PERFORMANCE ANALYSIS OF SURGE CURRENT PROTECTION USING SUPERCONDUCTORS

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Abstract

Increase in power generation capacity of electrical power systems has lead 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. 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. In this report, results of investigations carried out to assess the effectiveness of the options available for fault level management as well as, where necessary, their impact on voltage profiles and system stability are presented and discussed.

In this paper, Powerworld simulator was used in running a resistive type of SFCL.

Keywords: Circuit breaker, Fault Current Limiter, Superconducting Fault Current Limiter, Resistive SFCL

Introduction

Damage from a short circuit is a constant threat to any electric power system. Insulation damaged by aging, accident or lightning strike can unloose immense fault currents practically, the only limit on their size being the impedance of the system between their location and power sources **(www. Seminalsonly.com, 2006)**.

Conventional protection devices are installed for protection of excessive fault current in electric power systems, especially at the high voltage substation level, are the circuit breakers tripped by over-current protection relay which has a response time delay that allows initial two or three fault current cycles to pass through before getting activated. But, 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 first-cycle suppression of fault current by a SFCL results in an increased transient stability of the power system carrying higher power with greater stability. The comparison of conventional methods used for protection of single phase systems provides the information regarding the working of all types of relays especially overcurrent protection relays operation and its construction. The importance of SFCL, its features, advantages of SFCL over other protection devices has to be studied in detail in order to differentiate the operation of the SFCL clearly. **(Mohana, U.M. and Suganthi, S.T., 2012)**.

An ideal SFCL should have the following features:

- Zero or low impedance, zero or low voltage drop and zero or low power losses at normal operation,
- Large impedance in fault conditions,
- Quick appearance of impedance when fault occurs,
- Fast recovery after fault removal (half cycles or 8ms),
- Provide rapid detection and initiation of limiting action within less than one cycle or 16ms
- Reliable current limitation at determined fault current
- Be capable of addressing two faults within a period of 15 seconds and
- Good reliability **(www. Seminalsonly.com, 2006)**.

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. There are several kinds of SFCLs, which can be classified in three types such as the resistive type, the inductive type and bridge type SFCL. Each type of SFCL has its merits and demerits. Many studies have focused on the topology and capability of SFCLs. The inductive type SFCL is able to suppress the voltage drop and limit the fault current. The resistive type SFCL can consume the energy of the fault current and limit it. This capability can improve the power system stability. The bridge type SFCL is a kind of SFCL, which has zero impedance under the normal condition and large impedance under fault condition. Its advantage is the fault current limitation without any delay and smoothing the surge current waveform. But, it cannot limit the steady state fault current. Among the parameters of the FCL, the magnitude of the limiting impedance and its merits affects the current-limiting performance of the FCL much more than the other parameters. In other words, depending upon the kind of the FCL and its merits, the insertion of the FCL in to the power system can result in more severe interrupting problems. Therefore, it is important to study the interrupting behavior of circuit breakers in the presence of the kinds of FCLs. In this paper, a comparative study of the interrupting behavior of circuit breakers in the presence of the resistive type SFCL have been carried out **(Firouzi M., Aslani S., Gharehpetian G. B. and Jalilvand A., 2012)**.

Fault Current Limiter (FCL)

'FCL' is a variable-impedance device connected in series with a circuit to limit the current under fault conditions. The 'FCL' should have very low impedance during normal condition and high impedance under fault condition **(Vibhor,C., Rishi, P. S. and Seema, D., 2012)**. A complete circuit of this is shown in (EEI – Chicago, IL page 14). RSFCL.

It has potential to reduce fault level on the electricity power networks and may ultimately lead to lower rated components being used or to increased capacity on existing systems **(Vibhor et al., 2012)**.

The role of a fault current limiter

As mentioned earlier, the role of the FCL is to limit prospective fault current levels to a manageable level without a significant impact on the distribution system. Consider a simple power system model, as shown in Figure 1(a), consisting of a source with voltage V_S, internal impedance Z_S, load impedance Z_{LOAD}, and fault impedance Z_{FAULT} **(Rowley A. T., 1995)**.

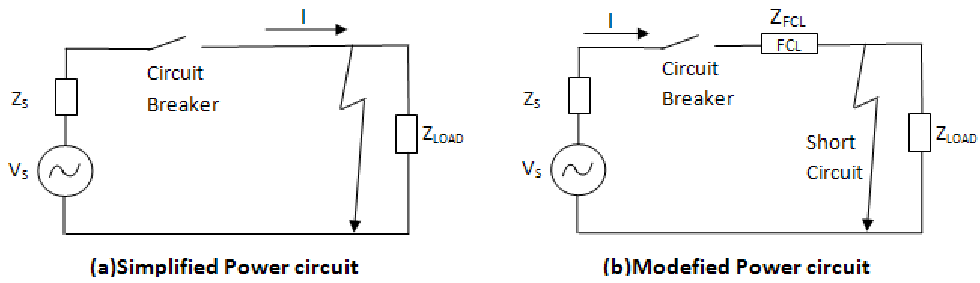

Figure 1. Simple Power Circuit with and without FCL

In steady state,

$$\mathbf{I_{line}} = \frac{\mathbf{V_s}}{\mathbf{Z_s + Z_{load}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{1}$$

When a fault occurs in a system,

$$\mathbf{I_{Fault}} = \frac{\mathbf{V_s}}{\mathbf{Z_s + Z_{Fault}}} \text{, } \mathbf{where\ Z_{Fault} << Z_{Load}} \ldots\ldots\ldots\ldots\ldots \mathbf{2}$$

Since the supply impedance Z_S, is much smaller than the load impedance, Equation (2) shows that the short circuiting of the load will substantially increase the current flow. However, if a FCL is placed in series, as shown in the modified circuit Figure 1(b), Equation (3) will hold true;

$$\mathbf{I_{Fault}} = \frac{\mathbf{V_s}}{\mathbf{Z_s + Z_{FCL} + Z_{Fault}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{3}$$

Equation (3) tells that, with an insertion of a FCL, the fault current will now be a function of not only the source Z_S and fault impedance Z_{FAULT}, but also the impedance of the FCL. Hence, for a given source voltage and increasing Z_{FCL} will decrease the fault current I_{FAULT}.

Ideal fault current limiter characteristics

Before discussing any further, it is important that some of the ideal characteristics be laid out for an FCL. An ideal FCL should meet the following operational requirements. **(Manish V., 2009)** :-

1) Virtually inexistent during steady state. This implies almost zero voltage drop across the FCL itself

2) Detection of the fault current within the first cycle (less than 16ms for 60Hz and 20ms for 50Hz) and reduction to a desirable percentage in the next few cycles.

3) Capable of repeated operations for multiple faults in a short period of time

4) Automatic recovery of the FCL to pre-fault state without human intervention

5) No impact on voltage and angle stability

6) Ability to work up to the distribution voltage level class

7) No impact on the normal operation of relays and circuit breakers

8) Finally, small-size device that is relatively portable, lightweight and maintenance free

In reality, one would like to have an FCL that would satisfy all of the foregoing characteristics. However, certain trade-offs and compromises have been made in nearly all categories and types.

Superconducting fault current limiter

Superconductor-based fault current limiters offer an alternative solution to controlling fault levels on the network. A superconducting fault current limiter (SFCL), unlike reactors or high-impedance transformers, will limit fault current without adding impedance to the circuit during normal operation. Most SFCLs are based on the “superconducting and normal” (SN) transition property.

Superconductors are the only materials that change their resistance automatically from zero to a high value when a certain ‘critical current’ is surpassed. Early superconducting fault current limiters were too expensive for wide application in electrical utilities, since they were based on superconducting materials, which can only operate under extremely low temperatures (-269°C). With the discovery of high temperature superconductors (HTSs) twenty five years ago, the cooling problem has been greatly reduced. These new materials can be operated at much higher temperatures (-196°C) and can be cooled simply by using liquid nitrogen **(Xueguang W., Joseph M., Nick J. and Goran S., 2003)**. There are various types of SFCLs as earlier mentioned, but in this paper, a resistive SFCL is considered.

Resistive SFCL Model

A resistive SFCL utilizes resistance increase upon quench of a superconductor. It has advantages such as simpler structure, smaller size, and possibly lower capital cost than other types. During normal operation, the superconducting element is in its superconducting state and the normal load current passes with theoretically no loss. In the case of a short circuit, the circuit current rises sharply and the superconductor undergoes a transition to its normal state, so a certain value of nonlinear resistance is created by self-sensing and self-triggering, thus limiting the fault current level **(Firouzi et al., 2012)**.

A diagram of the resistive SFCL is shown in Figure 2. The fault current pushes the superconductor into a resistive state directly and a resistance appears in the circuit. The advantage of the resistive SFCL is that the superconductor absorbs the energy of the fault current

Directly **(Xueguang et al., 2003)**.

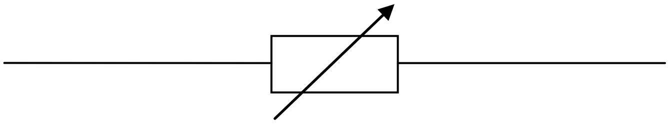

Figure 2. Resistive SFCL

Application of resistive sfcl

Resistive SFCL can be used in the following ways:-

Transformer circuit, Feeder circuit, Bus-Section Position, as shown in Figure 3(a,b,c)

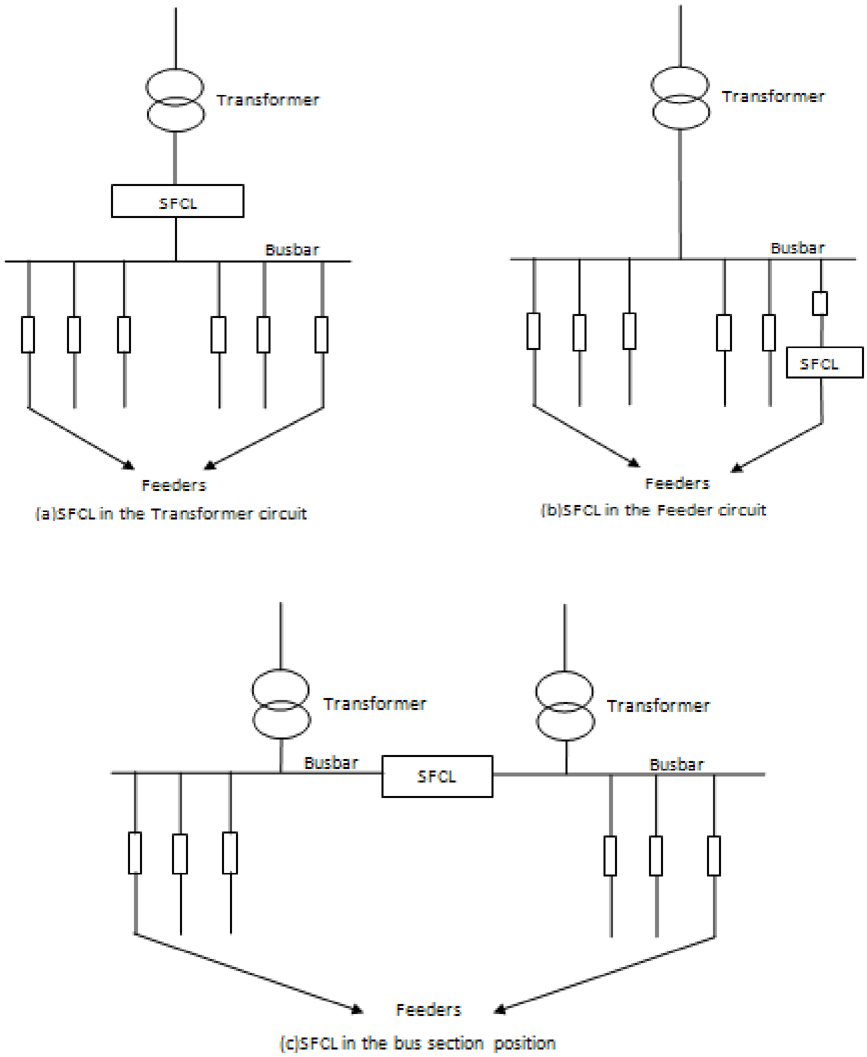

Fig 3. Typical applications of the SFCL

Figure 3(a) shows the SFCL in the main transformer circuit. The entire downstream busbar is protected by the SFCL. A large, low-impedance transformer can be used in this arrangement.

Figure 3(b) shows the SFCL in a feeder circuit. Individual feeder equipment, that is difficult to replace, such as underground cables or distribution switchgears, can be protected by the SFCL.

Figure 3(c) shows the SFCL connecting two busbars. The busbars are only separated by the SFCL during a fault **(Xueguang W., Joseph M., Nick J. and Goran S., 2003)**.

SFCL Performance: Modeling

A case study based on a typical substation has been considered. Some of the key parameters of this system at an aggregate level are summarized in Table 1. A total of five cases of studies involving five different percentage increase of Z_{FCL}. Out of the five, only one of it is represented as shown in figure 4(b) below.

Table 1 Summary of Test System Steady-State Parameters

Parameter Description	Value	Unit
System Voltage	33	kV
Substation Transformer	132/33	kV
Nominal Frequency	50	Hz
Transformer Short-Circuit Power	40	MVA
Source Short-Circuit Power	2400	MVA
Fault Impedance	$1x10^{-6}$	Ω
Internal Impedance	0.75	Ω
Load Impedance	15	Ω
Superconductor Critical Temperature	77	K
SFCL Phase wire diameter	0.08	m
SFCL Phase wire length	100	m
SFCL Critical current rating/phase	8.9	kA

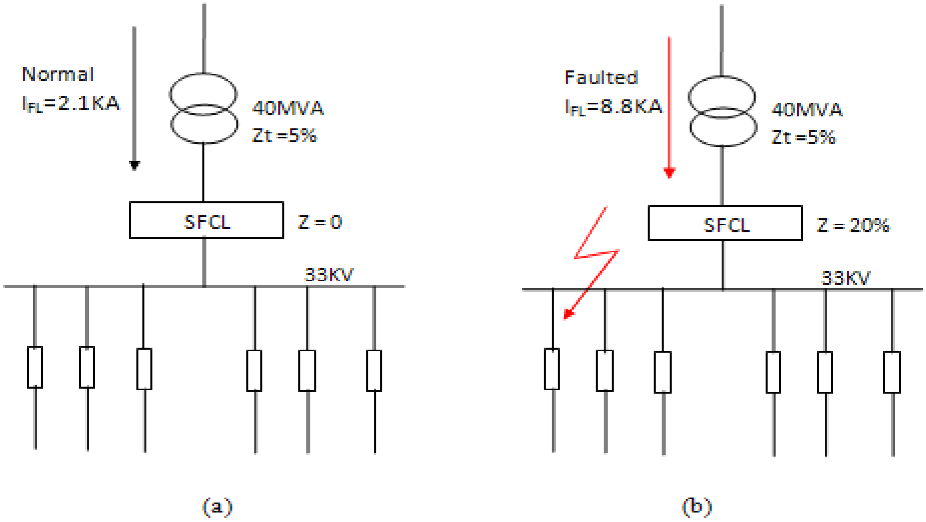

Figure 4 (a&b) Fault current controls with and without a SFCL

Results and discussion

Powerworld simulator was selected to design and implement the Resistive SFCL model.

In Figure 4.1, a large, low-impedance transformer (Zt=5%) is used to feed a busbar. The SFCL is installed between the transformer and the busbar for limiting the fault current. Normally, the SFCL does not affect the circuit, and the full-load current I_{FL} is 2.1kA. During a fault, the SFCL develops an impedance of 0.2 per unit (Z=20%), and the fault current I_{SC} is reduced to 8.8kA. Without the SFCL, the fault current would be 44kA**.** The adjustment of Z_{FCL} depends on the amount of fault that occur on the line and its distance to from point where the Z_{FCL} is located. Each of these values are tabulated in Table 2, for the same Fault current. It is seen that as the percentage values of the limiter increases, the fault current decreases. This is also illustrated in the graph in Figure 5.

Table 2 Fault current values with and without SFCL for different percentage increase of Z_{FCL} (Thomas, J. O., 2013)

	Magnitude of fault current		
	Without SFCL	With SFCL	
S/N	**kA**	**Z%**	**Fault Current (kA)**
1	**44**	**10**	**14.7**
2	**44**	**20**	**8.8**
3	**44**	**30**	**6.3**
4	**44**	**40**	**4.9**
5	**44**	**50**	**4**

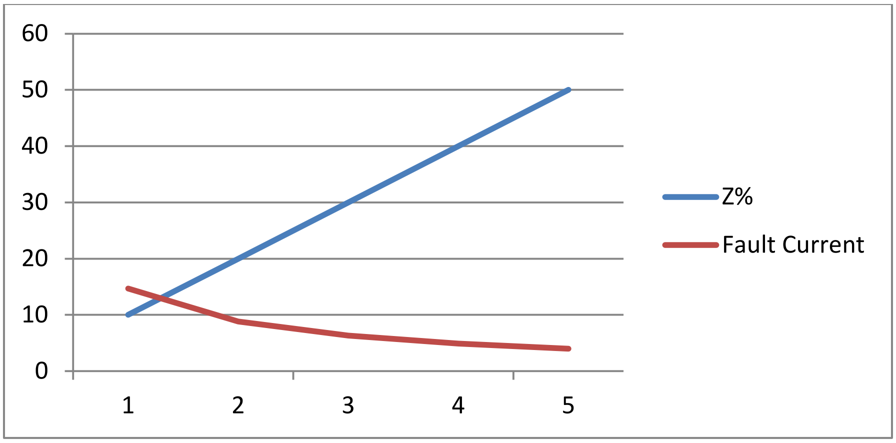

Figure 5. Graph illustrating the relative relationship between the fault current and the percentage increments as offered by the FCL.

Conclusion

Today, the problem of power quality improvement is very real. This report has reviewed the basic principles underlying the methods that can be used to reduce fault levels as well as their typical application. The particular superconductor fault current limiter proposed in the paper has the merit to meet the problem of voltage sags in distribution utilities with a solution that does not require control system and power electronic. The simulations performed prove the method effectiveness, as well as the possibility of building the 'FCL' with commercially available components. The results of the performance analysis of surge current protection using superconductors were in agreement with the analysis carried out by by **(Vibhor et al., 2012)** and **(Xueguang et al., 2003)**.

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