Development and application of a double-break vacuum on-load tap-changer

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Abstract—At present, the mainstream large-capacity vacuum on-load tap-changer generally uses a single resistance transition and there is a risk of breaking inter-stage short-circuit current. In order to improve the operational reliability of the vacuum tap-changer, this paper innovatively developed a double-break vacuum on-load tap-changer using dual transition resistances, which avoids the problem of inconsistent loads between the main vacuum tube and the transition vacuum tube, and theoretically avoids the inter-stage short-circuit accident, and completed the development, type test and trial run of the tap changer.

1. Introduction

Because vacuum on-load tap-changers have the advantages of less maintenance, no oil carbonization pollution, and low cost of use, they have been widely used in power systems. However, judging from the performance in recent years, the operation failure rate of vacuum on-load tap-changers is too high, and the consequences caused by its failure are also serious, especially the consequences caused by the performance degradation or damage of the vacuum tube are the most serious, which is more likely to cause the tap changer to ignite or the transformer to burn out. This paper analyzed the structural characteristics of current mainstream large-capacity vacuum on-load tap-changers, and found some shortcomings in the design of vacuum tap-changers, and proposed a design idea for double-break vacuum on-load tap-changers. And this paper also completed the development, type test and trial run of the double-break vacuum tap-changer.

2. Problems in large-capacity vacuum on-load tap-changers

By analyzing the structural characteristics of current mainstream large-capacity vacuum on-load tap-changers, such as SHZV from Shanghai Huaming, ZVM from Guizhou Changzheng, VR from MR, and VUC from ABB, it is found that the following problems generally exist in the current large-capacity vacuum on-load tap changers\cite{1}:

(1) The switching circuit generally adopts single resistance transition, and the switching load of the vacuum tube is inconsistent. Because the vacuum tube of the diverter switch has a larger external size than the arc contact, and with the increase of the stage capacity, the larger the single vacuum bubble is, the less amounts of vacuum bubbles will be used on the diverter switch. Therefore, the large-capacity switch on the market generally adopts double vacuum tube and single transition resistance, as shown in Figure 1.
In Figure 1, Vm is the main vacuum tube; Vt is the transition vacuum tube, and R is the transition resistance. In mechanical transmission, the opening and closing of the vacuum tube contact is controlled by a rotating cam disc track, and the cam disc is driven by a fast mechanism to reciprocate, which will inevitably cause a vacuum tube in one direction (such as single-to-double) to move first, and the vacuum tube in the other direction (such as double-to-single) to move later. If the Vm main vacuum tube moves first, its breaking current is the load current IN, and the recovery voltage of the fracture is IₜR. This is called "break first, then bridge". In this case, the breaking capacity of the Vm main vacuum tube is rated class capacity (the product of breaking current and fracture recovery voltage). In the other direction, the Vt transition vacuum tube will move first, and the Vm main vacuum tube will move later. This is called "bridge first, then break". In this case, the Vm breaking current will be the load current superimposed on the circulating current. The recovery voltage on the fracture is the superimposed level voltage of the recovery voltage IₜR. In this case, the breaking capacity of Vm is four times the rated level capacity [2].

Taking the VR type of MR company as an example, the task analysis of each contact of the single transition resistance switch is shown in Table 1. It can be seen that the main contact and the transition contact of the single transition resistance tap switch have a clear division of labor.

| Operation direction | main on-off contact | transition contact |
|---------------------|---------------------|---------------------|
|                     | contact | breaking current | recovery voltage | number of operations | contact | breaking current | recovery voltage | number of operations |
| A→B                 | MSV     | I                 | IₜR               | N/2                  | TTV     | \( \frac{I_{t}}{2} \pm \frac{U_{5}}{R} \) | \( U_{5} \pm IₜR \) | N/2                  |
| B→A                 | MSV     | I                 | IₜR               | N/2                  | TTV     | \( \frac{I_{t}}{2} \pm \frac{U_{5}}{R} \) | \( U_{5} \pm IₜR \) | N/2                  |

In order to avoid the situation that the vacuum tube is switched withstand four times the capacity, some products adopt the mechanical design of the cam plate to change the track. That is to say, let the vacuum bubble run on one track from single to double direction, and run on the other track from double to single direction, which can guarantee that the main vacuum bubble moves first, and the transition vacuum bubble moves later. Although this design solves the problem of switching withstand four times the capacity of the main vacuum tube, it also brings the risk of mechanical damage if the cam disc is not in place.
(2) The risk of switching withstand the short-circuit current between stages after the vacuum tube leaks. If a certain vacuum tube leaks, it will not be able to effectively extinguish the arc. The mechanical contacts connected in series with the branch will participate in breaking the current. Although the mechanical contacts also have a certain arc extinguishing ability, once the arc extinguishment fails, there will be an inter-stage short circuit between the mechanical contact fractures. The short circuit path has no impedance limitation, usually up to tens of thousands of amperes, which is likely to cause a tap changer deflagration accident[3], as shown in Fig.2.

Therefore, single-resistor transition is generally used for large-capacity vacuum on-load tap-changers, and there is a risk of breaking short-circuit current between stages. In order to improve the operational reliability of the vacuum tap-changer, this paper innovatively developed a double-break vacuum on-load tap-changer using double transition resistors. It avoids the problem of inconsistency in the load of the main vacuum tube and the transition vacuum tube, and theoretically avoids the inter-stage short-circuit accident of the tap changer[4].

![Fig.2 Short circuit between switch stages](image)

3. Design of double-break vacuum tap-changer

3.1 Design of double fracture vacuum tube

The double-break vacuum tube is an integrated form. As shown in Figure 3, its movable contacts are located in two independent arc extinguishing chambers, and the static contacts are shared, which can effectively reduce the size of the vacuum tube in series. When the arc is extinguished, it is operated by the vacuum tube synchronous operating mechanism, as shown in Figure 4.

3.2 Switching circuit design

The diverter switch transition circuit of the double-break vacuum tap changer is shown in Figure 5. It adopts the transition principle of double vacuum tube with double transition resistance, where A and B are main contacts, T1 and T2 are isolation contacts, V1 and V2 are vacuum tubes. The contact task of the switch is shown in Table 2. Comparing Table 1 with Table 2, it can be found that the contact task of the double transition resistance tap changer is rotated. In the double break switch, the main on-off branch and the transition branch are alternated. In the single-to-double switching, the V1 branch undertakes the disconnection task of the main on-off branch, and the V2 branch undertakes the transition branch task. On the contrary, in the double-to-single switching, the V1 branch undertakes the task of disconnecting the transition branch, and the V2 branch undertakes the main on-off task. Therefore, on the one hand, the burning loss of the two branch vacuum tubes is exactly the same,
which can greatly improve the overall electrical life of the switch. On the other hand, the dual resistance transition is realized without increasing the number of vacuum tube branches or changing the track, and the two-direction switching procedure is symmetrical [5].

![Integrated double-break vacuum tube](image1)

![Vacuum tube synchronous operating mechanism](image2)

### Fig.3 Integrated double-break vacuum tube

### Fig.4 Vacuum tube synchronous operating mechanism

| Table 2 | Task analysis of driverter switch contracts |
|---------|-------------------------------------------|
| Operation direction | main on-off contact | transition contact |
| | contact | breaking current | recovery voltage | number of operations | contact | breaking current | recovery voltage | number of operations |
| A→B | V1 | I | IR | N/2 | V2 | $\frac{1}{2}(U_s \pm U_s / R)$ | $\frac{1}{2}(U_s \pm I_v R)$ | N/2 |
| B→A | V2 | I | IR | N/2 | V1 | $\frac{1}{2}(U_s \pm I_v R)$ | $\frac{1}{2}(U_s \pm I_v R)$ | N/2 |

### 3.3 Design features of double-break vacuum on-load tap-changer

The double-break vacuum on-load tap-changer has triple protection, and its main technical features are as follows:

1. Independent arc-extinguishing double-break vacuum tubes are adopted, and the two vacuum tube fractures on each branch are opened and closed synchronously. On the one hand, the recovery voltage between the two fractures after the opening is divided by them, which is not easy to reignite. On the other hand, even if one of the fracture extinguishing chambers leaks, the other fracture can be opened normally. This is the first protection[6].

2. Even if the double-break vacuum tube on a branch leaks at the same time, the isolation contact T1 or T2 connected in series with it has the ability to break the current multiple times. At this time, the switching oil will decompose to produce gas, which can be used for early warning. This is the second protection[7].

3. There is always a transition resistance in the two branches. Even in the worst-case scenario, if the double-break vacuum tube cannot break the arc, nor can the mechanical contact break the arc, and cause a short circuit between single and double contact, there is always a transition resistance current limiting on the short circuit path. So the short circuit current of tens of thousands of amperes will not develop between single and double contact, but only the circulating current level (the level voltage is divided by the transition resistance), and the circulating current will eventually be broken by the mechanical contact. Therefore, an inter-stage short-circuit accident will not happen in the double-break switch in theory. This is the third protection[8].
3.4 Technical parameters
The double-break vacuum on-load tap-changer adopts a combined type and consists of a switch, a tap selector and a motor mechanism; the rated through-current is 1300A, the maximum rated voltage is 6000V, the rated capacity is 4950kVA, and the rated frequency is 50Hz. The connection method is three-phase neutral point connection, and the short-circuit capacity is: thermal stability 15kA/3S, dynamic stability 37.5kA (peak value), mechanical life 1.5 million times and electrical life 600,000 times.

![Diagram of double-break vacuum on-load tap-changer](image)

Fig.5 Action process of the double-break vacuum tap switch diverter switch

4. Trial run
The double-break vacuum on-load tap-changer developed in this paper has been connected to a 220kV main transformer for trial run for 6 months, with more than 1,000 switching times. From the oil chromatographic inspection and the hanging core inspection, the current performance is good.
5. Conclusion

In this paper, the structural characteristics of the current mainstream large-capacity vacuum on-load tap-changers are analyzed, and it is found that the current vacuum tap-changers generally only use a single resistance transition and there is a risk of breaking short-circuit current between stages. In order to improve the reliability of the vacuum tap-changer, this paper innovatively developed a double-break vacuum on-load tap-changer with double transition resistors, which avoids the problem of inconsistent loads between the main vacuum tube and the transition vacuum tube, and theoretically avoids the inter-stage short-circuit accident, and completed the development, type test and trial run of the tap changer.

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