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Superconducting Fault Current Limiter & Its Application

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Abstract— The Superconducting Fault Current Limiter (SFCLs) concept proposes two types of superconducting materials. Firstly, Resistive- SFCL (which is inserted directly in series with the circuit to be protected). Secondly, Inductive-SFCL(which is a transformer shorted by superconducting tube). We also study few applications of SFCLs which is proposed to limit the fault - current that occurs in power system. Fault current level has become a serious problem in transmission and distribution system operations. The application of the superconducting fault current limiter(SFCL) would not only decrease the stress on network devices , but also can offer a connection to improve the reliability of the power system. They also make electric power network more powerful and integrated.

Index Terms— Superconducting Fault Current Limiter(SFCLs),Fault Current Limiter(FCLs), Resistive -Superconducting fault Current Limiter, Inductive-Superconducting Fault Current Limiter , Low Temperature Superconductor(LTS), High Temperature Superconductor(HTS), Fault Current, Yittrium-Barium-Copper-Oxide(YBCO), Bismut-Strontium-Calcium-Copper-Oxide(BSCCO).

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1 INTRODUCTION

Increase in power generation capacity of electrical power systems has led to increase in the fault current level which can exceed the maximum designed short-circuit ratings of the switchgear. Many conventional protective devices installed for protection of excessive fault current in electric power systems, especially at the power stations are the circuit breakers, tripped by over-current protection relay. To overcome the high fault current , many kinds of fault current limiting devices have been used in the last decades. Current-limiting fuses, series reactors, and high-impedance transformers were used. They have the response time delay that allows initial of two and three fault current cycles to pass through before getting activated. Howe ever, these alternatives may cause other problems, such as loss of power system stability, high cost and increase in power losses, which may ultimately lead to decreased operational flexibility and lower reliability.

Superconducting Fault Current Limiter (SFCLs) is innovative electric equipment which has the capability to reduce fault current level within the first cycle of fault current. SFCL have zero impedance under the normal condition and large impedance under fault condition. There are several kinds of SFCLs being used for current limitation such as saturated iron care SFCL, inductive SFCL and resistive SFCL. Each type of SFCL has its merits and demerits and can be realized with low temperature superconductors (LTSs) and high temperature superconductors (HTSs). Saturated iron core SFCL, uses LTSs where inductive-SFCL and resistive-SFCL are usually designed by HTSs. A high temperature superconducting fault current limiter (SFCL) can be solution to reduce the level of short-circuit current during fault. SFCLs can contribute significantly to increasing the safety, availability of electrical systems in power stations. According to experts, they also have an important role to play in expanding the power grid.

2 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. The Fig 2.1 shows the arrangement of SFCL

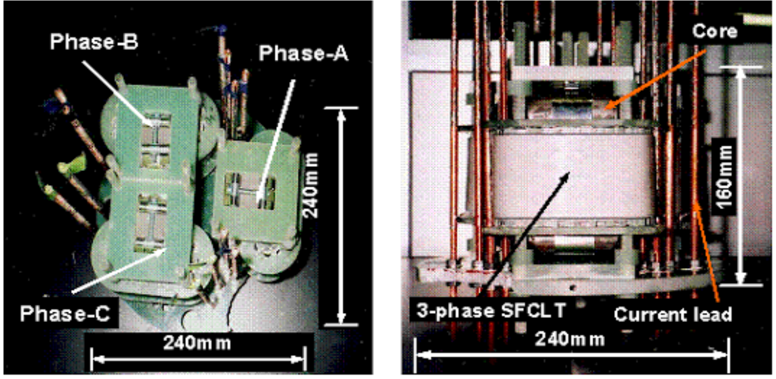

Fig 2.1 Arrangement of SFCL

Superconductivity is a phenomenon of exactly zero electrical resistance certain materials when cooled below a characteristic critical temperature. It is a quantum mechanical phenomenon.

Types of Superconductors:

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

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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.
Examples of LTS: Lead and Mercury.
Examples of HTS: YBCO, BSCCO, etc.

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.

3. 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.

3.1. 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. 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. 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.

3.2 FAULT-CURRENT PROBLEM

Electric power system designers often face fault-current 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 , high-impedance transformer , resulting in degraded voltage regulation for all the customers on the bus . 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 3.1 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.

3.3 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. 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;
- 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.

3.4 BENIFITS OF FCLS TO UTILITIES

FCLs offer numerous benefits to electric utilities . For instance , utilities spend millions of dollars each year to maintain and protect the grid from potentially destructive fault currents. These large currents can damage or degrade circuit breakers and other expensive T&D system components. Utilities can reduce or eliminate these replacement costs by installing FCLs.

Other benefits include:

- Enhanced system safety, stability , and efficiency of the power delivery systems.
- Reduced or eliminated wide-area blackouts , reduced localized disruptions, and increased recovery time when disruptions do occur.
- Reduced maintenance costs by protecting expensive downstream T&D system equipment from constant electrical surges that degrade equipment and require costly replacement . Improved system reliability when renewable and DG are added to the electric grid.
- Elimination of split buses and opening bus-tie breakers.
- Reduced voltage dips caused by high resistive system components.
- A larger transformer can be used to meet increased demand on a bus without breaker upgrades.
- A large , low impedance transformer can be used to maintain voltage regulation at the new power level.
- I2t damage to the transformer is limited.
- Reduced fault-current flows in the high-voltage circuit that feeds the transformer, which minimizes the voltage dip on the upstream high-voltage bus during a fault on the medium-voltage bus .
- An FCL can also be used to protect individual loads on the bus. The selective application of small and less expensive limiters can be used to protect old or overstressed equipment that is difficult to replace , such as underground cables or transformers in vaults.
- An FCL can be used in the bus-tie position . Such a limiter would require only a small load current rating but would deliver the following benefits:
- Separate buses can be tied together without a large increase in the fault duty on either bus.
- During a fault , a large voltage drop across the limiter maintains voltage level on the unfaulted bus.
- The paralleled transformers result in low system impedance and good voltage regulation ; tap-changing transformers can be avoided.
- Excess capacity of each bus is available to both buses, thus making better use of the transformer rating.

4. 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.

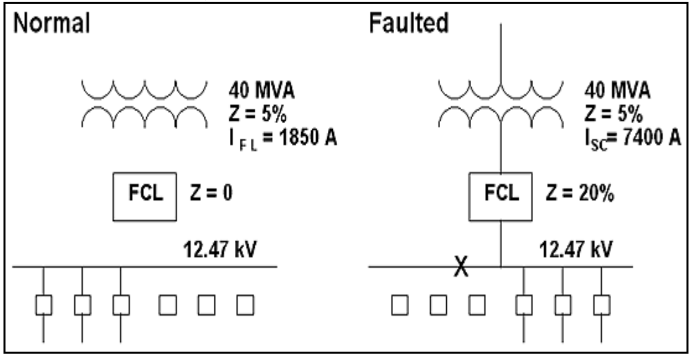

Fig 4.1 Fault control with a fault-current limiter

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 impedance 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 superconductors (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 discovery in 1986 of high temperature superconductors, which operate at higher temperatures and can be cooled by relatively inexpensive liquid nitrogen, renewed interest in superconducting fault-current limiters.

4.1 GENERALIZED CURRENT WAVEFORMS WITH AND WITHOUTFCL

Several characteristics of FCLs can be quantified for the three operating modes listed in fig 4.2. Because the size and weight of an installed FCL are a major concern to utilities, an indication of device footprint is also included.

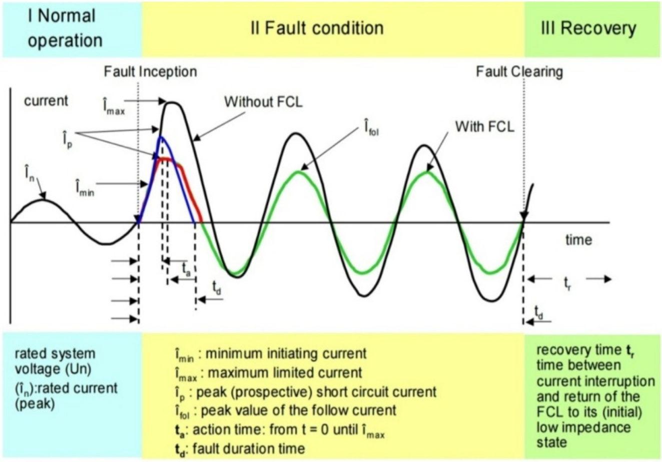

Fig 4.2 operation sequence of SFCL

Losses : The electrical losses (W) caused by alternating currents in superconducting materials or power consumed by switching devices in solid-state devices.

Steady-State Impedance : The impedance under normal operating conditions as seen by the network. Ideally, an FCL has no impact in a network under normal operating conditions.

Triggering : Describes the method of initiation of a fault response. Active FCLs utilize sensors and control schemes to trigger the action. Passive FCLs respond to faults through changes in material properties associated with increased current or magnetic field. For example, superconducting-to-normal transitions and permeability changes.

Recovery : The amount of time required by an FCL to recover from a limiting action before it can be re-energized. Recovery is a particular concern in SFCLs where time is required to re-cool the HTS.

Size/Weight : Encapsulates the physical size and weight of a device.

Distortion : Refers to irregularities in the shape of the AC current waveform that is introduced by switching electronics and the nonlinear magnetic characteristics of iron. Distortion is an issue with the follow current during a limiting action as the performance of downstream protection devices may be affected.

4.2 LIMITATIONS OF SFCLS

The fundamental property of any superconducting fault current limiter is its peculiar capability to change from one state with extremely low impedance to another state defined by substantial larger impedance.

The limitation characteristics of the superconducting fault current limiter is expected to met the following principle specifications :

- Activation current : Iactivation > 2.5 · Irated
- Limitation of the peak current value : Ipeak < 10 · Irated
- Limitation value of the current in the first half period : I1'st half period <7 · Irated
- Limitation value of the current in the succeeding periods : Ilimitation < 3 · Irated

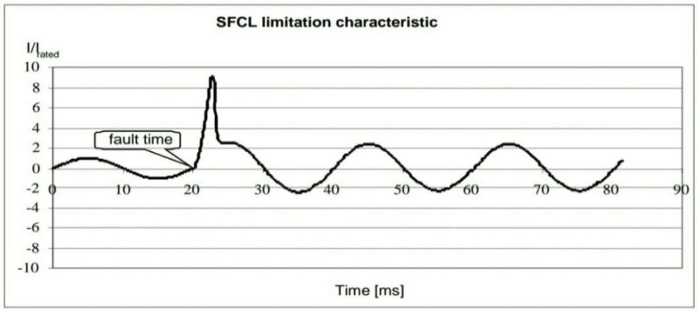

Fig 4.3 Limitation curve of the SFCL

4.3 Classifications Of SFCLs

Superconducting materials have a highly non-linear behavior they are very useful FCLs to be build. The low temperature superconductors operating at the temperature of liquid 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 YBa2Cu3O7 (often abbreviated YBCO) and is used for thin film techniques; Fig 4.4 shows the arrangements of YBCO elements in Transformer

- Bismut-Strontium-Calcium-Copper-Oxide,Bi2Sr2Ca nCun-1O2n+4+x, (abbreviated as BSCCO and with trade mark of the compound Bi-2212 / Bi-2223) are used for filament.

Magnesium Diboride (MgB2) has also emerged as a suitable candidate material for FCL devices. The major advantages of this material is its inexpensiveness, hence utilizing MgB2 is expected to reduce the cost for superconducting material 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 projects worldwide.

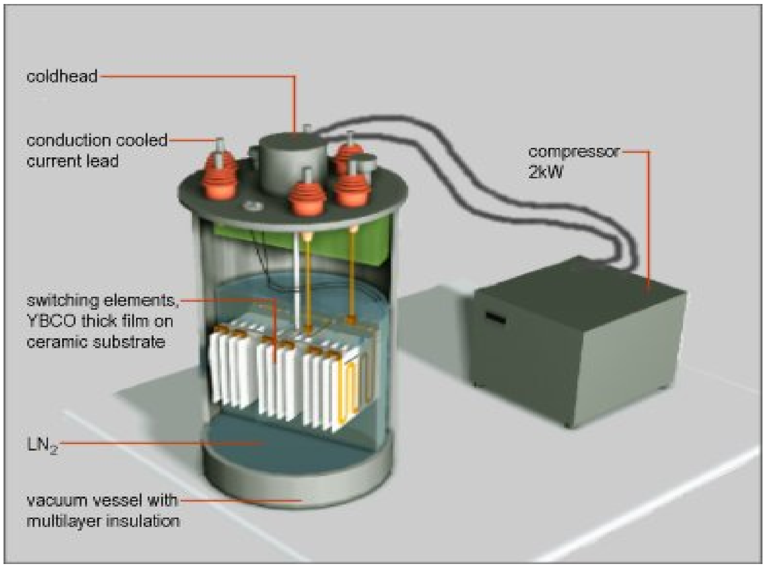

Fig 4.4 YBCO elements in Transformer

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.

1) Resistive type SFCL

The resistive type is a superconducting element connected 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 superconductor is in the superconducting state without resistance. If the current increases over the critical current, the superconductor 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 inductive ones . First commercial resistive FCL has been energized in late 2009 in Europe .Currently, two parallel projects in US aiming to build transmission voltage level resistive FCL are undergoing.

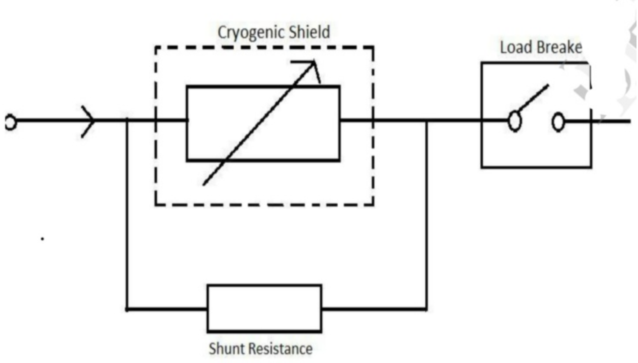

Fig 4.5 Resistive type SFCL

Superconducting wires for fault current limiter applications," In the recent decades the price of the YBCO coated conductor drops significantly and the performance has improved, therefore, it has gained significant attentions as the superconducting material for resistive type FCL and the research 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 conventional primary coil, and a rather special secondary "coil": a superconductor ring. When the current is normal, the superconductor ring gives a deexcitation . In normal operation the primary winding resistance and leakage inductance determine the impedance of the limiter. Thus during normal operating condition 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).

a) Inductive Shielded SFCL

This device is based on the principle of perfect diamagnetism of the superconductor , that is in superconducting state the magnetic field is expelled from the superconductor (fig 4.6). This effect was first discovered by Meißner and Ochsenfeld. It works like transformer, the superconducting element is a cylinder which forms the single turn short circuited secondary of an iron cored transformer which has part of the power line as its primary. In its superconducting state, this cylinder effectively screens the iron core from the primary, and a low inductance (i.e. impedance) is introduced in the line. However, when the current (and hence the magnetic field) increases above a certain level, the superconductor can no longer shield the iron core), flux enters the iron and a high impedance is inserted in the line which is to be protected.

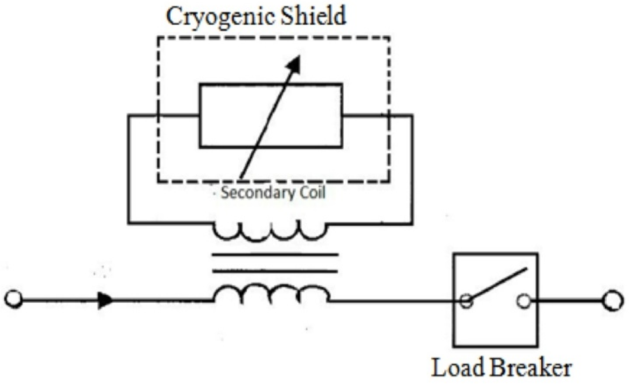

Fig 4.6 Inductive Shielded SFCL

The primary winding acting as the main current lead of the circuit is built in a way not to be exposed to the cryogenic part but to the temperature level of the environment. In normal operation the magnetic field is expelled from the superconductor. That means that the magnetic flux, generated by the primary winding, is not able to penetrate the iron core. Therefore the iron core doesn't cause any magnetization losses and the limiter inserts very low impedance to the network. Only in the resistive state when the superconductor is no longer able to expel the magnetic field, large impedance is inserted into the network.The secondary winding is divided into two parts, the superconductive winding and its normal conductive bypass. As the superconductor is based on an YBCO ceramic, changing from superconductive to normal state would dissipate so much energy into the ceramic material that it would be destroyed. Therefore a bypass coil is taking over the current flowing in the normal state. As long as the critical current of the superconductor is not reached, the secondary winding blocks the magnetic flux in the iron core. In case of a failure current the dissipated current into the secondary winding becomes much high that the superconducting state will be broken.

The voltage induced in the secondary by-pass winding by coupling of the iron core will cause the counter induction to reduce the current in the primary coil. The prospect of this type of limiter to be economically competitive is very low however there are still a few small, mostly university based academic projects active that utilize the "shielded core" type .

b) Saturated iron-core type SFCL

In the saturated-core FCL, two iron cores (one for each half of the cycle) are saturated by the dc magnetic field produced by a superconducting coil wrapped around each core. The main power line is wound around both cores and, when the current becomes high enough (i.e. a fault) the cores are driven out of saturation and the impedance rises - limiting the current.

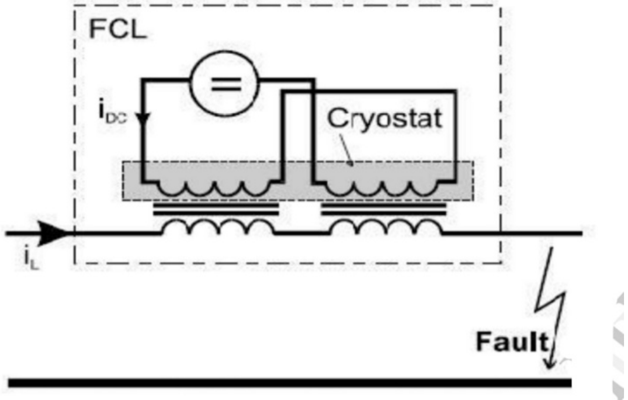

Fig 4.7 Saturated iron-core type SFCL

Fig.4.7, above shows a structure diagram of single-phase magnetic saturated core type SFCL, which is composed by iron cores, AC windings, superconducting DC winding, DC power and the control circuit. Under the normal operating condition, DC superconducting coil generate a lot of magnetic flux which can make the core saturated.

Therefore it offers very small impedance to the power system which has no adverse effect on normal transmission. When the short circuit fault occurs, the current surges, and fault monitoring system will instantly cut off the DC exciting-current within a few milliseconds by means of power electronic switch, such as insulated gate bipolar transistor (IGBT) or integrated gate commutated thyristor (IGCT), in the DC control circuit. Then both of the two cores go out of deep saturation status so that fault current in the two AC winding will produce large inductive EMF which can limit fault current.

The advantage of this concept is that it does not require the superconductor to become normal to operate. However, it requires approximately twice as much iron(two cores).This system doesn't use the special properties a superconductive material has and theoretically it could be built without using superconductive conductors. In 2009, a saturated iron-core SFCL device was experimentally tested in small-scale distribution networks in California, United States . In January 2010, the test field in California suffered a lightning-induced fault and the FCL device limited the fault current as designed. A field test in a 138 kV transmission network was planned for the end of 2011.

5.ADVANTAGES AND DISADVANTAGES

5.1 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 introduce unwanted side effects.
- SFCLs are economically competitive with expensive conventional solutions.
- Negligible loss during normal system operation .

5.2 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 temperature 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 instabilities (the so called hot spots). In order to protect the materials against these hot spots often a normal conducting bypass is employed.

6.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

6.1 LIMIT THE FAULT CURRENT

In electrical network, there are various faults, such as lightning, short circuits, grounding etc., which occurs large fault current. If these large currents are not properly controlled for power system security, there happens unexpected condition like fire, equipment and facility damage, and even blackout. Therefore, Circuit Breakers are installed and have the duty to cut off fault current, however, it takes minimum breaking time to cut, and sometimes fail to break.

Fault Current Limiter (FCL) is applied to limit very high current in high speed when faults occur. Different with normal reactor, normal impedance is very low and have designed impedance under faulted situation. Fault limiting speed is high enough that it can limit fault current within 1/4 cycle. Also, this function has to be recovered fast and automatically, too.

Various FCLs are developed and some of them are applied in power system. Most typical FCL is to change over circuit from low impedance circuit to high impedance circuit. Circuit breakers and/or power electronics devices are used to control FCL circuits. Fuse or snubber circuits are used to protect high recovery voltage. These FCLs are attractive as it implements normal conductor, however, there are weak points such as slow current limiting speed and big size in distribution and transmission level as well.

Superconducting fault current limiter (SFCL) has been known to provide the most promising solution of limiting the fault current in the power grid. It makes use of the characteristic of superconductor whose resistance is zero within critical temperature (Tc) and critical current (Ic). If fault current exceeds Ic, superconductor lose superconductivity and the resistance increase dramatically (called quench) and limit circuit current.The first installed one is developed by ABB . After that, various SFCLs are developed for distribution and transmission application to protect bus and/or feeder from high fault currents. Fig 6.1. shows recently developed and installed

SFCLs for distribution level.

Fig 6.1 SFCLs installed for distribution level

SFCL DEVELOPMENTS FOR TRANSMISSION LEVEL:

A superconducting fault current limiter (SFCL) in series with a downstream circuit breaker could provide a viable solution to controlling fault current levels in electrical distribution networks. In order to integrate the SFCL into power grids, we need a way to conveniently predict the performance of the SFCL in a given scenario. Short circuit analysis based on the electromagnetic transient program was used to investigate the operational behavior of the SFCL installed in an electrical distribution grid. System studies show that the SFCL can not only limit the fault current to an acceptable value, but also mitigate the voltage sag.

The transient recovery voltage (TRV) could be remarkably damped and improved by the presence of the SFCL after the circuit breaker is opened to clear the fault. Being a promising application of superconductors, the SFCL is considered to be one of the innovative devices of FACTS in electric power system. In the event of a single-phase short circuit in the load feeder, a very large fault current will pass through the SFCL. After the critical current is exceeded, within the first half cycle, the critical temperature is reached and the transition to the normal conducting state quickly takes place. In case of installing the SFCL the maximum short circuit current is limited within the first cycle of the fault.

In practice the SFCL might be used in distribution systems first . However, the function of the SFCL is only to limit the fault current at a chosen value until the conventional circuit breaker could eliminate the fault. An SFCL in series with a downstream circuit breaker could provide a fast and reliable means of reducing and interrupting increasingly higher short circuit currents.

Transient recovery voltage and transient overvoltage are both remarkably damped and improved by the presence of the SFCL after the circuit breaker is opened to clear the fault. This will thereby extend the breaker's life span and increase the chances of quickly achieving successful fault current interruption. The SFCL can be regarded as a very useful apparatus, shielding the distribution system from voltage decreases. The SFCL design probably requires that the limited fault current be between three and five times the steady-state current rating.

6.2 SECURE INTERCONNECTOR TO THE NETWORK

The application of the SFCL would not only decrease the stress on device but also offer an interconnection to secure the network. They can improve reliability and stability of power systems by reducing the fault current. If the bus-bars are coupled via a SFCL the short circuit power can be doubled. A further improvement can be obtained, if low impedance transformers in series with SFCLs are used. The most economical short-circuit-voltage of the transformers would be 10 %.

Application of SFCLs in the transformer feeders the admissible short-circuit capability of the substation can be obtained. In this way the short-circuit power of the station is increased to nearly three times in total. By this means also voltage-disturbing customers and high loadings can be connected directly to the MV station and the connection to the higher voltage level can be avoided. Compared to the investment costs for a connection to higher voltages level, e.g. the 110 kV grid, the installation of SFCLs in the way suggested will be an economical solution, reasonable costs for the SFCL presumed.

A similar situation exists regarding the connection of distributed generation and wind turbines to the MV grid. Here it becomes more and more difficult to connect such generators to the grid without a device limiting the short circuit current of the generator. In some MV stations the limits are already Reached by the contribution of the feeding 110/10 kV transformer and no more margin is left for additional short-circuit currents coming from distributed generation. Therefore nowadays these Generators have to be connected to the 110 kV Grid via an expensive generator transformer. By means of SFCL, those generators could be connected to the MV grid. By the SFCL application considerable cost savings can be achieved.

The investment costs, the maintenance costs and the power losses of the SFCL bus-coupler are related to that of the transformer bay. The investment costs as well as the maintenance costs of the SFCL solution are significantly lower. The power losses of the SFCL can be neglected compared to that of the coupling transformer. Assumed. If an installation with a new transformer is considered, the cost ratio of the SFCL solution exhibits about 35% compared to that of the transformer bay. Even if 50% of the transformer investment costs are taken into account only, i.e. a transformer being in service for half of its lifetime is installed, the cost ratio is less than 50%. With the increasing demand for power, electric power systems have become greater and are interconnected.

Generation units of independent Power producers (IPPs) and renewable energy have been interconnected to power systems to support the rising demands . As a result, faults in power networks incur large short-circuit currents flowing in the network and in some cases may exceed the ratings of existing circuit breakers (CB) and damage system equipment The problems of inadequate CB short-circuit ratings have become more serious than before since in many locations, the highest rating of the CB available in the market has been used. To deal with the problem, fault current limiters (FCLs) are often used in the situations where insufficient fault current interrupting capability exists.

Less expensive solutions such as current limiting reactors may have unwanted side effects, Such as increasing system losses, voltage regulation problems or possibly could compromise system stability. Smart grid is a modern electricity system. It uses sensors, monitoring, communications, automation and computers to improve the edibility, security, reliability, efficiency, and safety of the electricity system. Renewable energy technologies such as photovoltaic, solar thermal electricity, and wind turbine power are environmentally beneficial sources of electric power generation.

The integration of renewable energy sources into electric power distribution systems can provide additional economic benefits because of a reduction in the losses associated with transmission and distribution lines. SFCL at Integration point. This location of SFCL reduces the fault current coming from two sources. SFCL is in direct path of fault current only. When SFCL is installed at the integration point of wind farm with the grid , the wind farm fault current has been successfully reduced to265A. SFCL gives 67% reduction of fault current from wind farm and also reduce the fault current coming from conventional power plant because SFCL located in the direct path of any fault current flowing towards Fault.

The optimal location of SFCL is at integration point of two generating sources, for both distribution and customer grid faults. This location of SFCL in a power grid which limits all fault currents and has no negative effect on the DG source is the point of integration of the wind farm with the power grid for both distribution and customer grid faults.

6.3 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 system 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.

7.CONCLUSION

By growth of interconnections in electrical systems the short-circuit capacity increases. The maximal over-current is one of the most important dimensioning parameter for the power equipment The development of effective SFCLs is becoming very important in relation to rising fault current levels in modern power networks. The benefit of SFCLs application in power systems is reduction the current stresses on equipment during faults, transient stability of the power grid enhancement and reduction of voltage dips and sags. And in this paper the various application of SFCL in the power system are briefly discussed. Superconducting fault current limiters are anticipated as a solution for existing electric networks. The emerging solutions for fault current limiters are SFCL which has several merits such as low cost, high performance, coordination with conventional systems. Finally, our newly developed superconducting fault current Limiters would be promised solutions in order to solve the practical problems of conventional superconducting fault current limiters.

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