Modified Parallel resonance Type Fault Current Limiter

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Abstract

In this paper a new parallel resonance Fault Current Limiter (FCL) has been modified in a way that can sustain the magnitude of fault current and control it in a desired value. The operation is based on using parallel L&C resonance circuit with a resistor that reduces transient time and a pair of thyristors for controlling the value of fault current. Injected impedance can be controlled by changing firing angles of thyristors. Simulation with PSCAD/EMTDC software shows effectiveness of this topology for controlling fault current.

1. Introduction

The growth of electric power systems and their interconnections may result in fault currents levels that are more than the maximum short-circuit rating of the switchgears in some points of the grid [1]. For highly reliable power supply, fault current limiter (FCL) is becoming an essential part in the modern power system. The conventional technology used today to clear the fault is based on circuit breaker (CB) with over current relay [2]. The circuit breaker (C.B.) which is rated for the full system short-circuit current is placed to ensure the adequate protection of the power system during permanent faults. The typical operational time delay of practical circuit breaker ranges from few cycles to several seconds. During this time, only the system impedance can limit the fault current. Current limiting device is required to be introduced into the power system for limiting the fault current before opening the circuit breaker [3]. The implementation of FCLs in electric power systems is not restricted to suppress the amplitudes of the short circuits; they are also utilized to variety of performances such as the power system transient stability enhancement, power quality improvement, reliability improvement, increasing transfer capacity of system equipment, and inrush current limitation in transformers [4]-[11]. An ideal FCL should have the following characteristics [12]:

1) zero resistance impedance at normal operation ;
2) no power loss in normal operation and fault cases;
3) large impedance in fault condition;
4) quick appearance of impedance when fault occurs;
5) fast recovery after fault removed;
6) reliable current limitation at defined fault current;
7) good reliability ;
8) low cost ;

In [13] and [14] a new parallel resonance type FCL has been introduced. Fig.1 shows this FCL. Due to its novel topology it can sustain magnitude of fault in a constant value by inserting high impedance in fault time. Parallel capacitor and reactor that are tuned in network frequency puts high impedance in system during fault. Also a resistor has been added to this structure for reducing transient response that is harmful for power system equipment. For having constant value for line current in normal and fault condition, the injected impedance by FCL must be equal to the load impedance. However, it is difficult to equate these impedances exactly, and it is an ideal case because of load variation on distribution feeders [14]. As parameters for this FCL is set before installing, if we had faults in different distance in a transmission line or by any change in parameters of power system, we would have different values for fault currents. In this case the value of line current in normal operation and fault time will be different. This different is not pleasant for sensitive loads. A good FCL must have ability to adjust its impedance with different situations. In this paper, parallel resonance FCL has been modified in a way to able us for controlling the magnitude of fault. To achieve this aim a pair of thyristors has been placed in series with the reactor that can adjust injected impedance to the power system that is not possible in the previously introduced one. By controlling the firing angles of thyristors, fault current can be controlled in a desired value. Simulation with PSCAD/EMTDC software shows effectiveness of this topology as a FCL.

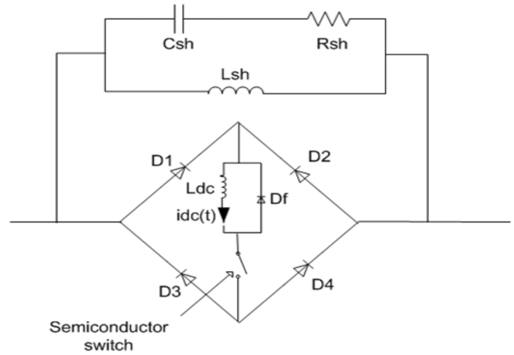

Fig. 1. Power circuit topology of the previous FCL

2. The topology and operation of the new FCL

Fig. 2 shows the single-phase power circuit topology of the proposed FCL. It is necessary to use a similar circuit for each phase in a three-phase distribution system. As operation and control system of this structure with previous one is the same, the next part is adopted from [13], [14]. This structure is composed of two main parts which are as follows:

1) Bridge part: This part consists of a rectifier bridge containing D_1 _D_4 diodes, a small dc-limiting reactor (L_{dc}), a self-turnoff semiconductor switch (such as a gate turnoff thyristor and an insulated-gate bipolar

transistor) and its snubber circuit, and a freewheeling diode (D_f).

2) Resonance part: This part consists of a parallel LC resonance circuit (L_{sh} andC_{sh}) (its resonant frequency is equal to power system frequency) and a resistor R_{sh} in series with the capacitor. And two thyristors that are in series with reactor.

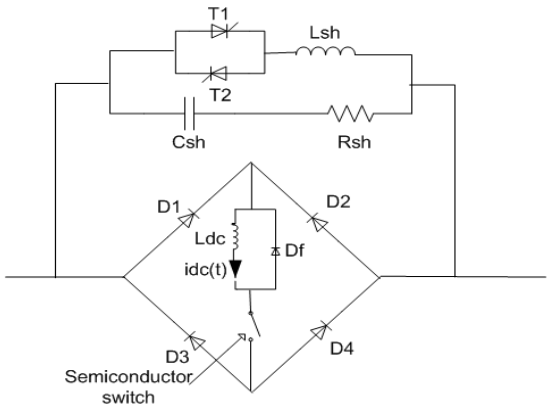

Fig. 2. Power circuit topology of the proposed FCL

The bridge part of the proposed FCL operates as a high-speed switch that changes the fault current path to the resonance part when the fault occurs. Obviously, it is possible to substitute this part with an anti parallel connection of two self-turnoff semi-conductor switches [15], [16]. Using a diode rectifier bridge has two advantages compared to two anti parallel switches as follows.

1) This structure uses only one controllable semiconductor switch which operates in the dc side instead of two switches that operate in the ac side. The control circuit is simpler because of no need for ON/OFF switching in the normal operation case.

2) It is possible to use a small reactor in series with the semiconductor switch at the dc side. This reactor plays two roles as follows.

   a) It is snubber for a semiconductor switch.

   b) It is as a current limiter at first moments of fault occurrence.

However, placing the dc reactor inside the bridge makes the voltage drop on it because of dc current ripple. However, the current ripple is low, and consequently, the voltage drop caused by it is not considerable in comparison with the feeder's voltage. Current ripple and voltage drop equations are studied completely in [6] and [17]. From the power loss point of view, in the normal condition, the proposed FCL has the losses on the rectifier bridge diodes, the semiconductor switch, and the small resistance of the dc reactor. Each diode of the rectifier bridge is ON in half a cycle, while the semiconductor switch is always ON. Therefore, the power losses of this FCL in the normal operation can be calculated as

$$P_{loss} = P_R + P_D + P_{SW} = R_{dc} I_{dc}^2 + 4 V_{DF} I_{ave} V_{SWF} I_{dc} \quad (1)$$

where:

I_{dc} : dc-side current which is equal to the peak of the line current(I_{peak});

R_{dc}: resistance of the dc reactor;

V_{DF}: forward voltage drop on each diode;

V_{SWF}: forward voltage drop on the semiconductor switch;

I_{ave}: average current of the diodes in each cycle that is equal to I_{peak}/π.

By Considering equation (1) and the small value of the dc reactor in this structure, the total power losses of the proposed structure become a very small percentage of the feeder's transmitted power.

Fig. 3 shows the control circuit of the proposed FCL [14]. In the normal operation of the power system, the semiconductor switch is ON. Therefore, L_{dc} is charged to the peak of the line current and behaves as a short circuit. Using the semiconductor devices (the diodes and semiconductor switch) and the small dc reactor causes a negligible voltage drop on the FCL. When a fault occurs, the dc current becomes greater than the maximum permissible current I_0 , and the control circuit detects it and turns the semiconductor switch off. Therefore, the bridge retreats from utility. At this moment, the freewheeling diode D_f turns on and provides free path for discharging the dc reactor. When the bridge turns off, the fault current passes through the parallel resonance part of the FCL. Consequently, large impedance enters to the circuit and prevents the fault current rising. In the fault condition, the parallel LC circuit starts to resonate. In this case, because of resonance, the line current oscillates with large magnitude [15], [16]. These oscillations may lead to damaging system equipment or putting them in stress. However, by placing a resistor (R_{sh}) in series with the capacitor, current transients damp quickly. In addition, by using R_{sh}, the drop on R_{sh} causes that the voltage across the capacitor is decreased during fault . When the fault disappeared, while the semiconductor switch is OFF, the parallel part of the FCL will be connected in series with the load impedance. Therefore, the line current will be decreased instantaneously. To detect this instantaneous reduction of the line current, I_L is compared with I_f that can be calculated from

$$I_f = |V_{PCC}|/|Z_{eq}| \quad (2)$$

where Z_{eq} is the equivalent impedance of the resonance part and V_{PCC} is voltage of point of common coupling.

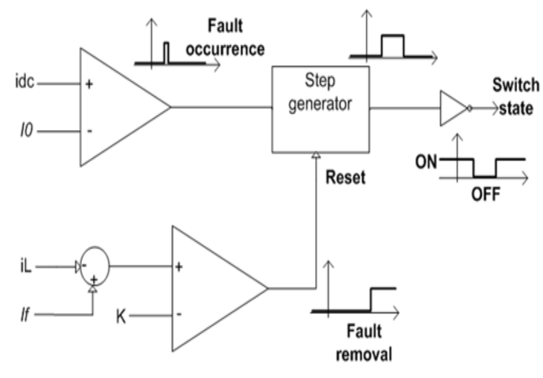

Fig. 3. Control system of proposed FCL

When the difference of I_L and I_f becomes greater than k as the fault removal sign, the control circuit turns the semiconductor switch on. Therefore, the power system returns to the normal state. The value of k can be calculated from

$$K=|V_{PCC}|/|Z_{eq}|-|V_{PCC}|/|Z_{eq}+Z_{L,min}| \quad (3)$$

where $Z_{L,min}$ is the minimum impedance of the load on the protected feeder [14]. As pointed, some of previously proposed FCL structures have ac power losses at the resonant circuit in the normal condition, because of placing a large inductor in the line current path [18], [19]. However, the proposed structure in this paper has very low losses in the normal condition, because the inductor is bypassed by the bridge part [13]. The FCL puts a constant impedance to the power system. If there is any difference between impedance of FCL and load impedance, firing angles of thyristors can change the magnitude of injected impedance by FCL to equate it to the load impedance. The equivalent impedance for FCL is as follows:

$$B_L(\alpha) = (1/L_{sh}\,\omega)\,[1-(2/\pi)\alpha-(1/\pi)\sin 2\alpha] \quad (4)$$

$$Z_{eq} = [\,R_{sh} - j/(\omega\, C_{sh})\,] \;\|\; [\,(L_{sh}\,\omega)/(1-(2/\pi)\alpha-(1/\pi)\sin 2\alpha)\,] \quad (5)$$

where:
α: firing angles of thyristors measured from the peak of voltage
$B_L(\alpha)$:equivalent admittance of reactor with changes of firing angle.
Z_{eq} : equivalent impedance of FCL.

3. Simulation results

Fig.4 shows power system used for simulation. Parameters of this circuit has been shown in table 1. Fault occurs at t=1second and lasts for 0.5 second. Fig. 5 shows line current without using FCL. As can be seen from this figure line current reaches to a high value that is not acceptable for power system and its equipments. Without using resistor in FCL topology line current will have oscillations with high magnitude [14]. Fig. 6 shows this oscillations. In fig. 7 FCL has been put in the line. In this case firing angles of thyristors (α) is 0° which it means that they don't have any effect on magnitude of FCL. Fault current in this situation due to its chosen parameters is less than prefault current. Fig. 8 shows that line current reached to its prefault value by setting firing angle to 30°. By increasing firing angle, line current even can be controlled in a wide range. Fig. 9 shows line current for $\alpha = 50^\circ$. It is obvious that using thyristors make line current in fault time distorted. For this example for $\alpha = 0^\circ$ the THD = 0.1%, for $\alpha = 30^\circ$ the THD = 16.98% and for $\alpha = 50^\circ$ the THD = 17.6% . As parameters like capacitor, reactor and resistor for FCL is determined in such a way that the FCLs impedance be equal to load impedance, firing angles would not choose high values and in this firing angles the THD for line current will be acceptable. Distorted line current with high THD during fault has bad affects on the operation of distance relay in power system [20]. Thus it is better to use this FCL in low firing angle. As line current assumed to be completely sinusoidal thus this injected current with little distortion doesn't has so much effect on power system. Fig. 10 shows reactor current with $\alpha = 30^\circ$.

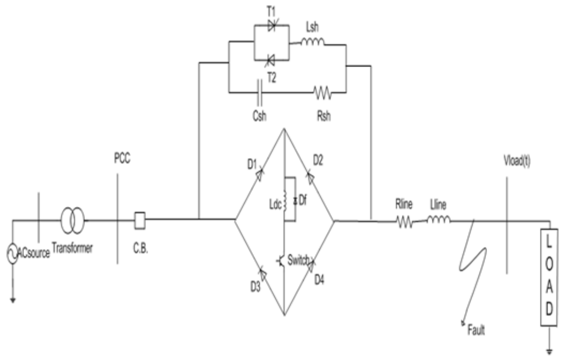

Fig. 4. Power circuit for simulation

Table 1. Parameters of power system

Source Data	V_{rms}=20kV, f=50Hz, R_s=0.57Ω, L_s=3mH
Transformer	20kV/6.6kV, 10MVA, 0.1 p.u.
FCL Parameters	C=68µF, L_{sh}=150mH, R_{sh}= 10Ω V_{df} =V_{DIGBT} = 3V, L_{dc}= 0.01H
Line Impedance	R_{line}=0.5 Ω, L_{line}=170mH
Load Impedance	R_l=15Ω, L_l=100mH

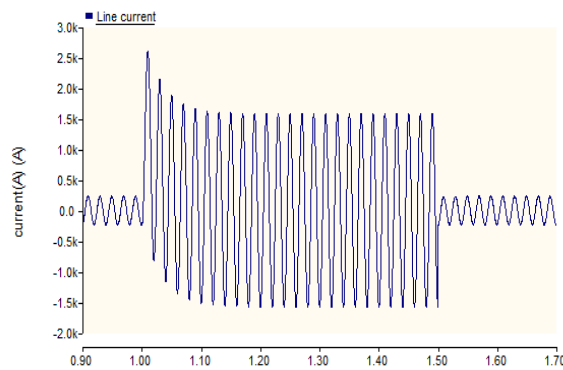

Fig. 5. Line current without FCL

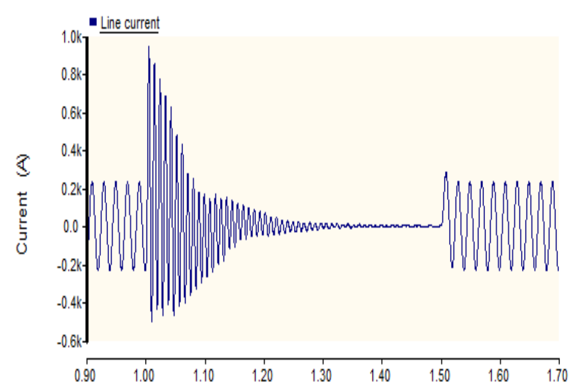

Fig. 6. Line current without using resistor in FCL topology

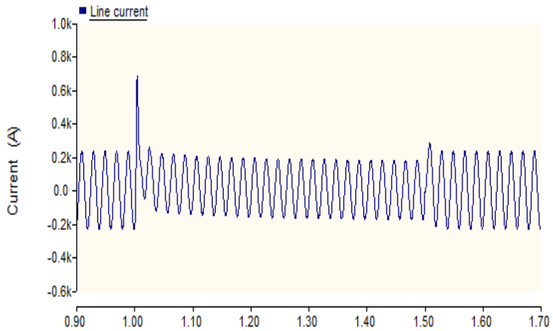

Fig. 7. Line current with α =0°

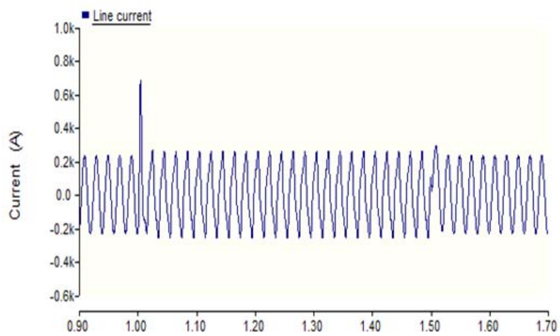

Fig. 8. Line current with α =30°

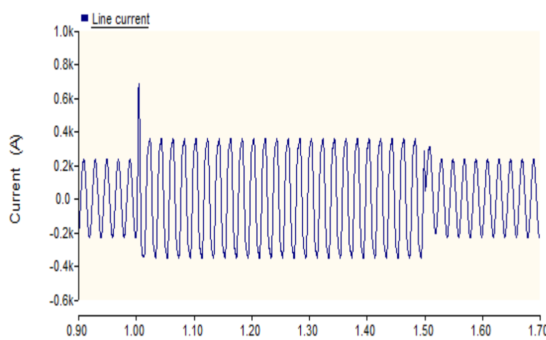

Fig. 9. Line current with α =50°

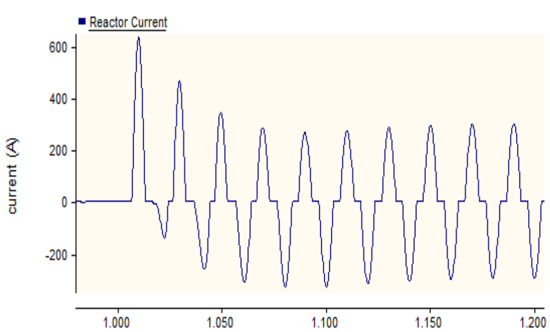

Fig. 10. Reactor current with α =30°

4. Conclusion

In this paper a parallel resonance FCL has been modified in a way that can control the magnitude of fault current that wasn't possible in previously introduced one. To achieve this aim a pair of thyristors has been added to the previous topology. By any changes in firing angles of thyristors the reactor's impedance changes and consequently the injected impedance by FCL will be controlled. Using non-superconducting reactor and dry capacitor leads to low construction and maintenance costs. Simulation results with PSCAD/EMTDC software shows effectiveness of this kind of FCL.

5. References

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