A Novel Multi-Functional Capacitive Fault Current Limiter to Enhance LVRT Capability of Wind Farm

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Abstract– In this study a new type of fault current limiter is introduced. Its function is to improve the capability of low voltage rid-through (LVRT) in fault operating conditions. The new structure has been proposed based on the capacitive bridge-type fault current limiter (BFCL) and the RL-type fault current limiter (FCL), which is modified to promote the low-voltage ride-through. This is in opposed to the conventional fault current limiters in which the limiter is bypassed in normal operating condition. To assess the efficacy of proposed fault current limiter, the time domain simulations were executed in PSCAD/EMTDC software and its function is compared with the RL-type FCLs in normal and symmetrical or asymmetrical fault conditions. Also its efficacy has been evaluated in a fixed speed based wind farm. The result of simulations showed that the proposed FCL improves the LVRT performance in fault operating condition in the wind farms.

Keywords: Capacitive Fault Current Limiter, LVRT, Wind farm

1. Introduction

The grid codes are assigned by the system operators to determine the conditions for wind farm and loads that are connected to the network during fault in the power system.[1-3] On the other hand, in long transmission lines, to send the power produced by generators, it is necessary to make the series compensation of the transmission line using series capacitors.[4] In the previous studies, the use of bridge type fault current limiters is an effective and relatively cost-effective method for improving the ability of low-voltage ride through.[5-9] The evolutionary process of the structure of this limiter to the proposed limiter will be described subsequently. Fig. 1(a) shows the structure of the superconductive bridge type fault current limiter. [10] As shown in this figure, this limiter consists of a superconductor as a limiter element, a diode bridge rectifier and a series interface transformer that prevents the sudden increase of fault current when short circuit occurs in the network. But as time passes, the superconductor current and the line current gradually increase linearly, until it reaches the peak value of the short-circuit current in the state without a limiter. To address this problem in reference [11], a resistor parallel to the T switch and in series with the superconductor was used as limiter. Fig.1(b) shows the structure of this limiter. In this structure, as soon as a short circuit occurs, the resistor is placed in the current path. So, the gradual increase in short-circuit current range is prevented.

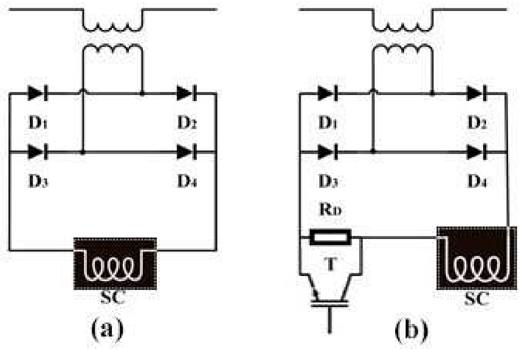

Fig.1 FCL structure (a) superconducting diode bridge, (b) superconducting diode bridge with resistance

The use of superconductor is not only expensive, but also requires a cooling system. So, Reference [12] suggests replacing a DC reactor instead of a superconductor as a limiter. Fig.2(a) shows the structure of this limiter. In this structure, it is possible to control the range of the fault current by controlling the switching time of T. The problem with this structure is that as the reactor is always in the path of the fault current, the tolerable current value must be at the level of the fault current. Reference [13] has proposed the new structure of Fig.2(b) to solve these problems. In this structure, the resistor is placed as a limiting element in parallel

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and on the AC side. In this structure, when a fault occurs in the system, the current passing through the DC reactor is cut off and by placing the RD in the current path, the fault current is limited. In reference [14], a new model of this structure was proposed using LD reactor instead of RD resistor to reduce the voltage drop in the distribution network. The structure of this model is shown in Fig.2(c).

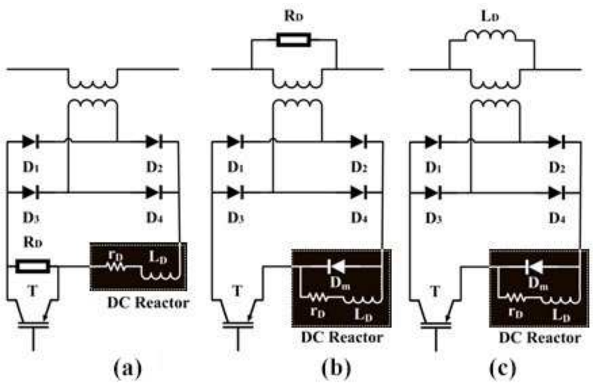

Fig.2 FCL structure (a) diode bridge of DC reactor type, (b) modified diode bridge with limiting resistor, (c) Diode Bridge with limiting reactor

In reference [15], as shown in Fig.3, the parallel resonance limiter structure is proposed using a diode bridge. In this structure, the parallel resonance circuit is used as the limiting impedance.

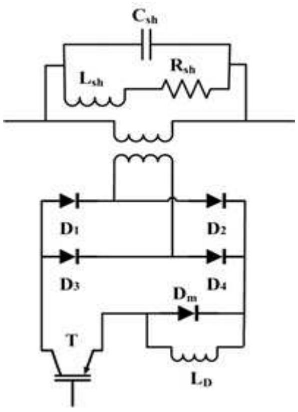

Fig.3 Parallel resonant diode bridge circuit

In [16], the use of RL limiter is proposed. RL type limiter circuit is shown in Fig.4(a). The Zno arrester in this type of limiter acts as a variable resistor during a fault. Although the use of RL limiter effectively increases the LVRT, this type of limiter cannot provide reactive power to support the voltage drop, and the addition of a reactor in the line, leads to excessive reactive power absorption in the system. so, the use of a reactive power compensator such as STATCOM is necessary to fulfill this requirement.

In this study, in order to address the problem of Previous structure A capacitor is paralleled with a resistor to provide the reactive power during and after the fault current and for the rapid recovery of the voltage, this feature also leads to an increase LVRT.

2. The structure of proposed multi-function capacitor limiter:

The limiter structure is shown in Fig.4(b) which is made up of the following components:

1-Diode bridge rectifier including D1 to D4

2- DC reactor that prevents damage to GTO

3- Semiconductor GTO switch (S)

4- Dmdiode which is in parallel with LD

5-Parallel capacitor

6- The ZnO varistor is for cutting the voltage of the capacitor, which limits the fault current and protects the limiter against overvoltage at the beginning of the fault.

3. Function of the proposed fault current limiter:

To study the function of limiter, the system is considered in two states including the normal state and function of the proposed limiter in improving the LVRT ability, which we will explain further.

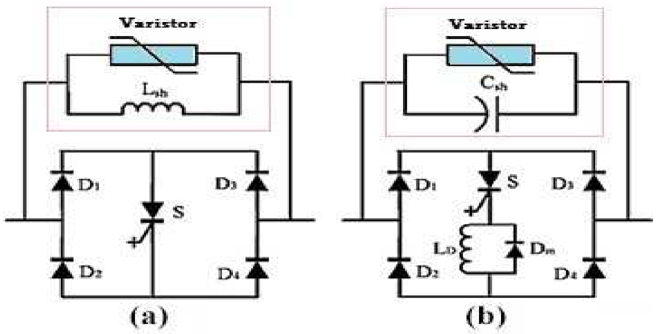

Fig.4 Structure of (a) RL-FCL and, (b) proposed FCL

3.1. Step 1: Limiter function in normal condition

In this case, the power network is in normal mode and the power passing through the line is lower than the reference level. The switch S is closed and the line current passes through it in both the positive and negative cycles. The capacitor is bypassed and the current does not pass through it. Also, the voltage of the varistor is lower than Vk (operation voltage of the varistor) and the varistor is inactive. Fig.5(a) and 5(b) show the equivalent circuit in this state, in the positive half-cycle and negative half-cycle of the line current, r espectively. In this case, the voltage drop of the limite r is negligible compared to the line voltage and can b e ignored.

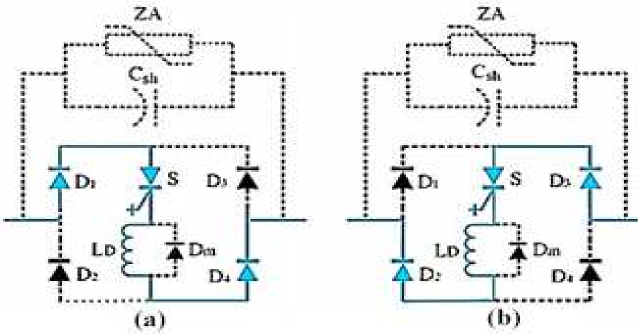

Fig.5 Proposed FCL normal operating mode (a) positive half cycle, (b) negative half cycle

3.2 Step 2: Function of the proposed limiter in improving the LVRT ability

The ability of the wind farm to reduce the adverse effects of the grid fault is called LVRT, the range of which is determined by the voltage profile. Fig.6 show s the LVRT voltage profile. According to this curve, u nder voltage drop conditions, the wind farm must rema in in the circuit for 150 ms above the line area. The characteristics of this curve are different for various gri d. When a short circuit occurs in the line, the terminal voltage of the wind farm reaches the threshold value, at this time the control system turns off Switch S and just the capacitor is placed in the circuit as shown in Fig.7(a). When the short-circuit current passes through the capacitor, the voltage of the capacitor exceeds the value of VK and the varistor is activated. In this case, the line current passes through the capacitor and varist or and the limiter acts as a resistor and eliminates the accelerator energy of the generator. varistor also protect s the limiter against overvoltage during switching, and the energy in the stray diode circulates as shown in Fi g.7(b). After fault correction, the system returns to its steady state and the control system turns off the S, An d this causes improving the performance of the LVRT under fault conditions.

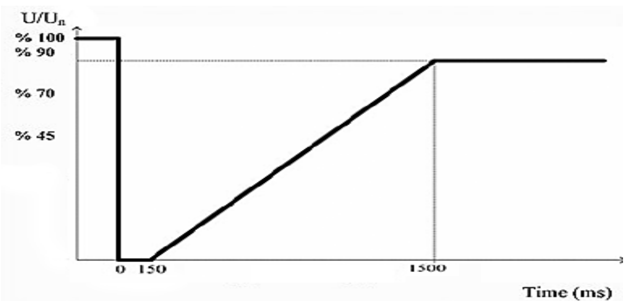

Fig.6 Requirements for wind farm behaviour during faults

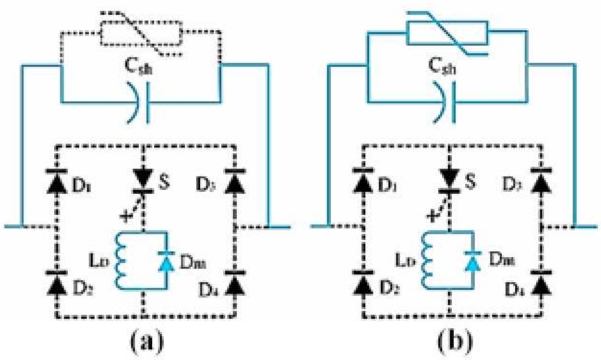

Fig.7 Equivalent circuit in fault condition When (a) $V_C<V_K$ and (b) $V_C>V_K$

4. Simulation

In this study, a wind farm equipped with fixed spe ed induction generator have been investigated and simu lated in PSCAD/EMTDC software. Fig.8 shows the stu died system in which the position of the limiter is de monstrated. In this figure wind farm is connected to th e transmission line that its length is 100 km. During the simulation period, the wind speed is equal to 14m/ s. The parameters of the simulated system are shown i n Table 1.

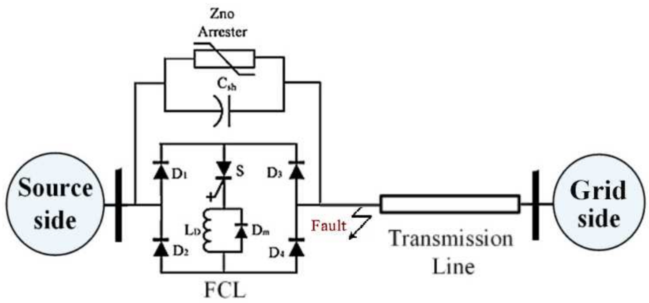

Fig.8 simulated power system

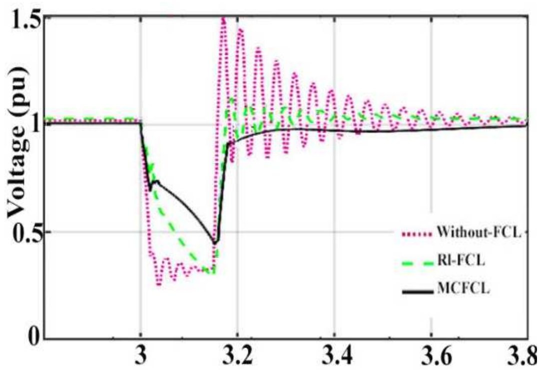

Fig.9 Terminal voltage of wind farm in single line to ground fault condition

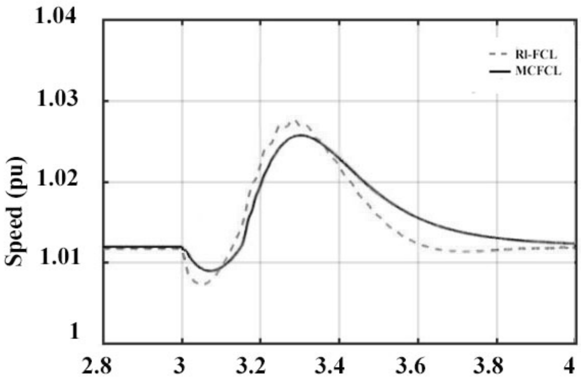

Fig.10 speed of rotor in single line to ground fault condition

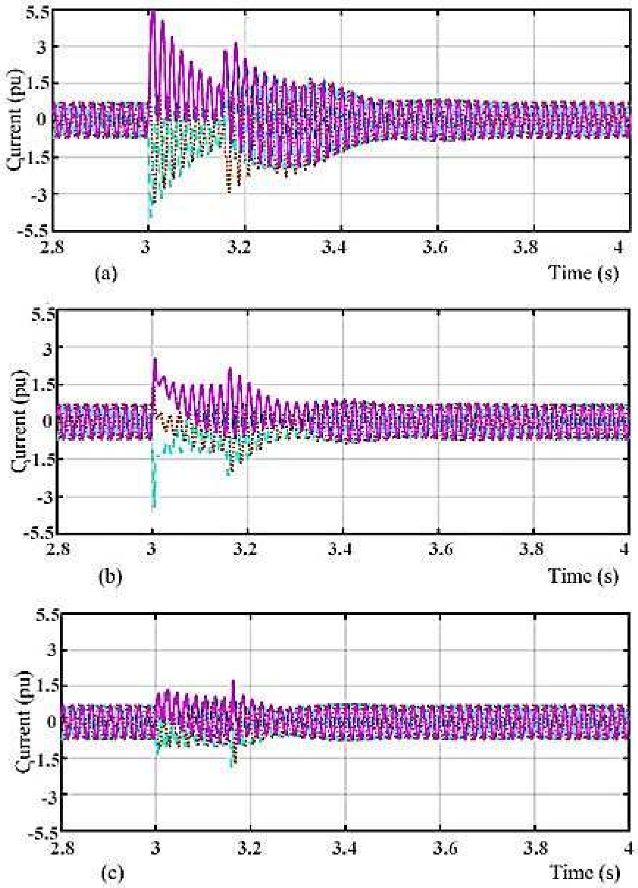

Fig.11. Stator current in the fault condition. (a) the non-FCL mode, (b) with the RL-FCL,(c) with the proposed limiter

The ability of the limiter to improve the LVRT con dition is investigated under single line to ground fault condition. The fault in the network happens in t=3s an d its length is 150 ms.

Fig.9 shows the waveform of the terminal voltage drop of wind farm for the non-FCL mode, with the R L-FCL and with the proposed limiter. By using the pr oposed and RL-type FCLs, the PCC voltage sag is eff ectively reduced. in other words the voltage drop in th e proposed FCL is lower than the RL-FCL.

Fig.10 demonstrates the FSIG rotor speed for the R L-FCL and with the proposed limiter. Considering this figure, the proposed FCL has lower oscillation compared to the RL-type SSFCL.

Fig.11 shows the stator current for the non-FCL mo de, with the RL-FCL and with the proposed limiter. A s shown in this figure, the fault current reaches to 5.5 pu in fault duration. By using the RL-FCL, the fault current is reaches to 3 and 2.3pu in fault period. But, the fault current is reaches to 1.7pu and 1.4 pu at dur ation of fault, respectively.

Table 1. Simulated system parameters

Induction Generator	Nominal power	2MVA
	Voltage	700V
	Frequency	50 Hz
	Constant of inertia	2s
	Resistance of stator	0. 006 Ω
	Stator leakage reactance	0.078 Ω
	Resistance of rotor	0. 016 Ω
	Rotor Leakage-reactance	0.1 Ω
	Mutual-Reactance	2.5 Ω
FCL	Csh	100uF
	VK	60kV
Grid	Voltage	132 kV
	Frequency	50Hz
	X/R ratio	5
Transmission Line	Resistance	0.272 Ω/km
	Reactance	0.372 Ω/km
	Length	100 km

5. Conclusion

In this study, a new structure for the fault current l imiter is presented and its performance is compared wi th the RL-FCL. The effectiveness of the proposed limit er is measured under a single line to ground fault con ditions in the transmission line in presence of fixed sp eed generator based wind farm. The results of the sim ulations showed that the proposed limiter is an effectiv e device to improve the LVRT ability of wind farm, a nd the capacitor in the limiter provides reactive power during and after the fault through less voltage drop d uring the fault and faster voltage recovery after the fa ult. Also, this limiter performs better than the RL-FCL and provides better voltage stability. On the other han d, the use of a DC reactor prevents the sudden increas e in current when the fault starts.

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