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Improving Transient Recovery voltage of circuit breaker using Fault Current Limiter

[1]Amir Heidary, [2, 3]Hamid Radmanesh, [2]Seyed Hamid Fathi and [1]Hamid Reza Rajabi Khamse
[1]Electrical Engineering Department, Islamic Azad University, Zanjan Branch, Zanjan, Iran
[2]Electrical Engineering Department, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
[3]Electrical Engineering Department, Islamic Azad University, Takestan Branch, Takestan, Ghazvin, Iran

Abstract: This study investigates influence of Fault Current Limiter (FCL) on short-circuits current level of substation bus bar splitter circuit breaker and its TRV. An approach for TRV evaluation is developed and applied for proposed power system as shown in this study. FCL circuit is connected to the power system in order to limit TRV. The limiter circuit consists of two equal windings which are turned around unique magnetic core. One of the windings is connected in series with the power system network and the other is connected to the network via series capacitor and power electronic switches. During normal operating condition, both tyristors are in on state and current of the primary and secondary windings are equal. This causes zero impedance of the limiter. During fault, faults current cause the power electronic switch to turn off which increases the limiter impedance. By increasing the limiter impedance, amplitude of TRV decreases substantially. The novel method presented in this study is a cheap and successful scheme.

Keywords: Circuit breaker, fault current limiter, transient recovery voltage

INTRODUCTION

Transient Recovery Voltage (TRV) represents the transient voltage appearing across the terminals of circuit breakers, following fault currents interruption. The circuit breaker interruption capability is limited by both the fault current and the TRV levels. TRV waveform depends on various factors as: the fault position (Terminal, Short-line or Transformer faults), the fault type (3LG, 2LG or 1LG fault), the parameters of the lines connected to the faulted bus-bars as (IEC56, 1992) define standard envelopes based on the requirements concerning TRV main parameters (Rate-of-Rise and Peak Value). If TRV waveform exceeds the standard envelope, the breaker may fail to interrupt the current, as high values of the Rate-of-Rise or the Peak Value may lead to thermal or dielectric failure in the breaker quenching chamber. In this study an approach for TRV computation is developed and the efficiency of different fault current limiting means (as substation bus-bars splitting) is evaluated from TRV point of view. Then, new suggested FCL is used for decreasing the amplitude of the occurred TRV. Although Circuit Breakers (CBs) in electric power systems are used to switch on and off the continuous load current under normal operation conditions, they are primary designed to break the short circuit current in case a fault occurs. In order to successfully break the current, the CB has to withstand the transient recovery voltage that arises across its terminals when the previous arc column rapidly loses conductivity after current zero. Besides the magnitude of the fault current itself, the TRV waveform is the most significant information needed for choosing the appropriate CB for a given application. In particular, the Rate-of-Rise-of-Recovery-Voltage (RRRV) is the essential parameter. Although manufacturers know the RRRV capability of their switchgear, customers often only have inadequate data about the TRV assigned with their particular application. Especially, the TRV waveform associated with power transformer secondary terminal faults is seldom known by the user with the necessary accuracy. On the other hand, transformers in electric systems are one of the most costly apparatus. To illustrate a typical situation of interest, Fig. 1 shows an equivalent circuit of the power system at an ungrounded phase-to-phase fault. As a worst case, the TRV across the first pole-to-clear of a three-phase CB clearing a terminal fault current is essentially determined by the transformer alone (Harner, 1968). Therefore, the source side is represented by three ideal single-phase voltage sources connected directly to the primary side (inputs). Because of the wye-delta configuration chosen for this example, the neutral of the source side is connected to the neutral bushing of the transformer and to the tank, both connected to ground. Harner and Rodriguez (1972) published a study on TRV associated with transformer secondary faults (Harner and Rodriguez, 1972). They measured the

Corresponding Author: Hamid Radmanesh, Hamid Radmanesh, Electrical Engineering Department, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran, Tel.: (+98-21) 64543335, Fax: (+98-21) 88212072

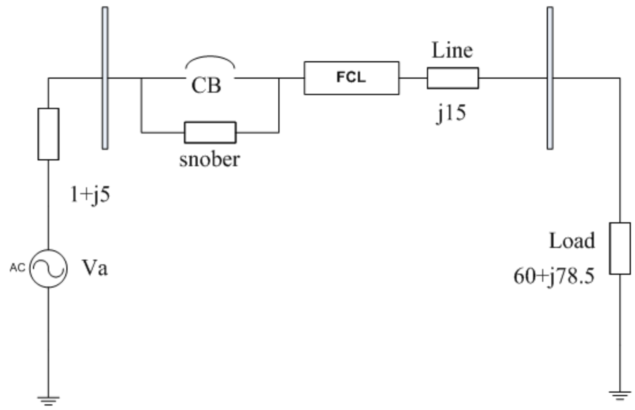

Fig. 1: Proposed power system configuration

TRV waveform across a model circuit breaker when breaking a sine-shaped current pulse. The latter was injected into the source side of the transformer by means of a low voltage ac source (Low-Voltage Current Injection method, LVCI). After investigating approximately 120 transformers, they stated in Harner and Rodriguez (1972), that mostly "the form of the transient is a displaced-cosine wave of a single frequency." Only in this case, the RRRV can be calculated directly from this frequency and the Amplitude Factor (AF), the latter giving the relation between the first peak values of the TRV to the recovery voltage in the steady state. Therefore, (Harner, 1968) assigned an equivalent frequency of oscillation in order to match the standard TRV waveform. He plotted the median and 90-percentile curves against the inherent three-phase fault current for several voltage classes, thus providing easy-to-use charts. These charts are still recommended within the US standards for high-voltage ac circuit breakers (ANSI, C37) and in the corresponding guidelines (IEEE, 1994). Similar study is reported in CIGRE (1970), where is plotted against the short circuit power for several voltage classes. There it is found that is almost inversely proportional to the rated voltage and approximately proportional to the short circuit power. However, the appropriate European standards (IEC 56, 1992) do not explicitly recommend these findings as guidelines (IEC 56, 1987). The only statement there is: "in the case of a short circuit immediately after a transformer, both the peak voltage and the RRRV may exceed the values specified in this standard." Although the charts in (IEEE, 1994) cover voltages from 4.2 to 765 kV, the data points for some of those classes are only few if not just one single data point (e.g., class of 765 kV; compare (ANSI C37, 2000). Impact of the inductive FCL on the interrupting characteristics of high-voltage cbs during out-of-phase faults has been given in Hongshun (2009). New three-phase inductive FCL with common core and trifilar windings is studied in Cvor (2010). In current study, improving transient recovery voltage of circuit breaker by using FCL has been investigated. Study of the system consists of two cases, at first, system modeling of power system without FCL and second, power system contains FCl. Finally compare the result of these two cases.

METHODOLOGY

Power system modeling: In those critical cases, the TRV must be measured, either by means of actual short circuit tests, which are rather expensive, or with the Low-Voltage Current Injection (LVCI) method that was introduced for the first time in Kotheimer (1955). From the considerations above, it is concluded that there is a strong need for an inexpensive tool to determine the TRV of power system during design and type testing, as well as of units already in service. Especially with respect to cost reduction for new installations and retrofit such a method becomes highly valuable. It is also used for modeling the transformer's transient behavior, especially for lightning surge studies (Hribernik and Richter, 2000; Moched *et al.*, 1993). All of those methods require a certain skill in modeling as well as highly sophisticated numerical mathematical tools for the parameter fitting. Therefore, a novel approach is presented in this study, where the TRV waveform amplitude is decreased successfully by applying suggested FCL circuit.

Computational model: One method for TRV suppuration was developed based on simulation of the breaker opening process in a three-phase equivalent network. The FCL structure is used for limiting the occurred TRV. The method is more accurate and faster as compared with the previous published study. Figure 1 shows proposed power system which is used in this study and Fig. 2 shows circuit of FCL structure.

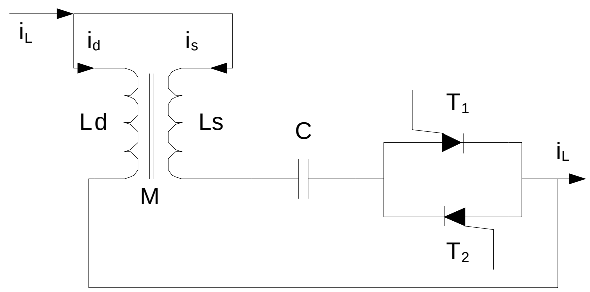

Fig. 2: Fault current limiter structure

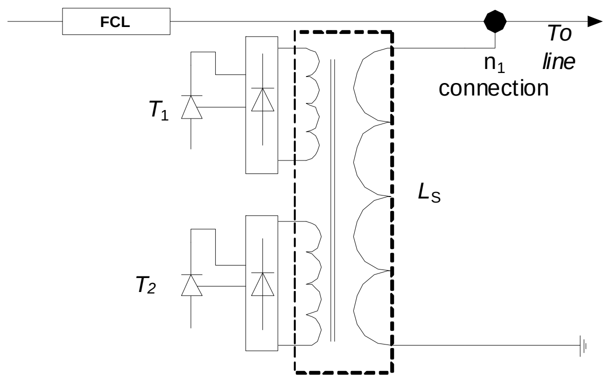

Fig. 3: Fault detector transformer

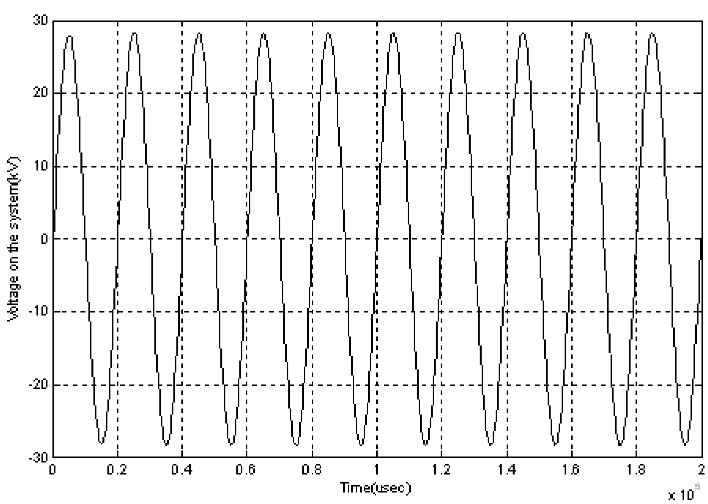

Fig. 4: Power system source voltage

Fault current limiter operation: The limiter circuit consists of two equal windings which are turned around unique magnetic core. One of the windings is connected in series with the power system network and other one is connected to the network via series capacitor and power electronic switch. During normal operation condition, both tyristors are in on position and current of primary the and secondary windings are equal. This cause to decrease impedance of the limiter to zero, when fault occurs, current of the first switched reaches to zero via fault detector transformer and cause to reach the second switch current to zero. These processes increase the limiter impedance and decrease the amplitude of the occurred TRV on the circuit breaker. The explained system configuration is shown in Fig. 3.

SIMULATION RESULTS

Simulation is done on the proposed power system while fault is occurred on the load bus bar. Duration of fault is 10 msec and after the fault occurring, circuit breaker disconnects the line in order to limit the fault. In this section, voltage on he circuit breaker has been analyzed in two cases. In the first case, circuit breaker application has been considered without FCL installation and in the second case; TRV on the circuit breaker is analyzed with considering FCL structure. This study is done in the 20 kV distributation network.

Figure 4 shows load bus bar voltage with 20 kV rms amplitude. This waveform is completely sinusoidal and frequency of it is 50 Hz. Figure 5 shows circuit breaker voltage while its amplitude reaches to 40 kV. Figure 6 shows TRV of the circuit breaker in extend view. By connecting FCL circuit to the power system line, fault current is controlled. In this case, FCL can control the fault current and causes to limit the magnitude of the TRV on the circuit breaker as shown in Fig. 7 and 8. Also, Fig. 9 shows power system current before and after occurring the fault.

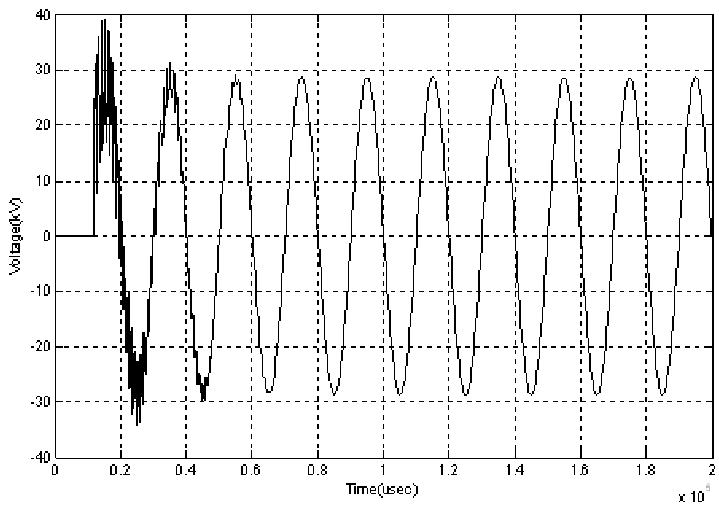

Fig. 5: Occurred TRV on the circuit breaker without connected FCL effects

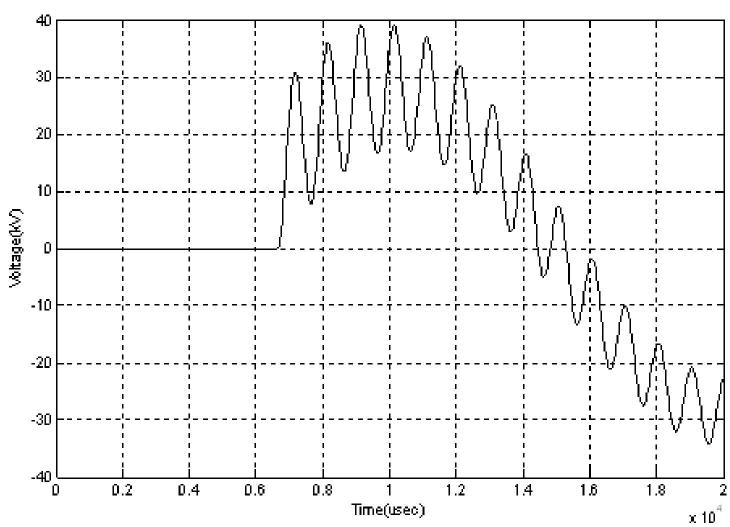

Fig. 6: Occurred TRV on the circuit breaker without connected FCL effects in expand view

Terminal Fault (TF) represents the fault occurring on the bus-bars or on a line, close to the bus-bars. TRV level depends proportionally to the fault current, but inverse proportionally to the number of the lines connected to thebus-bars (Chimklai and Marti, 1995; Hribernik, 2000; Pankaj and Selman, 1995). In TF case, the breaking

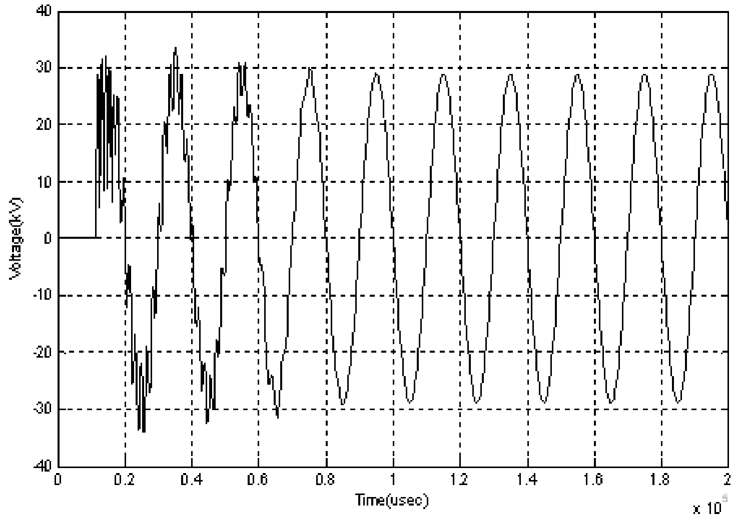

Fig. 7: Effect of FCL on the TRV

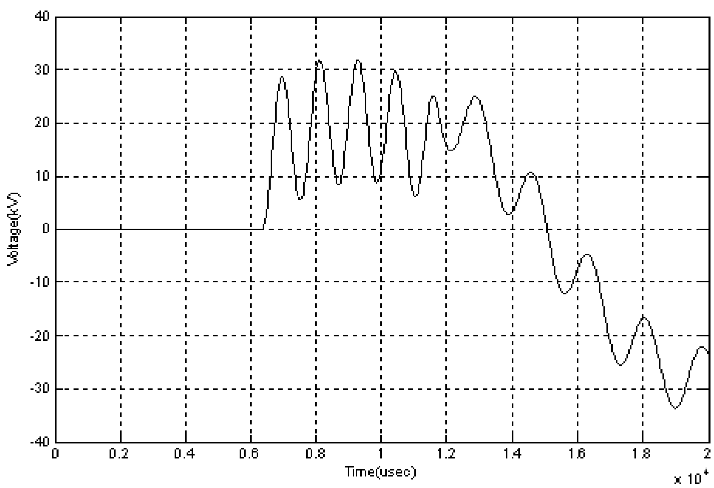

Fig. 8: Effect of FCL on the TRV in expand view

capability is limited especially by TRV Peak Value. TRV waveforms were evaluated for faults on each 161 kV lines connected to the bus-bar. Figure 4 emphasizes the influence on TRV Peak Value of the faulted line length, when the breaker on the line remote side is either opened or closed. TRV depends proportionally to the fault current, the faulted line parameters and the distance from the fault position to the bus-bar. The breaker capability is generally limited by TRV Rate-of-Rise. TRV waveforms were evaluated for different lines and fault position (1.5 km from the bus-bar). Figure 5 presents the influence of bus-bar splitting on TRV Rate-of-Rise for a 1LG fault on a typical line (wave impedance of 350 ohms). The figure emphasizes the TRV Rate-of-Rise decrease, due to the fault current reduction depending on the fault position. Characteristic TRV damped oscillatory waveforms for a 1 or 3 LG fault, at 2 km from the bus-bar, are presented in Fig. 6 (during a short period of 150 us from breaker opening). A high Rate-of-Rise (4.5 kV/us) is emphasized (due to a higher dominant frequency of 2.5-3 kHz, in the case of the Short-Line fault, in comparison with 500 Hz in the case of the Terminal Fault).

CONCLUSION

An approach for circuit breakers TRV computation was developed and the efficiency of current limiting mean was investigated, emphasizing that these mean improve the TRV level (despite of the fault current reduction). The main conclusions are as follows:

- The bus-bar splitting might lead to a higher TRV Rate of Rise and Peak value in the Terminal Fault case, but to a lower Rate-of-Rise in the Short-Line Fault case)

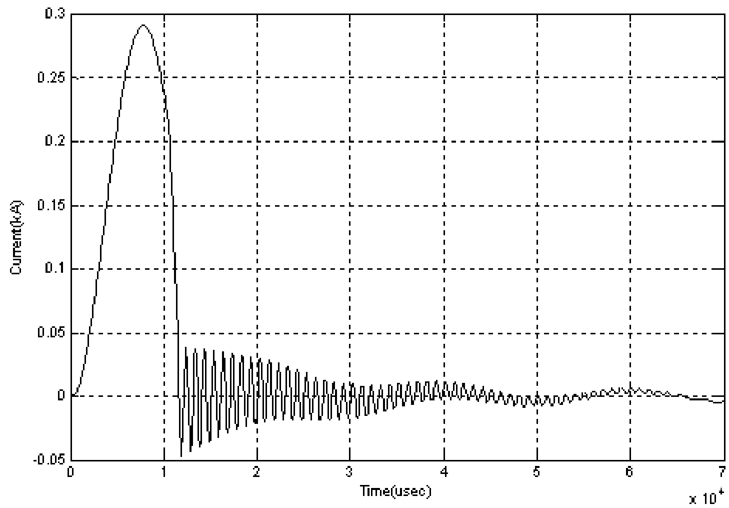

Fig. 9: Falut current with and without FCL effect

- Effect of FCL on the occurred TRV and circuit breaker protection against the TRV by connecting FCL. Connected FCL can decrease the amplitude of TRV and successfully control the TRV by increasing the impedance of the limiter circuit.

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