Calibration of pulse wave lightning protection component tester and analysis of measuring results

Xinyan Wang[1], Shang Wang[1],Xiaoyan Sun[1], Xiao Liu[1], Hongrui Yan[1], Xuefeng Ma[1]

[1]Shandong Engineering Research Center of Reliability Evaluation for Electric Energy Metering Devices， Shandong Institute of Metrology(SDIM), No.28, Qianfoshan East Road, 250014 Jinan, China,wxy9903@163.com

***Abstract* –A high precision calibration method, based on extreme value measurement, data storage, fast sampling and the simulation of actual use state, for new-type pulse wave lightning protection component tester was proposed after analyzing working principle and difficulties of measurement. This method replaced the conventional measurement method, reading method and sampling method for constant wave, ensured the accuracy of calibration at the same time, and realized the calibration of constant current, initial operating voltage, DC leakage current and DC breakdown voltage of the tester. This method met the requirements of accurate measurement of fast instantaneous signal, and improved the loading mode of traditional measurement by putting the varistor and DC resistor together as the load and simulating the breakdown state with voltage breakdown simulation device. By establishing a measurement model and evaluating the measurement uncertainty, it was concluded that the uncertainty was less than a third of the absolute value of the maximum permit error of the tester.**

***Keywords* –lightning protection component tester, NPLC, data storage, eliminate outliers, uncertainty analysis**

I. INTRODUCTION

Lightning protection element tester (hereinafter referred to as tester)was an instrument used to detect the DC parameters (varistor voltage, DC leakage current, DC breakdown voltage, etc.) of overvoltage protection elements such as metal oxide varistor[1] (MOV) and gas discharge tube (GDT). As it was widely used in the detection of surge protector or its components for low-voltage distribution system to ensure the lightning protection safety of electrical equipment and buildings[2], the tester need to be calibrated regularly to ensure its accuracy. Its classification mainly included pulse wave type vs continuous wave type, automatic type vs manual type.

The output of the tester was a fast instantaneous signal. The leakage current of the tester could not be measured by loading linear loads only and the d.c. breakdown voltage could not be measured without a load simulating the breakdown state of discharge tube. So, the calibration method of the pulse wave tester was significantly different from ordinary continuous wave tester[3-9].

There was no unified calibration specification for the calibration of the tester. Local calibration specifications or self compiled calibration specifications of each calibration institution[10-11], calibration device been developed[12-13], could only be used to calibrate the traditional continuous wave tester.

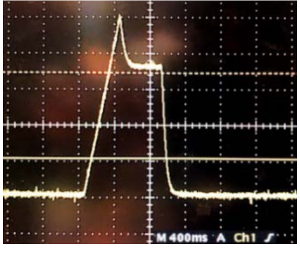
II. WORKING PRINCIPLE

The process of MOV detection by the tester was divided into the following two automatic and continuous steps, which could not be interrupted.

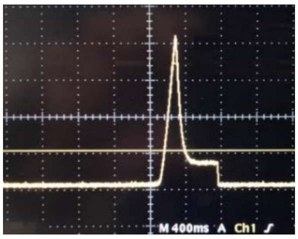
First, just as the current generated by the constant current source of the tester and applied to the MOV rised rapidly from the low value to 1 mA constant current, the voltage at both ends of the MOV measured by the tester was called initial operating voltage. The voltage was not more than 2 000 V usually, and its limit could not be set in advance. The boost time was not more than 400ms usually, as shown in Figure 1 (a).

Then the constant voltage source of the tester immediately applied 0.75 times initial operating voltage to the MOV, and the DC leakage current flowing through the MOV was measured at this time. Usually, the current was not more than 20μA, the duration of this step was not more than 400ms, as shown in Figure 1 (b).

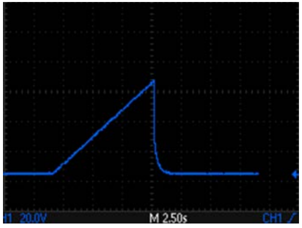
When the tester detects GDT, the DC voltage generated by the ramp voltage generator rised at a certain rising rate (100 V/s generally) until GDT breakdown. The breakdown voltage recorded by the peak voltmeter was the DC breakdown voltage of GDT. The voltage was not more than 2 000 V usually, as shown in Figure 1 (c).



（a） Waveform of MOV voltage



（b）Waveform of MOV current



（c）Waveform of GDT voltage

Fig. 1. Waveform.

III. CALIBRATION DIFFICULTIES

According to the working principle of the tester, the parameters to be calibrated included constant current, initial operating voltage, DC leakage current and DC breakdown voltage. The calibration difficulties of these parameters mainly included the generation, sampling of signal.

A. Constant current and initial operating voltage

When calibrating the constant current current and initial operating voltage of the tester, the output signal was impulse current and impulse voltage. The calibration method for continuous wave tester was no longer applicable.

In addition, if the load was not loaded, there was no current in the circuit. In order to make the current in the circuit reach 1mA, the output voltage of the tester would rise continually until it reached its rated maximum output voltage as the voltage limit could not be set, so the selected calibration value of voltage could not be calibrated.

B. DC leakage current

If a low resistance linear load, which was lower than the ratio of rated voltage of the tester to 1mA constant current, was loaded to calibrate the leakage current, the leakage current would reach 750 μA, then some testers would exceed 200 μA limit, even if it did not exceed the limit, it had no calibration significance because the current exceed the actual use state. But if the high resistance linear load was loaded, the output current could not reach 1mA on account of the tester was limited by the rated voltage, then the tester would stop the output due to automatically protection.

In addition, it could be seen from Fig.1 (b) that the leakage current was less than the maximum current in a continuous measurement process and the duration was less than 400 ms. The calibration method for the conventional constant wave tester was no longer applicable, and the extreme value function of the DMM(digital multimeter) could not be used and the data could not be read manually.

C. DC breakdown voltage

For the DC breakdown voltage, if the breakdown state of the discharge tube could not be simulated, the output voltage of the tester would increase to the maximum output voltage continually as the voltage limit could not be set, and the selected calibration value of voltage could not be calibrated.

IV. CALIBRATION METHOD AND RESULTS

A. Initial operating voltage

The calibration wiring diagram was shown in Fig.2. Connect the DMM with the Maximum DC current measurement function and the load resistor in series at both ends of the positive and negative poles of the tester.

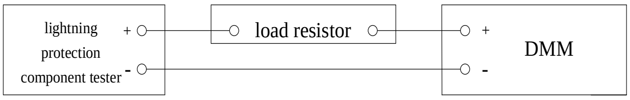


Fig. 2. Calibration wiring diagram of initial operating voltage and constant current

It was known that the loop current was 1 mA. According to the voltage value of the calibration value, the resistance of the load could be calculated by Ohm's law. And the voltage across the resistor could be adjusted to the predetermined calibration value by adjusting the load to this resistance. Set a reasonable sampling interval for the DMM, read the maximum current measured by the DMM, and multiply the maximum current by the resistance to obtain the actual value of the initial operating voltage.

As shown in Fig.3, the error caused by Δt (the DMM sampling interval) was proportional to Δt. The ratio was equal to the ratio of the MPEV(absolute value of the maximum permit error of the signal) and MPEV×T(the product of the MPEV and the rise time of the signal T). In order to ensure that the error caused by Δt was not greater than 1/4 of the MPEV, Δt of DMM should not be greater than 1/4 of MPEV×T.

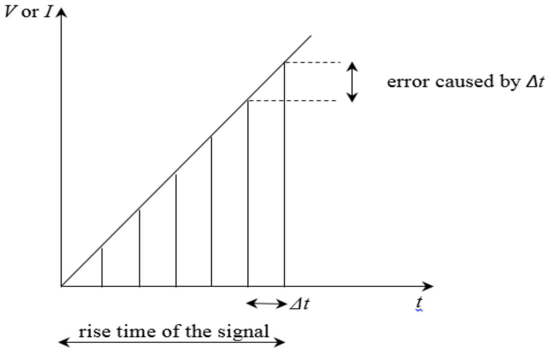


Fig. 3. Sampling interval

$$\mathit{\Delta t} \le \frac{1}{4}\,\text{MPEV}\times T$$

For example, when calibrating a tester with MPE of ± 2% and rise time of current of 400 ms, the sampling time should be set to

$$\mathit{\Delta t} \le \frac{1}{4}\times 2\%\times 400 = 2\ \text{ms}$$

Agilent 34410A DMM was selected in this paper. Press the config key to enter the integration interface and set the NPLC (Number of Power Line Cycles) of its integration time. The minimum sampling interval could reach 0.1 ms. The corresponding relationship between NPLC value and sampling interval was shown in Table 1[14].

Table 1. Relationship between NPLC value and sampling interval of 34410A.

NPLC	Reading rate (n/s)	Sampling interval (ms)
0.006	10 000	0.1
0.02	3 000	0.333
0.06	1 000	1
0.2	300	3.33
1	50	20

The calibration results was shown in Table 2.

Table 2. calibration results of initial operating voltage.

Show value of voltage (V)	Resistance of the load (MΩ)	Maximum current (mA)	Actual value of voltage (V)
100.5	0.1	1.009	100.9
501.2	0.5	1.005	502.5
1 002.8	1	1.004 3	1 004.3
2 003.1	2	1.004 5	2 009.0

B. Constant current

The calibration wiring diagram was shown in Fig.2.

Adjust the resistance load to 0.5 MΩ. Set a reasonable sampling interval for the DMM, read the maximum current measured by the DMM as the actual value of constant current.

The calibration results was shown in Table 3.

Table 3. calibration results of constant current.

Nominal value of current (mA)	Resistance of the load (MΩ)	Maximum current (mA)	Actual value of current (mA)
1	0.5	1.003	1.003

C. DC leakage current

The calibration wiring diagram was shown in Fig.4.The load resistor and varistor were connected in parallel, and then connected in series with the DMM with the DC current data storage function at both ends of the tester.

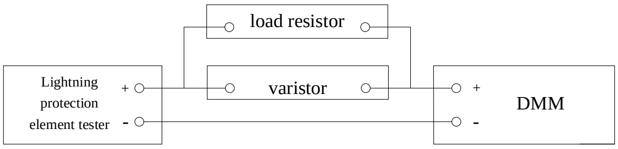


Fig. 4. Calibration wiring diagram of DC leakage current

Measure the varistor voltage U_N and DC leakage current I_L of varistor with the tester in advance, then the resistance of varistor $R_L \approx 0.75U_N/\ I_L$. The calibration value of DC leakage current was I, and the voltage in the calibration leakage current stage was about $0.75U_N$, then the total resistance of varistor and load resistor in parallel

$R \approx 0.75U_N/\ I$. So, the resistance of load resistor

$$R_Z = \frac{1}{\frac{1}{R} - \frac{1}{R_L}} \approx \frac{0.75U_N}{I - I_L} \qquad (1)$$

where：

R_Z ——the resistance of load resistor, MΩ,

U_N ——the varistor voltage of varistor, V,

I ——The calibration value of DC leakage current, μA,

I_L ——DC leakage current of varistor, μA.

Adjust the resistance of load resistor to this value to make the DC leakage current close to calibration value.

Set a reasonable data recording interval for the DMM to record all the data of this measurement process into its memory. Process the stored current data with the steps shown in Fig.5 to obtain the actual value of DC leakage current.

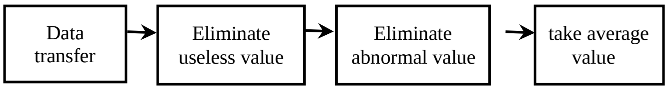


Fig. 5. Data processing steps

First, select USB memory, USB interface, serial interface, network interface, GPIB interface and other methods to transfer the measurement data stored in the DMM to the computer, and then use the word processing software to process the data.

Fig. 6 was a chart that draws all data in the form of line chart in MS Excel software, which revealed the current change curve of the whole measurement process. The part between the red vertical lines was the DC leakage current measurement data, which needed to be retained, and the other data needed to be eliminated.

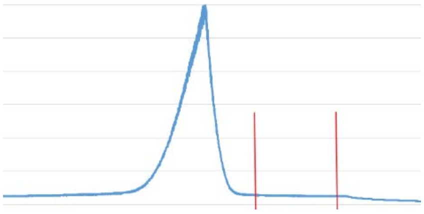


Fig. 6. data chart of current data in Excel

After eliminating useless values, choose Leida, Dixon, grobus and other rules[15] according to the number of remaining data, or chart function, VBA and macro commands in word processing software, to eliminate abnormal values.

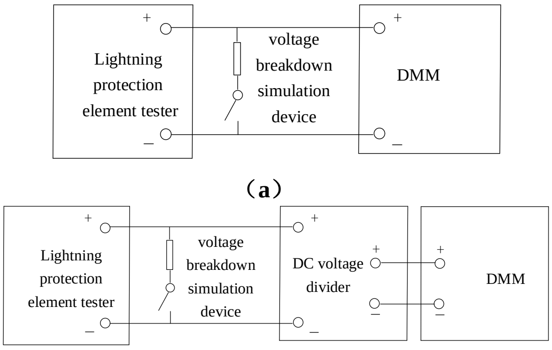
Finally, take the average value of the remaining data to obtain the calibration results, as shown in Table 4.

Table 4. calibration results of DC leakage current.

Show value of current (μA)	Resistance of the load (MΩ)	Varistor voltage of varistor (V)	DC leakage current of varistor (μA)	Actual value of current (μA)
19.6	24	450	6	20.4
105.7	3.3	450	6	106.9

D. DC breakdown voltage

The calibration wiring diagram was shown in Fig.6. When the calibration value was not greater than 1 000 V, connect the DMM with the maximum DC voltage measurement function with the voltage breakdown simulation device in parallel and then with the voltage output terminal of the tester, as shown in Fig. 7(a). When the calibration value was greater than 1 000 V, connect the primary end of the DC voltage divider in parallel with the voltage breakdown simulation device, and then with the voltage output end of the tester, and connect the secondary end of the DC voltage divider in parallel with the DMM, as shown in Fig. 7(b).



（a）

（b）

Fig. 7. Calibration wiring diagram of DC breakdown voltage

Control the action voltage of the voltage breakdown simulation device to trigger the breakdown of the device when the output voltage of the tester rised to the calibration value. Read the maximum voltage measured by the DMM and multiply it by the voltage division ratio of the DC voltage divider (take 1 if not used) as the actual value of the DC breakdown voltage.

The calibration results was shown in Table 5.

Table 5. calibration results of DC breakdown voltage.

Show value of voltage (V)	Action voltage of voltage breakdown simulation device (V)	Maximum voltage measured by the DMM (V)	Actual value of voltage (V)
100.9	100	101.5	101.5
502.1	500	503.2	503.2
1 004.2	1 000	0.100 67	1 006.7
2 007.7	2 000	0.200 84	2 008.4

V. UNCERTAINTY EVALUATION

A tester with MPE of ± 2% and current rising signal duration of 400ms was selected as the calibration object, and 34410A DMM, 0.01 DC voltage divider and standard high value D.C.resistor were selected as the calibration standard. The measurement uncertainty was analyzed as follows.

A. Measurement model

Measurement model of initial operating voltage was showed in equation(2).

$$V_n = I_0 \times R_Z \quad (2)$$

where

V_n——Actual value of initial operating voltage, V,

I_0 ——Current show value of DMM, mA,

R_Z——Resistance of standard high value D.C.resistor, kΩ.

Measurement model of constant current and DC leakage current was showed in equation(3).

$$I_n = I_0 \quad (3)$$

where

I_n ——Actual value of constant current and DC leakage current, μA,

I_0 ——Current show value of DMM, μA.

Measurement model of DC breakdown voltage was showed in equation(4).

$$U_n = kU_0 \quad (4)$$

where

U_n——Actual value of DC breakdown voltage, V,

k ——Voltage division ratio of the DC voltage divider (take 1 if not used),

U_0——Show value of DMM, V.

B. Measurement uncertainty component

1. Standard uncertainty introduced by measurement repeatability $u_1(U_0)$，$u_1(I_0)$
2. Standard uncertainty introduced by accuracy of DMM $u_2(U_0)$，$u_2(I_0)$
3. Standard uncertainty introduced by sampling interval of DMM $u_3(U_0)$，$u_3(I_0)$
4. Standard uncertainty introduced by accuracy of standard high value D.C.resistor $u_4(R_Z)$
5. Standard uncertainty introduced by accuracy of DC voltage divider $u_5(k)$

C. Summary of uncertainty component.

Uncertainty component was shown in Table 6-9.

Table 6. Initial operating voltage

Uncertainty components	Sensitivity Coefficiencts	Value	Type	Distribution	Divisors	Standard uncertainty
measurement repeatability	1	0.12%	A	Normal 1s	1	0.12%
accuracy of DMM	1	0.15%	B	Rectangular	$\sqrt{3}$	0.087%
sampling interval of DMM	1	0.125 %	B	Rectangular	$\sqrt{3}$	0.072%
accuracy of standard high value D.C.resistor	1	0.2%	B	Rectangular	$\sqrt{3}$	0.12%

Table 7. Constant current

Uncertainty components	Sensitivity Coefficiencts	Value	Type	Distribution	Divisors	Standard uncertainty
measurement repeatability	1	0.11%	A	Normal 1s	1	0.11%
accuracy of DMM	1	0.15%	B	Rectangular	$\sqrt{3}$	0.087%
sampling interval of DMM	1	0.125 %	B	Rectangular	$\sqrt{3}$	0.072%

Table 8. DC leakage current

Uncertainty components	Sensitivity Coefficiencts	Value	Type	Distribution	Divisors	Standard uncertainty
measurement repeatability	1	0.097 %	A	Normal 1s	1	0.097%
accuracy of DMM	1	0.175 %	B	Rectangular	$\sqrt{3}$	0.10%

Table 9. DC breakdown voltage

Uncertainty components	Sensitivity Coefficiencts	Value	Type	Distribution	Divisors	Standard uncertainty
measurement repeatability	1	0.12%	A	Normal 1s	1	0.12%
accuracy of DMM	1	0.008 %	B	Rectangular	$\sqrt{3}$	0.005%
sampling interval of DMM	1	0.083 %	B	Rectangular	$\sqrt{3}$	0.048%
accuracy of DC voltage divider	1	0.01%	B	Rectangular	$\sqrt{3}$	0.006%

D. Combine and expand

After combination and expansion, it was concluded that the uncertainty of initial operating voltage, constant current, DC leakage current and DC breakdown voltage were as follows: 0.41%, 0.32%, 0.28% and 0.26%. They were all less than a third of the absolute value of the maximum permit error of the tester.

VI. CONCLUSION

The calibration method proposed in this paper made use of the maximum measurement function and data storage function of the DMM, solved the problem of calibrating the pulse wave lightning protection component tester, especially met the requirements of accurate measurement of fast instantaneous signal and the simulation of the actual use state of the tester, and improved the load loading mode of traditional measurement. And the measurement uncertainty was less than a third of MPEV of the tester. It was concluded that this method was feasible and effective.

REFERENCES

[1] General Administration of quality supervision, inspection and quarantine. “Technical specification for metal oxide varistors(MOV)used in low-voltage apparatus”, GB/T 27746-2011, Beijing, China, 2011.

[2] General Administration of quality supervision, inspection and quarantine. “Technical code for inspection of lightning protection system in building”, GB/T 21431-2015, Beijing, China, 2015.

[3] Fuquan Wang, Jin Huang, Yinquan Zhou, “Analysis and Research on calibration method of varistor tester”, Industrial measurement, 2015, Vol.25, pp. 41-42, 44.

[4] Yanbo Liu, Tianyu Sun, “Research on calibration method of varistor tester”, Light industry standards and quality, 2016, Vol.1, pp. 21-23.

[5] Liaoning Ruiyu measurement and Testing Service Co., Ltd, “A measurement calibration method of lightning protection element tester”, CN202011525059.4, 2021-03-29.

[6] Henan Institute of Metrology, “A calibration method of lightning protection element tester based on fixed voltage timing method”, CN202011563076.7, 2021-02-19.

[7] Henan Institute of Metrology, “Calibration method of lightning protection element tester based on timing voltage measurement method”, CN202011563077.1, 2021-03-19.

[8] Ying Dou, Shupeng Zhang, Weiqun Yu, “Calibration method of varistor tester”, China Metrology, 2011, Vol.11, pp. 94-96.

[9] Qiuwei Mo, Huarong Mo, YuZhong, “Explore the calibration method and error analysis of lightning protection element tester”, Scientific and Technological Exploration, 2012, Vol.4, pp. 70, 85.

[10] Quality and technical supervision of Guangxi Zhuang Autonomous Region, “Calibration specification for lightning protection element tester, JJF（Gui）18-2009”, Nanning, China, 2009.

[11] Quality and Technology Supervision of Zhejiang Province, “Calibration specification for varistor DC parameter tester, JJF（Zhe）1088-2012”, Hangzhou, China, 2012.

[12] Jiaming Mi, “Development and application of calibration device for lightning protection element tester”, Railway Technical Supervision, 2014, Vol.42, pp. 20-22, 25.

[13] Qiuwei Mo, Huarong Mo, Yan Huang, “Briefly describes the verification device of lightning protection element tester and the method of calibrating lightning protection element tester”, China Science and Technology Expo, 2013, Vol.7, pp. 34-36.

[14] “Agilent 34410A/11A 6½ Digital multimeter User Guide”, 2006.

[15] Changchun Li, Kehao Chang, Yushan Liu, “Application of several outlier discrimination criteria in meteorological measurement data processing”, Electronic measurement technology, 2020, Vol.43, pp. 68-72.