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Research on Key Technical Parameters of 1100kV Live Tank Circuit Breaker for UHVDC Converter Station

DU Ning*, XIANG Zutao, HAN Bin, YANG Yue and XIANG Changyuan

State Key Laboratory of Power Grid Safety and Energy Conservation (China Electric Power Research Institute)
No. 15, Xiaoying east road, Qinghe, Haidian district, Beijing, China

***duning@epri.sgcc.com.cn**

Abstract. Many of UHVDC transmission projects planned and under construction are hierarchical connected to 500kV and 1000kV AC grid in China. Live tank circuit breakers are selected for switching 1000kV filters. During the development of 1100kV live tank circuit breakers, the closing inrush current and transient recovery voltage are key factors for structure of extinguishing chamber of circuit breakers. In this paper, the above factors are analyzed by simulation, and key technical parameters of 1100kV live tank circuit breakers for UHVDC converter station are proposed.
Keywords. 1100kV live tank circuit breaker, UHVDC converter station, inrush current, transient recovery voltage

1. Introduction
Recently, UHV technology has been developed rapidly in China. According to the planning of State Grid of China, UHV AC Three-Hua synchronous grid (include North China, Central China and East China) and 27 UHVDC loops will be completed in 2020. Along with rapid steps of UHV AC & DC grid construction, demand of live tank circuit breakers has been significantly increased. The receiving ends of partial ±800kV UHVDC projects are planned to hierarchical connected to 500kV and 1000kV AC grid [1-8], whose 1000kV capacitors are controlled by live tank circuit breakers.

During the development of 1100kV live tank circuit breakers, the closing inrush current and transient recovery voltage are key factors for structure of extinguishing chamber of circuit breakers, as well as important indicators to evaluate the transient performance of 1100kV live tank circuit breakers. In order to develop 1100kV live tank circuit breakers with high performance, modest cost, and reasonable parameters, electromagnetic transient simulation should be carried out, and the switching process of circuit breakers should be analyzed.

Relative to tank circuit breakers, the manufacturing cost of live tank circuit breakers is much lower, who has remarkable economic benefits [9]. However, the extinguishing chamber and anti-seismic design is more difficult due to its smaller size and higher center of gravity. The power adjustment range of UHV grid and the capacity of capacitors are large, and the filters should be frequent switched, which leads to a large inrush current for closing and a high transient recovery voltage for opening.

To solve the above problems, simulation studies have been made in this paper.

2. Simulation modeling

According to the target grid in the “13th Five-Year Plan” of State Grid of China, the short circuit current of receiving ends at 1000kV sides have been calculated. Results indicate that, the value of Zhalute-Qingzhou project is the largest, up to 53kA. Taking this project as an example for simulation modeling. The model consists of AC grid, and the main connection and control system of DC grid.

2.1. Modeling for AC system

Zhalute-Qingzhou project begins from Zhalute converter station in Inner Mongolia, and ends at Qingzhou converter station in Shandong. The total length of UHVDC lines is 1224km, and each pole consists two 12-pulse converters connected in series. The rated voltage, rated power and rated current of this project are ±800kV, 10GW, and 6.25kA respectively.

According to planning data for the year of 2020, Qingzhou converter station and Weifang UHV station is the same station. While in the newest engineering drawing, the above two stations are connected by two loop 1000kV AC lines. Using electromagnetic transient program, and modeling the AC grid nearby Qingzhou station, the three-phase short circuit currents under above two conditions are calculated at 1000kV bus in Qingzhou station. Results are as follows.

(1) If Qingzhou and Weifang stations are the same station, the short circuit current at 1000kV bus in Qingzhou station is 52.2kA;

(2) If Qingzhou and Weifang stations are connected by AC lines, the short circuit current at 1000kV bus in Qingzhou station is 28.2kA.

Obviously, compared to the planning data, the short circuit current for actual system in Qingzhou station is much lower. To invest the breaking capacity of circuit breakers, the model of system in this paper is established according to the planing data, and Qingzhou and Weifang UHV stations are set to the same station. Fig.1 illustrates the AC grid for the receiving end of Zhalute-Qingzhou project.

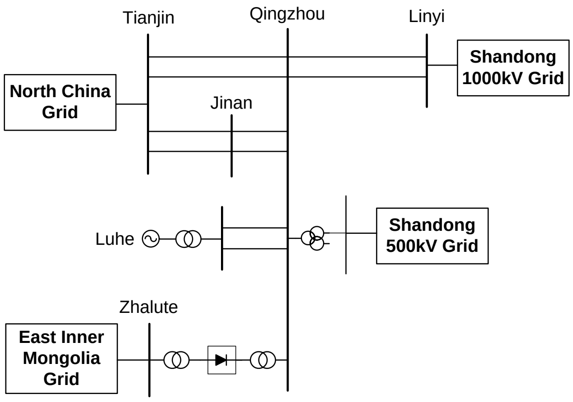
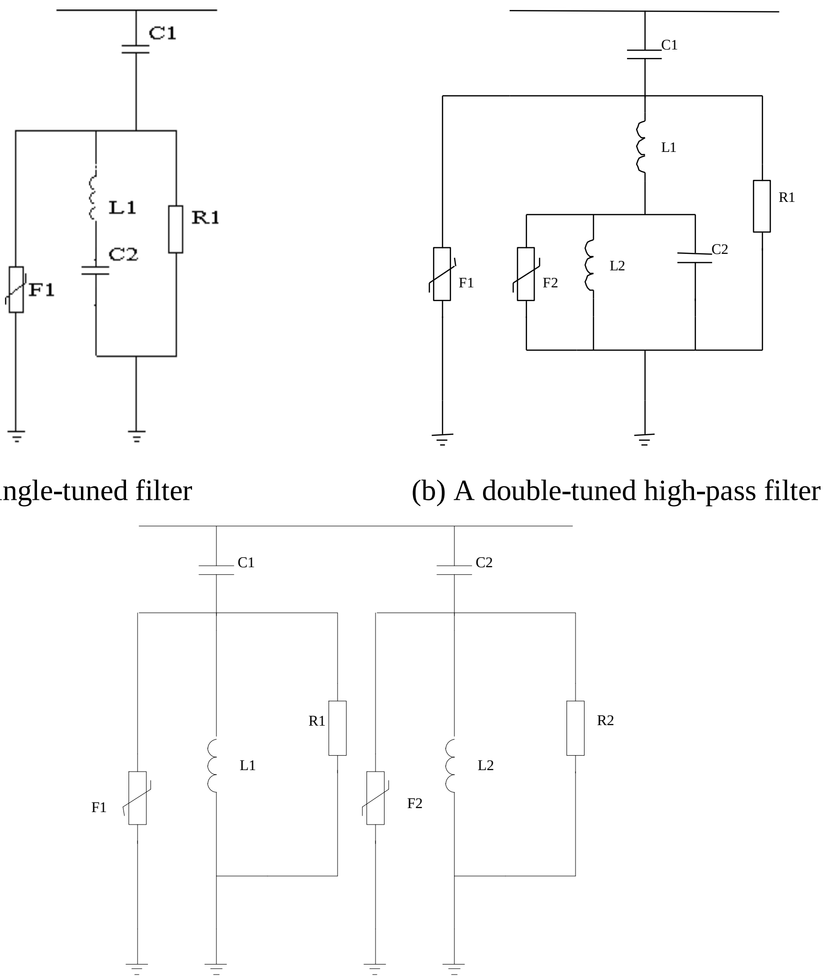


Figure 1. Diagram of AC grid for receiving end of Zhalute-Qingzhou project.

2.2. AC filters

There are 5 different kinds of typical AC filters in HVDC system, which consist of HP3, HP12/24, HP24/36, BP11/13, and SC [10-11]. HP3 is a single tuned filter, HP12/24 and HP24/36 are double-tuned high-pass filters and BP11/13 is a double-tuned band-pass filter. Fig.2 shows their circuit diagram.



(a) A single-tuned filter

(b) A double-tuned high-pass filter

(c) A double-tuned band-pass filter

Figure 2. Circuit diagram of AC filters.

The AC filters of the receiving end of Zhalute-Qingzhou project are connected to the 500kV and 1000kV AC buses. Following shows the configuration of AC filters.

(1) 500kV of Qingzhou station:

- 8 HP12/24 filters, 275Mvar;
- 2 HP3 filters, 275Mvar;
- 2 SC, 260Mvar.

(2) 1000kV of Qingzhou station:

- 10 HP12/24 filters, 270Mvar;
- 2 HP3 filters, 270Mvar.

2.3. Main electrical connection for UHVDC system

Generally, a hierarchical connection for UHVDC means that the The receiving ends are connected to two AC girds with different voltage ranks. For Qingzhou station, the HV transformer is connected to 500kV grid, and the LV transformer connected to 1000kV. Fig.3 shows the main electrical connection for the receiving end of UHVDC.

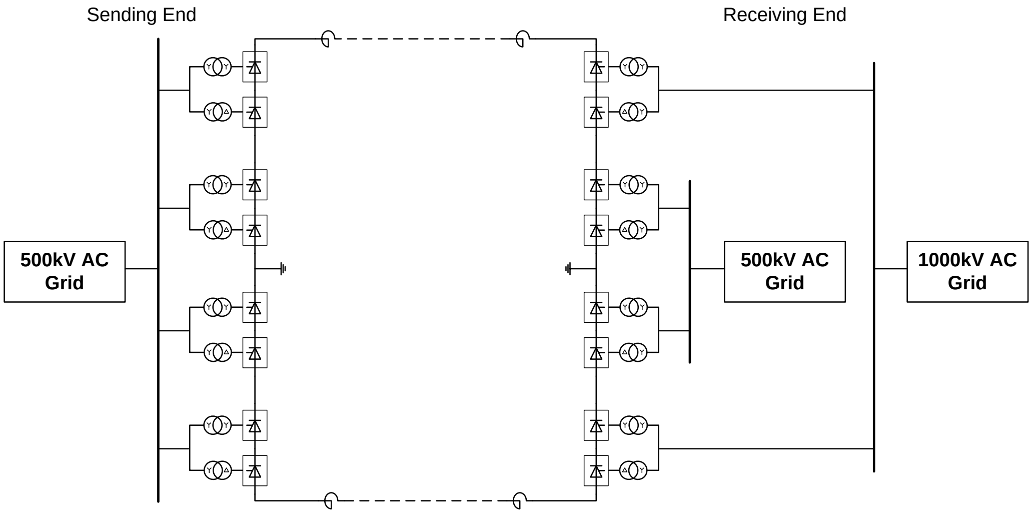


Figure 3. Diagram of a hierarchical connection of the receiving end of UHVDC.

2.4. Control system of UHVDC

The simulation model of control system for UHVDC is consistent with the actual controller, which consists of constant current control, constant voltage control, constant extinction angle control, voltage dependent current order limit, pole power control, converter transformer tap control, etc [12-13]. Generally, when HVDC works under steady-state operation, at the inverter side, the direct voltage is controlled by converter transformer trap, while the extinction angle keeps constant. At the rectifier, the direct voltage is controlled by extinction angle.

3. Inrush current

3.1. Standards

According to the national standard of China GB/T 11024.1-2010 [14], the magnitude of overcurrent caused by switching should be restricted to no more than 100 times rated current.

For AC filters with a 1000kV rated voltage, the rated currents and peak withstand currents with typical capacities are listed in Table 1.

Table 1. Typical rated currents and peak withstand currents for 1100kV AC filters.

Capacity of 3-phase filter (Mvar)	Rated current (kA)	Permitted peak withstand current (rms, kA)
210	0.110	11.0
270	0.142	14.2
315	0.165	16.5
420	0.220	22.0

3.2. Simulation results

The simulation was carried out in PSCAD/EMTDC. In this simulation, different conditions are considered, including the type and capacity of filters, series reactor, and the other filters' status. Results of closing rush currents for different filters are shown in Table 2 and 3.

Table 2. Rush currents of 1100kV circuit breakers closing SC (without closing resistor).

Capacity of SC (Mvar)	Series reactor (mH)	Rush current (kA)	Permitted current (kA)
210	2	13.4	11.0
	3	11.0	
	4	9.6	
270	2	15.2	14.2
	3	12.4	
	4	10.8	
315	2	16.3	16.5
	3	13.4	
	4	11.6	
420	2	18.6	22.0
	3	15.3	
	4	13.3	

Table 3. Rush currents of 1100kV circuit breakers closing HP3 and HP12/24 (without closing resistor).

Type of filter	Capacity of filter (Mvar)	Rush current (kA)	Permitted current (kA)
HP3	270	0.5	14.2
HP12/24	270	2.5	14.2

It is observed from Table 2 and Table 3 that:

For filters with the same capacity, rush current of closing a SC is much larger than that of closing a HP3 or HP12/24.

According to Table 1, the closing rush current will be easier to exceed the permitted withstand value for a SC with smaller capacity.

Closing resistors are usually employed to suppress rush current. Considering to use a 600 ohm or 1150 ohm closing resistor, whose action time is about 10ms. The simulation results are shown in Table 4. Obviously, the rush current of closing a SC decreases significantly when using a closing resistor. There are no distinct difference between the rush currents with the above two resistances.

Table 4. Rush currents of 1100kV circuit breakers closing SC (with closing resistor).

Capacity of SC (Mvar)	Closing resistor (Ω)	Series reactor (mH)	Rush current (kA)
315	600	2	0.9
	1150	2	0.8

4. Transient recovery voltage

During fault clearing process, when the short circuit current passes a current zero, it depends on the recovery process of dielectric insulating strength and arc gap voltage that whether the arc could be extinguished. So it is important to analyze the recovery voltage process when circuit breakers switching off a fault.

The transient voltage between contacts of the circuit breaker after arc extinction is called transient recovery voltage (TRV). When opening a short circuit fault, TRV is crucial for arc extinction. Generally, TRV has two criteria, including its magnitude and rate of rise (RRRV).

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4.1. Standards

In 2007, the power industry of China proposed the experimental standard of TRV for 1100kV circuit breakers in DL/T 402-2007 [15]. In 2009, a standardized technical guidance document of China - GB/Z 24838-2009 was presented [16]. Nowadays, IEC has added parameter requirements for 1100kV circuit breaker experiments to IEC 62271-100 2.1 2012 [17].

According to research on TRV of extension project of UHV Changzhi-Nanyang-Jingmen project by CEPRI, TRV of circuit breakers for series compensated UHV lines may exceed existing standards, and new experimental requirements has been proposed. Supplementary tests has been carried out, and test results prove that, UHV circuit breakers should sustain TRV up to 2610kV and RRRV up to 1.2kV/μs when opening a short circuit current of 9kA [18], which is apparently higher than the value in the existing standard (2245kV).

For circuit breakers switching off AC filter sub-banks, as the breaking current is far less than short circuit current, TRV requirement for circuit breakers could be suitably raised. There are no relative standards as yet.

4.2. Calculating results

In this section, switching overvoltages under various conditions are considered. Four UHV AC transmission lines connected to Qingzhou station and four UHV AC transformers in Qingzhou station are taken into account. Overvoltage calculating results are illustrated in Table 5.

Table 5. Rush currents of 1100kV circuit breakers closing SC (with closing resistor).

Conditions	Switching overvoltages (p.u.)
Closing unload lines	1.37
Closing unload transformers	1.21
Fault clearance of 1LG (with single-phase reclosing)	1.57
UHVDC emergency switch off	1.54
Fault clearance of 1LG (without single-phase reclosing)	1.49
Tripping of the last circuit breaker with a single circuit line in operation	1.54

A typical overvoltage waveform under the condition of single-phase permanent fault clearance with reclosing is illustrated in Fig.4.

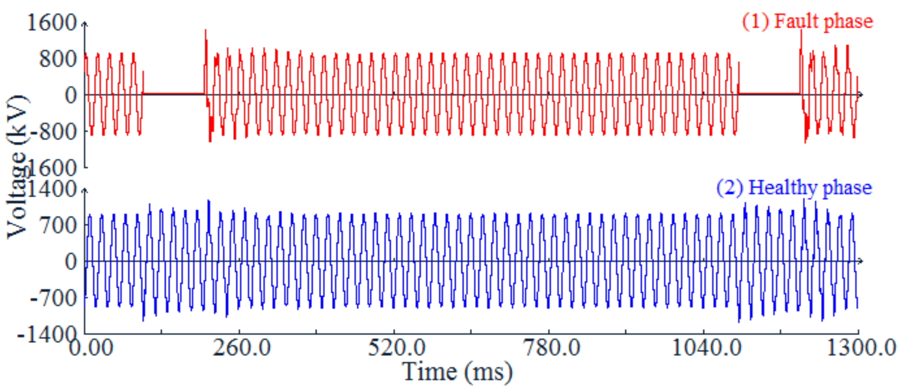

Figure 4. Overvoltage waveform of fault clearance of 1LG (with single-phase reclosing).

According to Table 5, the peak of switching overvoltages is 1.57p.u. Considering that a circuit breaker connecting a capacitor and a 1000kV bus. When the circuit breaker is open, in the electromagnetic transient process, the voltage on the capacitor keeps nearly invariant, and the bus voltage changes. Thereby the peak TRV will appear when the voltages on the bus and the capacitor are of the same magnitude bus opposite polarity, which is equal to twice the bus voltage. According to the national standard of China [19], switching overvoltage on 1000kV bus should be no more than 1.6p.u., so the theoretical maximum TRV for circuit breakers opening 1000kV filter sub-banks can be calculated as follows.

$$U_{TRVm} = \frac{\sqrt{2}}{\sqrt{3}} U_m \times 2 \times 1.6 = 2874\text{kV} \tag{1}$$

Where Um is the maximum operating voltage for 1000kV system, which is equal to 1100kV.

According to above analysis results, it is suggested that all circuit breakers for switching 1000kV AC filter sub-banks should withstand a TRV up to no less than 2874kV.

5. Conclusions

In this paper, Zhalute-Qingzhou UHVDC project is taken as an example, and the inrush current and transient recovery voltage for 1100kV live tank circuit breakers switching AC filters are analyzed. With the simulation results, we can come to the following conclusions.

(1) Inrush current

- For filters with the same capacity, the inrush current of closing a SC will be much larger than that of closing a HP3 or HP12/24.
- The inrush current for closing filters with smaller capacity will likely exceed the national standard, as the permitted value is lower.
- Applying a 600 ohm or 1150 ohm closing resistor will limit the inrush current in permitted scope. Resistors with the both resistance take nearly the same effect.

(2) Transient recovery voltage

- Switching overvoltages under various conditions are analyzed for Qingzhou converter station, and the peak value of phase-to-ground overvoltage is 1.57p.u.
- The theoretical maximum transient recovery voltage for circuit breakers opening 1000kV filters is 2874kV.
- It is suggested that all circuit breakers for switching 1000kV AC filter sub-banks should withstand a TRV up to no less than 2874kV.

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