Fault Current and Overvoltage Limitation in a Distribution Network with Distributed Generation units Through Superconducting Fault Current Limiter

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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 distribution network to loss its radial nature and the fault current level will increase. The SFCL is composed of an air-core superconducting transformer and a PWM converter. The SFCL equivalent impedance can be regulated for current limitation and possible overvoltage suppression. The SFCL restraining the fault current and overvoltage, and it can be avoiding damage on the relevant distribution equipment and improve the system safety and reliability. The effects of SFCL studied through theoretical derivation and simulation.**

Keywords —Distributed generation, overvoltage, short circuit current and superconducting fault current limiter.

I. INTRODUCTION

Almost in every field of modern civilization there is the requirement of electrical energy which has resulted in a considerable increase of electrical power consumption. The introduction of distributed generation causes harmonics and voltage variation in a power system, the introduction of DG is larger, the short circuit current in a distribution system is expected to be increased more, which can bring about the excess of the cut-off capacity of the circuit breaker as well as the problem of fault current. For solving these problems superconducting fault current limiter has been introduced. It is an element, inter-metallic alloy or compound that will conduct electricity without offering resistance below a certain temperature. Under normal operation a fault current limiter inserts negligible impedance into the network. When a fault occurs the limiter's impedance rises rapidly reducing the current flowing through it.

In recent years, superconducting fault current limiter has become one of the forefront topics of current limiting technology in the world. Fault current limiters using high temperature superconductor offer a solution to controlling the fault current level on utility distribution and transmission networks. In highly interconnected and expanded power system, faults of increased magnitude start creeping frequently into the system, so we have to look for a system that can help to reduce these increased magnitudes of fault current. The current limiting behaviour depends on their non-linear response to temperature, current and magnetic variations. For the application of some type of SFCL into a distribution network with DG units, a few works have been carried out and their research scopes mainly focus on current limitation and protection coordination of protective devices. In this paper taking the SFCL as an evaluation object its effect on the fault current and overvoltage in a distribution system with multiple DG units are studied.

II. ANALYSIS OF SFCL

A. *Principle of SFCL*

Many approaches have been proposed to limit the fault current in the past which includes the use of circuit breaker with ultra-high fault current rating, high impedance transformer and current limiting fuses. Circuit breakers are expensive, cannot interrupts fault currents until the first current zero comes and also they have limited lifetime. The high impedance transformers with their high losses make the system inefficient. The fuses have a very low withstand able fault current and it has to be replaced manually. Fault current is any abnormal current that flows through a circuit during the electrical fault conditions.

For this purpose we have introduced the Superconducting Fault Current Limiter. During normal operation, the impedance of Super Conducting Fault Current Limiter is zero, thus the SFCL conducts without losses. In the event of fault condition, electric current rises above the critical value. Thus the superconductivity of current limiter shut down, resistance of current limiter rises instantly, and thus it limits the fault current. SFCL is a new power device to automatically limit the fault current to a safe level with the superconducting property. A superconductor is a material that can conduct electricity or transport the electrons from one atom to another. Superconductor is used because of sharp transition from zero resistance at normal currents to finite resistance at higher current densities.

B. *Circuit Structure of SFCL*

The circuit structure of single phase voltage compensation type SFCL is shown in Fig. 1(a), which is composed of air core superconducting transformer and voltage type PWM converter. L_{s1}, L_{s2} are the self inductances of two superconducting windings. M_s is the mutual inductance. Z_1 is the circuit impedance and Z_2 is the load impedance. L_d and C_d are used for filtering high order harmonics caused by converter.

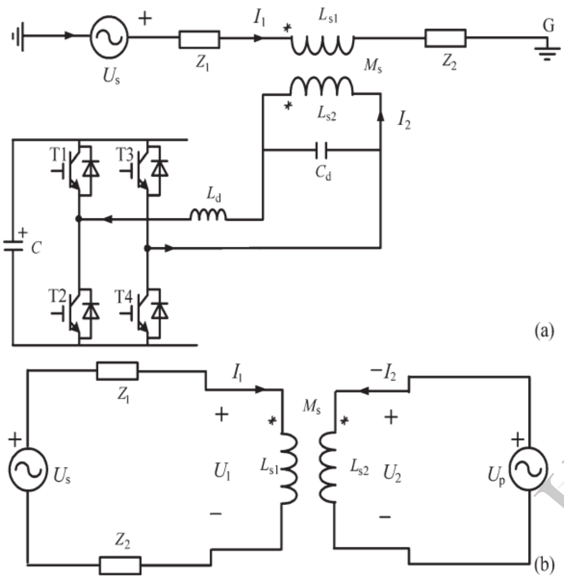

Fig. 1. Single phase voltage compensation type SFCL
(a) Circuit structure and (b) Equivalent circuit

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 U_p. By neglecting the losses of transformer, the SFCL's equivalent circuit is shown in Fig. 1(b).

In normal state, the injected current (I_2) in the secondary winding of the transformer will be controlled to keep a certain value, where 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. In the normal state, two equations can be achieved.

$$U_S = I_1(Z_1 + Z_2) + j\omega L_{S1} I_1 - j\omega M_S I_2 \qquad (1)$$

$$U_P = j\omega M_S I_1 - j\omega L_{S2} I_2 \qquad (2)$$

Therefore the impedance of SFCL is zero, and i_2 can be set as $i_2=U_sL_{s1}/L_{s2}/(z_1+z_2)(k)$, where k is the coupling coefficient and it can be shown as $k=M_s/L_{s1}/L_{s2}$. Under the fault condition Z_2 is shorted, the main circuit will rises from I_1 to I_2, and the primary voltage will increase to U_{1f}.

$$I_{1f} = \frac{(U_S + j\omega M_S I_2)}{(Z_1 + j\omega L_{S1})} \qquad (3)$$

$$U_{1f} = j\omega L_{S1} I_{1f} - j\omega M_S I_2 \qquad (4)$$

$$= \frac{(U_S j\omega L_{S1}) - I_2 Z_1 j\omega M_s}{(Z_1 + j\omega L_{S1})} \qquad (5)$$

III. APPLICATION OF SFCL

A. *System Model*

Superconducting fault current limiter offers ideal performance in electrical power system. SFCL have been interest for many years and offer an effective method for reducing the fault current. This is very attractive in a distribution system with distributed generated units. This paper describes the potential application of fault current limiter. It is shown that the SFCL, even with relatively small impedance are highly effective at reducing prospective fault current. The main applications of superconducting fault current limiter is in the main position, feeder position and in the bus-tie position.

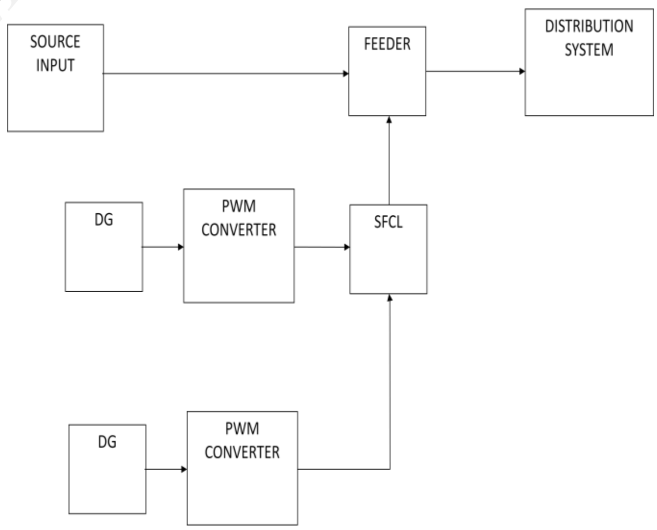

Fig. 2. Application of SFCL in distribution system.

The fault current limiter in the main position protects the entire bus. The fault current limiter in the feeder position protects an individual circuit on the bus. The two buses are tied, yet faulted bus receives the full fault current of only one transformer. The air-core superconducting transformer has many advantages such as magnetic saturation, absences of iron losses and also possibility of reduction in weight, size than the conventional iron-core transformers.

Superconducting fault current limiter consists of PWM converter and air core superconducting transformer. In this

simulation, fault current reduction can mainly depends on superconducting transformer. Transformers represent one of the oldest and most nature elements in the power transmission and distribution network.The air core superconducting power transformer has been investigated as the transformer having the function of the shunt reactor which is used to compensate the current in the transmission
system. However, since the air core superconducting transformer has no special paths for the magnetic flux, its winding has possibility of being exposed to a higher magnetic field than those of the iron core transformer. With the improvement of high temperature superconducting practical performance and application development of superconducting transformer have been progressed actively in the world.

IV. SIMULATION STUDY

For the purpose of reducing the fault current and overvoltage suppression, SFCL is created in MATLAB. The SFCL model was implemented by integrating simulink and simpowersystem block in MATLAB. Simulink and simpowersystem has number of advantages over its contemporary simulation software due to its open architecture, a powerful graphical user interface and versatile analysis and graphic tools. In this simulation, fault is injected in the source side. By using the superconducting fault current limiter fault current and overvoltage can be reduced. In compare to conventional technologies, SFCL provides faster response time, shorter recovery time and time adjustable response functions.

When a fault duty problem occurs, usually more than one breaker will be affected. Upgrade of these breakers has the disadvantage of not reducing the available fault current and overvoltage. For this purpose we have simulated SFCL in MATLAB, to reduce the fault current and overvoltage.

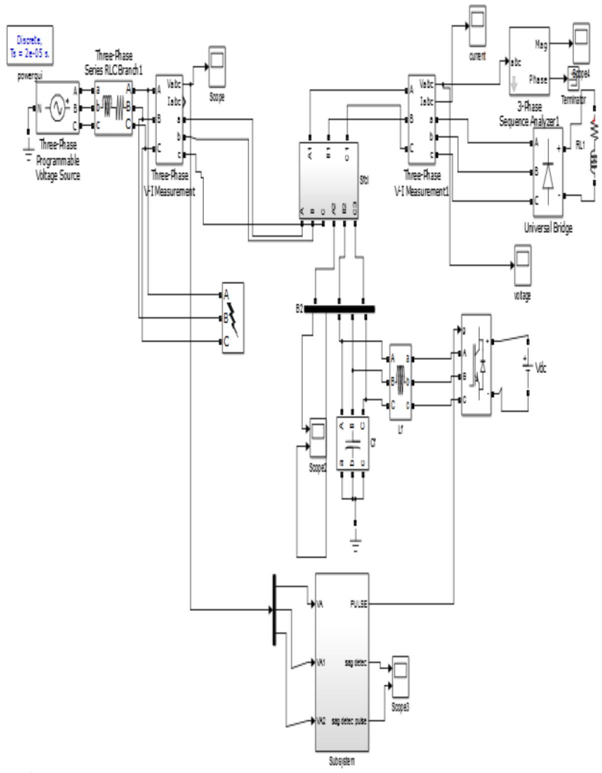

Fig. 3. Simulation diagram of distribution network with SFCL

In simulink diagram, the subsystem of SFCL mainly consists of linear transformer. By observing the voltage compensation type active SFCL's installation location, it can be found out that this device's current-limiting function should mainly reflect in suppressing the line current through the distribution transformer

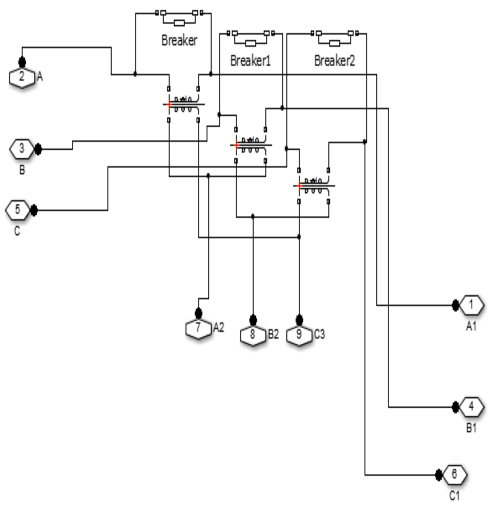

Fig. 4. Subsystem of SFCL

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Besides, as one component of fault current, natural response is an exponential decay DC wave, and its initial value has a direct relationship with fault angle. In other words, corresponding to different initial fault angles, the short-circuit current's peak amplitudes will be distinguishing. Through the application of the active SFCL, the influence of initial fault angle on the peak amplitude of the A-phase short-circuit current is analysed.

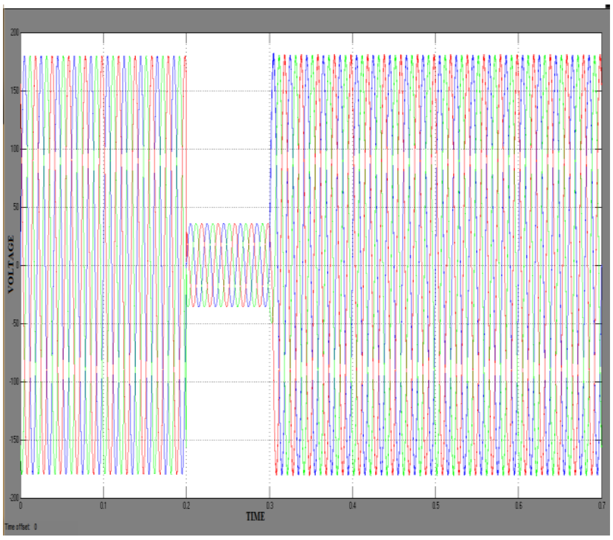

Fig. 5. Input voltage

For purpose of quantitatively evaluating the current limiting and overvoltage suppressing characteristics of the SFCL is created in MATLAB.

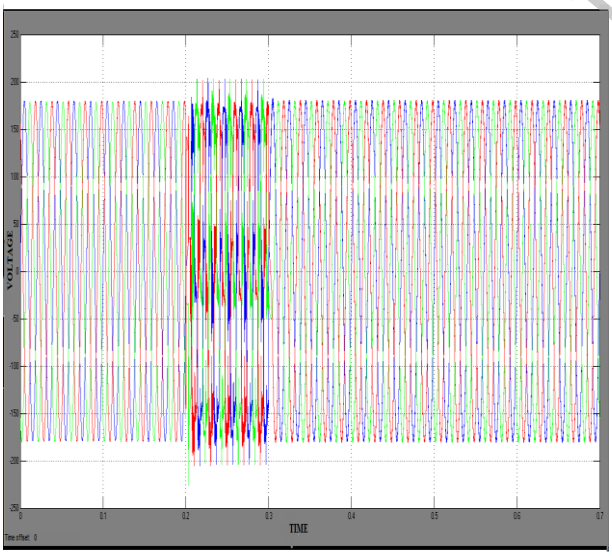

Fig. 6. Output voltage

Because of the injected fault current, there is some sag is introduced in the circuit. In this output voltage and current values, sag is compensated into normal values.

V. CONCLUSION

Electric power disruptions cause hundreds of millions of worth of economic loss of every year to the world's leading economies. With increase in generation, comes an increase in short circuit current in a transmission and distribution system during fault condition. Utilities usually predict how much fault current exists in the line and can forecast its increase over a period of time. This paper presented a reducing the fault current and overvoltage limitation in a distribution system by using superconducting fault current limiter. From the result of analysis fault current can be reduced and suppression of overvoltage can be done. The main objective of this is to reduce the ratio of overvoltage to normal voltage by using superconducting fault current limiter. Therefore, the study of coordinated control method for the renewable energy sources and the SFCL becomes very meaningful, and it will be performed.

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