Study of the On-site Calibration Technology for DC Voltage Transformer Based on Synchronous Data Acquisition

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Keywords: DC voltage transformer, DC standard voltage divider, synchronous data acquisition system, on-site calibration test

Abstract. This paper developed a DC high voltage standard device (including the DC standard voltage divider and the synchronous data acquisition system) for the on-site calibration test of DC converter station. After selecting the appropriate circuit for on-site calibration test, this paper completed the on-site test calibration of the DC voltage transformer in Fulong converter station. The result demonstrates that the DC high voltage standard device this paper developed has the ability to ± 800kV HVDC voltage transformer on-site calibration tests.

Introduction

Direct current transmission project in our country will become the largest in number, the longest in line and the largest in capacity in the world to 2020[1,2,3,4]. The DC voltage transformer's calibration test before installation and periodic calibration is important to ensure the safe operation of the HVDC transmission system. The on-site calibration test at rated conditions of DC voltage transformer in converter station is few studied in China.

In order to realize the on-site calibration of the voltage transformer at Fulong converter station in Xiangjiaba - Shanghai Fengxian ± 800kV HVDC transmission demonstration project, this paper developed a standard DC resistive divider used for on-site trials on the basic of analyzing the principle of dc transformer and accomplished the on-site calibration test at rated voltage.

The principle of DC voltage

The principle of DC voltage transformer is showed as Fig. 1. The DC voltage transformer consists of high voltage divider, secondary converter in the control room and transmission cable.

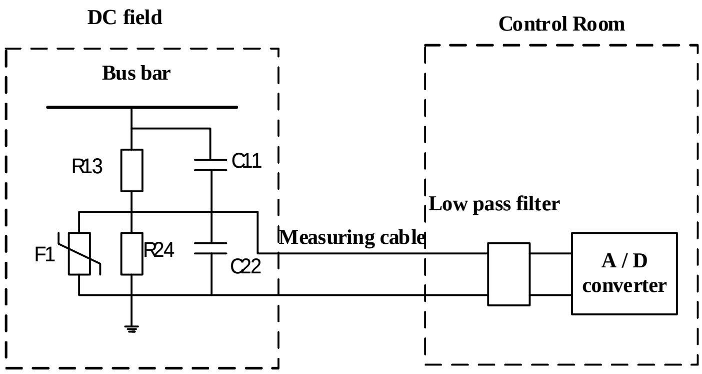

Fig. 1 The principle of DC voltage transformer

R13 and R24 are high and low voltage arm resistance, C11 and C22, respectively high and low voltage arm capacitor, F1 for the low-voltage arm voltage protection device. The capacitance parts play a role in balancing the distribution of lightning impulse voltage. The transmission cable connects the high voltage divider and the secondary converter in the control room. The secondary converter has two independent outputs and converts the measurement signal divider output to the signal control and protection system needed.

Standard Equipment

DC high voltage power supply Direct comparison method used in this paper in the calibration of DC voltage divider requires high stability DC high voltage power supply. The short-term stability of the DC high voltage power supply should be less than K/10(K is allowed error of the voltage divider being checked)[5]. When using synchronous data automatic acquisition system, the stability requirements can be greatly reduced. Considering the converter station is normal overhaul, the voltage on the primary string filter reactors and high-voltage divider should be boosted together in calibration. This paper estimated the high voltage test current should be larger than 8mA considering the count of insulators, the condition of insulator surface contamination as well as the condition of local weather. This paper select 1200kV / 10mA DC high voltage generator produced by Huadian Suzhou Electrical Technology Co., which rated output voltage is 1200kV rated output current is 10mA and voltage stability is less than 0.5% within 15 minutes under the test conditions.

Development of standard divider The instability between high voltage arm resistance and low resistance arm is the main reason for the resistor divider measurement error. The error comes mainly from the following aspects: (1) the change in resistance caused by temperature or heat produced by itself; (2) measurement error caused by corona discharge; (3) measurement errors caused by insulating bracket’s leakage current[6,7].

To reduce the voltage divider measurement error, this article takes the following measures in the development of the voltage divider:

a) Select RJP26 metal film resistors. The temperature coefficient is ± 25ppm / K, and single resistor maximum operating power is less than 1/10 of the rated power. Before assembling high voltage divider arm, numbered the each resistance and measured it’s temperature coefficient. Select the resistance close and opposite sign in temperature coefficient during assembly in order to further improve the stability of the high-voltage divider arm.

b) The divider uses three-stage series arrangement and the rated voltage of each stage is 400kV. Install a small equalizing ring between each stage and install a large equalizing rings in the entire top divider, which can uniform the distribution of divider’s electric field and reduced the corona discharge.

c) The divider consists of measuring layer and the shield layer, spirally distributing along the bracket from the top of divider. Shield resistance play a role in increasing the immunity of the proximity effect of the voltage divider, reducing the surface electric field strength of the resistive element and reducing the corona discharge and space conduction current.

d) Selection insulating materials as dielectric and package the resistor divider as a whole in order to reduce the leakage current in the insulating skeleton.

The basic structure of 800kV DC standard on-site resistor divider this paper developed is shown in Fig. 2. R is the measure resistance and r is the shield resistance. The connection style of resistance in the shield layer is displayed in Fig. 2. Leakage current flows into the earth along the insulation shell.

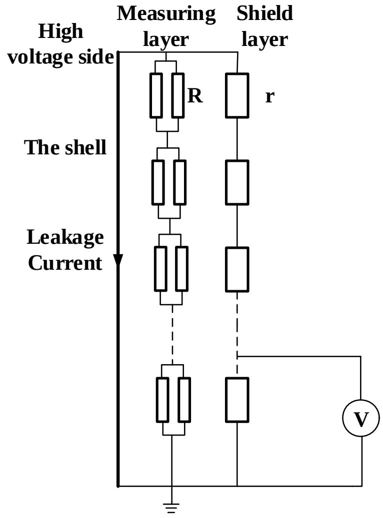

Fig. 2 The basic structure of 800kV DC divider

Calibration of standard divider Calibrate the dividing ratio and linearity of 800kV DC standard on-site resistor divider on the basic of 500kV DC voltage proportional standard established by The National High Voltage Metering Station. The rated pressure ratio of 500kV DC voltage proportional standard is 500kV / 5V, and the measurement uncertainty is 1×10^{-4}. And the rated pressure ratio of 800kV DC voltage proportional standard is 1200kV/12V.

Calibrate the dividing ratio and linearity of 800kV DC standard on-site resistor divider with the compensation method and the voltage ratio method. The results are shown in Tab.1. The difference between two kinds of methods is less than 0.01%. And in 0 ~ 500kV voltage range, the relative error of 800kV DC standard on-site resistor divider's voltage division ratio is less than 0.05% and the linearity is 0.03%.

Tab.1 Calibration results of 800kV standard resistor divider used on-site

Primary voltage(kV)	Compensation Method		Voltage ratio method	
	Actual voltage division ratio	Relative error (%)	Actual voltage division ratio	Relative error (%)
-50	100006	0.01	100005	0.01
-100	100006	0.01	100006	0.01
-150	100002	0.00	100002	0.00
-200	99998	0.00	100003	0.00
-250	99994	-0.01	100000	0.00
-300	99991	-0.01	99996	0.00
-350	99985	-0.01	99993	-0.01
-400	99981	-0.02	99989	-0.01
-450	99978	-0.02	99987	-0.01
-500	99976	-0.02	99984	-0.02

Then ensure linearity of the three-stage resistance in 800kV DC standard on-site resistor divider. Put the three stage of 800kV DC standard on-site resistor divider as the high voltage arm respectively and put the precision adjustable resistance box as low voltage arm. Adjust the resistance box so that the three divider dividing ratio approaches dividing ratio of 500kV DC voltage proportional standard. The linearity of the three-stage resistance in 800kV DC standard on-site resistor divider in 0 ~ 280kV voltage range is shown in Tab.2.

Tab.2 Linearity of each stage resistors

Voltage(kV)	Relative error of lower stage(10^{-4})	Relative error of middle stage(10^{-4})	Relative error of higher stage(10^{-4})
-40	-1.4	+1.2	+1.1
-80	-0.3	+0.8	+1.7
-120	-0.3	+1	+3.1
-160	-0.3	+0.7	+3.3
-200	-0.9	+0.2	+3
-240	-1.4	-0.6	+2.5
-280	-2.4	-1.6	+1.7
Linearity	-2.1	-2.8	+2.2

According to Tab.2, the linearity of the three-stage resistance are about 0.02%. The lower and middle stage resistance increase and the higher stage resistance decrease with the increase of the voltage. The total linearity is less than 0.02% after connecting three stage in series. Although the leakage current under high voltage will increases the linearity of partial pressure ratio, shield structure in standard divider will reduce the leakage current of measurement layer effectively. So the linearity of 800kV DC standard on-site resistor divider should be less than 0.05% in 0~800kV voltage range.

Synchronous data acquisition device Synchronous data acquisition device can be divided into master part and slave part. The master part and slave part are composed of GPS clock synchronization means test systems and high-precision digital multimeters. The schematic is shown in Fig. 3.

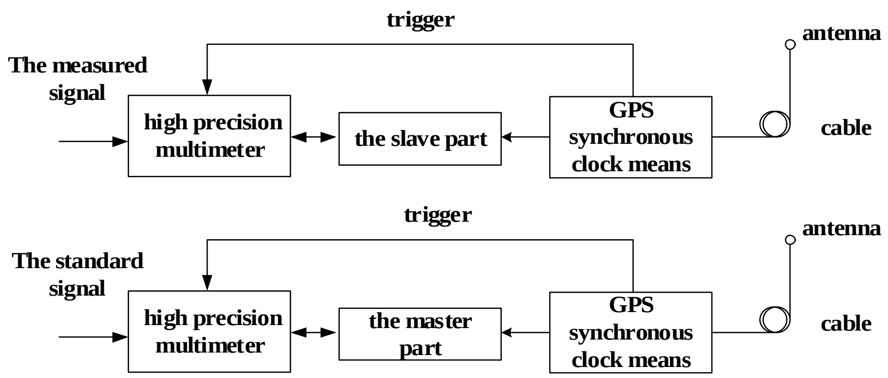

Fig. 3 The schematic of synchronous data acquisition device

GPS clock synchronization device receives GPS satellite positioning information by the GPS antenna, and obtain the second pulse and the absolute time information through the internal precise GPS timing board. Second pulse signal can be send to high-precision digital multimeter as the trigger signal, and the absolute time information can be send to the slave part through USB as measured data's absolute time identification. After GPS positioning, with the trigger of GPS synchronized clock pulses, the slave part controls high-precision digital multimeters through virtual instrument technology to synchronously measure the output signal of the measured transformer and obtain the measured data including the absolute time stamp.

The working principle of master part is the same as the master part, but the difference is that the master part synchronously measure the output signal of the standard transformer.

Calibration and results of on-site test

DC voltage transformer's on-site calibration test connection in Fulong converter station is shown in Fig. 4. Direct comparison method is applied in the on-site calibration [8]: connect the 800kV DC high voltage generator, DC standard resistor divider and DC voltage transformers being measured in parallel, then Synchronous data acquisition means measures the output voltage of the 800kV DC standard resistor divider and DC voltage transformers being measured.

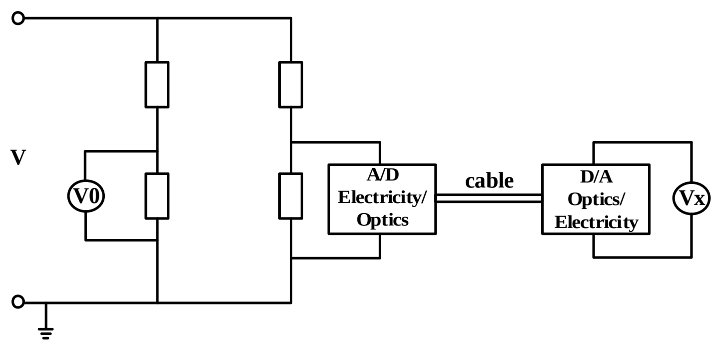

Fig. 4 Circuit of calibration test on-site

The input impedance of 34401A digital multimeter is 10MΩ. The low-voltage arm resistance of standard divider and measured DC voltage transformer were 10kΩ magnitude. The measurement error due to the input impedance of measurement instruments is about 0.1%, which need to be amended. The on-site calibration test data is shown in Tab.3.

Tab.3Data of calibration test on-site

Measuring point(kV)	Standard output(V)	Output of the sample(V)	Actual voltage division ratio of the sample	Relative error (%)
100	1.00898	4.74458	21266	0.08
200	2.03318	9.56084	21266	0.08
250	2.40216	11.2981	21262	0.06
350	3.41135	16.0509	21253	0.03
400	4.00599	18.8546	21247	-0.01
600	6.06606	28.5749	21229	-0.09
800	8.18020	38.5718	21208	-0.19

The measured voltage division ratio of the sample can be calculated by Eq. 1.

$$K_x = \frac{K_0 \times U_0}{U_x}. \quad (1)$$

K_0 is standard dividing ratio; U_0 is the standard output voltage after revised; U_x is the output voltage of the sample after revised.

The relative error of the sample’s voltage division ratio can be calculated by Eq. 2.

$$g = \frac{K_x - K_N}{K_N}. \quad (2)$$

K_x is the voltage division ratio of the sample; K_N is the nominal voltage division ratio of the sample.

When the voltage is 100kV, the measured voltage division ratio of the sample is 21266 and the relative error 0.08%. As the voltage increases, the measured voltage division ratio and the absolute value of the relative error of the sample decreases. When the voltage is 350kV~400kV, the relative error is about 0. When the voltage continues to rise, the voltage division ratio continues to decrease, but the absolute value of the relative error increases. When the voltage is 800kV, the measured voltage division ratio of the sample is 21208 and the relative error -0.19%.

According to the on-site calibration test data, it can be concluded that the relative error of DC voltage transformer’s voltage division ratio in Fulong converter station is about 0.08%~-0.19%, the accuracy class can meet the requirements of 0.2 and the linearity is 0.27%.

Conclusion

(1)Though the calibration of the voltage division ratio of 800kV DC standard on-site resistor divider with 500kV DC voltage proportional standard, this paper concludes that the relative error of 800kV DC standard on-site resistor divider's voltage division ratio is less than 0.05% and the linearity is 0.03% in 0~500kV range.

(2) Though the calibration of three stages' linearity of 800kV DC standard on-site resistor divider with 500kV DC voltage proportional standard, this paper concludes that the linearity of 800kV DC standard on-site resistor divider is less than 0.05% in 0~800kV voltage range.

(3)After the calibration of DC voltage transformer's voltage division ratio in Fulong converter station with the 800kV DC standard on-site resistor divider, the accuracy class of the DC voltage transformer can meet the requirements of 0.2 and the linearity is 0.27%.

In summary, the 800kV DC standard on-site resistor divider developed in this paper can apply in on-site calibration test in ±800kV HVDC voltage transformer.

References

[1] ZHAO Guoliang, WU Tao. Summarization for Development and Application Status of HVDC Technology [J]. North China Electric Power, 2006, 36(8): 28-31, 34.

[2] CEN Kaixin. The New Development of HVDC Power Transmission in China [J]. Guangdong Power Transmission Technology, 2006, 8(6):34-37.

[3] ZHAO Zhongyuan, FANG Zhi, QIU Yuchang, et al. Present Status and Development Trends for HVDC Converter Station [J]. Electric Power, 2002, 35(3): 48-51.

[4] Alexandrov G N. Economical Comparison of AC and DC Transmission lines [J]. High Voltage Engineering, 2008, 34(11): 2259-2261.

[5] National metrology verification regulation of the People's Republic of China. JJG 1007-2005, DC high voltage dividers [S]. Beijing: General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, 2005.

[6] WU Guangya, LUO Bing, WANG Hui. Reliability Analysis of ±800kV UHVDC Insulators [J]. High Voltage Engineering, 2008, 34(9): 1802-1806.

[7] Reynolds P H, Leszczynski S A. DC insulation analysis：a new and better method [J]. IEEE Trans on PAS, 1985, 104(7): 1746-1748.

[8] CHEN Zhong, CAI Zexiang. On-site DC Voltage Withstand Test of ±800kV DC Equipment [J]. High Voltage Engineering, 2009, 35(10): 2356-2360.