

IEEE Guide for Application of Optical Instrument Transformers for Protective Relaying

IEEE Power and Energy Society

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Power System Relaying Committee

IEEE Guide for Application of Optical Instrument Transformers for Protective Relaying

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Power System Relaying Committee
of the
IEEE Power and Energy Society

Approved 6 December 2017

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Introduction

This introduction is not part of IEEE Std C37.241–2017, IEEE Guide for Application of Optical Instrument Transformers for Protective Relaying.

Optical sensor technology for measurement of voltage and current in high-voltage electric power systems has been demonstrated for over 20 years. These sensors use optics and electronics to achieve accuracy, linearity, dynamic range, and efficient installation far beyond the capabilities of familiar electromagnetic and capacitive instrument transformers. Industrial products have been available for most of that time, with a widening array of choices and manufacturers. However, the industry transition to new sensors has been gradual, mostly due to the familiarity and reliability of conventional instrument transformers. Accordingly, the objective of this guide is to provide the reader with a factual understanding of the technical and practical bases for choosing optical instrument transformers (OITs) when familiar sensor technologies remain widely available.

This guide provides information on technologies of optical voltage and current sensors, their performance characteristics, their incorporation in measurement systems for protection and control, installation and maintenance requirements, testing requirements, and application considerations. It also provides information on reliability and redundancy matters, as well as the relevant industry standards.

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IEEE Guide for Application of Optical Instrument Transformers for Protective Relaying

1. Overview

1.1 Scope

This document provides a guide that covers the use of optical voltage and current sensor systems for protective relaying—including selection, installation, testing, and operations.

1.2 Purpose

This document is intended to provide guidance in the application and selection of optical instrument transformers for protective relaying.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/NCSL Z540-1, Calibration laboratories and measuring and test equipment—General requirements.¹

IEC 60044-7, Instrument transformers, Part 7: Electronic voltage transformers.²

IEC 60044-8, Instrument transformers, Part 8: Electronic current transformers.

IEC 61850-9-2, Communication networks and systems in substations—Part 9-2: Specific communication service mapping (SCSM)—sampled values over ISO/IEC 8802-3.

IEC 61869-6, Instrument transformers, Part 6: Additional general requirements for low-power instrument transformers.

IEC 61869-9, Instrument transformers, Part 9: Digital interface for instrument transformers.

¹ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>).

²IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch>) and the American National Standards Institute (<http://www.ansi.org/>).

IEEE Std 693™, IEEE Recommended Practices for Seismic Design of Substations.^{3,4}

IEEE Std 1588™, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

IEEE Std 1601™, IEEE Trial-Use Standard for Optical AC Current and Voltage Sensing Systems.

IEEE Std C37.92™, IEEE Standard for Analog Inputs to Protective Relaying from Electronic Voltage and Current Transformers.

IEEE Std C37.233™, IEEE Guide for Power System Protection Testing.

IEEE Std C37.238™, IEEE Standard for Use of IEEE Std 1588 Precision Time Protocol in Power System Applications.

IEEE Std C57.13™, IEEE Standard Requirements for Instrument Transformers.

IEEE Std C57.13.5™, IEEE Trial-Use Standard of Performance and Test Requirements for Instrument Transformers of a Nominal System Voltage of 115 kV and Above.

IEEE Std C57.13.6™, IEEE Standard for High Accuracy Instrument Transformers.

UCA International Users Group, Implementation guideline for digital interface to instrument transformers using IEC 61850-9-2, R3, 25 August 2005.

3. Definitions, abbreviations, and acronyms

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The IEEE Standards Dictionary Online should be consulted for terms not defined in this clause.⁵

intelligent electronic device (IED): A general term indicating a multipurpose electronic device typically associated with substation control and protection.

phasor: A complex equivalent of a sinusoidal wave quantity such that the complex modulus is the cosine wave amplitude, and the complex angle (in polar form) is the cosine wave phase angle.

pulse per second (PPS): A signal consisting of a train of square pulses occurring at a frequency of 1 Hz, with the rising edge synchronized with UTC seconds. This signal is typically generated by Global Positioning System (GPS) receivers.

3.2 Acronyms and abbreviations

ACSI	abstract communication service interface
BER	basic encoding rules
BIL	basic impulse insulation level

³The IEEE standards or products referred to in [Clause 2](#) are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers

(<http://standards.ieee.org/>). ⁵IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>.

CT	current transformer
CVT	capacitive voltage transformer
EHV	extra-high voltage
EMC	electromagnetic compatibility
EOVT	electro-optic voltage transformer
HV	high voltage
MTBF	mean time between failures
MU	merging unit
NCIT	non-conventional instrument transformer
OCT	optical current transformer
OIT	optical instrument transformer
OVT	optical voltage transformer
PMU	phasor measurement unit
VT	voltage transformer (or potential transformer).

4. Introduction

4.1 Overview

Optical sensor technology to replace current transformers (CTs) and voltage transformers (VTs) has been demonstrated for over 20 years. These sensors use optics and electronics to achieve accuracy, linearity, dynamic range, and efficient installation far beyond the capabilities of familiar electromagnetic and capacitive instrument transformers. Commercial products have been available for most of that time, with a widening array of choices and manufacturers. However, the commercial transition to new sensors has been gradual, in light of the familiarity and reliability of conventional instrument transformers. Accordingly, the objective of this guide is to provide the reader with a factual understanding of the technical and economic bases for choosing optical instrument transformers (OITs) when familiar sensor technologies remain widely available.

This guide provides information on technologies of optical voltage and current sensors, their performance characteristics, their incorporation in measurement systems for protection and control, installation, and maintenance requirements, testing requirements, and application considerations.

The following clause outlines the topics covered in detail in the remainder of the guide.

4.2 Optical voltage and current sensing technologies

[Clause 5](#) provides a review of the technologies for optical voltage and current sensors in the electric power industry. It introduces the reader to the scientific principles that optical instrument transformers use to measure electrical quantities. It illustrates the product packaging alternatives that arise from these measurement techniques.

4.3 Performance

[Clause 6](#) provides a review of technical behavior specifics of optical sensor solutions. Subclauses explain the following features and issues to be considered when using optical sensors:

- Accuracy and dynamic range (6.2)—covering accuracy and linearity of the sensors, including their ability to maintain accuracy over wide ranges of currents or voltages. This subclause lists available accuracy classes. Terminology for newer accuracy class specification (over a wider dynamic range) is reviewed here.
- Bandwidth or frequency response (6.3)—discussing the suitability of optical sensors for capturing transients and measuring harmonic components that ride on power frequency signals. This subclause explains how the sensor electronics and other elements in the measuring chain affect the frequency response of the sensor system.
- Noise and impact of noise on performance (6.4)—the output of all electronic devices, including optical sensor components, contains electrical noise components. This subclause provides an understanding of noise generation, how it can be a positive or negative impact on the performance of a specific function or application, and how to manage it.
- Stability and performance variation over time (6.5)—the components of any device can age and degrade over time. This subclause reviews the aging and possible performance changes of an optical sensor system, as well as mitigation factors and self-monitoring that should be designed into such systems.
- Performance variation over temperature (6.6)—optical-measurement techniques use physical properties of materials which are temperature dependent. A significant challenge in building an effective OIT is to compensate for temperature variations.
- Impact of vibration (6.6)—similar to temperature, vibration can have adverse impact on the performance of optical sensors. Mitigating the possible impact of vibration and physical movement is a key part of developing and packaging high-quality OITs.
- Technical requirements for high voltage (HV) substation use (6.7)—as optical instrument transformers have been deployed mostly in high-voltage substations, environmental requirements for HV or extra-high voltage (EHV) power apparatus also apply to optical instrument transformers. These include insulation, load and fault current limits, seismic withstand capability, and electromagnetic compatibility (EMC) requirements for the associated electronics. Optical sensors generally use simpler HV insulation due to the galvanic isolation provided by optical fibers and the lack of conductive parts in the insulating structure. A key advantage of optical sensors is compactness with superior safety in HV installations.

[Clause 6](#) helps the user decide on whether to use optical sensors, what key advantages can be expected, and what design factors and issues have to be accommodated in order to use an optical sensor successfully. Even though this guide focuses on protective relaying applications of optical instrument transformers, the performance characteristics explained here serve as valuable knowledge for use of optical sensors in any applications.

4.4 Interface requirements and issues

[Clause 7](#) provides a description of analog and digital output interfaces available for optical instrument transformers, as specified in industry standards. It also explains digital interfaces in the context of IEC 61850⁶, and covers system aspects of digital interfaces.

4.5 Applications

[Clause 8](#) explains benefits and considerations of using optical instrument transformers for a variety of applications. Some of the applications include line protection (transmission and distribution), improving the accuracy of line fault location, generator protection, transformer protection, bus protection, excitation

⁶Information on references can be found in [Clause 2](#).

measurements (V/Hz), use with phasor measurement units (PMUs), undervoltage load shedding, and measurement and protection for reactive devices, such as shunt or series capacitors.

4.6 Installation and commissioning

[Clause 9](#) contains information and considerations for the installation and commissioning of optical instrument transformers.

4.7 Testing of optical instrument transformers

[Clause 10](#) provides guidance on testing optical instrument transformers, including factory testing, site acceptance testing, commissioning tests, and on-site accuracy testing.

4.8 Reliability and redundancy

[Clause 11](#) provides a review of reliability and redundancy considerations for optical instrument transformer applications. It highlights the interaction between the optical instrument transformers and the overall protection scheme architecture.

4.9 Industry standards

[Annex B](#) presents an informative annex explaining IEEE and IEC standards related to optical instrument transformers available at the time of writing of this guide.

5. Technologies

5.1 Overview

[Clause 5](#) provides a summary of the technologies used to realize optical voltage or current measurement in high-voltage environments. The technologies for current measurement are discussed first, with voltage-sensing techniques following. Detailed information on various specific products or solutions available can be found in industry literature, including those listed in [Annex A](#), Bibliography.

5.2 Optical current measurement

5.2.1 Introduction

Over the last several years, current measurement systems based on optical devices have been developed. The first to be developed were hybrid devices, since they were closely related to conventional technology. These are discussed as Type 1 ([5.2.2](#)) and Type 2 ([5.2.3](#)). The latest technology is purely optical devices, described in Types 3 and 4 ([5.2.4](#)). This guide is mainly concerned with Types 3 and 4. All of these sensors use optics to isolate a high-voltage part of the system from a grounded part, as illustrated in [Figure 1](#).

Because an OCT is electronic in nature, one fundamental way an OCT differs from a CT is in the signal power involved. In all the OCT considered here, the current being measured is represented as modulated light. In a CT, the secondary signal has a power level of several watts. The power in the optical part of the OCT is typically a few μW .

Diversity is present in all elements of the system shown in [Figure 1](#). The sensor (or primary converter) itself may be optical or electronic; accordingly, the high-voltage part of the system may be active or passive. The insulator may be ceramic or polymer; it may be used to support the OCT or it may be suspended from it. Typically, but not universally, the insulator contains an optical fiber carrying the OCT signals. The way the

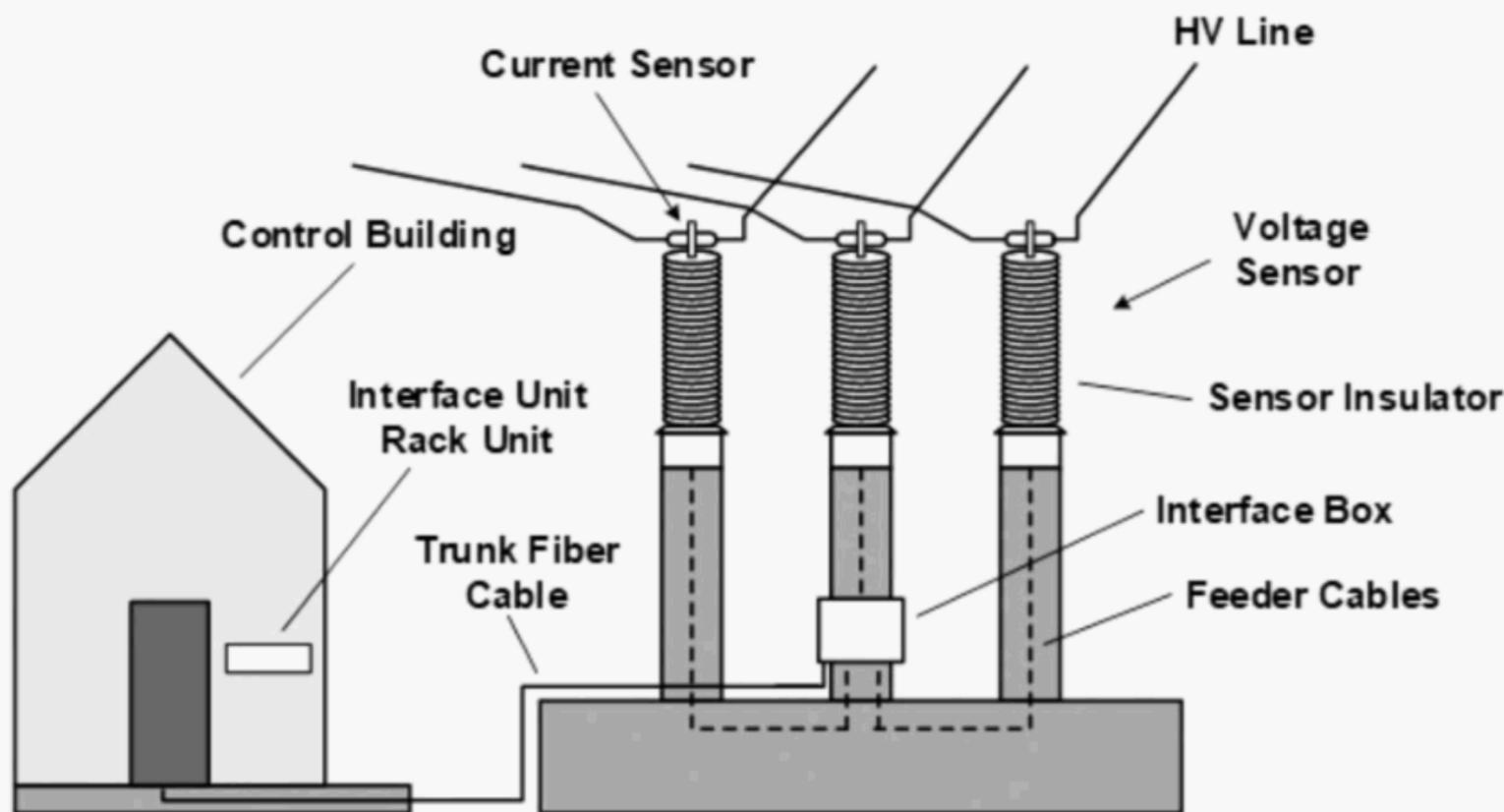


Figure 1—Essential elements of optical current transformer (OCT) or optical voltage transformer (OVT) system

current information is encoded in the fiber varies from system to system. This affects the design of the receiver (as part of the secondary converter) at ground potential. An interface unit connects the OCT system to the terminal device, which may be a protective relay, a revenue meter, or other equipment.

In order to organize the discussion of the different approaches that have been used to implement optical current transducers, the sensors have been arranged based on increasing order of difference from the conventional CT. Note that while the designation of sensor types is arbitrary, it serves the useful purpose of providing a classification system.

5.2.2 Type 1—conventional CT with optical readout

The wire-wound iron-core current transformer is well-described in literature and needs no discussion here. Adding an insulated optical information channel to such a CT, to effectively replace the copper wire output, as shown in [Figure 2](#), can result in a hybrid CT which retains some of the advantages of both conventional CTs and optical isolation.

5.2.3 Type 2—magnetic concentrator

In this approach, a magnetic circuit surrounds the conductor, but instead of the magnetic loop forming the core of a transformer, the field inside the magnetic core is measured optically in an air gap, as shown in [Figure 3](#).

An advantage of this approach is that the optical path is short and simple, and only a small amount of optical material is needed.

5.2.4 Types 3 and 4—optical path surrounding conductor

5.2.4.1 Introduction

If the mechanism by which a magnetic field is converted into an optical effect can be distributed around the current carrying conductor, a closed optical path surrounding the conductor can measure the current in a way analogous to the magnetic core of a conventional CT. In the listing, this is the first of the optical measurements

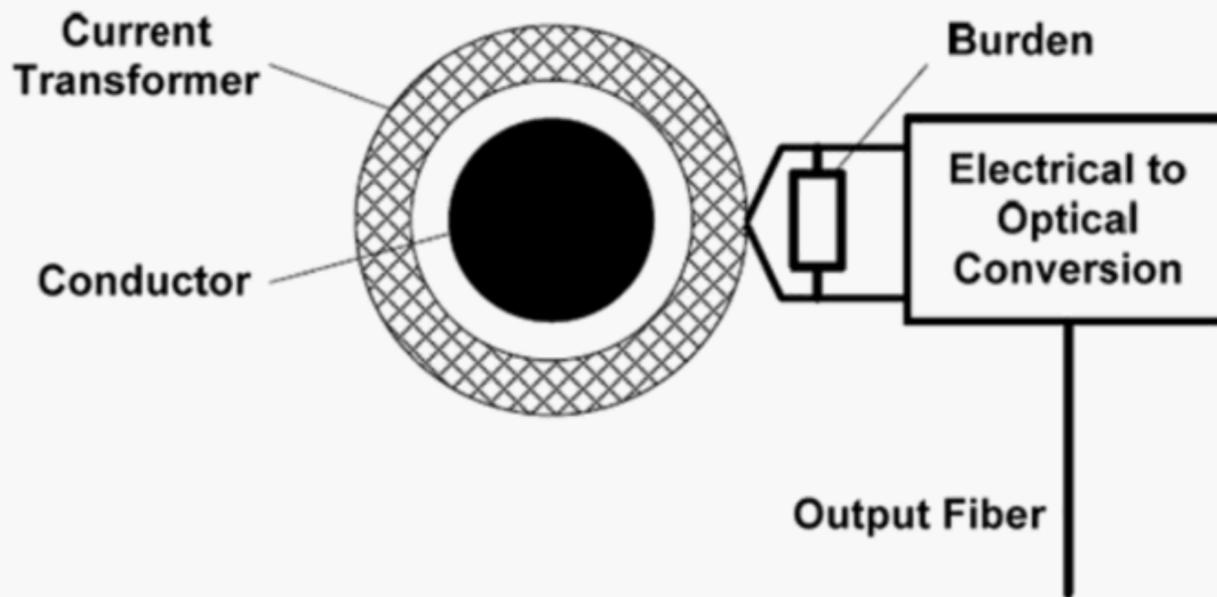


Figure 2—Conventional CT with optical readout

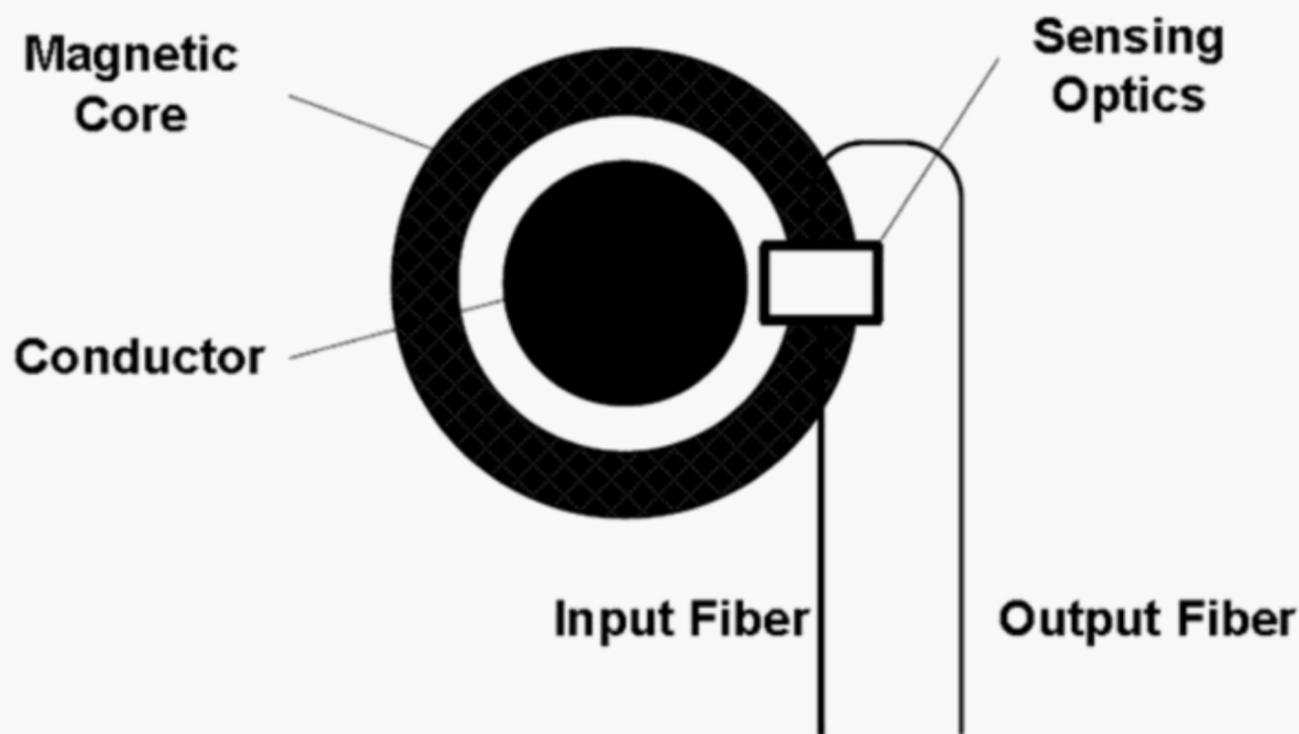


Figure 3—Magnetic concentrator with optical measurement

to contain no ferromagnetic components. In this guide, we refer to this type of OCT as purely optical CT, whereas Type 1 and Type 2 are considered to be hybrid optical technologies. There are two main variations to purely optical CTs: Type 3 and Type 4.

5.2.4.2 Type 3—bulk optics

The optical path is inside a block of optically active material, and the path encloses the conductor exactly once, as shown in [Figure 4](#). This kind of device is analogous to an optical implementation of the conventional CT.

5.2.4.3 Type 4—optical fiber

Here the optical path is inside a fiber that can be wound around the conductor an arbitrary number of times to achieve the desired sensitivity. There are several variations of this type of sensor. [Figure 5](#) shows one general arrangement.

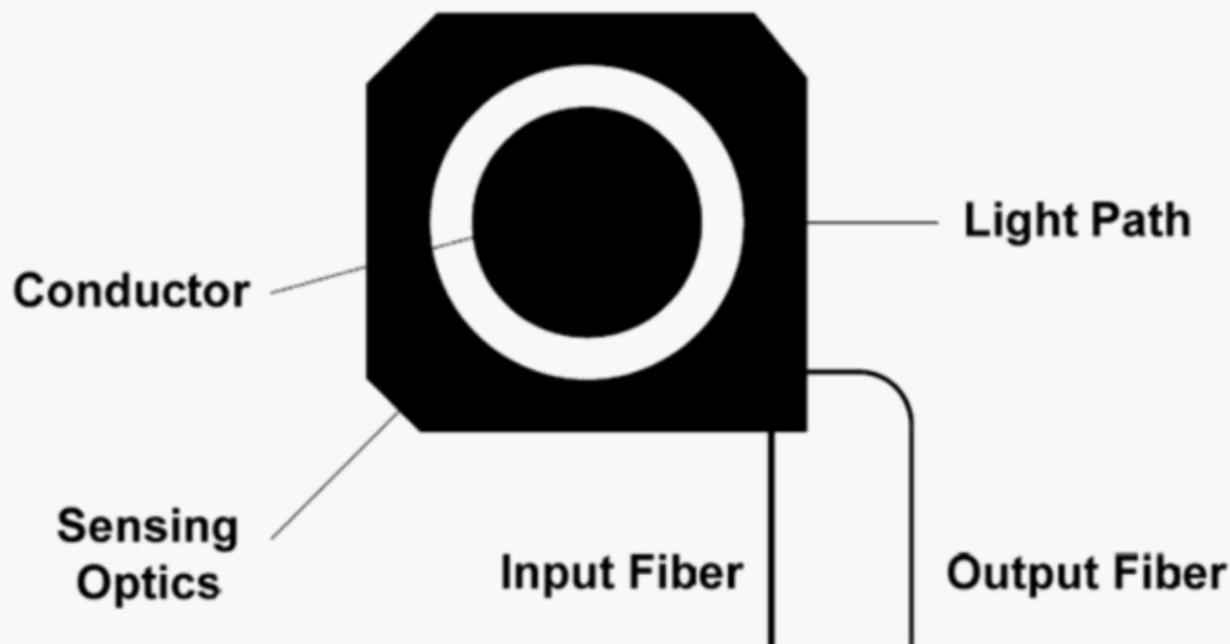


Figure 4—OCT using bulk optics

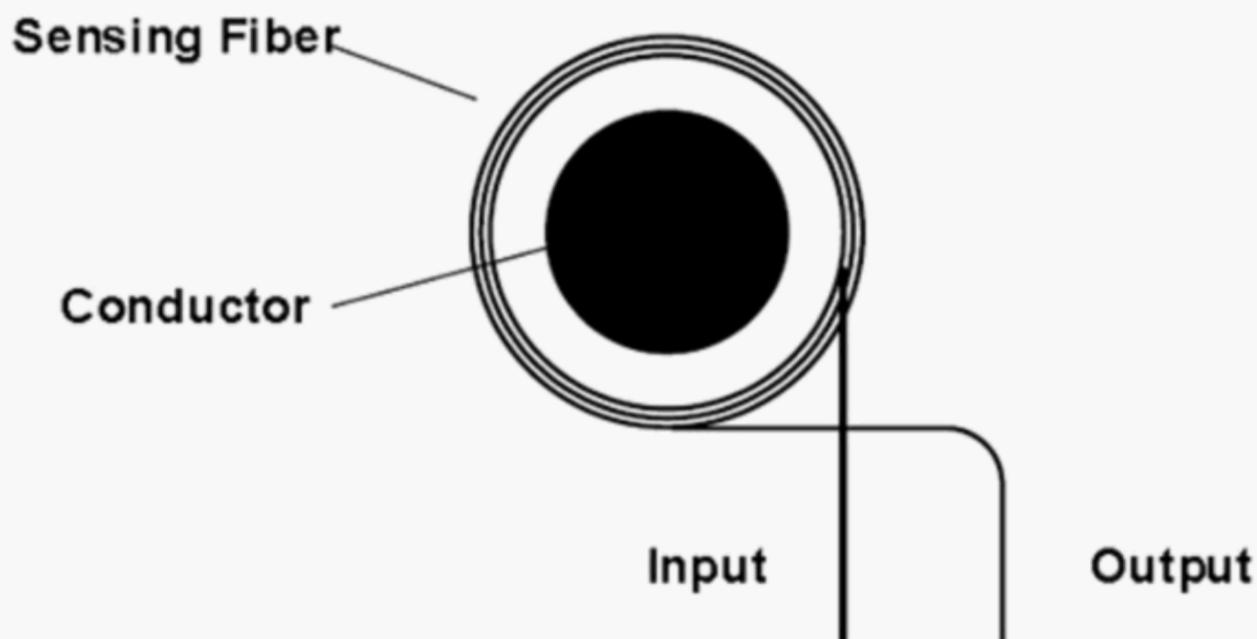


Figure 5—Fiber optics–based current measurement

5.3 Optical voltage measurement

5.3.1 Introduction

Unlike current sensors that surround the conductor, voltage sensors are connected between the line and some reference point (usually ground). The system shown in [Figure 1](#) is applicable to a voltage sensor except that the sensor is contained within the insulator column. Again, there are several types of voltage sensors that have been developed over the years, some of which are listed in the following subclauses.

5.3.2 Type 1—line-to-ground continuous integration

In this type of sensor, the voltage is obtained by integrating electric field from line to ground. The voltage signal is linear for small signals. [Figure 6](#) shows an optical voltage sensor based on line-to-ground integration of electric field. The high-voltage potential and the ground are brought across an electro-optic crystal where the voltage is measured by integrating the electric field along the length of the electro-optic crystal. [Figure 7](#) shows more details for an electro-optic voltage sensor's sensing mechanism, including the electronic circuit.

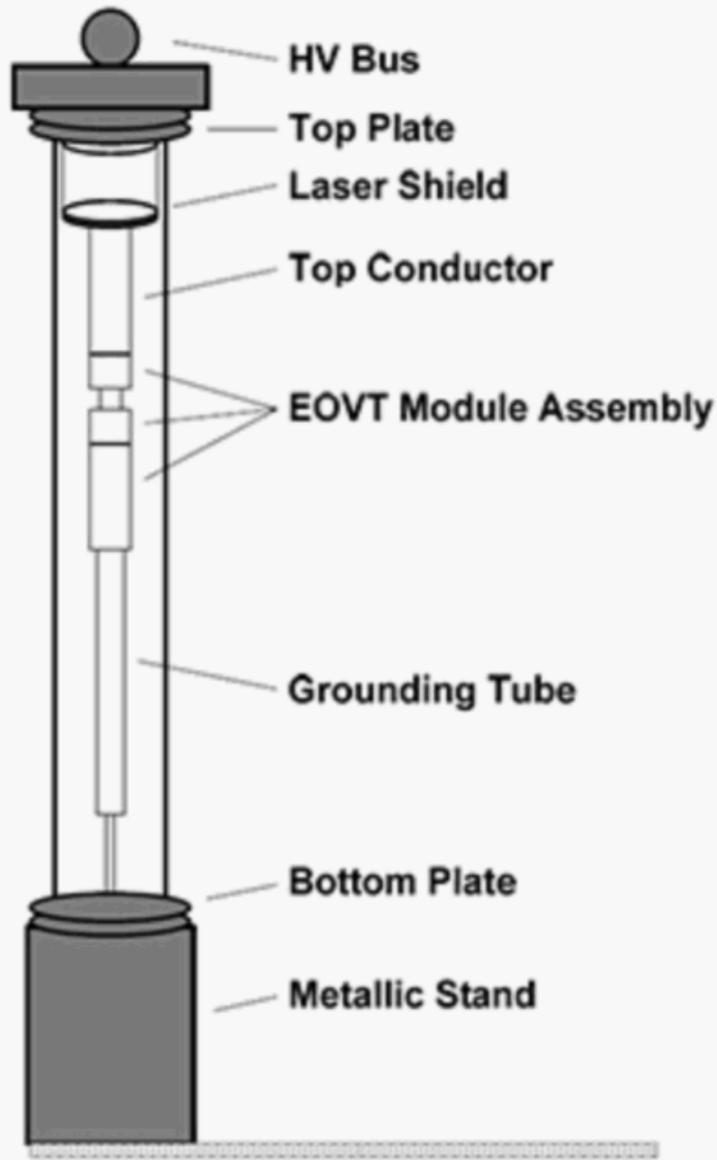


Figure 6—OVT based on line-to-ground integration

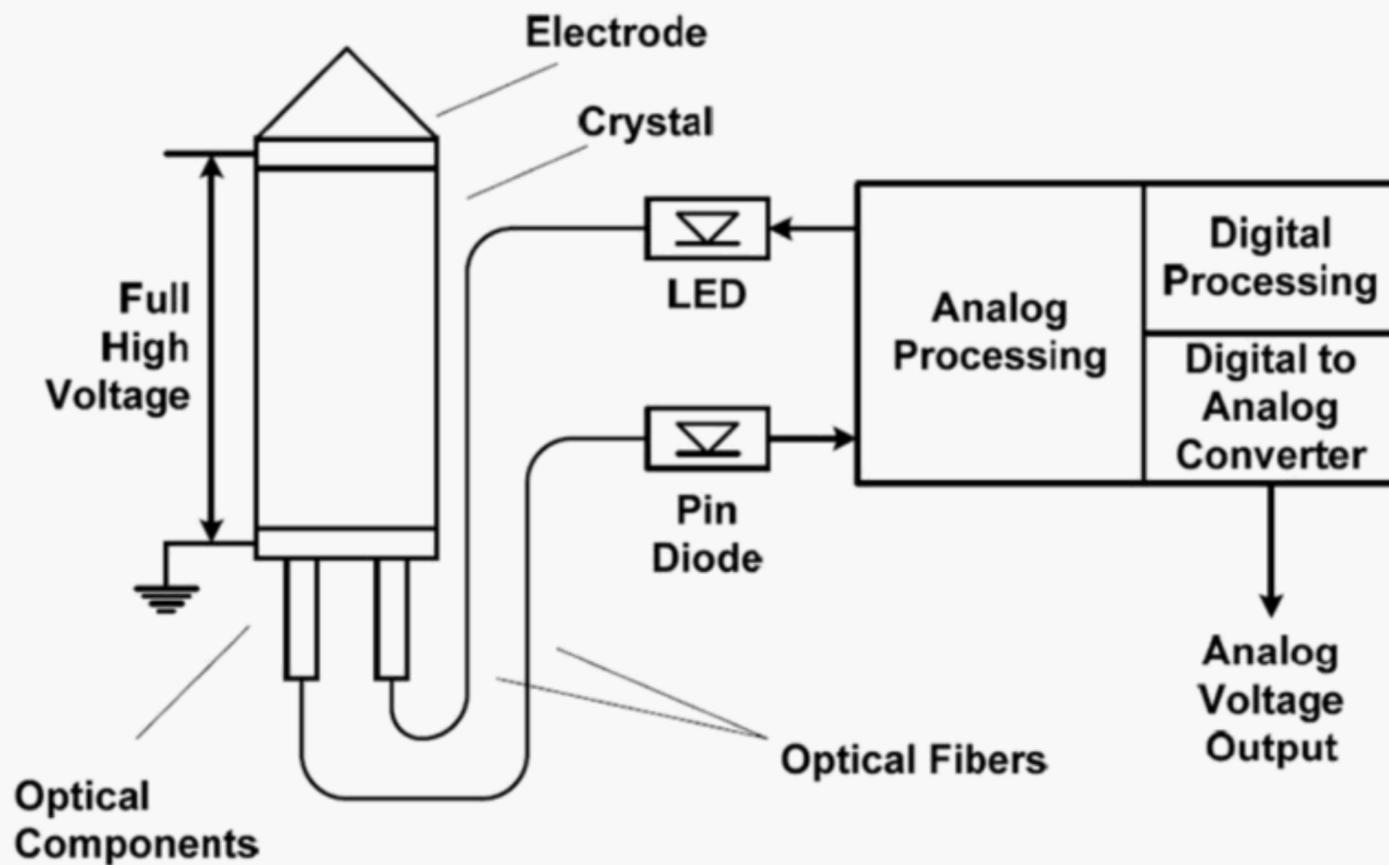


Figure 7—Electro-optic voltage transformer (EOVT) sample module assembly

5.3.3 Type 2—line-to-ground distributed integration

Several electro-optic field sensors are used (whose outputs are combined using, for example, the Gaussian quadrature method) to assess overall voltage. The quadrature method determines some basic elements of the design: the required number of sensors, exactly where they should be placed, and how heavily to weight each output. In [Figure 8](#), an example with three sensors is provided, and the locations of the sensors are shown for this particular design.

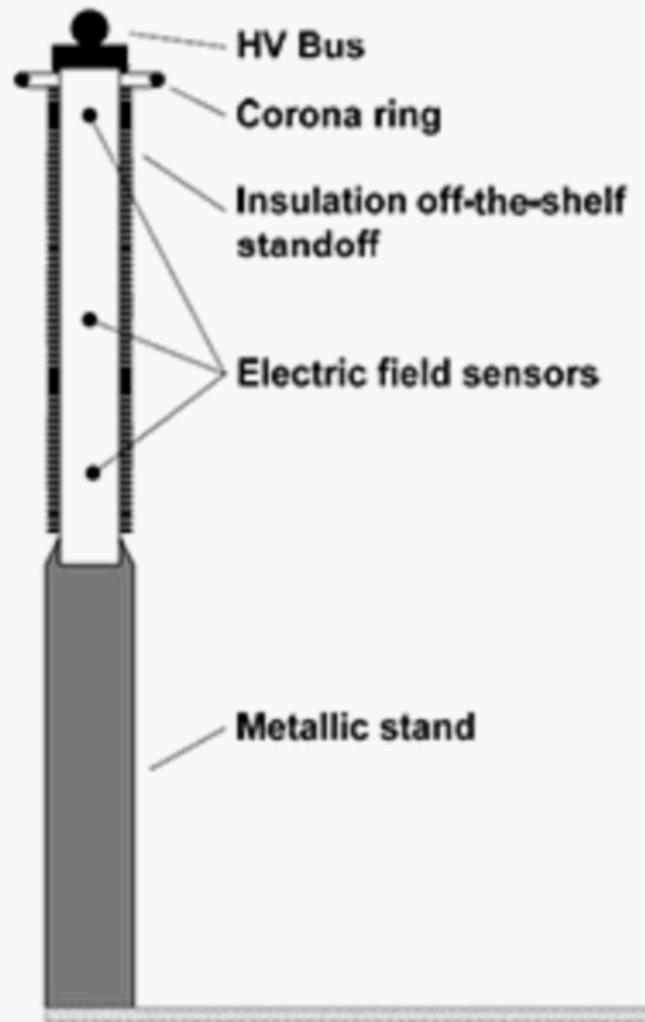


Figure 8—OVT based on distributed electric-field integration

6. Performance

6.1 Overview

The performance requirements of optical instrument transformers (OIT) depend to a large extent on the application(s) for which the OIT is intended to be used. The following categories classify some of the key performance requirements of OIT:

- Accuracy
- Bandwidth
- Noise
- Stability
- Temperature performance
- Immunity to vibration
- Substation requirements and other (e.g., dielectric ratings, thermal current, etc.)

6.2 Accuracy

6.2.1 Introduction

[Table 1](#) and [Table 2](#) show a summary of the IEEE accuracy requirements for typical conventional instrument transformers.

Table 1—Maximum magnitude and phase error for ANSI class type CTs (IEEE Std C57.13™)

ANSI CT type	Load current (%)	Maximum magnitude error (%)	Maximum phase error (degrees)
Relaying	10 to 2000	10	Not specified
Metering 1.2	10	2.4	2.08
	100	1.2	1.04
Metering 0.6	10	1.2	1.04
	100	0.6	0.52
Metering 0.3	10	0.6	0.52
	100	0.3	0.26

Table 2—Maximum magnitude and phase error for ANSI class VTs (IEEE Std C57.13)

ANSI VT type	Maximum magnitude error (%)	Maximum phase error (degrees)
Relaying	10	Not specified (10% composite error)
Metering 1.2	1.2	1.04
Metering 0.6	0.6	0.52
Metering 0.3	0.3	0.26

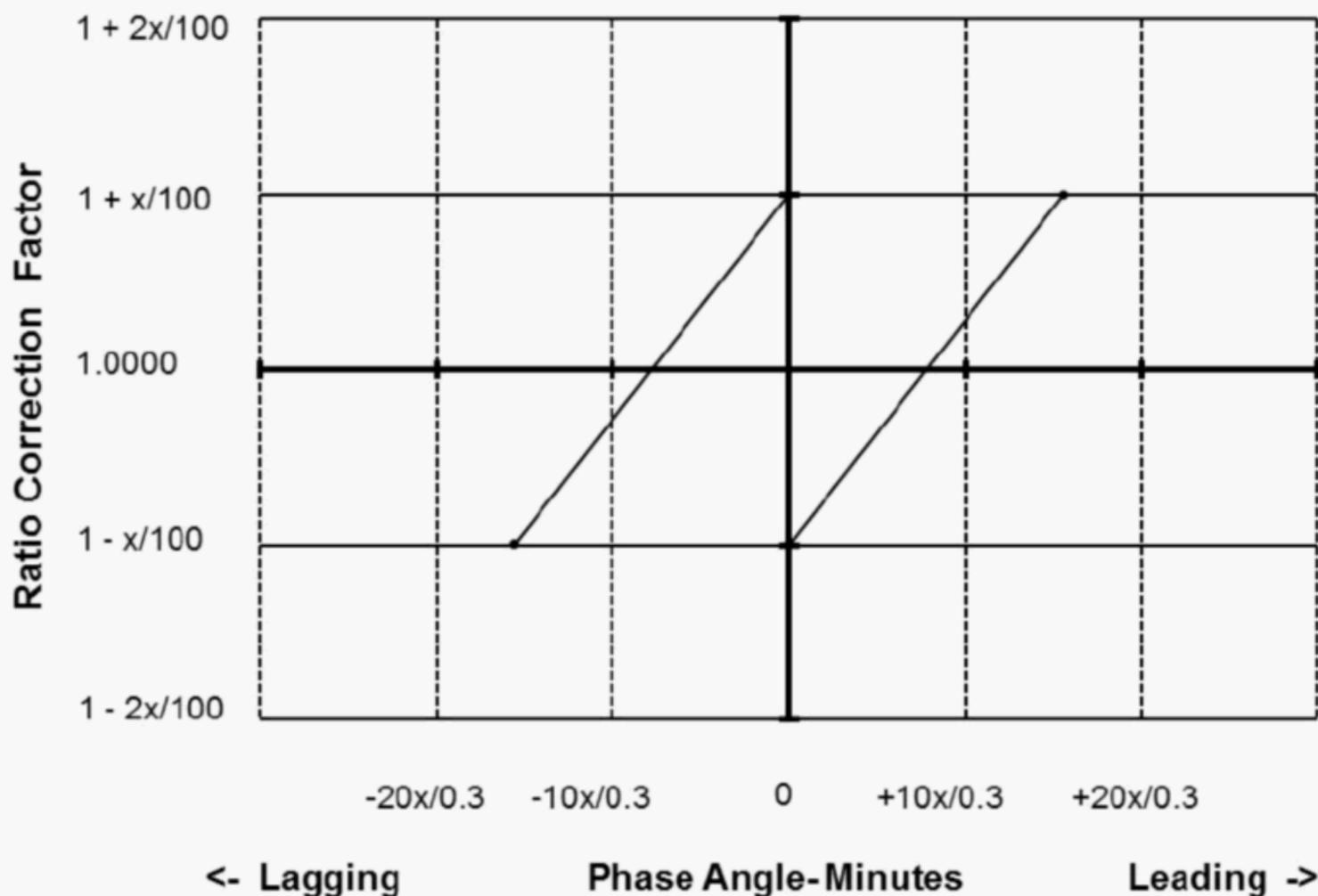
Depending on the application, the accuracy requirements for optical instrument transformers are divided into two main categories: metering and protection applications.

For metering, typical accuracy classes are IEEE class 0.3 or 0.15S (or IEC 0.2S) for optical current transformers; where accuracy classes 0.3, 0.15S, and 0.2S are defined in IEEE Std C57.13, IEEE Std C57.13.6™, and IEC 60044-8, respectively. There is an alternative accuracy class definition terminology introduced in IEEE Std 1601™ for wide dynamic range optical CTs. The accuracy class designation has the format xDRy-z where x is the basic accuracy requirement (see [Figure 9⁷](#)) and y-z represents the dynamic range in percent of rated current over which the accuracy is maintained. For example, accuracy class 0.15DR1–150 reflects that from 1% to 150% of the rated current an optical CT's error falls within the 0.15% parallelogram (see IEEE Std C57.13.6 or IEEE Std 1601). This type of accuracy specification is of particular interest for optical CTs as they are often used for wide dynamic range measurements. Previous standards did not include means for specifying accuracy over a wide dynamic range.

Even though the performance specifications are mainly focused on metering applications, certain accuracy-sensitive applications can take advantage of these performance characteristics for protection functions. For example, the ability of a fiber optic window-type CT to survive (and measure) a large amount of fault current while having high accuracy at very low current levels can be exploited for capacitor protection (imbalance current detection) applications (Rahmatian, et al. 2007 [\[B14\]⁸](#)). Similarly, a wideband, wide dynamic range fiber optic CT can be used during staged fault testing (and verification of protection functions) of series capacitor banks (Rahmatian, et al. 2005 [\[B16\]](#)).

⁷Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

⁸The numbers in brackets correspond to those of the bibliography in [Annex A](#).



NOTE—The transformer characteristics shall lie within the stated limits of the parallelogram at a prescribed current.

Figure 9—Limits for error for accuracy class x for current transformers for metering

For traditional protection applications, the basic accuracy class requirements for optical CTs are similar to those for conventional CTs. Nevertheless, unlike conventional iron core CTs, purely optical CTs (i.e., Types 3 and 4) do not introduce iron-core saturation issues. Accordingly, performance for protection applications can be improved.

The nature of the output interface of any specific optical CT or VT may also affect the effective accuracy of the sensor. For example, for low-energy analog electronic output, typical electronic circuits are limited to ± 10 V; accordingly, for an optical current transformer having a rated output of 200 mV, accuracy beyond 50 times rated current may be affected as the output clips at 10 V. Alternatively, if an output amplifier is used with maximum output current of 2 per unit (e.g., used with an optical CT for capacitor imbalance current detection), the accuracy of the analog output signal is significantly disturbed at current level above that maximum output level (even though the sensor at the digital level may be measuring the current accurately).

Typically, protection accuracy classes for optical CTs are 0.5% to 2% (e.g., IEC class 5P) at the rated current, with composite errors of 5% to 10% at 10 to 40 times rated current (e.g., IEC class 5TPE20). Also, typical sensor delay time for protection applications should be less than 0.2 ms, see IEEE Std C37.92™ (many devices meet < 0.05 ms).

Accuracy requirements for optical voltage transformers are very similar to those of conventional voltage transformers. Typical accuracy classes of IEEE/ANSI 0.6, 0.3, and 0.15, see IEEE Std C57.13, IEEE Std 1601, IEEE Std C37.92, or IEC 0.2, 0.5, and 3P, see IEC 60044-7, are commonly available from optical voltage transformers. Most optical voltage transformers are also very linear and maintain the same accuracy from a few percent to 200% of rated voltage (subject to the nature/limitations of the sensor's output interface).

6.2.2 CT matching

In some applications, e.g., certain differential protection schemes, CTs may need to be matched. The same concept is practiced today when using iron-core wound CTs, for example, for high-impedance bus-differential schemes. Accordingly, when using optical CTs for such applications, accuracy, bandwidth, delay time, and other performance characteristics of the CTs need to be matched for optimum performance.

6.3 Bandwidth

Optical instrument transformers can offer wide bandwidth. The optical sensing element itself can measure signals into the gigahertz-frequency range.

The actual frequency response of these sensors is usually limited by the electronics associated with the sensor, both for signal processing and for output signal conditioning. There are certain requirements specified in IEC 60044-8 and IEEE Std C37.92 for general electronic instrument transformers used for various applications. For revenue metering (and accuracy-sensitive protection applications), for example, relatively narrow bandwidth, including first few harmonics are generally required; typically, 1% accuracy in measuring lower harmonics (2nd to 5th) is sufficient. The IEC 60044-8 has requirements for accuracy of an electronic sensor to be used for power quality measurement at up to 50th harmonic (5% accuracy). For protection applications, typical 3-dB bandwidth of about 1 kHz to 3 kHz is required (IEEE Std C37.92 and IEC 60044-8). In some cases, for example, three-phase transformer protection applications, more accurate measurement at up to the 5th harmonic is used for protection applications.

Generally speaking, choosing a 3-dB bandwidth of 3 kHz (available from many optical instrument transformers) should conveniently cover most protection applications using analog output. When digital output is used (e.g., IEC 61850-9-2 process bus), it is recommended that the optical CT to have an anti-aliasing filter with a bandwidth of one-third or one-fourth of the sampling rate. Using typical (IEC 60044-8) sampling rate of 80 samples per cycle, the 3-dB bandwidth of the optical instrument transformer with digital output should be in the range of 1 kHz to 2 kHz. It may be worthwhile to consider that the effective bandwidth of the sensors having digital output compliant to common industry standards such as IEC 60044-8 is typically lower than the bandwidth available from low-energy analog outputs due to the limited sampling rate specified in these standards.

For special applications, such as detecting high-frequency resonances during reactor switching, optical CTs/VTs having bandwidths of several MHz are available (Rahmatian and Peelo [B15]). A fundamental factor that may limit the upper frequency for using optical sensors is the length of the optical sensing path; the longer is the length, the lower is the bandwidth. In principle, the wavelength of the electrical signal (voltage or current) to be measured should be at least an order of magnitude (a factor of 10) longer than the length of the sensing path (e.g., the sensing fiber length in a fiber optic current sensor). Refer to Rahmatian and Peelo [B15] or other literature on “electrical-optical wave walk-off” for more details.

Optical CTs (and some VTs) with dc measurement capability are available, e.g., for high-voltage direct current (HVDC) systems. When using optical dc CTs in process control, it is recommended that the bandwidth of the optical CT to be at least 5 kHz (preferably more than 10 kHz) to reduce signal group delays that may adversely affect control loop performance. This is of course not isolated to optical sensors; it is a requirement for any kind of sensor and the exact latency requirement depends on the specific application.

Optical VTs with near-dc measurement capability are available and can be used for measuring “decaying-dc” voltage on lines having trapped charges. Use of such OVTs together with point-on-wave switching technologies can improve reclosing over-voltages.

6.4 Noise

Most electronic devices (including optical instrument transformers) show some amount of noise in their outputs. The amount of noise depends on a number of factors, including the technology used, the nature of the output interface, and the bandwidth and accuracy of the sensor system. It is important to keep in mind that the presence of noise is not necessarily a negative attribute. In fact, in some cases, if the noise is white noise (random and averaging to zero) it can be useful.

For most protection (and power quality) applications, typical noise levels of optical instrument transformers have no impact on the functions of the relays (and the power quality meters). Most relays filter the signal received from instrument transformers looking for power frequency (or first few harmonics of that) before making any decisions; accordingly, the typical wide-band white noise of optical instrument transformers is filtered out with little impact on the power frequency signal.

For revenue metering applications, also, the white noise of optical CTs usually has no impact on active power measurement. Most advanced revenue meters integrate voltage and current signals received from the instrument transformers for measuring active energy; accordingly, the white noise of the optical CT (which is not correlated with the ac signal from VT) integrates to zero over some time. The amount of noise may be important when measuring rms current and/or reactive power calculations by a meter (using active power measurement and rms current measurement) at low current levels. Again, if metering grade devices are used in accuracy-sensitive protection applications, impact of noise on measurement and key trigger levels have to be taken into account.

The signal to noise ratio (SNR) for optical VTs is generally very strong (noise very small compared to the ac signal being measured) since the voltage signal magnitude is very strong (90% to 110% of rated voltage). Optical CT noise, on the other hand, may be significant compared to current signal being measured, for example, when line current is significantly smaller than the rated current. When SNR for current signals is low, noise may constitute a significant part of measured rms current, and accordingly, where rms current is used for decision making (e.g., protection setting thresholds), possible impact of noise needs to be considered. In many cases SNR for a fiber optic CT can be improved using more fiber turns.

There are various sources of noise in electronic devices and optical instrument transformers. The dominant noise contributor is usually “shot noise” (physically related to randomness of the arrival of photons at the photo detector). Shot noise is effectively white noise—meaning its average value is zero and it has a normal distribution (usually described by its variance: 1-sigma value). The 1-sigma (or rms) amount of noise in optical instrument transformers depends on the bandwidth of the sensor. Shot noise grows with the square-root of bandwidth. The current-equivalent-noise for a typical optical CT (using 1.3 um light source, with a few

microwatts of optical power received on the photo-detector) is on the order of $0.2 \sqrt{f}$

A turn \sqrt{f} ; that is, for
 Hz

example, the 1-sigma noise level of a fiber CT with 20 fiber turns and 10 000 Hz bandwidth is equivalent to 1 A

rms primary current = $\frac{1}{0.2 \sqrt{10000}} \times 10000$. When using an OCT of this kind for measuring 10 A rms current,

$$-1 \times 100\%$$

+

$$\left(\frac{10}{2} \quad \frac{1}{2} \right)$$

6.5 Stability

Optical CTs and VTs need to show stability (same accuracy over time) comparable with those for magnetic and capacitive systems (or better). The main potential cause of accuracy drift in optical instrument transformers is uncontrolled aging of some key components of the electronics associated with the optical sensors. For example, change in wavelength of an aging light source can cause change in accuracy if not appropriately compensated in the optical sensor electronics circuitry.

It is important for the manufacturer and the user to communicate and address the potential causes of accuracy changes in the sensor. Understanding the behavior of the sensors (including their associated electronic circuitry) and having self-monitoring features, as well as documented maintenance procedures, are key to achieving good long-term performance from any sensor system.

Ideally, in addition to self-diagnostics features implemented in the sensor system, the manufacturer can recommend and/or provide tools and procedures for verifying the performance of the sensor system while installed in field. For example, portable optical spectrum analyzers can be used to verify if the wavelength of the light source has changed (which in turn may result in change in the accuracy/calibration of the sensor). Preferably, these procedures should be able to be performed without requiring an outage of the power system (e.g., the substation or bus where the optical sensor is installed). The particular process for field verification of key sensor sub-systems depends on the design of the sensor, and manufacturers are encouraged to consider maintainability as a key design parameter when developing the product.

6.6 Temperature and vibration

The optical CT/VT needs to maintain its accuracy and bandwidth performance over its entire operating temperature. The operating temperature for the outdoor sensing elements (e.g., sensor head or columns) and the indoor parts of the sensor (e.g., sensor electronics) may be different. IEC 60044-8 provides temperature profiles for verifying the performance of the optical sensor system over temperature.

Several optical sensing systems use a temperature sensor for compensating for temperature dependence of the voltage or current sensors. When the optical CT/VT uses a temperature sensor for achieving higher VT/CT accuracy, the accuracy and/or performance of the temperature sensor should be verified periodically (e.g., every few years).

The optical CT/VT needs to maintain its accuracy and bandwidth performance while experiencing normal substation vibrations, including circuit breaker (CB) operation. The most challenging vibration environment for optical sensors is usually for CB-mounted CTs. Specifically, per IEC 60044-8, 5 ms after the last opening of the circuit-breaker, the rms value of the secondary output signal of the optical CT at the rated frequency calculated over one period, which should theoretically be 0, shall not exceed 3% of the rated secondary output.

Design of the packaging of the optical sensors is key for the sensor performing well under vibration and shock conditions.

6.7 Other technical performance requirements

Naturally, optical CTs/VTs need to survive their environment—substations. Accordingly, the basic impulse insulation level (BIL) and dielectric requirements for optical sensing columns are the same as those for other substation equipment and conventional instrument transformers. Please refer to IEEE Std 1601 for specific details.

Most optical CTs use simple conductor design, and accordingly can handle very high current levels for a short period of time. Accordingly, meeting typical thermal current requirements for CTs should not be difficult for optical CTs. Nevertheless, the device is typically type tested for its thermal current rating similar to conventional CTs.

Seismic requirements for substation equipment are provided in IEEE Std 693™. Please refer to IEEE Std 1601 for specification of the sections in IEEE Std 693 that optical instrument transformers need to comply with.

EMC requirements for the electronics associated with optical CTs and VTs, as well as other environmental requirements, are similar to other electronics (e.g., relays and meters) used in substation environments. Please refer to IEEE Std 1601 and/or IEC 60044-8 for specific environmental requirements and standards that optical sensor systems need to satisfy.

6.8 Final note

Generally, performance and application are very much dependent on each other. One should always consider them simultaneously. For example, capacitor bank imbalance-current-based protection application requires some accuracy at very low currents, but the bandwidth need not be large (slow sensors), whereas simple current-limiting overcurrent protection application requires fast measurement (fraction of a cycle) of very high currents without saturation or clipping by the sensor.

7. Interface requirements and issues

7.1 Overview on interfaces

7.1.1 Analog interfaces

7.1.1.1 Introduction

With analog interfaces, an analog signal is used as input to the relay. The waveform of that signal represents the waveform of the measured value. The analog-to-digital conversion is done in the relay. The main differences between the various standards are in the electrical characteristics of the signal.

There are two main categories of analog interface specifications:

- a) High-energy analog interfaces; conventional instrument transformers typically support these interfaces.
- b) Low-energy analog interfaces; electronic and low-power instrument transformers that do not have the high energy available typically support these interfaces.

The following international standards define various analog interfaces:

- IEEE Std C57.13
- IEEE Std C37.92
- IEC 60044 series
- IEC 61869 series (under development)

7.1.1.2 IEEE Std C57.13

IEEE Std C57.13 has been used for wire-wound magnetic-core VTs and CTs over the past few decades (with various updates and revisions). This standard defines several CT or VT ratios and burden-handling capabilities for various accuracy classes.

For a CT, rated output (secondary) currents of 5 A and 1 A are prescribed. Accuracy classes of 0.15%, 0.3%, 0.6%, or 1.2% are specified for measurement at the rated current. At 10% of rated current, typically, twice the amount of error as compared with the rated current is allowed. For high-current protection functions, composite errors of 5% and 10%, and peak error of 10% are specified at 20 times the rated currents. Various standard burden levels are specified for each accuracy class.

For a VT, rated output (secondary) voltages close to 69 V and 120 V are prescribed (for metering applications, the 120 V output is usually used). Accuracy classes of 0.15%, 0.3%, 0.6%, or 1.2% are specified for measurements in the range 90% to 110% of the rated voltage. At other voltages (typically up to 190% of rated voltage) higher errors are allowed. Various standard burden levels are specified for each accuracy class. Please see IEEE Std C57.13 for details.

7.1.1.3 IEEE Std C37.92

IEEE Std C37.92 specifies low-energy electronic interfaces, typically less than 10 V, for use with electronic relays. The rated outputs for metering and protection class CTs are 4 V and 200 mV, respectively. The rated output for a VT is 2 V. IEEE Std C37.92 also provides various requirements for the bandwidth and output impedance (burden capability) of an electronic CT/VT as well as details on the type and the length of the output cables used. Please see IEEE Std C37.92 for more details.

7.1.1.4 IEC 60044 series

The IEC 60044 series of standards cover conventional and non-conventional instrument transformers. More specifically, IEC 60044-7 and IEC 60044-8 cover electronic (including optical) voltage and current transformers, respectively. They provide a number of relevant performance requirements, in line with the requirements for magnetic core instrument transformers (including accuracy classes and allowed errors). They also specify low-voltage analog rated output values, somewhat similar to what is prescribed in IEEE Std C37.92. IEC 60044-8 further provides requirements for a digital interface for electronic instrument transformers, both voltage- and current-measuring devices. It introduces the concept of a merging unit (MU) where the results of measurements (sampled values) from a number of VTs and CTs (synchronized) are provided in a prescribed digital format. Since the publication of IEC 60044-8, the proposed digital output format (MU output) has evolved into what is prescribed in a UCA guide for use of IEC 61850-9-2 (known as the 61850-9-2LE), and further evolved into IEC 61869-9 as a commonly-accepted standard. See [7.1.1.5](#) for further details.

7.1.1.5 IEC 61869 series

The IEC 61869 series of standards replace the IEC 60044 series of standards. They cover conventional and non-conventional instrument transformers. More specifically, IEC 61869-7 and IEC 61869-8 cover electronic (including optical) voltage and current transformers, respectively, including their analog low-voltage outputs. IEC 61869-6 includes common clauses for all low-power (including electronic) instrument transformers, and IEC 61869-9 provides details for the digital output of electronic instrument transformers.

7.1.2 Digital interfaces

7.1.2.1 Introduction

With digital interfaces, a stream of data is used as input to the relay. That stream of data contains the sampled values of the measured signals. The analog-to-digital conversion is done in the sensor. The main differences between the various standards are in the encoding of the values (data representation), in the communication protocols used, and in the synchronization method.

One challenge of the digital interfaces is in the correlation of the different samples to the absolute time. There are two main concepts for this problem:

- a) The use of “synchronized sampling.” All data sources are synchronized to a global clock. The individual samples are directly or indirectly tagged with the time information. This method is supported by IEC 61850-9-2 and IEC 61869-9 and appears to have more acceptance by relay manufacturers.
- b) The use of a “fixed delay method.” Here, the assumption is that there is a well-known and fixed delay between the instant where a sample was acquired and the instant where the sample is received by the data sink. The data sink has to correlate the different samples. This method is prescribed in IEC 60044-8 and is not commonly supported by manufacturers at this time. This method is not discussed any further in this document.

The following international standards define commonly-accepted digital interfaces, consistent with the synchronized sampling concept:

- IEC 61850-9-2
- IEC 61869-9

7.1.2.2 The IEC 61850 family of standards

Compared to other interface specifications for non-conventional instrument transformers (NCITs), IEC 61850 is not restricted to the interface between NCITs and protection or metering devices. IEC 61850 is a series of standards that consists of several parts. A second edition of the standard has been published. The title of IEC 61850 is “Communication networks and systems for power utility automation.” IEC 61850 is not restricted to the specification of communication interfaces. It includes information models of the equipment, the specification of a configuration language used to exchange configuration information between tools from different manufacturers of substation automation equipment and specification of conformance testing of the communication interfaces.

IEC 61850-7-2 defines a set of abstract information exchange models called abstract communication service interface (ACSI). Of relevance for the interface between protection and instrument transformers is the model for the transmission of sampled values. That model is assuming synchronized sampling with a fixed, configurable sampling frequency. While IEC 61850-7-2 defines the information exchange in an abstract way, the protocol specification is done in the so-called mappings. IEC 61850-9-2 is the mapping for the sampled value transmission model (note that the mapping for all other models defined in 61850-7-2 is provided in IEC 61850-8-1). IEC 61850-9-2 supports the full flexibility of the abstract model defined in IEC 61850-7-2. IEC 61850-9-2 is using the following communication protocols:

- Presentation layer: ASN.1 using basic encoding rules (BER) (ISO/IEC 8824-1 and ISO/IEC 8825)
- Link redundancy (optional; introduced in edition 2): Parallel Redundancy Protocol and High Availability Seamless Ring (IEC 62439-3)
- Data link layer: Priority tagging/VLAN and CSMA/CD (IEEE Std 802.1Q and ISO/IEC 8802-3)
- Physical layer: Fiber optic transmission system 100-FX recommended (ISO/IEC 8802-3)

The UCA International Users Group published “Implementation guideline for digital interface to instrument transformers using IEC 61850-9-2.” This implementation guideline is an agreement, of the vendors participating in the UCA users group, on how the first implementations of digital interfaces to instrument transformers would be. Basically, the implementation guideline defines the following items:

- The content of the message comprising the voltage and current information for the three phases and for neutral. This is identical to IEC 61850-9-1 and IEC 60044-8.
- Two options for the sampling rate: 80 or 256 samples per nominal period.
- The use of scaled integer values to represent the information, including the specification of the scale factors for current and for voltage.

7.1.2.3 The IEC 61869 family of standards

The IEC 61869 series is a more recent IEC standard series for instrument transformers replacing the former IEC 60044 series. IEC 61869-9 deals with the digital interface of instrument transformers from a products standard perspective. It refers to IEC 61850-9-2 and provides an implementation profile, mostly in line with the guideline of the UCA International Users Group.

7.2 Some background information on digital interfaces

7.2.1 The information model according to IEC 61850

The core element of the information model is the logical node. A logical node can be considered as a container for function-related data. Logical nodes contain data. Data and the data attributes represent the information. The name of a logical node class is standardized and comprises always four characters. Basically, we can differentiate between two kinds of logical nodes:

- Logical nodes representing information of the primary equipment (e.g., circuit breaker—XCBR, or current transformer—TCTR). These logical nodes implement the interface between the switchgear and the substation automation system.
- Logical nodes representing information of substation automation functions. Examples are any kind of protection functions (e.g., distance protection—PDIS) or the measurement unit—MMXU.

The logical nodes involved in the acquisition of measured information are shown in Figure 10. TCTR is the logical node for a current transformer, TVTR the one for a voltage transformer. Note that the logical nodes representing primary equipment are typically single phased. Therefore, we need three instances of a logical node TCTR or TVTR. In the example of Figure 10, the instance name includes the phase identification as a prefix (e.g., A for phase A). The output of the logical nodes TCTR and TVTR are samples representing the waveform on the power line. Several logical nodes representing substation automation functions are using that waveform. The examples shown in Figure 10 are MMXU—measurement unit (the function to calculate e.g., rms values), MHAI—harmonic calculation, MSQI—sequence calculation, Pxxx—any kind of protection functions, RSYN—synchrocheck, and RADR—waveform recording, analog channel.

Some data of the logical node TCTR are: Amp—the current, ARtg—the rated current, and HzRtg—the rated frequency.

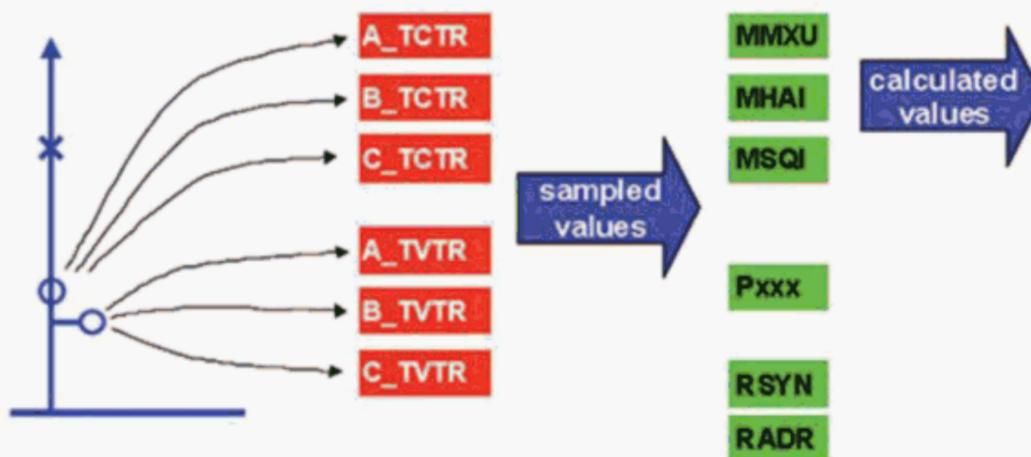


Figure 10—Acquisition of measured information

7.2.2 The merging unit

The concept of a merging unit is introduced in IEC 60044-8 and IEC 61869-9. A merging unit may be used with the digital interface and provides the interface from the electronic current and voltage transformers to the secondary equipment, such as protection or metering devices. A merging unit creates a time-coherent set of samples with three-phase voltages, three-phase currents, and neutral voltage and current.

Figure 11 shows the principle of a merging unit. Under the viewpoint of IEC 61850 data model, the merging unit implements the logical nodes TCTR and TVTR representing the current and voltage transformers in the data model. The secondary converter is typically part of the instrument transformer, while the merging

unit may be located in the control cubical. The link between the secondary converter and the merging unit is proprietary, and can be analog or digital.

With the digital interface according to IEC 60044-8, the merging unit is mandatory. IEC 61850-9-2 does not necessarily require a merging unit. The secondary converter can directly have an output according to

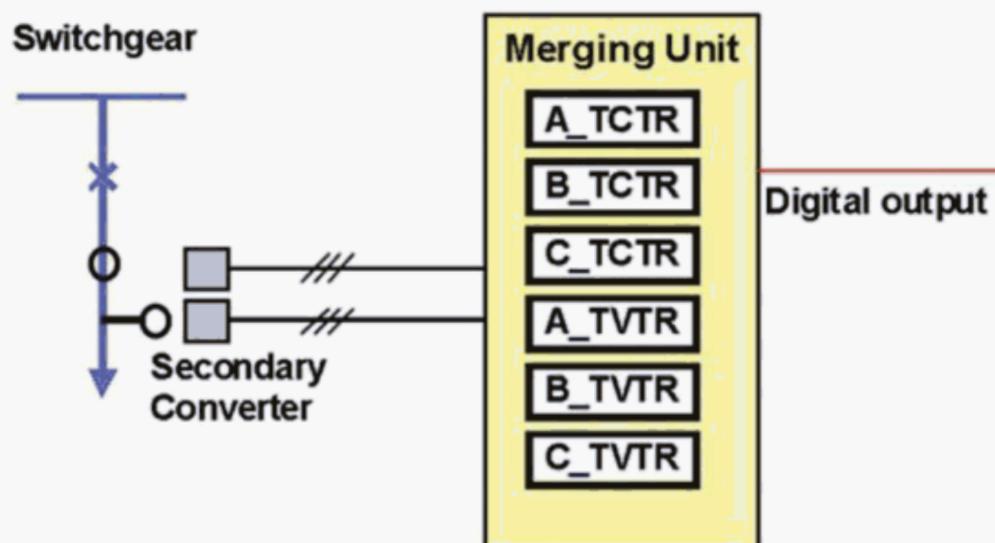


Figure 11—The principle of a merging unit

IEC 61850-9-2. However, system considerations like the requirement of synchronized sampling and the existence of a synchronization network make the use of a merging unit suitable in a first step. Therefore, the implementation guideline of the UCAInternational Users Group is also using the concept of the merging unit.

The concept of the merging unit may also be used to integrate conventional instrument transformers in a system with digital interfaces in the relays. In that case, the link between the instrument transformer and the merging unit would be a high-energy analog signal.

7.2.3 Synchronized sampling versus fixed delay

For most applications, it is important that samples from different sources can be time correlated to each other. If the samples are sent from different IEDs, there are two possibilities to correlate the samples:

- Synchronize the sampling to the time.
- Guarantee a fixed transmission delay from source to the sink, and resample and resynchronize the samples at the sink.

Since IEC 61850 can be used over communication networks where it is not always possible to guarantee a fixed transmission delay, it is necessary to use the first approach with synchronized sampling. It is not necessarily required that the synchronization is to an absolute time. It may be sufficient to have a relative synchronization of the different sample sources.

System aspects for time synchronization of sample sources are provided in 7.3.1.

7.2.4 Data representation: scaled versus real

IEC 61850 supports both floating point representation of the data as well as scaled integer representation. With floating point representation, the value shall be the primary value with the choice to use e.g., kV or V.

The integer representation is using a 32-b integer where the value is scaled; the scale factor can be provided as part of the IEC 61850 data model. In the implementation guideline, it is suggested to use the following scaling:

- 0.001 for the current
- 0.01 for the voltage

Using these values, it is possible to cover all application ranges from the lowest to the highest voltage and currents both for metering accuracy as well for the dynamic range required by protection.

7.3 System aspects using digital communication

7.3.1 Synchronization network

As discussed, IEC 61850 requires the sources of the sampling to be synchronized. While synchronization to global time is not required, it is important that the sources of sampled values used by a given application are all synchronized to the same source. The required synchronization accuracy depends on the application and is in principle determined by the acceptable phase error if the application would use analog inputs. As a consequence, an application needs to know the status of the samples it receives. This includes:

- Confirmation that the source of the sampled values is synchronized
- To what clock the source is synchronized

Having this information available, an application can decide if it can use the samples or not.

With the requirement that the sources of sampled values need to be synchronized, the availability of a function depends now as well on the availability of the synchronization function including the synchronization network. If multiple samples are acquired within the same physical device, they can always be considered to be synchronized between themselves. As an example, samples from one merging unit are implicitly sampled at exactly the same time.

To not compromise availability of the most critical protection functions, their availability should not depend on a synchronization network and a clock. Therefore, the sampling of the information required as input may be realized in one physical IED. As an example, a merging unit as defined earlier fulfills that requirement for a line protection that relies on one measurement point. For a line protection in a breaker-and-half configuration, it may be required to combine two logical merging units in one physical device.

To further reduce the dependency on a particular (separate) synchronization network for distributing a 1PPS signal, a synchronization mechanism that runs over the same Ethernet network used to transmit the sampled values may be used. This is a profile of IEEE Std 1588™ as defined in IEC 61850-9-3 or IEEE Std C37.238™.

7.3.2 Mixed mode

In a real substation, we can have the situation that certain protection devices need to use analog inputs from both conventional sensors and those with a digital output based on IEC 61850-9-2. A typical example is a transformer differential protection in a substation that uses sensors with a digital interface on one voltage level and conventional sensors on the other voltage level.

This can be solved in principle in two ways:

- a) The protection device supports both analog as well as digital inputs for the current and voltage measurements.

- b) A merging unit for conventional sensor inputs is introduced to the system to convert the analog data into the digital format. In that case, the protection device only needs to support digital interface.

In case a), the protection device needs to be synchronized as well to the same source as the sensors or the related merging units with the digital interface.

7.3.3 Migration

Special considerations are required when migrating a substation by gradually introducing sensors with digital interfaces. As an example, in a system without busbar voltage measurement, the synchrocheck function may be required to use temporarily both digital and analog inputs. Possible solutions have been discussed in Andersson, Brand, and Brunner [B1].

8. Applications

Applications of optical instrument transformers for protection and control include:

- Transformer protection and excitation measurement (Volts/Hz)
- Line protection (transmission and distribution)
- Phasor measurement units (PMUs)
- Generator protection
- Undervoltage load shedding
- Reactive devices, such as shunt and series capacitors
- Bus protection
- More accurate fault location
- Other general protection applications

The value of optical instrument transformers can be better appreciated where high precision or good frequency response in measurements is important. The frequency response of conventional capacitor voltage transformers is consistent mainly at the fundamental frequency. The low-frequency response of conventional voltage and current transformers is poor due to saturation.

High precision is often important for undervoltage load shedding applications where accurate measurements close to normal operating voltages are required. For measurements near normal operating voltage, the high metering accuracy of the optical VT can benefit the application.

Some of the more precise applications, such as phasor measurement, can benefit from the optical instrument transformers and their wide dynamic range, i.e., inherent linearity of the optical sensors over a very wide range of current and/or voltage. When streaming data from such devices to a phasor data concentrator (PDC), the user should be aware of data quality (accuracy) from the optical sources versus conventional instrument transformers for compatibility and comparison purposes.

Good frequency response of an optical VT may be important when measuring the oscillatory or transient voltages on a long transmission line with shunt reactor compensation. The low-frequency oscillations may not be measured accurately by a capacitor voltage transformer. For single phase-tripping applications, it could be valuable to determine whether or not the secondary arc has been extinguished—optical VTs and CTs have the bandwidth and dynamic range to show both large fault current as well as small harmonic-rich signals. [Figure 12](#) and [Figure 13](#) show signals captured using optical CTs during a single-phase line-to-ground fault and the secondary arc seen after the single-pole tripping, respectively.

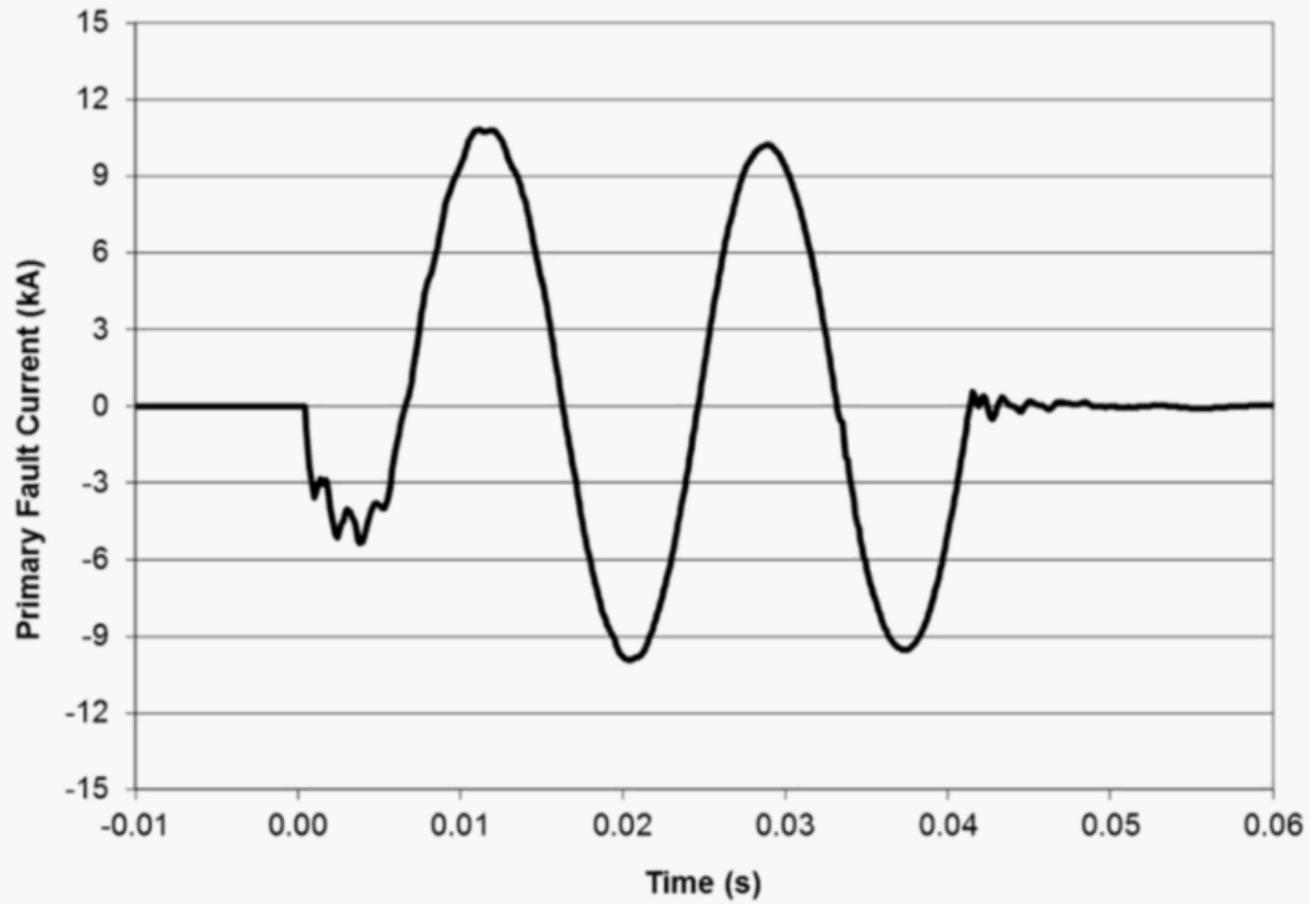


Figure 12—Primary fault current during a series capacitors bank single-phase line-to-ground fault

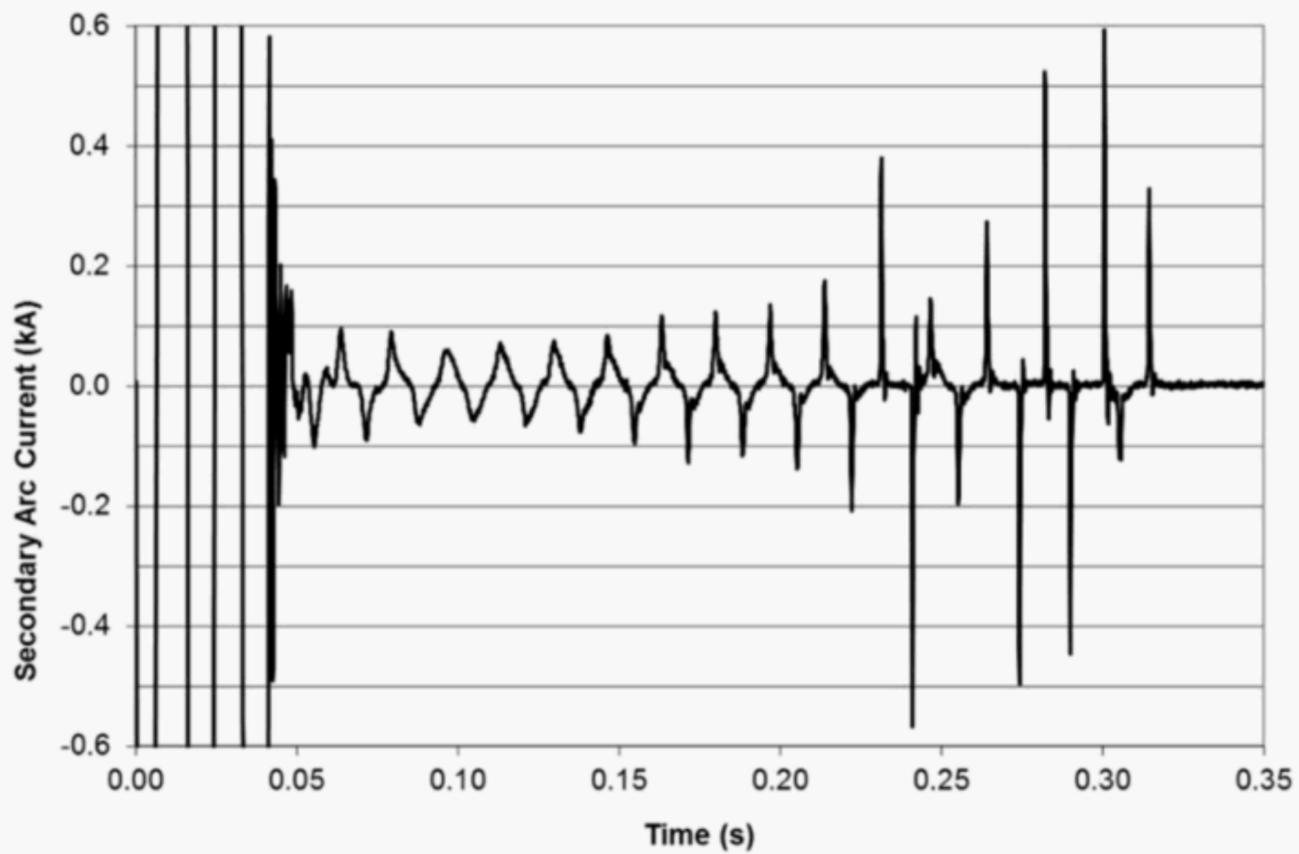


Figure 13—Secondary arc current after single-phase tripping of a single-phase line-to-ground fault

New protection applications using the transients associated with short circuits can also benefit from the better high-frequency response of the optical VT compared to the conventional CVT. Similarly, low-frequency performance of the optical VTs can be beneficial for synchronized switching on re-closing on lines with trapped charges. Figure 14 shows voltage measurements by a line CVT, a bus CVT, as well as a line optical VT after the circuit breaker opens on a 500 kV line. This monitored line in particular is running in a double circuit arrangement with the neighboring circuit still energized. The OVT shows the voltage on the line including the effects of the trapped charges (at the time of circuit breaker opening) and the induced voltage from the neighboring circuit. The line CVT output collapses, effectively providing no information within a quarter cycle after the circuit breaker opens.

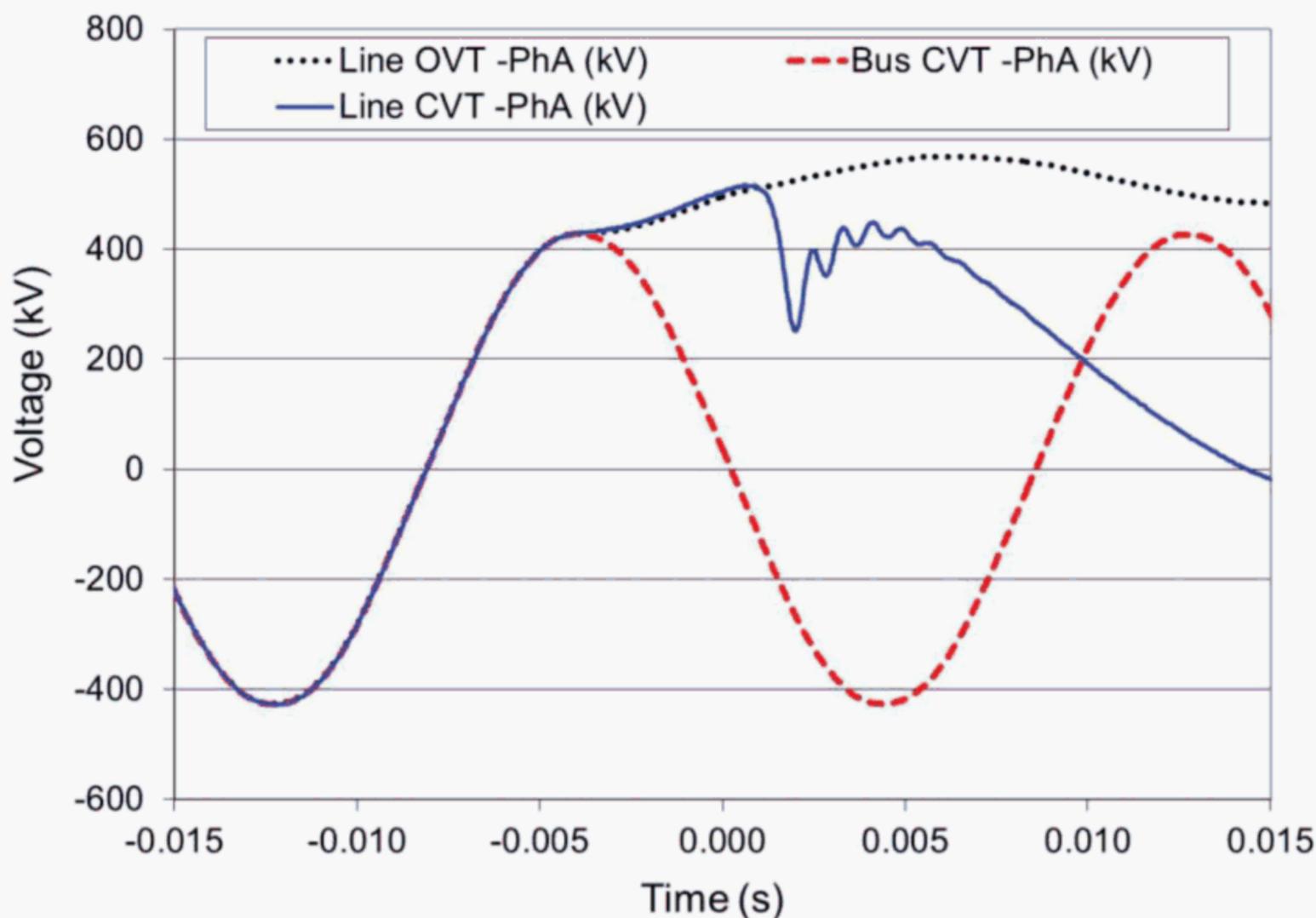


Figure 14—Voltage waveforms at the secondary of a line CVT, a bus CVT, and a line optical VT (OVT) during the opening of the circuit breaker (line de-energization). The wide bandwidth of the OVT (including its near-dc performance) results in the OVT being able to reproduce the actual voltage on the primary conductor, showing the effects of the trapped charges (near dc) and the induced voltage from the neighboring circuits

Since the transient offset of fault currents often cause CT saturation, the optical CT can bring value to applications such as bus protection where unequal performance of conventional current transformers challenge the security of differential protection.

The long time constants of offset decay during reactor energization can also degrade the performance of conventional current transformers and the good low-frequency response of the optical CT can benefit the protection applications.

Protection of generators running excited at low frequency (for example during startup) can also benefit from the accurate low-frequency response of OVTs and OCTs.

A practical approach to using newer technology, in some cases, may be to use the solution where risk and impact of device unavailability is lower. For example, certain protection applications may include cases where redundancy or the requirements for coordination with other schemes are inherent to the overall protection application. For instance, the voltage input for a transformer over-excitation protection can be supplied using optical voltage transformers. In this example, there are other protection systems that provide some level of overlapping protection in the absence of voltage. Meanwhile, in case of a failure of any part of the OVT, the alarms associated with the loss of voltage measurement initiate the need for maintenance. Another example in transformer protection is with use of optical current and voltage instrument transformers when loss of current or voltage disables partial protection. Where reliability of the measuring equipment is of concern, e.g., loss of an OVT, there should be another type of protection that mitigates the need for high reliability from any single device.

An attractive set of applications for optical CTs are niche applications where a very unique feature of the optical CT is exploited. These applications may be enabled by the nature of the fiber CT, and do not replace conventional techniques, rather augment and/or add to those techniques. Deployment of optical CTs and VTs in such cases can increase the overall reliability of the power system. Examples include:

- a) Direct transformer current differential protection using “effectively-flux-nulling” fiber optic CTs. Following is a simplified example to illustrate a potential application: a 500 kV to 230 kV single phase 500 MVA transformer has a voltage ratio of 2.0833. For simplicity, assuming it is a fixed ratio transformer (no load-tap changer), a fiber CT can be wrapped 25 times around the 500 kV bushing and 12 times around the 230 kV bushing, measuring a net current flux of zero. In case of a transformer internal fault, it can measure the net internal current, and coupled with a simple over-current relay can perform transformer internal fault protection.
- b) A three-phase transformer with the fiber CT wrapping around all three bushings to measure net (ground) current (similar to measuring zero-sequence current, but in this case using only one CT and summing current phasors at the optical/magnetic level).
- c) Performing high-impedance generator fault protection. For example, consider a generator with 10 000 A current flowing through it. Imagine there is a 10 A high-impedance stator fault current. Using two separate iron-core CTs (or any two CTs), a 0.1% difference for measuring current entering and exiting the generator cannot be achieved reliably. However, using fiber optic CT (of the appropriate design), same fiber CT can be wrapped (if necessary, several times) around both conductors (the input and output of the generator) and a net 10 A current difference in presence of a common mode 10 000 A current can be detected. This is a feature of certain fiber optic CTs having better than 20 ppm (= 0.002%) rejection of the currents outside of the fiber loop due to similar uniformity in their sensitivity to magnetic field/current.
- d) Cable differential protection. In cases where there is no facilities (e.g., power supply) for installing relays and communication infrastructure at one (or both) end(s) of the power cable (for example an overhead line transition to a cable going under a highway), one can use passive optical CT head and run the fiber parallel to the cable to the nearest substation and have currents measured from the two ends of the cable at one location and perform cable protection and fault location.
- e) Use of fiber optic CTs (with passive CT heads) on series capacitor platforms (and perhaps optical VTs for MOV voltage measurement).
- f) Use of high-voltage window-type fiber CTs (low ratio CTs) for detecting unbalance current (detecting small current differences between two conductors) in capacitor banks.

In the case of line protection utilizing power line carrier, provisions for standalone external coupling capacitor voltage transformer is needed as the optical instrument transformers do not provide the coupling voltage transformer.

In general, for any critical protection application, there should be provisions to avoid common-mode failure of main 1 and main 2 protection schemes (no single point of failure). For example, in high-voltage line protection applications utilizing distance or directional overcurrent protection, use of a redundant OVT system may be required to avoid the possibility of a single point of failure.

In the case of new stations where there is no need to combine secondary signals with conventional instrument transformers, the application of optical instrument transformers may be easier than in the case of existing stations with existing conventional instrument transformers. Most extensions of existing stations may need to interface CTs on new equipment with conventional CTs on existing equipment. When protection zones include both conventional and optical CTs, protection systems may need to be sufficiently flexible to accept inputs from either type. If currents are summed externally to the protection systems, special care may be needed to sum the signals from different technologies.

In applications where both current and voltage inputs are needed, it may be efficient to apply OCT and OVT with necessary hardware to support the protection and control equipment.

To expedite substation yard work, use of combined optical CT/PT together with standalone optical CTs may be an efficient way to provide signal measurement redundancy while minimizing HV equipment installation cost.

Another key consideration in using electronic technology is backward compatibility and ease of upgrade where the electronics (or amplifiers if applicable) used in conjunction with the primary optical-measurement devices need to be easily upgradable, or backward compatible, as technological advancements make existing electronics installations obsolete, or parts become unavailable.

9. Installation and commissioning

9.1 Introduction

Installation and commissioning of optical current and voltage systems have some differences from that of traditional instrument transformers. This is primarily due to the following differences:

- The use of lightweight materials and designs of the primary sensor reduces mechanical requirements and simplifies installation.
- The use of fiber optic cabling between the primary sensor and secondary converters introduces new types of materials and requires new competencies at the time of installation.
- Secondary converters either collocated with the primary sensor or located in the control room typically require a power source and use some sort of human-machine interface for installation and commissioning of the system.
- Low-level secondary outputs or digital outputs (IEC 61850-9-2) change the wiring requirements for secondary protection equipment.

There are several items that should be considered as part of the installation and commissioning process, however the following general items should be considered throughout the process:

- a) Education of contractors and utility personnel on the particulars of optical system installation and operation.
- b) Communication between all subcontractors during each stage of installation and commissioning.

The following sections outline particular items that should be considered at each stage of the planning, installation, and post-installation process.

9.2 Planning

The following is a checklist of items to consider as part of the planning process:

- a) While some performance criteria, such as the output level, may be configurable at the time of installation, it is still important to provide the manufacturer with as much performance criteria as possible at the time of order to enable the system to be designed and tested to meet the user's requirements. This includes electrical as well as environmental requirements.
- b) All subcontractors should have access to the manufacturer's documentation and be aware of the specific requirements for installation of optical systems.
- c) All personnel should receive the appropriate training.
- d) Structural subcontractors should refer to manufacturer documentation for information on column base mounting requirements for proper pedestal design.
- e) Check with the manufacturer to see what, if any, clearance requirements are required between the bus bar/conductor and the primary sensing device.
- f) For systems with cable-management boxes mounted to one or more of the pedestals, the structural and electrical subcontractors should determine the location of cable-management boxes and verify that the feeder cables from the primary sensors are long enough to reach the cable-management box.
- g) Verify which cables are provided by the manufacturer and which cables should be ordered separately. Review relevant fiber optic cable standards (some provided in [Annex A](#)) for more information.
- h) In some instances, fiber optic cabling is ordered independently of the optical system. It is important to review the manufacturer's documentation for information on the proper type of fiber (direct bury, single mode, wavelength) and to review the distance of cable runs to determine the correct type and length of fiber to order.
- i) The manufacturer's connection diagrams and the project planning documentation should be reviewed to determine the correct types and lengths of copper cabling to order (if any).
- j) If installing redundant systems, consider installing parallel independent conduits to improve redundancy.
- k) Consider installing trunk cables with spare fibers and/or conductors so that additional cables do not have to be pulled in the event of a broken fiber or damaged conductor.
- l) If the secondary converter is to be installed in the control room, rack space should be allocated for the secondary converter.
- m) Verify the secondary converter power supply requirements prior to ordering to ensure an appropriate power supply is available.
- n) Secondary converters typically cannot supply the same amount of power as inductive transformers, so it is important to note the system's burden requirements and verify the secondary equipment (e.g., relays) and cabling does not exceed the secondary converter capabilities. Note that cable length is not normally an issue, since the secondary converter is typically collocated with the secondary equipment.
- o) Optical systems quite often have mechanisms for reporting failures to a central monitoring system (e.g., pressure switches, alarm contacts, SCADA). Where possible, these mechanisms should be used for monitoring and detection of failures or degradations in the optical system.
- p) Communications personnel with fiber optic splicing equipment and capabilities should be enlisted for installation.
- q) Testing personnel should establish commissioning and test requirements.

- r) Testing personnel should make sure the correct signal generation and measurement equipment is available at the time of commissioning. The OIT manufacturer may provide guidance on the types of test equipment that may be required.
- s) Some optical systems are capable of generating test signal outputs, which can be useful for verifying connectivity between the secondary converter and the secondary equipment.
- t) If the optical system has human machine interface software, the software should be installed on the computer that is used for installation and/or monitoring.
- u) Develop documentation (e.g., using available product manual, etc.) for the system (i.e., schematics) and develop plans for ongoing preventative maintenance. This may include defining maintenance intervals, the test equipment required, and the development of testing procedures (including written test plans, maintenance personnel training, and outage/equipment isolation requirements, especially if primary injection will be required). During the development of documentation and training programs for maintenance personnel, consideration may be given to the likelihood that the personnel providing ongoing support may not be the same personnel that were involved during installation/commissioning.

9.3 Installation

9.3.1 Introduction

Installation of an optical system typically involves several sub-projects that are completed independently. The following sections outline items that should be considered as part of each sub-project.

9.3.2 Fiber optic cable installation

These items should be considered as part of the fiber optic cable installation:

- a) Care should be taken when pulling fiber optic cables to ensure that the pulling sleeve only pulls on the protective outer jacket.
- b) The bend radius of the fiber optic cable should be no less than 2 cm or 10 times the cable diameter, whichever larger, to reduce the probability of the cable being damaged or the light being impeded (excessive light loss). Consult the manufacturer's recommendations for additional information.
- c) Unprotected fibers and all splices should be stored inside splice trays or splice boxes to avoid damaging the exposed fibers and connections.
- d) Where possible, extra fiber service loops should be kept in case additional splicing is required in the future.
- e) Depending on the environmental conditions, a tent may be required in order to provide appropriate conditions for performing fiber optics splicing.
- f) Follow the manufacturer's connection diagrams and double check all splices and connections. It is possible to cross the fibers and cables between the primary sensor and secondary converter and have the system appear to work normally, however there may be calibration errors and the system is likely to malfunction in the future.
- g) A methodology should be in place for measuring the integrity of fiber optic splices. This data should be recorded as part of the installation report.
- h) If applicable, ground the metallic armor of the fiber optic cable in the control room using appropriate grounding connectors.

9.3.3 Electrical installation

These items should be considered as part of the electrical installation:

- a) Electrical contractors should verify that the site is ready.
- b) The cable-management box should be mounted and feeder/trunk cables run and copper terminations completed.
- c) Follow the manufacturer's instructions with respect to grounding of cables between the outdoor primary equipment and the secondary converter.
- d) Secondary connections should comply with manufacturer wiring diagrams.
- e) Adequate airflow should be provided to the secondary converter electronics to avoid overheating and shortened life expectancy.
- f) If applicable, the alarm contacts or SCADA interface for reporting failures should be connected to the central monitoring system.

9.3.4 Column installation

These items should be considered as part of the column installation:

- a) Handling procedures for optical columns are different from those for conventional instrument transformers. It is important to review unpacking and lifting instructions prior to uncrating the columns.
- b) The columns used for most optical systems can be laid down horizontally and stored horizontally indefinitely.
- c) Do not attempt to disassemble any part of the optical system unless the manufacturer's instructions indicate it is safe to do so. Removing or disassembling the optical sensor may cause irreparable damage to the sensor.
- d) If applicable, the pressure switch alarm contacts should be connected to the central monitoring system.
- e) Care should be used to ensure the columns are installed in the correct order (phase A, B, C). The mating between the primary sensor/column and the secondary converter is important for calibration and columns should not be interchanged without following the manufacturer's instructions.
- f) If the columns are installed with the wrong polarity, it may be possible to change the polarity through the human-machine interface software and avoid having to move the columns or change the secondary wiring.

9.4 Post-installation

If the optical system has human-machine interface software, the software should be used to perform the following:

- a) Verify there are no system alarms.
- b) Save a copy of the system event log.
- c) Save system diagnostic information such as health-monitoring parameters for long-term analysis of the system performance.
- d) Save a copy of the system configuration.

If the optical system has alarm contacts or other means of reporting failures to a central monitoring system, the reporting mechanism and response of the central monitoring system should be tested to verify that failures and degradations are detected and reported appropriately.

If the optical system is to be used for revenue metering and local government regulations require sealing, verify the system is sealed (either physically or through acceptable electronic means) and that none of the settings related to output accuracy can be modified.

For more information on post-installation testing, refer to [Clause 10](#).

10. Testing of optical instrument transformers

Optical instrument transformers consist of four subassemblies: phase column, electronics module, fiber optical cables, and connectors. These four components need individual testing, either during commissioning or during regular maintenance.

The standard method for verifying the accuracy of an optical sensor is the same as that used for conventional CTs and PTs: a primary injection test with accurate measurement of the output using accurate instruments, or the relays and meters connected to its outputs. In general, such injection testing is used only during commissioning or maintenance. However, for accuracy testing of instrument transformers, a high-precision reference-measurement transformer should be used.

There are four types of recommended testing:

- Factory testing
- Testing after receiving at user site
- Testing at commissioning
- Additional tests on site

Factory testing is conducted according to either IEC 60044-7, IEC 60044-8, ANSI/IEEE Std C57.13, or IEEE Std 1601. Depending on customer's specifications, special tests such as at extreme temperatures may be conducted at the factory or special test facilities. ANSI/NCSL Z540-1 can provide more information on calibration and uncertainty requirements of the test circuit elements.

At the user's site, it is recommended to test the optical instrument transformers before erection. A simple test may consist of measuring attenuation of the optical path to verify that the unit was not damaged during transport.

During the commissioning of an optical instrument transformer, the optical losses of fibers are typically measured along with the losses of the optical columns using, for example, a hand-held optical power-loss meter. The steps may be as follows:

- Measure losses of cables
- Measure losses of column itself
- Measure losses of the whole system

These measurements should be within the factory test data provided by the manufacturer. After connecting the fibers with the optical columns and the electronics, the entire optical path loss, including connectors, are measured by the optical instrument transformer's electronics itself. If both measurements are within acceptable levels as per manufacturer's information, the commissioning has been successful.

The user (or a regulatory authority) may require regular maintenance intervals and/or in situ accuracy verification, e.g., every five years. Primary injection with some vendors' optical current transformers may be easier than for conventional CTs; the injected primary current can be lower than the rated primary current due

to the linearity of the current sensing effect (e.g., the Faraday effect). A major benefit for utilities is the use of lighter and more compact primary source current generators. The effective transformation ratio of the optical CT may be changed on site via software so that a lower primary current injection can be used to achieve target output signal levels.

Figure 15 shows an example circuit for testing an optical CT using primary injection and comparison with a portable reference CT. As an example, a simplified set of steps for in situ accuracy measurement of optical CTs are provided as follows:

- Disconnect instrument transformer (may not be necessary for some devices) from the line.
- Connect the primary terminals to a test loop in conjunction with a high-precision reference CT and a power supply.
- Inject current in the loop and compare the output of the reference CT with the optical CT by means of a voltage or current comparator.

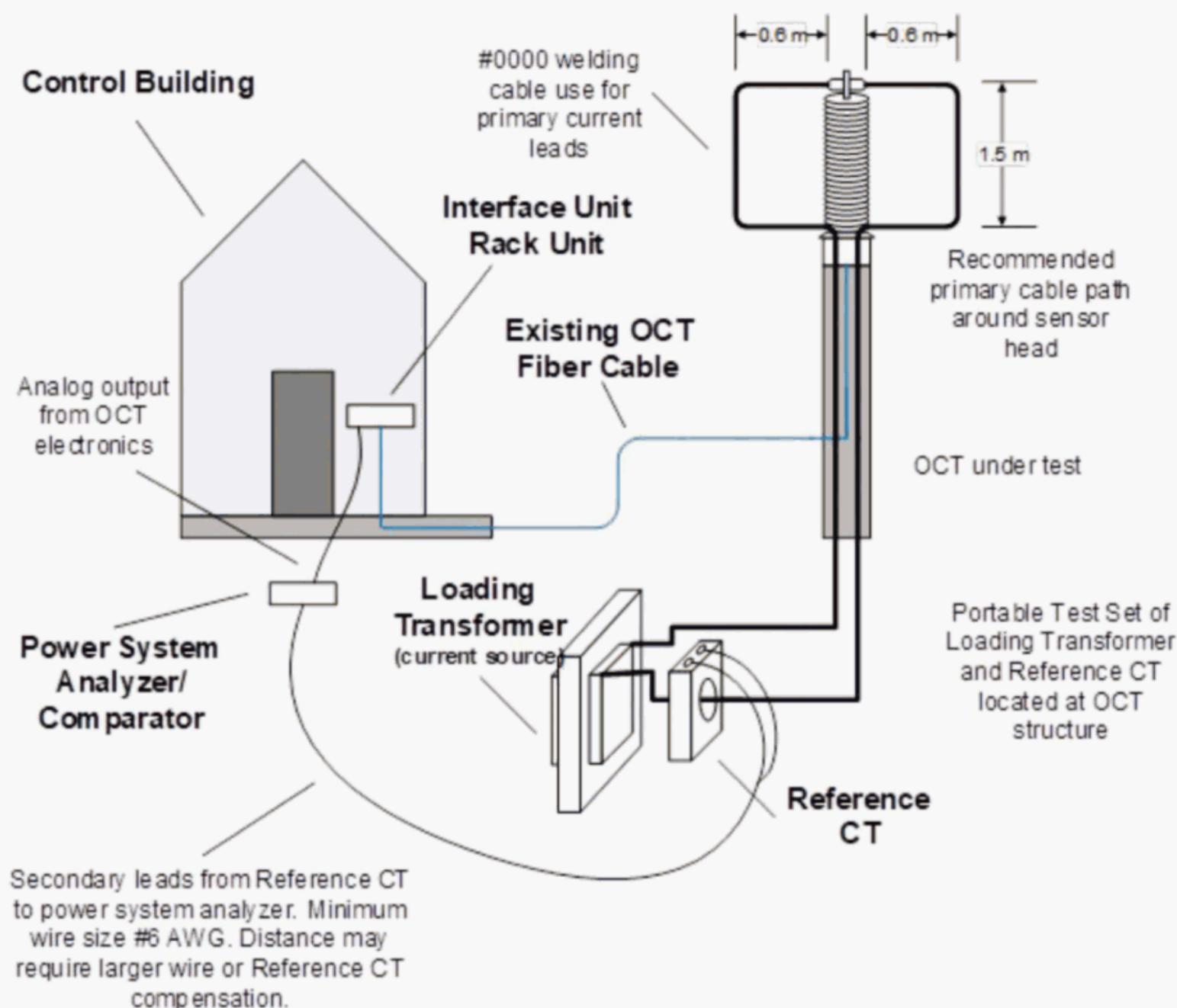


Figure 15—Example: Accuracy testing for an optical CT using primary injection and comparison with a portable reference CT

Use of high-quality power supplies for current or voltage injection can improve results of accuracy measurements. In cases where power is used from the substation ac supply, the waveform may not be a clean power-frequency sinusoidal and cause difficulties for comparing the output of the device under test and the reference instrument transformer, depending on the bandwidth of the reference instrument transformer. A calibrated signal generator with nicely filtered power frequency (typically 60 Hz or 50 Hz) sinusoidal signal may provide improved results.

Some optical instrument transformers with electronic interfaces have user access ports that permit the user to read primary values, even when no relay or meter is connected. This is helpful for initial checks and for troubleshooting measurement problems.

Subsystems of some optical instrument transformers can also be verified with procedures specified by the manufacturer of the particular device.

Examples of test and maintenance features in commercial optical sensors include the following:

- Self-monitoring of optical light levels, light source drive currents, internal chassis power supply voltage levels and temperatures. Parameters are logged automatically at startup for future comparison. These include automatic measurement of fiber cable length and optical losses of each channel. An alarm is raised for problems.
- Sensor electronics test mode generates an internal digital signal (50 Hz or 60 Hz) representing rated current or voltage. This data stream is passed through the sensor's analog-to-digital converter if IEEE Std C37.92 interface is used or through the merging unit interface if IEC 61850-9-2/61869-9 is used. The user checks the relay or meter reading to see if the rated secondary value is being received.
- Sensor electronics store trends of key sensor parameters for analysis.

IEEE Std C37.233™ provides more information for testing power system protection systems and may be helpful to determine additional tests when optical instrument transformers are used as part of a protection system.

11. Reliability and redundancy

11.1 Reliability

An optical current and voltage-sensing system provides information for protective relaying to respond during system events. When compared to traditional iron-core voltage and current transformers, the output signals from optical devices are typically generated using electronics operating in both high-voltage and low-voltage environments. As these signals are conditioned in some manner, the designer has to provide sub-systems containing both electronic and optical components. The portion of the sub-systems that provides digital output as prescribed in IEC 61850-9-2 is also called the merging unit (MU).

Control systems are nominally designed to provide long life and to reduce life cycle problems. It is important that the manufacturers and users help prevent problems with the overall optical system by applying good engineering, design, alarm monitoring, installation, and preventive maintenance practices.

For an optical current or voltage-sensing system (see [Figure 16](#)), there are typically four main components:

- Sensor phase column assembly
- Interconnection wiring and fiber optics
- Ground-level electronics, including signal conditioning, output ac driver electronics circuitry, and the merging unit for digital outputs
- Fiber optic and wire ground-level connectors

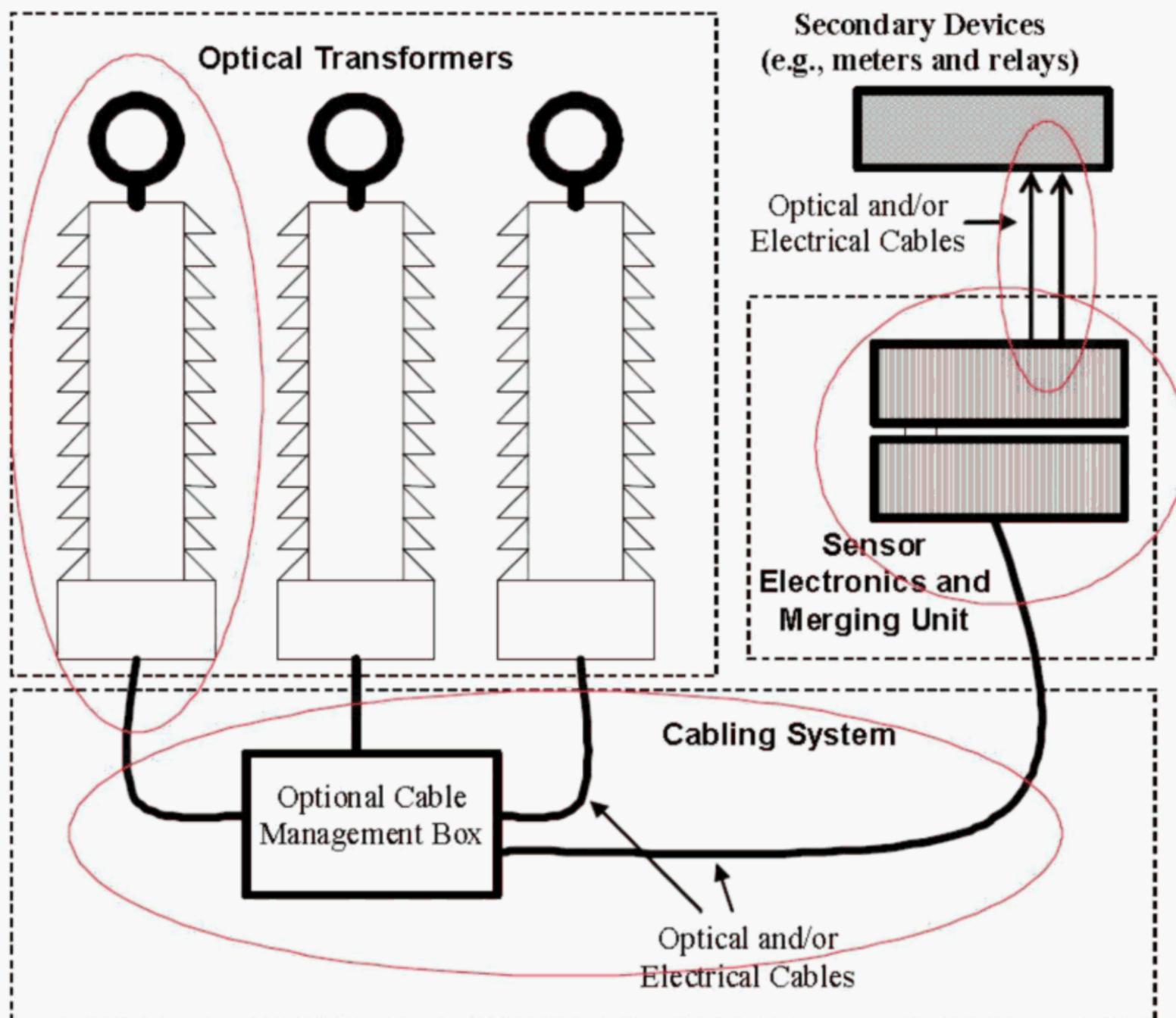


Figure 16—Schematic of a typical optical sensor system

Each of these components can be assessed for their likelihood of having problems by creating a list of all the items that can become non-functional, or would result in poor performance of the current or voltage sensors' output. The problems can be assessed on both the individual components and the complete current and voltage-sensing system.

Each of the following components may have one or more of the following failure modes:

- a) Sensor phase column assembly
 - 1) Reduced dielectric withstand due to surface contamination/leakage current
 - 2) Loss of gas pressure (if incorporated into the design)
 - i) When gas is an integral part of the insulation design, loss/leakage of gas directly translates to lower dielectric performance (lower high-voltage withstand) for the column assembly.
 - ii) If the gas is used solely for seal indication (e.g., sealing moisture out), then the loss of pressure may not affect the immediate dielectric withstand. Losing the seal may allow moisture ingress over time and reduce dielectric performance.
 - 3) Corrosion of components

- 4) Damage to optical components (loss of optical continuity)
- b) Interconnection wiring and field cables
 - 1) In practice the mean time between failures (MTBF) of the passive optical fibers are so long that they are difficult to ascertain. Optical fiber itself has historically achieved reliabilities equivalent to an MTBF of tens of thousands of years. In an all fiber design, failures are commonly attributed to workmanship at the installation. Poorly spliced fiber is typically detected (alarmed) within a matter of days to weeks of field installations when properly monitored. In general, this type of failure is not expected, and if a failure does occur, the solution is typically to repair the connection on site. Also, this type of failure is usually observed and resolved during the installation and commissioning.
 - 2) Excavation damage.
 - 3) Water ingress into cable assemblies or ducts (and ice formation).
 - 4) Rodents: rodent-resistant cable jacketing is typically used.
- c) Ground-level electronics, including signal conditioning and output ac driver electronics circuitry
 - 1) Cooling fan/ventilation system degradation or failure causing overheating of electronics (if incorporated into the design). Use of mechanically moving parts (e.g., rotating fans) is generally considered to be a reliability concern.
 - 2) Extreme temperatures (e.g., if electronics are outdoors) accelerate component aging and reduce MTBF values.
 - 3) For protection and metering applications, a separate amplifier may be used to provide a conventional 1 A output. The amplifier has its own failure modes including power supply and output amplifier failure. The amplifier may monitor its own power supply and amplifier output and may include alarm outputs for connection to SCADA for remote indication.
 - 4) Sensor's optical source (LED or laser) may be chosen and used in a manner to have very high reliability (and long MTBF). Choosing a very reliable light source is a key part of designing a reliable optical sensor system; and designing a reliable temperature and drive current control circuitry for the light source is at least as critical as the quality of the light source itself.
- d) Fiber optic and copper ground-level output cables connected to protective relaying and metering equipment including those digital output signals for IEC 61850 process bus. Output cable construction may be different depending on the output signals from the sensors.
 - 1) Excavation damage.
 - 2) Water ingress into cable assemblies.
 - 3) Rodents.
 - 4) Length and loading of the electrical output cables should be chosen to comply with output load-handling capability of the electronic chassis. Generally, for low-voltage outputs, shielded twisted-pairs should be used.

In addition to known failure modes, an optical current and/or voltage-sensing system most likely does not cause a catastrophic event, such as the following:

- Oil leaks
- Fire
- Explosion
- Inadvertent opening of the CT secondary circuit
- Damage due to high electromagnetic forces

Self-monitoring functionalities routinely provided in optical sensors are a key factor in improving reliability of the overall protection system. These facilities are capable of issuing a signal when the performance of the sensor becomes outside specification. The signal can be used to block protection systems depending on the sensor, as well as initiating an alarm.

Thus, if the sensing system is not performing within specification, the associated protection system(s) may also be prevented from performing within specification. Applications that include blocking of protection systems may also need to consider the redundancy issues discussed in [11.2](#).

As part of commissioning testing, performance of the electronics and/or primary installation are often examined to determine whether there is any offset of the voltage recorded, and/or whether there is any “railing” of the voltage at a very high values. Also, when the voltage and current units are de-energized without grounds installed, the voltage induction on the bus may be examined to verify whether the output of the voltage function electronics oscillate, and also the magnitude of any oscillations. If the design of the electronics includes a cutoff value in the detection circuits, tests should be conducted to determine performance and impact to the application.

11.2 Redundancy in an optical sensing system

Redundancy is also an important consideration in the selection and deployment of an optical sensing system. Many systems have the ability to have multiple sensing fibers in a single sensor column (multiple sensors per phase). The redundant sensor fibers can either go to a single secondary converter with redundant sensor electronics, or to redundant secondary converters. Having multiple secondary converters is somewhat analogous to having multiple secondary taps feeding primary and secondary protection relays. In addition, the modern sensing system has many advantages over conventional VTs and CTs in the form of self-supervision capability and alarms which should lead to lower mean time to repair (MTTR) and consequently increase availability. The degree of redundancy required depends on many factors such as application area (bulk power system versus sub-transmission or distribution), the criticality of the application (what are the consequences if there is a failure, what backup protection is available), economic considerations, etc.

As redundancy has to be considered for the protection system as a whole, the discussions in the IEEE PES Power System Relaying and Control Committee report are valid for optical sensing systems as well. (IEEE PSRC [\[B3\]](#)).

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] Andersson, L., K.-P. Brand, and C. Brunner, "Optimal migration to IEC 61850-9-2 based non-conventional instrument transformers," PowerGrid 2008, Milano, Italy, June 3–5, 2008.

[B2] IEC 62439-3 Industrial Communication Networks—High Availability Automation Networks—Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR).⁹

[B3] IEEE PSRC Working Group I19, Report: Redundancy considerations for protective relaying systems, 2010.¹⁰

[B4] IEEE Std 802.1Q™, IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks.^{11,12}

[B5] IEEE Std 1138™, IEEE Standard for Testing and Performance for Optical Ground Wire (OPGW) for Use on Electric Utility Power Lines.

[B6] IEEE Std 1222™, IEEE Standard for Testing and Performance for All-Dielectric Self-Supporting (ADSS) Fiber Optic Cable for Use on Electric Utility Power Lines.

[B7] IEEE Std 1591.1™, IEEE Standard for Testing and Performance of Hardware for Optical Ground Wire (OPGW).

[B8] IEEE P1591.2–2017, IEEE Approved Draft Standard for Testing and Performance of Hardware for All-Dielectric Self-Supporting (ADSS) Fiber Optic Cable.

[B9] IEEE Std 1591.3™-2011, IEEE Standard for Qualifying Hardware for Helically-Applied Fiber Optic Cable Systems (WRAP Cable).

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[B11] ISO/IEC 8802-3 Information Technology—Telecommunications and Information Exchange between Systems—Local and Metropolitan Area Networks—Specific Requirements—Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications.¹³

[B12] ISO/IEC 8824-1 Information Technology—Abstract Syntax Notation One (ASN.1): Specification of Basic Notation.

⁹IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch>) and the American National Standards Institute (<http://www.ansi.org/>).

¹⁰Available: <http://www.pes-psrc.org/>.

¹¹The IEEE standards or products referred to in Annex A are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

¹²IEEE publications are available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

¹³ISO publications are available from the International Organization for Standardization (<http://www.iso.org/>) and the American National Standards Institute (<http://www.ansi.org/>).

[B13] ISO/IEC 8825 Information Processing Systems—Open Systems Interconnection—Specification of Basic Encoding Rules for Abstract Syntax Notation ONE (ASN.1).

[B14] Rahmatian, F., J. Blake, C. Glasow, D. F. Peelo, G. Polovick, and B. Sunga, "Application of optical AC and DC current sensors in EHV compensation systems," CIGRE SC A3 Colloquium, Rio de Janeiro, Brazil, paper PS3-1, Sep. 12-13, 2007.¹⁴

[B15] Rahmatian, F. and D. F. Peelo, "Use of Optical Instrument Transformers for High-Voltage Testing," CIGRE General Session 43, paper A3-301, Aug. 23-27, 2010.

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¹⁴CIGRE publications are available from the Council on Large Electric Systems (<http://www.e-cigre.org/>).

Annex B

(informative)

Industry standards

B.1 Overview

There are a couple of national and international bodies involved in activities in the area of electronic current transformers (CTs) and voltage transformers (VTs) including their interfaces. For details and abbreviations, see [B.2](#) through [B.5](#). In particular, these bodies are:

- Working groups of IEC TC38 and IEC TC57
- Working groups of IEEE PES-PSRC and PES-PSIM
- Working groups of CIGRE SC A3
- UCAInternational Users Group

[Table B.1](#) provides an overview on these activities (a document in *italics* is a guide or a report; the other documents are standards).

Table B.1—Overview of standards and guides related to optical sensor systems

Scope Standards body	1	2	3	CT/VT product aspects	Interface	Application of CT/VT
IEC TC57	x	x	x		IEC 61850 (mostly IEC 61850-7-2 and IEC 61850-9-2)	
IEC TC38	x	x	x	IEC 60044	IEC 60044-8	
IEC TC38	x	x	x	IEC 61869	IEC 61869-9 and IEC 61869-13	
IEEE PES PSRC		x	x		IEEE Std C37.92	
IEEE PES PSRC	x					IEEE Std C37.110
IEEE PES PSRC			x			IEEE Std C37.241 (this guide)
IEEE PES TXFR	x			IEEE Std C57.13		
IEEE PES PSIM	A.	B.	C. x	IEEE Std 1601 1601	IEEE Std 1601	IEEE Std
CIGRE SCA3/B5		x	x	A3.15,A3.31	A3.15,A3.31	B5.24
UCAIUG	x	x	x		Guide (“61850-9-2LE”)	

1: conventional CT/VT
2: electronic CT/VT
3: optical CT/VT

B.2 IEC—International Electrotechnical Commission

IEC prepares international standards for electrical, electronic, and related technologies.

IEC consists of technical committees (TCs). TCs of relevance in the context of this guide are:

- TC38—Instrument transformers

- TC57—Power systems management and associated information exchange
- TC95—Measuring relays and protection equipment

TC57 has prepared the international standard IEC 61850, which is applicable for the information exchange between all devices within a substation.

TC38 is preparing the international standard IEC 61869 as a replacement of the former IEC 60044. This standard is basically a product standard. As part IEC 61869-9, the implementation requirements on the digital interface are specified based on IEC 61850. It is intended that this part incorporates the guideline issued by the UCA International Users Group. Other factors under consideration for inclusion in IEC 61869-9 are:

- Use of IEEE Std 1588 for synchronization
- Various time-synchronization issues
- Other collections of data (other data set than that specified in the UCA Guide) for current- and voltage-measurement data to be included in the message
- Reference frequency response profiles for certain applications (including protection relaying)

Also, IEC 61869-13 covers the standalone merging unit, which has the same output interface as the merging unit defined in IEC 61869-9, and further has standard inputs (1 A/5 A/100 V traditional signals) with specific performance requirements.

B.3 IEEE—Institute of Electrical and Electronic Engineers

IEEE develops global industry standards in a broad range of industries including power and energy. IEEE standards are typically used in the ANSI market.

IEEE consists of societies, which again are structured into committees. The IEEE society for the power industry is the IEEE Power and Energy Society (PES). The following committees of PES are of relevance in the context of this guide:

- PSRC: Power Systems Relaying Committee
- PSIM: Power Systems Instrumentation and Measurement

IEEE Std C37.92 was prepared by PSRC and covers a number of performance parameters (e.g., accuracy, bandwidth, noise level, etc.) as well as low-energy analog interface (< 10 V) relevant to optical instrument transformers to be used for relaying applications.

IEEE Std 1601 was prepared by PSIM (in collaboration with IEEE PES Transformers Committee, Instrument Transformers Subcommittee) and specifically covers all aspects of optical CTs and VTs. IEEE Std 1601 uses significant reference to IEEE Std C37.92, IEEE Std C57.13, IEEE Std C57.13.5, and IEC 60044-7/8 as appropriate.

B.4 CIGRÉ—International Council on Large Electric Systems

CIGRÉ is a leading worldwide organization on electric power systems. It facilitates the exchange of engineering knowledge and information for generation and high-voltage transmission of electricity. It further synthesizes state-of-the-art and world practice. CIGRÉ does not publish standards. The reports published by

CIGRÉ are very often related to the application of new standards, or are summarizing requirements for future standards.

CIGRÉ consists of study committees. The following study committees are of relevance in the context of this guide:

- A3: High-voltage equipment
- B5: Protection and automation

SC A3, Working Group 15 (WG15) prepared a report “Non-conventional instrument transformers.” This report consists of two parts. Part I—primary sensors, explains the fundamental physical aspects of the different technologies, the influencing parameters, and discusses benefits and limitations. Part II—communication, gives an overview on the different analog and digital interfaces, discusses requirements for a metering system, and discusses system aspects. A separate part on testing of NCITs (Part III—testing and calibration, discusses accuracy measurement, verification of the calibration on site, and EMC tests) is a subject of a new working A3.31.

CIGRÉ SC B5 initiated WG B5.24 to work on “Protection requirements on transient response of voltage and current digital acquisition chain.” The static accuracy of a complete measuring chain is well defined by different IEC/IEEE and other standards, while the lack of clear definition for dynamic response represents a potential threat for the required high availability of protection functions. This working group has targeted to determine the minimum requirements on transient response of a complete signal-processing chain, including all merging units and non-conventional instrument transformers. The working group’s efforts have resulted in the creation of a set of “frequency mask” requirements in IEC 61869-6/9 for low-power (non-conventional) instrument transformers, helping define the performance of the measuring system over frequency.

B.5 UCA International Users Group

UCAInternational Users Group is the users group for IEC 61850 and other industry standards. The goal of the UCAInternational Users Group is to support users of IEC 61850.

A working group of the technical committee has prepared the “Implementation guideline for digital interface to instrument transformers using IEC 61850-9-2.” The scope of that guideline is to define a minimum set of functionalities existing in IEC 61850-9-2 that should be used by the first implementations of manufacturers of instrument transformers with a digital interface. It is also widely referenced as IEC 61850-9-2 LE (“Lite Edition”). Most of the content of this guideline is being integrated into Standard IEC 61869-9.

Consensus

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