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Reducing the Fault Current and Over Voltages in a Distributed System with DG Units Through SFCL

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Abstract**: Electricity is the driving force behind the industry and subsequently economy. The introduction of DG into a distribution network may bring lots of advantages, such as emergency backup and peak shaving. The presence of these sources will lead the electricity generation from many small resources is becoming one of the major systems in distribution generation to feed electrical loads. The effect of fault current and induced over voltages under abnormal conditions must be taken into account seriously. The effect of fault current can be limited by applying an active superconducting fault current limiter (SFCL). The active SFCL is composed of an air core of super conducting transformer and a pulse width modulator PWM) converter. The magnetic field in the air core can be controlled by adjusting the converters output current and the active SFCL'S equivalent impedance can be regulated for current limitation and overvoltage suppression. During the study process in view of the changes in the locations of the DG units connected to the system, the DG unit's injection capacities and the fault positions, the active SFCL'S current limiting and overvoltage suppressing characteristics are simulated in MATLAB. The simulation results show the active SFCL can play an important role to prevent the fault current and overvoltage, and it can contribute to avoiding damage on the relevant distribution equipment and improve the systems safety and reliability.**

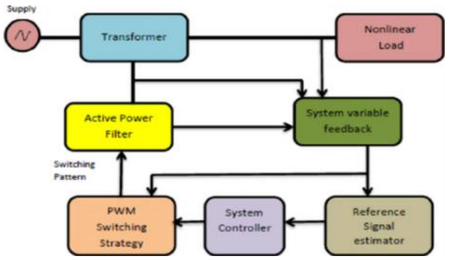
Keywords**: SFCL, Active Filters, Types of FCL'S, Principle of SFCL.**

1. Introduction

Due to increased consumption demand and high cost of natural gas and oil, Distributed Generation, which generates electricity from many small energy sources, is becoming one of main components in distribution systems to feed electrical loads. The introduction of DG into a distribution network may bring lots of advantages, such as emergency backup and peak shaving. However, the presence of these sources will lead the distribution network to lose its radial nature, and the fault current level will increase. Besides, when a single-phase grounded fault happens in a distribution system with isolated neutral, over voltages will be induced on the other two health phases, and in consideration of the installation of multiple DG units, the impacts of the induced over voltages on the distribution network's insulation stability and operation safety should be taken into account seriously. Aiming at the mentioned technical problems, applying superconducting fault current limiter (SFCL) may be a feasible solution.

A. Active Filters

Active Filters are commonly used for providing harmonic compensation to a system by controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power or voltage control at high voltage distribution level. These functions may be combined in a single circuit to achieve the various functions mentioned above or in separate active filters which can attack each aspect individually.



B. Types of FCL'S

The concept of using the superconductors to carry electric power and to limit peak currents has been around since the discovery of superconductors and the realization that they possess highly non-linear properties. More specifically, the current limiting behavior depends on their nonlinear response to temperature, current and magnetic field variations. Increasing any of these three parameters can cause a transition between the superconducting and the normal conducting regime. The current increase can cause a section of superconductor to become so resistive that the heat generated cannot be removed locally. This excess heat is transferred along the conductor, causing the temperature of adjacent sections to increase. The combined current and temperature can cause these regions to become normal and also generate heat. The term "quench" is commonly used to describe the propagation of the normal zone through a superconductor. Once initiated, the quench process is often rapid and uncontrolled.

Superconducting fault current limiter: Superconductors offer a way to break through system design constraints by presenting impedance to the electrical system that varies depending on operating conditions. Superconducting fault current limiters normally operate with low impedance and are "invisible" components in the electrical system. In the event of a fault, the limiter inserts impedance into the circuit and limits the fault current with current limiters, the utility can provide low impedance; stiff system with a low fault-current level SFCL can be divided into three types.

1. Resistive type SFCL
2. Inductive type SFCL
3. Solid state fault current limiter
4. Shielded-core SFCL
5. Saturable core SFCL

2. Structure and Principle of the Active SFCL

The circuit structure of the single-phase voltage compensation type active SFCL, which is composed of an air-core superconducting transformer and a voltage type PWM converter. Ls1, Ls2 are the self-inductance of two super conducting windings, and Ms is the mutual inductance. Z1 is the circuit impedance and Z2 is the load impedance. Ld and Cd are used for filtering high order harmonics caused by the converter. Since the voltage-type converter's capability of controlling power exchange is implemented by regulating the voltage of AC side, the converter can be thought as a controlled voltage source Up. By neglecting the losses of the transformer, the active SFCL's equivalent circuit is shown.

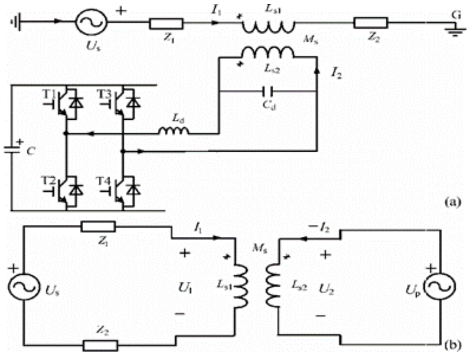


Fig. 1. Structure of SFCL

In normal (no fault) state, the injected current (I2) in the secondary winding of the transformer will be controlled to keep a certain value, where the magnetic field in the air-core can be compensated to zero, so the active SFCL will have no influence on the main circuit.

When the fault is detected, the injected current will be timely adjusted in amplitude or phase angle, so as to control the superconducting transformer's primary voltage which is in series with the main circuit, and further the fault current can be suppressed to some extent. Below, the suggested SFCL's specific regulating mode is explained. In normal state, the two equations can be achieved.

$$U_s = I_1 (Z_1+Z_2) + j\omega L_{s1} - j\omega M_s I_2 \quad (1)$$

$$U_p = j\omega M_S I_1 - j\omega L_{s2} I_2 \quad (2)$$

According to the difference in the regulating objectives of I2, there are three operation modes:

1) Making I2 remain the original state, and the limiting impedance.
2) $Z_{SFCL\,1} = Z_2 (j\omega L_{s1}) / (Z_1 + Z_2 + j\omega L_{s1})$.
3) Controlling I2 to zero, and $Z_{SFCL\,2} = j\omega L_{s1}$.
4) Regulating the phase angle of I2 to make the angle difference between U s and jωMs I2 be 180. By setting $Z_{SFCL\,3} = Cz1/(1-c) + j\omega L_{s1}/(1-c)$.

The air-core superconducting transformer has many merits, such as absence of iron losses and magnetic saturation, and it has more possibility of reduction in size, weight and harmonic than the conventional iron-core superconducting transformer. Compared to the iron-core, the air-core can be more suitable for functioning as a shunt reactor because of the large magnetizing current, and it can also be applied in an inductive pulsed power supply to decrease energy loss for larger pulsed current and higher energy transfer efficiency.

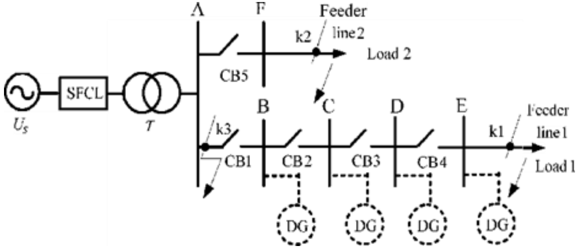


Fig. 2. Applying the SFCL into a Distribution Network with DG

3. Simulation block diagram and results

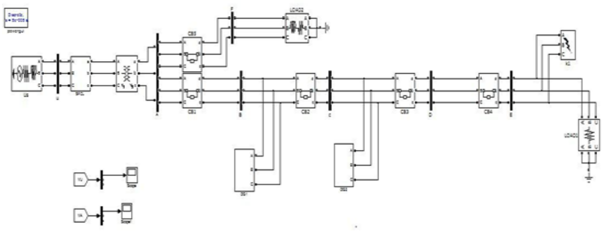


Fig. 3. Circuit diagram with SFCL1

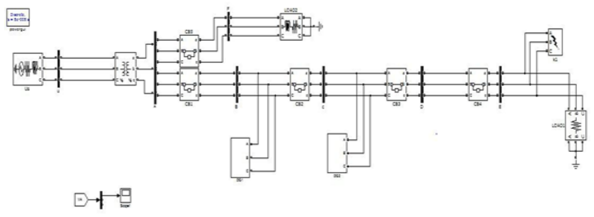


Fig. 4. Circuit diagram without SFCL1

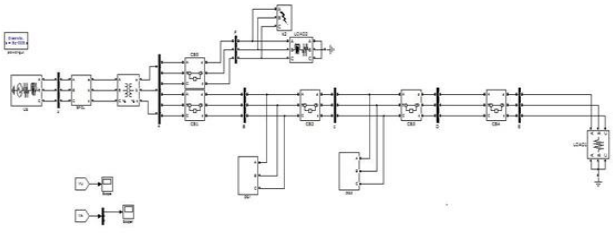


Fig. 5. Circuit diagram with SFCL2

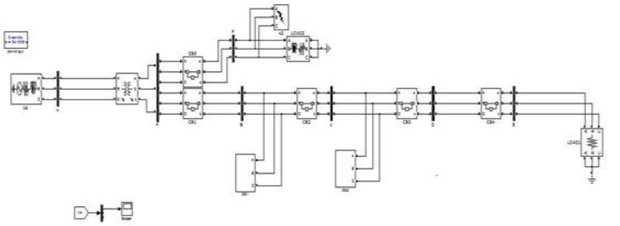


Fig. 6. Circuit diagram without SFCL2

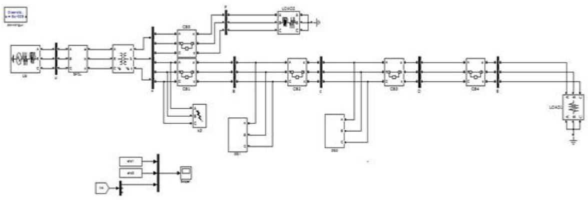


Fig. 7. Circuit diagram with SFCL3

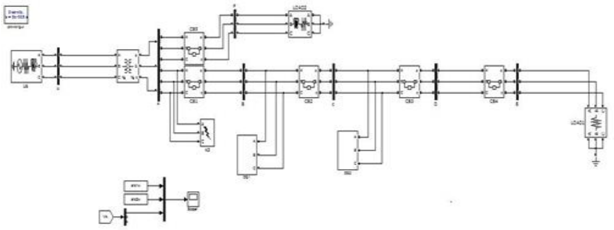


Fig. 8. Circuit diagram without SFCL3

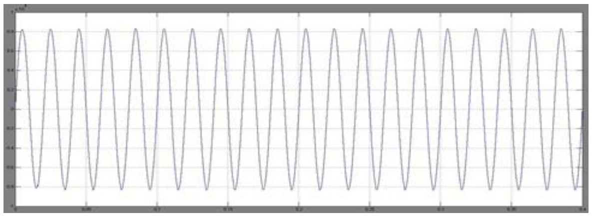


Fig. 9. Current limiting waveform at point K1 using SFCL

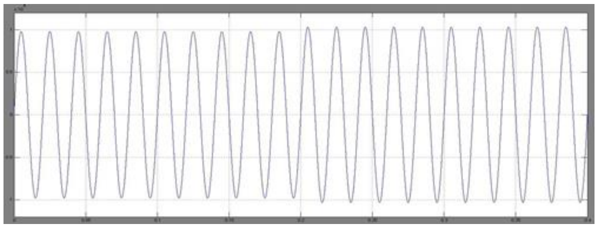


Fig. 10. Fault current waveform at point K1 without using SFCL

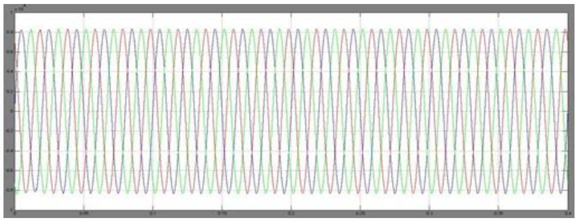


Fig. 11. Current limiting waveform at point K2 using SFCL

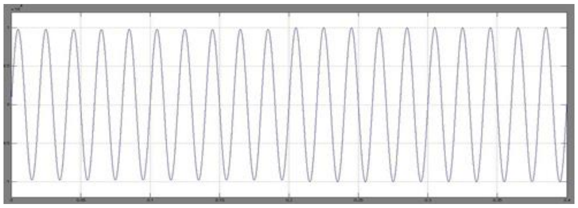


Fig. 12. Fault current waveform at point K2 without using SFCL

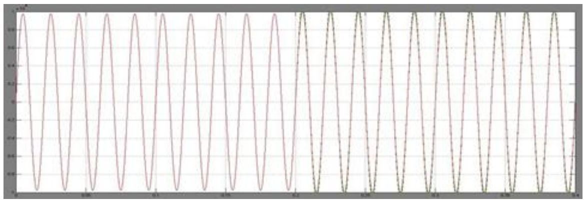


Fig. 13. Current limiting waveform at point K3 using SFCL

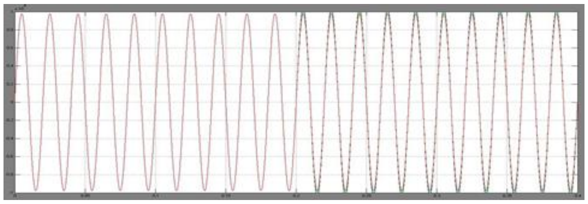


Fig. 14. Fault current waveform at point K3 without using SFCL

4. Conclusion

In this paper, the application of the active SFCL into in a power distribution network with DG units is investigated. For the power frequency overvoltage caused by a single-phase grounded fault, the active SFCL can help to reduce the overvoltage's amplitude and avoid damaging the relevant distribution equipment. The active SFCL can as well suppress the short-circuit current induced by a three-phase grounded fault effectively, and the power system's safety and reliability can be improved. Moreover, along with the decrease of the distance between the fault location and the SFCL's installation position, the current-limiting performance will increase.

In recently years, more and more dispersed energy sources, such as wind power and photovoltaic solar power, are installed into distribution systems. Therefore, the study of a coordinated control method for the renewable energy sources and the SFCL becomes very meaningful, and it will be performed in future.

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