

## Chapter 7

# Transformer Model for TRV at Transformer Limited Fault Current Interruption

**Masayuki Hikita**

*Kyushu Institute of Technology, Japan*

**Hiroaki Toda**

*Kyushu Institute of Technology, Japan*

**Myo Min Thein**

*Kyushu Institute of Technology, Japan*

**Hisatoshi Ikeda**

*The University of Tokyo, Japan*

**Eiichi Haginomor**

*Independent Scholar, Japan*

**Tadashi Koshiduka**

*Toshiba Corporation, Japan*

### ABSTRACT

*This chapter deals with the transient recovery voltage (TRV) of the transformer limited fault (TLF) current interrupting condition using capacitor current injection. The current generated by a discharging capacitor is injected to the transformer, and it is interrupted at its zero point by a diode. A transformer model for the TLF condition is constructed from leakage impedance and a stray capacitance with an ideal transformer in an EMTP computation. By using the frequency response analysis (FRA) measurement, the transformer constants are evaluated in high-frequency regions. The FRA measurement graphs show that the inductance value of the test transformer gradually decreases as the frequency increases. Based on this fact, a frequency-dependent transformer model is constructed. The frequency response of the model gives good agreement with the measured values. The experimental TRV and simulation results using the frequency-dependent transformer model are described.*

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## INTRODUCTION

In high voltage electric power systems, especially 300 kV and 550 kV systems, very high capacity power transformers, up to 1500 MVA, have been used. When faults occur at the secondary sides of the transformers, circuit breakers (CB) interrupt the fault currents. Transient recovery voltages (TRV) appear across the CBs due to the current interruptions. The TRV values may be in excess of the standard values and severely affect the CBs. These phenomena are known, but the detailed characteristics of TRVs, such as rate of rise of recovery voltage (RRRV), peak value, and oscillation, have not been fully studied. Therefore, due to safety considerations, circuit breakers with higher voltage levels than the relevant system voltage have often been applied. To select suitable CB ratings, the TRV characteristics of the transformer limited fault (TLF) current interrupting condition must be understood.

Since very high capacity power transformers are presently used in high capacity systems, there have been circumstances in which the TLF interrupting currents could not be fully covered by 10% of the rated terminal fault breaking currents (T10 duty). At present, TLF is presumed to be verified in accordance with T10 duty within the scope of the terminal faults (TF: T100, T60, T30, T10) under IEC standards.

On the other hand, leakage inductance at the power-frequency domain cannot be applied for the TRV calculation, the frequency of which is generally far higher than several kHz.

In these indecipherable situations, transformer models of the high frequency region should be studied to identify clearly the TRV at TLF conditions.

## TRANSIENT RECOVERY VOLTAGE

When a circuit breaker interrupts a current, a voltage across the circuit breaker contacts is

generated to oppose the non-linear change of the interrupted current, due to a circuit transient phenomenon. This voltage is called the transient recovery voltage (TRV), which is the voltage difference between the source side and the load side of the circuit breaker.

Figure 1 shows three typical transient voltages that are generated when interrupting simple resistive, capacitive, and inductive circuits. In the case of resistive circuit interruption (Figure 1(a)), the TRV ( $V_s - V_L$ ) is a simple sinusoidal system voltage with a maximum value of 1.0 p.u. In capacitive circuit interruption (Figure 1(b)), the TRV ( $V_s - V_L$ ) will appear as a  $(1 - \cos)$  wave with a maximum value of 2.0 p.u. following current interruption. In inductive circuit interruption (Figure 1(c)), the TRV ( $V_s - V_L$ ) will appear as a sinusoidal system voltage following a high-frequency oscillatory voltage wave caused by the inductive circuit and the stray capacitance.

## Transformer Models and Frequency Range

Over the past decades, several studies have been conducted on parameters associated with the TLF current interrupting with the goal of drafting TRV standards. Several groups, such as Harner (1968), have proposed norms and standards related to TRV parameters for the highest levels of fault currents encountered. Parrot (1985) published a valuable review on the subject of transformer TRV. Most cases used a leakage inductance value of 50/60 Hz and a stray capacitance to analyze the TRV. The leakage inductance was calculated directly from the percent impedance, the transformer voltage, and power ratings. The values obtained were inductances at 50/60 Hz and were not necessarily effective inductance values for the TRV frequency of the transformer. These characteristic parameters for the TRV frequency region can hardly be determined analytically on the basis of transformer design data. In most studies, though these circuit constants were carefully chosen and

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