A Review on Super Conducting Fault Current Limiter (SFCL) in Power System

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ABSTRACT- 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. They have the response time delay that allows initial of two or three fault current cycles to pass through before getting activated. Superconducting Fault Current Limiter (SFCL) is innovative electric equipment which has the capability to reduce fault current level within the first cycle of fault current. The application of the fault current limiter (FCL) would not only decrease the stress on network devices, but also can offer a connection to improve the reliability of the power system. This paper reviews the application of superconducting fault current limiter in power system.

Keywords- Fault, Distribution Substation, Protection, Sfcl

INTRODUCTION

The recent increase in power demand has been pressuring industries to continuously extend or expand power sources and transmission and transformer systems [1]. On the other hand, the equivalent impedance of power systems is decreasing. Accordingly, the fault current magnitude in power systems is increasing. Because of such developments, and the rising need to counter this trend, current-limiting technology has been getting much attention as it can efficiently limit the short-circuit faults and improve power system reliability. The introduction of new generating facilities by independent power producers and increasing load demand can result in fault current over duty on existing transmission system protective equipment. Conventional solutions to fault current over duty such as major substation upgrades, splitting existing substations buses or multiple circuit breakers upgrades could be very expensive and require undesirable extended outages and result in lower power system reliability. Due to the difficulty in power network reinforcement and the interconnection of more distributed generations, fault current level has become a serious problem in transmission and distribution system operations. The utilization of fault current limiters (FCLs) in power system provides an effective way to suppress fault currents.

Large-scale power systems are required to meet the increasing demand for electricity. For such systems, the fault current that occurs for short-circuit faults is higher and existing breakers may not be suitable for current interruption. In addition, the large voltage generated by electromagnetic induction can lead to communication failures. To address these issues, power system reorganization and circuit breaker upgrades can be considered. Fault condition may result in an electric power transmission system from events such as lightning striking a power line, or downed trees or utility poles shorting the power lines to ground .The fault creates a surge of current through the electric power system that can cause serious damage to grid equipment. Switchgears, such as circuit breakers, are deployed within transmission substations to protect substation equipment.

When power delivery networks are upgraded or new generation is added, fault levels can increase beyond the capabilities of the existing equipment, with circuit breakers in an "over-duty" condition. This problem necessitates upgrades such as the modification of substations or replacement of multiple circuit breakers. Increased fault currents due to load growth and industry structural changes have become a significant factor in system planning and operation. Equipment and personnel safety, power quality, and overall system reliability are all at stake if techniques and tools are not found to mitigate the higher levels of fault current in today's grid.

CONVENTIONAL SOLUTION

The existing conventional solutions to transmission-level fault current over-duty resolve the problem with varying degrees of effectiveness. Some are costly and/or have negative impact on system reliability and integrity. Some of these solutions are [2]:

1.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.

2.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.

3. 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.

4.Current limiting reactors and high impedance transformers- Fault current limiting reactors limit fault current due to the voltage drop 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.

5. 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. Also, opening the breaker upstream to the fault affects zones that were not originally impacted by the fault.

SUPERCONDUCTING FAULT CURRENT LIMITER

Superconducting Fault Current Limiter (SFCL) is innovative electric equipment which has the capability to reduce fault current level within the first cycle of fault current [3]. The application of the fault current limiter (FCL) would not only decrease the stress on network devices, but also can offer a connection to improve the reliability of the power system. There are various types of FCLs, which are made of different superconducting materials and have different designs. They are categorized into three broad types: the resistive type, the inductive type and bridge type SFCL. We discussed the operating characteristics of SFCL introduced into a simplified power transmission model system. It was finally revealed that SFCL could satisfactorily bring about the functions of fault current suppression and power system stability improvement .Along with the development of national economy in China, the supply capacity increases, the structure of power grid is strengthened and power supply and reliability enhances unceasingly. But with the expansion of power systems, the level of power system short-circuit capacity and fault short circuit current is increasing, and the level of local power grid short-circuit current exceeds the capacity of operating equipment, the power grid and electrical equipment safety is threated seriously. To limit the short-circuit current and reduce the impact of short-circuit current for the device, the conventional measures to limit the level of short-circuit current mainly comes from three aspects: power structures, system operation mode and equipment. However, the cost of limiting short-circuit current through transformation of power structure is extremely expensive. Change the system operation mode, such as electromagnetic ring off, disconnect the mother switch, two separate buses run etc., can effectively reduce the level of short-circuit current, but the reliability of power grid is reduced to some extent. Installation of traditional limiting current reactors or high impedance transformers will increase network losses and reduce the system stability. Therefore, in order to protect the security of power system equipment, limiting short-circuit current in the power system become extremely pressing issue. With the progress of superconducting technology and superconducting materials research and the development of power electronics technology, superconducting fault current limiter (SFCL) will bring new thinking is for current-limiting technology of power system. In this paper, the structure and working principle of several SFCLs which perform high in the actual power grid is analysed on the base of classification of SFCLs, and the advantages and disadvantages of the SFCLs are discussed. It will be provided a reference for in-depth study.

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

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. shows recently developed and installed SFCLs for distribution level. [4]


(a) (b) (c)

Fig. Distribution class SFCLs, (a) Boxberg, Germany (b) Shandin, USA, (c) Kochang, Korea

place	developer	Voltage (kV)	Type	status
ABB P/P, Swiss	ABB	10.5	R-type	Operated 1997(6month)
Puji S/S, China	Innopower	10.5	Saturable Core	In operation (2008~)
SCE Shandin S/S USA	Zenergy Power	15	Saturable Core	In operation (2009~)
Tokyo Gas, Japan	Toshiba	6.6		In operation (2007~)
Lancashire, U.K	Nexans SC	12	R-type	In operation (2010~)
Boxberg P/P, Germany	Nexans SC	12	R-Type	In operation (2009~)
San Dionigi S/S Italy	CESI RICERCA	9	R-Type	In operation (2011~)
Kochang, Korea	KEPRI/LS	22.9	Hybrid	In operation (2009~)
SCE, USA	AMSC/Siemens	115	R-Type	In operation (2011~)
AEP, USA	ZenergyPower	138	Saturable Core	In operation (2011~)

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. [5]In this paper, short circuit analysis based on the electromagnetic transient program was used to investigate the operational behaviour 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.

SECURE INTERCONECTOR 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 %. By 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 [6]. 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, marked as Location 3 in Fig4.4. 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 1. 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. [5]

REDUCES VOLTAGE SAG

[7]In this paper, the effects of a superconducting fault current limiter (SFCL) installed in loop power distribution systems on voltage sags are assessed and analysed. 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. Analysed 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.

CONCLUSION

Now a days a superconducting fault current limiters are very attracted solution to limit the fault current. 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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