Investigation of Distance Relay Performance in Presence of Resistive Bridge-Type Fault Current Limiter (RBFCL)

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Abstract – Due to the development of fault current limiters (FCLs) for employment in high voltage (HV) level power system, the possibility of utilizing them in transmission systems has increased. Installation FCLs have significantly advantages to flexible and reliable operation of power system. Despite the more advantages of installation FCLs, it affects on the transmission lines protection system, which is commonly protected with distance relays. FCLs change the impedance of transmission lines during fault, which can lead to failure operation of distance relay. In this work, the effect of resistive bridge-type fault current limiter (RBFCL) on the apparent impedance seen by distance relay is investigated. For achieve this, first, the RBFCL is modeled in PSCAD/EMTDC and then the effect of its impact on the distance relay characteristic is evaluated. To this study different short circuit fault including single line to ground (SLG) and line to line (LL) faults are taken in to account. Simulation results reveal the adverse impact of the RBFCL on distance relay performance.

Keywords: Restive Bridge-Type Fault Current Limiter (RBFCL), Transmission Lines, Distance Relay Characteristic .

1. Introduction

The response to the growth demand of electricity, in many countries, makes expansions of power plants, transmission line and distribution systems. It has led to short circuit current level intensifies in some point of grid. This condition put the series equipments of grid under large fault currents with high and rather intolerable thermal and electromagnetic stresses, which can lead to mal-operation of protection systems. There are several conventional solution for handling Traditionally, handling these increasing short circuit currents these increasing short circuit currents, which require the high costly replacement of some apparatus such as switchgears and circuit breakers (CBs) or the imposition of layout changes in the grid facilities. These solutions decreased the operational flexibility and reliability of power system. Application of fault current limiters (FCLs) in power system is a novel approach to cope with the aforementioned problems without replacement of system apparatus with high ratings. FCLs allow exiting equipments to stay in service, even if the short circuit current level exceeds its tolerable and short-time withstand current during fault condition [1-3].

Considering aforementioned drawbacks, it is expected the FCL is extensively employed in transmission lines and distribution systems in future. Therefore, it is inevitable to investigate the aspects of installation and presence of FCLs in the operation and equipments of power system. One of them is the impact of FCLs on transmission lines protection systems, which realized by distance relay. It is expected that the presence of FCLs impose impedance change during fault, which can cause overreach error in impedance measurement of distance relay. Providing low impedance path to flow line current at normal operation mode and large impedance path to limit fault current in the shortest possible time are an ideal FCL characteristic [2-5].

Recently, in the literature different types of FCLs have been suggested and documented, which can be classified into following categorized [5-10]:

- Superconducting FCLs (SFCLs) include inductive SFCL[6], resistive SFCL[7], transformer-type SFCL[8], sutured iron-core SFCL[9] and bridge-type SFCL[10]
- Non- superconducting FCLs (NSFCLs) include resonance FCL (RFCL)[11], solid-state FCL(SSFCL)[12]

Application of SFCLs in power system offers a reliable and secure interface for limiting fault current with significant advantages. Presence of the SFCL not only

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decline the thermal and mechanical stresses on system apparatus but can also enhance the substation reliability [13], and distribution system power quality [14], limit high transient inrush current of power transformers in distribution systems [15], reduce the transient recovery voltage (TRV) across of circuit breakers (CBs) [16] and improve transient stability of power systems and wind power plants [17] by reducing the fault current. However, they require high cost superconducting materials, which make infeasible for application in high voltage level. Recently, the application of SSFCLs attracts more attention due to development of high voltage and current power electronic-based switches.

In literatures, the aspects of FCL application on distance relay performance less are considered. In [18-19], the distance relay performance with and without using of sutured core SFCL has been investigated. The work in [18] presents the impacts of BSFCL on distance relays characteristics under different symmetrical and unsymmetrical faults has been investigated by analytical and simulation study. In [19], the procedure of apparent impedance calculation for a transmission line in presence of resistive SFCL (RSFCL) based on the frequency sequence component is studied.

This paper studies the impact of RBFCL on distance relay characteristics. Simulations were carried out by using PSCAD/EMTDC software. In this study, the performance of distance relay with and without RBFCL under single line to ground (SLG) and line to line (LL) faults are taken in to account.

2. RBFCL Principle Operation

The per-phase schematic diagram of the SSFCL is depicted in Fig. 1. It consists of following parts:

- bridge circuit (D1-D4),
- Insulated-gate bipolar transistor (IGBT) semiconductor switch (T)
- DC reactor (Ld)
- Freewheeling diode (Dm).
- Insulated transformer
- Limiting resistor (Rd)

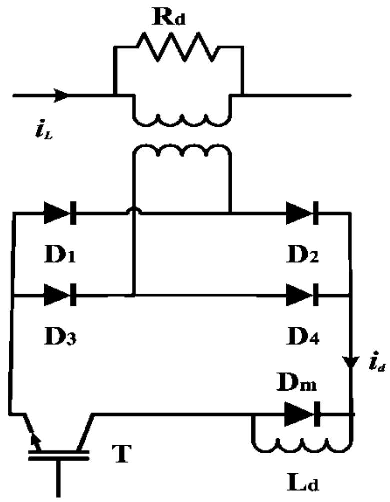


Fig. 1. RBFCL power circuit

The principle operation of the RBFCL is divided into steady-state and fault operation mode. For steady-state operation mode, the IGBT semiconductor switch (T) is closed, which makes a low impedance path for flowing the line current (i.e. iL) through the D1-Ld-D4-T path for positive half electrical cycle and D2-Ld-D3-T path for negative half cycle, respectively. The rectifier bridge circuit converts the ac line current to dc (i.e. id), which flows through the DC reactor (Ld). The following current through DC reactor (id) increases to the peak value of the iL, and it enters to the steady-state operation. When the id is charged to constant value, it offers no impedance. The impedance of the limiting resistor (RD) is relatively large, as a consequence, the iL flows through the rectifier circuit and the Ld path and the RD current is very low during this mode. The resistance of the DC reactor, the T and D1-D4 produce some power losses and voltage drop, which are ignorable during this mode. When a fault occurs, the control system detects the fault and control system makes the T open. Therefore, the RD is inserted in series with the line and the fault current is limited.

The DC reactor not only limit the rate of increasing fault current, but also it protect the T and D1-D4 at fault inception instants. Also, when the T is opened, the DC reactor current freewheels through the Dm during fault.

3. Distance Relay

The main function of distance relay is determining the fault position in transmission lines by measuring the impedance. It depends on the distance of fault point to distance relay location in transmission lines. For achieve this, the distance relay evaluates the voltages and currents to calculate the impedance. Equations (1) and (2) show the impedance calculation expressions of the measured impedance by the line-to-line (LL) and line-to-ground (LG) short circuit faults by distance relay, respectively.

$$Z_{LL} = \frac{U_L}{I_L} \quad (1)$$

$$Z_{LG} = \frac{U_{LG}}{I_{LG} + K\varepsilon I} \quad (2)$$

Here, the subscript LL in (1) can be AB, CA or BC phases. Also, the subscript LG represents the phases A, B, or C. the I0 represents the zero-sequence current of line current. K represents the compensation factor, which is represented by $K = (Z0 - Z1)/3Z1$, where Z0 and Z1 are the zero and positive-sequence impedance of the transmission lines from view point of the distance relay during fault[21-22]. Table 1 presents the needed input signals for calculate the symmetrical and unsymmetrical faults impedance.

Table 1. Input Signals for calculate impedance through distance relay

Input signals	*Voltage Variable*	*Current Variable*
A to G fault	V_A	I_A and I_0
B to G fault	V_B	I_B and I_0
C to G fault	V_C	I_C and I_0
A to B fault	V_{AB}	I_{AB}
B to C fault	V_{BC}	I_{BC}
A to C fault	V_{AC}	I_{AC}

4. Simulation Results and discussion

In this studied work, the single line diagram shown in Fig. 2 is simulated. It comprises two 132kV and 200km parallel transmission lines including the Line A and Line B. The RBFCL is inserted at the transmission line B, as shown in Fig. 2. The simulated system includes two infinite bus system is presented by two equivalent voltage sources, Es as sending bus and Er as receiving bus, respectively. The ratio of Es/ER is 0.98<200. The parameters of simulated system shown in Fig. 2, have been listed in table 1. The positive, negative and zero sequence impedance of lines A and B are 0.0178 +j0.3139 (Ω/km), and 0.2952+j1.0399 (Ω/km), respectively. Six input signals are measured for LG and LL short circuit faults protection. The Fast Fourier Transform (FFT) algorithm is used for each measuring signals to determine the line impedance include the resistance and reactance of the fault. Also, for avoiding aliasing error, an anti-aliasing low pass filter is used [18].

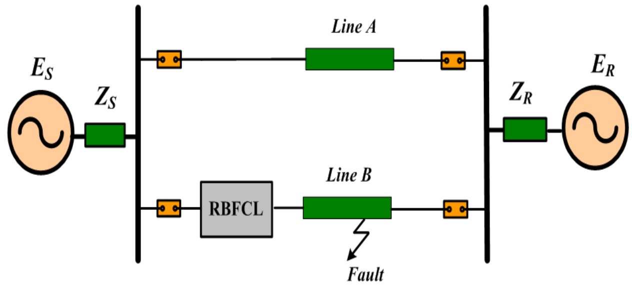


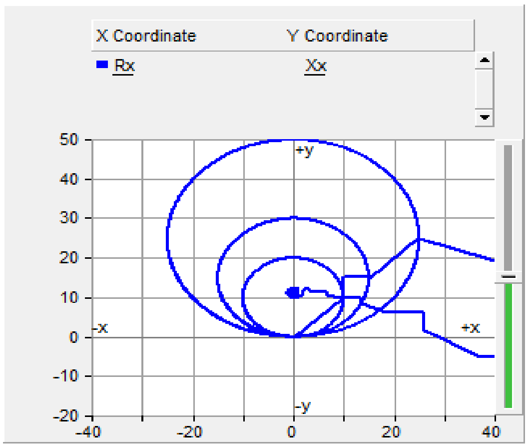
Fig. 2. The test system

4.1.1 SLG Fault

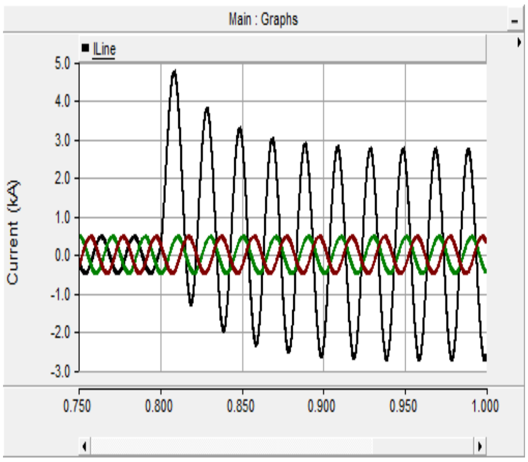
To check the behavior of distance relay in presence of the RBFCL, a LG fault i.e. A-G is simulated on transmission line B at distance of 100km from the beginning of line B, as shown in Fig. 2. Fig. 3(a) and (b) demonstrate the short circuit fault current and the calculated impedance by distance relay without using the RBFCL. Fig. 4(a) and (b) demonstrate the short circuit current and calculated impedance by distance relay with using the RBFCL. It can be observed from Fig. 3 and Fig. 4 that the short circuit fault current of phase A is reduced from 5kA to 1.2kA in presence of the RBFCL during fault. Also, it can be observed, that the impedance seen by the distance relay has been considerable under reached.

4.1.2 LL Fault

Fig. 5(a) and (b) demonstrate the short circuit current and apparent impedance without using the RBFCL for A-B fault. Fig. 6(a) and (b) demonstrate the short circuit fault current and apparent impedance with using the RBFCL for A-B fault. It can be observed from Fig. 6(a) that the short circuit fault current of phase A is reduced from 4kA to 2kA by using the RBFCL during fault. Fig. 6 (b) demonstrates the impedance seen by the distance relay, with and without using the RBFCL during A-B fault. It can be observed from this figure, that the impedance seen by the distance relay has been considerable under reached for A-B fault, too.

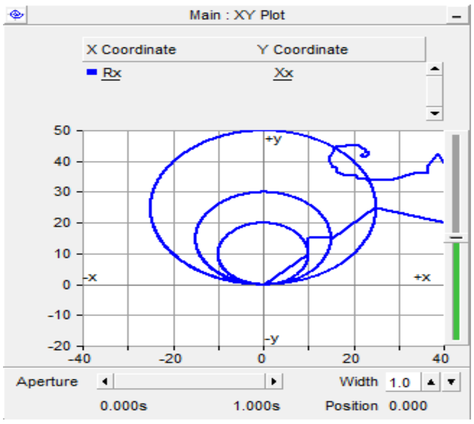


(a) Apparent impedance

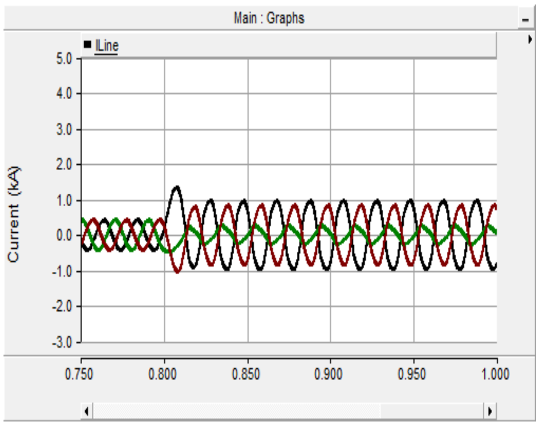


(b) Short circuit fault current

Fig. 3. (a) Apparent impedance, (b) Short circuit fault current in the case of without using RBFCL for A-G fault

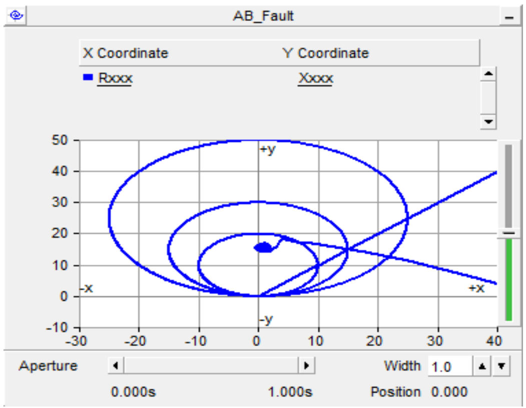


(a) Apparent impedance

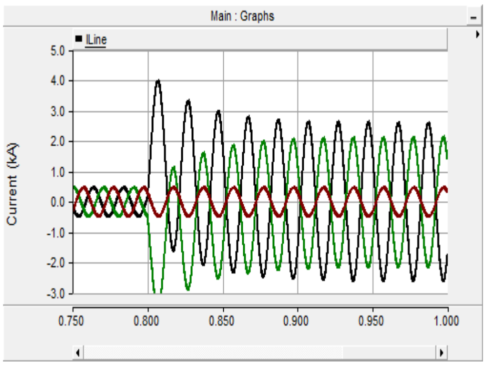


(b) Short circuit fault current

Fig. 4. (a) Apparent impedance, (b) Short circuit fault current in the case of using RBFCL for A-G fault

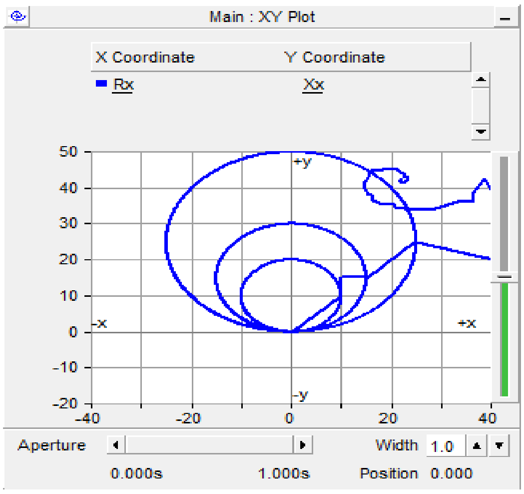


(a) Apparent impedance

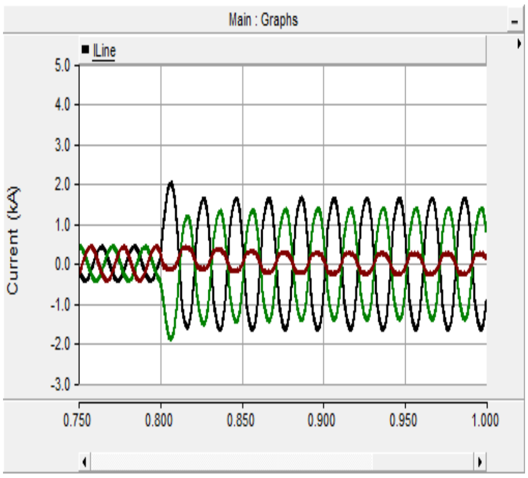


(b) Short circuit current

Fig. 5. (a) Apparent impedance, (b) short circuit current, in the case of without using RBFCL for A-B fault



(a) Apparent impedance



(b) Short circuit current

Fig. 6. (a) Apparent impedance, (b) short circuit current, in the case of using RBFCL for A-B fault

5. Conclusion

In this paper, the performance of distance relay characteristic in presence of the RBFCL has been investigated. Simulation results of this study reveals that the limiting impedance of the RBFCL has significant impact on the impedance seen by the distance relay for A–G and A-B faults. This impact is represented as considerable under-reaching. Also, the RBFCL performance causes the impedance of the distance relay converge with low speed to reach the steady state value.

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