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A Review on Application of Superconducting Fault Current Limiters in Power Systems

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Abstract— The electrical energy is more essential in the modern domestic and industrial scenario and it's being transferred by the grid system. While the transmission, it is often some problems like transmission losses, short circuits and etc. It causes the power failures in power system network due to the protective devices. But it causes also some unnecessary failures due to fluctuations and disturbances which create by the faults in power system network. The continuous process of system network is disturbed by these unnecessary power failures. Hence, the research in failure preventive system in the power transmission system is always encouraging. Superconducting fault current limiter (SFCL) is such one productive system to overcome the failures due to the fault current and the research in this particular area seems emerging. This paper provides the comprehensive review of superconducting fault current limiters. The excess attention is made on understanding the phenomenology, types, advantages and applications of SFCL device.

Keywords— Super conductivity, Meissner effect, Super conducting fault current limiters, Types of SFCL, Features of SFCL.

I. INTRODUCTION

An electric power distribution system is a power system network which distributes the electric power to various customer loads. It contains a number of feeders such as power sources and loads. This distribution system should have some protective systems to prevent from the various types of faults. A fault is an unintentional short circuit in an electrical circuit. The fault current creates some transient in the power system. There are various types of faults in the power system such as single line-ground fault, line-line fault, double line-ground fault and etc. in these faults; the most commonly occurring fault is single line to ground fault around 70-80% in three phase power system [1]. The fault current magnitude is higher than the 10 times of normal rated current. This will cause severe damages on the power system operation and equipment. So we have to use the protective devices to avoid the serious damages in power system by the fault current. We are using many protective devices like fuses, circuit breakers, air core reactors and etc., which are commonly used in the power system [2].

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The fuse is a protective device which isolates the entire feeder at the fault condition. Once the fault was cleared, the fuse should be replaced manually. The air core reactor adds some additional impedance in the power system and has some losses at the normal time. The circuit breaker is a commonly used as a protective device in the power system which trips the entire feeder during faulty conditions. It is a mechanical device and it has some chances of mechanical malfunction. So it has reliability problems in the power system. To overcome these problems, we have to move the next level of protective device which gives good protection and reliability in power system. The Superconducting Fault Current Limiters (SFCLs) is the well developing device based on the superconducting principle. In this paper, the simple comprehensive review of basic operation principle, types, requirements and advantages of Superconducting Fault Current Limiters (SFCLs) are discussed.

II. SUPERCONDUCTIVITY

The superconductivity is a special character of the SFCL. This superconducting behaviour is used to automatic protection the SFCL.

A. Principle of Superconductivity

It is a phenomenon occurring in certain materials at low temperatures, characterized by the complete absence of electrical resistance and the damping of the interior magnetic field [3].

B. Properties of Superconductors

The superconductors have zero resistance and no magnetic field at low current condition. This is the special property of the superconductors compares with the other normal conductors [3].

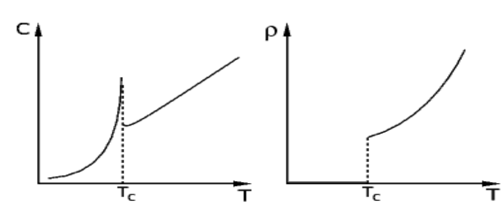

Figure.1 Behaviourof heat capacity (C) and resistivity (ρ) at superconducting phase transition.

The superconductors have the superconducting phase transition property. The characteristic of superconductivity appears only the temperature of superconductor (T) below the critical temperature of superconductor (T_c). When the

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temperature of the superconductor exceeds the critical temperature, the superconductor loses its superconducting characteristic and becoming a normal conductor. The electrical heat capacity of the superconductor is proportional to temperature at normal regime. At superconducting transition, it suffers a discontinuous jump and thereafter cases to be linear shown in figure.1. The resistance of the superconductor is very low (or) zero at below the critical temperature and it will increased proportional to the temperature shown in figure.1. Every superconductor is having a critical temperature value based on its property [3].

The Meissner effect is the other property of superconductors. When a superconductor is placed in a weak external magnetic field (H), the field penetrates for only a short distance (λ), called penetration depth, after which it d cays rapidly to zero [3].

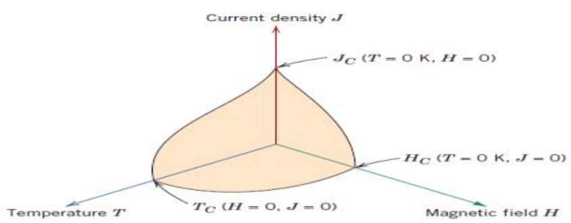

Figure.2 Critical temperature, current density and magnetic field boundary separating superconducting and normal conducting states.

C. Behaviour of Superconductors

The current limiting behaviour of the superconductor depends on their non-linear response of temperature (T), current density (J) and magnetic field (H) variation. The characteristic curve is shown in figure.2. This curve is explained the properties of superconductor placed in a constant magnetic field and a constant temperature. When the current density of superconductor increased, it can cause the temperature raise. Above the critical temperature the behaviour changed from superconductor to normal conductor regime. This will increase the resistance of the superconductor rapidly.

III. PHENOMENOLOGY OF SFCL

The distribution power system consists of many protective schemes to protect the power system from the fault. The most commonly used protective methods are fuses, circuit breakers, air core reactors and etc. [2]. These methods are having some limitations. The performance of the normal protective methods is described by TABLE.1. If the electrical power systems will be expanded or more interconnected in future, the fault current levels also increased beyond the capabilities of existing protective equipment in the power system. So we need to make changes the equipment. This will be more costly and difficulty. The superconducting fault current limiter is the developing protective device used in power system to overcome the limitations of the previous devices.

The Superconducting Fault Current Limiter (SFCL) concepts involve the switching of a superconducting element from the superconducting to normal state. The resistance of the SFCL is very low at normal operation of the power system. So there are no any extra losses due to presence of SFCL in the system. But the resistance of SFCL increases very high with respect to the fault current at the transient state. This increased resistance adds with the system impedance and limits the magnitude of the fault current. The basic concept of the superconducting fault current limiters is very low impedance at normal condition and high impedance during fault condition.

A. Types of Superconducting Fault Current Limiters

The superconducting fault current limiter is basically classified in three types as Resistive type SFCL, Inductive type SFCL, Bridge type SFCL. These types are shown in the figure.3 [5]

Table 1. Traditional Ways of Fault Current Protection [4]

Device	Advantages	Disadvantages
Circuit breaker	Quality proven & Reliable	It is a zero current breaking device. High costs and has limited lifetime.
High impedance transformer	Commonly used device	It has high losses. So inefficient in power system.
Fuse	Simple	It must be replaced by manually at every breakage.
Air-core reactor	Quality Proven& Traditional device	It causes large voltage drop. It causes large power loss during normal operation.
System reconfiguration (bus splitting)	Quality Proven& Preferred for fast-growing power systems.	It reduces power system reliability. It reduces flexibility of system operating. High cost due to CBs implementation.

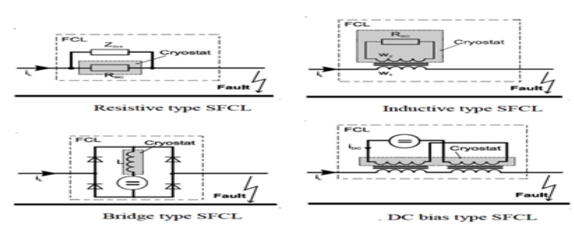

Figure.3Various types of superconducting fault current limiters [5].

The resistive type SFCL is one of the simplest methods of SFCL. It has very low resistance of R_{sc} during the normal operation of power system. So the superconducting element R_{sc} dissipates only low energy at normal condition. In the faulted condition, the fault current increases above the critical value. So the superconducting resistance R_{sc} value increases rapidly with respect to the fault current.. That means the superconductor becomes to resistive state after its critical temperature (T_c) and limits the fault current. The shunt resistance (Z_{sh}) is needed to avoid the hot spots during quench, to adjust the limiting current and to avoid over-voltages due to fast current limitation [5]-[7].

The Inductive type SFCL works as the transformer principle. It acts as a shorted superconducting secondary winding of transformer. And the power system line acts as a primary winding of transformer. If fault occurs the superconductor resistance is increased and it transferred into the primary side by $K^2= (w_1 / w_2)^2$. So the impedance of line increased in power system. And also the fault current has been limited by the SFCL [5], [8].

The Bridge type SFCL contains thyristor bridge circuit with shunt inductance coil. Under normal steady state condition, the combination of AC and DC currents remains low enough to allow of all thyristors to be forward bias. So the inductive coil is bypassed the system current flow. But faulted condition the AC current is greater than the bias current. So two combinations of thyristor sets gets forward bias one by one with including of inductance coil in each positive and negative half cycles vice-versa [5], [9]-[11].

The DC bias type SFCL is one of the hybrid type methods. The superconducting coils reduce the power losses in the bias coils. In normal condition the both coils are saturated by the DC bias. So the two air coil impedances Z_{w1} and Z_{w2} of SFCL are very low. In the fault condition the coils are out of saturation by the large AC current in the system. So the two air coil impedances are increased rapidly and limit the fault current [5], [10].

B. Features Required to SFCL

An ideal superconducting fault current limiter should have some important features [5], [6], [14]-[16].

- It should have very low impedance (nearly zero), low voltage drop and low power losses at normal operation.
- It should have large impedance at the time of fault occurrence.
- It should have very fast appearance of impedance at the time of fault occurrence.
- It should have fast recovery process after removal of the fault.
- It should have reliable current limitation of the fault current.
- It should maintain good reliability in the power system at fault condition.
- It should have withstanding ability of high temperature rise over a fault period.
- It should have fully automated operation of fault current limiting and recovery process to avoid the manual malfunction operations.
- It should have low cost, low volume and less maintenance.

C. Advantages and Applications of SFCL

A superconducting fault current limiter has more advantages to compare the other protective methods in the power system. The SFCL applications are used for the following applications [12], [13].

- It is used to avoid the damaging of equipment due to increased rating of short circuit current.
- It is used to avoid the replacement of equipment due to increased capacity of power system.
- It is used in lower fault rated equipment.
- It is used to avoid series reactor, split buses, bus-tie breakers.
- It is used to reduce voltage dips on adjacent feeders due to fault condition.
- It has used to improve the power system transient stability.
- It is used to improve the power quality of the power system.
- It is used to reduce rating of circuit breaker increasing capacity.

D. Positioning of SFCL

The placement position of SFCL is very important in the power system.

- It has placed at incoming position of a feeder. It protects the feeder and all valuable downstream equipment which are connected in that feeder.
- It has placed at outgoing position of a feeder. It only limits the fault current passing through it.
- It has placed at tie-bus position of any two buses. It allows two buses in connection at the raising of fault current on any one of the buses.

These are the correct positions to placing the SFCL device in the power system network. The placement of SFCL is very important in the power system. Because the current limiting level is varies depend upon the placement of SFCL. It is used at the important feeders which are should be in connection with protective manner.

There are three important consideration factors to apply the developed SFCL in the power systems which are following below [17], [18].

- The first one is optimal placement. The optimal placement of developed SFCL is one the important factor to be considered in power system. Because the SFCL needs the correct placement to limiting the fault current in effective manner.
- The next factor is value of the resistance. The optimal resistive value of series connected SFCL is one of the important factor in transmission line during the short circuited condition.
- And the last one factor is protection coordination. The protective coordination of SFCL and the other existing protective devices such as circuit breaker and recloser.

These are the important factors to be considered to applying the SFCL in the power system. These factors are used to improve the SFCL efficiency and improve the power system stability and reliability.

IV. CONCULSION

The modern power consists of many interconnections and interfacing feeders. So there are many chances to occurrence of short circuit faults. To overcome these problems, the developed superconducting fault current limiter was introduced and it can limit the fault current in power system with protective manner. It has used to solve many power system problems like voltage sag, power transients, coordination problems and etc. The SFCL is more protective and safety operation in power system compared to the other commonly used device like fuses, core reactors and circuit breakers. Thus the principle, operation, types, behaviours, features and properties ware discussed in briefly in this paper. It concludes the SFCL is the advanced protective device which limits the fault current in protective and safety manner.

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