Tripping Current and Short Circuit Current of High Voltage Tester

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Abstract: Tripping current and short circuit current are important technical specifications of high voltage tester, and frequently required to be verified according to the stipulation of relevant test standard during laboratory assessment. However, it is in difficulty to verify the short circuit current by direct measurement because of the existence of overload protection. A indirect calculation method for short circuit current is introduced in this article
Key words:. High voltage tester, Tripping current, Short circuit current, verification

1. Introduction

According to standard IEC60335-1:2001 clause 13.3, the high-voltage source used for the test is to be capable of supplying a short circuit current I_s between the output terminals after the output voltage has been adjusted to the appropriate test voltage. The overload release of the circuit is not to operate for any current below the tripping current I_r. The values of I_s and I_r are given in table 5 for various high-voltage sources.

Table 5 – Characteristics of high-voltage sources

Test voltage [a] V	Minimum current mA	
	I_s	I_r
<4000	200	100
≥4000 and <10000	80	40
≥10000 and ≤20000	40	20
NOTE The currents are calculated on the basis of the short circuit and release energies of 800 VA and 400 VA respectively at the upper end of the voltage ranges		
a The measurement uncertainty of the test voltage is not to exceed		

During laboratory assessment, it is frequently required to show the documentation that the high voltage source used for the test has the capability of supplying a short circuit current I_s of 200mA. Many laboratories are puzzled about it, because there is difficulty to measure the short circuit current directly for the reason that the overload release of the high voltage tester operates when the tripping current reached.

2. Theoretic analysis

2.1 Typical construction of high voltage tester

Figure 1 gives the block diagram of a common used high voltage tester, model TOS5050 (manufactured by KIKUSI, Japan). It comprises of 6 block: Relay, Voltage regulator, H.V. transformer, Output terminal, Current detector, and Control circuit.

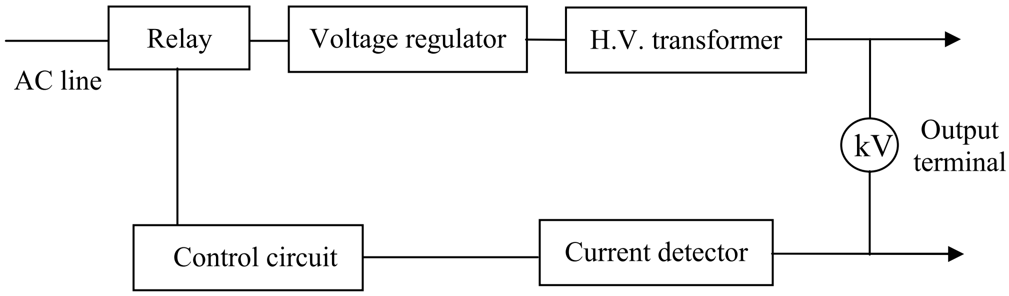

Fig. 1 Block diagram of TOS5050

2.2 Equivalent model of high voltage source

The high voltage source is generated by Voltage regulator, and boosted by H.V. transformer. The equivalent circuit of H.V. transformer is shown in figure 2, where L and H are terminals of low voltage and high voltage, and V'_H 、 I'_H are output voltage and current of high voltage terminal which have been converted to the low voltage terminal. The output power of the high voltage source is given by the equivalent circuit as:

$$P_{out} = V'_H \cdot I'_H = V_H \cdot I_H \quad (1)$$

where, V_H 、 I_H are actual output voltage and current of high voltage terminal.

Under the case of short circuit of high voltage terminal, the output current is given as:

$$I'_H = \frac{V_L}{Z_1 \cdot (1 + \frac{Z'_2}{Z_m}) + Z'_2} \quad (2)$$

where, V_L is the input voltage of the low voltage terminal of the H.V. transformer, namely the output voltage of the Voltage regulator. Z_1 is the leakage impedance of the primary winding of the H.V. transformer, and Z'_2 is the leakage impedance of the secondary winding of the H.V. transformer, which has been converted to the primary winding. Z_m is the magnetic field exciting impedance of the H.V. transformer. and:

$$Z_1 = r_1 + jX_1$$
$$Z'_2 = k^2 \cdot Z_2$$
$$Z_2 = r_2 + jX_2$$
$$Z_m = r_m + jX_m \quad (3)$$

k is the converting ratio of H.V. transformer, of typical value 1/25 and 1/50. For the reason that the leakage impedance of the transformer is extremely small in comparison with the magnetic field exciting impedance, $Z_2 << Z_m$, and as a result:

$$Z_2' = k^2 \cdot Z_2 << Z_m$$

the formula for the calculation of the short circuit current can be simplified as:

$$I_H' \approx \frac{V_L}{Z_1 + Z_2'} \qquad (4)$$

$$I_H = k \cdot I_H' \qquad (5)$$

Figure 3 gives the simplified equivalent circuit under the condition of short circuit of output terminal.

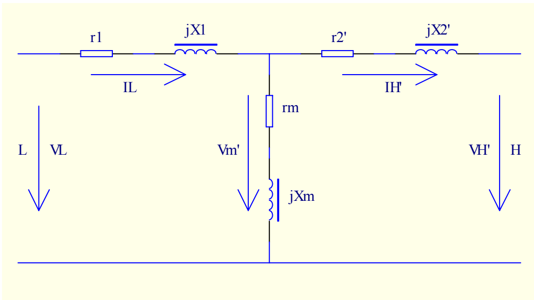

Fig. 2 Equivalent circuit of H.V. transformer

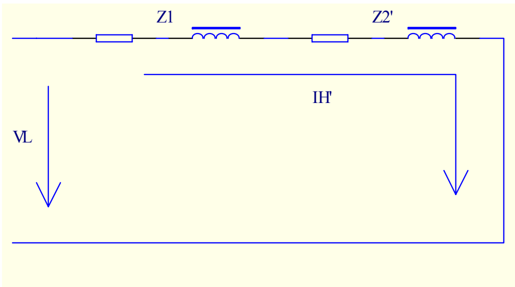

Fig. 3 Simplified equivalent circuit

2.3 Tripping current I_r and short circuit current I_s

Equation (1) shows the output power of high voltage source P_{out} is the product of output voltage V_H and output current I_H. For certain output voltage V_H, the output current I_H is determined by the output power of H.V. transformer P_{out}. Accordingly, under the condition of set test voltage, the tripping current of the high voltage source lies on the maximum output power of the H.V. transformer. For a high voltage tester with appropriate output test voltage, the requirement for the tripping current is the stipulation for the capacity of the high voltage source, e.g., a tripping current of 100mA is stipulated for a high voltage tester with the highest test voltage of 5kV, the capacity of the H.V. transformer of the tester should be at least 500VA.

It is distinct from equation (4), for certain output voltage of Voltage regulator V_L, the short circuit output current of high voltage terminal I_H' is inverse proportion to the value of the leakage impedances of the primary and secondary wingding of the H.V. transformer $Z_1 + Z_2'$. The larger value of impedance $Z_1 + Z_2'$, the smaller current I_H'. Wherefore, the stipulation for the short circuit output current I_H' is the requirement for the leakage impedances of the primary and secondary winding of the H.V. transformer.

Supposing the equivalent impedance of the device under test (DUT), which has been converted to the primary winding, is Z_d', the output voltage between the high voltage terminals can be derived from figure 2 as:

$$V_H' = \frac{Z_d'}{Z_1 \cdot (1 + \frac{Z_2' + Z_d'}{Z_m}) + Z_2' + Z_d'} \cdot V_L \qquad (6)$$

It indicates, for certain output voltage of Voltage regulator V_L, the output test voltage between the high voltage terminals V'_H is related to the equivalent impedance of the DUT Z'_d, the magnetic field exciting impedance Z_m, and the leakage impedances of the primary and secondary winding of the H.V. transformer Z_1 and Z'_2. For ideal transformer, $V'_H = V_L$, because of $Z_1 = Z'_2 = 0$. It means the output test voltage which has been converted to the primary winding is equal to the output voltage of the Voltage regulator. However, for general transformer, the output test voltage which has been converted to the primary winding V'_H differs from the output voltage of the Voltage regular V_L according to the parameters Z_1, Z'_2, Z_m, and Z'_d. Figure 4 gives the curve of V'_H/V_L varying versus Z_1/Z'_d (suppose $Z_1 = Z'_2 = 1\% Z_m$).

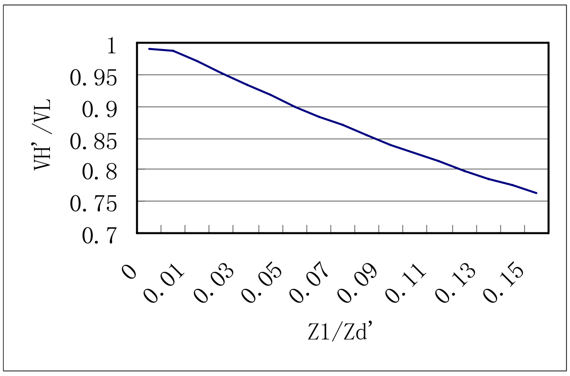

Fig. 4. Output test voltage varying vs. leakage impedance of H.V. transformer

The curve shows that V'_H/V_L decreases when Z_1/Z'_d increases. In the condition that output voltage of the Voltage regulator V_L and the equivalent impedance of the DUT Z'_d are determined, the output test voltage V'_H decreases as leakage impedance Z_1 and Z'_2 increases. Two calculation examples are given from the curve:

-- V'_H/V_L =**0.90** as Z_1/Z'_d =**0.05**, when the leakage impedance of the winding of the transformer Z_1 reaches the 5 percent the impedance of the DUT, the output test voltage which has converted to the primary wingding drops to the 90 percent of the output voltage of Voltage regulator.

-- In the test condition that the required output test voltage is 5kV, and the output current pass through the DUT is 100mA, to ensure the output test voltage drop within the limit of 3%, the leakage impedances of the primary and secondary winding of the H.V. transformer, which has been converted to primary winding, shall not exceed 0.8 Ω, for the typical converting ratio of H.V. transformer $k = 1{:}25$.

3. Verification of short circuit current

Commonly used high voltage tester has the function of overload current protection. The overload release of the circuit operates when the output current reach the tripping current I_r. In order to carry out the direct measurement of the short circuit output current, the protective circuit needs to be rendered inoperative, which may result in damage to the instrument. So, it is in difficulty to measure the short circuit current of the tester directly. As substitute, a sort of indirect measurement method of short circuit current is introduced here.

It can be derived from equation (6):

$$I'_H = \frac{V_L}{Z_1 \cdot (1 + \frac{Z'_2 + Z'_d}{Z_m}) + Z'_2 + Z'_d} \quad (7)$$

Equation (7) shows, for a given impedance of DUT Z'_d, the short circuit current I'_H is depended on the output voltage of Voltage regulator V_L, and the impedance parameters of the transformer Z_1、Z'_2、Z_m. As a general rule, $Z_1 \approx Z'_2$. Under the condition of a determined value of V_L, if two measurement values of output current I'_H with different known DUT impedance Z'_d are obtained, the short circuit current which has been converted to the primary winding I'_S can be easily calculated with the condition $Z'_d = 0$.

In practice, V_H is selected as the minimum required output test voltage, for example 500V. If the stipulated short circuit current can be outputted under this test voltage, the high voltage tester is capable of supplying required short circuit current under any other higher test voltage. An adjustable resistance with appropriate value and adequate rated power, for example one with max. value not less than 10 kΩ and with min. power of 100W for 200mA current measurement, is selected as load impedance Z_d. Two measurement of current I_H is carried out with appropriate resistance of Z_d. The converting ratio k of the H.V. transformer can be referred to the User Manual of the instrument. By following conversion:

$V_L = k \cdot V_H$ （V_H is the open circuit value）

$$I'_H = \frac{1}{k} \cdot I_H$$

$$Z'_d = k^2 \cdot Z_d$$

the short circuit current which has been converted to the primary winding I'_S can be calculated, and the actual short circuit current is given as:

$$I_S = k \cdot I'_S$$

Example:

Table 2 gives five groups of measurement data under different load impedance carried out on high voltage tester model TOS5051, of which the converting ratio of H.V. transformer is $k = 1/25$. Two of the five groups of the data are selected for the calculation of equation (7), and the results are:

$$Z_1 = Z'_2 = \mathbf{2.89\Omega}$$

$$Z_m = \mathbf{88.1\Omega}$$

When $Z'_d = \mathbf{0}$, the calculated result is $I_S = \mathbf{136}\, mA$. The measurement and calculation results shows the instrument checked outputs a short circuit current of 136mA under the minimum test voltage of 500V. If 200mA short circuit current is required, the minimum output test voltage shall be not less than 734V.

Table 2 Output current of high voltage tester model TOS5051 with different load

№	V_H /V (Loaded)	V_H /V (Open circuit)	I_H /mA	Load impedance /kΩ	V_L /V	I'_H /mA	Z'_d /Ω
1.	500	560	11.8	42.4	22.4	295	67.8
2.	500	700	50.0	10.0	28.0	1250	16.0
3.	500	740	63.0	7.94	29.6	1575	12.7
4.	500	820	83.0	6.02	32.8	2075	9.6
5.	500	880	100	5.00	35.2	2500	8.0

4. Conclusion

Tripping current and short circuit current are two of the important technical specifications of high voltage tester, and relevant test standard gives appropriate stipulation. Tripping current depends on the capacity of H.V. transformer of the high voltage tester, and short circuit current determined by the test voltage and the impedance parameters of the H.V. transformer. For a high voltage tester incorporating a H.V. transformer of 500VA, if the range of output test voltage is 0~5kV, the max. output current is 100mA. Tripping current, or the capacity of the H.V. transformer can be referred to the technical specifications of the high voltage tester, otherwise, it can be verified by direct measurement. However, because of existence of the function of overload protection of commonly used tester, it is in difficulty to verify the short circuit current by direct measurement. As substitute, indirect calculation method can be used for the verification of short circuit current.