IEC/IEEE 62582-5

Edition 1.0 2015-06

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

**Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods –
Part 5: Optical time domain reflectometry**

**Centrales nucléaires de puissance – Instrumentation et contrôle-commande importants pour la sûreté – Méthodes de surveillance de l'état des matériels électriques –
Partie 5: Technique de rétrodiffusion**

IEC/IEEE 62582-5:2015-06(en-fr)

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International Standard IEC/IEEE 62582-5 has been prepared by subcommittee 45A: Instrumentation, control and electrical systems of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation, in cooperation with the Nuclear Power Engineering Committee of the IEEE Power & Energy Society[1], under the IEC/IEEE Dual Logo Agreement between IEC and IEEE.

This publication is published as an IEC/IEEE Dual Logo standard.

The text of this standard is based on the following documents:

FDIS	Report on voting
45A/1008A/FDIS	45A/1021/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC/IEEE 62582 series, published under the general title *Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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1 A list of IEEE participants can be found at the following URL: http://standards.ieee.org/downloads/62582/62582-5-2015/62582-5-2015_wg-participants.pdf.

INTRODUCTION

a) Technical background, main issues and organisation of the Standard

This IEC/IEEE standard specifically focuses on optical time domain reflectometer methods for condition monitoring for the management of ageing of optical fibres and cables in electrical equipment installed in nuclear power plants.

This IEC/IEEE standard is the fifth part of the IEC/IEEE 62582 series. It contains detailed descriptions of condition monitoring based on optical time domain reflectometer measurements on optical fibres and cables.

The IEC/IEEE 62582 series of standards is issued with a joint logo, which makes it applicable to management of ageing of electrical equipment qualified to IEEE as well as IEC Standards.

Historically, IEEE Std 323™-2003 introduced the concept and role that condition based qualification could be used in equipment qualification as an adjunct to qualified life. In equipment qualification, the condition of the equipment for which acceptable performance was demonstrated is the qualified condition. The qualified condition is the condition of equipment, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions.

Significant research has been performed on condition monitoring techniques and the use of these techniques in equipment qualification as noted in NUREG/CR-6704, vol.2 (BNL-NUREG-52610) and JNES-SS-0903, 2009.

It is intended that this standard be used by test laboratories, operators of nuclear power plants, systems evaluators and licensors.

b) Situation of the current standard in the structure of the IEC SC 45A standard series

IEC/IEEE 62582-5 is the third level IEC SC 45A document tackling the specific issue of application and performance of optical time domain reflectometer measurements in management of ageing of optical fibres and cables in electrical instrument and control equipment in nuclear power plants.

IEC/IEEE 62582-5 is to be read in association with IEC/IEEE 62582-1, which provides requirements for application of methods for condition monitoring of electrical equipment important to safety of nuclear power plants.

For more details on the structure of the IEC SC 45A standard series, see item d) of this introduction.

c) Recommendations and limitations regarding the application of this standard

It is important to note that this standard establishes no additional functional requirements for safety systems.

d) Description of the structure of the IEC SC 45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

The top-level document of the IEC SC 45A standard series is IEC 61513. It provides general requirements for I&C systems and equipment that are used to perform functions important to safety in NPPs. IEC 61513 structures the IEC SC 45A standard series.

IEC 61513 refers directly to other IEC SC 45A standards for general topics related to categorisation of functions and classification of systems, qualification, separation of systems, defence against common cause failure, software aspects of computer-based systems, hardware aspects of computer-based systems, and control room design. The standards referenced directly at this second level should be considered together with IEC 61513 as a consistent document set.

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 are standards related to specific equipment, technical methods, or specific activities. Usually these documents, which make reference to second-level documents for general topics, can be used on their own.

A fourth level extending the IEC SC 45A standard series, corresponds to the Technical Reports which are not normative.

IEC 61513 has adopted a presentation format similar to the basic safety publication IEC 61508 with an overall safety life-cycle framework and a system life-cycle framework. Regarding nuclear safety, it provides an interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework IEC 60880 and IEC 62138 correspond to IEC 61508-3 for the nuclear application sector. IEC 61513 refers to ISO as well as to IAEA GS-R-3 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA).

The IEC SC 45A standards series consistently implements and details the principles and basic safety aspects provided in the IAEA code on the safety of NPPs and in the IAEA safety series, in particular the Requirements SSR-2/1, establishing safety requirements related to the design of Nuclear Power Plants, and the Safety Guide NS-G-1.3 dealing with instrumentation and control systems important to safety in Nuclear Power Plants. The terminology and definitions used by SC 45A standards are consistent with those used by the IAEA.

NOTE It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g., to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied that are based on the requirements of a standard such as IEC 61508.

NUCLEAR POWER PLANTS – INSTRUMENTATION AND CONTROL IMPORTANT TO SAFETY – ELECTRICAL EQUIPMENT CONDITION MONITORING METHODS –

Part 5: Optical time domain reflectometry

1 Scope and object

This part of IEC/IEEE 62582 contains methods for monitoring the attenuation condition of optical fibres and cables in instrumentation and control systems using optical time domain reflectometer (OTDR) measurements in the detail necessary to produce accurate and reproducible measurements. It includes the requirements for the measurement system and conditions, and the reporting of the measurement results.

The different parts of IEC/IEEE 62582 are measurement standards, primarily for use in the management of ageing in initial qualification and after installation. IEC/IEEE 62582-1 includes requirements for the application of the other parts of IEC/IEEE 62582 and some elements which are common to all methods. Information on the role of condition monitoring in qualification of equipment important to safety is found in IEEE Std 323. Detailed descriptions of methods for OTDR measurement of the quality and functionality of fibre optic cables are given in IEC 61280-4-1 for multimode attenuation and in IEC 61280-4-2 for single-mode attenuation.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61746-1, *Calibration of optical time-domain reflectometers (OTDR) – Part 1: OTDR for single mode fibres*

IEC 61746-2, *Calibration of optical time-domain reflectometers (OTDR) – Part 2: OTDR for multimode fibres*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
annealing <of radiation-induced attenuation>
recovery of radiation-induced attenuation of an optical fibre by temperature (thermal annealing) and/or transmission light power (photobleaching)

Note 1 to entry: Annealing is related to fibre material and to dose rate and exposure.

3.2
attenuation annealing time
time that is necessary to decrease the attenuation to a certain fraction (e.g., ½ or 1/e) of the attenuation immediately after the end of the irradiation

3.3
graded index fibre
optical fibre having a graded index profile in which the refractive index varies continuously in the core as a function of distance from the axis

[SOURCE: IEC 60050-731:1991, 731-02-11 and 731-02-15, modified]

3.4
index of refraction
the index of refraction (group index) is defined as:

$$IOR = \mathrm{c}/c_{\mathrm{fibre}} \quad (1)$$

where

IOR is the index of refraction;

c is the velocity of light in vacuum (299 792 458 m/s);

c_{fibre} is the velocity of light in the fibre.

IOR determines the length of the cable over which the OTDR measurements are made.

3.5
optical attenuation
$A(\lambda)$
measure of the decreasing transmission light power in a fibre at a given wavelength. The definition is:

$$A(\lambda) = \left| 10 \lg \left(P1(\lambda)/P2(\lambda) \right) \right| \quad (2)$$

where

$A(\lambda)$ is the attenuation, in dB, at wavelength λ;

$P1(\lambda)$ is the transmission light power traversing one cross-section (marker 1);

$P2(\lambda)$ is the transmission light power traversing a second cross-section (marker 2).

Note 1 to entry: It depends on the nature and length and condition of the fibre and is also affected by measurement conditions.

Note 2 to entry: The term loss is used synonymous with attenuation in this International Standard.

3.6
optical attenuation coefficient
$a(\lambda)$
attenuation per unit length, defined as:

$$a(\lambda) = A(\lambda)/L \quad (3)$$

where L is the unit length in km.

3.7
optical time domain reflectometer
device for characterizing an optical fibre whereby an optical pulse is transmitted through the optical fibre and the optical power of resulting light scattered and reflected back to the input is measured as a function of time

[SOURCE: IEC 60050-731:1991, 731-07-08, modified]

3.8
step index fibre
fibre having a uniform *IOR* within the core

Note 1 to entry: The step is the shift between the core and the cladding, which has a lower *IOR*.

4 Abbreviations and acronyms

Al	Aluminum
A/D	Analog/digital
F	Fluorine
FUT	Fibre under test
Ge	Germanium
GI	Graded index
IOR	Index of refraction (Group index)
LSA	Least square approximation
OH	Hydroxide ion
OTDR	Optical time domain reflectometer
P	Phosphorus
RIA	Radiation induced attenuation
Si	Silicon
SI	Step index
SNR	Signal to noise ratio
UV	Ultra-violet
2PA	Two point approximation

5 General description

Optical time domain reflectometry is a measurement technique for characterising an optical fibre whereby an optical pulse is transmitted through the optical fibre and the transmission light power of the resulting light scattered and reflected back to the input is measured as a function of time. The result is reported as the attenuation coefficient (in dB/km).

OTDR measurements are useful in estimating the attenuation coefficient for fibres with uniform attenuation and for identifying and localizing defects and localized losses. The method gives results that are accurate, reproducible and related to practical use.

Details about attenuation uniformity of optical fibres can be found in IEC TR 62033.

6 Applicability and reproducibility

This International Standard is limited to the use of an OTDR as an instrument for monitoring the attenuation of optical fibres and optical cables as part of management of ageing. The method is not suitable for monitoring the condition of fibre with respect to mechanical integrity.

In general optical fibres are sensitive to ageing, e.g., due to exposure to ionising radiation, which manifests itself mainly through the increase of the optical attenuation, see also Annexes A and B. The attenuation (in dB/km) is used as an indicator of ageing for both optical and hybrid (electrical-optical) cables, with in-situ access, whilst these cables are being operated in nuclear environments.

OTDR measurements allow analysis of the condition of the entire fibre, particularly of longitudinal subsections of the fibre, or even identification of discrete points such as splices. It also permits calculation of the fibre length, although this is outside the scope of this international standard.

Optical cables in safety related applications in nuclear power plants may be shorter than in general applications. Measurement of short optical cables (< 500 m) requires OTDR instruments with high resolution.

The OTDR measurement is affected by the propagation speed and the backscattering behaviour of the fibre. Best accuracy is obtained by measuring the attenuation from both ends of the fibre and averaging the two backscatter traces. Therefore, measurements shall normally be repeated from both ends. This is especially useful in case of unexpected discontinuities. However, the improvement to the accuracy from measurements on both ends is limited and measurements from one end are acceptable in cases where two ends are not accessible.

7 OTDR measurements procedure

7.1 General

For condition monitoring one supervisory channel over all cable segments shall be accessible for OTDR measurements. This could be one spare fibre in each cable segment, one multiplexer channel or the use of an OTDR wavelength not disturbing the data transmission in a fibre (or vice versa) using splitters.

7.2 Instrumentation

An OTDR may contain a number of parts, or modules, which provide the required functions. These include a waveform generator (laser diode), a detector, a signal processing function and a display. The instrument will also provide facilities to allow connection to the fibre cable under test, such as a directional coupler and a fibre connector. The configuration of the OTDR is shown in Figure 1.

The contact between the instrument fibre (adaptor cord) and the FUT shall be of a type assuring repeatability and be clean and free from debris. A mechanical splice is usually used as the contact.

The OTDR shall have a sufficient dynamic range to allow measurement over the FUT.

The instrument may contain facilities for changing the wavelength of the test pulses. In addition, the OTDR may allow operation in either single-mode or multimode configuration.

A typical design of an OTDR consists of two main parts. These include the main frame, with a microprocessor and a waveform display; and a plug-in unit that houses the laser diode, the detector, a directional coupler and the fibre connector. Different plug-in units with separate wavelengths can be used together with the same main frame. The plug-in units can be adapted to either single-mode or multimode applications.

The configuration of the OTDR is shown in Figure 1.

A sequence of pulses of light is sent from a laser diode, and is transmitted via an optical directional coupler and an optical connector into the fibre. The back scattered light, due to Rayleigh scattering, is reflected back to the OTDR via the connector and is led through the directional coupler to the detector. The detector converts the light to an electrical analogue signal, which is amplified and sent to an A/D converter. A microprocessor treats the digital signal and generates a presentation on the waveform display. The adaptor cord is typically

1 km to 2 km long and may act as an attenuator. It is usually connected to the FUT with a mechanical splice. In this way dirt is avoided in the OTDR-connector.

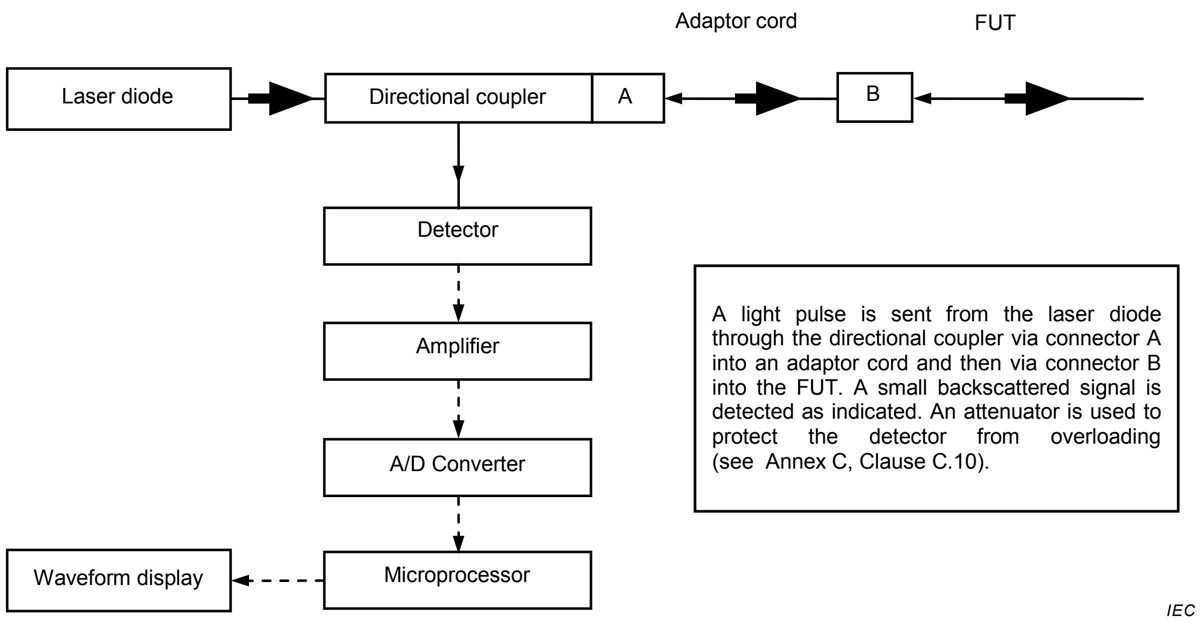

Figure 1 – Block functions of the OTDR

7.3 Measurement wavelengths

For single-mode fibres, it is recommended that the attenuation at wavelength 1 310 nm, 1 550 nm and 1 625 nm is reported. For multimode fibres it is recommended that the attenuation at wavelength 850 nm and 1 300 nm is reported. If wavelengths other than these are used in the field application, the attenuation at those wavelengths shall be reported in addition.

7.4 Calibration

The OTDR equipment shall be calibrated, including the internal clock (for timing accuracy) and the laser emitter (for pulse energy and pulse duration). The calibration shall be performed in accordance with IEC 61746-1 for single-mode fibres, IEC 61746-2 for multimode fibres.

7.5 Precautions for OTDR measurements

Consecutive and comparative OTDR measurements shall be performed using the same parameters, particularly for the pulse energy and duration. Also the wavelength of operation for the condition monitoring equipment shall be selected within the range of wavelengths being transported by the FUT and under operation. Special attention shall be given to the maximum transmitted light power. To avoid photobleaching, the power shall be limited to $\leq 1\ \mu W$. The values of the parameters used shall be recorded and reported. Guidance for the selection of measurement parameters is given in Annex C.

Ageing and additional attenuation can make it necessary to increase pulse durations and averaging time, as well as change marker positions, see Annex C.

7.6 Conditioning

For laboratory measurements after artificial thermal ageing, the specimen shall be conditioned at a laboratory temperature of (25 ± 5) °C and a relative humidity of 45 % to 75 % for at least 3 h prior to measurement.

For laboratory measurements after artificial exposure to ionising radiation, the OTDR measurements shall be made as soon as possible after the exposure. The laboratory temperature shall be (25 ± 5) °C and the relative humidity shall be 45 % to 75 %. The temperature at which the measurements are made and the time between the finishing of the exposure and the start of the measurements shall be reported.

NOTE Due to annealing, the effect on the attenuation from ageing in ionising radiation will revert after finishing the exposure. The rate of reversion depends on the surrounding temperature – the higher the temperature, the higher the rate of reversion. See Annex B.

For field measurements, the temperature of the surrounding atmosphere shall be recorded.

7.7 OTDR measurement

Prior to the start of the condition monitoring program, all the parameters of the OTDR shall be determined and fixed, in order to optimise the measurements, both in terms of accuracy and acquisition time. The following parameters shall be selected, stored for consecutive measurements, and reported:

- measurement points (marker 1 and marker 2 in Figure 2);
- wavelength of test;
- pulse duration;
- distance range (the instrument selects power level when the distance range has been set);
- type of connection between the adaptor cord and the FUT;
- number of pulses for averaging;
- backscattering coefficient;
- *IOR* (group index).

Guidance on selection of parameters is given in Annex C.

A pulse duration shall be selected that is long enough to obtain an OTDR trace which visualises the entire FUT, and short enough to optimise the resolution. Repeated measurements may be needed, using longer/shorter pulse durations in order to optimise the resolution.

A typical OTDR trace presenting the received backscattered power versus the distance along the FUT is presented in Figure 2 together with set values and calculated results. Figure 3 gives two examples of possible faults in the cable, identified by the OTDR.