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Research of Long-Term Drift of the National High-Voltage DC Standard

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***Abstract* – The high-voltage direct current (DC) technology is widely used in electrophysical, environmental, electrical, power plants and systems. Power transmission DC is more economical than on alternating current, therefore high DC lines are built in many countries. The high-voltage DC is used for testing of the insulation of capacitors, cables, rotating machines, etc. For these types of insulation, the detection of significant defects is effective at high direct voltage. The National high-voltage DC standard of Ukraine has already undergone several modernizations to improve its metrological characteristics and reliability during operation from 1999. Research of the metrological characteristics of the this standard allows to increase the accuracy and reliability of calibration of high-voltage DC working standards of accredited calibration laboratories.**

I. INTRODUCTION

The high-voltage direct current (DC) technology is widely used in electrophysical, environmental, electrical, power plants and systems. Power transmission on DC is more economical than on alternating current, therefore high DC lines are built in many countries of the world. It is possible to transmit large powers with less losses through them [1,2].

The high-voltage DC is used for acceptance or maintenance testing of the insulation of capacitors, cables and rotating machines. For these types of insulation, the detection of significant defects is effective at high direct voltage, at which there is no danger of powerful partial discharges and there is practically no destructive effect on defect-free insulation [2].

An urgent task is to ensure the metrological traceability of high-voltage DC working standards and measuring instruments. An important role in this is played by the national standards of different countries. They provide the highest level of working standard calibrations for accredited calibration laboratories [3,4].

II. NATIONAL HIGH-VOLTAGE DC STANDARDS

Less than twenty countries have high-voltage DC standards that have voltages above 150 kV. In addition, these standards differ significantly in their accuracy. The best such standards include the national standards of such countries as Sweden, Finland, Australia, Turkey, Canada, Germany, France, Spain [5].

The State Primary Standard of a Unit of DC Electric Voltage of range from 1 kV to 180 kV (National High-Voltage DC Standard) functions in State Enterprise "Ukrmetrteststandard" (UMTS, Kyiv, Ukraine) since 1999. During operation, the National High-Voltage DC Standard has already undergone several modernizations to improve its metrological characteristics and reliability. The standard has a long-term history of research of its characteristics.

Metrological characteristics of National High-Voltage DC Standard:

- range of reproduction of nominal values of high-voltage DC from 1 kV to 180 kV;
- standard deviation of the measurement result when reproducing a unit of high-voltage DC does not exceed $5 \cdot 10^{-5}$;
- expanded measurement uncertainty is $3.6 \cdot 10^{-4}$;
- instability for the year does not exceed is $3 \cdot 10^{-4}$.

During the COOMET.EM-S7 supplementary comparison [6] was established metrological characteristics of National High-Voltage DC Standard have high stability and a reserve for improvement.

A general view of the national standard is presented on Fig. 1.

III. RESEARCH OF THE NATIONAL HIGH-VOLTAGE DC STANDARD OF UKRAINE

The basis of the National High-Voltage DC Standard is the combined measures of high-voltage DC (CMs). These measures consist (Fig. 2) of unambiguous DC measures (UMs) with a nominal voltage of 1 kV on Zener diode (VD), a current stabilization unit for the measuring circuit (BS) and a voltmeter (V). UMs are implemented on Zener diodes, which are selected and tested according to special methods [7].

Metrological characteristics of UM:

- nominal voltage value for (U_{UMn}):

Fig. 1. The general view of National high-voltage DC standard.

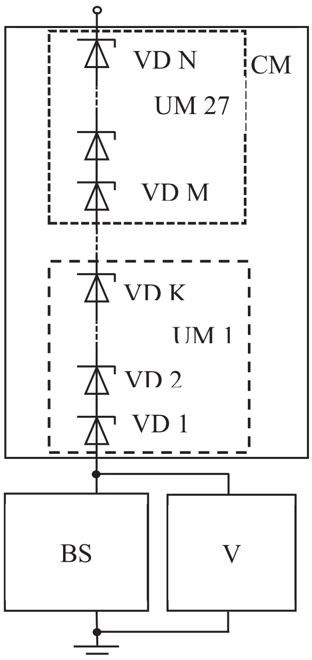

Fig. 2. The generalized structural scheme of CM.

unambiguous measure of type I (UM1… UM10) is 1 kV; unambiguous measure of type II (UM11… UM27) is 10 kV;

- deviation of the actual voltage value from the nominal value of the voltage measure is $1{\cdot}10^{-4}\ U_{UMn}$;
- instability of the actual voltage value of unambiguous measure not more than is $2{\cdot}10^{-4}\ U_{UMn}$.

Metrological characteristics of BS:

- the range of stabilization of the operating current of UMs: range I is from 10 to 100 V; range II is from 100 to 1000 V;
- nominal value of stabilization current is 5 mA;
- deviation of the actual value of the stabilization current from the nominal value is ±5 μA.

Measurement of the high-voltage DC is based on the differential method of measurement. The value of DC voltage is calculated by the equation:

$$U_{SS} = U_{SSs} + \Delta U_{SSV}, \tag{1}$$

where $U_{SSs} = \sum_{k=1}^{N} U_{OS\ k}$ is the true value of the high-voltage DC of CMs at 180 kV, in volts; $U_{OS\ k}$ is the DC voltage of k-th UM, N is numbers of UMs in the combined measure ($N = 180$); ΔU_{SSV} is the measured value of DC voltage of a precision voltmeter, in volts [7].

The combined standard measurement uncertainty of high-voltage DC of the National High-Voltage DC Standard is calculated by the equation:

$$u_{c\ SSs} = \frac{1}{U_{SSs}} \sqrt{\left(\sum_{k=1}^{N} u_{OS\ k}^{2} + u_{SSV}^{2} \right)}, \tag{2}$$

where $u_{OS\ k}$ is the standard measurement uncertainty of k-th UM; u_{SSV} is the standard measurement uncertainty of measurement high DC voltage by precision voltmeter [7,8].

IV. RESEARCH OF LONG-TERM DRIFT OF THE NATIONAL STANDARD

The National High-Voltage DC Standard has been constantly researched since 1999. Its modernizations have improved metrological characteristics.

Table 1 and in Figs 1–3 show the results of determining the standard deviation (SD) reproduction of the CM output voltage of the standard from 1999 to 2021. The value of SD in relative units is in the range from $0.04{\cdot}10^{-6}$ to $10.4{\cdot}10^{-6}$.

The following remarks can be made from Figs 1–3:

- with increasing voltage, the relative value of SD decreases;

Table 1. Change of SD for voltage range from 1 kV to 180 kV.

U_n	Year/SD								
	2021	2019	2016	2013	2010	2007	2004	2000	1999
1	0.89	1.23	0.50	2.46	1.33	1.19	2.85	10.40	2.20
2	0.71	0.74	0.83	1.24	0.95	1.46	1.60	5.05	1.20
3	0.45	0.5	0.55	1.02	0.70	0.97	1.54	3.37	0.77
4	0.4	0.42	0.46	0.80	0.57	0.81	1.18	2.53	0.70
5	0.38	0.41	0.44	0.72	0.56	0.76	0.97	2.05	0.62
6	0.3	0.35	0.39	0.63	0.53	0.67	1.02	1.71	0.67
7	0.28	0.32	0.35	0.55	0.46	0.61	0.88	1.47	0.47
8	0.28	0.3	0.33	0.51	0.42	0.62	0.78	1.29	0.44
9	0.26	0.29	0.33	0.51	0.44	0.61	0.72	1.15	0.39
10	0.27	0.3	0.35	0.52	0.47	0.62	0.68	1.04	0.36
20	0.14	0.17	0.19	0.28	0.27	0.33	0.60	0.85	1.10
30	0.09	0.12	0.14	0.19	0.21	0.24	0.42	0.69	0.83
40	0.07	0.09	0.11	0.15	0.17	0.19	0.35	0.60	0.68
50	0.07	0.08	0.09	0.13	0.14	0.16	0.29	0.52	0.66
60	0.08	0.07	0.08	0.12	0.12	0.14	0.33	0.46	0.55
70	0.08	0.06	0.07	0.10	0.11	0.13	0.29	0.42	0.52
80	0.08	0.06	0.07	0.10	0.10	0.11	0.25	0.39	0.56
90	0.07	0.05	0.06	0.09	0.09	0.10	0.23	0.36	0.54
100	0.05	0.05	0.06	0.08	0.09	0.10	0.21	0.35	0.50
110	0.04	0.04	0.06	0.08	0.08	0.09	0.19	0.33	0.47
120	0.04	0.04	0.05	0.07	0.08	0.09	0.20	0.31	0.44
130	0.04	0.04	0.05	0.07	0.07	0.08	0.31	0.30	0.42
140	0.04	0.04	0.05	0.06	0.07	0.08	0.35	0.29	0.39
150	0.04	0.04	0.04	0.06	0.07	0.07	0.41	0.27	0.37
160	0.03	0.03	0.04	0.05	0.06	0.07	0.45	0.26	0.35
170	0.03	0.03	0.04	0.05	0.06	0.07	0.45	0.24	0.34
180	0.03	0.03	0.04	0.05	0.06	0.06	0.45	0.23	0.34

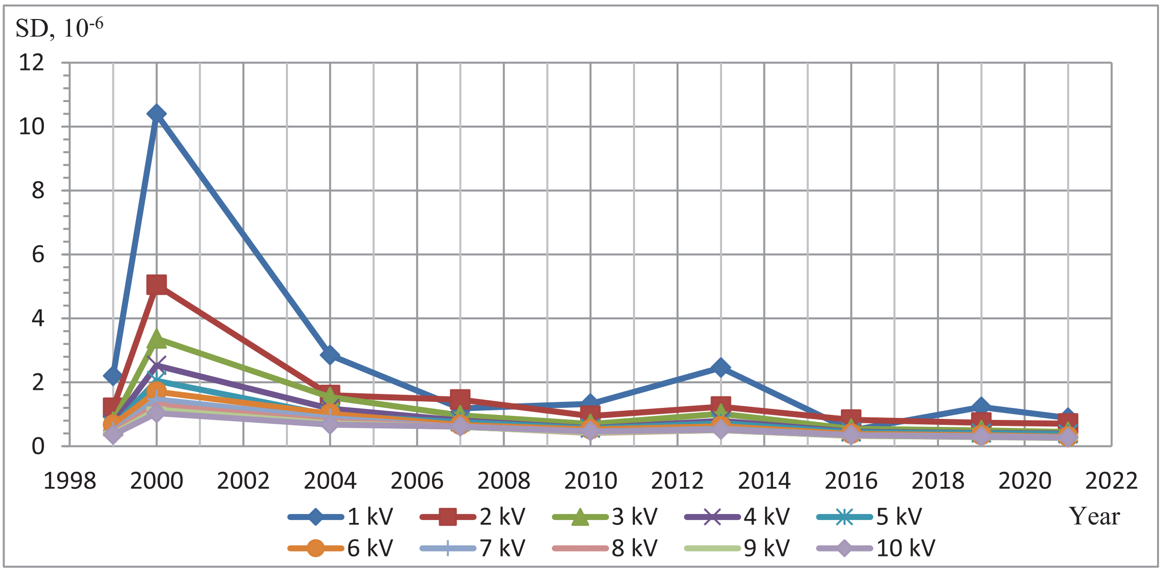

Figure 1. Change of SD for voltage range from 1 kV to 10 kV.

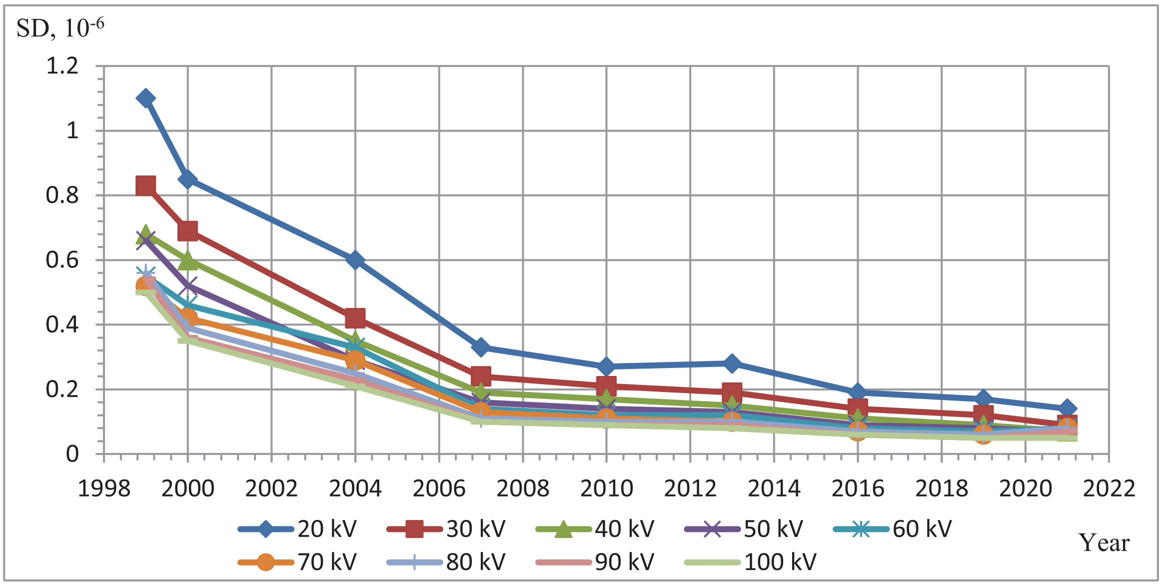

Figure 2. Change of SD for voltage range from 20 kV to 100 kV.

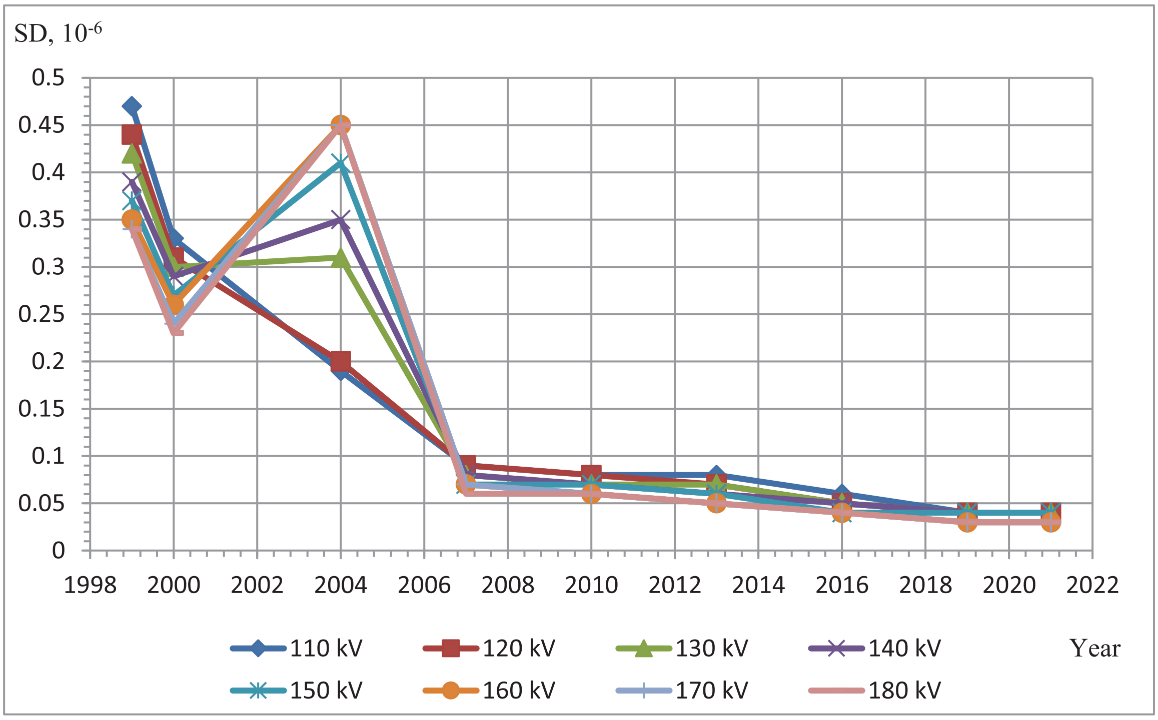

Figure 3. Change of SD for voltage range from 110 kV to 180 kV.

- in the period from 1999 to 2007 there was a significant decrease of SD;
- for the voltage range from 130 kV to 180 kV in 2004 there was a significant increase in SD, with its further decrease in subsequent years.

Analysis of research results for this period indicates the following reasons:
- since 2007 the Fluke 9100 E calibrator, which has much higher metrological characteristics than the calibrator previously used, has been used to research of UMs of types I and II;

- significant reduction of SD, which was observed in the period from 1999 to 2007, caused by the natural aging of low-voltage Zener diodes and the stabilization of its electrical characteristics;
- the decrease in the value of SD with increasing voltage is associated with a decrease in the impact of high-voltage electric fields on UM of type II, which are used for voltages above 100 kV;- a significant increase in SD for the voltage range from 130 to 180 kV is due to the high value of instability of one section of the UM, which corresponds to the nominal voltage of the standard 130 kV, after its repair the nature of SD change in subsequent years.

V. CONCLUSION

The research of the National High-Voltage DC Standard for long-term period allows you to constantly monitor it metrological characteristics. Accurate determination of the characteristics of the this standard allows to increase the accuracy and reliability of calibration of high-voltage DC working standards of accredited calibration laboratories.

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