Analysis of a SVC Device Filter Capacitor Bank Circuit Breaker Explosion

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Abstract. When SVC device is in operation mode, it can provide fast dynamic reactive power compensation for the system when the power grid is disturbed greatly, and it can improve the voltage stability of the system. With the growing popularity of SVC devices in China, it is particularly important to study the faults of SVC devices in the process of operation. In this paper, the recent explosion of filter capacitor bank breaker in SVC device of a substation which was put into operation earlier in China is analyzed in detail. Through the inspection of equipment after failure, combined with the background of computer monitoring system, relay protection, and fault recording, the failure process is analyzed, and finally five preventive measures are put forward. It can provide guidance for the operation and maintenance of other station capacitor bank breakers, especially for the station capacitor bank breakers installed with SVC device, so as to ensure the safe and stable operation of the power grid.

1. Introduction
With the continuous expansion of the "west to East" DC transmission scale, the backbone grid of China Southern Power Grid will maintain the characteristics of strong direct current and weak AC, which is one of the key factors affecting the stability of the system. Once the DC single pole or double pole is locked, the load will be transferred to the AC system in an instant, which will make the voltage of the AC system drop rapidly or even lose stability. At this time, if the fast recovery ability of the bus voltage of the AC system can be improved, the stability ability of the system can be improved. Dynamic reactive power compensation can effectively strengthen the voltage support ability of AC system and improve the stability of power grid[1-6].

As an earlier SVC device put into operation in China, recently, an explosion happened to the filter branch circuit breaker about ten minutes after it was put into operation. Through the analysis of the event, it can provide the operation and maintenance of capacitor bank breakers in other stations, especially for similar stations equipped with SVC device to provide the pre accident anticipation, so as to avoid the recurrence of similar faults.

2. Fault condition
On December 19, 2019, the capacitor bank of FC11 filter branch of SVC device in a 500 kV substation exploded and caught fire ten minutes after it was put into operation. The circuit breaker of this branch failed to trip due to the low lock of SF6 air pressure, and the fault was removed by the circuit breaker at the low-voltage side of the upper main transformer. The fault did not cause the load loss of the main network.
2.1 Equipment parameters and protection configuration
SVC equipment of a 500 kV substation includes a group of thyristor controlled reactors (TCR), four group of fixed capacitors (FC), Namely FC3, FC5, FC7, FC11. The structure of SVC device is shown in Figure 1.[7-8]

Fig.1 Structure of SVC

Tab.1 Equipment parameters and protection configuration

| No. | Equipment name | Equipment parameters | Protection configuration               |
|-----|----------------|----------------------|----------------------------------------|
| 1   | 301            | 3AP1-FG              | RCS978CF Low voltage side backup protection |
| 2   | 311, 312, 313, 314 | LW24-72.5           | PSC692                                 |
| 3   | 315            | LW24-72.5            | PST693                                 |
| 4   | SVC           |                      | RXPE 2009                              |

Tab.2 Parameters of 4 FC Branches in SVC

| FC  | Installed capacity/kvar | Fundamental compensation capacity/kvar | Reactor inductance/mH |
|-----|-------------------------|----------------------------------------|-----------------------|
| FC3 | 78 000                  | 59 046                                 | 9.931                 |
| FC5 | 65 280                  | 45 304                                 | 4.036                 |
FC7  72 000  57 456  1.591
FC11 60 480  47 658  0.767

Tab.3  Part of the control strategy in SVC

| No | Policy description               | Trip logic | Fixed value |
|----|----------------------------------|------------|-------------|
| 1  | Synchronous phase shift          | All trips  | 180ms       |
| 2  | Under voltage at 35kV side       | All trips  | 2s          |

The model of fault circuit breaker is LW24-72.5, Put into operation in May 2009. The Capacitor protection model is PSC692. The setting value of current section I is 2.8A. Time limit of current section I is 0.2s. TA Transformation ratio is 1500/1. Circuit breaker 301 uses RCS978CF low-voltage side backup protection of main transformer. Over current section III fixes value 3A. Over current section III time limit is 0.5s and trip low-voltage side breakers. The TA transformation ratio is 3000/1.

2.2 On site inspection after failure
Through field inspection of the fault circuit breaker, it was found that the phase C arc extinguishing chamber of the fault circuit breaker was blown up and fell to the ground. The pillar of phase C is burnt out, and the pillar of phase B is burnt out to a great extent. The lawn on the ground was burnt out.

![Fig.3 Photo of the fault](image)

2.3 SOE, protection and fault recording analysis
Call the SOE message of the computer monitoring system, and organize the relevant message into table 4:

| Time             | Event log                                 |
|------------------|-------------------------------------------|
| 13:44:07:422ms   | 314 circuit breaker closing               |
|                  | 314 circuit breaker mechanism SF6 low air |
|                  | pressure locking                          |
| 13:46:23:229ms   | 314 capacitor protection action           |
| 13:53:28:062ms   | Backup protection action of               |
|                  | the first set of electrical quantity      |
|                  | protection of main transformer            |
| 13:53:28:191ms   | Backup protection action of               |

Tab.4  Accident record by SOE
2.4 Failure process analysis

According to the fault recording, phase C grounding occurs about 2 minutes after the 314 circuit breaker is closed. As the 35kV reactive power compensation of the station is ungrounded system, single-phase ground fault does not trip. The voltage of phase C to ground is 0, and the voltage of phase A and B to ground increases 1.732 times.

About 9 minutes after the 314 circuit breaker is closed, the c-phase grounding develops into BC two-phase grounding, and the BC phase to ground voltage is 0.
After another 0.2 seconds, the over current section I of the 314 capacitor protection branch first meets the operation conditions, but the 314 breaker cannot be opened due to the low locking of SF6 air pressure of the 314 breaker mechanism, and the fault persists.

After another 0.3 seconds, the backup protection at the low-voltage side of the main transformer meets the action conditions, and the 301 breaker is opened. The protection strategy of SVC device acts to cut off all circuit breakers of SVC system: 311, 312, 313, 315 circuit breakers.

3. Preventive measures

It has been nearly 11 years since the circuit breaker was put into operation in 2009. During this period, no technical transformation has been carried out. The equipment is seriously aged and the performance of the circuit breaker has declined significantly. The large SVC device installed in the station adopts air core reactor can avoid the influence of magnetic saturation on reactor parameters. However, due to the lack of magnetic core restriction inside the reactor, the strong magnetic field generated under the working condition brings strong interference to the secondary equipment and the grounding system of the accessories. During the operation of SVC device, the low-frequency and strong magnetic field produced by reactor will affect the nearby grounding system, induce current for a long time, and then generate heat continuously, which is easy to cause serious consequences such as corrosion and fracture of grounding grid, ablation of grounding terminal [9-12]. Since the SVC device of the station is put into operation, except for the days during the annual maintenance and equipment trip, the other 340 days are in operation every year. According to the regulations, the single-phase ground fault of 35kV ungrounded system can continue to operate for 2 hours when the single-phase ground current is less than 5A. However, this fault developed into two-phase fault after less than 10 minutes under the condition of meeting the regulations. It was verified again that under the SVC device environment, the performance of the circuit breaker decreased faster than under normal conditions. In order to avoid similar incidents, the following precautions can be taken.

1) Pay more attention to the background abnormal signal of the monitoring system. The indirect cause of this event is that the SF6 air pressure of 314 circuit breaker mechanism is low and locked, resulting in the failure of opening. The 314 circuit breaker is not equipped with circuit breaker protection, so it can not cut off the fault quickly through the failure protection of circuit breaker protection, only through the action of the upper level protection. Causes the breakdown aggravation, the equipment damage degree aggravation. If the operator finds the signal in time and opens the circuit breaker in advance, the event can be avoided.

2) Shorten the maintenance period of operation and maintenance strategy of circuit breakers for capacitor banks. The closing inrush current will be produced when the circuit breaker of capacitor bank is closed. Compared with the conventional circuit breaker, its closing pre breakdown arc ablation area is larger and the temperature is higher. So, the mass loss caused by the arc ablation is larger, and the mechanical wear between the dynamic and static contacts is more serious, even more than the arc ablation, which is the main reason of the mass loss. If the capacitor has large capacity of single group, large closing inrush current, frequent operation, more serious mechanical wear between moving and fixed contacts of the circuit breaker. It is significantly shorter electrical life of the circuit breaker [13-15].

3) Adjust the SVC device control strategy. The SVC device is equipped with a 500kV side over-voltage control strategy: when the 500kV bus voltage is monitored to exceed the set value and meet the duration, the filter capacitor bank branches FC11 and FC7 are cut off. First, cut off the FC11 branch. When the 500kV bus voltage still exceeds the set value after cutting off the FC11 branch, continue to cut off the FC7 branch. When the voltage of 500kV bus drops, FC7 branch will be closed automatically, and the voltage will not rise to the fixed value. Continue to close FC11 branch to ensure that TCR inductive reactive power is equal to FC3, FC5, FC7 and FC11 total capacitive reactive power for most of the day, and ensure that the maximum level of reactive power reserve can rapidly support the voltage when the power supply voltage changes, so as to improve the stability of power grid. Because only the 500kV bus voltage of a certain station is used as the trigger condition, the FC filter branch needs to be opened and closed many times in a day. In particular, FC11 branch road
basically opens and closes more than twice a day. It has been nearly 11 years since 314 capacitor bank breaker was opened and closed, which has reached 2 * 365 * 11 = 8030 times. Close to the mechanical and electrical life of the normal operation of the circuit breaker. As an important 500kV substation of China Southern Power Grid, the station is connected to the automatic voltage control (AVC) system of China Southern Power Grid. The AVC system can automatically open and close the capacitor bank according to the control strategy of the whole system. When the over-voltage control strategy of 500kV side of SVC device is withdrawn and AVC system is used, the opening and closing times of FC11 branch can be greatly reduced, the frequent operation can be avoided, and the mechanical and electrical life of the circuit breaker can be shortened.

4) Optimize the operation logic of 35kV reactive power compensation and single-phase ground fault bus protection in ungrounded power system of station. In the early stage of fault, the 35kV bus protection reports "Ta disconnection blocking", and the bus differential protection does not act. If it can optimize the action logic of 35kV reactive compensation and single-phase grounding fault bus protection of ungrounded station power system, for example, the complex voltage blocking of high-voltage level bus protection can be opened, the whole bus can be cut off through the bus protection in case of real fault, and the fault aggravation can be controlled to the maximum extent.

5) Strengthen the monitoring of the computer monitoring system data after the capacitor bank breaker is closed. The computer monitoring system is connected with phase a, B and C current and reactive power of capacitors. When the capacitor bank breaker is closed, the capacitor can be monitored in the computer monitoring system. If any abnormality is found, the fault branch can be cut off manually in time to avoid the occurrence of the event.

4. Epilogue
In recent years, SVC device has been widely used at home and abroad. The SVC device of the substation described in this paper, as the SVC device put into operation earlier in China, has a reactive output capacity of 210 Mvar, which is the largest output capacity in China at that time. The explosion event of the filter capacitor bank breaker of SVC device in this station is particularly typical. This paper analyzes the explosion in detail and puts forward the preventive measures. It can provide guidance for the operation and maintenance of other station capacitor bank breakers, especially for the station capacitor bank breakers installed with SVC device, so as to ensure the safe and stable operation of the power grid.

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