Transient Recovery Voltage Influenced by Transformer Delta Winding in UHV Transmission System

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Abstract-- **It is understood that in case of three phase breaker terminal fault, TRV(Transient Recovery Voltage) for first pole gives most severe duties and therefore, BTF(Breaker Terminal Fault) testing duties for circuit breaker is defined by first pole clearing condition in the standard. It is noted that duties for first pole are not always severe among three phases in TRV study on future UHV AC transmission systems in Japan. Authors found that the reason for this phenomenon is existence of delta winding of large power transformer. Summation of the transient voltage of three phases is kept constant by delta winding and this causes another oscillation on the transient recovery voltage of each phase. In sometimes TRV of third phase reaches highest peak voltage among three phases.**

Keywords: **transient recovery voltage, UHV, transformer**

I. INTRODUCTION

INVESTIGATIONS and discussions for creating international standard are undergoing on the UHV AC transmission systems [1]. Among these, interrupting duties of circuit breakers are one of the most important items. However, it is not conducted fully enough for understanding an advanced phenomenon understanding of interrupting duties. Authors tried to understand the phenomena of interrupting duties of breaker terminal fault.

According to the detailed analysis results that had been done in the past [2] [3], results of TRV duties of BTF were not always in line with general understandings. Authors tried to clarify the cause. The general understanding is described bellow.

BTF duty is defined based on three phase interruption condition and the peak voltage value Uc is expressed as product of first pole-to–clear factor Kpp and amplitude factor Kaf. See Eq.(1) [4].

$$U_c = U_r \sqrt{\frac{2}{3}}\, k_{pp}\, k_{af} \qquad (1)$$

Where,

U_c TRV peak
U_r Rated voltage
k_{pp} First pole-to-clear factor
k_{af} Amplitude factor

First pole-to-clear factor Kpp is expressed as eq.(2) using positive sequence impedance Z_1 and zero sequence impedance Z_0 (assuming positive impedance Z_1 are equal to negative sequence impedance Z_2).

$$K_{pp} = \frac{3Z_0}{2Z_0 + Z_1} = \frac{3\alpha}{2\alpha + 1} \qquad (2)$$

Where,

K_{pp} first-pole-to-clear factor
Z_0 zero sequence impedance
Z_1 positive sequence impedance
α Z_0/Z_1

IEC standard specifies Kpp=1.3 for effectively earthed neutral system.

Second pole-to-clear factor Kps is expressed as eq (3).

$$K_{sp} = \frac{\left(-\frac{3}{2} - j\frac{\sqrt{3}}{2}\right)Z_0 - j\sqrt{3}Z_1}{Z_0 + 2Z_1} = \frac{\left(-\frac{3}{2} - j\frac{\sqrt{3}}{2}\right)\alpha - j\sqrt{3}}{\alpha + 2} \qquad (3)$$

Third pole pole-to-clear factor Kps is usually 1.0.

In case of effective earthed system, assuming that Kpp=1.3, then Kps=1.27. In this test duty for the first pole can cover that of second and third pole. If the circuit breakers are used for network that have small α, relation of three phase duties may be different. In Japanese UHV AC systems α is almost 1.0 and Kpp will become 1.0 to 1.2. If we are going to specify

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the testing duties based on the analysis result, we need to pay attention to this point.

II. Computation Circuit

We have conducted calculations for TRV of BTF for planned Japanese UHV transmission systems by using EMTP-ATP. Figure 1 shows a circuit for calculation. Operating voltage of power transformer at substation A,B,C,D, and E are 1100kV(primary), 550kV (secondary) , and 168kV (tertiary). Tertiary windings of each transformer are of delta connected. Fault point located at the point P near substation B in Fig.1 and three phase short circuit and earth fault. Inherent TRVs without metal oxide surge arrester for the circuit breaker of B-C transmission line at substation B are calculated.

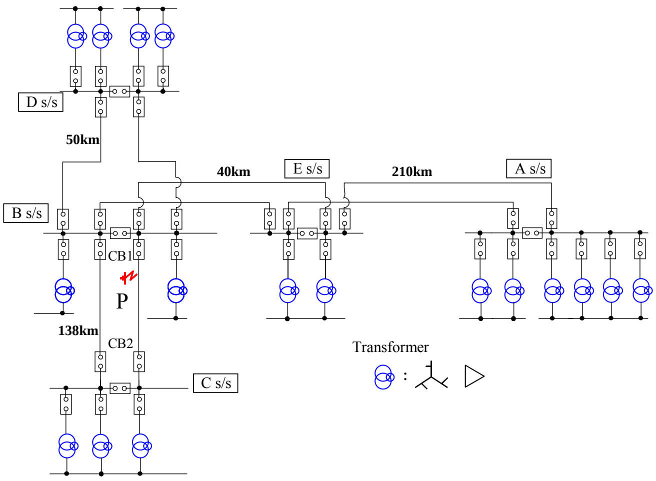

Fig. 1 UHV transmission network for study

III. TRV Computation

A. With delta (Δ) Winding Connection

First, TRVs are calculated under the condition of with tertiary winding of power transformers connected as delta. With this condition four cases are calculated.

Case 1-1 is a case of three phase successive interruption (normal operation) and Case 1-2 to 1-4 are single interruption of first, second, and third phase respectively. The maximum TRV peak value of each cases are shown in Table 1 and TRV waveforms are shown in Fig.2. In Fig.2 zero-sequence voltage is summed up value of three phases.

Table 1.
The maximum TRV peak value with delta windings

		First phase interruption	Second phase interruption	Third phase interruption
Case1-1	Three phases interruption	1299kV	949kV	1569kV
Case1-2	Single phase interruption	1299kV	-	-
Case1-3		-	1214kV	-
Case1-4		-	-	1169kV

B. Without delta (Δ) winding Connection

Next, same cases are calculated under the condition that all delta connection of tertiary windings of all transformers is opened. Again, case 2-1 is a case of three phase successive interruption (normal operation) and Case 2-2 to 2-4 are single interruption of first, second, and third phase respectively. The maximum TRV peak value of each cases are shown in Table 2 and TRV waveforms are shown in Fig.3. In Fig.2 zero-sequence voltage is summed up value of three phases.

Table 2.
The maximum TRV peak value without delta windings

		First phase interruption	Second phase interruption	Third phase interruption
Case2-1	Three phases interruption	1566kV	1185kV	1174kV
Case2-2	Single phase interruption	1566kV	-	-
Case2-3		-	1423kV	-
Case2-4		-	-	1255kV

IV. Discussion

From Table 1 and Fig.2, following things are observed for the condition that tertiary windings of transformer are delta connected.

1. In case 1-1, the maximum TRV peak appears at the third phase (U-phase) and is 1569kV.
2. Zero-sequence voltage after interruption is almost zero. Transient recovery voltage of each phase is oscillating so that these summations are kept to be zero. Therefore TRVs are affected by the other phase's oscillation.
3. In case 1-2, 1-3, and 1-4, each TRV is not affected by the other phase's oscillation of TRV. The maximum TRV peak value of third phase in case 1-4 was 1169kV and this is lower than 1569kV in case 1-1.

From Table 2 and Fig.3 following things are understood for TRVs with delta winding opened.

4. In case 2-1, TRV peak values of each case are different from that with delta winding connected
5. Zero-sequence voltage after interruption is not zero. So it is understood that the reason why the zero-sequence voltage in Fig.2 are zero is delta connection of tertiary windings.

From the results of case 1-2 and 2-1, first pole-to-clear factor of the network is confirmed as shown in Table3. First pole-to-clear factor is derived from steady state voltage at single line open condition.

Table 3 first pole-to-clear factor

	Case1-2(with Δ)	Case2-2(without Δ)
Steady state voltage	902kVp	1065kVp
first-pole-to-clear factor	902kV/898kV=1.00	1065kV/898kV=1.19

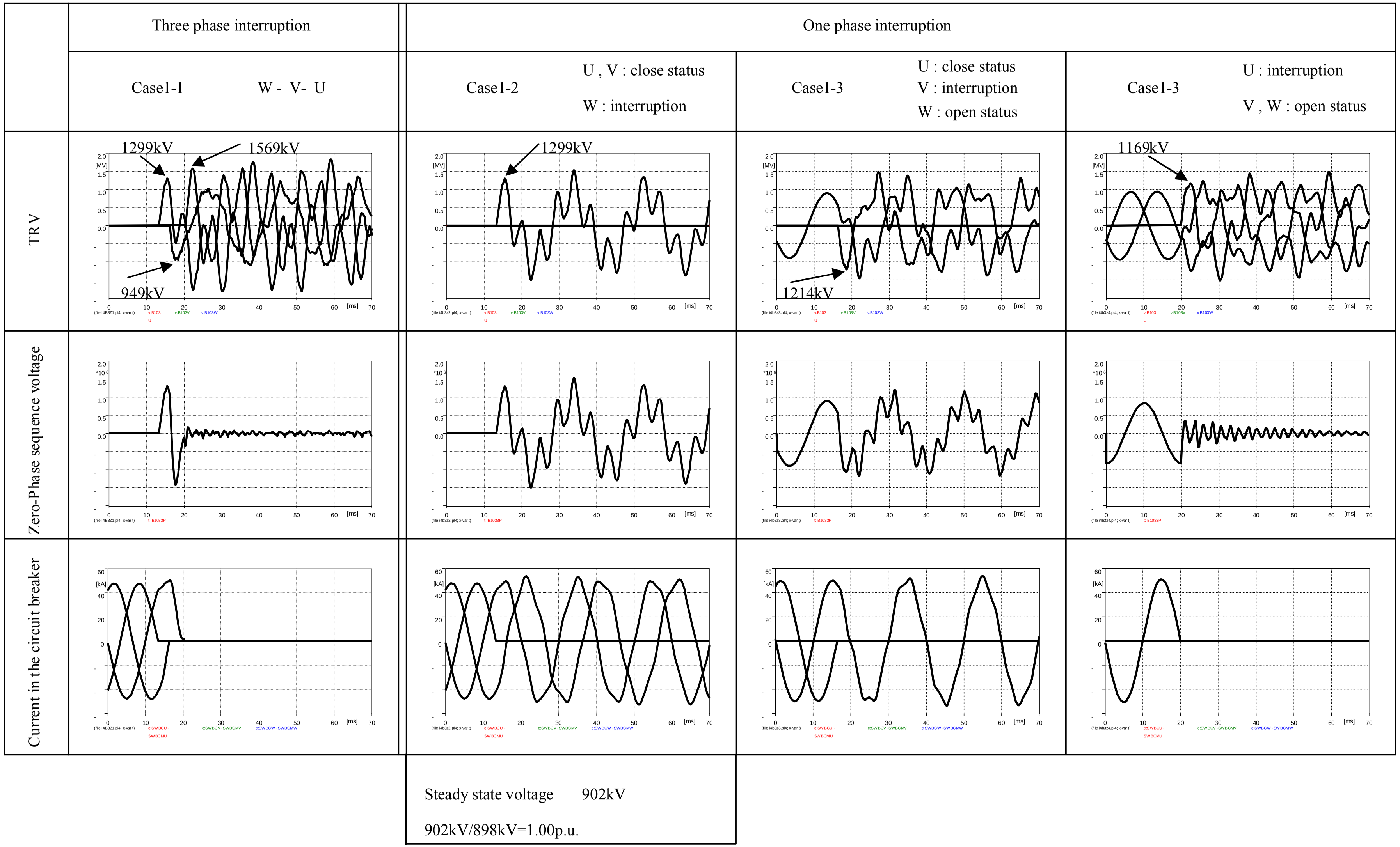

Fig.2 TRV computation with Δwinding in the transformer

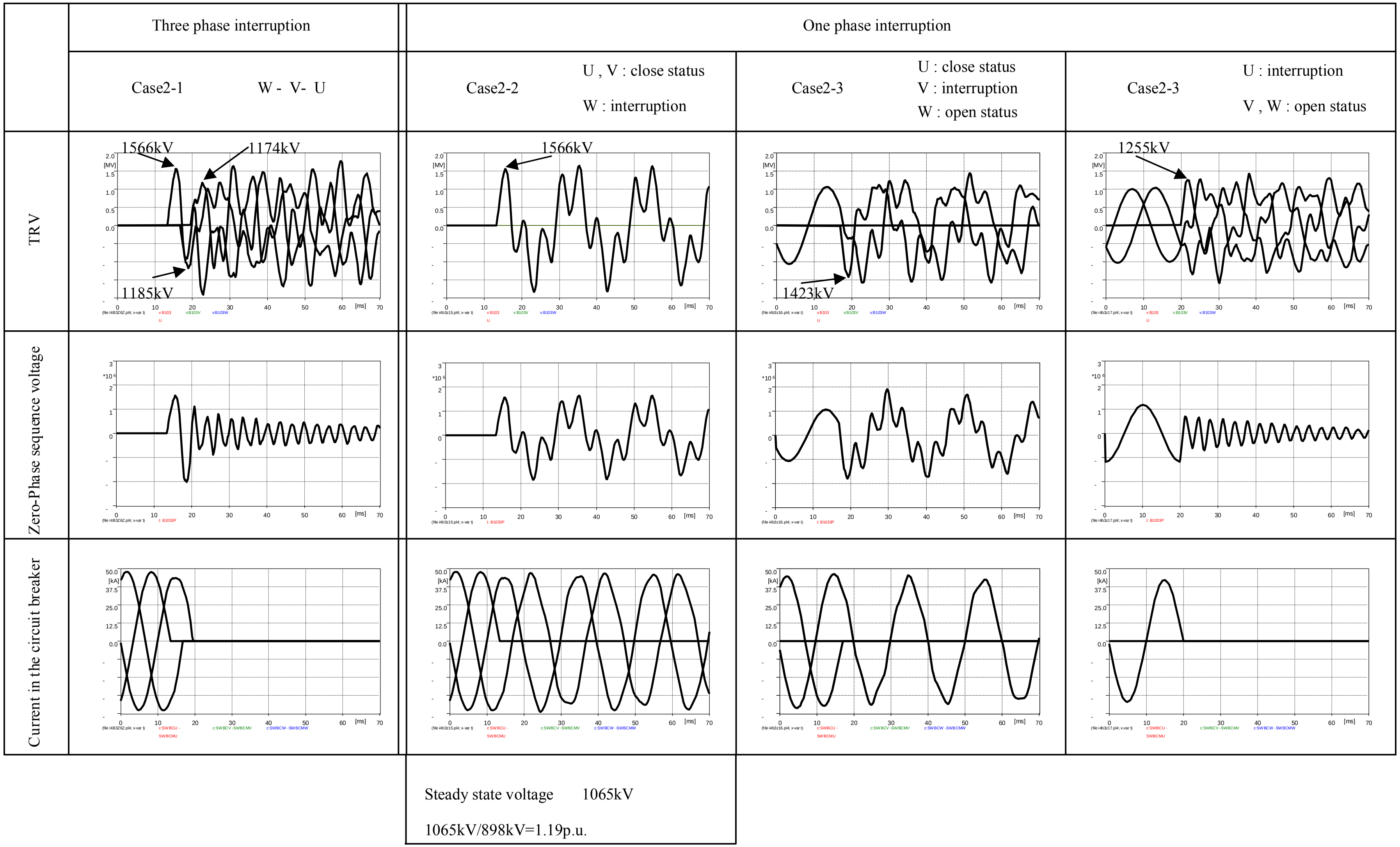

Fig.3 TRV computation without Δwinding connection in the transformer

As for the deference of first pole-to-clear factor between Case 1-2 and 2-2, it can be described as follows.

6. In case 2-2 zero-sequence impedance of the network larger than that of case 1-2 due to open condition of delta connection. This lead to the larger first pole-to-clear factor in Case 2-2 than Case 1-2.
7. First pole-to- clear factors of the two conditions is lower than 1.3, which is IEC standard value. Since positive and negative impedance of transmission line tends to be smaller in inverse proportion to the system voltage, and fault current feed from large generators and transformers that have a large X_0/X_1 ratio.

V. Conclusions

1) The transient recovery voltage at three phase earth fault is investigated in Japanese UHV transmission systems. The maximum TRV peak appears at the third phase with delta windings.
2) In case that three phase fault were interrupted single interruption of first, second, and third phase only , TRV peak of third phase is not the highest.
3) This phenomena were caused by the delta connection of power transformer tertiary windings. Zero-sequence voltage after interruption kept to be zero due to delta windings. With delta connection, each TRVs of the first, second, and third phase are affected by the other phase's oscillation. Also, when the delta connection opened, first pole-to clear factors are large due to high zero sequence impedance of network.
4) In higher voltage network such as UHV, ratio of X_0/X_1 tends to be large and therefore, first pole-to clear factor tends to be lower than specified in IEC.

TRV(Transient Recovery Voltage) for first pole has been thought to give most severe duties among three phases in case of three phase breaker terminal fault. Therefore, in the standard test duties are defined for first pole to cover three phases. In this paper analysis results showed that TRVs for first pole are not always severest among three phases in the UHV systems.

VI. References

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