Voltage Sag Mitigation in Power Systems by using Bridge Type Fault Current Limiter

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***Abstract*- In this work, a bridge type fault current limiter (BFCL) is proposed to mitigate the voltage sag in power systems. Using the IGBT as a semiconductor switch at the dc current path leads to quicker operation of the BFCL is possible. This BFCL structure uses a simple control method for the generation of gate pulse to the IGBT .The IGBT gate pulse is generated with the help of relational operators and S-R flip-flop. The proposed BFCL is capable of limiting the short circuit current by placing the mentioned shunt impedance in the structure of the BFCL and mitigate the voltage sag during the fault. In addition, the BFCL does not use a superconducting inductor which has high construction cost. Simulations results are made by using MATLAB/Simulink software with and without BFCL.**

***Index terms*- Bridge-type fault current limiter (BFCL), insulated-gate bipolar transistor (IGBT), power quality (PQ), shunt impedance.**

I.INTRODUCTION

Generally, the power quality (PQ) is referred to “the ability of the electric utilities to supply electric power without any interruption”. Most common power quality problems occur in power systems are voltage sag, voltage swell, voltage spike, harmonic distortion, long interruptions, very short interruptions, noise, and voltage unbalances. Voltage sag is an important power quality problem because of sensitive load growth. The main causes for voltage sag are short circuit faults on transmission or distribution system (most of the times on parallel lines)[1]. Voltage sag is defined by the IEEE 1159 as the decrease in the RMS voltage level to 10%-90% of nominal, at the power frequency for the duration of the half to one minute [2].

The most commonly used voltage sag compensator is the dynamic voltage restorer (DVR), which injects a compensation voltage with the required magnitude, and phase angle in series with the sensitive feeder[3].

An ideal FCL should have the following characteristics [4] :

1 No power loss during normal operation
2 zero impedance during normal operation
3 large impedance during fault condition
4 fast in operation at the event of fault
5 low cost

At the event of a fault, the voltage sag is proportional to the short circuit current value. The FCL in the electric power system not only limits the fault current in the event of faults but also used to improve the power system transient stability, power quality, and reliability [5].

Superconducting fault current limiters have good characteristics to limit the fault current due to their variable impedance in the normal and fault conditions [6]. These are not available because of the cost of superconductors is high. So, better choice will be the no superconducting FCL but it exhibits power loss which is negligible as compared with the total power provided by the feeders [7].

In this paper, a bridge type fault current limiter is proposed for the voltage sag and the phase angle jump mitigation at point of common coupling (PCC).In section II, the BFCL configuration and principle of operation is discussed. Then, in section III, the BFCL control strategy is discussed. In section IV, the MATLAB/Simulink software is applied to investigate the behaviour of the BFCL with the considered power system and simulation results are analyzed.

II. BFCL CONFIGURATION

AND PRINCIPLE OF OPERATION

The BFCL is composed of two sections: (i) The Bridge Part (ii) The Shunt Part. The bridge part is composed of diodes D_1–D_4, a small-valued dc inductor L_{dc} and a very small value resistor R_{dc} are connected in series with a parallel free-wheeling diode D_5 placed with an IGBT switch in series .The shunt path composed of a resistor R_{sh} and an inductor L_{sh} , are connected in series and it is in parallel to the bridge part as in Fig. 1.

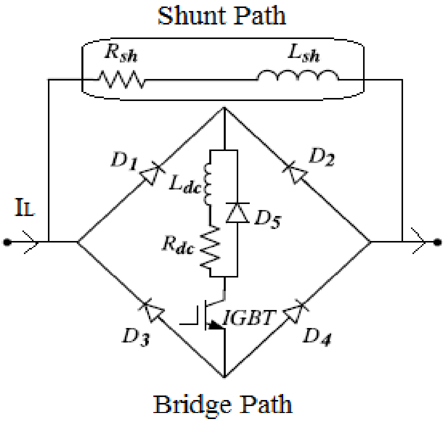

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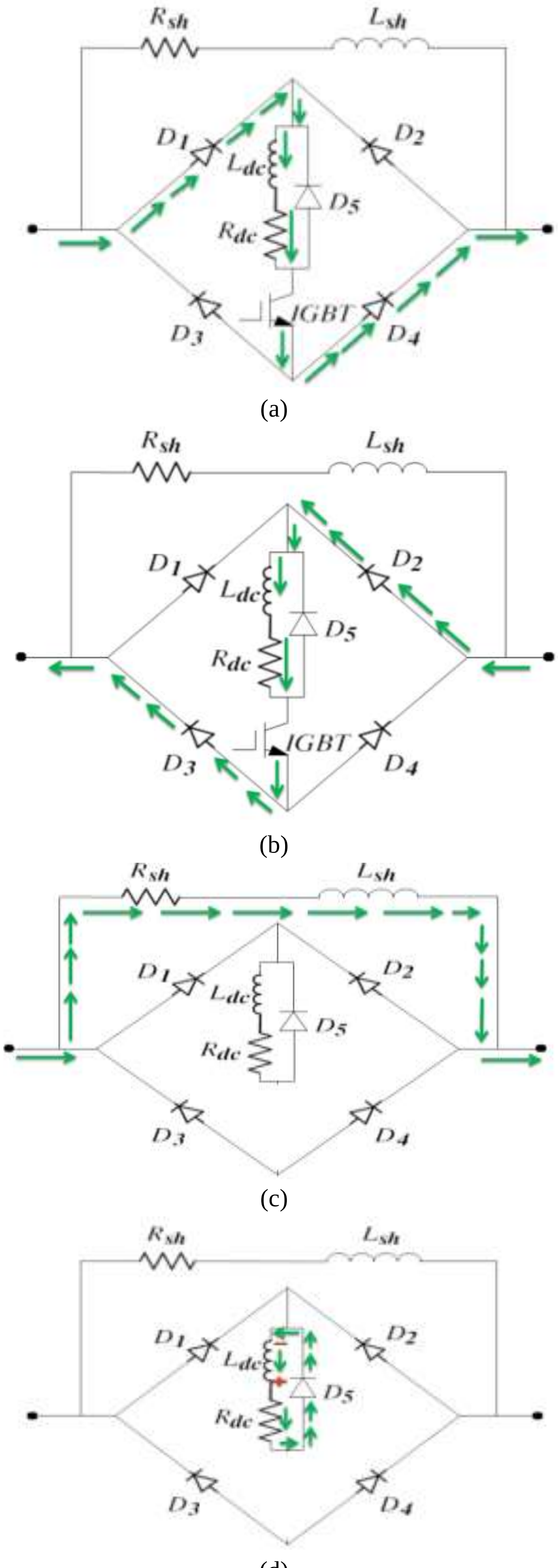
Fig.1. Bridge Type Fault Current Limiter

The BFCL operation is shown in Fig.2.The IGBT switch in the bridge part remains closed during normal operating condition. During the positive half cycle of electrical frequency, the line current flows from D_1 - R_{dc} - L_{dc} –D_4 and for the other half cycle ,the line current flows from D2 - L_{dc} - R_{dc} -D3. So, the current through the inductor (L_{dc}) , flows in the same direction and this current is the d.c current I_{dc} . The inductor (L_{dc}) is charged with the peak current and acts as a short circuit. In steady-state operation, the IGBT turn-on resistance, the inductor (L_{dc}) inherited resistance and the diode forward voltage drop cause some voltage drop, but this voltage drop is quite negligible compared to line drop. The power losses of the proposed BFCL in normal operation can be calculated as

$$P_{Loss} = P_{Rdc} + P_D + P_{IGBT}$$
$$= I_{dc}^2 R_{dc} + 4V_{DF} I_{avg} + V_{IGBT} I_{dc} \qquad (1)$$

Where I_{dc} is the dc current (peak value of line current); V_{DF} is the forward voltage drop on each diode; V_{IGBT} is the voltage drop across IGBT; I_{avg} is the diode average current that is equal to I_{peak}/π.

The shunt path impedance is chosen high enough, the complete line current to flow through the bridge except a very small leakage current. When a fault occurs, initially the line current tends to increase suddenly, but the inductor (L_{dc}) limits the increasing rate of line current. The safe operation is maintained because the IGBT switch is saved from the high value of di/dt.



(a)

(b)

(c)

(d)

Fig.3. BFCL Operation

Advantages of bridge type fault current limiter (BFCL):

- Simple bridge structure,
- No complexity.
- Easy to implement.
- Simple control structure.
- Effective for transient stability improvement.
- Less costly.

By considering "(1)", the small value of d.c reactor is used, the total power loss of the BFCL become a very small when compared to the transmitted power of the feeder.

A.BFCL in distribution network

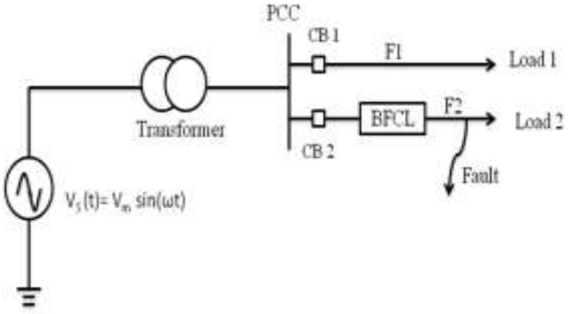


Fig.2. Single line diagram of power system

Fig.2. represents the single line diagram of power system. This figure shows a substation with two feeders F1 and F2 with load. At the event of the fault on F2, the voltage sag occurs nearby substation PCC.

III. BFCL CONTROL STRATEGY

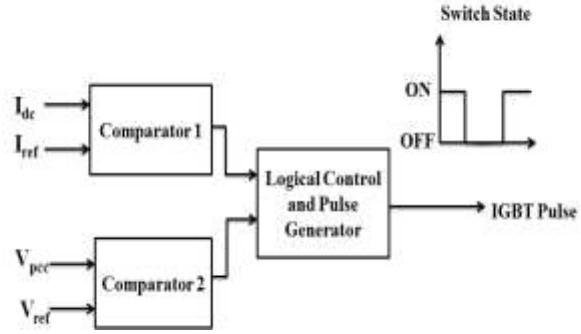


Fig.4. BFCL Controller

The BFCL controller is shown in Fig. 3. It is composed of two comparators and a pulse generator. Signals from two comparators are collected, and an appropriate IGBT gate control signal V_{gt} is sent via pulse generator. The line current and the line voltage are some parameters, can be used in the BFCL controller. Here, the dc current (I_{dc}), through the inductor (L_{dc}) is used to control the IGBT switch.

The inductor (L_{dc}) current is very sensitive to current through the line and its response is faster than the line current (I_L) or other parameters. So, by using I_{dc} as a control parameter, quicker control is achieved. This is only used to turn off the IGBT switch. When I_{dc} exceeds I_{dcref}, the IGBT is turned off. The bridge is open circuited and the line current is bypassed to the shunt part having a high impedance. The shunt part limits the fault current. This I_{dcref} value is found to be optimum for the system under consideration. A lower value is likely to cause unwanted appealing of the shunt path due to output power fluctuation and current harmonics at the dynamic operation. A higher value will cause a delay in the BFCL controller response. As I_{dc} becomes almost zero after IGBT opening. Therefore, to turn on the IGBT, choosing another control parameter is required. Here, the line current (I_L) is used .As the I_L is less than the I_{Lref} , the IGBT switch is turned on and the system is brought back to normal operation. During the open circuited period of the bridge part, the free-wheeling diode and the IGBT provides a path to discharge the stored energy in them. Hence, the IGBT turn-on instant is avoided during high switching current.

IV. SIMULATION MODELING, RESULTS AND DISCUSSIONS

In this work, simulations are made by using the MATLAB/Simulink software considering a balanced fault at PCC. It is considered that the balanced fault occurs at 0.2s and cleared at 0.3s.The simulation time is 0.5s .The proposed BFCL has been implemented on the considered test system as shown in Fig.5. Without using BFCL, the substation PCC voltage drops severely. The parameters used for the simulation as given in Appendix.

A balanced fault is applied on the test system with BFCL as shown in Fig.6.When the BFCL is installed in the feeder 2 performs two functions such as it reduces fault current as well as it restores the non-faulted feeder voltage to the nominal voltage. So, the BFCL improves the voltage sag of the supply network.

The BFCL simulation circuit and its controller as shown in Fig.7.The BFCL controller generates IGBT gate pulse with the help of relational operators and S-

R flip-flop. Fig.8. and Fig.9.depicts the BFCL shunt branch and dc reactor current during the balanced fault condition. Fig.10. depicts the BFCL IGBT gate pulse during the balanced fault .It has some time delay for the settling of the output.Fig.11.depicts the PCC voltage without BFCL during balanced fault.Fig.12 depicts the PCC voltage with BFCL during balanced fault. By placing BFCL in the F2, when the fault occurs, the BFCL inserts large impedance into the fault line and prevents the voltage sag as well as phase angle jump at the PCC. Fig. 13 depicts the load 1 voltage with BFCL during balanced fault.

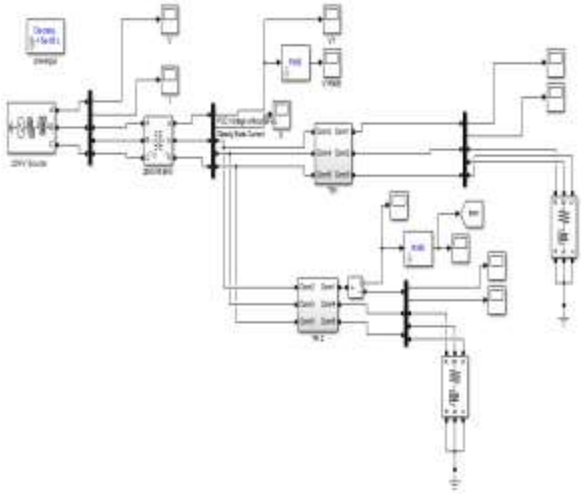


Fig.5. Simulink model for the test system considered

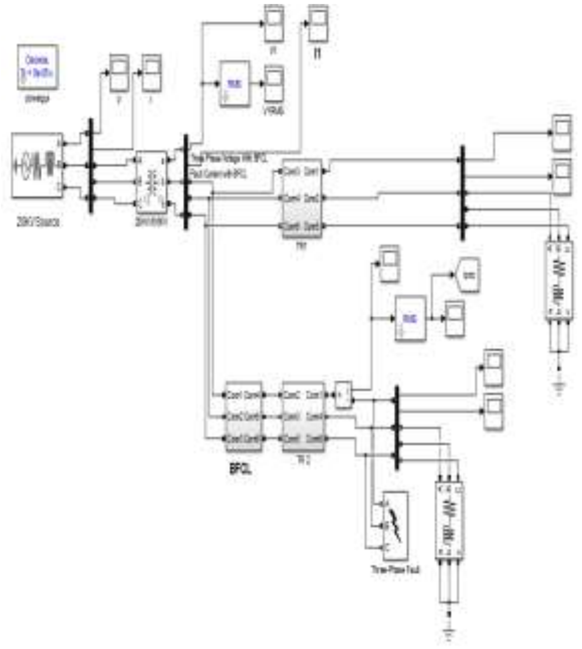


Fig.6. Simulink model with balanced fault and with BFCL

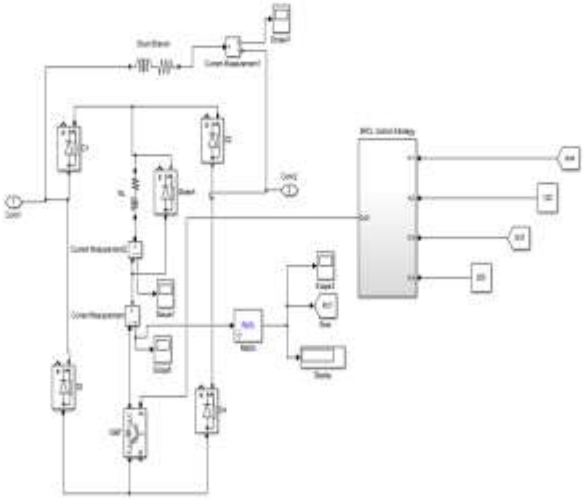


Fig.7. BFCL simulation model and its controller

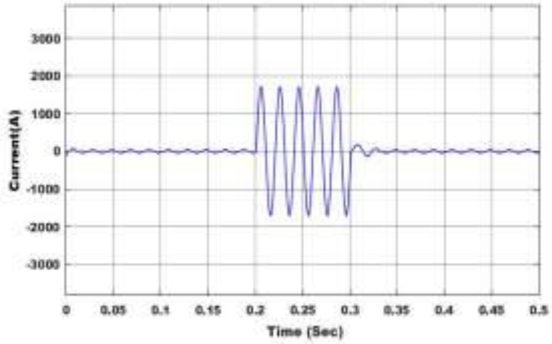


Fig.8. BFCL Shunt branch current

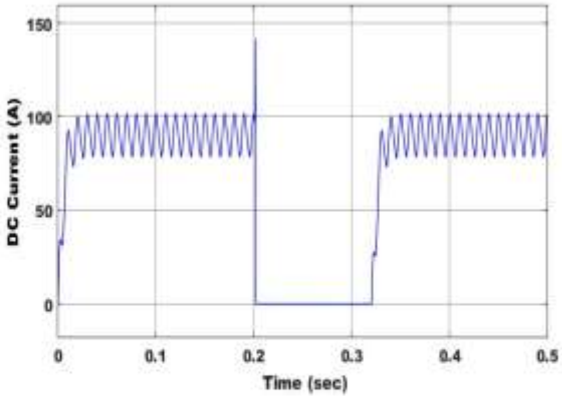


Fig.9. BFCL D.C reactor current

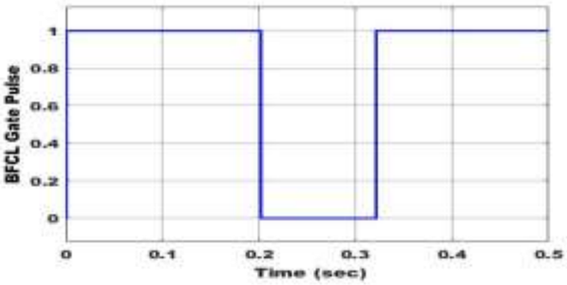


Fig.10. IGBT gate pulse

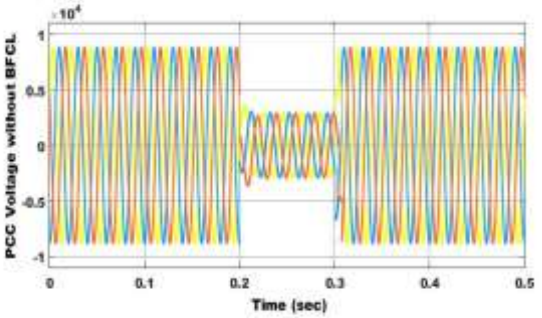


Fig.11. PCC voltage without BFCL during balanced fault

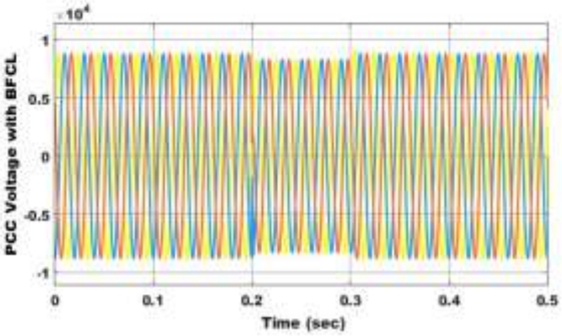


Fig.12. PCC voltage with BFCL during balanced fault

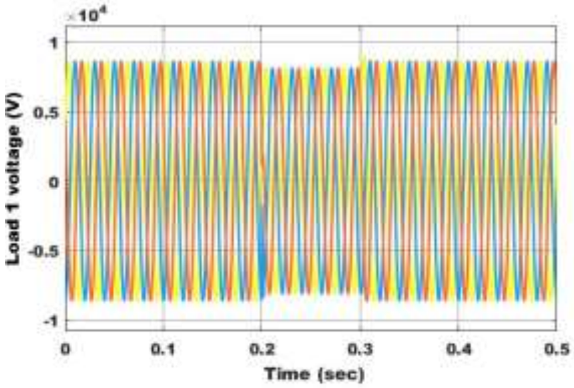


Fig.13. Load 1 voltage with BFCL during balanced fault

V. CONCLUSION

In this work, the bridge type fault current limiter (BFCL) is introduced to mitigate the voltage sag as well as to limit the fault current. By using IGBT as a semiconductor switch in the dc current path instead of thyristors at the bridge part, the BFCL has high speed. This type of FCL is useful for the power quality improvement because of voltage sag and phase angle jump mitigation. The performance of the proposed BFCL is analyzed with the help of a three phase power system network. In our future study, we will implement the hardware of BFCL.

APPENDIX

Source Data	Power Source	20KV,50Hz,X/R ratio=5 Total impedance =1.608 Ω
	Transformer	20KV/6.6KV 10MVA, 0.1 p.u.
Feeder Data	Feeder 1	j0.314Ω
	Feeder 2	j0.157Ω
BFCL Data	DC Side	Switch Type : IGBT L_{dc} = 0.01H R_{dc}=0.5Ω
	Shunt Branch	L_{sh} =0.00008 H R_{sh}=2.5Ω
Load Data	Load 1	10+j15.7Ω
	Load 2	15+j31.4Ω

Table. I Simulation Parameters

VI. ACKNOWLEDGMENT

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