UDC 001.4:389.14:621.317 DOI:

Metrological traceability chains for high DC voltage and voltages ratio

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Abstract

The current stage of scientific and technical development is characterized by the widespread use of high-voltage technology. Metrological traceability has such important elements as calibration of measurement standards and measuring instruments and evaluation of measurement uncertainty. The range of values of specific measurands, the range of necessary measurement uncertainties and the measurement standards used are presented as metrological traceability chains. Building such chains for different types of measurements is important for national metrology institutes and calibration laboratories.

An urgent task is to build metrological traceability chains for high direct current voltage measuring instruments. The proposed metrological traceability hierarchy chains are used in the State Enterprise "Ukrmetrteststandard" for calibration of working standards and working measuring instruments for high DC voltage and voltages ratio. These chains can be used also by accredited calibration laboratories, which carry out calibration of working measuring instruments for high direct current voltage and voltages ratio according to their own scope of accreditation.

Keywords: high DC voltage; voltages ratio; metrological traceability chain; measurement standard; measurement; measurement uncertainty.

Received: 15.12.2021 Edited: 12.02.2022 Approved for publication: 21.02.2022

1. Introduction

The current stage of scientific and technical development is characterized by the widespread use of high-voltage technology in electrophysical, environmental, electrical, power plants and systems. This necessitates the development of measurement standards and measuring instruments for high voltage measurements for steady state and transient modes. Transmission of energy on direct current (DC) is more economical than on alternating current. High DC voltage lines have been built in many countries around the world. With such lines, more power with less loss can be transmitted [1, 2].

High DC voltage is used in acceptance or preventive tests of insulation of capacitors, cables and rotating machines. For these types of insulation, the detection of significant defects is effective at high DC voltage, at which there is no danger of powerful partial discharges and virtually no destructive effect on defect-free insulation. In high DC voltage tests, the strength of the surge current is also measured and thus additional information about the insulation condition is obtained [2].

Metrological traceability has such important elements as calibration of measurement standards and measuring instruments and evaluation of measurement uncertainty [3–7]. Metrological traceability chains, the range of values of specific measurands, the range of necessary measurement uncertainties and the measurement standards used are shown. Building such chains for different types of measurements is important for national metrology institutes and calibration laboratories. An urgent task is to build metrological traceability chains for high DC voltage measuring instruments.

2. The State Primary Standard of the Unit of DC Electric Voltage

The State Primary Standard of the Unit of DC Electric Voltage in the range from 1 kV to 180 kV (DETU 08-04-99) has been functioning at the State Enterprise "Ukrmetrteststandard" (UMTS, Kyiv, Ukraine) since 1999 [8]. It provides precise measurements of high DC voltage.

Metrological characteristics of DETU 08-04-99 (The National Standard of High DC Voltage):

– range of reproduction of nominal values of high DC voltage from 1 kV to 180 kV;

– standard deviation of the measurement result when reproducing the unit of high DC voltage does not exceed 5×10^{-5};

– expanded measurement uncertainty is 3.6×10^{-4};

– annual instability does not exceed 3×10^{-4}.

DETU 08-04-99 consists of stationary and mobile parts:

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stationary part:

– compiled measure of high DC voltage of 180 kV (MVN-180);

– device for stabilization of working current of measures of high DC voltage (NB-1000);

– precision DC voltage meter;

mobile part:

– compiled measures of high DC voltage of 10 kV (MVN-10);

– the device of stabilization of working current of measures of high-voltage DC (NB-100);

– precision DC voltage meter.

A general view of DETU 08-04-99 is presented in Fig. 1.

The step of the high DC voltage reproduction for DETU 08-04-99 is 1 kV in the range from 10 kV to 180 kV.

The composite DC voltage measures MVN-10 and MVN-180 are based on single-value DC voltage measures of two types (I and II), which are implemented on Zener diodes. Single-value measures of type I have a nominal voltage of 1 kV, and type II measures have a nominal voltage of 10 kV. Normalized metrological characteristics of DETU 08-04-99 are provided by current flow through the electric voltage composite measures, which is stabilized by the stabilization device at the level of 5 mA ± 5 μA.

Fig. 1. The general view of the State Primary Standard of the Unit of Electric Voltage of Direct Current

The value of DC voltage measured using DETU 08-04-99 is calculated by the equation:

$$U_{SS} = U_{SSs} + \Delta U_{SSV}, \quad (1)$$

where: $U_{SSs} = \sum_{k=1}^{N} U_{OS\,k}$ is the true value of the DC high voltage of compiled measures at 180 kV, in volts;

$U_{OS\,k}$ is the DC voltage of k-th single-value measure, N is numbers of single-value measure in the compiled measure (N = 180);

ΔU_{SSV} is the measured value of DC voltage of a precision meter, in volts.

The combined standard measurement uncertainty of high DC voltage of DETU 08-04-99 is calculated by the equation:

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

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

Metrological characteristics of DETU 08-04-99 are at the level of characteristics of installations of similar purpose of such technically developed countries as Sweden, Finland, Australia (all for highest level of DC voltage – 1000 kV), Turkey, Canada, Germany, France, Spain, Bulgaria, Chinese Taipei, Singapore, and the Russian Federation (Table 1) [9]. The Swedish national standard has the best largest value of voltage and the best measurement uncertainty.

3. Metrological traceability chain for high DC voltage

Measurements of high DC voltage are performed using:

– electrostatic kilovoltmeters;

– differential high-voltage amplitude voltage meters;

– high-voltage meters based on high-resistance resistive dividers;

– high-voltage meters based on the electro-optical Kerr effect;

– high-voltage meters based on the method of additional resistances.

The working measurement standards are high DC voltage meters with the following metrological characteristics:

– range of high DC voltage measurements from 1 kV to 180 kV;

– expanded measurement uncertainty from 0.0012 to 0.012.

Table 1

Metrological characteristics of the best national standards for high-voltage DC

National metrology institute (country)	The largest value of the DC primary voltage range	Expanded relative measurement uncertainty
RISE (Sweden)	1000 kV	2.0×10^{-6}
MIKES (Finland)	1000 kV	1.0×10^{-4}
NMIA (Australia)	1000 kV	3.0×10^{-4}
VNIIMS (Russian Federation)	800 kV	3.0×10^{-4}
UME (Turkey)	400 kV	4.0×10^{-3}
NRC (Canada)	300 kV	3.0×10^{-5}
PTB (Germany)	300 kV	1.0×10^{-4}
LNE (France)	250 kV	3.2×10^{-5}
NMC (Singapore)	200 kV	7.0×10^{-5}
CMS (Chinese Taipei)	200 kV	1.0×10^{-4}
LCOE (Spain)	200 kV	1.0×10^{-4}
BIM (Bulgaria)	200 kV	1.2×10^{-3}
UMTS (Ukraine)	180 kV	3.6×10^{-4}

The working measuring instruments include high DC voltage meters and kilovoltmeters.

High DC voltage meters have the following metrological characteristics:

– voltage measurement ranges from 1 kV to 180 kV;

– expanded measurement uncertainty from 0.0057 to 0.016.

Kilovoltmeters have the following metrological characteristics:

– voltage measurement ranges from 1 kV to 100 kV;

– expanded measurement uncertainty from 0.0058 to 0.058.

A metrological traceability chain for measuring high DC voltage is proposed, which consists of three levels of the calibration hierarchy and is based on the conducted analysis (Fig. 2). At the first level (level 1) of the hierarchy there is DETU 08-04-99, at the second level (level 2) – working high DC voltage standards and at the third level (level 3) – working measuring instruments (high DC voltage meters and kilovoltmeters). The descending branches of the chain show the measurement standards or measuring instruments (marked 4) and their measurement uncertainties (marked 2).

4. Metrological traceability chain for high DC voltages ratio

Working standards for high voltages ratio are mainly based on meters with a high-voltage resistance divider.

Working measuring instruments are widespread: voltage meters based on resistive dividers, kilovoltmeters, voltage dividers and DC voltage transformers.

High DC voltage dividers have the following metrological characteristics:

– range of measurements from 1 kV to 180 kV;

– expanded measurement uncertainty 0.0057 to 0.025.

High DC voltage transformers have the following metrological characteristics:

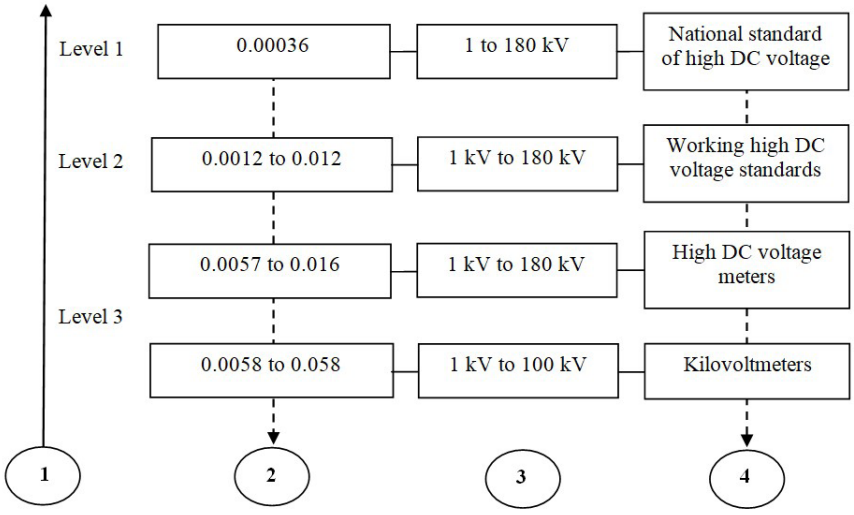

Fig. 2. Metrological traceability chain for high DC voltage:
1 – metrological traceability; 2 – measurement uncertainty; 3 – measurand value; 4 – calibration hierarchy

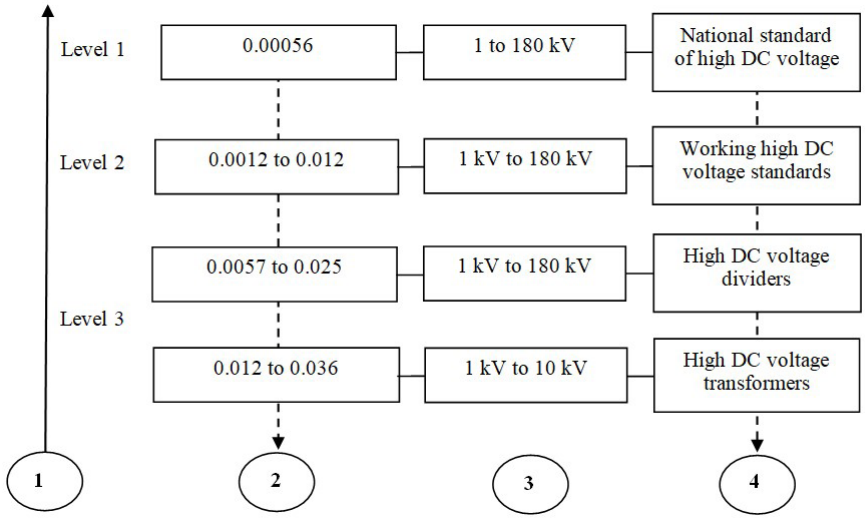

Fig. 3. Metrological traceability chain for high DC voltages ratio:
1 – metrological traceability; 2 – measurement uncertainty; 3 – measurand value; 4 – calibration hierarchy

– range of measurements from 1 kV to 106 kV;

– expanded measurement uncertainty 0.012 to 0.036.

A metrological traceability chain for measuring high DC voltages ratio is proposed, which also consists of three levels of the calibration hierarchy and is based on the conducted analysis (Fig. 3). At the first level (level 1) of the hierarchy there is also DETU 08-04-99, at the second level (level 2) – working high DC voltage standards also, and at the third level (level 3) – working measuring instruments (high DC voltage dividers and high DC voltage transformers). The branches of the chain 3 and 2 together show the measurement result that can be achieved.

4. Conclusion

The proposed metrological traceability hierarchy chains are used at the State Enterprise "Ukrmetrteststandard" for calibration of working standards and working measuring instruments for high DC voltage and voltages ratio. These chains can be used also by accredited calibration laboratories, which carry out calibration of working measuring instruments for high DC voltage and voltages ratio according to their own scope of accreditation.

Ланцюги метрологічної простежуваності для високої напруги постійного струму та відношення напруг

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Анотація

Сучасний етап науково-технічного розвитку характеризується широким використанням високовольтної техніки. Це зумовлює необхідність розробки еталонів і засобів вимірювальної техніки для вимірювань високої напруги. Передавання енергії на постійному струмі економічніше, ніж на змінному. Лінії високої напруги постійного струму побудовані в багатьох країнах світу. За допомогою таких ліній можна передавати більше потужності з меншими втратами. Метрологічна простежуваність має такі важливі елементи, як калібрування еталонів і засобів вимірювальної техніки та оцінка невизначеності вимірювань. Діапазон значень конкретних вимірюваних величин, діапазон необхідних невизначеностей вимірювань і використовувані стандарти представляються ланцюжками метрологічної простежуваності. Побудова таких ланцюгів для різних типів вимірювань є важливою для національних метрологічних інститутів та калібрувальних лабораторій. Актуальним завданням є побудова ланцюгів метрологічної простежуваності для засобів вимірювання високої напруги постійного струму.

Запропоновані та представлені ієрархічні ланцюги метрологічної простежуваності, які використовуються в ДП "Укрметртестстандарт" для калібрування робочих еталонів і робочих засобів вимірювань високої напруги постійного струму та відношення напруг. Ці ланцюги складаються з трьох рівнів ієрархії калібрування. У обох цих

ланцюгах на першому рівні ієрархії знаходиться національний еталон високої напруги постійного струму, на другому рівні – робочі еталони високої напруги постійного струму і на третьому рівні – робочі вимірювальні прилади. Запропоновані ланцюги можуть використовуватися також акредитованими калібрувальними лабораторіями, які здійснюють калібрування робочих засобів вимірювальної техніки високої напруги постійного струму та відношення напруг відповідно до власної сфери акредитації.

Ключові слова: висока напруга постійного струму; відношення напруг; ланцюг метрологічної простежуваності; еталон; вимірювання; невизначеність вимірювання.

Цепочки метрологической прослеживаемости для высокого напряжения постоянного тока и отношения напряжений

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Аннотация

Метрологическая прослеживаемость имеет такие важные элементы, как калибровка эталонов и средств измерительной техники и оценка неопределенности измерений. Диапазон значений конкретных измеряемых величин, диапазон необходимых неопределенностей измерений и используемые стандарты представлены цепочками метрологической прослеживаемости. Построение таких цепочек для различных видов измерений важно для национальных метрологических институтов и калибровочных лабораторий.

Предложены и представлены цепочки метрологической прослеживаемости, которые используются в ГП "Укрметртестстандарт" для калибровки рабочих эталонов и рабочих средств измерений высокого напряжения постоянного тока и соотношения напряжений. Эти цепочки могут использоваться также аккредитованными калибровочными лабораториями, которые проводят калибровку рабочих средств измерительной техники высокого напряжения постоянного тока и соотношение напряжений в соответствии с собственной сферой аккредитации.

Ключевые слова: высокое напряжение постоянного тока; отношение напряжений; цепь метрологической прослеживаемости; эталон; измерение; неопределенность измерения.

References

1. Schon K. High Voltage Measurement Techniques. Fundamentals, Measuring Instruments, and Measuring Methods. *Springer Nature Switzerland AG*, 2019. 466 p. doi: 10.1007/978-3-030-21770-9_1
2. Küchler A. High Voltage Engineering. Fundamentals-Technology-Applications. *Springer Vieweg*, Berlin, 2018. 650 p. doi: 10.1007/978-3-642-11993-4
3. JCGM 200:2012. International vocabulary of metrology – Basic and general concepts and associated terms (VIM). 3rd edition. JCGM, 2007. 108 p.
4. Velichko O.N. Traceability of measurement results at different levels of metrological work. *Measurement Techniques*, 2009, vol. 52, no. 11, p. 1242–1248. doi: 10.1007/s11018-010-9428-7
5. Velychko O., Gordiyenko T. Application of systems thinking to the establishment of metrological traceability chains. *Ukrainian Metrological Journal*, 2021, no. 4, pp. 3–7. doi: 10.24027/2306-7039.4.2021.250348
6. JCGM 100:2008. Uncertainty of measurement – Guide to the expression of uncertainty in measurement (GUM:1995). JCGM, 2008. 138 p.
7. EA-04/02 M. Evaluation of the Uncertainty of Measurement in Calibration. EA, 2013. 75 p.
8. Velychko O., Vendychanskyi R. Research of the National Primary Standard of the High DC Voltage. Digest of 2018 *Conf. on Precision Electromagnetic Measurement*. Paris, France, 2018 (June 8–13). 2 p.
9. The BIPM key comparison database (KCDB). Available at: http://kcdb.bipm.org