

# FAULT CURRENT LIMITERS – PRINCIPLES AND APPLICATION

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**Abstract:** In this paper a new type electrical devices, designed for use in medium voltage and high voltage grids, has been explained – the fault current limiters. Their principals of operation and different structures have been proposed. The comparative analysis and their possible estimation have been made.

**Keywords:** fault current limiters, power system faults

## INTRODUCTION

The short circuit faults are the most destructive ones among the numerous faults occurring in power distribution systems. Sometimes the short-circuit faults generate over current more than 20 times the rated current. The consequences of inevitable fault current in electrical network usually mean thermal or mechanical stress for the affected equipment. The normal power flow is interrupted by the protection relays. 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 directly linked 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].

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.

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 application of a fault current limiter (FCL).

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 [2]:

- 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,  $I_s$ -limiters) takes special place.  $I_s$ -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. A service call is required to replace the fuse after each event [3]. Therefore they are not object of this paper.

### **FAULT CURRENT LIMETER TYPES**

A numerous classifications of FCLs have been known [3,4,5]. One of them is used by CIGRE WG A3.10 [6]:

- passive FCL - increase the source impedance at nominal and fault conditions;
- active FCL - fast increasing circuit electrical parameters after fault detection.

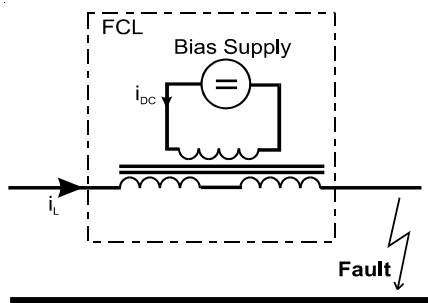
At last three decades the modern technologies and new materials have been used to make devices with proper parameters. Therefore the common used FCLs classification is:

#### **Non-superconducting FCL**

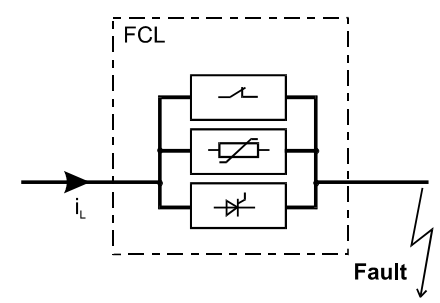
The different types FCLs have been designed:

- saturable core FCLs (fig.1) – they exploit the non-linear characteristics of ferromagnetic materials to realize a high inductance. In normal case, the core is saturated by a bias current; the coil inductance is negligible. If the fault occurs, the magnetic core is taken out of saturation, the coil attain a high inductance and limits the fault current. The designs differ in the core shape, core bias arrangement and magnetic design [5].
- solid-state FCLs – they use the high power semiconductor devices - SCR, GTO, IGBT to realize a FCL. The solid-state FCL could be classified into three major groups:
  - The serial types FCLs are composed of bidirectional controlled switch and bypass circuit (fig.2). The bypass circuit contains normal state bypass, fault current bypass, over voltage protection bypass and a snubber. The normal state bypass usually is an electromechanical switch. Its purpose is to reduce the losses and distortion in the normal state. The fault current bypass restricts the fault current – some schemes turn off the switches to interrupt the current, other modulate the fault current to keep it within the acceptable limits. The over voltage protection bypass and the snubber are essential, because they limit the voltage and  $dv/dt$  across the semiconductor switch and absorb some amount of the energy, stored in the line inductance [5].

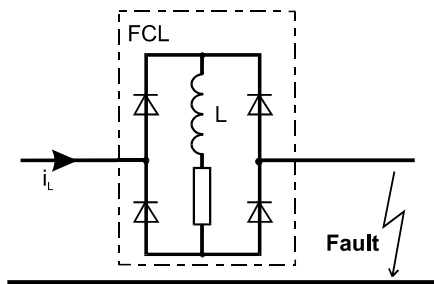
- The bridge types FCLs are realized using a current-fed diodes/ thyristors full bridge arrangement (fig.3). The current rating of diodes/ thyristors and the limiting reactor are dictated by the peak fault current. Since the current limiting reactor is on the DC side of the rectifier, during the fault conditions the inductor is subject to high DC voltage which could cause inductor saturation, the current increases very fast and FCL may lose the current limiting capabilities. Another disadvantage of these devices is a significant conduction losses in normal state operation [5].
- The resonance types FCLs use switches to reconfigure their topologies either into the normal state or into the fault condition are composed (fig.4). They employ series resonant circuit tuned to the line frequency and thus present negligible impedance to the line. Under the fault conditions the circuit is switched to the fault state sub-topology and much higher impedance is presented to the line. The resonance FCLs reduce the fault current but they do not have interruption capability [5,7].



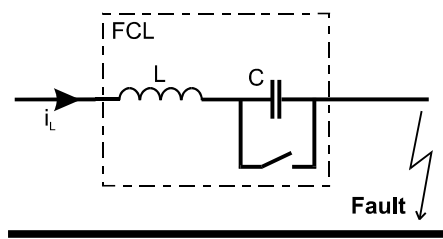
**Fig.1.** Saturable core FCL



**Fig.2.** Serial type solid-state FCL



**Fig.3.** Bridge type solid-state FCL



**Fig.4.** Resonance type solid-state FCL

### Superconducting FCL

Because 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<sup>nd</sup> 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 [3]:

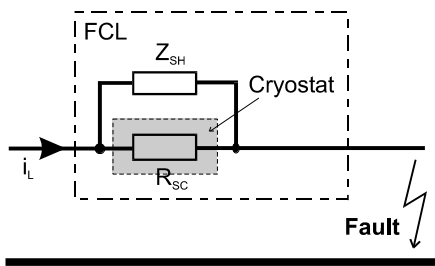
- Yttrium-Barium-Copper-Oxide  $YBa_2Cu_3O_7$  (often abbreviated YBCO) and is used for thin film techniques;

- Bismut-Strontium-Calcium-Copper-Oxide  $\text{Bi}_2\text{Sr}_2\text{Ca}_n\text{Cu}_{n-1}\text{O}_{2n+4+x}$ , (abbreviated as BSCCO and with trade mark of the compound Bi-2212 / Bi-2223) are used for filament.

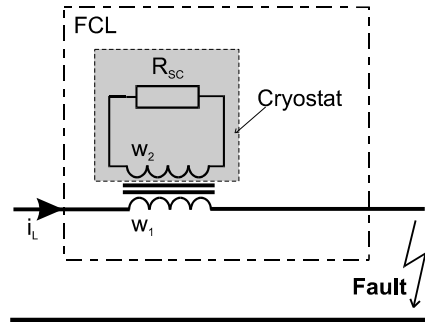
There are three major type superconducting fault current limiters (SFCLs):

- The resistive type SFCLs is shown in line with the source and load (fig.5). During the normal operation the current is flowing through the superconducting element  $R_{SC}$  dissipates low energy. If the current rises above the critical current value the resistance  $R_{SC}$  increases rapidly. The dissipated losses heats the superconductor above the critical temperature  $T_c$  and the superconductor  $R_{SC}$  changes its state – from superconducting into the resistive state, some resistance is generated and fault current is reduced. This phenomenon is called “quench of superconductors”. When the fault current has been reduced, the element  $R_{SC}$  recovers its superconducting state. The parallel resistance or inductive shunt  $Z_{SH}$  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. They are vulnerable to excessive heat during the quench state [1,2,4].
- The inductive type SFCLs works like transformer with shorted superconducting secondary winding (fig.6). In normal operation the primary winding resistance and leakage inductance determine the impedance of the limiter. If the fault occurs, the resistance of the secondary winding is the superconductor quenches. The value  $R_{SC}$  is transferred into the primary side by the  $k^2=(w_1/w_2)^2$  and the FCL impedance increases [1,3]. Despite of the size and the weight this type FCL led to prototypes of higher power rating the resistive FCL [3];
- The bridge type SFCL is shown in fig.7. Under normal operation the combined DC current and AC current remains low enough to allow all of the diodes or thyristors to be biased forward and therefore the AC current bypasses the inductance. In these conditions the FCL impedance is low, the total voltage drop and loss are dominated by the power diodes. If a fault occurs and the magnitude of the AC current exceeds the DC bias current two diodes will switch into a blocking mode for each half cycle and insert the inductor into the circuit. The coil impedance will limit the transient current. If thyristors are used instead of the diodes it is possible to turn off the current within the half-cycle. The main disadvantage of bridge type FCL is the relatively high total losses [8,9,10].

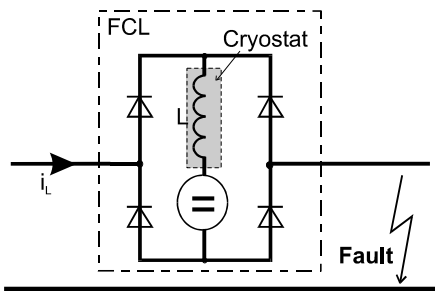
Besides these three basic types there are a variety of other concepts for SFCLs realization but their principles of operation are very close to these major types. As example the DC biased type SFCLs is shown in fig.8. The principal of pre-magnetized iron cores is the same as the saturable core FCLs (fig.1). The superconducting coils reduce the power losses in the bias coils. In normal operation the currents in both iron cores are driven into saturation with direct current. As a result the impedance is low, consisting mainly of the two air coil impedances  $Z_{w1}$  and  $Z_{w2}$ . In the case of a fault the large AC current will drive the two coils out of saturation and into the region of high permeability on the magnetization curve resulting in a significant increase of the apparent coil inductance [9]. The main advantage of this type SFCL is the use of DC instead AC for the superconductor and avoiding of AC losses. The major disadvantage is the size of the devise – it has to be approximately twice the size of such a transformer [3];



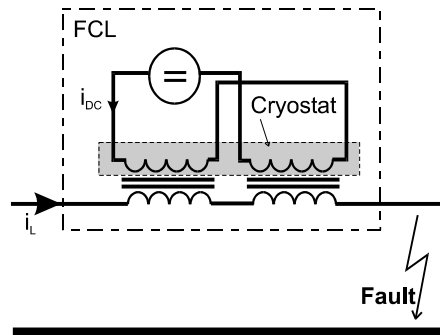
**Fig.5. Resistive type SFCL**



**Fig.6. Inductive type SFCL**



**Fig.7. Bridge type SFCL**



**Fig.8. DC bias type SFCL**

The common part of all these devices is the cryostat, creating the low temperatures for superconductivity hold up.

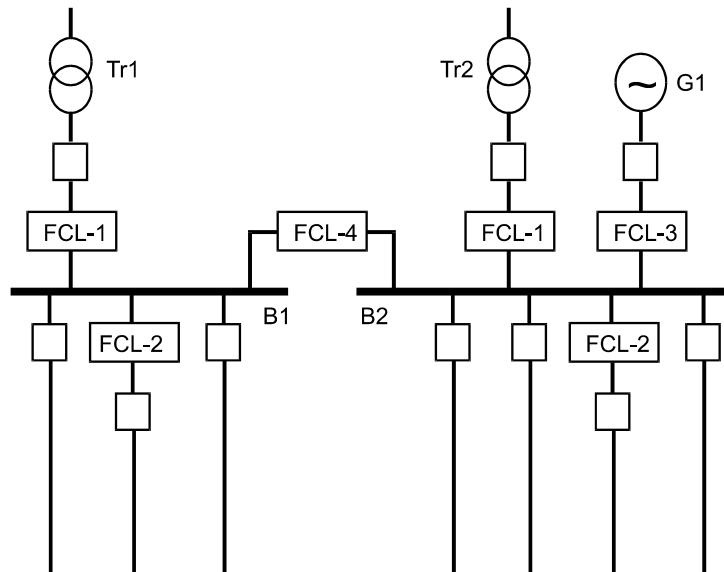
### APPLICATION

The FCLs applications afford an opportunity to [2,11,12]:

- avoid equipment damaging;
- avoid equipment replacement;
- use lower fault rated equipment;
- avoid series reactor, split busses, bus-tie breakers;
- reduce voltage dips on adjacent feeders;
- enhance power grid transient stability.

The FCLs can be installed in three main places in distribution substations (fig.8) [1,2]:

- incoming feeder position. The FCL protect the feeder and all downstream equipment that are valuable and sometimes is difficult to replace;
- outgoing feeder position. The FCL only limit the fault current passing through that feeder;
- bus-tie position. The FCL allows two buses to be tied together without significantly raising fault current on either bus.



**Fig.8.** FCLs connection points in power grid

In the main incoming feeder position the fault current is higher as FCL limit all currents coming from the main breaker and falling into outgoing feeders. The bus-tie position FCL would have lower losses under normal operating position, because it has not continuously carry the full load current as feeder positioned FCLs.

The optimal locations for FCL depend on the structure of the power system and other aspects - such as generators location or type of used generators [13] or protection relay scheme [14] etc.

## CONCLUSIONS

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 FCLs is becoming very important in relation to rising fault current levels in modern power networks. The benefit of FCLs 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.

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.

## ACKNOWLEDGEMENTS

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