-breakers are commonly used, reliable protective devices. The circuit-breakers for high current interpru ting capabilities are expensive and have huge dimensions. They need regular maintenance because they have certain Iimited number of operation cycles.
- Air-core reactor and transformers with increased leakage reactance increase the impedance of distribution network and consequently limit the short-circuit currents [15].

There have been an increase in the number of studies on the alternative solution to improve the reliability of electrical systems and one of them is the usage of a fault current limiter (FCL). The supreme purpose of the installation of FCL in the transmission and distribution system is to suppress the fault current. The FCL is a series element which offers quite small impedance when operating in a normal operation. If the fault occurs the FCL increases its impedance and hence prevents large current stresses which would have probably resulted in damaging, mechanical forces, degrading and extra heating of electrical equipment These FCLs are needed to be able to combat transmission and distribution currents and voltages. There are certain expectations from the FCLs when it comes to performance. They need to have low impedance, low power loss and low voltage drop during normal operation and huge impedance during fault conditions. This property shall block the ongoing large fauIt current in the faulty state of operation. FCLs should have a very short recovery time and they are required to limit the value of current before the first peak of the fault current. They are supposed to accurately respond to any value of fault current magnitude and/or phase combination. For a sufficient time, they should be able to withstand the faulty conditions. They have to have high thermal en duran ce, good reliability and a long Iife. Plus, they should also have fully automated operation and fast recovery time to quickly switch to normal state after fauIt rem oval. Not just this, they are required to minimize the cost of power generation and transmission, i.e. they should have a low cost and low volume of their own [10].

SUPER CONDUCTING FAULT CURRENT LIMITER

A high temperature superconducting fault current Iimiter (SFCL) comes up with a promising solution to survive the various short circuit faults in a modern power system. Today, the superconducting materials possess the ability to meet the performance considerations of power system components.

Thus, a prominent portion of the proposed FCL designs apply the use of superconducting materials in order to achieve the fault current limiting action. SFCL is a new power device to automatically limit a fault current to a safe level with superconducting property. The SFCLs have by far satisfied nearly all the requirements of an efficient current limiter, few of them mentioned in the previous article. The transformer type superconducting fault current limiter [16] is one type of SFCL.

SUPERCONDUCTING FAULT-CURRENT LIMITER

Conventional FCLs are of three types: series type, shunt type, and solid-state diodes type.

1. Series Type : Working of this type of FCL takes place by shorting the capacitor in tuned LC parallel resonance circuit. Disadvantages : Large size, High capital cost, High operating cost.
2. Shunt Type : It works by opening a bypass switch, in parallel with an impedance which is normally closed. Disadvantages : Difficulty in switching, Slow reaction time.
3. Solid-state diode types : Works by using current conservation law in a bridge. Disadvantages : Applicable only for high voltage systems.

From this it is conclude that, no conventional FCL is Technically and economically efficient. Exciting developments in superconducting technologies had overcome these problems. First SFCL made from low temperature material, in 1983. Which is of material NbTi having high current carrying capacity & easy to manufacture . Again it has one drawback i.e. high cooling cost. To overcome these drawbacks HTSFCLs are developed HTS is more suitable than LTS for SFCL because,

1. It requires less refrigeration cost
2. Better thermal stability
3. It has high normal specific resistance

It is necessary to improve the current carrying capacity of HTS to meet the power system requirements. Substrate used in parallel to superconductor, limits the normal state resistance of SFCL.Therefore SFCLs are constructed using YBCO, Bi-2223 and Bi-2212 film are commonly used substrate materials. There specific resistance is nearly 100times higher than the superconducting material. This superconducting film type FCL has good coolant performance, short recovery time, and can meet the need of re-closer easier than LTSFCL and HTSFCL.

- SFCLs is a new power device to automatically limit a fault current to safe level with the superconducting property.
- When superconductor is cooled down to critical temperature (about -186°C) or less , the resistance becomes zero. However , superconductor looses.
- Superconductivity and resistance occurs rapidly (quench), when excessive current flows and exceeds certain value (critical current). SFCL device uses this property .
- A superconductor is a material that can conduct electricity or transport electrons from one atom to another with no resistance

Superconductors offer a way to break through system design constraints by presenting impedance to the electrical system that varies depending on operating conditions. Superconducting fault-current limiters normally operate with low impedance and are "invisible" components in the electrical system . In the event of a fault, the limiter inserts impedance into the circuit and limits the fault current. With current limiters, the utility can provide a low impedance, stiff system with a low fault-current level. operate at higher temperatures and can be cooled by relatively inexpensive liquid nitrogen, renewed interest in superconducting fault-current limiters.

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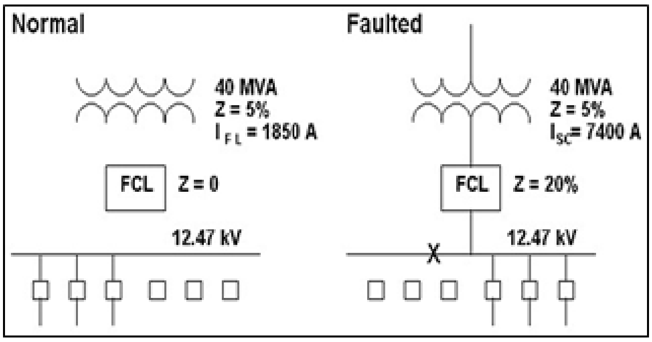

Fig 4.1 Fault control with a fault-current limiter

In Fig. 4.1, a large , low-impedance transformer is used to feed a bus. Normally, the FCL does not affect the circuit. In the event of a fault, the limiter develops an imped-ance of 0.2 per unit (Z = 20%) , and the fault current ISC is reduced to 7,400 A. Without the limiter, the fault current would be 37,000 A. The development of high temperature supercondu-tors (HTS) enables the development of economical fault-current limiters. Superconducting fault-current limiters were first studied over twenty years ago. The earliest designs used low temperature superconductors (LTS), materials that lose all resistance at temperatures a few degrees above absolute zero. LTS materials are generally cooled with liquid helium, a substance both expensive and difficult to handle. The dis-covery in 1986 of high temperature superconductors, which operate at higher temperatures and can be cooled by rela-tively inexpensive liquid nitrogen, renewed interest in su-perconducting fault-current limiters.

V. CLASSIFICATIONS OF SFCLS

Superconducting materials have a highly non-linear behavior they are very useful FCLs to be build. The low tem-perature superconductors operating at the temperature of liq-uid helium (4K) as well as high temperature superconductors, called II-nd generation (2G) superconductors with critical temperature around the boiling point of nitrogen (77K) have been studied. The two most important 2G superconducting ceramics are used industrially as a coated conductor:

• Yittrium-Barium-Copper-Oxide $YBa_2Cu_3O_7$ (often abbre-viated YBCO) and is used for thin film techniques; Fig 4.4 shows the arrangements of YBCO elements in Transformer

• Bismut-Strontium-Calcium-Copper-Oxide,$Bi_2Sr_2Ca_nCu_{n-1}O_{2n+4+x}$, (abbreviated as BSCCO and with trade mark of the compound Bi-2212 / Bi-2223) are used for fil-ament.

Magnesium Diboride (MgB_2) has also emerged as a suitable candidate material for FCL devices. The major ad-vantages of this material is its inexpensiveness, hence utilizing MgB_2 is expected to reduce the cost for superconducting ma-terial used in the SFCL. Superconducting fault current limiter (SFCL) is an ideal current limiter, but it is still only in the researching stage. The technical performance of superconducting fault current limiters has been demonstrated by numerous successful pro-jects worldwide.

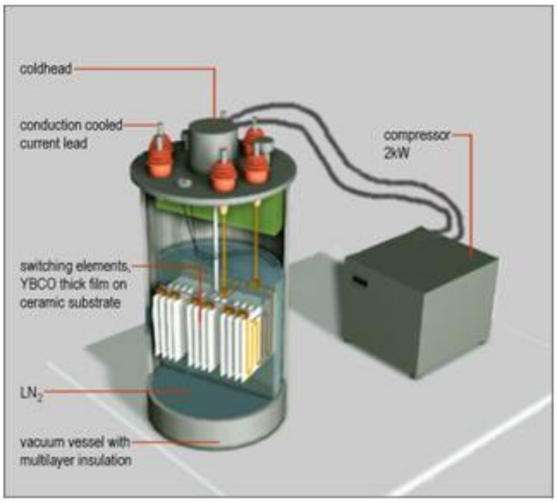

Fig 4.4 YBCO elements in Transformer

Superconducting fault current limiters are basically of two types:

1. The resistive SFCL is simply connected in series with the network.
2. The inductive SFCL is based on a transformer with a superconducting shielding tube in the secondary.

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1) Resistive type SFCL

The resistive type is a superconducting element con-nected in series with the network as shown in fig 4.5. It is the simplest type of SFCL. It can be just only a low temperature superconducting wire or a certain length of high temperature superconductors. When the current is normal, the supercon-ductor is in the superconducting state without resistance. If the current increases over the critical current, the supercon-ductor goes into its normal state and it has a high resistance connected in series with the network. This resistance will limit the current. A parallel resistance is required to be connected with the superconducting element. The parallel resistance or inductive shunt is needed to avoid hot spots during quench, to adjust the limiting current and to avoid over-voltages due to the fast current limitations. The resistive SFCLs are much smaller and lighter then the in-ductive ones. First commercial resistive FCL has been ener-gized in late 2009 in Europe .Currently, two parallel projects in US aiming to build transmission voltage level resistive FCL are undergoing.

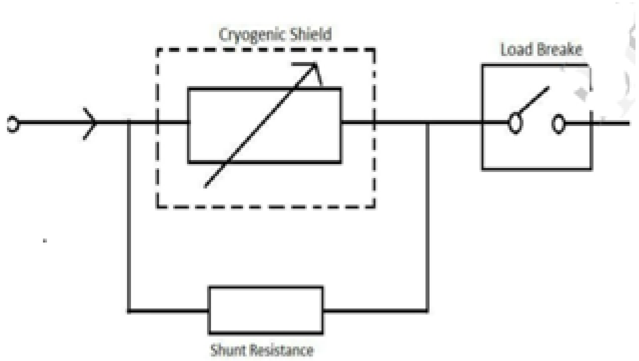

Fig 4.5 Resistive type SFCL

Superconducting wires for fault current limiter appli-cations," In the recent decades the price of the YBCO coated conductor drops significantly and the performance has im-proved, therefore, it has gained significant attentions as the superconducting material for resistive type FCL and the re-search on it has been carried out worldwide. In October 2011, a 138 kV, 0.9 kA resistive SFCL was successfully tested in a high-voltage transmission grid .

The tested system proved to reduce fault current levels by more than 50 percent.

2) Inductive type SFCLs

The inductive type is a special transformer connected in series with the network. This transformer has a convention-al primary coil, and a rather special secondary "coil": a super-conductor ring. When the current is normal, the superconduc-tor ring gives a deexcitation . In normal operation the primary winding resistance and leakage inductance determine the im-pedance of the limiter. Thus during normal operating condi-tion the FCL exhibits a low impedance (approximately the leakage reactance). When the current increases over the critical current, the superconductor ring goes into normal state. In this case the FCL represents high impedance (approximately the main field reactance).

ADVANTAGES AND DISADVANTAGES

ADVANTAGES OF SFCLS

• SFCL is applied with the distribution generation
• SFCL reduce the level of short-circuit current during a fault.
• No external control s needed.
• Rapid response.
• SFCLs are invisible in normal operation and do not intro-duce unwanted side effects.
• SFCLs are economically competitive with expensive con-ventional solutions.
• Negligible loss during normal system operation.

DISADVANTAGES OF SFCLS

• Requires cooling which result in increase in its cost .
• One current disadvantage is that there is energy loss caused by the current leads passing from room tempera-ture to cryogenic temperature that will result in a loss of approximately 40-50 W/kA heat loss per current lead at cold temperature.
• Superconductors tend to the development of thermal in-stabilities (the so called hot spots). In order to protect the materials against these hot spots often a normal conduct-ing bypass is employed.

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APPLICATIONS OF SFCLS

Applications of SFCL in power system
1) Limit the fault current
2) Secure interconnector to the network
3) Reduces the voltage sag at distribution system

REDUCES VOLTAGE SAG

The effects of a superconducting fault current limiter (SFCL) installed in loop power distribution systems on voltage sags are assessed and analyzed . The power distribution sys-tem will be operated to a type of loop. In this case, voltage drops (sags) are severe because of the increased fault current when a fault occurs. If SFCL is installed in the loop, power distribution system, the fault current decreases based on the location and resistance value of the SFCL, and voltage sags are improved. Analyzed according to fault. The results found that the voltage sags at loop distribution system is more severe than radial distribution system by the increased fault current. Moreover, the results of simulation represent the SFCL with bigger resistance is needed to improve the voltage sags in loop system. When SFCL is applied to a radial power distribution system. In case parallel connection Of radial systems via the SFCL which can make voltage dips less severe. Results in this paper shows that the improvement of voltage sags caused by fault current decreased by installing fault current limiter.

VI. FUTURE PROSPECTS AND CONCLUSION

The use of SFCL was first pioneered at Boxberg in 2009 in Upper Lusatia which was developed, built and commissioned by Nexan Superconductors. In recent times, TEPCO is supposed to develop a three-phase Iimiter in the upcoming years and this Iimiter shall be tested in the grid within this century. The true application for the superconducting FCL is at transmission voltages of 500 kV. Millions of worth of financial loss is caused every year to the world's leading economies by electric power disruptions. Energy demand is growing rapidly worldwide and instant and sustainable solutions are required to improve the energy supply.

The introduction of new devices like superconducting fault current Iimiters, is a must. They use the electrical properties of HTS to instantaneously protect power grids against short circuits and thereby prevent costly outages. They are key member of a family of ultra-fast HTS devices and machines used for electrical power. It is found that feeder locations of power stations and wind generators are the most economical places for SFCL. With the progress of superconducting technology and superconducting materials research and the development of power electronics technology, superconducting fault current Iimiters (SFCL) will inculcate new means for current-limiting technology in fault analysis sector of power system engineering in the coming future.

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