Review on Positioning of Superconducting Fault current limiters in Transmission Network

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Abstract:*In an effort to prevent damage to existing power system equipment and to reduce customer downtime, protection engineers and utility planners have developed elaborate schemes to detect fault currents and activate isolation devices that interrupt the over-current sufficiently rapidly to avoid damage to parts of the power grid. Fault current limiters (FCLs) with the capability of rapidly increasing their impedance, and thus limiting high fault currents are being developed. In this study, an application of superconducting fault current limiter (SFCL) is discussed to limit the fault current that occurs in power system.*

The utilization of fault current limiters (FCLs) in power system provides an effective way to suppress fault currents and results in considerable saving in the investment of high capacity circuit breakers. In this work, a feasibility analysis of the positioning of a superconducting fault current limiter in a power system has been presented.

Keywords: *Distributed generations, protection methods, Current limiters, SFCL, MFCL etc.*

I. INTRODUCTION

In a smart grid, transmission and distribution infrastructure will be better able to handle possible bi-direction energy flows, allowing for distributed generation such as wind turbines, photovoltaic (PV) farms and other power resources. However, one critical problem of these integrations is the excessive increase in a fault current due to the presence of distributed generation within a smart grid By the multiple routes from power plant to conventional grid, AC and DC microgrid, the excessive fault current in one microgrid could affect the neighbouring microgrid and it could be able to cause a domino effect which leads a blackout eventually. Therefore, smart power devices which could protect smart grid from the increasing fault current are required for the reliability and the safety of power systems

Superconducting fault current limiters (SFCLs) utilize superconducting materials to limit the current directly or to supply a DC bias current that affects the level of magnetization of a saturable iron core. These devices have the promise of controlling fault currents to levels where conventional protection equipment can operate safely. A significant advantage of proposed FCL technologies is the ability to remain virtually invisible to the grid under nominal operation, introducing negligible impedance in the power system until a fault event occurs. Ideally, once the limiting action is no longer needed, an FCL quickly returns to its nominal low impedance state.
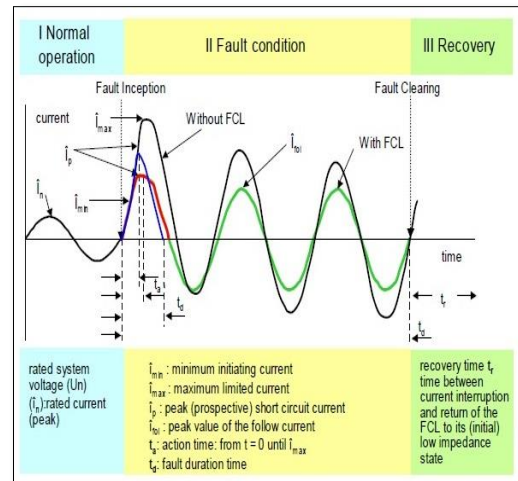

Fig.1. Characteristics of Fault Current Limiters into three operating modes

II. LITERATURE SURVEY

Various methodologies for reducing fault current levels are commonly used in the power industry. In which the most conventional ones comprises of construction of new substations, the upgrading of circuit, splitting existing substation busses. Although these operational practices serve the purpose for customer, *t*hese practices involve a non-negligible degradation in terms of reliability of power system under actual operating conditions, which may eventually cause significant economic losses and thereby increasing the need for further investment [1] Series reactors and solid state fault current limiters are also common strategies for reducing the fault levels in existing power grids, but these devices cause a noticeable voltage drop, therefore considerable power losses during the normal operation of the network [2,3].

Whenever a short circuit condition or electric fault occurs, the designed SFCL uses its property to trigger the fast transition from its superconducting state to the so-called quenched state. The state in which quench occurs is characterized by a high electrical resistivity, used to limit the first peak of the fault current to rated operational levels, either by ensuring the automatic recovery of the protection scheme with no disruptions on the supply, or by allowing enough time for the prompt activation of conventional protection systems such as circuit breakers [4, 5]. Generally, when fault occurs, it may generate voltage sags for the transient period between 0.5 and 60 cycles, which affect the

consumers connected in the power system network according to their location. Integration of distributed generation units cause some serious problems like increase in magnitude of fault current. i.e. when there is occurrence of fault, current get increased which may harm the system equipment. [6].

The existing conventional solutions to transmission-level fault current over-duty resolve the problem with varying degrees of effectiveness. Some are costlyand/or have negative impact on system reliability and integrity. Some of these solutions are:
a)Construction of new substations-Fault current over-duty coupled along with other factors may result in a utility selecting this solution, which will correct immediate problems, as well as providing for future growth. However, this is the most expensive of all the conventional solutions.[7,8]

b) Bus splitting: This entails separation of sources that could possibly feed a fault by the opening of normally closed bus ties, or the splitting of existing busses. This effectively reduces the number of sources that can feed a fault, but also reduces the number of sources that supply load current during normal or contingency operating conditions. This may require additional changes in the operational philosophy and control methodology.[9]

c) Multiple circuit breaker upgrades—when a fault duty problem occurs, usually more than one breaker will be affected. Upgrade of these breakers has the disadvantage of not reducing available fault currents and their associated hazards, as well as the often prohibitive expense of replacing the switchgear within a substation.[10]

d) Current limiting reactors and high impedance trans-formers—Fault current limiting reactors limit fault current due to the impedance across their terminals,which increase during the fault. However, current limiting reactors also have a voltage drop under normal loading conditions and present a constant source of losses. They can interact with other system components and cause instability. [11, 12]

e)Sequential breaker tripping—A sequential tripping scheme prevents circuit breakers from interrupting excessive fault currents. If a fault is detected, a breaker upstream to the source of fault current is tripped first. This reduces the fault current seen by the breaker within the zone of protection at the location of the fault. This breaker can then open safely. A disadvantage of the sequential tripping scheme is that it adds a delay of one breaker operation before final fault clearing. [13]

III. SFCL FOR FAULT CURRENT CONTROL

The reliability of the power systems is the most important factor for their efficient operation. It is not possible to completely eliminate the faults in the system but it ispossible

to lower the harmful effects of the faulton the systems by decreasing the current duringfault. SFCL is an innovative fault current limiter. It works on the principle of Superconducting Property. It is inactive e under normal condition. It is in active under fault condition; it inserts some resistance into the line to limit the fault current. It suppresses the fault current within first half cycle only. It operates better than Circuit breakers, Relays, because the Circuit breakers takes minimum 2-3 cycles before they getting activated.

The effect of SFCL on micro grid fault current observed. The optimal place to SFCL is analysed for application in power transmission network.Fig. 2 shows a simplified equivalent circuit representation of the SFCL in a transmission system. Here the SFCL is represented by an HTS element shown as variable resistance in parallel with a reactor. Under normal operating conditions, the peak of the AC current level of the power transmission network is always below the critical current level of the superconductor, therefore there is essentially not voltage drop across the device and there are no I^2R losses.
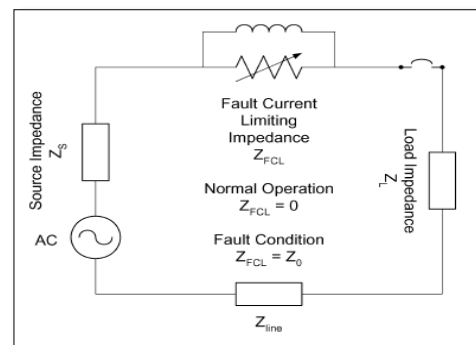

Fig.2. Equivalent circuit of SFCL in a power system

The device is "invisible" to the grid. When the fault occurs, the fault current level exceeds the critical current level of the superconductor, creating a quench condition. The superconductor is forced to transition to the high resistive state and most of the fault current is shunted into the parallel inductor to introduce the current limiting impedance Z_0 into the grid to limit the fault current.
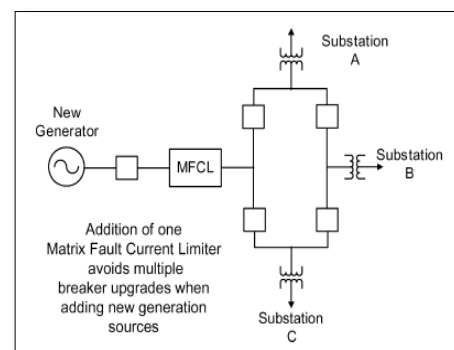

Fig.3. Application of MFCL to ease of new generation

Fig. 3 shows an example application of the MFCL to alleviate a fault duty problem when new generation sources are introduced. The introduction of the new generator could result in breaker over-duty problems on multiple breakers shown in the ring bus in the figure. An alternative approach is to use an MFCL to reduce the available fault cur-rent to a lower, safer level so the existing switchgear can still protect the grid. In the example of Fig. 3, the MFCL is placed in series with the generator to reduce its contribution of fault cur-rent, avoiding the cost of upgrading the four breakers in the ring bus.

IV. MFCL AS CURRENT FAULT CONTROLLER

Table I summarizes the conventional solutions and their respective pros, cons and relative cost. The expected cost of the MFCL relative to the conventional solutions. This consideration makes the MFCL an attractive alternative, since it also minimizes the outage time.As shown in Table I, the MFCL is expected to be cost-competitive with all of the solutions with the exception of current limiting reactors and sequential breaker tripping.

Table I: MFCL vs. traditional solutions

Solution	Advantage	Disadvantage	Relative Expense	Relative Expense to MFCL
New Substation	Provides for future growth	Expensive and lengthy to install	Most expensive solution	MFCL less expensive
Bus Splitting	Separates sources of fault current	Separates sources of load current from load centers and undermines system reliability	High, if split bus not already installed	MFCL less expensive
Multiple Circuit Breaker Upgrades	Most direct solution with no adverse side effects	Difficult to schedule outages; Bus work reinforcement also required	High to medium, depending on # of breakers	MFCL less expensive than most multiple breaker upgrades
Current Limiting Reactors	Easy to install	Voltage drop and power losses; potentially cause instability	Medium to low	MFCL cost higher
Sequential Breaker Tripping	No major hardware installation involved	Expands impact of fault to wider range of the system	Low	MFCL cost higher

There is a limit to the effectiveness of adding current limiting reactors as more and more of these devices are added into the grid. One final consideration is that HTS FCLs may be essential for the application of other devices such as HTS cables in the grid. The very low impedance of HTS cables results in a high level of fault current, which could be mitigate

V. IMPACT ON PROTECTION SCHEMES

The application of superconducting fault current limiters in the utility network will require new integration issues to be addressed. As devices like the MFCL come closer to commercial reality, these issues are now being considered by various industry groups. The characteristic of the MFCL impedance appearing only during the fault must be considered in the implementation of protective relay schemes. The development of testing standards and procedures also has to consider the variable impedance nature of the device. During the fault, the HTS material heats up and must cool back down to return to a superconducting state before the device is invisible to the system again. The time to return to a super-conducting state is typically termed the "recovery" period. The cool-down period is proportional to the amount of time that the material was heating up during the fault, both in terms of the duration and the magnitude of fault current.

The length of the recovery period will also be a function of the conditions under which the recovery must take place. In some applications, the MFCL device will not be carrying any current during the recovery, which will result in the fastest recovery period. In some applications, the device will have to carry nominal load current during the recovery, which will provide some constant level of background heat generation in the device that will lengthen the recovery period. This would be the case for both applications shown in Figs. 2 and 4. In this case, the HTS elements are not bypassing the parallel inductors, so the MFCL will present some impedance to the system during this recovery.

CONCLUSIONS

This research has established a viable approach to fault cur-rent limiting at transmission level voltage applications. A single phase proof-of-concept prototype has been successfully demon-strated in a nongrid test. The next step is to scale the design to high voltage and address the anticipated application require-ments as noted in the previous section.

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