

STUDY OF SUPERCONDUCTING FAULT CURRENT LIMITER (SFCL) TECHNOLOGY FOR OPTIMAL POWER PLANT PERFORMANCE AND GRID EXPANSION

T.Prabhu

Electrical and Electronics Engineering

SSN College Of Engineering, Chennai, Tamilnadu.

Email: prabhut070@gmail.com

Abstract - This paper presents the application of Superconducting fault current limiters (SFCL) for smart grids in order to reduce possible effect of abnormal fault current. Increased demand results in increased generation capacity in power systems which has lead to increased fault current. At present several conventional protective devices are installed to reduce fault currents in electrical power systems. Predominantly used is circuit breaker which gets tripped off after two to three cycles of fault current by over-current protection relay. Thus they have a response delay of initial two to three cycles before getting activated. SFCL is an innovative electrical equipment which is capable of reducing fault current within first cycle itself and thus providing improved transient stability. In this paper the performance of SFCL for a three phase system is tested using simulink tool and the results are analyzed during both presence and absence of SFCL.

Keywords - Smart grids, Fault current, Superconducting Fault current Limiter, micro grid, fault current limitation.

1. Introduction

SHORT circuit in powerplants and electricity grids are highly expensive as high currents can damage system components and cause downtime. As power grids are upgraded for higher capacities this situation is likely to happen frequently. 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 most important physical property dominating the current limiting behavior of the SFCL is the electric field current density characteristics of High Temperature Superconductors (HTS) which is dependent on temperatures.

The model should be adaptable with little modifications for various fault scenarios. It should be able to model the effects of different fault durations, different magnitudes, and cater for any point of fault occurrence with respect to voltage waveform. The model should also execute without excessively long simulation times. So we have developed an Electromagnetic Transient Program (EMTP) model of high temperature resistive type SFCL based on

characteristics of HTS. Real time circuit current is as an input signal to the SFCL model, and the output of the model is controlled by an advanced controlled time-dependent resistance.

In a three-phase power system, each phase of the SFCL must be modeled independently because they will operate independently, particularly during unbalanced primary system faults, which represent the predominant mode of fault in power distribution systems (particularly in overhead systems). Each phase will have a dedicated superconducting wire (or several wires) which form a superconducting element. This means that within the first cycle of fault current during a three-phase to earth fault, each phase of the SFCL will develop resistance at a slightly different time, hence creating a momentary phase unbalance. Unbalanced faults may only cause a quench in only one or two phases of the SFCL. Independent operation of each phase must be represented such that the effects on the overall power system can be evaluated for all fault types at various locations.

The paper is organized as follows. Section II deals with characteristics and modeling of SFCL. The appropriate model of SFCL to be used for a electrical power system is designed using MATLAB simulink. Section III deals with use of SFCL in a power system model and analysis of its behavior is done. The results and observations obtained are tabulated and studied in Section IV. Finally, Conclusions of this study is given in Section V.

2. Modelling of SFCL:

A. Simple structure of a resistive SFCL:

SFCL works on the following principle. The core of the device is made of superconducting material which has zero resistance for a particular temperature which results in reduced loss. However with increase in temperature they become normal conductors with high resistance. The transition time between superconducting and normal state is very less. During short circuit high current density results in increase in temperature which transits superconductor to normal conductor with high resistance. It is not only fast but also strong such that fault current is reduced in milliseconds. After a brief fault clearing phase it reactivates automatically without any maintenance. In order to keep superconductor at a low temperature inexpensive liquid nitrogen is used.

The simple structure of a resistive (non inductive winding) SFCL unit is shown below. A unit consists of the stabilizer resistance of the n th unit, $R_{ns}(t)$; the superconductor resistance of the n th unit, $R_{nc}(t)$, which is connected with $R_{ns}(t)$ in parallel; and the coil inductance of the n th unit, L_n .

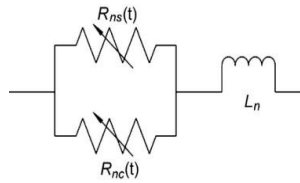


Fig. 1 Simple Structure Resistive SFCL Circuit

The subscript n denotes the number of connected units. The values of $R_{nc}(t)$ and $R_{ns}(t)$ of the SFCL are normally zero in a normal steady-state condition. However, they become nonzero time-varying parameters due to the larger current than the critical current for maintaining the superconducting state during a fault according to their unique characteristic. This behavior is named as *quenching*. The value of total resistance (R_{sfcl}) of the SFCL during a fault depends on the total number of units in Fig. 1, which are connected in series. The value of L_n is determined by the wound coils. This has to be as small as possible because the inductance causes ac loss under a normal condition. In practice, the coil is wound to have very small inductance. Therefore, the value of L_n is so small that its effect can be ignored. Then, the associated equation for R_{sfcl} is expressed by (1) to describe its quenching and recovery characteristics

$$R_{sfcl}(t) = \begin{cases} 0, & (t > t) \\ R_m \left[1 - \exp\left(\frac{-(t-t_0)}{T_{sc}}\right) \right]^{\frac{1}{2}}, & (t_0 \leq t < t_1) \\ a_1(t - t_1) + b_1, & (t_1 \leq t < t_2) \\ a_2(t - t_2) + b_2, & (t_2 \leq t) \end{cases} \quad (1)$$

where R_m is the maximum resistance of the SFCL in the quenching state, T_{sc} is the time constant of the SFCL during transition from the superconducting state to the normal state. Furthermore, t_0 is the time to start the quenching. Finally, t_1 and t_2 are the first and second recovery times, respectively.

Resistive SFCL Model:

The three phase resistive type SFCL was modeled considering four fundamental parameters of a resistive type SFCL. These parameters and their selected values are:

- 1) transition or response time ,
- 2) minimum impedance and maximum impedance ,
- 3) triggering current and
- 4) recovery time .

Its working voltage is 22.9 kV shows the SFCL model developed in Simulink/Sim-PowerSystem. The SFCL model works as follows. First, SFCL model calculates the RMS value of the passing current and then compares it with the characteristic table. Second, if a passing current is larger than the triggering current level, SFCL's resistance increases to maximum impedance level in a pre-defined response time. Finally, when the current level falls below the triggering current level the system waits until the recovery time and then goes into normal state.

The SFCL characteristic table shown plays a main role which consists of standard parameter values of SFCL. The SFCL model can also be implemented using EMTP. The current limiting resistance value is calculated and this value is implemented in the simulation model. The important parameter to be given in SFCL is the current limiting resistance value. It is stored in the SFCL characteristic table. In order to avoid harmonics caused by transients, filter is used. The SFCL model developed is tested in three phase test systems and the current waveforms are recorded with the presence and absence of SFCL.

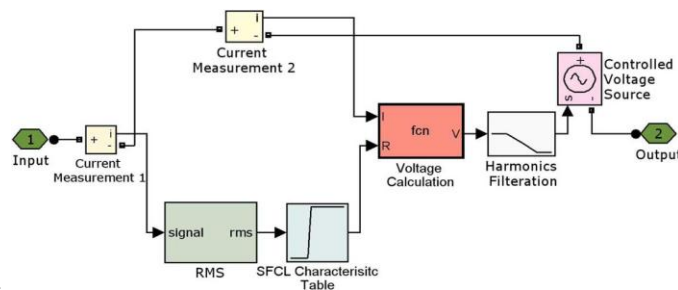


Fig. 2 Single phase SFCL model developed in Simulink

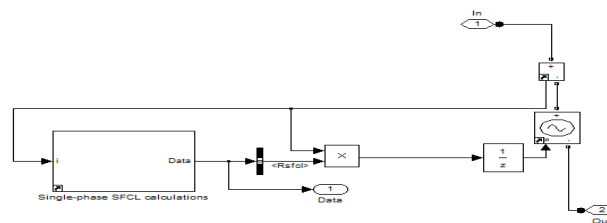


Fig. 3 Single Phase SFCL simulated using simulink

3. Power System Model

The SFCL model discussed in previous section is implemented along with a power system model with the help of Simulink tool as shown in Fig 4. In this model, Synchronous machine represents the conventional power plant.

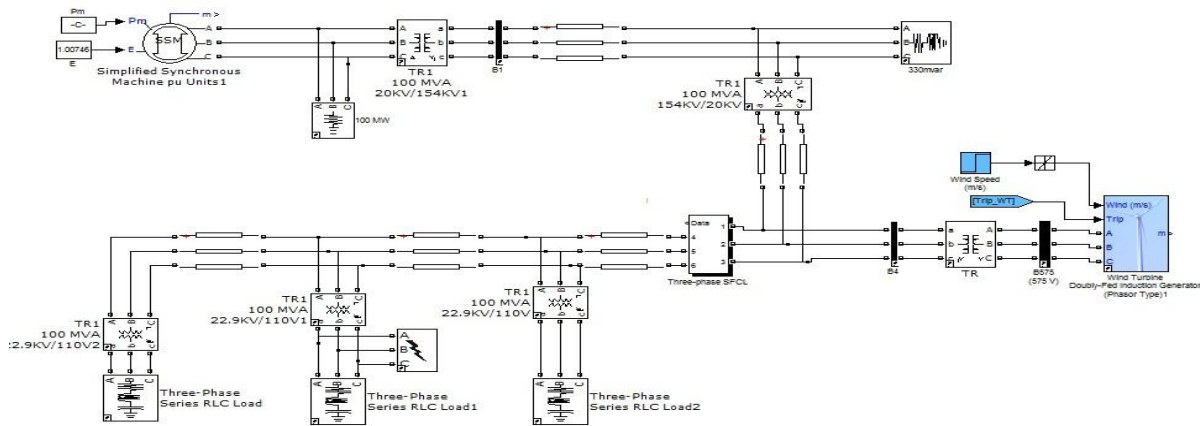


Fig. 4 Simulated Power System Model Using Simulink

It is a 3-phase 100 MVA plant connected with 5 Km long 154 KV distributed-parameters transmission line through a step up transformer TR1. A three phase load is connected to the power plant. The fault occurred here is three phase to ground fault. Here the SFCL model developed for single phase is converted to three phases and attached as a subsystem in the distribution line. The SFCL model shown above is implemented for three phase. Additional data such as variation of temperature and variation of R_{sfcl} with respect to fault current is also obtained by connecting the data to the bus.

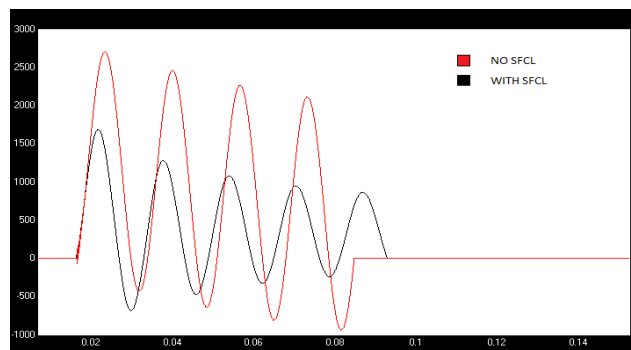


Figure.5 Reduction in Fault Current with SFCL in Phase A

The comparison results of the three phase system during the presence and absence of SFCL is shown in the Fig.5. The first waveform (red) indicates the current value without SFCL. Current value is above 2000A ($\approx 2700A$). The second (black) waveform indicates the current value with SFCL. Current value is limited below 2000A ($\approx 1650A$).

4. RESULTS AND DISCUSSION

The performance characteristics indicating the relationship between the SFCL impedance (Ohms) and reduction in fault current (%) is shown in Fig.6. From the graph it is seen that, as impedance increases the percentage of reduction in fault current also increases. So, SFCL limits the fault current in the first cycle than any other devices. The simulation results show the validity and effectiveness of suggested scheme and also the ability of the SFCL to reduce the inrush current. By using SFCL for limiting the fault current the system reliability and integrity is increased. The SFCL withstands short circuit currents for a longer period.

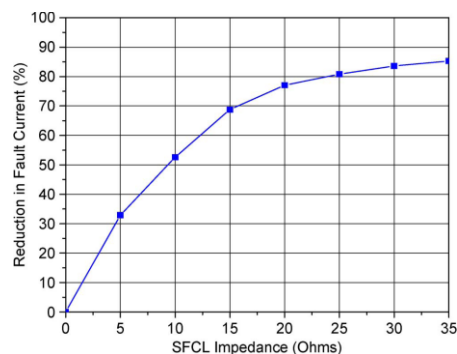


Fig 6. SFCL performance evaluation graph indicating the relationship between SFCL impedance and reduction in fault current

A. Variation of Superconducting Resistance [R_{sfcl}]: The variation of superconducting resistance (R_{sfcl}) and with respect to time is shown in Fig. 7. As explained earlier, the resistance is Zero before fault occurs and increases exponentially during initial fault condition and reaches a steady state value during fault to behave like a normal conductor and reduces gradually after first and second recovery times.

B. Strategic Location of SFCL: For the above simulink model SFCL is placed at three different points. One at power plant, one at wind turbine and the final one at integration point between conventional power plant and wind turbine.

From fig. 8. It is clear that the SFCL placed at integration point provide better fault current control than other areas. Thus whenever a secondary unit is added like wind or solar unit there is no need a high voltage transformer and transmission lines to connect them with main grid. By using SFCL at integration point between two units excellent results are obtained.

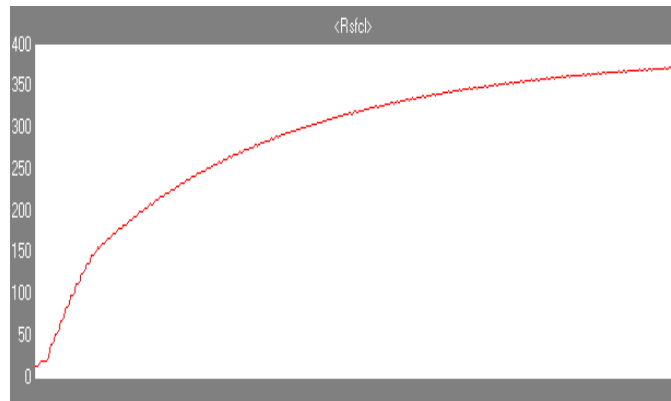


Figure 7. Variation of Superconducting Resistance $[R_{sfcl}]$

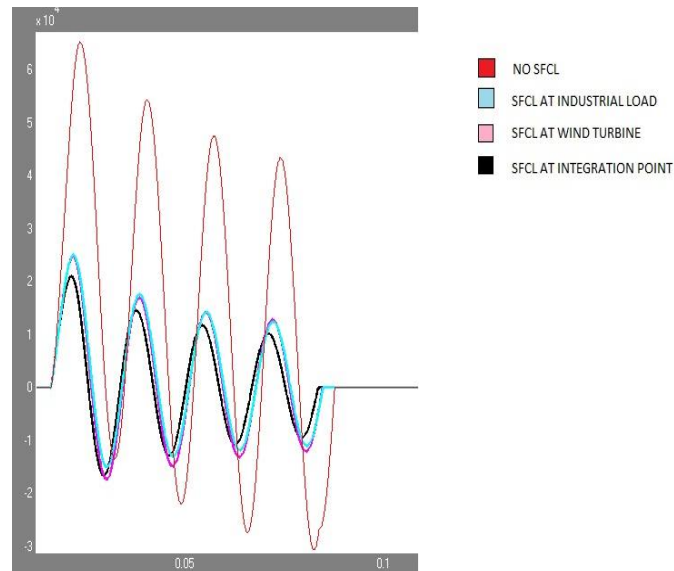


Fig. 8. Fault currents for various locations of SFCL

5. Conclusion

The above tests conducted using the SFCL single-phase prototype showed the excellent current limiting capability of the fault current. It also provides fault current limiting actions in the first half of cycle ($t < 5\text{ms}$), reducing effectively the short circuit currents to much smaller current amplitudes. Results of simulations are very satisfactory and fully describe the behavior of SFCL devices for all nominal and limiting conditions. These results are very important for studying the behavior and to evaluate the impact of SFCL devices on transmission lines and many electrical apparatus networks and also to give useful hints to the design of practical SFCL devices. Thus SFCLs are materials which have the ability to conduct electricity without loss of energy. They utilize superconducting materials to limit the current directly. The main advantage is it is 20 times less costly in terms of initial capital costs. Also expanding transmission lines and plant capacity is made easy by SFCL. From the comparison results and performance characteristics it is proved that the SFCL is a promising novel electric equipment to reduce excessive fault current in electric power systems effectively. In practical application of this novel device into electrical networks, it causes favorable impacts on the electric power system.

REFERENCES

- [1] S. Sugimoto, J. Kida, H. Arita, C. Fakui, and T. Yamagiwa, "Principle and characteristics of a fault current limiter with series compensation," *IEEE Trans. Power Delivery*, vol. 11, no. 2, pp. 842–847, Apr. 1996.
- [2] T. Jamasb, W. J. Nuttall, and M. G. Pollitt, *Future Electricity Technologies and Systems*. Cambridge: Cambridge Univ. Press, 2006, pp. 8397, 235–246.
- [3] B. C. Sung, D. K. Park, J. W. Park, and T. K. Ko, "Study on a series resistive SFCL to improve power system transient stability: Modeling, simulation and experimental verification," *IEEE Trans. Industrial Electron.*, vol. 56, no. 7, pp. 2412–2419, Jul. 2009.
- [4] Litos Strategic Communication, "The Smart Grid: An Introduction," 2008 [Online]. Available: <http://www.oe.energy.gov/SmartGridIntroduction.htm>, Prepared for U.S. Department of Energy.
- [5] R. Strzelecki and G. Benysek, *Power Electronics in Smart Electrical Energy Networks*. London, U.K.: Springer-Verlag London Ltd., 2008, pp. 203–213.
- [6] J. Driesen, P. Vermeyen, and R. Belmans, "Protection issues in microgrids with multiple distributed generation units," in *Power Conversion Conf.*, Nagoya, April 2007, pp. 646–653.