# Analysis of Implementing Instantaneous Short Circuit Test with Gas Circuit Breaker as Make Switch

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## I. Research Background

High voltage section has built a large-capacity short-circuit test lab. In internationally renowned laboratory short-circuit laboratories, make switch, which is extremely accurate but expensive, is often used to carry out instantaneous short-circuit tests. In our short-circuit test lab, the gas circuit breaker (GCB) is used to carry out instantaneous short-circuit tests for various distribution-level power equipment, and it is found that the K value (see below for the definition) during the test can meet the requirements of the electric test standard. This paper uses Matlab to simulate and explain why the short-circuit current performed with GCB can meet the requirements of the electric test standard.

## II. Principle of instantaneous short circuit test

According to the characteristics of power equipment and actual power lines, experts worldwide have conceived the test circuit of instantaneous short-circuit test and its circuit model (Fig. 1). We can establish the relationship between test voltage $U_m$ and short-circuit current $I_k$.

$$U_m \sin(\omega t + \alpha) = L_k \frac{di_k}{dt} + i_k R_k \quad \text{.........(1)}$$

The solution to equation (1) is $i_k = \frac{U_m}{\sqrt{R_k^2 + (\omega L_k)^2}}[\sin(\omega t + \alpha - \emptyset_k) - \sin(\alpha - \emptyset_k) e^{-\left(\frac{R_k}{L_k}\right)t}]$ .....................(2)，where

$$\emptyset_k = tan^{-1}\left(\frac{\omega L_k}{R_k}\right)$$

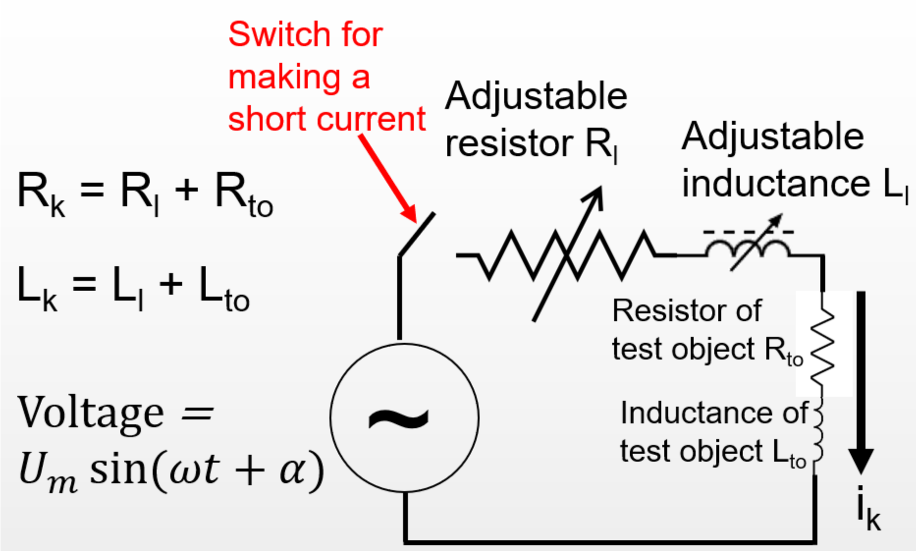


Fig. 1 Test circuit of instantaneous short circuit and its lumped circuit model

When performing the test, we can adjust $U_m$, $R_l$, and $L_l$ to control the short-circuit current.

Assuming α= 0, we plot $\frac{\sqrt{2}i_k}{\left(\frac{U_m}{\sqrt{R_k^2+(\omega L_k)^2}}\right)} = \sqrt{2}[\sin(\omega t + \alpha - \emptyset_k) - \sin(\alpha - \emptyset_k)e^{-\left(\frac{R_k}{L_k}\right)t}]$ (Fig. 2) for $\frac{\omega L_k}{R_k}$ = 12, 10, 8, 6, 4, 2. It is found that if $\frac{\omega L_k}{R_k}$ is larger, then the first peak value of current is higher. For short-circuit current, the ratio of the absolute value of the first peak value to the RMS value is named as K in the electric test standards (IEC, IEEE and CNS). We can expect that when $\frac{\omega L_k}{R_k}$ approaches zero, the impedance of the test circuit and the test object is very close to a resistance, so K approaches $\sqrt{2}$. Fig. 3 shows the relationship between K and $\frac{\omega L_k}{R_k}$ when α= 0.

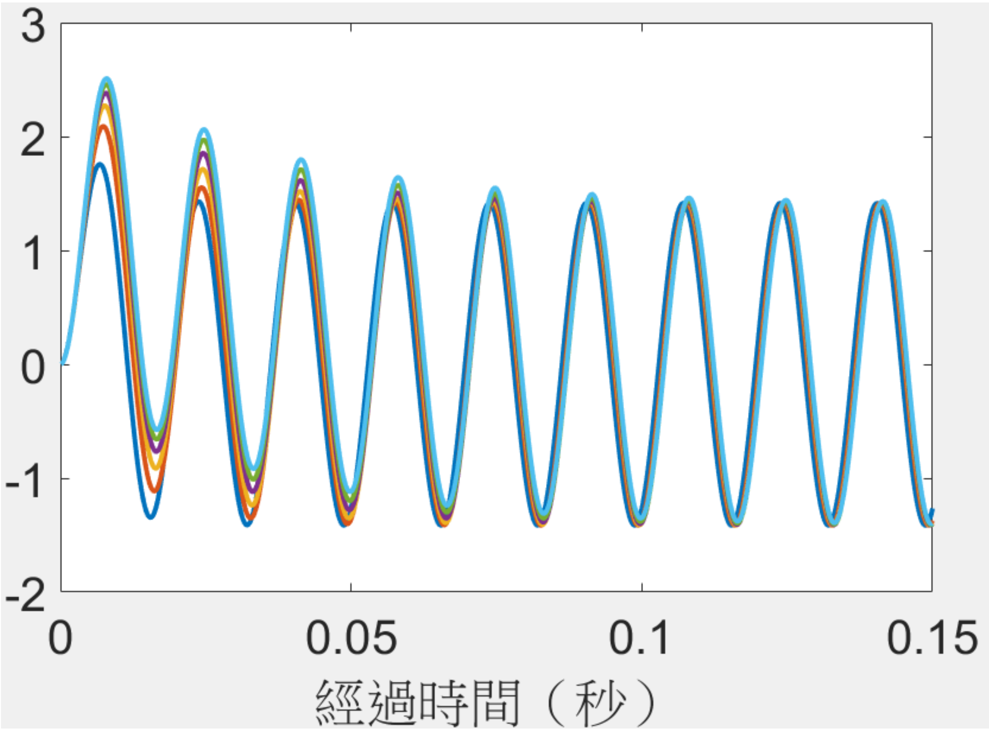


Fig. 2 Effect of $\frac{\omega L_k}{R_k}$ on peak current

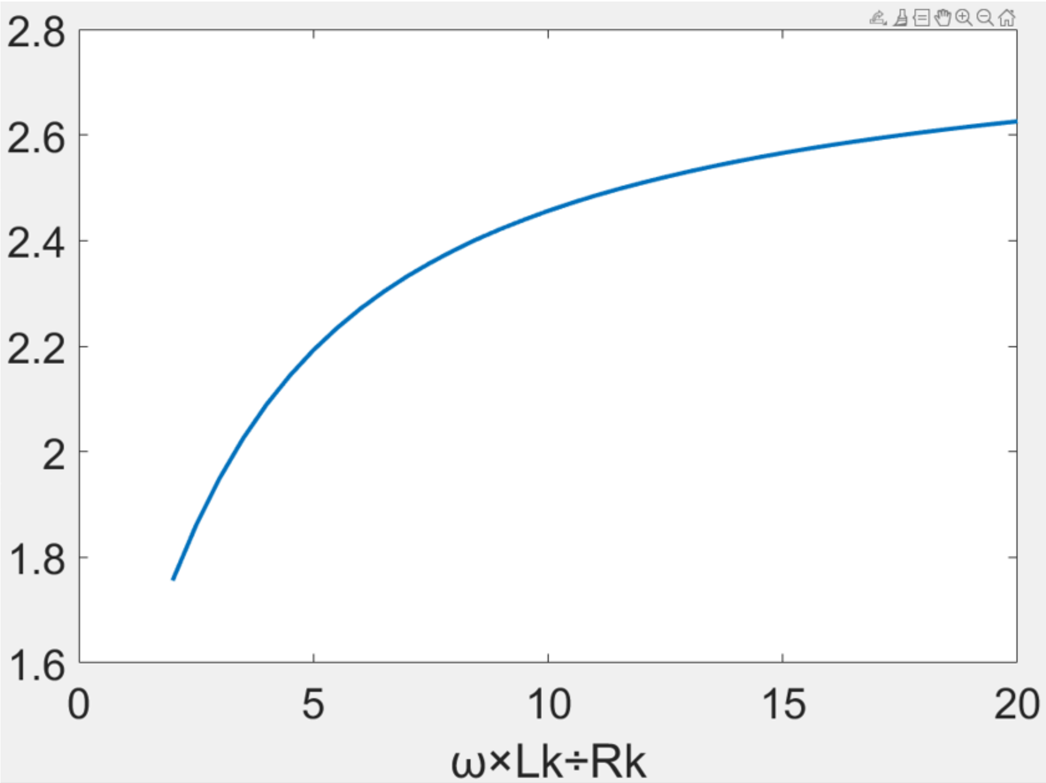


Fig. 3 When $\alpha = 0$, the relation between $\frac{\omega L_k}{R_k}$ and K-value

In addition, we can prove through simulation and experiment that when $\frac{\omega L_k}{R_k}$ is a constant value, if the short-circuit current is made when the test voltage is about equal to zero (α≈ 0). The maximum value of K can be achieved. Because the purpose of the instantaneous short-circuit test is to simulate the most severe mechanical stress on power equipment when a short-circuit fault occurs on the power line; since the mechanical stress exerted on power equipment by short-circuit fault is positively correlated with the instantaneous short-circuit current value, the electric test standard must have some requirements on K value. Since the electric test standard has some requirements on K value, the moment when the short-circuit current is made must not deviate too far from the time when test voltage is equal to zero.

## III. Research results

Table 1 shows the most stringent K-value requirements in the electric test standards when performing instantaneous short-circuit tests on different power equipment. There is some margin for K value of the transformer and CT; that is, it is not necessary to reach the specified K value when the instantaneous short circuit test is carried out.

| **Primary classification** | **secondary classification** | **Requirement on K value** | **Note** |
|---|---|---|---|
| Switching power equipment | Switchgear[YHW1] | No | The peak withstand current test and short-time withstand current test can be carried out separately, and the peak withstand short-circuit current is applied for more than 0.3 seconds. |
| | GIS | No | |
| | Circuit breaker | No | |
| Winding power equipment | PT | No | |
| | CT | ≧ 2.5 | Only IEC standard specifies K value. |
| | Transformer | When X/R ≧ 14，K ≧ 2.5 | CNS and IEC have the same requirement on K value. |
| Others | Lightning arrester | ≧ 2.5 | IEEE and IEC have the same requirement on K value. |

Table 1 The most stringent K-value requirements in the electric test standards

IEC requires that for CT the peak current is 2.5 times $I_{th}$, the symmetrical current is $\sqrt{\frac{I_{th}^2}{test\ time}}$, and the test time is between 0.5 and 5 seconds. Therefore, K is equal to $\frac{2.5I_{th}}{\sqrt{\frac{I_{th}^2}{\text{test time}}}} = 2.5\sqrt{\text{test time}}$, so the minimum allowable K value is equal to $2.5\times\sqrt{0.5} = 1.7678$, which is 29.3% smaller than 2.5. According to IEC's transformer test standard, the peak current must be between 95% and 105% of the specified value, and the symmetrical current must be between 90% and 110%. Suppose we carry out instantaneous short-circuit test with 95% of the specified peak current and 110% of the specified symmetrical current. In that case, the K value becomes 95÷110 = 86.4% of the specified value, so the margin of the K value is 13.6% for transformer short circuit test. In addition, when the short circuit test of lightning arrester is performed, because the place where short circuit occurs in lightning arrester is actually a wire, the reactor on the test circuit can be adjusted to the maximum during the test. In this case, the theoretical maximum K value is usually greater than 2.65, and 2.5 is 5.6% smaller than 2.65, so the margin of K value is 5.6% for lightning arrester short circuit test.

We want to find $A_1$ and $A_2$, so that when α is between $-A_1^o$~$A_2^o$ (360° is equal to sixtieths of a second, $A_1 > 0$ and $A_2 > 0$), the actual K value is only 5% less than the theoretical maximum K value.

We define another two parameters: acceptable making angle deviation = $\frac{A_1+A_2}{2}$, and optimal making angle = $\frac{A_2-A_1}{2}$. For different $\frac{\omega L_k}{R_k}$, we use equation (2) to get $A_1$ and $A_2$ by Matlab simulation, and finally plot " $\frac{\omega L_k}{R_k}$ vs. acceptable making angle deviation " and " $\frac{\omega L_k}{R_k}$ vs. optimal making angle " (Fig. 4). We found that the larger the $\frac{\omega L_k}{R_k}$ is, the smaller the acceptable making angle deviation is. Still, the acceptable making angle deviation is always greater than 25°. We also found that the larger the $\frac{\omega L_k}{R_k}$ is, the closer to 0° the optimal making angle is.

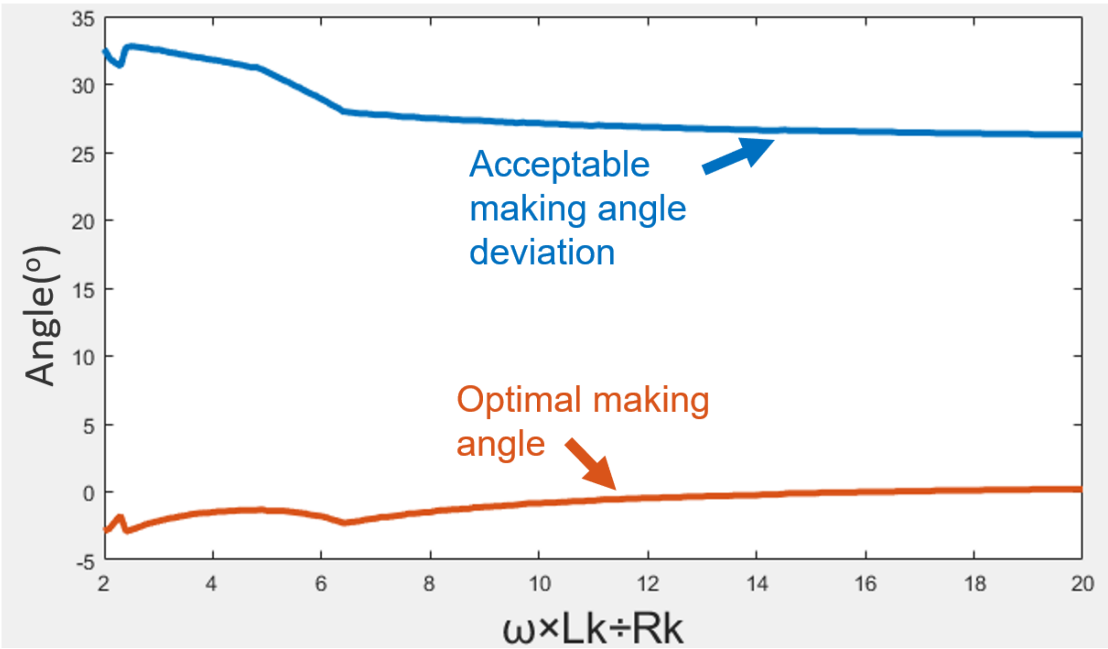


Fig. 4 Relationship between $\frac{\omega L_k}{R_k}$ and acceptable making angle deviation/ optimal making angle

After inquiring the local circuit breaker manufacturers in Taiwan, the making accuracy of circuit breakers is usually ±1 ms. The electric angle of 1 ms is qual to 0.001 ÷ (1 ÷ 60 ÷360) = 21.6°, and the making accuracy of 21.6° is less than 25°, which means that the actual K value of short-circuit current can be at least 95% of the theoretical maximum K value with a making accuracy of 1 ms. The above simulation results and the fact that the circuit breaker is used as make switch in our lab can be used to explain that when using GCB to perform instantaneous short-circuit tests for various distribution-level power equipment, the K value can meet the requirements of electric test standards.

## III. Conclusion

The gas circuit breaker (GCB) is used as the make switch to carry out the instantaneous short-circuit test for various distribution-level power equipment. It is found that the K value during the test can meet the requirements of the electric test standard. In this paper, the lumped circuit model is used to analyze short circuit test, and Matlab is used to simulate it. The simulation results can be used to explain the above phenomenon successfully.