Design and Application of a Superconducting Fault Current Limiter in Wind Energy System

KANTHA ADILAKSHMI¹, ROSAIAH MUDIGONDLA²

¹PG Scholar, Dept of EEE, Arjun College of Technology & Sciences, Ranga Reddy(Dt), Hyderabad, TS, India.  
²Assistant Professor, Dept of EEE, Arjun College of Technology & Sciences, Ranga Reddy(Dt), Hyderabad, TS, India,  
E-mail: rosaiaho228@gmail.com.

Abstract: Nowadays, the main energy supplier of the worldwide economy is fossil fuel. However has led to many problems such as global warming and air pollution. Therefore, with regard to the worldwide trend of green energy, Wind energy, Solar energy and Fuel cell technology has become one of the most promising energy resources. Smart grid will integrate renewable energy resources into the future power grid, in order to supply more efficient, reliable, and responsive electric power. In this paper, an application of superconducting fault current limiter (SFCL) is proposed to limit the fault current that occurs in power system, SFCL is a device that uses superconductors to instantaneously limit or reduce unanticipated electrical surges that may occur on utility distribution and transmission networks. 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 and result in considerable saving in the investment of high capacity circuit breakers is felt. In this work, a resistive type SFCL model was implemented by integrating Simulink and Sim Power System blocks in Matlab. The designed SFCL model could be easily utilized for determining an impedance level of SFCL according to the fault-current-limitation requirements of various kinds of the smart grid system. Wind farm is considered and their performance is also evaluated.

Keywords: Fault Current, Micro Grid, Smart Grid, Superconducting Fault Current Limiter, Wind Farm.

I. INTRODUCTION

Smart grid is a term used for future power grid which integrates the modern communication technology and renewable energy resources for the 21st century power grid in order to supply electric power which is cleaner, reliable, effervescent and responsive than conventional power systems. Smart grid is based on the principle of decentralization of the power grid network into smaller grids (Microgrid) having distributed generation sources (DG) connected with them. One critical problem due to these integrations is excessive increase in fault current due to the presence of DG within a micro grid [1]. Conventional protection devices installed for protection of excessive fault current in power systems, mostly at the high voltage substation level circuit breakers tripped by over-current protection relay which has a response-time delay resulting in power system to pass initial peaks of fault current [1]. But, SFCL is a novel technology which has the capability to quench fault currents instantly as soon as fault current exceeds SFCL’s current limiting threshold level [2]. SFCL achieves this function by losing its superconductivity and generating impedance in the circuit. SFCL does not only suppress the amplitudes of fault currents but also enhance the transient stability of power system [2][3]. Up to now, there were some research activities discussing the fault current issues of smart grid [5], [6]. But the applicability of SFCLs into micro grids was not found yet. Hence, in order to solve the problem of increasing fault current in power systems having multiple micro grids by using SFCL technology is the main concern of this work.

The utilization of SFCL in power system provide them most effective way to limit the fault current and results inconsiderable saving from not having to utilize high capacity circuit breakers. With 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. Being many SFCL design concepts are being evaluated for commercial expectations, improvements in superconducting materials over the last 20 years have driven the technology [4]. Case in point, the discovery of high-temperature superconductivity (HTS) in 1986 drastically improved the potential for economic operation of many superconducting devices. Based on the previous works, this paper presents feasibility analysis results of positioning of the SFCL and its effects on reducing fault current in smart grid having AC and DC micro grid together. The detailed power system was implemented with AC micro grid having wind farm and low voltage DC grid connected with photovoltaic farm. Transient analyses were performed for the worst case faults with the different SFCL arrangements. From the simulation results, it was possible to determine the strategic installation placement of SFCLs in power systems which limits all abnormal fault currents and has no negative effect on the distributed generation resources.
II. HIGH TEMPERATURE SUPERCONDUCTOR TAPES TESTS

A high power dc short circuit test platform is built to verify the limiting effect of the second generation (2G) high temperature superconductor (HTS) tapes in dc power systems. The platform is composed of a step-down transformer, an uncontrolled rectifier bridge and a short-circuit control circuit, as shown in Fig.1. The system voltage is provided by an isolated transformer. The low voltage level is good for the safety of the test system, so the test is conducted when the voltage is 20 VAC. So the dc voltage behind the rectifier bridge is about 25 V. Superconducting limiting module of two types of HTS tapes, respectively produced by the Physics Department of Shanghai Jiao Tong University (SJTU) and American Superconductor Corporation (AMSC), are applied to the dc system to prove the current limiting ability of superconducting materials. Short circuit test with the limiting module are conducted when the transformer supplies 20 VAC. The circuit current is obtained by testing the voltage of the line resistor. Short circuit current and the resistance of the superconducting limiting module in 20 VAC systems are simulated.

![Fig. 1. Overall test platform.](image)

Fig. 1. Overall test platform.

II. BASICS OF SFCL

Superconducting fault current limiter is a promising technique to limit fault current in power system. Normally non-linear characteristic of superconductor is used in SFCL to limit fault current. In a normal operating condition SFCL has no influence on the system due to the virtually zero resistance below its critical current in superconductors. But when system goes to abnormal condition due to the occurrence of a fault, current exceeds the critical value of superconductors resulting in the SFCL to go resistive state. This capability of SFCL to go off a finite resistive value state from zero resistance can be used to limit fault current. Different types of SFCLs have been developed until now [10-13]. Many models for SFCL have been designed as resistor-type, reactor-type, and transformer-type etc. In this paper a resistive-type SFCL is modeled using simulink. Quench and recovery characteristics are designed on the basis of [14].

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

Where \(R_m\) is the maximum resistance of the SFCL in the quenching state, \(T_{\text{sc}}\) 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.

A. Superconducting Fault Current Limiters (SCFCL)

Upper conductors are widely adopted in FCL topologies, mostly because they offer superior performance by presenting negligible normal operation impedance, when the temperature and magnetic field on them are below critical values \((T_c, H_c)\). Besides, superconductors can also provide inherent fast current limiting characteristics and repetitive operation with auto-recovery.

Characteristics of SCFCL:

- **“Superconductivity”:** When refrigerated below the critical temperature \(T_c\), the superconductors have very low resistivity (almost zero to dc current), which means low conduction copper losses.

- **“Quenching”:** The resistance of the superconductor will increase rapidly when large current flows through it and drives the material beyond its critical temperature. In this case, the superconductor coil will “quench" the current with substantial amount of impedance presented in the circuit.

Many SCFCL technologies take advantage of one or both of the above characteristics. For example, the resistive type and magnetic assisted resistive type SCFCL’s utilize the superconductivity in normal operations, while the quenching characteristic is used to limit the fault current in these FCL types. On the other hand, in some topologies, such as in saturated-core FCL’s and bridge-type FCL’s, superconductors are sometimes used only as zero-loss conductors when carrying high current is necessary.

B. Types of SCFCL

**Resistive Type:** Resistive superconductor FCLs use the quenching effect of superconducting materials. It is the simplest form of SCFCL. Fig.2. demonstrates the principle topology of a resistive type SCFCL device. The main current carrier SC is a low inductance superconductor. Shunt resistor R is necessary to suppress hot-spot and overvoltage on the superconductor during quenching transients. Figure 2.3 illustrates an example configuration of the resistive type SCFCL elements. Because of the low resistance of the silver substrate of TYPE-I superconductors, large number of elements are required to achieve the desired current limitation goal. This increases both the material costs and the operation AC losses, in thatmore
superconducting materials are subject to carrying AC current. Hence, this configuration is suitable for the TYPE-II conductors, which have highly resistive substrates. Their feasibility is being studied and tested in many different countries.

**Fig.2. Resistive type superconductor FCL.**

**Magnetic Assisted Resistive Type:** As implied by its name, the magnetic assisted resistive SCFCL works similar in principle to the resistive SCFCL described above. A copper coil is connected in parallel with the superconductor elements. Also, this shunt coil is physically wrapped around elements. During normal operation, the superconductor carries all the normal operation current and presents little impedance to the power network. Under fault, the resistance of the shunt coil has the same function as the shunt resistor in the resistive type SCFCL, bypassing the fault current and preventing hot-spots caused by inhomogeneous quenching of the superconductor. Other than this, a voltage drop caused by the initial quench is seen by the shunt copper coil, and builds up a magnetic field inside the coil. This magnetic field effectively accelerates the quenching process of the superconductor, since the superconductors' critical temperature reduces substantially when exposed to external magnetic fields (as shown in Fig.3[6, 88]). This type of SCFCL applies to the TYPE-I superconductor enabling it with performance improvements such as faster and more homogeneous quenching process.

**Fig.3. Schematic of magnetic assisted resistive type SCFCL.**

**III. WIND ENERGY**

The modern lifestyle depends tremendously on the use and existence of fossil fuels. With levels of these fuels constantly decreasing, we should act now to become less dependent on fossil fuels and more dependent on renewable energy sources as shown in Fig.4. Renewable energy provides 19% of electricity generation worldwide. Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas. The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

**Fig.4. Wind Farm.**

Wind energy is a free, renewable resource, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of clean, non-polluting, electricity. Unlike conventional power plants, wind plants emit no air pollutants or greenhouse gases. According to the U.S. Department of Energy, in 1990, California's wind power plants offset the emission of more than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants that would have otherwise been produced. It would take a forest of 90 million to 175 million trees to provide the same air quality.

Advantages of Wind-Generated Electricity

- Wind energy is a free, renewable resource, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of clean, non-polluting, electricity.
- Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a higher initial investment than fossil-fuelled generators.

Although wind power plants have relatively little impact on the environment compared to fossil fuel power plants, there is some concern over the noise produced by the rotor blades, aesthetic (visual) impacts, and birds and bats having been killed (avian/bat mortality) by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.
IV. MATLAB/SIMULATION RESULTS

Simulation results of this paper is shown in below Figs.5 to 14.

Fig.5. Simulink circuit of proposed system without SFCL.

Fig.6. Simulation result for short circuit current at C1 without sfcl.

Fig.7. Simulation result for short circuit current at C2 without sfcl.

Fig.8. Simulink circuit of proposed system with SFCL module.

Fig.9. Simulink design for SFCL.

Fig.10. Simulation result for short circuit current at C1 with sfcl.

Fig.11. Simulation result for short circuit current at C2 with sfcl.

Fig.12. Simulink circuit for wind based sfcl.
V. CONCLUSION

As a kind of clean energy technique, the wind power generation offers the advantages of renewable energy source. However, the high cost and relatively low efficiency of power generation in the past compared to other energy sources such as oil, gas, hydro. This paper presented feasibility analysis results of positioning of the SFCL and its effects on reducing fault current in smart grid having AC and DC micro grid together. In order to determine the SFCL in neighbouring AC and DC smart grid, AC and DC SFCL models were designed to perform for the worst case faults with the different SFCL arrangements. From the simulation results, the optimal strategic installation placement of SFCLs in power systems, which limits all abnormal fault currents and has no negative effect on the distributed generation resources, has been proposed.

VI. REFERENCES


Author’s Profile:

Kantha Adilakshmi Received B.E in Electrical and Electronics Engineering From Osmania University Hyderabad in 2013,She is Currently Pursuing M.Tech (Power Electronics And Electric Drives) From J.N.T.U, Hyderabad India. She Research interests include Power Converters,HVDC Transmission, Renewable Energy Resources and Power Electronic Control of DC Drives..

Mr. Rosaiah ,At present is a Associate Professor in the department of EEE in Arjun college of Technology&Sciences Hyderabad Telengana, India. He Received B.Tech degree in EEE from J.N.T.U Hyderabad in 2010,He received M.Tech degree in Power Electronics& Drives from Ayaan College Of Engineering& Technology In 2014. Moinabad, R.R. Dist, J.N.T.U.H.