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Optical voltage and current instrument transducers for Digital Substation applications

Replacement of conventional equipment is a must

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Development of Smart Grids and Digital Substations –
how these changes will affect substation infrastructure?

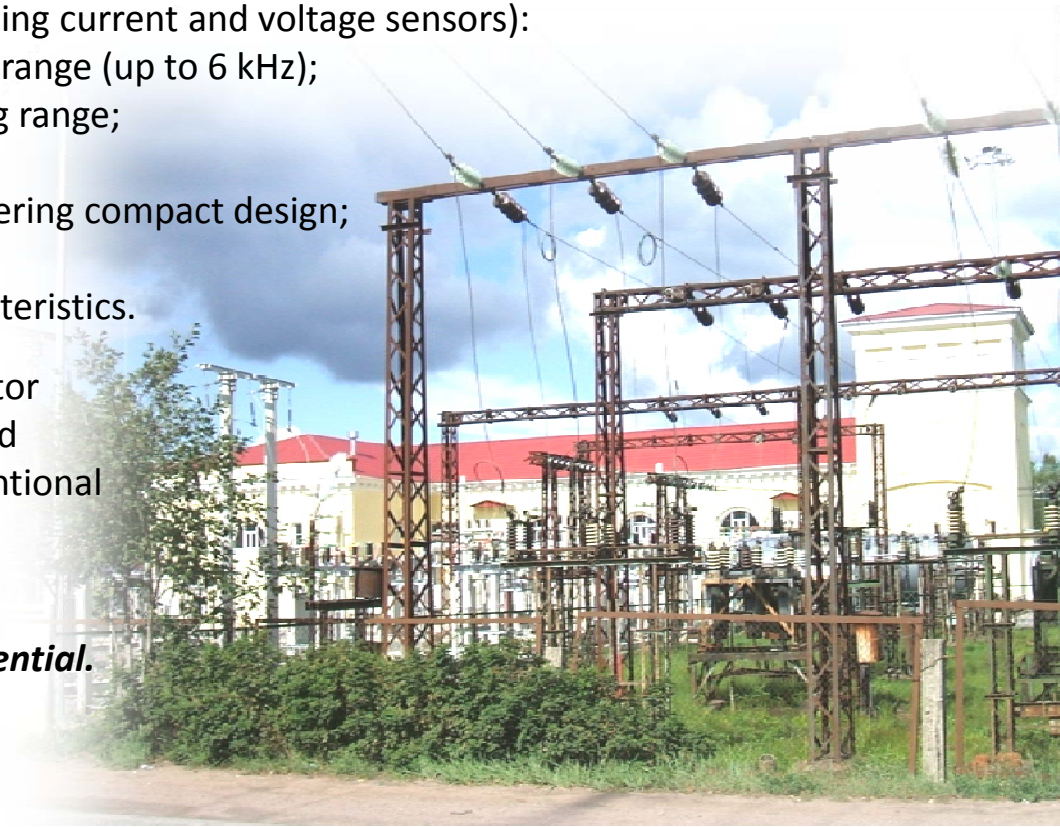
Conventional analogue-type systems (current and voltage transformer installations, meter reading systems, protection and automation systems etc.) will need to be replaced with digital alternatives.

Basic requirements for digital equipment (including current and voltage sensors):

- High speed of operation; extended frequency range (up to 6 kHz);
- Excellent overload capabilities; wide operating range;
- No effect of short-circuits;
- High-performance electrical insulation considering compact design;
- Light weight; simple installation;
- Excellent fire protection and ecological characteristics.

Current sensors of Rogowsky or magnetotransistor type and voltage sensors based on capacitive and resistive dividers are good alternatives to conventional transformers (mainly to electromagnetic ones).

However, it is sensors of optical type that have been recognized as having the best market potential.



Implementation challenges of optical transformers (especially rated below 35 kV)

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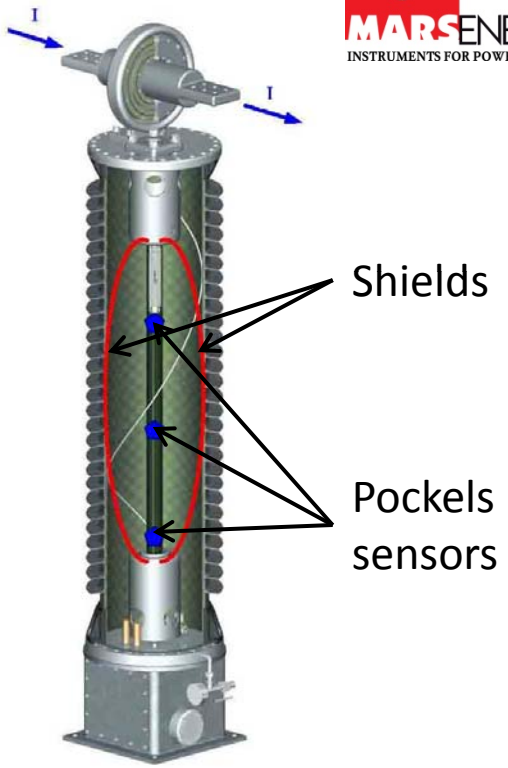
High production cost of optical voltage transformers (based on Pockels effect) resulting from some technical and technological issues considerably limits their wide use.

Despite this fact, optical voltage transformers rated at 110 kV have already become commercially available. This can be explained by balancing of their initially high cost by lower costs of installation (compared to conventional VTs).

However such a benefit may only be achieved at a level of 110 kV or above.

That's most likely why optical transformers rated at 35 kV (or below) have not gained a widespread use in electric energy industry up to now.



Optical voltage instrument transformer
U_{nom} = 110÷750 kV

Magneto-optical instrument current transducer and electro-optical instrument voltage transducer

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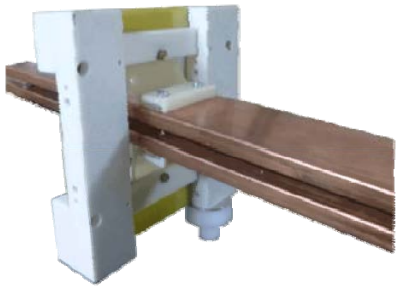
To bridge the gap, Mars-Energo has started development of an optical voltage transducer rated at 35 kV or below and optical current transducer that combine simple and compact design with reasonable price.
Here are the results:

Magneto-optical instrument current transducer
based on Faraday effect



Electro-optical instrument voltage transducer
based on effect
of electro-gyration

Magneto-optical instrument current transducer and electro-optical instrument voltage transducer

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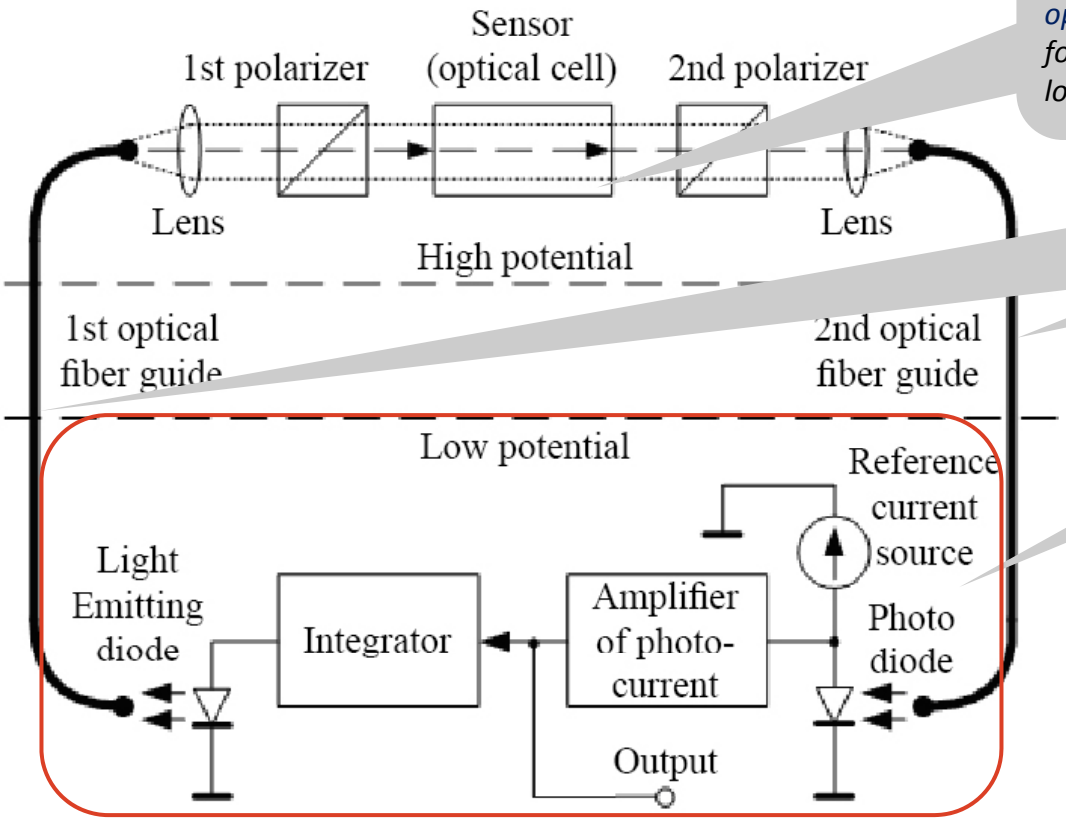
Block diagram of Universal Measurement Converter



Magneto-optical (Faraday) cell for current measurements or *electro-optical (electro-gyration) cell* for voltage measurements located on high-potential side

Two fiber optic guides provide

- Optical connection between optical sensors and electronic unit;
- Galvanic isolation between high-potential and low-potential sides

Electronic unit located on low-potential side

A simplified block diagram of the Universal Measurement Converter is shown in the figure. Depending on the optical sensor in use (magneto- or electro-optical cell), the Converter can be used for voltage or current measurements.

Measurement equipment of new generation
Magneto-optical instrument AC and Pulse Current Transducer MOT-ME-5

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Purpose

The purpose of the Transducer is to convert instantaneous values of primary (high) AC or pulse current into the proportional values of secondary (low) current or into SV (Sampled value) data. Based on magneto-optical (Faraday) effect, it consists of an optical sensor (Faraday cell) and optoelectronic unit.

Operating principle

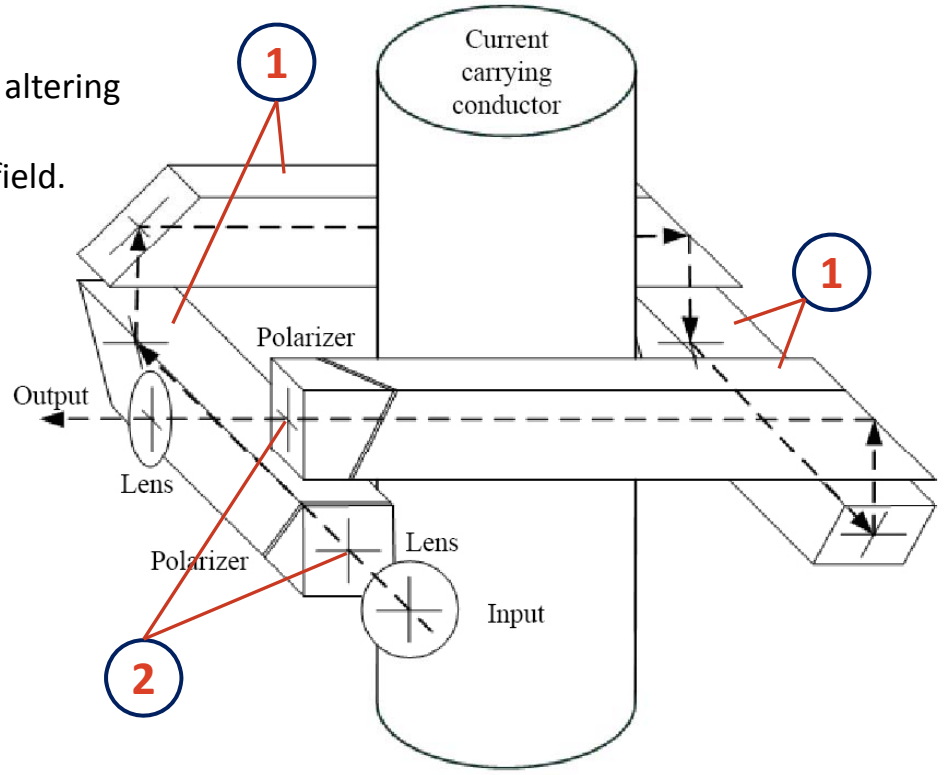
The Faraday effect is a magneto-optical phenomenon of altering the polarization plane of linearly polarized light when the light beam travels through a medium in a magnetic field.

Design:

1. *Four prisms* located in sequence along the optical path of the light make up an optical sensor. The prisms made of conventional diamagnetic glass form a close loop around the current carrying conductor.
2. *Polarizers* are integrated in the prisms.

Benefits:

1. Low noise level
2. Simple design of optoelectronic unit



Faraday cell

Measurement equipment of new generation

Magneto-optical instrument AC and Pulse Current Transducer MOT-ME-5

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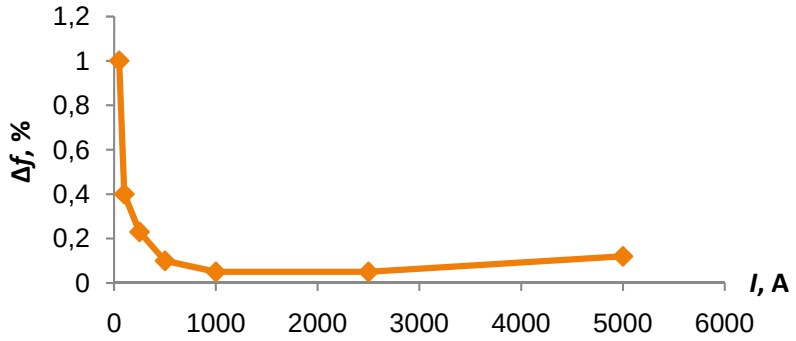
Specifications of the prototype

Current measurement range	0.1 …6 kA with permissible short-term overload of 100 kA
Operating frequency	1 Hz … 10 kHz
Ratio measurement error, Δ*f*	0.2…0.5 %
Angle measurement error, Δδ	2’

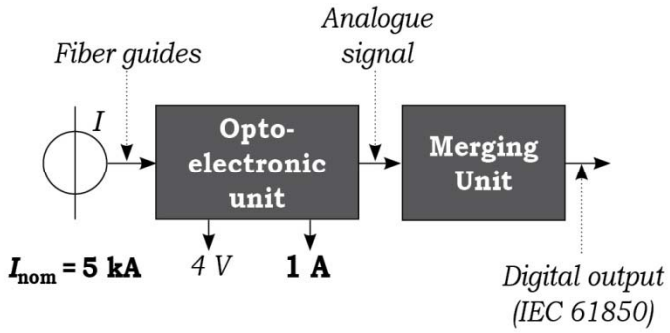
Preliminary test results

Tests were carried out in the lab (under calibration conditions)

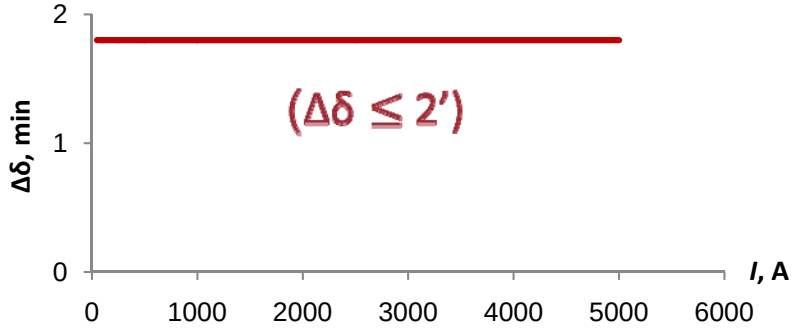
Ratio error



Block diagram of Current Transducer



Angle error



Measurement equipment of new generation

Magneto-optical instrument AC and Pulse Current Transducer MOT-ME-5

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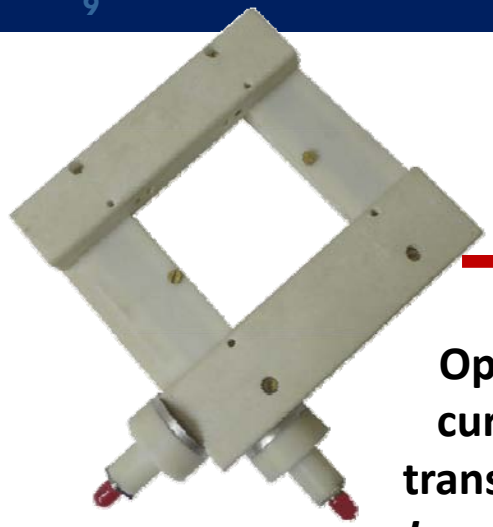
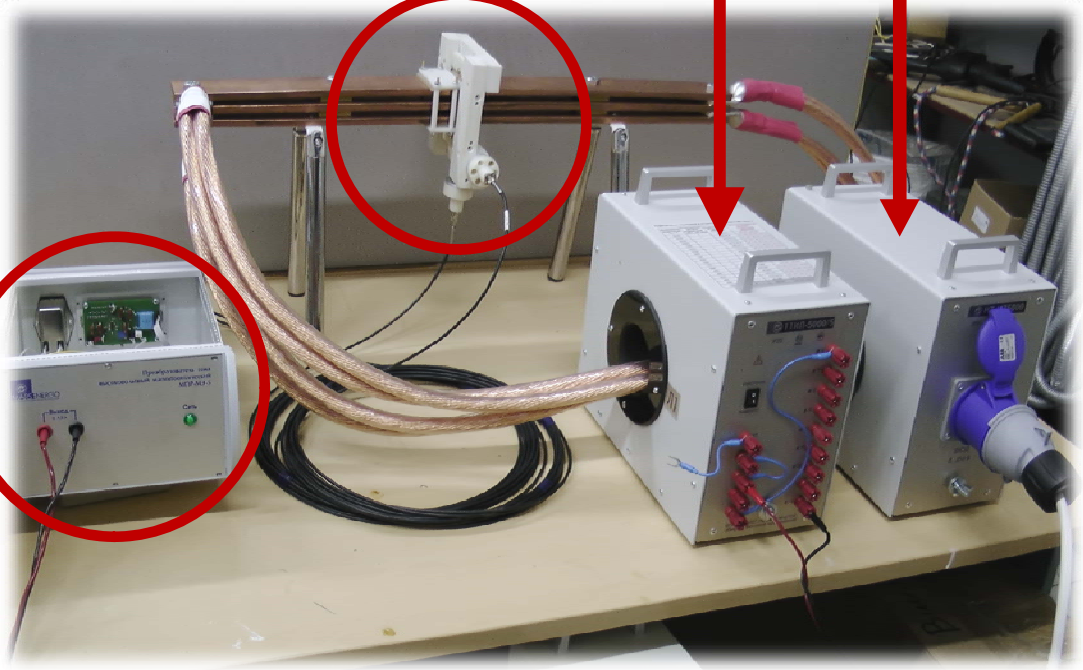


Reference current transformer

Source of current

Optical current transducer I_{nom} = 5 kA

Optoelectronic unit



Measurement equipment of new generation

Electro-optical instrument AC and Pulse Voltage Transducer ELT-ME-35, 100

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Purpose

The purpose of the Transducer is to convert instantaneous values of primary (high) AC or pulse voltage into the proportional values of secondary (low) voltage or into SV (Sampled value) data. Its operation is based on electro-optical effect of electro-gyration.

Operating principle

The electro-gyration effect is a phenomenon of a change in optical activity of centrosymmetric crystals under an external electric field induced by the measured voltage.

Workpiece for producing crystal of required length

Electro-optical effect of electro-gyration 50 years later

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History of discoveries

Longitudinal magneto-optic effect was discovered by Faraday

Linear electro-optic effect was discovered by Pockels

Effect of electro-gyration was discovered. It was almost simultaneously described by K. Aizu, Japan, and I.S. Zheludev, Russian Federation, and experimentally verified by O.G. Vlokh, Ukraine, in 1969

Electro-optical effect of electro-gyration 50 years later

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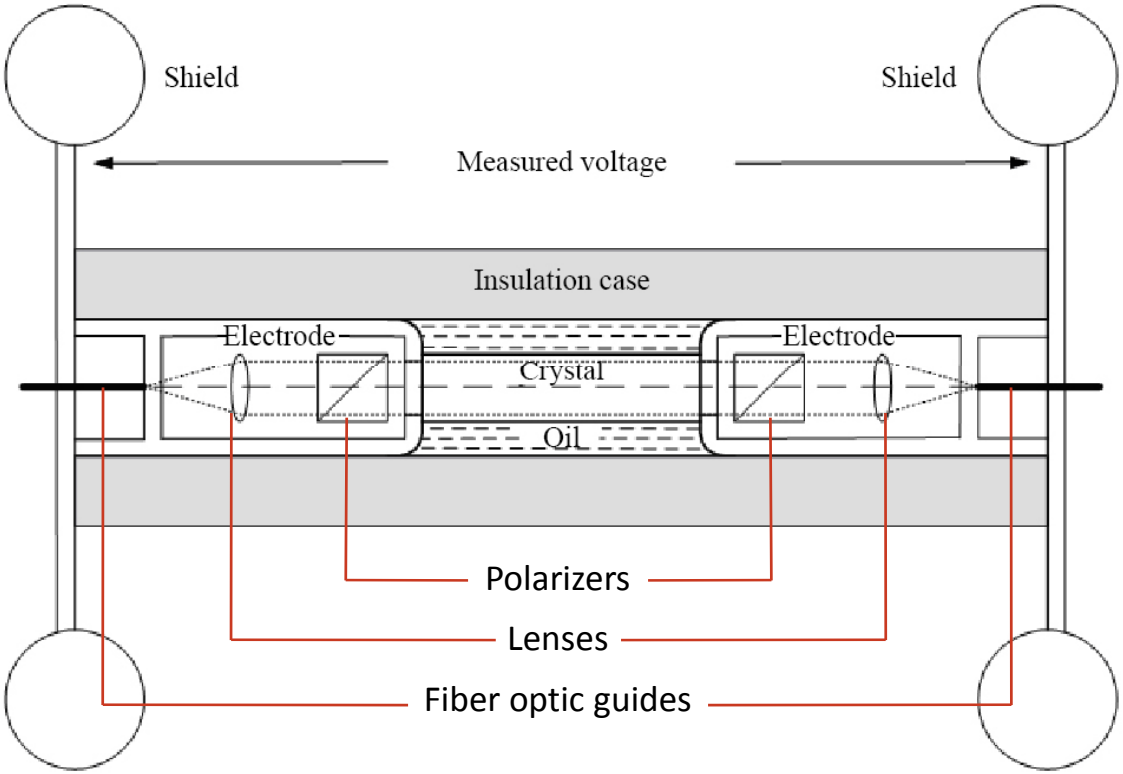
Electro-gyration effect (linear type) - electric-field induced excitation or change in optical activity of some crystals that causes rotation of polarization plane of linearly polarized light, propagating through the crystal, by an angle that depends on the strength of electric field, length of the light path in the crystal, and electro-gyration constant.



$$\varphi = G\int_1^2 \vec{E}d\vec{l} = G \times U$$

G — electro-gyration constant of the crystal;

$\vec{E}$ — vector of electric field strength;

$d\vec{l}$ — elementary part of the path on the interval between the electrodes

Measurement equipment of new generation
Electro-optical instrument AC and Pulse Voltage Transducer ELT-ME-35, 100

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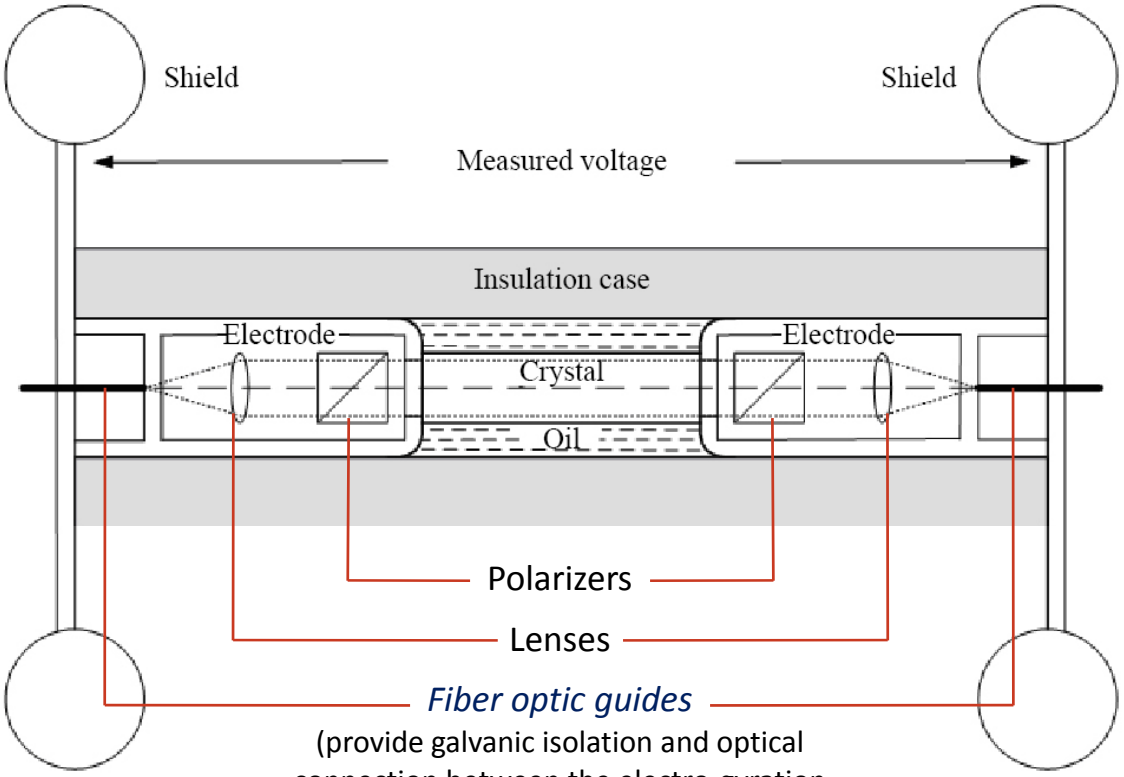
Design

- *Electro-gyration cell* – measured voltage is applied to its electrodes,
- *Electronic unit* – desired signal is taken from its output



Design feature:

Measured voltage is directly applied to the ends of a centrosymmetric crystal.

Design benefits:

1) Phase-to-phase voltage measurements;
2) No piezoelectric effect.

Measurement equipment of new generation

Electro-optical instrument AC and Pulse Voltage Transducer ELT-ME-35, 100

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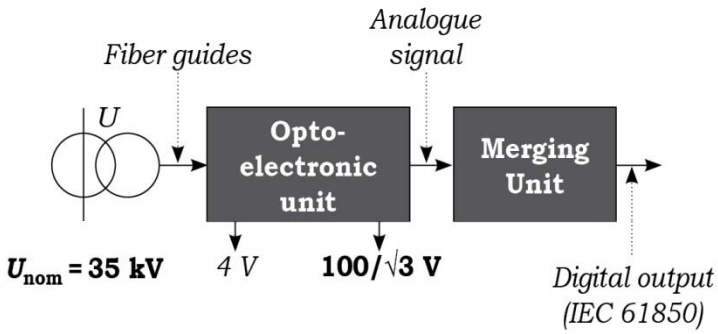
Specifications of the prototype

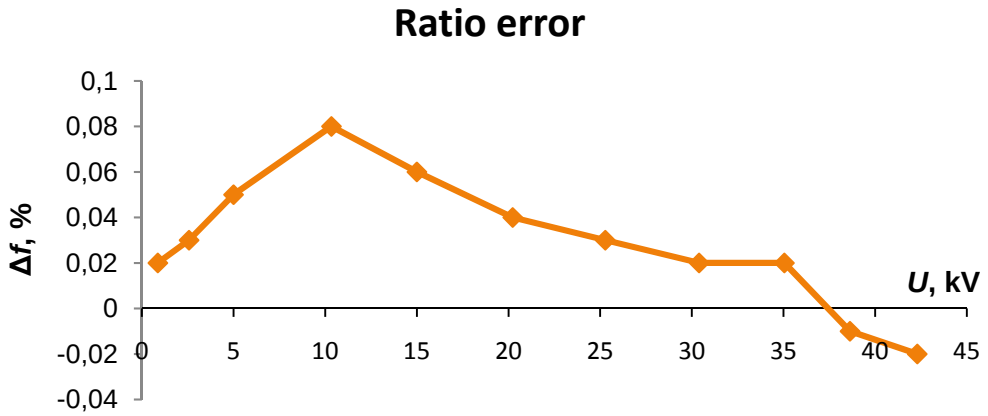
Nominal values of measured voltage	35; 110 kV
Operating frequency	1 Hz … 10 kHz
Ratio measurement error	0.2…0.5 %
Angle measurement error	2’

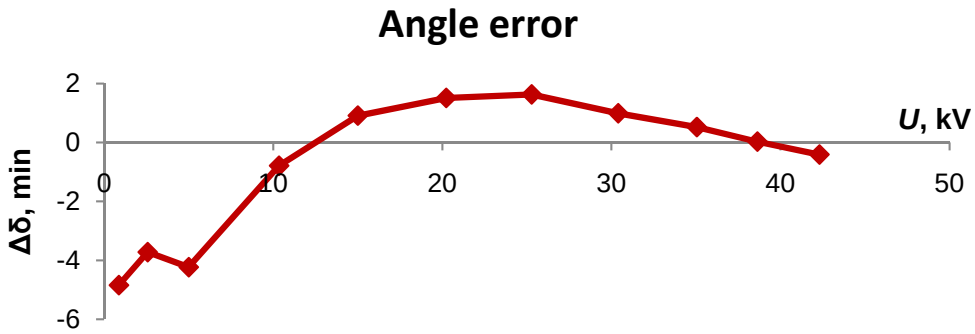
Block diagram of Voltage Transducer



Preliminary test results

Tests were carried out in the lab (under calibration conditions) on 30.04.2014





Measurement equipment of new generation

Electro-optical instrument AC and Pulse Voltage Transducer ELT-ME-35, 100

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Optical voltage transducer rated at 35 kV

Optoelectronic unit

IVT and ICT in digital substation environment

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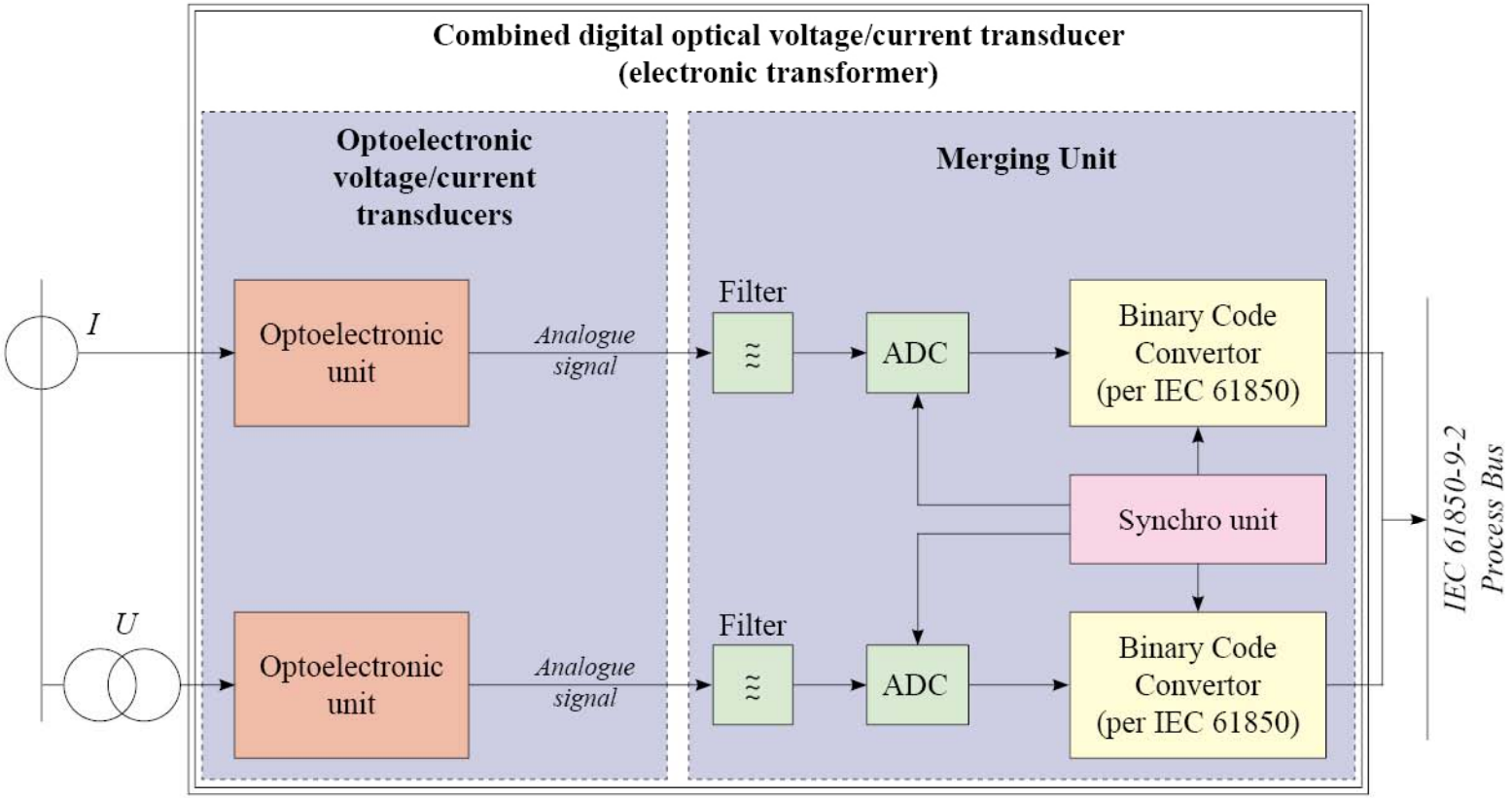

IEC 61850 Testing Tools
Testing of current and voltage transformers

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Test Set for testing of voltage and current transformers ETS 61850

Multifunctional reference meter Energomonitor 61850

High Voltage IVT Test Set

ICT Test Set

Transition from conventional (induction-type) instrument transformers to transducers of optical type

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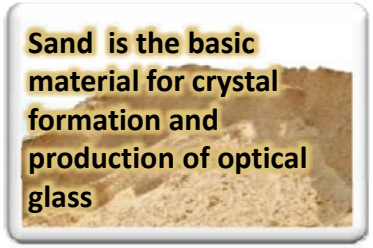
Review of changes in production technologies

Conventional instrument transformers

+ Large-scale production areas + Adverse effects connected with use of epoxy compounds + Production technology applied from the early 20th century = **Induction-type instrument transformers**

Optical instrument transducers



+ Electronic components + State-of-the-art processing technologies = **Optical instrument transducers**

Change in price over years

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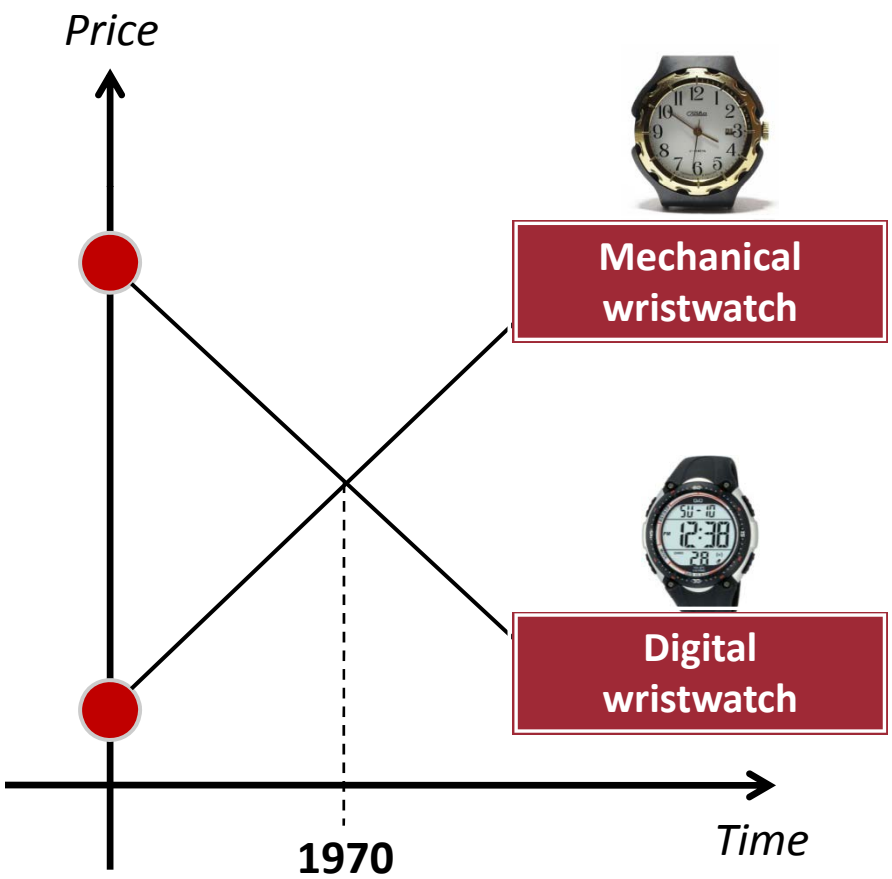

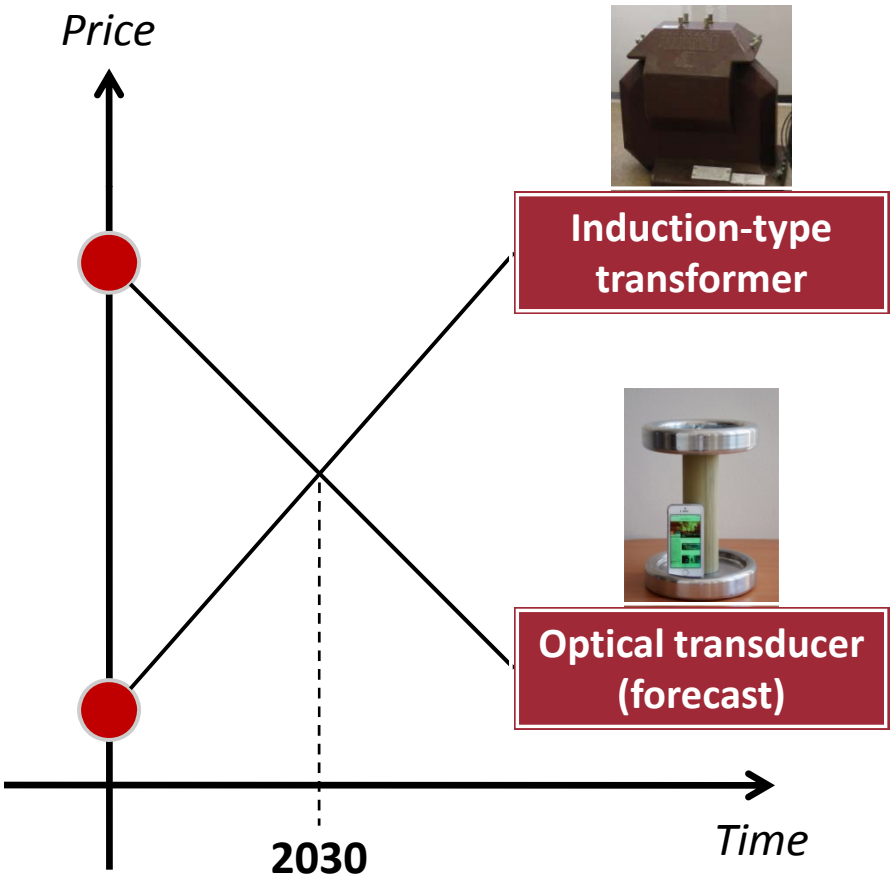

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