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Fibre optic sensors - Part 7-3: Voltage measurement - Polarimetric method

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Fibre optic sensors – Part 7-3: Voltage measurement – Polarimetric method

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FIBRE OPTIC SENSORS –

Part 7-3: Voltage measurement – Polarimetric method

FOREWORD

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The text of this International Standard is based on the following documents:

Draft	Report on voting
86C/XX/FDIS	86C/XX/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61757 series, published under the general title *Fibre optic sensors*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

This document is part of the IEC 61757 series, which is dedicated to fibre optic sensors. Generic specifications for fibre optic sensors are defined in IEC 61757.

The individual parts of the IEC 61757 series are numbered as IEC 61757-*M*-*T*, where *M* denotes the measure and *T* the technology of the fibre optic sensor. The IEC 61757-7-*T* series is concerned with voltage measurements.

Voltage measuring techniques are essential for controlling and diagnosing apparatus that support industry and society. Optical voltage sensors based on electro-optic effects have been developed to serve as voltage measuring devices. These sensors enable advanced voltage measurements without encountering the issues related to conventional electrical voltage sensors. Hence, they have been applied in various fields including power systems.

Given the expected potential of this new fibre optic voltage sensing technology, several kinds of optical voltage sensors covering a wide range of applications have been developed by various manufacturers. The design of these voltage sensors depends on the specific application, which determines the target voltage to be measured, the configuration of the sensor, the signal processing method, and the installation method. When developing a new optical voltage sensor, the sensor performance and characteristics have to be specified and evaluated.

To facilitate the use of fibre optic voltage sensors, it is important to define terms that characterize the performance and functionality of these sensors. It is also important to clearly specify how these specifications can be evaluated. Clearly defined terms and evaluation procedures help to develop more efficient sensors and to smoothly transfer this new sensor technology from the suppliers to the users. This document defines a set of methods for evaluating the performance and characteristics of fibre optic voltage sensors. However, this document does not quantify any performance targets, because these depend on the specific application of the sensor. It is nevertheless expected that this document helps to define specific quantitative targets for the sensor performance when a fibre optic voltage sensor is developed for a given practical application.

This document is based on the standard OITDA FS 02 [1][1] published by the Optoelectronic Industry and Technology Development Association (OITDA). All the figures and tables in this document are identical to those in OITDA FS 02 except for the translation from Japanese to English.

[1] The numbers in brackets refer to the bibliography

FIBRE OPTIC SENSORS –

Part 7-3: Voltage measurement – Polarimetric method

1 Scope

This part of IEC 61757 defines the terminology, structure, and performance characteristics of fibre optic voltage sensors using a polarimetric measurement method. The document specifies test methods and procedures for measuring the most important performance parameters of these sensors. It addresses only the voltage sensing element and not the additional devices that are unique to each application.

The document does not specify the required performance values of optical polarimetric fibre optic voltage sensors, because these specifications depend on the designated application of the sensor and are typically defined by the user of the sensor. The required performance values are usually defined when designing a sensor for a specific application.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61757:2018, *Fibre optic sensors – Generic specification*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61757:2018 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
electro-optic effect
change in the optical characteristics of a material under the influence of an electric field

Note 1 to entry: Pockels and Kerr effects are examples of electro-optic effects.

Note 2 to entry: Electro-optic is often erroneously used as a synonym for opto-electronic.

Note 3 to entry: The most common effect results in a change in refractive index.

[SOURCE: IEV, 731-01-42]

3.2
intensity modulation method
in an optical voltage sensor, method of converting birefringence information into light intensity by passing light through a wave plate, a Pockels cell, and a polarization separation element in this order, and creating an optical signal corresponding to the measured voltage

3.3
interferometric method
in an optical voltage sensor, method in which two orthogonal linearly polarized light components are passed through a Pockels cell and then converted into the same polarization state, so that

they interfere with each other and are converted into light intensity to create an optical signal corresponding to the measured voltage

3.4
maximum measurable frequency
highest frequency of voltage variations that can be measured by an optical voltage sensor

3.5
maximum measurable voltage
largest voltage that can be measured by an optical voltage sensor

3.6
minimum measurable frequency
lowest frequency of voltage variations that can be measured by an optical voltage sensor

3.7
operating temperature range
range of temperature within which an optical voltage sensor shall satisfy the defined performance

3.8
optical activity
property of rotating the plane of polarization

3.9
optical part
part consisting of lens, prism, mirror, and optical element, like a phase modulator, in an optical voltage sensor

Note 1 to entry: While the term "sensor part" focuses on the component position (see Clause 4), the term "optical part" focuses on the component materials.

3.10
optical voltage sensor
component, module, subassembly, assembly, or device that can detect voltage using the Pockels effect

Note 1 to entry: The optical voltage sensor consists of a sensor unit, an optical transmission unit, and a signal processing unit (see Clause 4).

3.11
photo-conductivity
photo-electric effect characterized by a variation of electrical conductivity

[SOURCE: IEV, 731-01-62]

3.12
piezoelectric effect
generation of an electric field in response to an applied mechanical stress or generation of a stress in response to an applied electric field

Note 1 to entry: A more complete definition is given by IEV, 121-12-86.

3.13
Pockels coefficient
coefficient that indicates the difference in the refractive indexes of the birefringence that occurs in response to the electric field applied to the substance

Note 1 to entry: See Annex A for details.

3.14
Pockels effect
electro-optic effect in which an applied electric field makes an optically isotropic substance birefringent, the difference of refractive indexes being proportional to the magnitude of the electric field strength

[SOURCE: IEV, 731-01-42]

3.15
rated voltage
rated value of the voltage assigned by the manufacturer to a component, device, or equipment and to which operation and performance characteristics are referred

3.16
required specifications
list of specifications an optical voltage sensor shall satisfy

3.17
transient characteristics
phenomena of changing the voltage value that is output from an optical voltage sensor when the voltage to be measured deviates from the defined voltage value over a short period of time

3.18
voltage divider
device comprising resistors, inductors, capacitors, or a combination of these components such that, between two points of the device, a desired fraction of the voltage applied to the device can be obtained

Note 1 to entry: A voltage divider acquires part of the voltage applied to the entire device between two points of the device.

[SOURCE: IEV, 311-02-32 – Modified: Removed "transformer(s)" from definition]

3.19
warm-up time
duration between the instant after which the power supply is energized and the instant when the measuring instrument may be used, as specified by the manufacturer

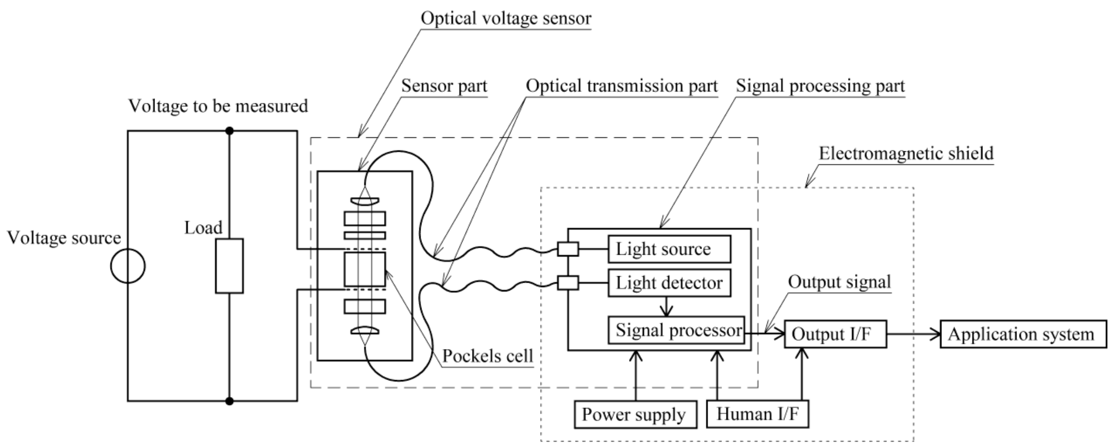
[SOURCE: IEV, 311-03-18]

4 Components of optical voltage sensor using polarimetric method

4.1 General description

Figure 1 shows a schematic diagram of the various elements of which an optical voltage sensor is composed. In this document, the optical voltage sensor is divided into three parts: a sensor part, an optical transmission part, and a signal processing part. Each of these parts can be exposed to different physical environments.

The sensor part of the optical voltage sensor contains a Pockels cell that is connected to two electric conductors whose voltage difference is to be measured. It is connected via two optical fibres to the signal processing part, which calculates the voltage measured by the sensor part. While the sensor part is placed adjacent to the electric conductors, the signal processing part is generally placed in a remote location and thus exposed to a different environment than the sensor part.



Source: OITDA FS 02 [1], reproduced with the permission of the Optoelectronic Industry and Technology Development Association (OITDA).

Figure 1 – Measurement system using optical voltage sensor

The optical fibres that connect the sensor part to the signal processing part is called the optical transmission part.

The light source for generating the optical signal transmitted to the sensor part via optical fibre is typically included in the signal processing part. Likewise, the light detector for receiving the optical signal transmitted from the sensor part via optical fibre is included in the signal processing part, which also contains the power supplies.

More details on the specific functions of each part can be found in Annex A.

NOTE The sensor part can include elements for controlling polarization and phase of the optical signal and a voltage divider for adjusting the voltage applied to the Pockels cell. The signal processing part can have elements for controlling polarization and phase of the optical signal in addition to the light source, power supply, and light detector.

A component, module, subassembly, assembly, or device that comprises a sensor part with a Pockels cell, an optical transmission part, and a signal processing part is called an optical voltage sensor.

See Annex B for more details on the specific features of polarimetric fibre optic voltage sensors and Annex C for design considerations and performance specifications.

4.2 Classification of Pockels cells

Pockels cells can be divided into two classes. Some Pockels cells have longitudinal modulation elements in which the light transmission direction and the voltage application direction are parallel, whereas other Pockels cells have transverse modulation elements in which the light transmission direction and the voltage application direction are orthogonal to each other.

More details on the operation of Pockels cells can be found in Annex A.

5 Characteristic tests

5.1 General information

Clause 5 specifies a characteristic test method for the optical voltage sensor. The input-to-output (I/O) characteristics are described in 5.2 and are the basis of the test. Subclause 5.3 describes the warm-up time, which is not considered in conventional voltage sensors. Subclause 5.5 defines the input parameter dependency for each test method and 5.6 the external environment dependency.

Subclause 5.4 describes the voltage conditions for obtaining characteristic parameters. The parameters to be acquired are listed in Table 1, which specifies for each parameter whether tests are required or just optional. The measurement results are summarized in an inspection report (see Annex D) and shown to the user.

Table 1 – List of parameters to be obtained

<table>
<tr><th>No.</th><th colspan="3">Parameters</th><th>Required or optional</th></tr>
<tr><td>1</td><td colspan="3">I/O characteristics</td><td>Required</td></tr>
<tr><td>2</td><td colspan="3">Warm-up time</td><td>Required</td></tr>
<tr><td rowspan="5">3</td><td rowspan="5">Parameter dependency</td><td rowspan="2">Input parameter dependency</td><td>Frequency characteristic</td><td>Required for type test</td></tr>
<tr><td>Transient characteristic</td><td>Required for type test</td></tr>
<tr><td rowspan="3">External environment dependency</td><td>Steady state temperature characteristic</td><td>Required for type test
Optional for routine test for outdoor use sensors</td></tr>
<tr><td>Transient temperature characteristic</td><td>Required for type test
Optional for routine test for outdoor use sensor</td></tr>
<tr><td>Shock and Vibration</td><td>Optional</td></tr>
</table>

5.2 Input-to-output characteristics

5.2.1 General

The input-to-output (I/O) characteristics are the most basic performance parameters of optical voltage sensors. Figure 2 shows the I/O characteristics of a typical fibre optic voltage sensor. Ideally, the voltage to be measured is the same as the output voltage reported by the sensor. In practice, the output voltage can deviate from the voltage to be measured, thus resulting in a measurement error. These errors are caused by the following three factors:

a) noise;

b) sensitivity change;

c) non-linearity.

There are two types of noise. In some cases, the noise is correlated with the voltage to be measured, and in other cases it is not. Therefore, these two types of noise shall be characterized separately. DC offsets in the output voltage should be distinguished from noise.

Sensitivity change is a variation in the proportionality between reported output voltage and the voltage to be measured.

Non-linearity is the phenomenon that the sensitivity of the voltage sensor changes as a function of voltage to be measured, so that the relationship between the reported output voltage and the voltage to be measured deviates from a straight line.

Figure 2 illustrates the effects of noise, sensitivity change, and non-linearity on the reported output voltage.