Enhancement of Fault Current and Overvoltage by Active Type superconducting fault current limiter (SFCL) in Renewable Distributed Generation (DG)

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Abstract – The Active Superconducting Current Controller (ASCC) is a new type of Fault Current Limiters which can limit the fault current in different modes and also has the particular abilities of compensating active and reactive power for AC main circuit in the normal state. The use of the ASCC disturbs the operation of Over Current Relays (OCR) used in the distribution system. In consideration that applying superconducting fault current limiter (SFCL) may be a feasible solution, in this paper, the effects of a voltage compensation type active SFCL on them are studied through theoretical derivation and simulation. 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. 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 [10]. 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. In this work a resistive superconducting fault current limiter designed.

Index Terms—Distributed generation (DG), distribution system, overvoltage, short-circuit current, voltage compensation type active superconducting fault current limiter (SFCL)

1. INTRODUCTION

In recent years, with the great development of interconnected power grid, the power network structure becomes increasingly complicated, and the system short circuit capacity and short circuit current have reached a new level which could exceed the allowable currents of the circuit breakers. The increase of the fault current has imposed a severe burden on the related machinery in the grid, and the stability of the power system is also damaged. The fault current limiters (FCL) are regarded as the suitable solution to solve excessive fault current problems. [1] Active superconducting fault current limiter (ASFCL) voltage compensation type is a novel topology of FCL. This type SFCL not only preserves the merits of bridge type SFCL such as the automatic switch to the current limiting mode and without the quench of the superconductor, but also has the particular abilities of controlling the steady fault current and compensating active and reactive power for AC main circuit in the normal state. Fig. 1 shows the circuit structure of the three phase active SFCL, which is consisting of three air-core superconducting transformers and a three-phase voltage source converter.

As a result, faults in power networks incur large short-circuit currents flowing in the network and in some cases may exceed the ratings of existing circuit breakers (CB) and damage system equipment The problems of inadequate CB short-circuit ratings have become more serious than before since in many locations, the highest rating of the CB available in the market has been used. To deal with the problem, fault current limiters (FCLs) are often used in the situations where insufficient fault current interrupting capability exists [1]. Less expensive solutions such as current limiting reactors may have unwanted side effects, Such as increasing system losses, voltage regulation problems or possibly could compromise system stability. Smart grid is a modern electricity system. It uses sensors, monitoring, communications, automation and computers to improve the edibility, security, reliability, efficiency, and safety of the electricity system. Renewable energy technologies such as photovoltaic, solar thermal electricity, and wind turbine power are environmentally beneficial sources of electric power generation [3]. The integration of renewable energy sources into electric power distribution systems can provide additional economic benefits because of a reduction in the losses associated with transmission and distribution lines.

In this work a SFCL model is designed. SFCL is an innovative fault current limiter. It works on the principle of Superconducting Property. It is inactive e under normal condition. It is in active under fault condition; it inserts some resistance into the line to limit the fault current. It suppresses the fault current within first half cycle only. It operates better than Circuit breakers, Relays, because the Circuit breakers take minimum 2-3 cycles before they getting activated. The effect of SFCL on micro grid fault current observed. The optimal place to SFCL is determined [10].

We have proposed voltage compensation type active SFCL in previous work [7], and analyzed the active SFCL's control strategy and its influence on relay protection [8, 9]. In addition, an 800 V/30 a laboratory prototype was made, and its working performances were confirmed well [10]. In this paper, taking the active SFCL as an evaluation object, its effects on the fault current and overvoltage in a distribution network with multiple DG units are studied.

2. THEORETICAL ANALYSIS

2.1. Structure and Principle of the Active SFCL

As shown in Fig. 1(a), it denotes 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 superconducting windings, and Ms is the mutual inductance.Z1is the circuit impedance andZ2is 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 in Fig. 1(b).
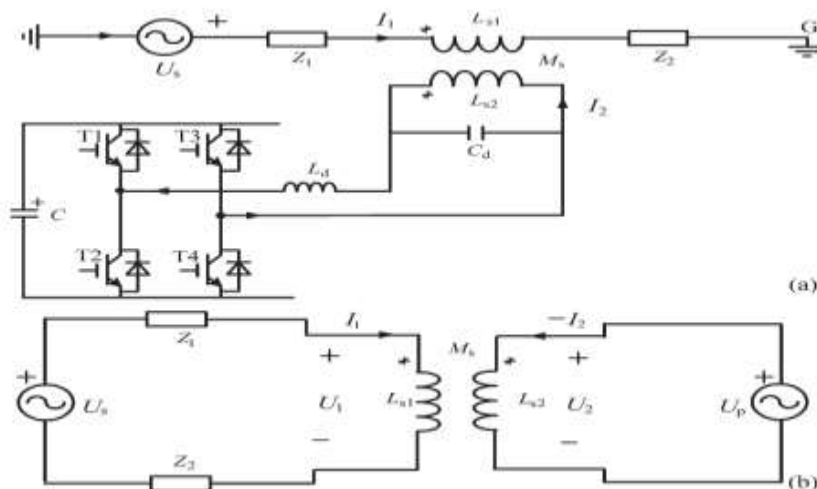

Fig. 1. Single-phase voltage compensation type active SFCL. (a) Circuit structure and (b) equivalent circuit.

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.

$$\dot{U}_s = \dot{I}_1(Z_1 + Z_2) + j\omega L_{s1}\dot{I}_1 - j\omega M_s\dot{I}_2 \tag{1}$$

$$\dot{U}_p = j\omega M_s\dot{I}_1 - j\omega L_{s2}\dot{I}_2. \tag{2}$$

Controlling I2 to make $j\omega L_{s1}\dot{I}_1 - j\omega Ms\,\dot{I}2=0$ and the primary voltage U1 will be regulated to zero. Thereby, the equivalent limiting impedance ZSFCL is zero (ZSFCL=U1/I1), and I2 can be set as $\dot{I}2 = \dot{U}2\sqrt{Ls1/Ls2}\,/(Z1+Z2)k$, where k is the coupling coefficient and it can be shown as k=Ms/$\sqrt{Ls1/Ls2}$.Under fault condition (Z2is shorted), the main current will rise from I1to I1f, and the primary voltage will increase to U1f.

$$\dot{I}_{1f} = \frac{(\dot{U}_s + j\omega M_s\dot{I}_2)}{(Z_1 + j\omega L_{s1})} \tag{3}$$

$$\dot{U}_{1f} = j\omega L_{s1}\dot{I}_{1f} - j\omega M_s\dot{I}_2$$

$$= \frac{\dot{U}_s(j\omega L_{s1}) - \dot{I}_2 Z_1(j\omega M_s)}{Z_1 + j\omega L_{s1}} \tag{4}$$

The current-limiting impedance ZSFCL can be controlled in:

$$Z_{SFCL} = \frac{\dot{U}_{1f}}{\dot{I}_{1f}} = j\omega L_{s1} - \frac{j\omega M_s \dot{I}_2 (Z_1 + j\omega L_{s1})}{\dot{U}_s + j\omega M_s \dot{I}_a}$$
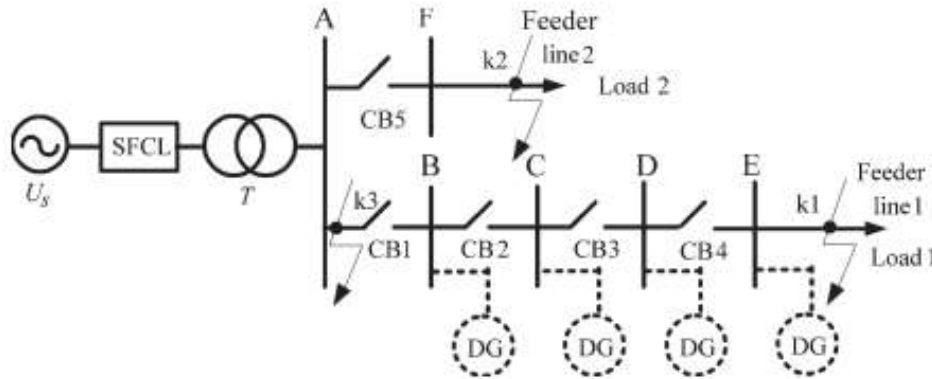
(5)

Fig. 2. Application of the active SFCL in a distribution system with DG units.

According to the difference in the regulating objectives of I2, there are three operation modes:
1) MakingI2 remain the original state, and the limiting impedanceZSFCL−1=Z2 (jωLs1)/(Z1+Z2+jωLs1).
2) ControllingI2to zero, andZSFCL−2=jωLs1.
3) Regulating the phase angle of I2 to make the angle difference between˙ Us and jωMs˙I2 be 180∘.Bysetting jωMs I2=−c˙Us, and ZSFCL−3=cZ1/(1−c)+jωLs1/(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 [9], [8]. Compared to the iron-core, the air-core can be more suitable for functioning as a shunt reactor because of the large magnetizing current [5], 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 [6], [7]. There is no existence of transformer saturation in the air-core, and using it can ensure the linearity of ZSFCL well.
2.2. Applying the SFCL into a Distribution Network with DG
As shown in Fig. 2, it indicates the application of the active SFCL in a distribution network with multiple DG units, and the buses B-E are the DG units' probable installation locations. When a single-phase grounded fault occurs in the feeder line 1 (phase A, k1 point), the SFCL's mode 1 can be automatically triggered, and the fault current's rising rate can be timely controlled. Along with the mode switching, its amplitude can be limited further. In consideration of the SFCL's effects on the induced overvoltage, the qualitative analysis is presented. In order to calculate the over voltages 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)±j√3/2, where m=X0/X1, and X0 is the distribution network's zero-sequencereactance,X1is the positive-sequence reactance [6]. Further, the amplitudes of the B-phase and C-phase over voltages can be described as:

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

(6)

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

3. SUPERCONDUCTING FAULT CURRENT LIMITER

Superconducting Fault Current Limiter (SFCL) is innovative electric equipment which has the capability to reduce the fault current level within the first cycle of fault current [1]. 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 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. Though once initiated the quench process is uncontrolled, the extent of the normal region and the temperature rise in the materials can be predicted.

4. MATLAB/SIMULINK RESULTS

For purpose of quantitatively evaluating the current-limiting and overvoltage-suppressing characteristics of the active SFCL, the distribution system with DG units and the SFCL for the other DG, it can be installed in an arbitrary position among the Buses C–E (named as DG2). To reduce the converter's design capacity, making the SFCL switch to the mode 2 after the fault is detected, and the detection method is based on measuring the main current's different components by Fast Fourier Transform (FFT) and harmonic analysis.
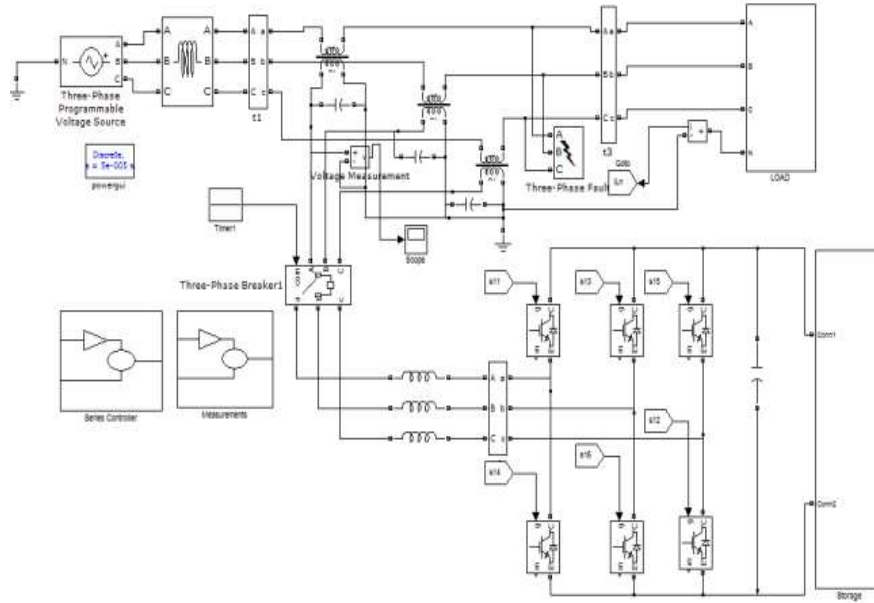
Case: 1 Without SFCL and with the active SFCL

Fig. 3. Matlab/Simulink model of three pahse the short-circuit occurs a k3 point. Without SFCL and with the active SFCL

Figure3 Shows Matlab/Simulink Model of Three Pahse the Short-Circuit Occurs A K3 Point. Without SFCL and With the Active SFCL
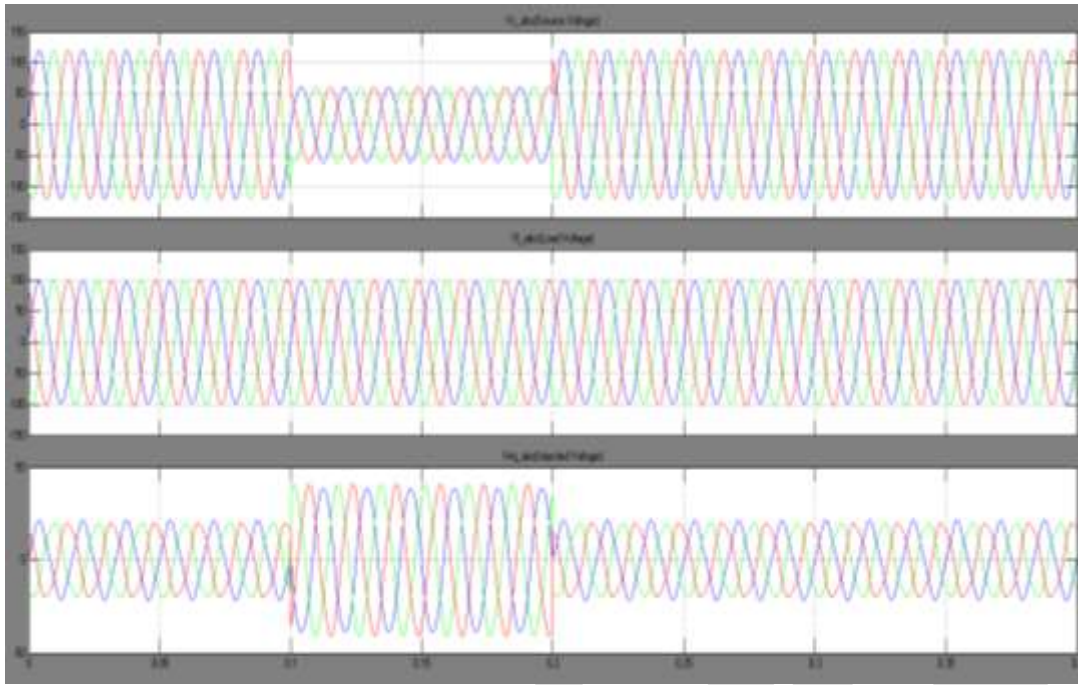
Fig. 4. Voltage waveforms when the three-phase short-circuit occurs a k3 point. Without SFCL and with the active SFCL

Figure4 shows the Voltage waveforms when the three-phase short-circuit occurs a k3 point. Without SFCL and with the active SFCL
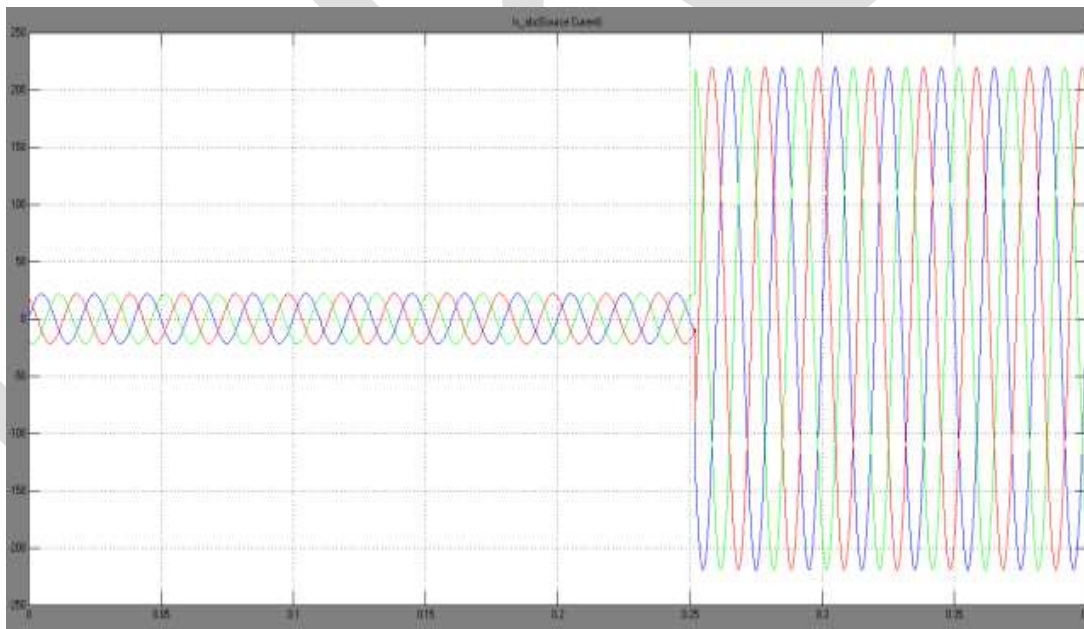

Fig. 5. Line current waveforms when the three-phase short-circuit occurs a k3 point.
Figure5 shows the Line current waveforms when the three-phase short-circuit occurs a k3 point
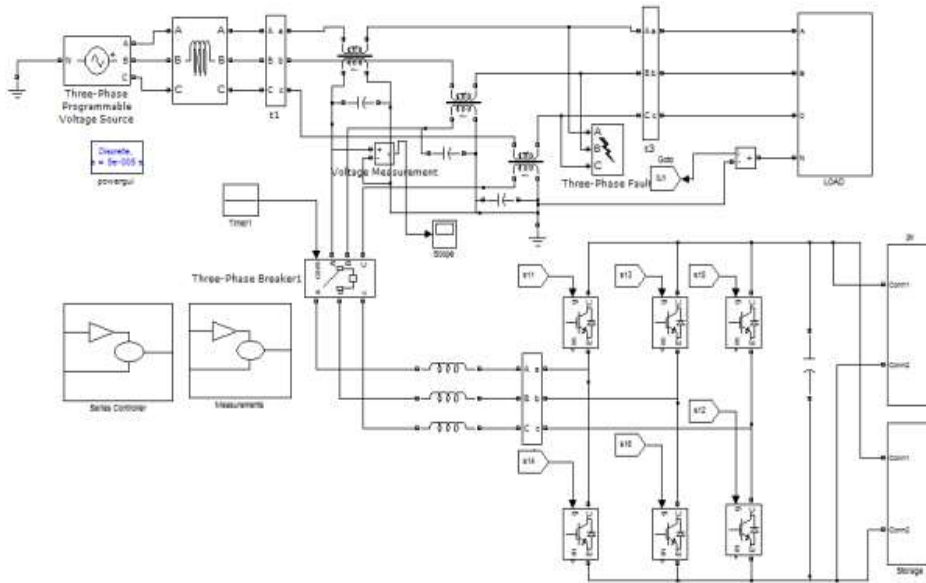Case: 2 Without SFCL and with the active SFCL with pv

Fig. 6. Matlab/Simulink model of three pahse the short-circuit occurs a k3 point. Without SFCL and with the active SFCL with PV.

Figure6 Shows Matlab/Simulink Model of Three Pahse the Short-Circuit Occurs A K3 Point. Without SFCL and With the Active SFCL with PV
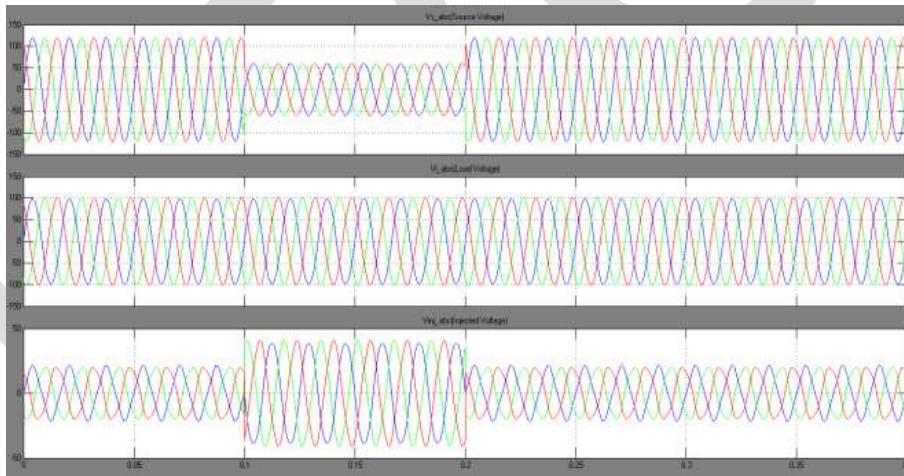

Fig. 7. Voltage waveforms when the three-phase short-circuit occurs a k3 point. Without SFCL and with the active SFCL with PV.

Figure7 shows the Voltage waveforms when the three-phase short-circuit occurs a k3 point. Without SFCL and with the active SFCL with PV.
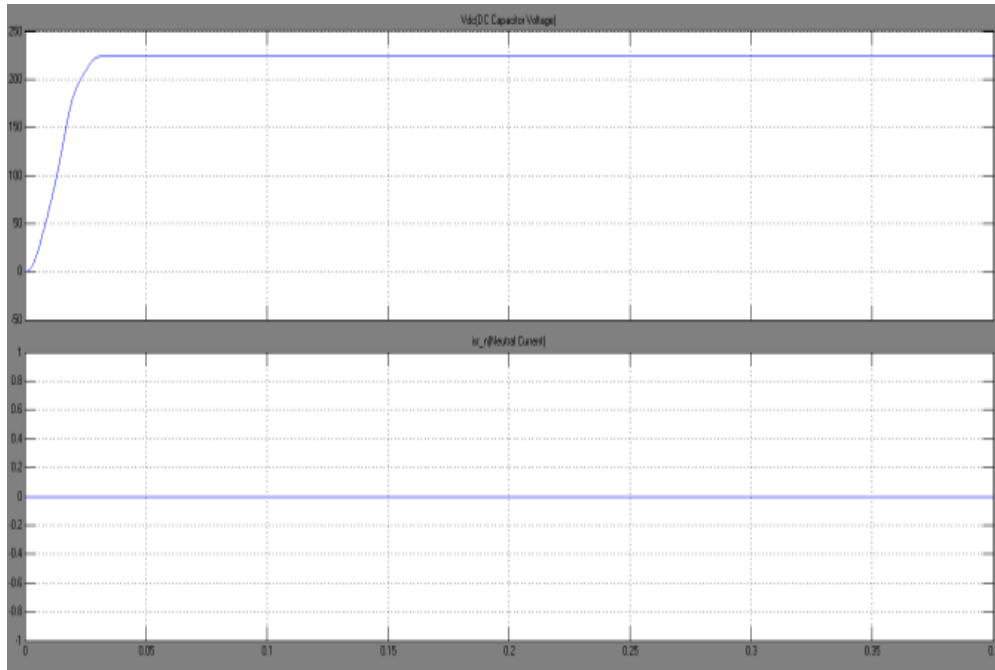
Fig. 8. Photovoltaic voltage

Figure8 shows Without SFCL and with the active SFCL with photovoltaic voltage.
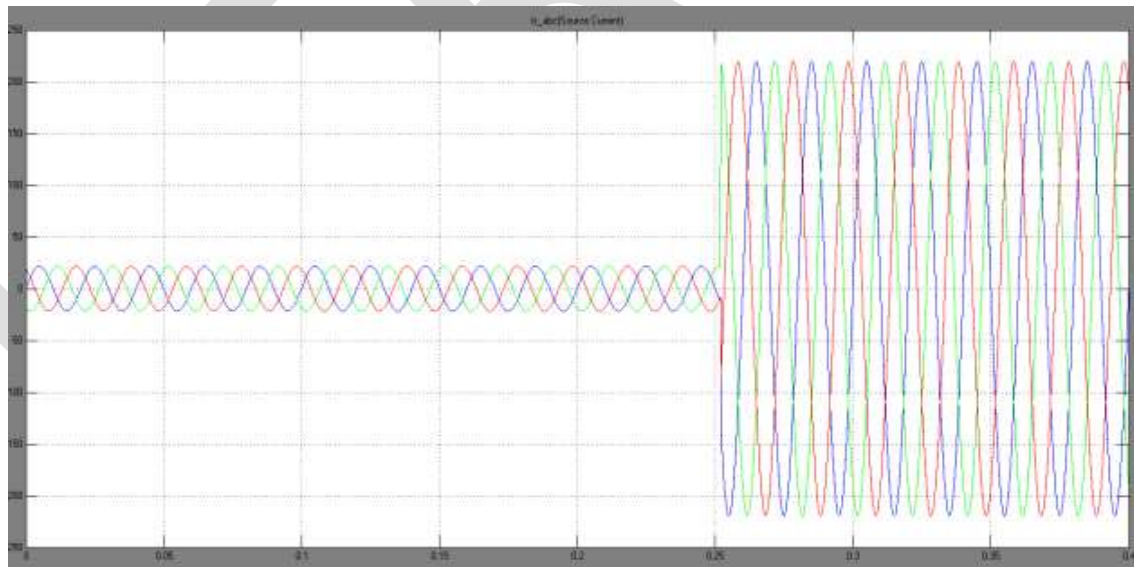

Fig. 9. Line current waveforms when the three-phase short-circuit occurs a k3 point with PV

Figure9 shows the Line current waveforms when the three-phase short-circuit occurs a k3 point with PV

5. 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. 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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