Study on TRV of circuit breaker in two substation operational ways and its countermeasure

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Abstract: To verify a vacuum breaker's feasibility, when a transformer substation chooses a vacuum circuit breaker, it takes two different actual operational ways to cut off a transformer. This paper, using the power system computer aided design/electro magnetic transient in DC system (PSCAD/EMTDC) software, simulates the substation system and studies transient recovery voltage (TRV) caused by the two different ways which can cut off a with load transformer or a no-load transformer. Simulation and calculation results show that TRV indexes of the first way are much higher than that of the second one, and their TRV indexes are both in a permissible range. The breaker is proved to be available. Besides, this paper proves that paralleling resistance has a good effect when the indexes exceed the standard. The resistance value depends on specific circumstances.

Key words: transient recovery voltage(TRV); power system computer aided design/electro magnetic transient in DC system (PSCAD/EMTDC); transformer; vacuum circuit breaker

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Whether the transient recovery voltage(TRV) of a vacuum circuit breaker meets GB1984 − 2003 is important to a power system. To verify that, after a 35-kV substation chooses a vacuum circuit breaker, it uses two operational ways to cut off a transformer in an actual operation.

Vacuum circuit breaker shows excellent interruption and dielectric recovery characteristics after the current crossing zero[1]. But when it switches out a no-load transformer, it will lead to a high overvoltage which greatly exceeds transformer's insulation level. Under ideal conditions, when the current crosses zero, the arc extinguishes and the TRV occurs across the gap[2]. As one of inherent characteristics in power systems, TRV is an important factor affecting switching course of test circuit breaker[2]. There are many researches on TRV at home and abroad[3-9]. But most of them just concentrate on extra high voltage system, and neglect the distribution system. Japanese always pay much attention to TRV matters. When they design a substation, they must think about the TRV matters. On the contrary, Chinese rarely studies on it at present[10]. After breaker explosion accidents, they always cannot find out the causes. Therefore, in distribution system, using computer simulation and calculation to verify TRV indexes of the two operations methods is necessary. Besides, proposing a specific method to reduce the indexes is extremely practical and meaningful.

1 Calculation cases

TRV only has existence time from dozens of microseconds to dozens of milliseconds. Its peak and up rate are major indexes. This paper aims at a 35-kV substation. To verify the breaker's feasibility, this substation must calculate the two indexes of TRV to know if it meets the standard.

1.1 Engineering background

The 35-kV substation has two paralleling transformers which are the same type. The transformation ratio is 35 kV/6 kV, rated capacity is 5 000 kW, and other main parameters are shown as

* Short-circuit loss: $\Delta P_S = 6.75$ kW.
* Short circuit voltage: $V_S\% = 7\%$.
* Load loss: $\Delta P_0 = 36.7$ kW.
* No-load current: $I_0\% = 0.9\%$.

The basic parameters as follows are calculated by

$$R_T = \frac{\Delta P_S V_N^2}{S_N^2} \times 10^3 = 0.33\ \Omega, \qquad (1)$$

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$$X_T = \frac{V_S\%}{100} \times \frac{V_N^2}{S_N} \times 10^3 = 17.15\ \Omega, \qquad (2)$$

$$G_T = \frac{\Delta P_o}{V_N^2} \times 10^{-3} = 3 \times 10^{-5}\ \text{S}, \qquad (3)$$

$$B_T = \frac{I_0\%}{100} \times \frac{S_N}{V_N^2} \times 10^{-3} = 3.7 \times 10^{-5}\ \text{S}. \qquad (4)$$

The equivalent simplification diagram of the transformer substation is shown in Fig. 1.

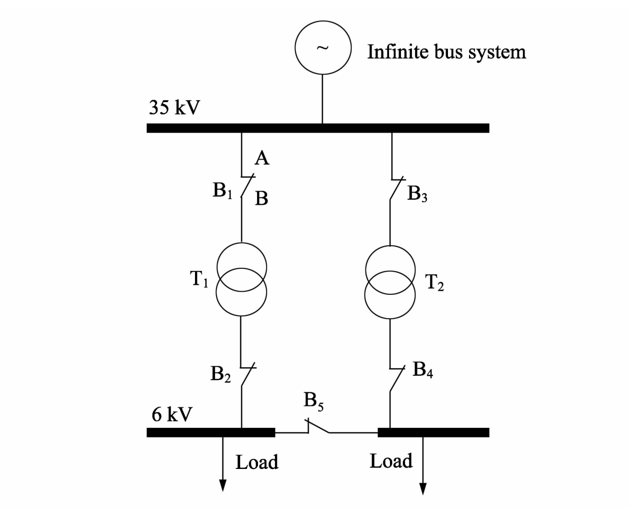

Fig. 1 Equivalent simplification diagram of the substation

As Fig. 1 shows, the two operational ways are as follows:

* Disconnect breaker B_2 and let the transformer T_1 be in no-load condition, then open breaker B_1.
* When breakers B_3, B_4 and B_2 are in closed conditions, cut off circuit breaker B_1.

To improve the operation efficiency, the two parallel operating transformers T_1 and T_2 should meet the following requirements.

* When transformers are in no-load conditions, there is no circumfluence between them.
* The two transformers with load can reasonably distribute the load.
* The two transformers with load share same-phase current.

This substation chooses two transformers with the same type and connection way, and thus it meets the above requirements. Therefore, TRV from the break-brake operation can be calculate.

1.2 TRV of the first operational way

Take a signal phase transformer for example, and use PSCAD/EMTDC software to simulate the first operational mode. The system circuit is shown in Fig. 1. When the system operates for about 0.105 s, cut off circuit breaker B_1.

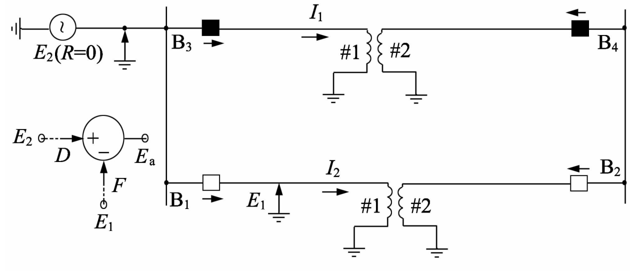

Fig. 2 System circuit of the first operational way

Fig. 3 shows that at the moment of break-bake operation, there will be a TRV with amplitude about 50 kV. At last, the voltage of breaker B_1 will stably be a power frequency recovery voltage with amplitude about 50.85 kV, which is just the bus voltage.

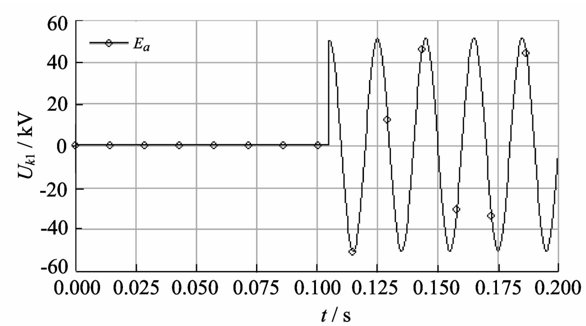

Fig. 3 Breaker B_1's end voltage of the first operational way

The up rate of TRV is got by

$$RRRV = \left.\frac{dU_{ck}}{dt}\right|_P = \frac{U_{ck}}{t_c}, \qquad (5)$$

where $RRRV$ is the up rate of TRV, U_{ck} is used to define the first reference voltage and t_c is used to define the time that U_{ck} appears.

According to Fig. 3, $RRRV$ is calculated by

$$RRRV = \frac{50\ \text{kV}}{250\ \mu\text{s}} = 200\ \text{V}/\mu\text{s}. \qquad (6)$$

According to the standard TRV indexes of a 40.5-kV system, TRV indexes of the first operational way are in a permissible range.

1.3 TRV of the second operational way

When system operates for 0.105 s, disconnects breaker B_1 and uses PSCAD/EMTDC to simulate this case. The system circuit is shown in Fig. 4.

Fig. 5 shows that at the moment of break-brake operation, there will be a TRV with amplitude about 87.8 V. At last, the voltage of breaker B_1 will stably be a power frequency recovery voltage with amplitude about 61.2 V.

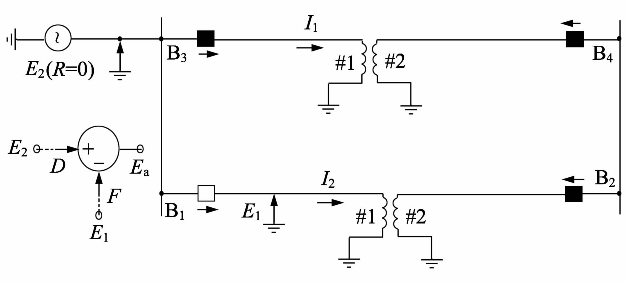

Fig. 4 System circuit of the second operational way

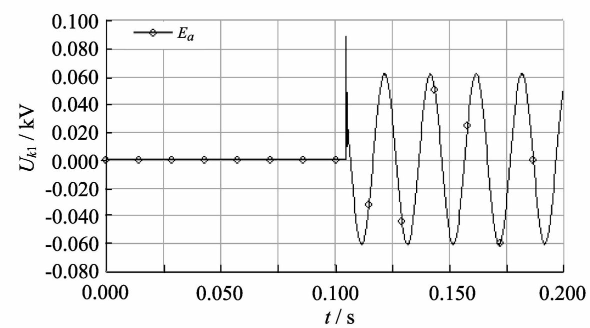

Fig. 5 Breaker B_1's end voltage of the second operational way

As Fig. 5 shows, *RRRV* is got by

$$RRRV = \frac{87.8\ \text{V}}{250\ \mu\text{s}} = 0.351\,2\ \text{V}/\mu\text{s}. \qquad (7)$$

According to the standard TRV indexes of a 40.5-kV system, TRV indexes of the second mode are in a permissible range.

Compared the two cases, it can be concluded that switching out the transformer in the first mode, there will be a TRV with higher amplitude appearing between both contacts of breaker B_1. Both *RRRV* and power frequency recovery voltage of the first one are higher than those of the second one.

1.4 Analysis of TRV indexes

According to Fig. 1, when breaker B_1 is closed, both ends of the breaker have an approximately equal voltage. After the breaker operates as the second operational mode and system operates stably, side A will have a 35-kV power-frequency recovery voltage which equals the bus voltage. Then the 6-kV low voltage bus side can boost side B's voltage level as high as 35 kV through transformer T_1 with 38.5 kV/6.3 kV rated ratio. Thus, both side A and B are at the same voltage level, which makes the breaker have lower indexes of TRV.

After the breaker operates in the first mode and the system operates stably, side A has a 35-kV power frequency voltage while voltage of side B is 0. Thus both side A and side B have a 35-kV voltage difference. In addition, when a no-load transformer operates normally, it works as a magnetizing inductance. Thus cutting off a no-load transformer is just opening a small capacity inductance load. At the moment, there will be a TRV with higher indexes appearing both breaker's A and B sides[11].

From the above analysis, it is clearly known that TRV indexes all meet the requirements.

2 Method to reduce TRV indexes

When the TRV indexes exceed the standard and overvoltage occurs, to limit the overvoltage caused by cutting off the no-load transformer, take a parallel break-brake resistance and a parallel capacitor as methods. When parallel a 500-pf capacitor to a 5 000-pf one, cut off breaker B_1 with the second mode. The simulation results are obtained as Fig. 6 shows.

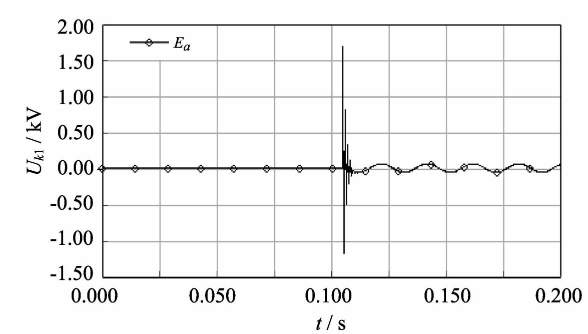

Fig. 6 Breaker B_1's ends voltage after paralleling a 5000pf capacitor

From Fig. 6, it can be seen that after paralleling a capacitor, an oscillating voltage is produced between the operational both ends of B_1. That goes against devices' operation safe. Input and output a capacitor will lead to repeated breakdown, while input a resistance, it does good to restrict inrush current.

Therefore, the method to parallel a resistance is adopted. Given reducing recovery voltage and resistance heat capacity, the value of this resistance ranges from 250 Ω to 3 kΩ. After paralleling a 3-kΩ resistance, let B_1 operate as the first mode and get the simulation result as Fig. 7 shows. At the moment of break-brake opening, there will be a TRV with amplitude about 4 kV. And the voltage of breaker B_1 will be stably a power frequency recovery voltage with amplitude about 51 kV.

As Fig. 7 shows, *RRRV* is got by

$$RRRV = \frac{4\,000\ \text{V}}{250\ \mu\text{s}} = 16\ \text{V}/\mu\text{s}. \qquad (8)$$

Eq. (8) shows that after paralleling a 3-kΩ resistance, the indexes of breaker's TRV will be reduced greatly. When parallel other resistances' val-

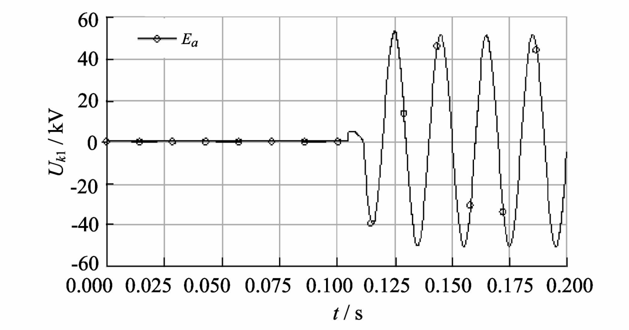

Fig. 7 Breaker B_1's ends voltage after paralleling a 3 kΩ resistance

ues, the indexes of the TRV are shown in Table 1.

Table 1 Different TRV indexes corresponding different paralleling resistance values

R /kΩ	U_{ck} /kV	t_1 /μs	U_{pp} /kV	t_2 /s	$RRRV$ /(V·μs^{-1})
3	4	250	4.4	0.106 5	16
2	2.7	250	3	0.106 5	10.8
1	1.275	250	1.55	0.106 5	5.1
0.5	0.7	250	0.785	0.106 5	2.8
0.25	0.35	250	0.4	0.106 5	1.4

where R is the paralleling resistance, U_{ck} is reference voltage, t_1 is the time when U_{ck} appears, U_{pp} is peak of voltage and t_2 is the time when U_{pp} appears.

Table 1 shows that the smaller the parallel resistance values are, the more obvious effects they will do. When parallel a 500-Ω resistance, the amplitude of TRV is 785 V and the up rate is 2.8 V/μs, which is small enough. Besides, the smaller the parallel resistance's values are, the more energy they need. After a comprehensive consideration, this paper chooses a 500-Ω parallel resistaoce to deal with the high TRV.

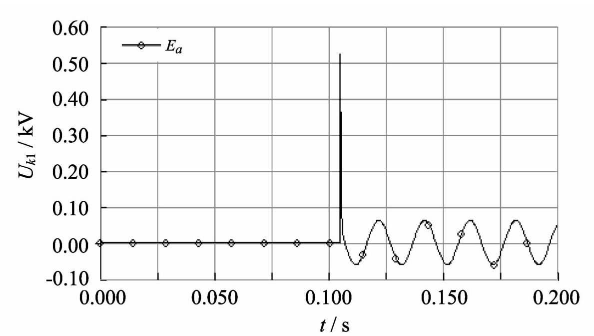

Fig. 8 Breaker B_1's ends voltage after paralleling a 500-Ω resistance

After paralleling a 500-Ω resistance, let B_1 operate as the second mode, the simulation result is shown in Fig. 8 and $RRRT$ is

$$RRRV = \frac{525\ V}{250\ \mu s} = 2.1\ V/\mu s. \qquad (9)$$

From Fig. 8 and Eq. (9), it is clearly known that TRV of U_{ck} is 525 V and the up rate is 2.1 V/μs. So it can operate normally.

3 Conclusion

According to the above simulation results, the following conclusions can be drawn.

1) When a 35-kV side's breaker cuts off the transformer as the first operational way, it will lead to a TRV with higher indexes than to take the second mode. But TRV indexes of both modes are allowable.

2) When TRV indexes exceed the standard, paralleling a resistance can reduce the indexes greatly. The smaller the resistance value is, the more obvious effect it will have.

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