Minimizing of Fault Current Using SFCL Technology

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Abstract— Fault current limiters are the effective solution for most of the power system failures nowadays. Superconducting fault current limiters are used as effective way of fault current limiting. Most of the problems or failures in system are due to overloading of system lines thus flashover or fire hazards. This all will occur mostly at the time of fault because fault current will be of a large value than system can withstand. By expanding system, we have to increase the fault current level also. Otherwise system will collapse soon. The better way is to use current limiters. The fault current limiters limit current at the event of fault. Superconducting fault current limiters use superconducting material for current limiting.

IndexTerms—SFCL(Superconducting Fault Current Limiter), Microgrid

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I. INTRODUCTION

In today's scenario there are tremendous growths in power system and interconnected networks such as grids. These growths are expected to continue in future. As there is any occurrence of accidental events like lightning, a large amount of power flows through the grid which results in a failure of the system. These faults can generate surge currents more than one hundred times the normal operating current, hence damage the expensive grid-connected equipments. Therefore protection of the system is an important consideration to avoid harm to the system parameters and system equipments from large amount of current during fault [1] [3]. A Fault Current Limiter (FCL) is a device which limits the short circuit current during fault in a power transmission network. Fault current limiters (FCL) provide an effective way to suppress fault current and result in considerable saving in the investment of high capacity circuit breakers. A various types of fault current limiters uses variety of new techniques for limiting excess fault current [4]. However focus is on superconducting technologies i.e. Superconducting Fault current Limiters (SFCL). Whereas non-superconducting technologies contain devices like simple inductors or variable resistors are also known as Fault Current Controllers. Due to the rapid growth in the power generation systems there is a growth in fault current level, which may cross the rated capacity of available circuit breaker. Replacement of these existing switchgears due to increased fault level will not be the feasible option by considering cost parameter. By considering all these parameters it is necessary to use some reliable means to minimize fault current level and hence allow the circuit breaker to operate at lower fault Currents. Superconducting Fault current Limiters provides an effective way to suppress fault current [3], [6]. Current limiting behavior of these superconductors depends on their non-linear characteristics with Temperature, current and magnetic field variations. If there is Increase in any one of these three parameters can cause transition of superconducting state to normal state. As per the development of superconducting materials SFCLs are of three types [3],

- Low Temperature SFCL
- High Temperature SFCL
- Superconducting Film Type SFCL

II. TECHNOLOGIES

A. Non-Superconducting:- Fault Current Limiters that do not depend on Superconducting materials to perform the current limiting action. It contains current limiting fuses, solid-state devices & many other [3].

B. Superconducting:- Fault current Limiters that depend on Superconducting material to perform the current limiting action. More specifically, the current limiting behavior depends on the non-linear characteristics of superconductors with temperature, current and magnetic field variations. If we increase any one of these parameters can cause transition from superconducting to normal state[3]

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III. TYPES OF SFCL

3.1.1 Resistive type SFCL

Resistive SFCLs utilize the superconducting material as the main current carrying conductor under normal grid operation. The principle of their operation is shown in the one-line diagram at the top of Figure 1. As mentioned above, the lower figure is a normalized plot of voltage across RSC as a function of the ratio of current through the device, ILine, to the "critical current", IC, of the superconducting element. At present, for HTS materials, the convention is to define "critical current" as the current at which a voltage drop of 1.0 μV/cm is observed along the conductor. When a fault occurs, the current increases and causes the superconductor to quench thereby increasing its resistance exponentially. The current level at which the quench occurs is determined by the operating temperature, and the amount and type of superconductor. The rapid increase in resistance produces a voltage across the superconductor and causes the current to transfer to a shunt, which is a combined inductor and resistor. The shunt limits the voltage increase across the superconductor during a quench. In essence, the superconductor acts like a switch with millisecond response that initiates the transition of the load current to the shunt impedance. Ideally, the incipient fault current is limited in less than one cycle.

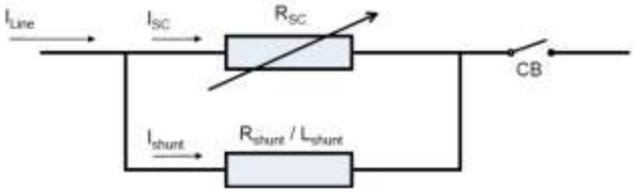

Figure 1: Resistive SFCL.

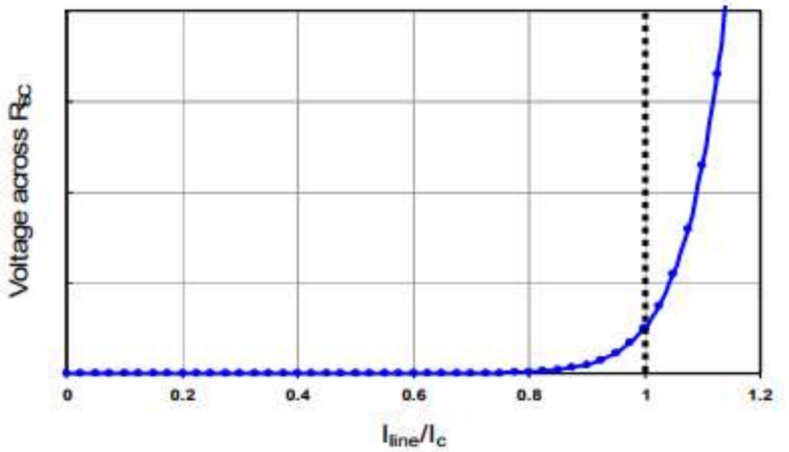

Figure 2: Resistive type SFCL with shunt element plot of Voltage and Current with constant magnetic field and temperature

Early resistive SFCL designs experienced issues with “hot spots”, or non-uniform heating of the superconductor during the quench. This is a potential failure mode that occurs when excessive heat damages the HTS material. Recent advances in procedures for manufacturing HTS materials coupled with some creative equipment designs have reduced the hot-spot issue. The grid characteristic of the resistive SFCL after a quench is determined by the shunt element. Thus, because the shunt is typically quite reactive, a resistive SFCL typically introduces significant inductance into the power system during a fault. During the transition period when current is being transferred from the superconductor to the shunt, the voltage across the combined element shown in Fig 2-1 is typically higher than it is after the current has transitioned into the shunt. The dynamics of this process depend on the two elements and their mutual inductance. The quench process in resistive SFCLs results in heat that must be carried away from the superconducting element by the cryogenic cooling system. Typically, there is a momentary temperature rise in the superconducting element that causes a loss of superconductivity until the cryogenic system can restore the operating temperature. This period of time, known as the recovery time, is a critical parameter for utility systems (which may see multiple fault events occurring close together in time) and is a key distinguishing characteristic among various SFCL designs. Some resistive SFCLs include a fast switching component in series with the superconducting element. This switch quickly isolates the superconductor after most of the current has transitioned to the shunt element, allowing the superconducting element to begin the recovery cycle while the limiting action is sustained by the shunt. The fast-acting switch reduces the peak temperature within the superconductive material and allows for faster recovery times than for purely resistive SFCLs. This type of SCFL is sometimes referred to as a hybrid SFCL.

ADVANTAGE:

- Smaller and lighter than inductive SFCL.

DISADVANTAGE:

- Energy Loss

3.1.2 INDUCTIVE TYPE SFCL

Inductive SFCLs come in many designs; the simplest design is a transformer with a closed superconducting ring as the secondary. In unfaulted operation, there is no resistance in the secondary and so the inductance of the device is low. The inductive limiter can be modeled as a transformer (Figure 4.2).

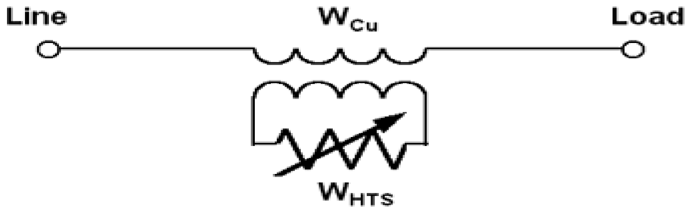

Figure 2: Inductive type SFCL

The impedance of this limiter in the steady state is nearly zero, since the zero impedance of the secondary (HTS) winding is reflected to the primary. In the event of a fault, the large current in the circuit induces a large current in the secondary winding cause’s loss of superconductivity. The resistance in the secondary is reflected into the primary circuit and limits the fault.

ADVANTAGE:

•Advantage of this design is that there is no heat ingress through current leads into the superconductor, and so the cryogenic power load may be lower.

DISADVANTAGE:

•A large amount of iron is required and hence inductive SFCLs are much bigger and heavier than resistive SFCLs.

3.1.3 INDUCTIVE FCL WITH SHIELDED-CORE

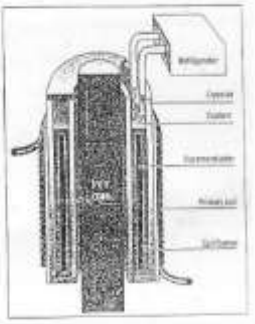

Figure3: Shielded iron core SFCL

One of the first SFCL designs developed for grid deployment was the shielded-core design. Figure 4:3 shows the scheme of a shielded iron core SFCL, which is made up of a primary winding around an iron core with a superconducting cylinder in between. This SFCL is also called an inductive SFCL because its structure is similar to a transformer with a short circuit secondary winding. During normal operation, the current in the superconducting cylinder is lower than its critical current and it screens all the flux from the iron core. The impedance of the device, which consists of the resistance of the primary winding and the stray inductance, is very low. In the event of a fault, the current in the superconducting cylinder exceeds the critical current and the cylinder starts to develop a resistance. The magnetic flux penetrates into the iron core, so the inductance of the primary winding increases. The equivalent impedance of the device becomes the inductance of the primary winding and the referred cylinder resistance to the primary in parallel

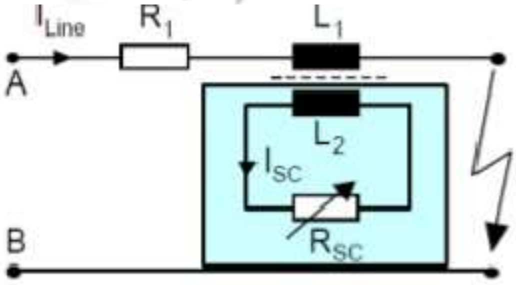

Figure 4: Shielded-Core SFCL

ADVANTAGES:

- No current leads are needed, and since the number of turns of the secondary winding can be much smaller than the primary turns.
- Short superconductors are needed and the voltage drop in the cryogenic part of the device is very low.

DISADVANTAGE:

- Main drawbacks are their relatively large volume and high weight.

3.1.4 INDUCTIVE FCL WITH SATURATED IRON CORE

Unlike resistive and shielded-core SFCLs, which rely on quenching of superconductors to achieve increased impedance, saturable core SFCLs utilize the dynamic behavior of the magnetic properties of iron to change the inductive reactance on the AC line. The saturated iron - core concept utilizes two iron cores per phase as shown in Figure 4.5. A conventional copper coil could be used to saturate the cores during normal operation. However, in order to reduce I2R losses in the copper coil and to make the device acceptable to the users, developers have opted to use a superconducting coil for saturating the core. The most attractive feature of this FCL is simplicity and a fail - safe mode of operation. Faults of long durations can be handled and recovery from a fault is instantaneous, enabling the device to handle multiple successive faults in rapid succession, such as auto - recloses on a protected line or circuit breakers with existing reclosing logic. Explained below is the principle of operation. During normal operation, large ampere - turns created with DC in the secondary superconducting HTS coil drive the core into saturation. This lowers impedance of the copper coil in the primary AC side near to that of an air - core coil. During a fault, a large fault current demagnetizes the core and drives it from the saturated to unsaturated state (Linear B – H region).

Figure.5: Inductive FCL concept with saturated iron core

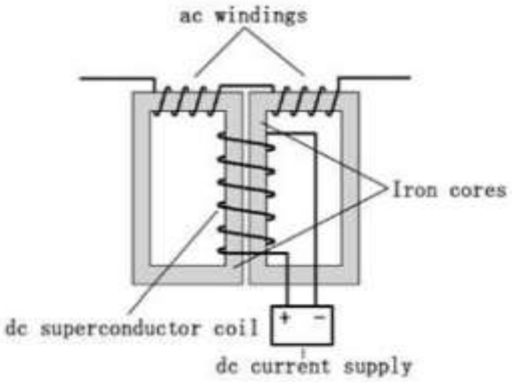

Figure 6: Saturable-Core superconducting fault current limiter.

This increases the primary AC coil impedance. The increased impedance limits the fault current to the desired level. Since an AC wave has both positive and negative peaks to magnetize the iron core, it becomes necessary to employ two separate cores for each phase. Each core has a normal (copper) coil in series with the line being protected. One core works with the positive peak of the AC and the other with the negative peak. A three - phase arrangement of this concept is shown in Figure 5 , which has six primary copper coils (two for each phase) and a common secondary DC HTS coil for saturating all cores simultaneously. This device, installed in the Avanti Circuit of Southern California Edison in March 2009, became the first SFCL to operate in a US utility system. Abbott has described operation of such a limiter. A major drawback of saturable-core SFCL technology is the volume and weight associated with the heavy iron core; however, manufacturers hope to improve this issue in future prototypes. Zenergy has recently tested a prototype saturable core SFCL based on an entirely new design concept that is four times smaller than its predecessor. Grid ON, an Israeli-based startup company, is in the process of developing saturable core concept intent on reducing size and weight to more accommodating levels for commercial use.

ADVANTAGES:

- No heat ingress.

DISADVANTAGE:

- Large amount of iron is required,
- Bigger in size hence heavier.

3.1.5 DC BIASED IRON CORE TYPE SFCL

In this type of construction contains two iron-core coils, which goes into saturation when DC-biased current is introduced under normal condition. These two cores are placed in series path of fault. When these two cores are operating in saturation mode there inductances are low. When there is occurrence of fault these coils come out of saturation and the coil inductance increases rapidly.

Advantages:

- Requires less superconductor material,
- Small cryogenic cooling system required.

Disadvantages:

- Bulky due to use of iron core.

3.1.6 THE BRIDGE SFCL

The limiter works is not based on superconducting materials from the superconducting state to normal state transition, but to use a superconducting material in the DC state of unimpeded carrier characteristics. This SFCL employs solid state technology to control the flow of current through a superconducting inductance. Figure 7 for the bridge type SFCL single-phase circuit. It consists of diode bridge D1-D4, the superconducting coil L and the composition bias supply Vb, Vb for the superconducting coil to provide bias current IL. In a failed state, when i amplitude increased to I0 when i was a half weeks in the diodes D3 and D4 is not conducting, while the negative half weeks in the Dl and D2 is not conducting, superconducting coils in series on the line is automatically , fault current was limited by a large inductance L.

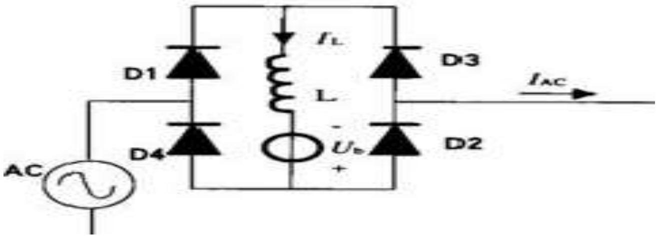

Figure 7: The structure of Bridge SFCL

However, during normal operation, the superconducting coil current amplitude by more than the DC circuit, so by the introduction of low loss current leads large. It also needs the power diode bridge and the bias power, the system is more complex. The inductor does not have to be made of superconducting material, but superconducting material can be used to minimize the losses. In addition, during normal conditions, the inductor only carries DC current, which makes a superconductor an ideal choice. Thyristors can be used to replace the diodes, so it is possible for them to turn off the current at the next current zero crossing after a fault occurs.

ADVANTAGES:

- No AC losses in the superconducting coil because it is operating with DC current. Fast recovery after the fault clears because the coil remains in the superconducting state during the fault.
- The trigger current level can be adjusted by the DC current source.
- Does not require a room temperature/cryogenic interface in the power line.

DISADVANTAGES:

- AC losses in the semiconductors are relatively high.
- No fail safe mechanism.
- If one of the semiconductors fails and creates a short circuit, the SFCL cannot limit the fault current.

IV. FCL COMPARISON CRITERIA

FCL Comparison criteria given as

1. Normal Operation
2. Operation During the fault limiting action
3. Recovery period.

The comparison criteria can be shown by a figure-

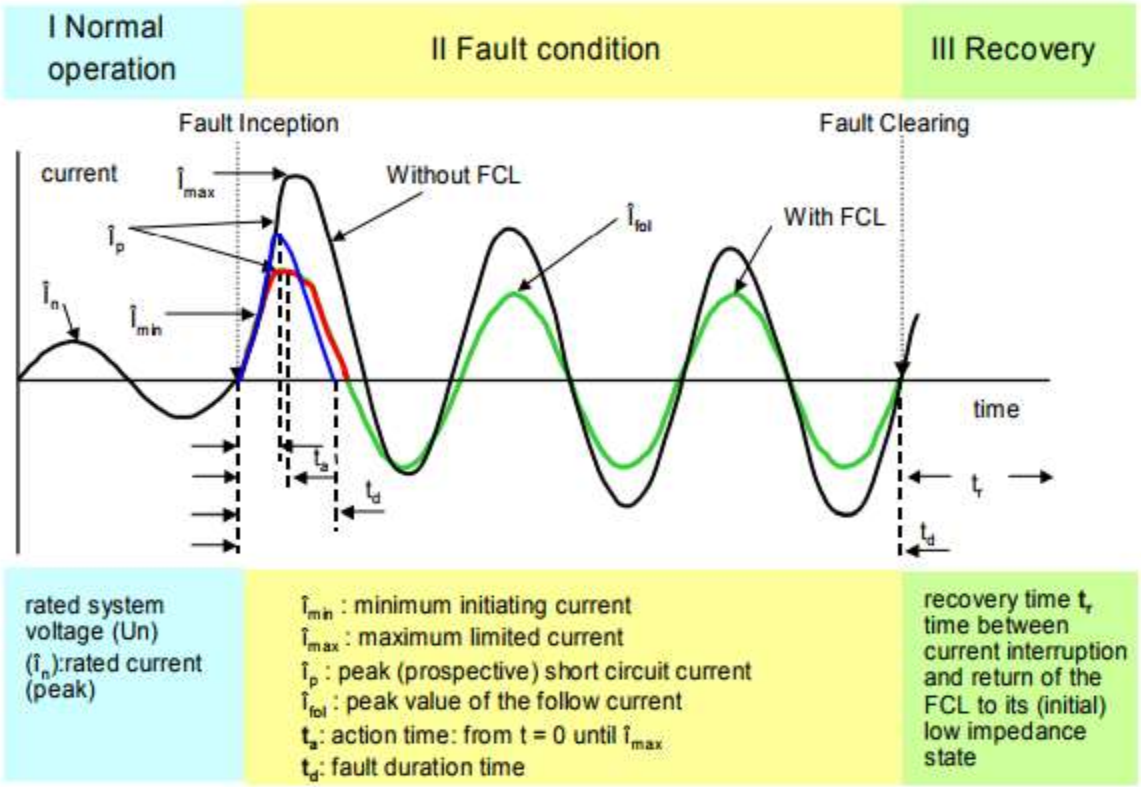

Figure -8: Characteristics of SFCL

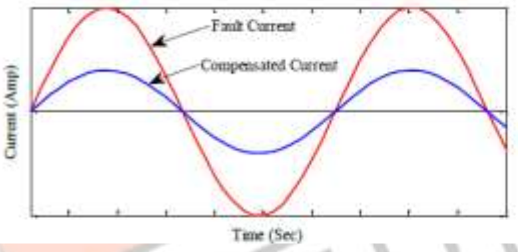

Figure 9: SFCL effect on fault and normal current

V. CONCLUSION

Utilities always look for ways to get more out of their existing equipment. The HTS FCLs present an option to rein in the fault current levels to within the capability of existing equipment. To help address these problems, with R & D funding from the US Department of Energy, equipment manufacturers, electric utilities, and researchers from private industry, universities, and national laboratories are teaming up to spur innovation and development of new technologies, tools, and techniques. Because of these efforts, the future electric grid will likely incorporate technologies very different from those that have been traditionally employed. The S FCL is one of these technologies, and the first units are already being deployed commercially. Manufacturers and users are already working on developing standards for FCLs under IEEE. With the use of 2G HTS, SFCLs have to compete with the conventional breakers in cost, size, long operation feasibility and cryogenic reliability. The most compact SFCL at distribution voltage levels are viable in the near future. Some projects have already started recently to develop SFCL prototypes for transmission voltage levels. To commercialize SFCLs, it is essential to further improve their properties (e.g. superconductor AC loss) and reliable, compact and low-cost cryocoolers. There are many possible locations in power systems where FCLs installation offers technical and economical benefits. The bus-tie position appears to be the most economical option among other alternatives

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