Analysis of Fault Current Limiter (FCL) for Voltage Sag Mitigation through MATLAB/SIMULINK

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Continues growth of electrical energy demand is resulting in a corresponding increase in the short circuit in power system, which results in voltage sag problems and threat to power quality in the system. Several solutions have been implemented, including the use of Fault Current Limiter (FCL), in order to reduce circuit breakers rated capacity and to limit the electromagnetic stress in associated equipment. This paper presents a study of the impact of fault current limiter in power system performance and hence improving the power quality. In order to evaluate the impact of fault current limiter in power system performance, simulation models of power system performance with 'FCL' are used. For simulation model development, MATLAB simulation tool "SIMULINK" software is used. A distribution system fed from single source is used to assess the impact of 'FCL' to power system performance.

Keywords: Fault Current Limiter (FCL), Voltage Sag, Power Quality, MATLAB/SIMULINK.

1. INTRODUCTION

In today circumstances, rapid development of power network cause the fault current of the system increased greatly. The levels of fault current in many places have often exceeded the withstand capacity of existing power system equipment. As implication to this matter; security, stability and reliability of power system will be negatively affected[1]. Thus, limiting the fault current of the power system to a safe level can greatly reduce the risk of failure to the power system equipment due to high fault current flowing through the system. Because of that, there is no surprise to fault current limiting technology has become a hotspot of fault protection research since this technology can limit the fault current to a low level[2,3].

2. FAULT CURRENT LIMITER (FCL)

'FCL' is a variable-impedance device connected in series with a circuit to limit the current under fault conditions[4]. The 'FCL' should have very low impedance during normal condition and high impedance under fault condition[5,6].

2.1. What is FCL?

'FCL' is a device that has potential to reduce fault level on the electricity power networks and may ultimately lead to lower rated components being used or to increased capacity on existing systems[4].

A simple series 'LC' circuit tuned at the net frequency, with the capacitor shunted by a Metal Oxide Varistor (MOV), proves to be well suited 'FCL' as it limits the short circuit current to an acceptable level[7,8].

2.2. The Role of a Fault Current Limiter

Consider the simple power network, shown in Fig. 1, consisting of a supply (voltage, V_S and impedance, Z_S) and a load (Z_{LOAD}).

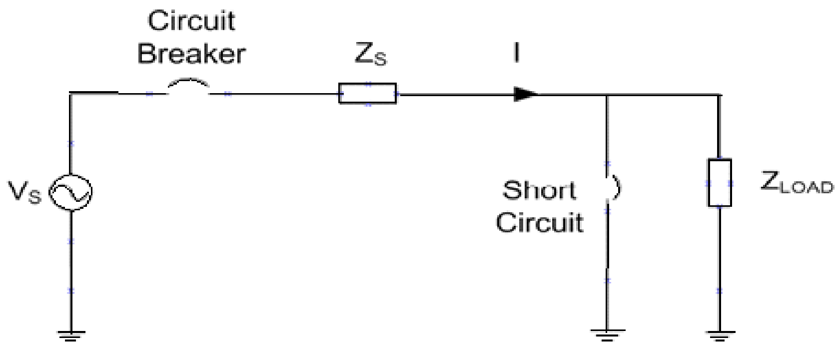

Fig. 1: Simple Power Network

$$I = V_S / Z_S + Z_{LOAD} \qquad \text{-(1)}$$

If a fault occur and cause load to be shorted out, the circuit current will be given by equation (2) as:

$$I = V_S / Z_S \qquad \text{-(2)}$$

Since the supply impedance, Z_S is much lower than the load impedance, the current during fault are significantly large compared to normal current. Although circuit breaker will eventually stop this fault current, it does do it immediately, taking about 2-3 cycles to act. Within this period of time, damage can occur to components between the supply and load. The role of a fault current limiter is to prevent damage faster than 2-3 cycles of a fault current rising[9,10].

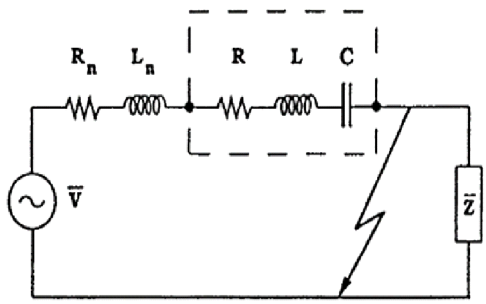

Fig. 2: Simple Power Network with FCL

Fig. 2 shows the similar power circuit with additional of fault current limiting element with impedance. To work as a Fault Current Limiter, Z_{FCL} should automatically increase on the occurrence of the fault. Ideally, ZFCL would equal zero in the normal (non-fault) state and equal to Z_{LOAD} when a fault occurs. Even if the Z_{FCL}=Z_S during the presence of fault, the fault current will be half that without the 'FCL' in the circuit[9].

3. THE FCL CIRCUIT AND ITS OPERATION

The principle scheme of the proposed 'FCL' is shown in Fig. 3. It consists of a series tuned at the net frequency (50Hz or 60Hz) and a 'MOV' (designed for high energy absorption) in parallel with the capacitor. The 'FCL' must be placed immediately downstream of the breaker of feeder[8].

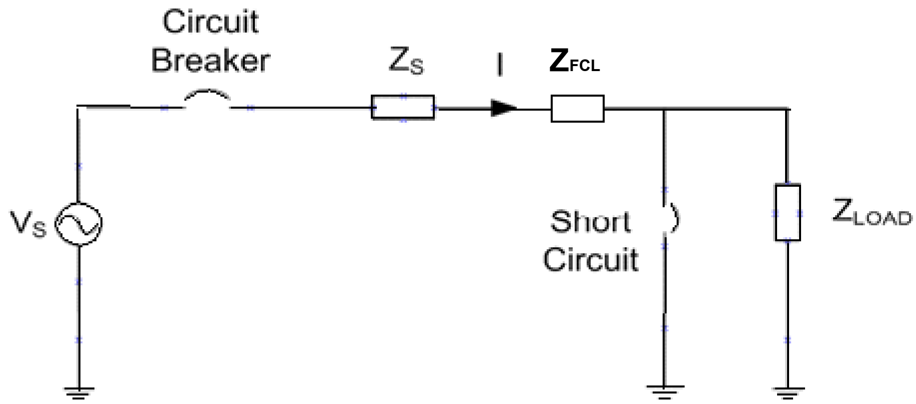

Fig. 3: The principle scheme of the proposed FCL

During normal operation, the circuit is almost transparent. Only a slight decrease of the downstream short circuit power is given by the resistance of series natural reactor. The voltages on the reactive components have the same values, given by the product of line current with the reactance 'X' = ωL = 1/ωC and of opposite signs[1].

In case of a short circuit downstream of the limiter, the 'LC' circuit has the peculiar characteristic to force a gradual increase of the current. This property determines a 'smooth' short circuit transient, very different from the usual one and very useful to reduce the voltage disturbance in the distribution system. This behavior is evident in Fig. 4 upper plotting, where a simulated case is reported[1,11].

Infinite values of 'X' are possible to meet the resonance condition. It's easy to verify that the higher the reactance 'X', the slower shown that the increase is largely independent on increase with smaller values of 'X'. Also the voltage on both the 'L' and 'C' will increase in case of short circuit, but it be shown that the increase is largely independent on 'X'[1].

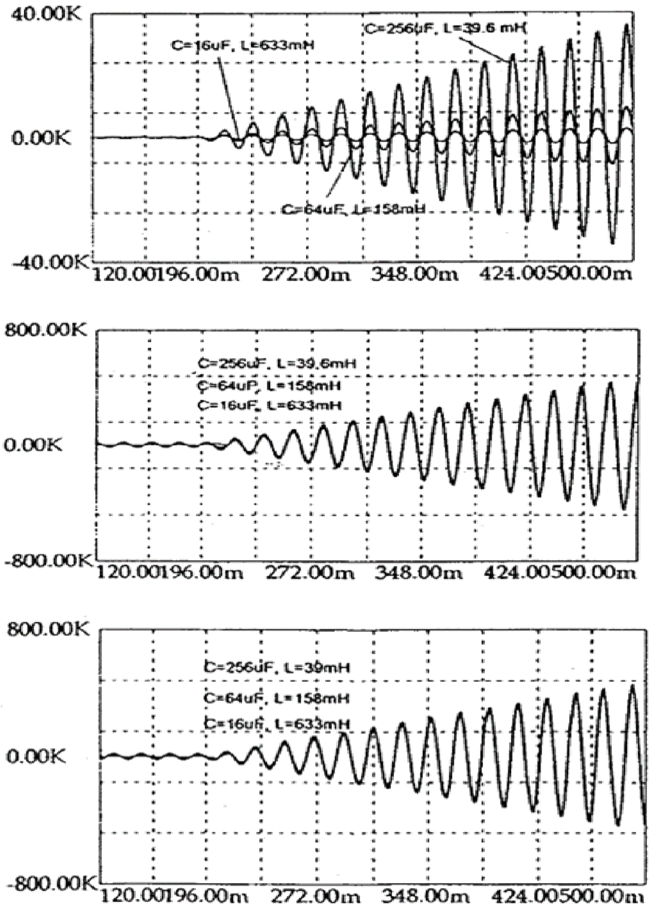

Fig. 4: Short Circuit Transient with the 'LC' Series Circuit (no 'MOV')
Upper Part: Line Current (Ampere); **Middle Part:** Voltage across Capacitor (Volt), **Lower Part:** Voltage across Inductor (Volt)

If a metal oxide varistor with adequate protection level is placed across the capacitor 'C', the 'MOV' will remain inactive during normal operation and will clip the capacitor voltage once that its protection level is reached. From this moment on, the 'MOV' must be able to absorb the relevant energy for the number of cycles necessary for the line breaker to definitely open. During the 'MOV' intervention, as shown in simulation results, the current can be properly limited[11].

The main 'FCL' parameters to be chosen are the reactance 'X' and the varistor protective level. The latter can be fixed for instance at about 2 p.u., the crest voltage across the capacitor when the line is carrying its nominal current. In order to choose the reactance value, a proper compromise must be made considering the following aspects:

(i) the capacitor and inductor voltage increasing rates during the transient are practically not depending on 'X'.

(ii) at the beginning of a fault, until the 'MOV' intervention, the short circuit current increase is the slower, the higher 'X'.

(iii) 'C' must not be too small, to avoid excessive voltages on the 'L' and 'C' in steady-state and because a small 'C' means a large 'L' , with the consequent increase of the series reactor's resistance and relevant losses.

(iv) The smaller, the higher, but the lower will be the protection level of the 'MOV' and the related nominal voltage of the capacitor and inductor[11].

3.1. Proposed FCL Performance: MODELING

A case study based on a typical situation has been considered. With reference to the Fig. 5 lay-out the following main values have been assumed:

(i) Primary voltage (HV side) 132 kV-50 Hz, with a short circuit power of 2400 MVA, secondary voltage (MV side) 20 kV, insulated neutral.

(ii) Main transformer 132/20 kV, 40 MVA, short circuit voltage Ucc = 13%, copper losses 0.6%.

(iii) Ten departing lines of rated power 5 MVA and 10 km length each (line's parameters: parameters: series resistance 0.224 Ω /Km, series inductance 1.13mH/km, capacity 10.3nF/Km.

(iv) Line's actual loads are 4.4 MW and 2.3 MVAR (PF 0.88) each.

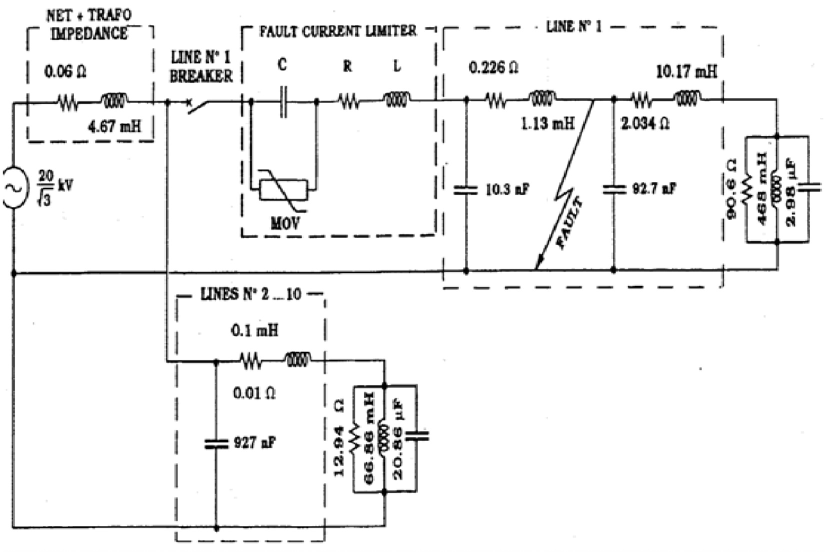

Fig. 5: Single Phase Model of the Net including the FCL

4. SIMULATION

4.1. Without Fault Current Limiter

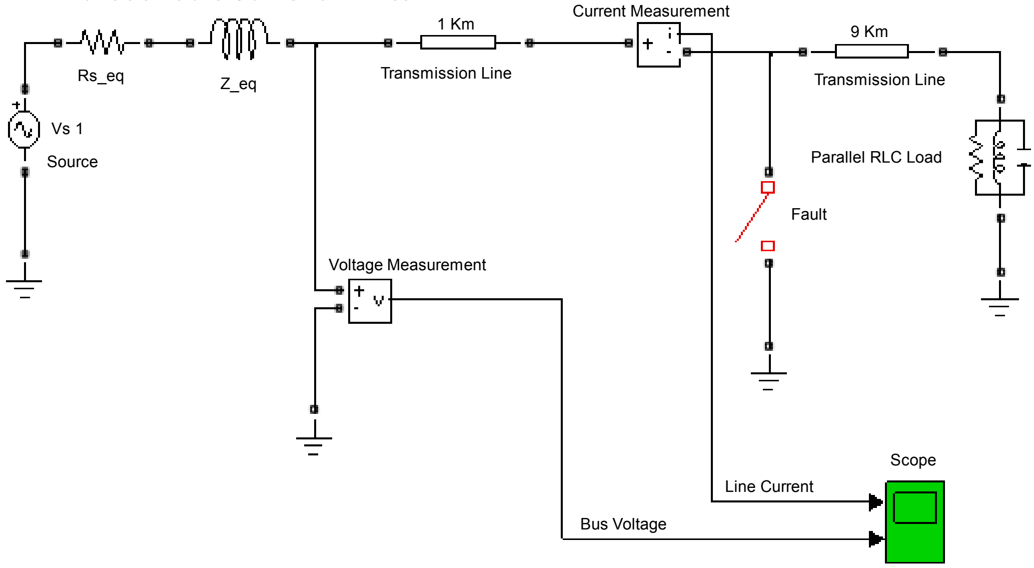

Fig. 6: Model of Single Phase Line having Line to Ground Fault

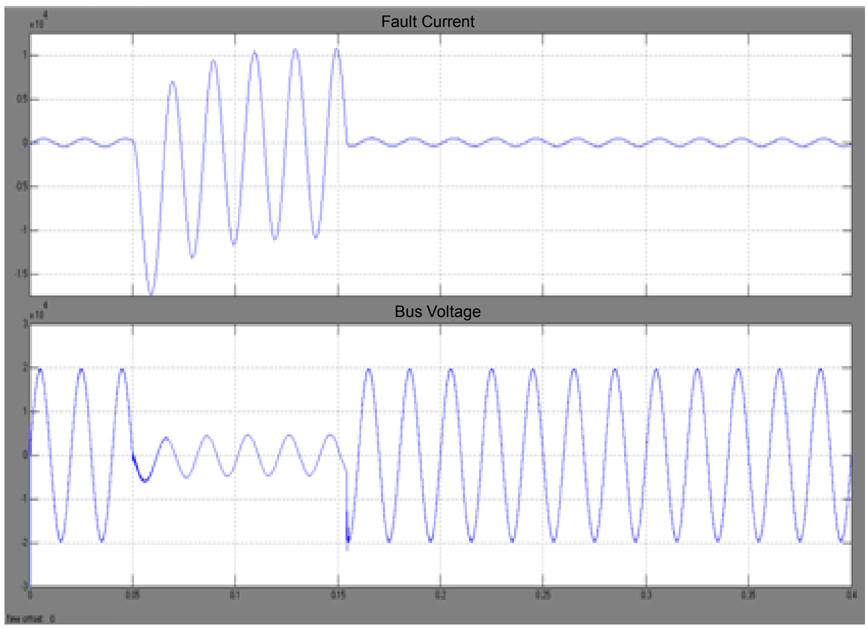

Fig. 7: Simulation Result 1: Fault Current (Ampere) and Bus Voltage (Volt)

4.2. With Fault Current Limiter but no 'MOV'

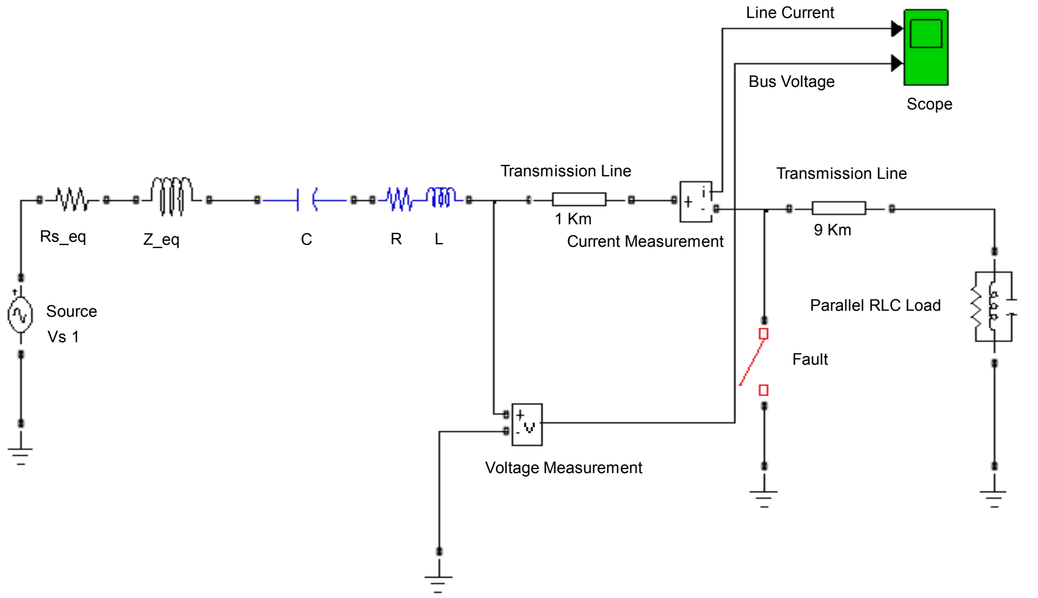

Fig. 8: Model of Single Phase Line having Fault Current Limiter but no 'MOV'

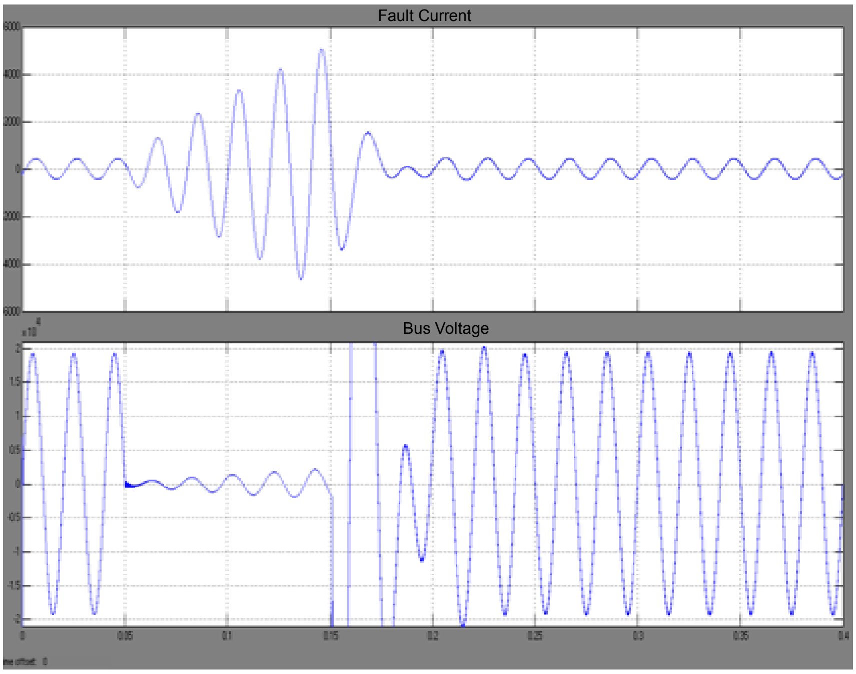

Fig. 9: Simulation Result 2: Fault Current (Ampere) and Bus Voltage (Volt)

4.3. With Fault Current Limiter

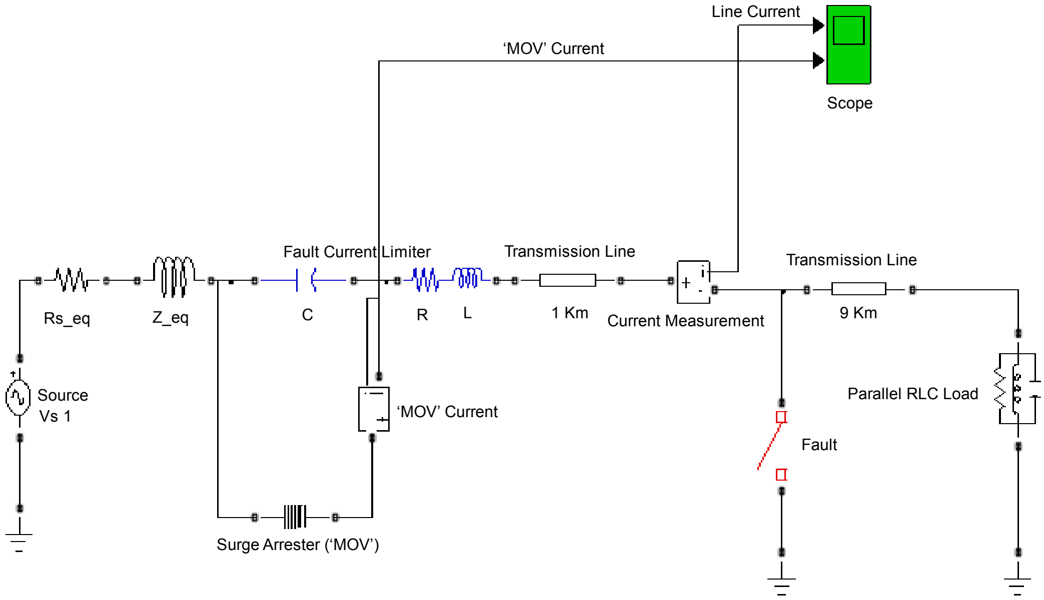

Fig. 10: Model of Single Phase Line having Fault Current Limiter and 'MOV' (Surge Arrester)

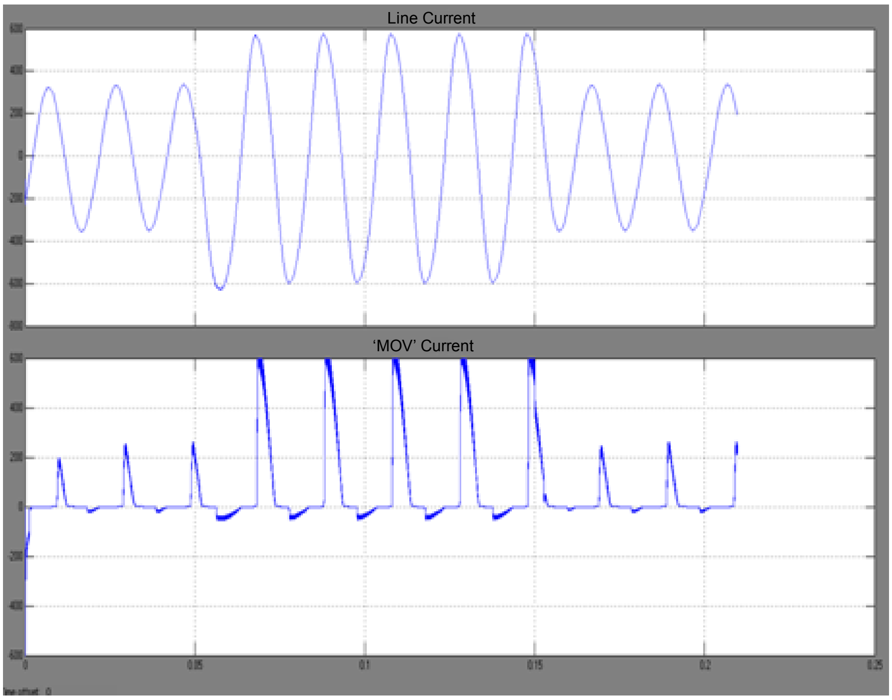

Fig. 11: Simulation Result 3: Line Current (Ampere) and 'MOV' Current (Ampere)

5. RESULTS AND DISCUSSIONS

From the simulation result 1 in Fig. 7 it is evident that, line current rises at a high value and bus voltage drops to a low level during the faults. Result 2 in Fig. 9 shows the behavior of the 'LC' circuit acting as a Fault Current Limiter but with no 'MOV', hence we get a continuous rise in fault current and bus voltage with time. Result 3 in Fig.e 11 shows after placing the 'MOV' in parallel with capacitor, 'FCL' perfectly limit the fault current to a significant level.

Simulation results show that the 'FCL' detects the fault current and minimize the fault current upto safe limit. Simulation results proved that 'FCL' effectively limiting the current during fault incident.

6. CONCLUSION

Today the problem of power quality improvement is very real. The particular fault current limiter proposed in the paper has the merit to meet the problem of voltage sags in distribution utilities with a solution that does not require control system and power electronic. The simulations performed prove the method effectiveness, as well as the possibility of building the 'FCL' with commercially available components.

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