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The Fault Level Reduction in Distribution System Using an Active Type SFCL

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Abstract- The electricity generation from many small resources is becoming one of the major systems in distribution generation systems 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 type superconducting fault current limiter (SFCL), the active SFCL is composed of an air-core superconducting transformer and a PWM converter. The magnetic field in the air-core can be controlled by adjusting the converters output current, and then the active SFCLs equivalent impedance can be regulated for current limitation and possible overvoltage suppression. During the study process, in view of the changes in the locations of the DG units connected to the system, the DG units injection capacities and the fault positions, the active SFCLs current-limiting and overvoltage suppressing characteristics are both simulated in MATLAB. The simulation results show that the active SFCL can play an important role in restraining the fault current and overvoltage, and it can contribute to avoiding damage on the relevant distribution equipment and improve the systems safety and reliability.

Index Terms- Distribution Generation, power quality (PQ), Active type SFCL.

I. INTRODUCTION

Demand of energy is increasing day by day. To fulfill this demand, distributed generation (DG) units are integrated with conventional grid. This integration not only effect grid planning but also impacts on operation of distribution grid. This penetration causes increase in fault current level. With the increasing of short-circuit current of the power grid, by use of series reactor to limit short-circuit current is feasible, but the introduction of series reactor could change the transient recovery voltage and have effect on the circuit breakers interrupting performance [9]. To mitigate this increase in fault level, Superconducting fault current limiter (SFCL) of resistive type is introduced in a system. SFCL not only minimize the fault current level but also improve the voltage profile, harmonics and transient stability of a system in case of different faults [6]. Based on the considerations in creating a smart grid roadmap, an integrated application of renewable energy sources and superconducting power devices may bring more positive effects. Since the active SFCL has higher controllability and flexibility than a common resistive- or inductive-type SFCL, its application may give better results [3]. The three-phase voltage compensation type active superconducting fault current limiter (SFCL) is composed of three air-core superconducting transformers and a three-phase four-wire PWM converter. The primary winding of the air-core superconducting transformer is in series with AC main circuit, and the second winding is connected with the PWM converter. The electromagnetic condition in the transformer can be changed by the compensating current offered by the PWM converter. In addition, it can compensate the reactive power and complement the active power that the non-linear load requires by controlling VSI's output voltage or current and thus, perform the power conditioning operation, the demand side management and the uninterruptible power supply.

II. SFCL IN DISTRIBUTION SYSTEM

Fig. 1 shows proposed distribution system with distributed generators including affect of active type super conducting fault current limiter.

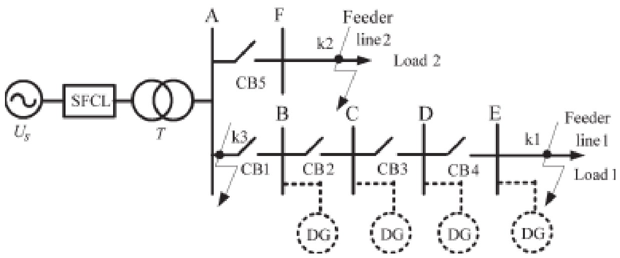


Fig 1: Single line diagram of SFCL in distribution system with distribution generation units

The Power system engineers and protection engineers have developed clear schemes to sense fault current under abnormal conditions and activate protecting devices that interrupt the over currents rapidly to avoid the damage of different equipments and sections in the power grid. Even the increasing levels of fault currents are exceeding the rupturing capacities of existing devices. The shunt inductive compensation is used in several sections of power distribution to limit fault currents but these devices will insert fixed reactance in the utility system. This causes continuous voltage drop, power loss and reduction in system efficiency. But the shunt reactors can improve the stability of the power system. The required performance of fault current limiters (FCLs) is that they have to give a rapid rise in impedance to limit the high fault currents.

With this great challenge, the power system protection engineers have developed the good fault current limiters. A significant advantage of proposed FCL technologies is the ability to remain virtually invisible to the grid under nominal operation, introducing negligible impedance in the power system until a fault event occurs. Ideally, once the limiting action is no longer needed, an FCL quickly returns to its nominal low impedance state.

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. While many FCL design concepts are being evaluated for commercial use, improvements in superconducting materials over the last 20 years have driven the technology to the forefront. Case in point, the discovery of high-temperature superconductivity (HTS) in 1986 drastically improved the potential for economic operation of many superconducting devices. This improvement is due to the ability of HTS materials to operate at temperatures around 70K instead of near 4K, which is required by conventional superconductors. The advantage is that the refrigeration overhead associated with operating at the higher temperature is about 20 times less costly in terms of both initial capital cost and O&M costs.

In consideration of the SFCL's effects on the induced overvoltage, the qualitative analysis is presented. In order to calculate the overvoltage's induced in the other two phases (phase B and phase C), the symmetrical component method and complex sequence networks can be used, and the coefficient of grounding G under this condition can be expressed as

$$G = -1.5m/(2+m) \pm j\sqrt{3/2}$$

where $m = X_0/X_1$, and X_0 is the distribution network's zero-sequence reactance, X1 is the positive-sequence reactance [16]. Further, the amplitudes of the B-phase and C-phase overvoltage's can be described as:

$$U_{BO} = U_{CO} = \sqrt{3}\left|\frac{\sqrt{G^2+G+1}}{G+2}\right| U_{AN}$$

Where U_{AN} is the phase-to-ground voltage's root mean square (RMS) under normal condition.

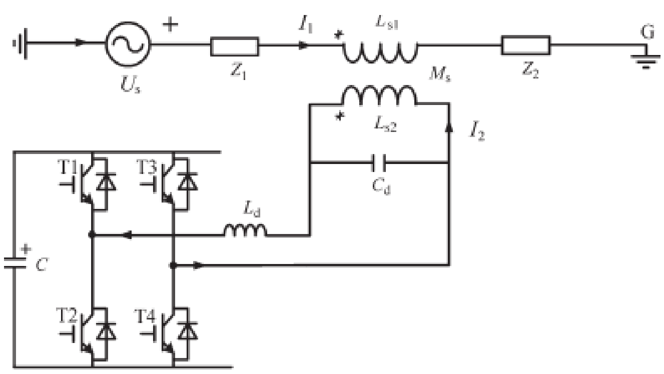


Fig.2 Single-Phase Voltage Compensation Type Active SFCL Circuit Structure

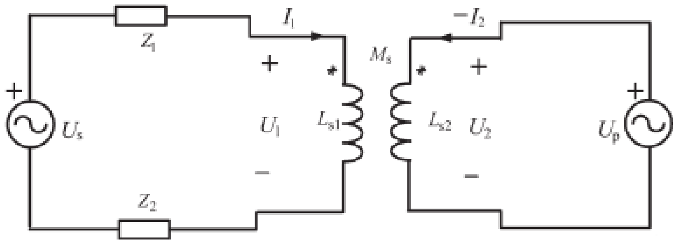


Fig.3 Single-Phase Voltage Compensation Type Active SFCL Equivalent Circuit

In normal (no fault) state, the injected current (I_2) 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.

$$\dot{U}_s = \dot{I}_1(Z_1+Z_2) + J\omega L_{s1}\dot{I}_1 - J\omega\dot{I}_2$$

$$\dot{U}_p = J\omega M_s\dot{I}_1 - J\omega L_{s2}\dot{I}_2$$

Controlling I_2 to make $J\omega M_s\dot{I}_1 - J\omega L_{s2}\dot{I}_2 = 0$ and the primary voltage U1 will be regulated to zero. Thereby, the equivalent limiting impedance Z_{SFCL} is zero $(Z_{SFCL} = U_1/I_1)$ and I_2 can be set as $\dot{I}_2 = \dot{U}_s\sqrt{L_{s1}/L_{S2}}/(Z_1+Z_2)K$, where k is the coupling coefficient and it can be shown as $K = M_s/\sqrt{L_{s1}/L_{s2}}$. Under fault condition (Z_2 is shorted), the main current will rise from I1 to I1f, and the primary voltage will increase to U_{1f}.

$$\dot{I}_{1f} = \frac{\dot{U}_s + j\omega M_s\dot{I}_2}{Z_1 + j\omega L_{s1}}$$

$$\dot{U}_{1f} = j\omega L_{s1}\dot{I}_{1f} - j\omega M_s\dot{I}_2 = \frac{\dot{U}_s(j\omega L_{s1}) - \dot{I}_2 Z_1(j\omega M_s)}{Z_1 + j\omega L_{s1}}$$

The current-limiting impedance ZSFCL can be controlled in:

$$Z_{SFCL} = \frac{\dot{U}_{1f}}{\dot{I}_{1f}} = j\omega L_{s1} - \frac{j\omega M_s\dot{I}_2\,(Z_1 + j\omega L_{s1})}{\dot{U}_s + j\omega M_s\dot{I}_A}$$

According to the difference in the regulating objectives of *I*2, there are three operation modes:

1) Making I2 remain the original state, and the limiting impedance

$$Z_{SFCL-1} = Z_2(j\omega L_{s1})/(Z_1 + Z_2 + j\omega L_{s1})$$

2) Controlling I_2 to zero, and $Z_{SFCL-2} = j\omega L_{s1}$

3) Regulating the phase angle of I_2 to make the angle difference between $\dot{U}_s$ and $j\omega M_s\dot{I}_2$ be 180◦. By setting $j\omega M_s\dot{I}_2 = -c\dot{U}_s$ and

$$Z_{SFCL-3} = cZ_1/(1-c) + j\omega L_{s1}/(1-c)$$

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 [11],

[12]. Compared to the iron-core, the air-core can be more suitable for functioning as a shunt reactor because of the large magnetizing current [13], 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 [14], [15]. There is no existence of transformer saturation in the air-core, and using it can ensure the linearity of Z_{SFCL} well.

III. SIMULATION RESULTS

The proposed distribution system with DGs with and without active SFCL is simulated using MATLAB/SIMULINK. First the distribution system is studied under no fault conditions and then it is studied under single line to ground fault from unsymmetrical nature and triple line to ground fault from symmetrical nature with and without active SFCL. The fault currents at different buses are reduced with the use of active type SFCL in the distribution generation systems.

SIMULATION PARAMETER

Parameters used for SFCL

Parameter	Value
Primary Inductance	50mh
Secondary Inductance	30mH
Mutual Inductance	32.9mH
Inductance(L_d)	120mH
Capacitance(C_d)	350µF

Parameters Used For Distribution Transformer

Parameter	Value
Rated Capacity	5000KVA
Transformation Ratio	35KV/10.5KV

Parameters Used For Feeder Line

Parameter	Value
Line Length	L_{AD}=5KM, L_{AB}=3KM, L_{AC}=27KM
Line Parameter	$(0.259+j0.093)\Omega/KM$

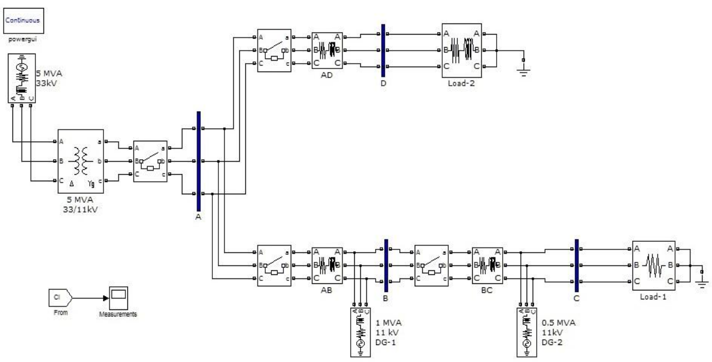
Parameters Used For Distrbution Generation Units

Parameter	Value
Distribution Generation Unit-1	1 MVA,11 KV
Distribution Generation Unit-2	0.5 MVA,11 KV

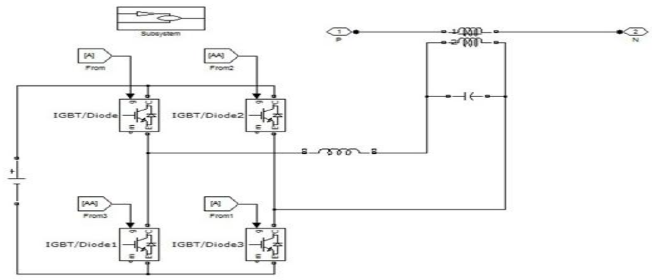
Parameters Used For Power Load

Parameter	Value
Load-1	50Ω
Load-2	(10+j12)Ω

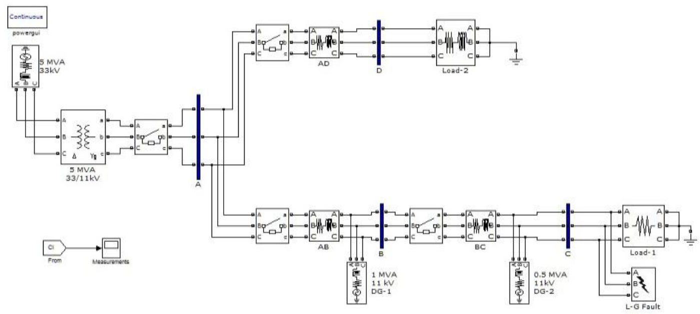
A. Proposed Simulation Diagram of Distribution System with Distribution Generation Units.



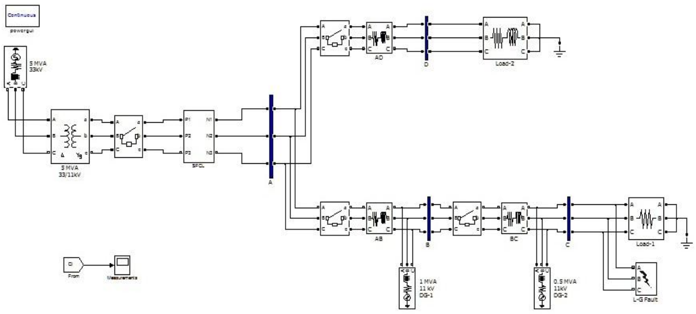
B. Proposed Simulation Diagram of single phase Active-Type SFCL



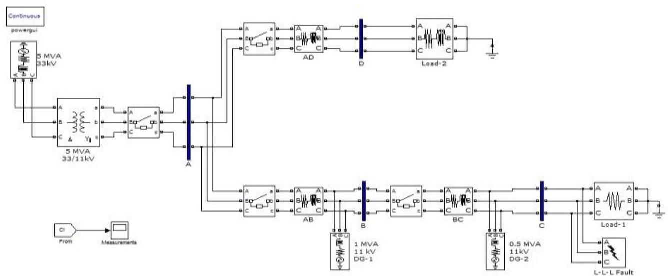
C. **Proposed Simulation Diagram of Distribution System with Distribution Generation Units at L-G Fault**



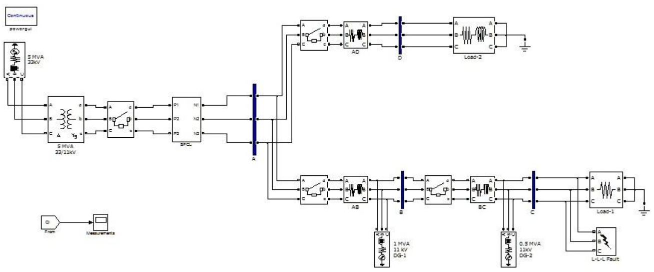
D. **Proposed Simulation Diagram of Active-Type SFCL Interconnected Distribution System with Distribution Generation Units at L-G Fault**



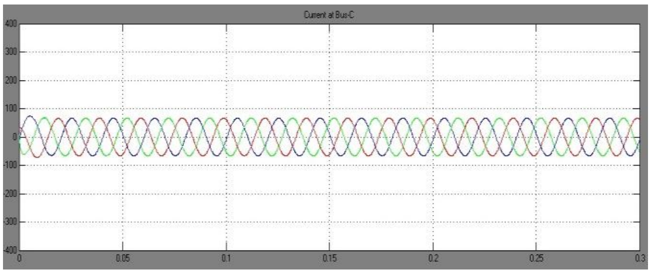
E. **Proposed Simulation Diagram of Distribution System with Distribution Generation Units at L-L-L Fault**



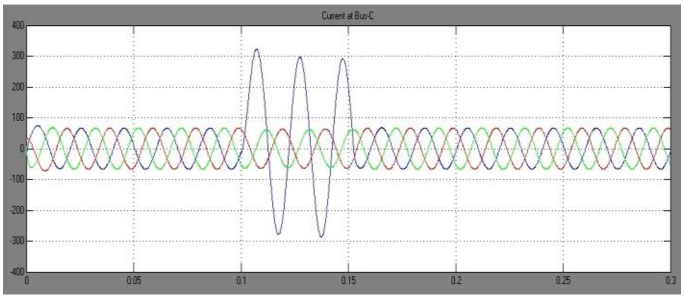
F. **Proposed Simulation Diagram of Active-Type SFCL Interconnected Distribution System with Distribution Generation Units at L-L-L Fault**



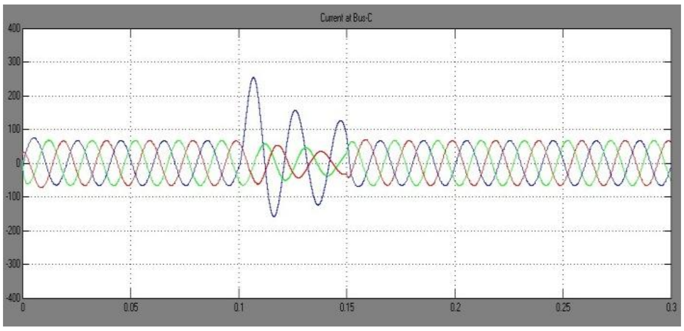
Distribution system with distribution generation units at no fault condition at bus C



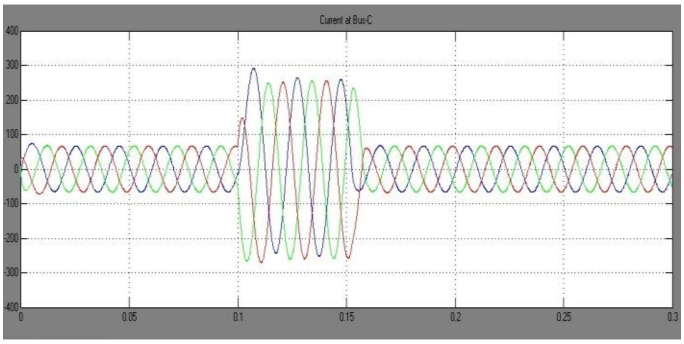
Distribution system with distribution generation units at L-G fault condition at bus C



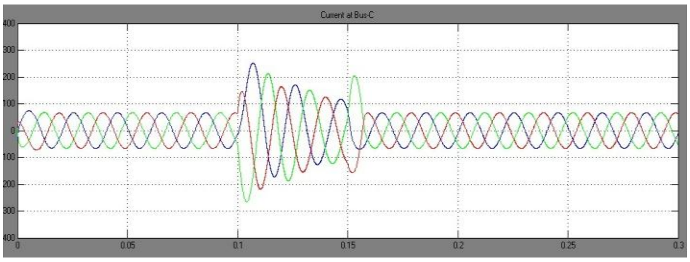
Distribution system with distribution generation units at L-G fault condition at bus C with SFCL



Distribution system with distribution generation units at L-L-L fault condition at bus C



Distribution system with distribution generation units at L-L-L fault condition at bus C with SFCL



IV. CONCLUSION

The effect of the active superconducting fault current limiter in a distribution generation network with DG units is scrutinized. The active SFCL can reduce the fault MVA level and short circuit current under abnormal conditions such as three phase ground fault, double phase to ground and single phase to ground faults. And the use of active SFCL into a distribution generation network with DG units improved the system safety and reliability and also stability. It is observed that the performance of active SFCL is better if the distance between installation of SFCL and the location of fault reduced. In present days, the use of electrical power generated by renewable energy sources is rapidly increasing. So the active type super conducting fault current limiter will give better coordinator control for renewable energy sources in distribution generation network. The suppression in fault level is verified MATLAB/SIMULINK software.

RESULT ANALYSIS

TYPE OF FAULT	INSTANT	FAULT-CURRENT LEVEL	
		WITHOUT SFCL	WITH SFCL
LINE TO LINE FAULT	AT 1ST INSTANT	330AMP	250AMP
	AT 2ND INSTANT	300AMP	150AMP
	AT 3RD INSTANT	290AMP	130AMP
TRIPLE LINE FAULT	AT 1ST INSTANT	330AMP	250AMP
	AT 2ND INSTANT	300AMP	150AMP
	AT 3RD INSTANT	290AMP	130AMP

Whenever the fault occurs in distribution system with distribution generation units the fault current level is 330amps at 1st instant, 300amps & 290amps at 2nd & 3rd instants simultaneously. By inter-connecting active-type SFCL to distribution system with distribution generation units the fault current is dropped to 250amps at 1st instant, 150amps & 130amps at 2nd & 3rd instants simultaneously.

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