

Research on Key Technical Parameters of Main Equipments for UHV Converter Station in High Altitude Area

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SUMMARY

The Qinghai region in China is an important national clean energy base and it is of great significance to build UHVDC (Ultra High Voltage Direct Current, $\pm 800\text{kV}$) power transmission project. The proposed converter station in Qinghai is the highest altitude UHV converter station of the world, about 3000 meters above sea level, which will cause problems such as reduced insulation performance and heat dissipation in the converter station. The existing key technical parameters of the main equipment of the UHV converter station have been unable to adapt to the actual needs. Therefore, further study of the technical parameters of the main equipment in the station combined with the environment characteristics of the high altitude and large temperature difference is of great significance for promoting the construction of the UHV converter station in Qinghai.

First of all, based on the actual needs of the project, the key technical parameters of the converter transformer under high altitude conditions were studied. Besides, the temperature change limit of the converter transformer was corrected, and an appropriate change of the converter transformer structural parameters was proposed. The modification of the external insulation according to the altitude would increase the external insulation distance. Therefore combining the conditions of large-scale equipment transportation and the on-site assembly, the corresponding parameters of the insulation structure and the performance parameters of the mechanical structure were proposed. According to the requirements of sand resistance and strong ultraviolet radiation resistance, the technical requirements for the coating assembly system of the exposed part of the converter transformer are put forward.

Secondly, the key technical parameters of tank circuit breaker for switching capacitive device which is applied for 750kV AC filter sub-bank in China was studied. In order to solve the problem of the decrease of external insulation capacity for breaker under the conditions of high altitude and large temperature difference, the external insulation correction value and technical parameters of the heating device

were proposed. The requirements of technical parameters for anti-aging and anti-sanding under conditions of large sandstorms and strong ultraviolet rays were proposed. Methods of improving the stability of circuit-breakers which frequently switch capacitive devices was studied, and new technical parameters for circuit breakers and test plans for reliability improvement were proposed.

Thirdly, the key electrical and structural technical parameters of converter valve and cooling device under high altitude conditions were studied. The design requirements of the external insulation correction value, voltage sharing and insulation coordination of the converter valve under high altitude conditions were proposed. The structural parameters of the converter valve under high altitude conditions were proposed. The technical parameters of converter valve cooling device in high-altitude and low-temperature areas were studied, and the technical requirements for special heat-dissipating design brought about by the reduction of heat exchange capacity were proposed.

The research results show that this paper solves the technical difficulties in the selection of main equipment in UHV converter stations at high altitudes, and the proposed key technical parameters of the main equipment meet the actual needs of the project.

KEYWORDS

High Altitude, UHVDC, Converter transformer, Tank circuit breaker, Converter valve

I. Introduction

The Qinghai region in China is an important national clean energy base and it is of great significance to build UHVDC (Ultra High Voltage Direct Current, $\pm 800\text{kV}$) power transmission project for delivering clean energy.

The Qinghai-Henan $\pm 800\text{kV}$ UHVDC transmission project starts at Hainan Converter Station in Qinghai Province and ends at Zhumadian Converter Station in Henan Province. The length of the DC line is about 1600km, and the bipolar DC line is one return. Two 12-pulse converters per pole are connected in series. The rated voltage is $\pm 800\text{kV}$, the rated DC transmission capacity is 8000MW, and the rated DC current is 5000A. The Hainan converter station is usually operated as a rectifier station, and the Zhumadian converter station is usually operated as an inverter station.

The climate characteristics in Hainan area : dry, strong sunshine, large evaporation, low atmosphere pressure, windy, sandstorm, long cold in winter, short cool in summer, large temperature difference between day and night. According to meteorological data, the average annual temperature is $4.1\text{ }^\circ\text{C}$, the extreme high temperature is $33.7\text{ }^\circ\text{C}$, the extreme minimum temperature is $-28.9\text{ }^\circ\text{C}$, and the altitude is about 3000m.

The proposed converter station in Qinghai is the highest altitude UHV converter station of the world, about 3000 meters above sea level, which will cause problems such as reduced insulation performance and heat dissipation in the converter station. The existing key technical parameters of the main equipment of the UHV converter station have been unable to adapt to the actual needs. Therefore, further study of the technical parameters of the main equipment in the station combined with the environment characteristics of the high altitude and large temperature difference is of great significance for promoting the construction of the UHV converter station in Qinghai.

II. Converter Transformer

The converter transformer has complex technology, high process requirements, and need to withstand the mixing of AC and DC electric fields^[2]. Besides the transformers for Hainan station operates under harsh environments such as high altitude, strong ultraviolet rays, large temperature difference, and weak AC system which put forward higher requirements of the key technical parameters. In particular, it is subject to the size limits of large-scale equipment transport and on-site assembly requirements, which further increases the difficulty of equipment development.

A. key technical parameters

The converter transformers for Qinghai station are designed as single phase, double windings, on-load voltage regulation, oil immersed. The type of cooling is OFAF or ODAF, and the neutral points of line windings are connected to earth directly. The key technical parameters are showed as Table 1.

Table 1 The converter transformer key technical parameters for Qinghai station

	Unit	Line winding	Valve windings	
			Y	Δ
	Y/ Δ			
Rated voltage at tap ± 0 , phase to earth	kVrms	447.5	99.8	172.9
Maximum voltage, steady state, phase to earth	kVrms	461.9	103.0	178.5
Rated power (SN2w)	MVA	415	415	415
Rated continuous current, without redundant cooling in service, at nominal tap	Arms	911	4082	2357

1.1p.u. overload current(continuous), with redundant cooling in service, at minimum tap	Arms	1072	4596	2654
1.1p.u. overload current(2h), without redundant cooling in service, at minimum tap	Arms	1072	4596	2654
1.2p.u. overload current(2h), with redundant cooling in service, at minimum tap	Arms	1186	5088	2938
Line winding tap changer, Number of steps			+25/-5	
Line winding tap changer , Step size	%		0.86	
Reactance	%		21	

B. Special consideration for transformer temperature rise and structure

If the altitude of the installation site is higher than 1000m and the altitude of the test site is less than 1000m, the allowable temperature rise limit during the test shall be reduced as follows. For air-cooled transformers, the limit of temperature rise should be reduced by 1K for each additional 250m height [3-4]. Therefore, the temperature rise limit of the converter transformer of Hainan Converter Station is corrected 8K. Moreover, according to IEC60071-2, the external insulation withstand level of converter transformer and bushing is corrected. The above corrections pose a huge challenge to the design and manufacture of transformer.

In response to special requirements such as high altitude, the following optimization measures have been taken to prevent the temperature rise from exceeding the standard: reducing the current density of the coil, reducing the heat generation of the wire cake; increasing the heat dissipation oil passage, increasing the heat dissipation area of the wire cake; increasing the cooler capacity.

As to the structure consideration, the single-phase double-winding on-load tap-changing transformer adopts a two-column parallel structure. The valve side windings are fully insulated, and the upper and lower ends are respectively formed with angled ring insulators. The head end of the line side winding is a 750kV end outlet structure, and a sufficient number of formed angled ring insulators are also used at two sides of the terminal.

C. Special consideration for insulator

The converter transformer tank is inside the boxing and is not susceptible to wind, sand and strong ultraviolet rays. The line winding side is exposed, so special consideration is required for sand resistance and anti-aging properties of insulation coat. The high temperature silicone rubber composite insulation coat has strong advantages in these respects, and the composite insulation coat needs to meet the following test requirements [5].

1) Thermomechanical prestress test: The test temperature range is -50 °C ~ +70 °C. After a series of prestressing (electric, mechanical, hot and cold, boiled) tests, the sealing performance and mechanical properties of the composite insulator can still satisfy the operating requirements.

2) Blowing sand test: Through the simulation of the high wind and sand environment on the composite insulator, the sample has no cracks and shedding, no obvious scratches, abrasion and wear. Then the thickness of the shed is measured, and the deepest wear does not exceed 0.3 mm.

3) Accelerated aging test: The insulator is irradiated with an ultraviolet lamp at a radiation intensity of 500 W/m² for a long time, and the initial elongation at break is still greater than 150% after continuous irradiation for 5000 h.

III. Tank circuit breaker for Switching Capacitive Device

The tank breaker in converter station is mainly used for switching AC filter(ACF) and capacitor frequently. In the previous DC transmission projects, tank breakers

were damaged occasionally. Besides due to the high altitude and large temperature difference in terminal Qinghai, the operation stability will be more lower.

A. key technical parameters

The key technical parameters of tank breaker for switching ACF or capacitor in terminal Qinghai are showed below.

Table 2 The key technical parameters of tank breaker for switching capacitive device in Hainan station

Parameters		Unit	Value
	Rated voltage	kV	800
	Rated frequency	Hz	50
	Rated current	A	5000
Power frequency withstand voltage(1min)	across open contacts		960+460
	Phase-earth	kV	960
LIWL (1.2/50s)	across open contacts	kV	2100+650
	Phase-earth		2100
SIWL (250/2500s)	across open contacts	kV	1300+650
	Phase-earth		1550
The short-time withstand current and duration		kA/s	63/2
The peak withstand current		kA	170

In addition, the insulation level of the equipment needs to be corrected for altitude, refer to the altitude correction method of IEC60694. Among them, the rated power frequency 1min withstand voltage, the rated lightning impulse withstand voltage peak altitude correction coefficient is recommended to select 1.28, the rated operational impulse withstand voltage peak (phase-earth) altitude correction factor is recommended to choose 1.20.

B. Special consideration for transformer tank circuit breaker

The rated air pressure of the tank circuit breaker chamber usually is 0.6 MPa. To prevent liquefaction of the SF6 gas, it is necessary to add heating cables to the circuit breaker tank. The heating cable is designed according to one main and one standby, and has automatic and manual start function. When the ambient temperature is lower than -25 °C, it starts automatically and stops heating according to the change of ambient temperature.

The technical parameters of the insulation coat are the same as the C part of II converter transformer.

In order to achieve the purpose of dustproof, sandproof and waterproof, the mechanism case and the control cabinet doors are designed as double doors and reliably sealed. The control cabinet is provided with breathing holes, and cables are added cable gland at the cable entrance of the mechanism case.

C. Methods for improving the operation stability

1) Select the appropriate closing resistor

When the filter is normally put into operation, the closing of the circuit breaker will generate a closing inrush current that will impact the filter. In order to reduce the inrush current, the phase selection closing device will be installed on the 550kV AC filter group circuit breaker. However, the closing time of the 800kV circuit breaker is difficult to control within ±1ms, and the phase selection closing device is not ideal [6]. A closing resistor is required to limit the inrush current.

Through simulation calculations, the BP11/13 and HP3 type circuit breakers use 1500Ω closing resistors, and the HP24/36 and SC type group circuit breakers are recommended 600 Ω closing resistors. The maximum closing inrush current that the tank breaker for switching capacitive device is reduced from 21.7 kA to 7.2 kA. Figure 1 shows the maximum closing inrush current that occurs when a SC-type tank breaker is installed with a 600Ω closing resistor.

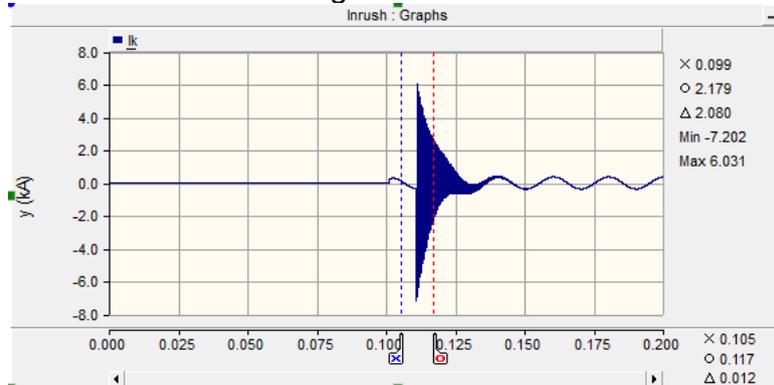


Fig 1 Maximum closing inrush current waveform of SC type tank breaker with a 600Ω closing resistor

2) Add the C2 life test

The C2 life test is 4 identical C2 (BC) tests. One of the C2 (BC) tests included 120 closing and 96 opening. During the test, the closing resistance is considered to be normal. The closing current is taken as 10kA, the opening current is taken as 400A, and the test voltage coefficient is taken as 1.3. The test conditions are more stringent, and very high requirements are imposed on the circuit breaker equipment. Therefore, the test can further improve the operational reliability of the circuit breaker equipment. Even if some products fail to pass the test, the test results can find out the limit number of opening and closing of the circuit breaker under test. It helps operators to replace equipment in time before the end of the circuit breaker life.

IV Converter Valve

The structure of the thyristor converter valve is complex, involving more than 20 insulating material, withstanding various voltages, electric fields. How to determine the components of the converter valve, insulation reinforcement of different materials at high altitudes and the cooling method and capacity of the valve cooling system are very critical.

A. key technical parameters of converter valve

Four 12-pulse converter valve groups are designed for Hainan station. And each 12-pulse group shall be constructed as double valves(MVU), single tower, suspended from the valve hall ceiling with 6-inch thyristors.

The normal power flow is 8000MW from Terminal Qinghai to Terminal Henan. Besides the overload capability of the project is relatively high, showed in Table 3.

Although the main challenge for converter valve in Terminal Qinghai is the insulation issue. So the selection of altitude correction factors is the most important. The altitude correction factor K_a is based on the dependence of the atmosphere pressure on the altitude.

$$K_a = e^{m\left(\frac{H}{8150}\right)}$$

Where H is the altitude above sea level(in meters) and the value of m is as follows. For co-ordination lightning impulse withstand voltage, m equals to 1.0. For co-

ordination switching impulse withstand voltages, m is the function of switching impulse withstand voltage^[7]. The factors K_a are selected appropriately according to the standards and accumulated experience.

Table 3 Converter valve overload capability and maximum d.c. current for full voltage bipolar operation in normal direction under normal conditions

Max. Ambient Temperature (°C) Outdoor Dry bulb/ Valve Hall	Overload Duration	Redundant Cooling not in Operation			Redundant Cooling in Operation		
33.7/60°C	3 Second	1.3 p.u.	10400MW	5857	1.3 p.u.	10400MW	5857
	2 Hour	1.1 p.u.	8800MW	5628	1.2 p.u.	9600MW	6231
	Continuous	1.0 p.u.	8000MW	5046	1.1 p.u.	8800MW	5628

Besides, the max air temperature in the valve hall in which valves are mounted is 60°C. So it's necessary to correct the temperature factor K_b according to the altitude.

$$K_b = \frac{273+t_0}{273+t}$$

Where t_0 is the standard reference temperature, 20°C, and t is max air temperature. Thus the corrected switching and lightning withstand voltages for the main electrical nodes are showed in Table 4.

Table 4 Corrected insulation level for the main electrical nodes

Insulation level	Unit	Value
Across valve		
- SIWL	kV _{crest}	646
- LIWL	kV _{crest}	644
DC bus line side		
- SIWL	kV _{crest}	1915
- LIWL	kV _{crest}	2615
DC bus Valve side		
- SIWL	kV _{crest}	1915
- LIWL	kV _{crest}	2615
Yytransf phase valve side		
- SIWL	kV _{crest}	1495
- LIWL	kV _{crest}	1939
Middle point, HV 12 pulse bridge		
- SIWL	kV _{crest}	1131
- LIWL	kV _{crest}	1373
Ydtransf phase valve side		
- SIWL	kV _{crest}	789
- LIWL	kV _{crest}	915
Neutral bus		
- SIWL	kV _{crest}	707
- LIWL	kV _{crest}	835

B. Special consideration for valve insulation structure

At high altitude, the air pressure in the valve hall is significantly reduced, which will cause the insulation strength of the converter valve to decrease, the initial discharge voltage of the converter valve to decrease, and the corona starting voltage to decrease. Therefore special consideration is given to the parameters and design of the insulation structure of the converter valve.

Firstly, the electric field simulation of the converter valve should be performed, and the air gap of the external insulation electrical strength between the valve layers is determined according to the electric field division and the actual air clearance analysis. Switching impulse, lightning impulse and power frequency U50 test should be performed on this gap.^[8]

Secondly, the valve module test of the 8.5kV thyristor should be carried out to test the external insulation withstand capability of the valve module. The test items include switching impulse, lightning impulse, power frequency and DC U50 test, power frequency and DC partial discharge test.

Thirdly, during the valve structure design, the maximum electric field strength of the metal components and the surface of the insulator in the valve should be calculated. By optimizing the structural design and the layout of each structure in the valve, the maximum electric field strength should be less than the corona field strength, avoiding corona discharge during operation. Moreover, the insulating material should be made of a material resistant to corona discharge, which reduces the risk of aging due to corona discharge.

C. Special consideration for valve cooling equipment

Hainan converter station has four completely independent valve cooling systems, each of which is a composite cooling system consisting of an air cooler and a closed water-cooling tower.

At high altitudes, the air is thin, and the amount of heat dissipated by the air cooler and each component is greatly reduced. Therefore, special consideration should be given to the selection and design of the motor and external cooling fan of the valve cooling equipment^[9].

At the temperature and altitude of the Hainan converter station, the main circulation pump motor load must not exceed 86% of the rated output. The selection of the make-up water pump and air-cooler fan motor is also based on the main circulation pump motor for high altitude correction.

In the external cooling fan selection process, full consideration is given to the effects of changes in air quality, such as heat transfer coefficient, air quality, air flow, external pressure of the fan, etc., and these parameters are incorporated into the design of the external cooling fan for accurate calculations of heat dissipation.

V Conclusion

Based on the Qinghai-Henan UHVDC transmission project, this paper conducts an in-depth study on the key technical parameters of the main equipments in the converter station.

First of all, the key technical parameters and temperature rise limit of the converter transformer under high altitude conditions were proposed. And the suitable type of insulator material was recommended. Secondly, the key technical parameters of tank circuit breaker for switching capacitive devices were proposed, attached with heating cables and sandproof measures. Besides, the appropriate closing resistor and C2 life test are the effective methods to improve operation stability. Thirdly, the key technical parameters and corrected value of converter valve and cooling device under high altitude conditions were studied. And related design optimization and core component selection were recommended.

The research solve the technical difficulties in the selection of main equipment in UHV converter stations at high altitudes, and the proposed key technical parameters of the main equipment meet the actual needs of the project.

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