Reliability Enhancement by Using SFCL in A Distribution System with Distributed Generation Units

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Abstract :

The power distribution system with distributed generation (DG) units, its fault current and overvoltage under disturbance conditions ought to be taken into account. In consideration that applying superconducting fault current limiter (SFCL) may be a feasible arrangement, in this paper, the impacts of a voltage compensation typr active SFCL on them are contemplated through theoretical derivation and simulation. The active SFCL is made out 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 conceivable over voltage concealment. During the examination procedure, in perspective of the changes in the locations of the DG units associated with the framework, the DG units injection capacities and the fault positions, the active SFCLs current-limiting and over voltage suppressing characteristics are both simulated in MATLAB. The simulation comes about demonstrate that the active SFCL can play an undeniable part in restraining the fault current and overvoltage, and it can add to avoiding damage on the relevant distribution system with distributed generation and enhance the systems safety and reliability.

Key Words: Distributed generation (DG), Reliability, distribution system, overvoltage, short-circuit current, voltage compensation type active superconducting fault current limiter (SFCL).

I. INTRODUCTION

Because of expanded utilization request and high cost of natural gas and oil, distributed generation (DG), which produces power from numerous little vitality sources, is getting to be one of primary parts in distribution frameworks to sustain electrical burdens [1]– [3]. The presentation of DG into a distribution system may bring loads of preferences, for example, crisis reinforcement and pinnacle shaving. Be that as it may, the nearness of these sources will lead the distribution system to lose its outspread nature, and the fault current level will increment. Plus, when a solitary stage grounded fault occurs in a distribution framework with detached unbiased, over voltages will be initiated on the other two wellbeing stages, and in light of the establishment of numerous DG units, the effects of the prompted over voltages on the distribution system's protection stability and task security ought to be considered truly. Going for the said specialized issues, applying superconducting fault current limiter (SFCL) might be an attainable arrangement. For the use of some sort of SFCL into a distribution connect with DG units, a couple of works have been done, and their examination scopes for the most part center around current-confinement and change of assurance coordination of defensive gadgets [4]– [6]. In any case, with respect to utilizing a SFCL for smothering the actuated overvoltage, the investigation about it is generally less. In perspective of that the presentation of a SFCL can affect the coefficient of establishing, which is a noteworthy supporter of control the initiated overvoltage's plentifulness, the difference in the coefficient may expedite constructive outcomes controlling.

Over voltage. We have proposed a voltage pay write dynamic SFCL in past work [7], and examined the dynamic SFCL's control technique and its effect on hand-off insurance [8, 9]. Furthermore, a 800 V/30 A research center model was made, and its working exhibitions were affirmed well [10]. In this paper, taking the dynamic SFCL as an assessment protest, its consequences for the fault current and overvoltage in a distribution connect with numerous DG units are contemplated. In perspective of the adjustments in the areas of the DG units associated into the distribution framework, the DG units' infusion limits and the fault positions, the present restricting and overvoltage-smothering characteristics of the dynamic SFCL are researched in detail.

II. LITERATURE SURVEY

A. *Structure and Principle of the Active SFCL*

As appeared in Fig. 1(a), it means the circuit structure of the single-stage voltage pay write dynamic SFCL, which is made out of an air-core superconducting transformer and voltage-type PWM converter. Ls1, Ls2 are the self-inductance of two superconducting windings, and Ms is the common inductance. Z1 is the circuit impedance and Z2 is the heap impedance. Ld and Cd are utilized for sifting high request music caused by the converter. Since the voltage-type converter's ability of controlling power trade is actualized by managing the voltage of AC side, the converter can be thought as a controlled voltage source Up. By dismissing the misfortunes of the transformer, the dynamic SFCL's proportional circuit is appeared in Fig. 1(b).

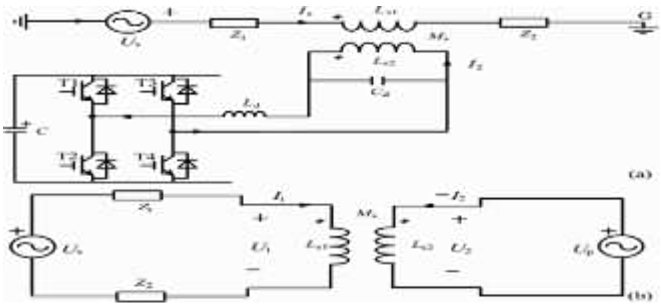

Fig. 1. Single-phase voltage compensation type active SFCL. (a) Circuit structure and (b) equivalent circuit.

In typical (no fault) express, the infused current (I2) in the secondary widing of the transformer will be controlled to keep a specific esteem, where the attractive field noticeable all around center can be remunerated to zero, so the dynamic SFCL will have no impact on the fundamental circuit. At the point when the fault is identified, the infused current will be opportune balanced in sufficiency or stage edge, in order to control the superconducting transformer's essential voltage which is in arrangement with the principle circuit, and further the fault current can be smothered to some degree. Underneath, the proposed SFCL's particular directing mode is clarified. In ordinary express, the two conditions can be accomplished.

$$\dot{U}_S = \dot{I}_1(Z_1 + Z_2) + j\omega L_{S1}\dot{I}_1 - j\omega M_S\dot{I}_2 \qquad (1)$$

$$\dot{U}_p = j\omega M_S\dot{I}_1 - j\omega L_{S2}\dot{I}_2. \qquad (2$$

Controlling I2 to make jωLs1 I˙1 − jωMs I˙2 = 0 and the essential voltage U1 will be managed to zero. Along these lines, the comparable restricting impedance ZSFCL is zero (ZSFCL = U1/I1), and I2 can be set as ˙ I2 = ˙Us_Ls1/Ls2/(Z1 + Z2)k, where k is the coupling coefficient and it can be appeared as k = Ms/√Ls1Ls2. Under fault condition (Z2 is shorted), the fundamental current will ascend from I1 to I1f , and the essential voltage will increment to U1f

$$I˙1f = (˙Us + j\omega Ms\, I˙_2) / (Z1 + j\omega Ls1) \qquad (3)$$

$$U1f = j\omega Ls1\, I˙1f - j\omega Ms\, I˙2$$
$$= ˙Us(j\omega Ls1) - I˙2Z1(j\omega Ms)/Z1 + j\omega Ls1. \qquad (4)$$

The current-limiting impedance ZSFCL can be controlled in:

$$ZSFCL = ˙U1f / ˙1f = j\omega Ls1 - j\omega Ms\, I˙2(Z1 + j\omega Ls1) / ˙Us + j\omega Ms\, I˙a. \ (5)$$

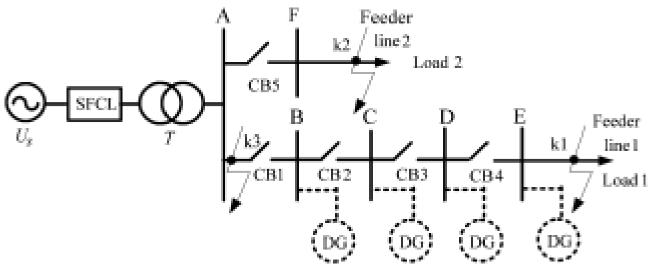

Fig.2: Application of the active SFCL in a distribution system with DG units.

As indicated by the distinction in the managing goals of I2, there are three activity modes:
1) Making I2 remain the first state, and the restricting impedance $Z_{SFCL-1} = Z_2(j\omega Ls1)/(Z_1 + Z_2 + j\omega Ls_1)$.
2) Controlling I2 to zero, and $Z_{SFCL-2} = j\omega Ls_1$.
3) Regulating the stage edge of I2 to have the edge effect amongst ˙Us and jωMs I˙2 be 180◦. By setting jωMs ˙ I2 = −c ˙Us, and ZSFCL−3 = cZ1/(1 − c) +jωLs1/(1 − c).

The air-core superconducting transformer has numerous benefits, for example, nonappearance of iron misfortunes and attractive immersion, and it has greater plausibility of diminishment in size, weight and consonant than the ordinary iron-center superconducting transformer [11], [12]. Contrasted with the iron-center, the air-center can be more reasonable for working as a shunt reactor in view of the vast polarizing current [13], and it can likewise be connected in an inductive beat power supply to diminish vitality misfortune for bigger beat present and higher vitality exchange effectiveness [14], [15].There is no presence of transformer immersion noticeable all around center, and utilizing it can guarantee the linearity of ZSFCL well.

B.***Applying the SFCL In to a Distribution Network With DG***

As appeared in Fig. 2, it shows the utilization of the dynamic SFCL in a distribution connect with numerous DG units, and the transports B-E are the DG units' plausible establishment areas. At the point when a solitary stage grounded fault happens in the feeder line 1 (stage A, k1 point), the SFCL's mode 1 can be naturally activated, and the fault current's rising rate can be convenient controlled. Alongside the mode exchanging, its plentifulness can be constrained further. In light of the SFCL's consequences for the initiated overvoltage, the subjective examination is exhibited. Keeping in mind the end goal to compute the over voltages prompted in the other two stages (stage B and stage C), the symmetrical part strategy and complex grouping systems can be utilized, and the coefficient of establishing G under this condition can be communicated as G = −1.5m/(2 + m) ± j√3/2, where m =X0/X1, and X0 is the distribution system's zero-arrangement reactance, X1 is the positive-succession reactance [16]. Further, the amplitudes of the B-stage and C-stage over voltages can be depicted as:

$$U_{BO} = U_{CO} = \sqrt{3}(\sqrt{G_2} + G + 1/G + 2)U_{AN} \quad (6)$$

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

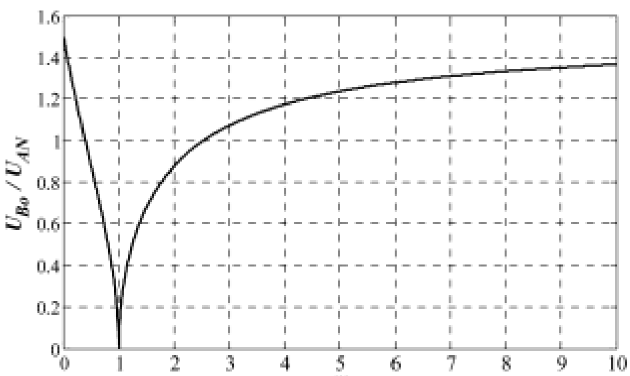

Fig. 3. Relationship between the reactance ratio m and the B-phase overvoltage.

As appeared in Fig. 3, it implies the connection between the reactance proportion m and the B-stage overvoltage. It ought to be brought up that, for the distribution framework with confined nonpartisan point, the reactance proportion m is typically bigger than four. Contrasted and the condition without SFCL, the presentation of the dynamic SFCL will build the power distribution system's certain arrangement reactance under fault state. Since X0/(X1 + ZSFCL) < X0/X1, introducing the dynamic SFCL can diminish the proportion m. And after that, from the purpose of the perspective of applying this recommended gadget, it can bring down the overvoltage's plentifulness and enhance the framework's wellbeing and unwavering quality. Moreover, considering the adjustments in the areas of the DG units associated into the distribution framework, the DG units' infusion limits and the fault positions, the particular impacts of the SFCL on the fault current and overvoltage might be unique, and they are altogether imitated in the reproduction investigation.

III. SIMULATION ANALYSIS

For reason for quantitatively assessing the present restricting and overvoltage-smothering characteristics of the dynamic SFCL, the distribution framework with DG units and the SFCL, as appeared in Fig. 2 is made in MATLAB. The SFCL is introduced in the behind of the power supply Us, and two DG units are incorporated into the framework, and one of them is steadily introduced in the Bus B (named as DG1). For the other DG, it can be introduced in a discretionary position among the Busses C– E (named as DG2). The model's principle parameters are appeared in Table I. To diminish the converter's plan limit [17], doing the SFCL change to the mode 2 after the fault is recognized, and the identification technique depends on estimating the primary streams of various segments by Fast Fourier Transform (FFT) and Harmonic Analysis.

A.Overvoltage-Suppressing Characteristics of the SFCL

Assuming that the infusion limit of every DG is about80% of the heap limit (stack 1), and the fault area is k1,k2,k3 focuses (stage An is shorted), and the fault time is t = 0.2 s, the recreation is done when the DG1 is found B and DG2 is introduced at the Bus E. The reproduction comes about the SFCL's overvoltage-stifling characteristics, and the waveforms with and without the SFCL are both recorded.

B. Current-Limiting Characteristics of the SFCL

By watching the voltage remuneration compose active SFCL's establishment area, it can be discovered that this present gadget's present constraining capacity ought to for the most part reflect in smothering the line current through the distribution transformer. There upon, to gauge the most genuine fault characteristics, the accompanying conditions are composed: the infusion limit of every DG is around 100% of the heap limit (stack 1), and the two DG units are independently introduced in the Busses B and E. Moreover, the three-stage fault happens at k1, k2, and k3 focuses separately, and the fault happening time is t = 0.2 s. Thus, the line current characteristics are imitated.The Simulation comes about shows the line current waveforms with and without the dynamic SFCL when the three-stage cut off at k3 point. In the wake of introducing the dynamic SFCL, the main pinnacle estimation of the fault streams (iAf, iBf, iCf) can be constrained to 2.51 kA, 2.69 kA, 1.88 kA, separately, conversely with 3.62 kA, 3.81 kA, 2.74 kA under the condition without SFCL. The diminishment rate of the normal fault streams will be 30.7%, 29.4%, 31.4%, separately. Fig. 6 demonstrates the SFCL's present constraining exhibitions when the fault area is separately k1 point and k2 point (choosing the stage A current for an assessment). Alongside the abatement of the separation between the fault area and the SFCL's establishment position, the present restricting proportion will increment from 12.7% (k1 point) to 21.3% (k2 point). Also, as one part of fault present, regular reaction is an exponential rot DC wave, and its underlying quality has an immediate association with fault edge. At the end of the day, comparing to various beginning fault points, the short out current's pinnacle amplitudes will recognize. Through the utilization of the dynamic SFCL, the impact of starting fault edge on the pinnacle abundancy of the A-stage impede is investigated in Fig.13, where the fault area is k3 point. It can be seen that, under the conditions with and without the SFCL, the short out current's pinnacle plentifulness will be littlest when the fault point is around 130◦. At this fault edge, the power distribution framework can quickly accomplish the consistent progress from ordinary state to fault state.

3.1 FAULT AT K1: The fault is created at k1 point.

3.1.1 Without SFCL:

Circuit model and output wave forms of source voltage and load current without using SFCL are shown in below figures.

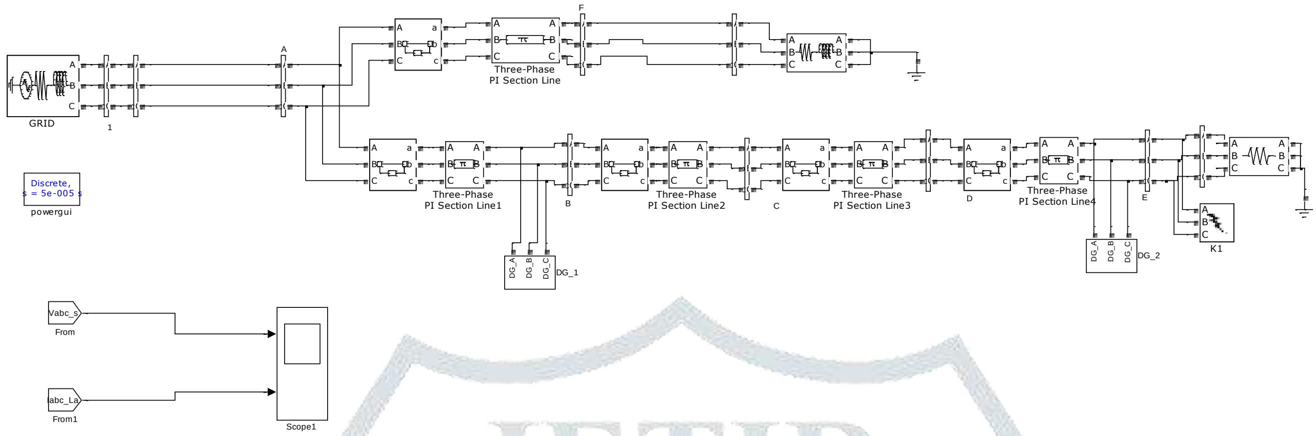

Figure 4: Circuit model for k1 fault without SFCL

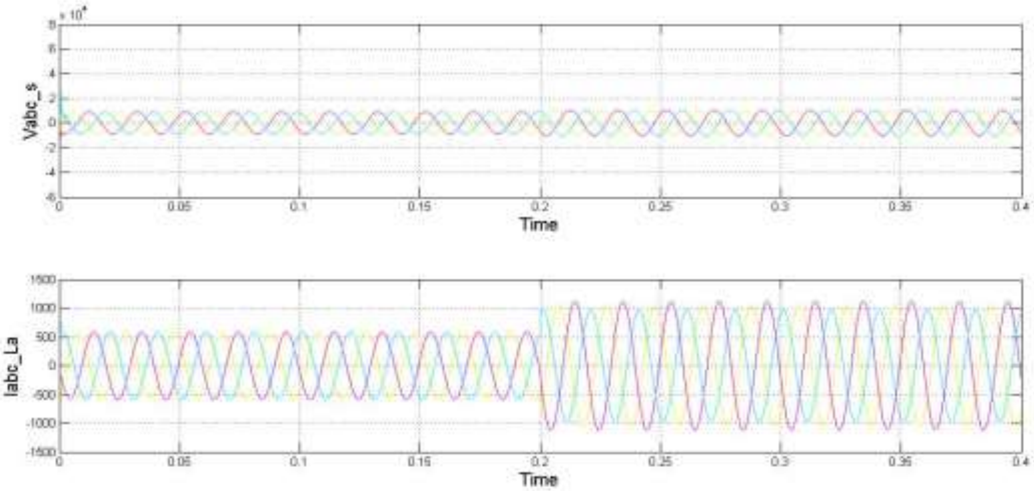

Figure 5 : Source voltage and Load current for k1 fault without SFCL

3.1.2 With SFCL:

Circuit model and output wave forms of source voltage and load current with using SFCL are shown in below figures.

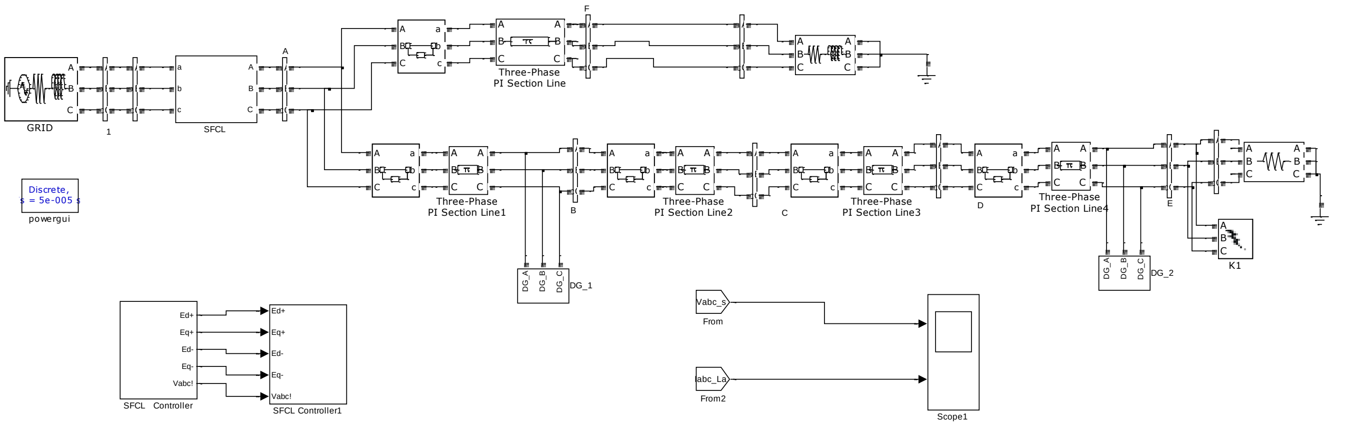

Figure 6 **:** Circuit model for k1 fault with SFCL

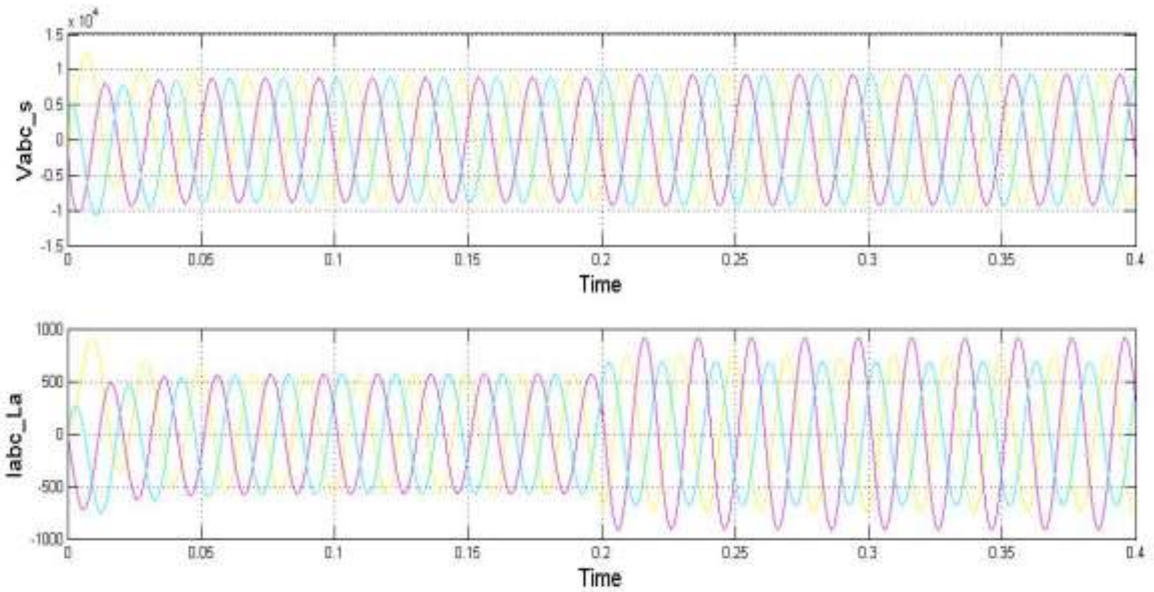

Figure 7: Source voltage and Load current for k1 fault with SFCL

3.2 FAULT AT K2: The fault is created at point k2.

7.2.1 Without SFCL:

Circuit model and output wave forms of source voltage and load current with out using SFCL are shown in below figures.

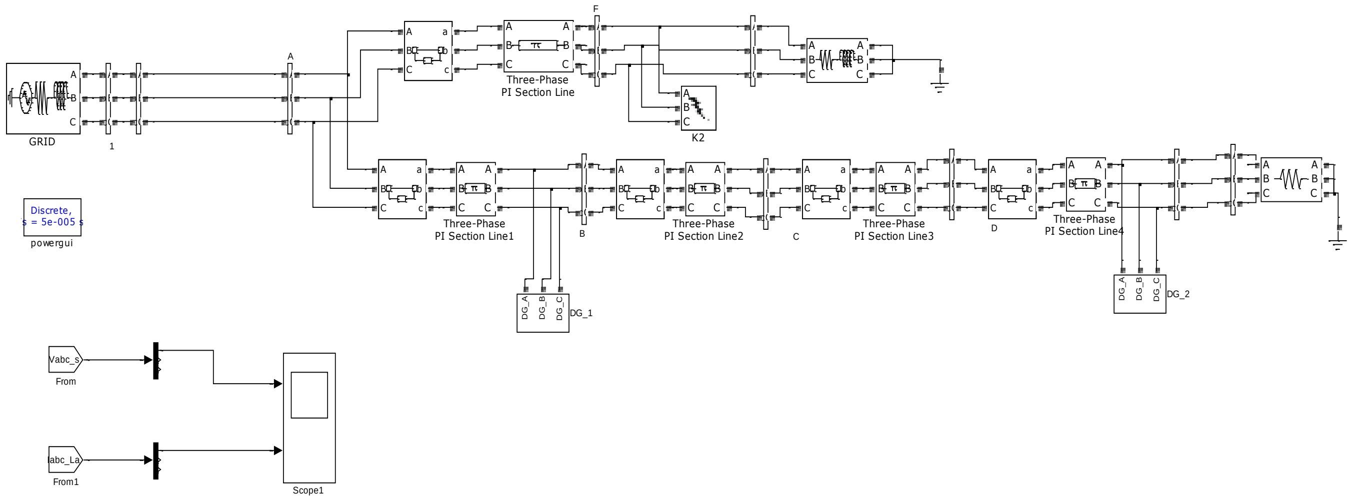

Figure 8: Circuit model for k2 fault with out SFCL

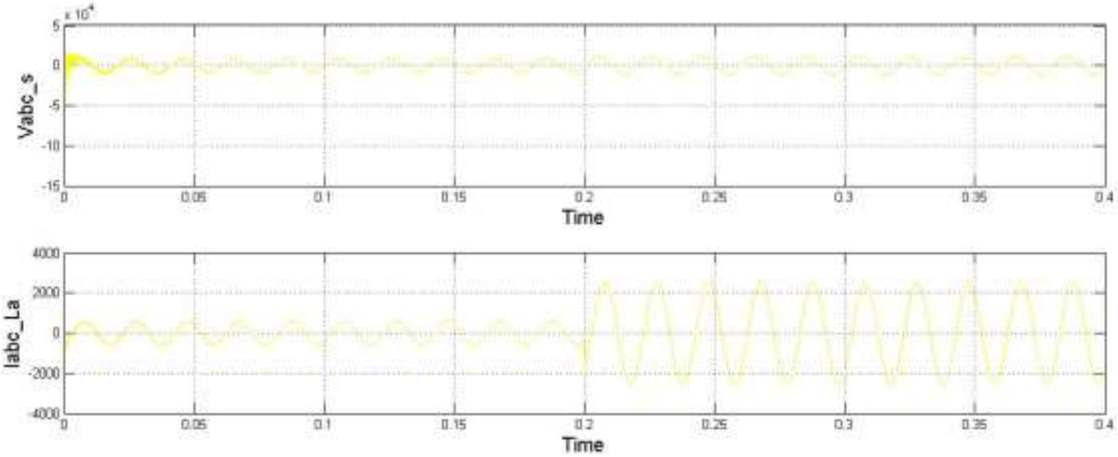

Figure 3.6: Source voltage and Load current for K_2 fault without SFCL

7.2.2 With SFCL:

Circuit model and output wave forms of source voltage and load current with using SFCL are shown in below figures.

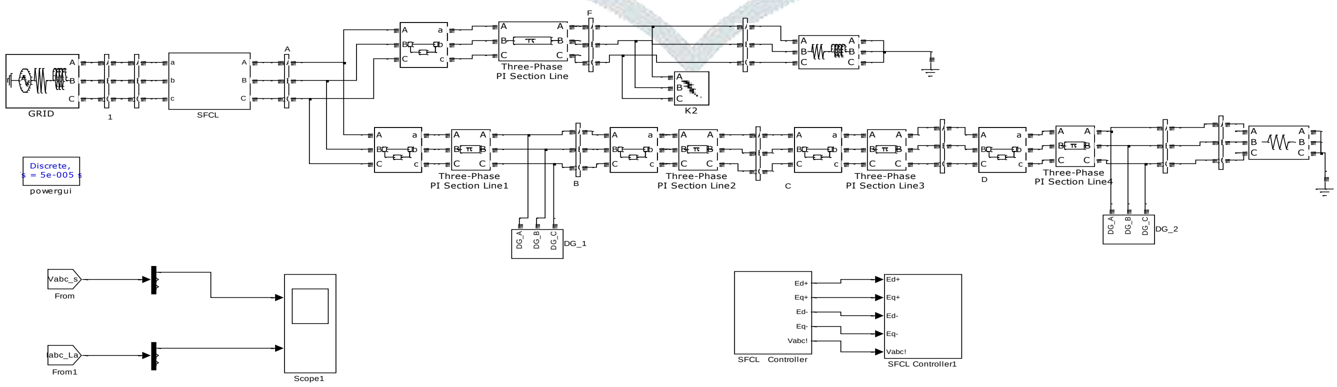

Figure 8**:** Circuit model for K_2 fault with SFCL

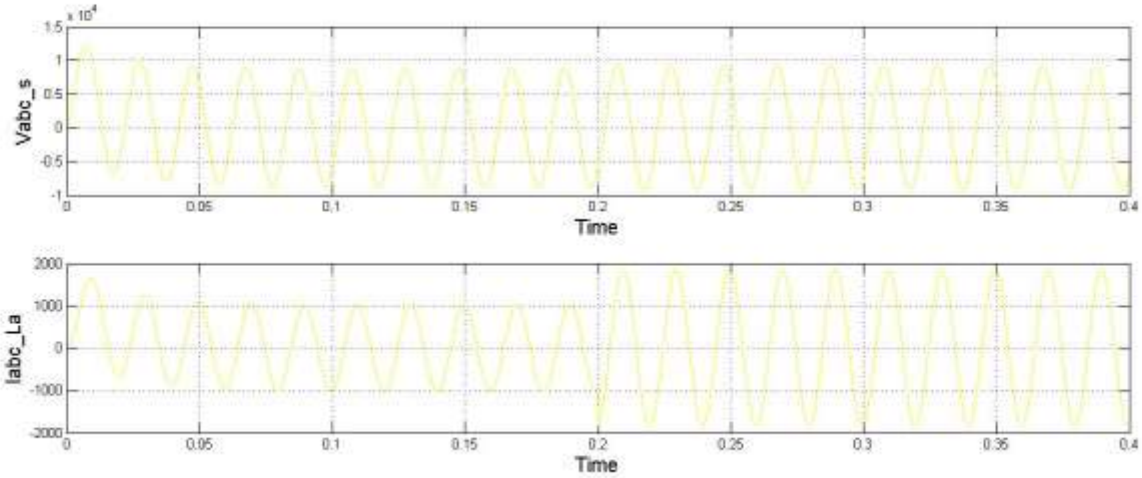

Figure 9: Source voltage and Load current for K_2 fault with SFCL

3.3 FAULT AT K3: If the fault is occurred at point K_3.

3.3.1 Without SFCL:

Circuit model and output wave forms of source voltage and load current without using SFCL are shown in below figures 3.9 and 3.10.

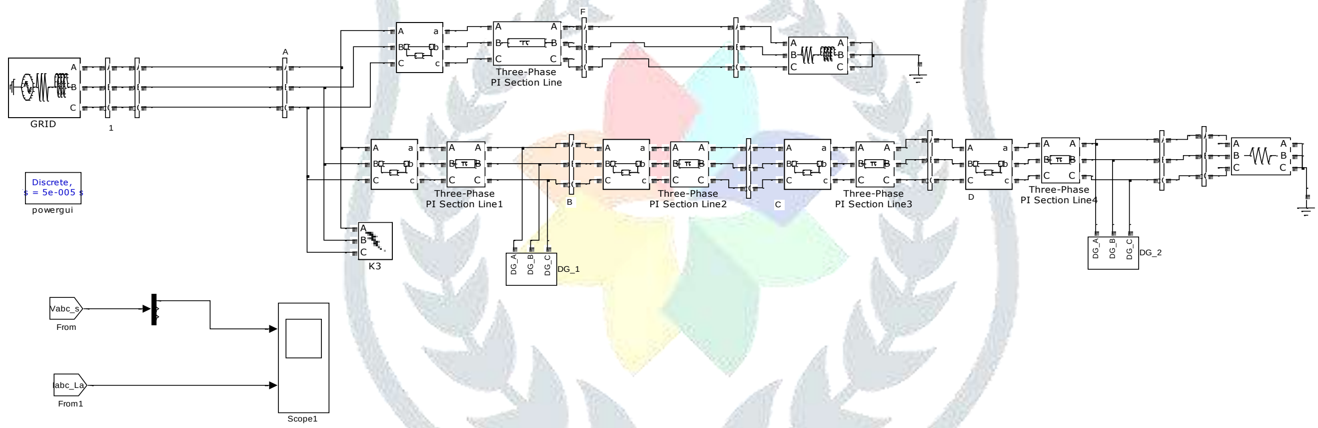

Figure 10 **:** Circuit model for K_3 fault without SFCL

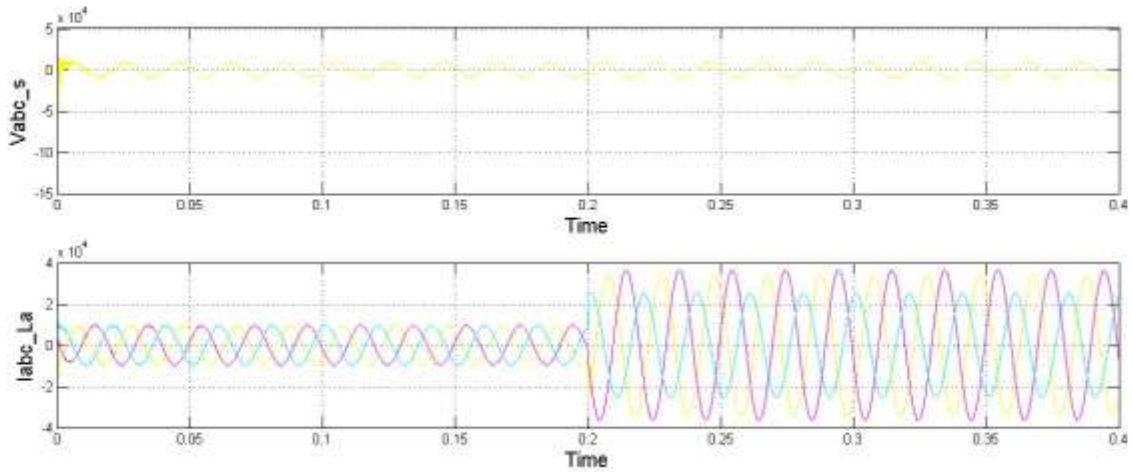

Figure 11: Source voltage and Load current for K_3 fault without SFCL

3.3.2 With SFCL:

Circuit model and output wave forms of source voltage and load current with using SFCL are shown in below figures.

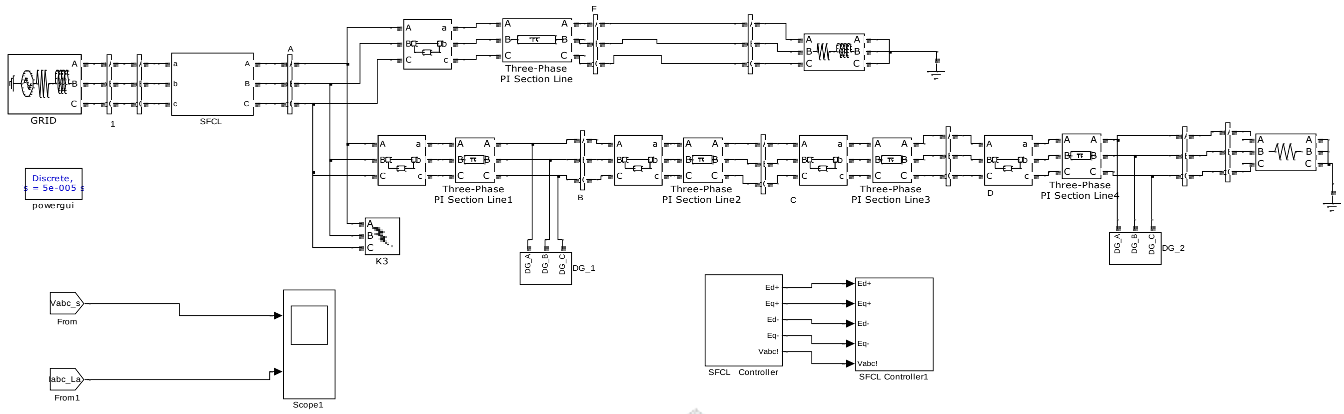

Figure 12**:** Circuit model for k3 fault with SFCL

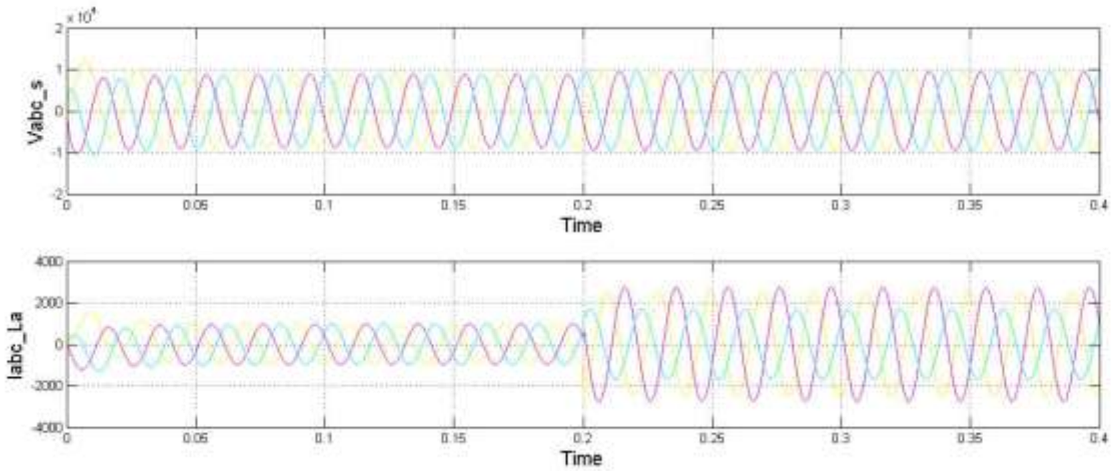

Figure 13: Source voltage and Load current for k3 fault with SFCL

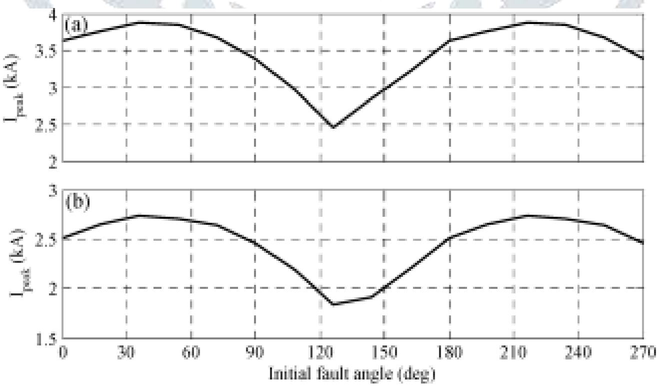

Fig. 14. Influence of initial fault angle on the peak amplitude of the A-phase Short-circuit current. (a) Without SFCL and (b) with the active SFCL.

IV. CONCLUSION

In this paper, the application of the active SFCL into in a power distribution network with DG units is studied. For the power frequency overvoltage caused by a single-phase grounded fault, the active SFCL can help to decrease the overvoltage's amplitude and avoid damaging the distribution equipment. The active SFCL can as well reduce the short-circuit current induced by a three-phase grounded fault and the power system's safety and reliability can be increased. However, 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.