7TH INTERNATIONAL CONFERENCE ON ELECTROMECHANICAL AND POWER SYSTEMS
October 8-9, 2009 - Iaşi, Romania

IMPLEMENTATION OF THE OPTICAL CURRENT AND VOLTAGE TRANSDUCERS IN THE POWER SYSTEMS

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Abstract **– The purpose of this paper is to present the new types of the high voltage instrument transformers based on the optical principles. The need implementation in the power systems of the new measurement technology is required by the many disadvantages of the conventional transformer based on the electromagnetic principle and by the important progress in the secondary protection systems. In the same time the optical measurement technology corresponds to the UE imposed regulations, concerning the environment quality.**

Keywords: *power system, high voltage instrument transformer, optical principles.*

1. INTRODUCTION

The purpose of each power system is to maintain the continuity of the power delivery. The protection component of a power system ensure that the effects of a possible fault to be minimised or eliminated. The instrument transformers give access to the high currents and voltages within the grid, by supplying the protection circuits with low-level signals that ensure the proper operation of the protection systems. The most part of the instrument transformers installed up to now are conventional ones and, due to the electromagnetic linkage, they distort the signals in different stages. In order to avoid these aspects, there are two ways of action: the improving of the protection systems to become less sensible to the distortions, or the improving of the instrument transformers respectively. The second way ensure proper images of the primary signals.

This second approach can be fulfilled by the proper design of the instrument transformers, based on *the optical measurement of the current and of the voltage* [1] , [3], [4], [5], [6]. [7], [8].

The implementation of the new optical technology for the current and voltage measurement is a natural consequence of the European Union Regulations concerning the environment quality. These regulations concern not only the electromagnetic pollution, but also the pollution induced by the classical insulation technologies as oil and SF_6.

2. STEADY OF THE ART FOR THE MEASUREMENT COMPONENTS OF THE STATION'S DIAGRAMS

The measurement transformers are necessary within the power systems in order to ensure the vital information concerning the direct operational parameters (current, voltage, frequency) and the indirect ones (active power, reactive power, power factor etc.). This information is essential for the operation of these systems.

In the actual power systems, the manufacturing problems lied by the operation principle of the transformers include aspects given by: capability to support high dynamic stress (electro-dynamic forces, over voltages, over-currents); insulating systems and transmission of the signals to the ground potential; elimination of the influences of the disturbing electromagnetic fields.

In this context, the new technical solutions consist in placing the sensor within a proper structure, often heavy and space consumer. The weight of this infrastructure for the current and voltage sensors fundamentally depend on the operation principle of the sensor and on the interface. In other words, it depends on the way of obtaining, transmitting and on the devices implied in the treatment of this information.

In the classical power systems, the information on the "current" or on the "voltage" must have a consistent power support, in order to ensure the operability of the devices that treat the information [3]. In the modern power systems, the power of signals within the secondary circuits, as support of the information, was reduced dramatically, from tens of volt-amps to fractions of volt-amps. For manufacturing reasons, this reduction did not influence the sensors' infrastructure, especially in the case of the sensors for high and very high-voltage systems, where the insulation is very important. When a fault occurs in a power system, the

measurement of the current is a critical input for the protection relays that monitor the system. These current or voltage relays detect if the monitored area is affected or not by the fault and must be disconnected, or if the operation conditions are not perturbed and the area must rest connected in order to ensure the power distribution. An accurate image of the signals can improve the ability of the relay to disconnect correctly when it is needed and therefore, to prevent unnecessary disconnections.
During a fault, a well-known phenomenon occurs: the iron core of the conventional transformer saturates due to the high magnetic field produced by the high fault currents. This phenomenon impedes the correct representation of the primary current and consequently affects the measurement process. The problem is that all the conventional transformers are submitted to this phenomenon if their iron core is not over-dimensioned.
The mechanism for CT saturation depends on the physical design of the current transformer, the amount of steel in the “core” of the transformer, the connected burden, the winding resistance, the remanence flux in the iron core, the fault level, and the system X/R ratio (which can cause a larger DC offset to occur).
Taken together, these dependencies make the analysis of CT saturation complex.
The problem of CT saturation in iron core instrument transformers can be avoided altogether by using an optical current sensor. Optical current sensors contain no magnetic components and do not have any saturation effects associated with them.

3. THE OPERATION PRINCIPLE OF THE ELECTRO-OPTIC INSTRUMENT TRANSFORMERS

Following the using of the digital protection and control systems, the load of the conventional transformers was reduced and the elimination of the electromagnetic interferences becomes an essential demand. In these conditions, the development of the new measuring devices was considered as essential.
The optic sensors are inherently, different by the conventional iron transformers. They measure the primary current based on the optical effect of the electric current and so, offer a numeric image of the current. This signal must be then converted in the continuous form, possible to be amplified.
Therefore, instead of directly measuring the current or the voltage, the changes of the properties of certain materials, due to the surrounding electric or magnetic fields can be measured.
The unconventional measurement devices are based on the changes of the optic properties of certain materials placed in electric or magnetic fields: the Faraday effect, the Kerr effect and the Pockels effect. All the unconventional optical sensors are based on these effects that highlight the rotation of the polarization plan of the light that crosses the material [7].

3.1 Optical current transformer

An optical current transducerincludes the following components: a sensor arranged adjacent to a conductor through which flows the electric current to be measured, a light source for generating a measuring light, a detector for detecting the measuring light emitted from the sensor, a coupling optical system for optically connecting the sensor, the light source and the detector and a signal processing system for processing the signal transmitted from the detector.
The electric current flowed through the conductor by using a Faraday effect of light which passes through the sensor. The sensor is formed by an optical fiber, the optical fiber being wound around the conductor, and the two ends of the optical fiber being arranged to form a closed loop of the optical fiber.
Fig. 1 shows an example of an optical current transducer for a gas insulated switchgear [8].

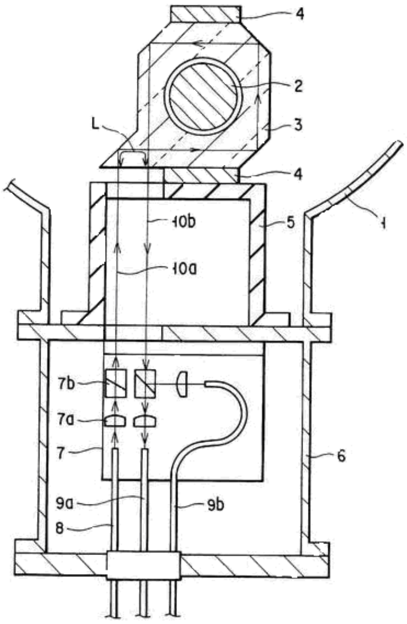

Fig.1 - Example of optical current transformer

The conductor (2) allowing a high voltage electric current to flow therein is included in a tank (1), the voltage of which is the ground potential. A block-shape sensor (3) made of lead glass or the like is disposed to surround the conductor (2), the sensor (3) being fixed by a fixing member (4). To enable the conductor (2) to permit a high voltage electric current to flow, the fixing member (4) of the sensor (3) is attached to the tank (1) through an insulating pipe (5) so that the fixing member (4) of the sensor (3) is insulated from the tank (1). A box (6) including an optical system is attached below the tank (1). The box (6) includes a coupling optical system (7), a light transmitting fiber (8) and two light receiving fibers (9a) and (9b).

The coupling optical system (7) comprises a lens (7a) and a polarizer (7b). The fibers (8), (9a) and (9b) are optically connected to the sensor (3) through the coupling optical system (7). The light receiving fibers (9a) and (9b) respectively receive light which has been, by the coupling optical system (7), divided into components linearly polarized into two directions perpendicular to each other to transmit the light components to a signal processing system.

Initially, light emitted from the light source is allowed to pass through the light transmitting fiber (8), and then introduced into the coupling optical system (7). Light is, in the coupling optical system (7), formed into a linearly polarized light (10a) in the form of a substantially parallel beam to propagate through a space in the insulating pipe (5). Thus, the linearly polarized light (10a) is incident on the sensor (3) made of the lead glass, and then circulated around the conductor (2) in such a way that the linearly polarized light is reflected repeatedly in the sensor (3 and is emitted from the sensor 3. During this propagation, the polarization plane of light is rotated by an angle corresponding to the level of an electric current due to the Faraday effect induced by the electric current which flows in the conductor (2).

The light emitted from the sensor (3) is formed into a linearly polarized light (10b) which propagates through the space, and then again is incident on the coupling optical system (7) so that light is divided into two components polarized linearly in the two directions perpendicular to each other and then respectively is incident on the two light receiving fibers (9a) and (9b).

Hereinafter, the light which is emitted from the polarizer (7b) and transmitted to the light receiving fiber (9a) or (9b) through the sensor (3) is called the polarized measuring light. In Fig.2, the polarized measuring light includes the linearly polarized light (10a), the light transmitted in the sensor (3), and the linearly polarized light (10b). The incident light in the form of the two components is processed by the signal processing system so that the angle of rotation, that is, the level of the electric current which flows in the conductor 2 is measured.

3.2 Pockels cell electro-optic sensor coupled to solid voltage divider

An electro-optic voltage sensor comprises a voltage divider connected to an electric line and to ground and having two insulating compartments separated by an intermediate electrode connected to a Pockels cell. The intermediate electrode supplies to the Pockels cell a reduced voltage derived from the voltage supplied by the electric line to the voltage divider. Each insulating compartment comprises a homogeneous dielectric block with a thickness dependent on the division ratio of the voltage divider.

Fig.2 shows an example of an electro-optic voltage transducer [4].

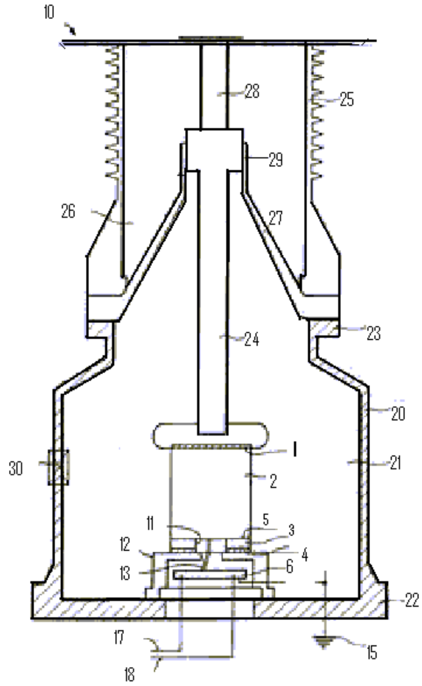

Fig.2 - Example of optical voltage transformer

The Pockels cell comprises an electro-optic crystal, for example an oxide of bismuth and germanium or of bismuth and silicon, input optical fiber connected to a light-emitting diode emitting an incident light beam through a polarizer and a phase-shifter plate. On passing through the electro-optic crystal the polarization of the incident light beam varies. An analyzer on the path of the transmitted light beam converts the polarization variation at the output of the crystal into a variation of luminous intensity conveyed by an output optical fiber to a photodiode detector in a remote electronic unit. The polarization variation depends on the voltage applied between the conductive faces of the electro-optic crystal. The ratio of the instantaneous luminous power received by the photodiode to the continuous power emitted by the light-emitting diode depends on the applied voltage U in the form of a sine of the product where k is an electro-optic coupling coefficient characteristic of the crystal of the Pockels cell used. The Pockels cell can determine an applied voltage U up to a typical value 10000 volts, usually called the quarter-wave voltage of the electro-optic crystal .The electro-optic voltage sensor (10) comprising a voltage divider (1) like that previously described disposed inside a shielded enclosure (20), made of metal, for example, and filled with a pressurized insulating gas (21), for example dry nitrogen N2 or sulfur hexafluoride SF6. The base (22) of the shielded enclosure is electrically connected to ground at (15). A frame (12) inside the screened enclosure (20) on the base (22) supports the voltage divider (1) and contains a Pockels cell (4). A conductive wire (13) connects the intermediate electrode (5) and a conductive face of the electro-optic crystal of the Pockels cell (4), the other conductive face being connected to ground at (15). In this way a total voltage V applied to the voltage divider generates a reduced voltage U at the lower block (3) and at the Pockels cell, the electrical impedance of which is around 1000 times greater than that of the lower block (3).

The Pockels cell (4) contains an optical fiber (17) associated with a light-emitting diode (sender) and an optical fiber (19) associated with a photodiode (receiver) connected to an electronic unit for acquiring signals representative of the continuous luminous power emitted and the instantaneous luminous power received. Processing the signal provides access to the reduced voltage U and calculates the total voltage V from the thickness g2 and g3 of the two blocks of the voltage divider.

An insulator (25) made of porcelain, for example, or a composite material and of cylindrical or frustoconical shape is mechanically assembled, for example screwed, to the shielded enclosure at a fixing shoulder (23). The insulator (25) is filled with a pressurized gas (26), usually of the same kind as that (21) contained in the shielded enclosure (20), for example sulphur hexafluoride SF6. A support cone (27) holds an electric conductor (28) from the electric line.

The electric conductor (28) is disposed inside the insulator (25) and extends into the shielded enclosure through an annular opening (29) at the top of the support cone (27). The electric conductor (28) connects the armature (7) of the upper dielectric block (2) of the voltage divider (1) to an electric line supported by the insulator (25).

Table 1 – The comparison of the input-output characteristics of the conventional and optical current transformers

COMPARISON OF CHARACTERISTICS				
RATED VOLTAGE	PARAMETERS	CURRENT TRANSFORMERS		
		The company		
		TRENCH Germania/ SAS (SF_6)	TRENCH Germania/ IOSK oil+porcelain)	NxtPhase Canada / TIOC
123kV/ 115kV NxtPhase	BIL – Base Impulse level [kV]	550	550	550
	Min. flashover distance[mm] /Standard creepage distance [mm]	1216/2880	1200/3815	2610
	Height [mm]	2660	1630	1650
	Static Withstand [kN]	-	-	3
	Standard load secondary [VA]/Precision class	5 A	120/0.2/3P 300/0.5/3P 400/1/3P	$1A_{rms}$ nominal value /load 2,5 VA/cosφ=0.9
	Net weight [kg]	350	240	77
245kV/ 230kV	BIL - Impulse withstand [kV]	1050	950	1050
	Min. flashover distance[mm] /Standard creepage distance [mm]	2350/6135	2200/6300	5357
	Height [mm]	4140	2400	3025
	Static Withstand [kN]	-	-	4
	Standard load secondary [VA]/Precision class	Second load current 1A/2A/5A	Second load current 1A/2A/5A	$1A_{rms}$ rated value/load 2,5 VA/cosφ=0.9
	Net weight [kg]	880	380	180
420kV/ 500kV NxtPhase	BIL - Impulse withstand [kV]	1425	1425	1800
	Min. flashover distance[mm] /Standard creepage distance [mm]	3728/10155	3200/11550	10290
	Height [mm]	5780	4920	4600
	Static Withstand [kN]	-	-	6
	Standard load secondary [VA]/Precision class	Second load current 1A/2A/5A	Second load current 1A/2A/5A	$1A_{rms}$ rated value/load 2,5 VA/cosφ=0.9
	Net weight [kg]	1550	1000	318

4. ELECTRO OPTICAL TRANSFORMERS DEVELOPED BY PRESTIGIOUS COMPANYS

The company ABB currently has two commercial: DOIT - Digital Optical Instrument Transformer; MOCT - Magneto Optical Current Transfomer; EOVT - Electro Optical Voltage Transformer.

The company AREVA offers the optimum primary sensor solution to satisfy a wide variety of customer requirements: CTO - Current Transformer with Optical sensor; BMO - Bus- or Breaker-Mounted Optical current sensor; VTO - Voltage Transformer with Optical sensor; CMO - Combined Measurement with Optical sensors; CVCOM - Current & Voltage COMmunication.

AIRAK developer and supplier of optical sensors and systems for electrical monitoring and control for medium voltage: Optical sensor current / voltage; Optical Electronics Module; Comunication equipment.

NXTPHASE currently has two commercial: Optical current transducer– NXCT; Optical voltage transducerNXVT.

Table 2 – The comparison of the input-output characteristics of the conventional voltage transformers from TRENCH and the optical instrument voltage transformers from NXTPHASE

COMPARISON OF CHARACTERISTICS				
RATED VOLTAGE	PARAMETERS	VOLTAGE TRANSFORMERS		
		The company		
		IEPC Romania/ TT Capacitor	TRENCH Germania/ TT Capacitor	NxtPhase Canada / TIOT
123kV/ (115kV)	BIL - Impulse withstand [kV]	550	550	550
	Min. flashover distance[mm] /Standard creepage distance [mm]	2,7cm/kV	2590	2610
	Weight [mm]	2050	1899	1650
	Static Withstand [kN]	-	12	3
	Standard burden secondary [VA]/Precision class	120 VA/ 0,5/0,5/3P	120/0.2/3P 300/0.5/3P 400/1/3P	69 V_{rms} /115 V_{rms} or 120 V_{rms} Input Power: 70 – 300 V_{dc}
	Net weight [kg]	485	410	113
245kV/230kV	BIL - Impulse withstand [kV]	950	950	1050
	Min. flashover distance[mm] /Standard creepage distance [mm]	2,7cm/kV	5210	5357
	Weight [mm]	3370	2905	2845
	Static Withstand [kN]	-	6,2	4
	Standard burden secondary [VA]/ Precision class	120 VA/ 0,5/0,5/3P	120/0.2/3P 300/0.5/3P 400/1/3P	69 V_{rms} /115 V_{rms} or 120 V_{rms} Input power: 70 – 300 V_{dc}
	Net weight [kg]	760	570	236
420kV/500kV	BIL - Impulse withstand [kV]	1425	1425	1800
	Min. flashover distance[mm] /Standard creepage distance [mm]	2,4cm/kV	9900	10290
	Weight [mm]	4680	4420	4420
	Static Withstand [kN]	-	3,6	6
	Standard load secondary [VA]/ Precision class	120 VA/ 0,5/0,5/3P	120/0.2/3P 300/0.5/3P 400/1/3P	69 V_{rms} /115 V_{rms} or 120 V_{rms} Input power: 70 – 300 V_{dc}
	Net weight [kg]	980	750	682

Table 3 - The main output characteristics of the current transformers and of the terminals

The company	REL / REC		Trench – Germania		NXTPhase- Canada		RET	
Rated voltage	I_b – Base current for input I 0.1– 10.0 in steps of: 0.1 Default value: 1A	U_b – Base voltage by input U 30.000 – 500.000 step: 0.001 Default value: 63.509 V	TT capacitor	TC oil	TIOT	TIOC	Current inputs	Voltage inputs
123 kV, 245 kV, 420 kV			120/0,2/3P 300/0,5/3P 400/1/3P		69V/115V 120V 135 W typically		< 0.25 VA for I_N =1 A and 5A	<0.2 VA for U_N = 100/110 /115/120V
123 kV				120/0,2/3P 300/0,5/3P 400/1/3P		1A / 2,5VA/ cosφ =0,9	Power consumption 35W	Power consumption by input module: max. 0,5W
245 kV, 420 kV				1A/2A/5A		1A / 2,5VA/ cosφ =0,9		

5. THE CURRENT AND VOLTAGE TRANSFORMERS WITHIN THE STATION ȚÂNȚĂRENI

The update of the 400kV Station Țânțăreni is based on the ABB digital protection, control and monitoring system, designed for the high voltage stations. It allows the operation of three distinct systems: the command-control system, the monitoring system, the metering system.

Following the technical update of the station, the measuring transformers are conventional ones, from TRENCH - Haefely:

• Current transformers with oil and porcelain insulator, type IOSK 400kV;

• Current transformers with SF6 and composite material insulator;

• Capacitive voltage transformer with oil and porcelain insulator;

Table 1 presents a comparison of the input-output characteristics of the conventional current transformers from TRENCH and the optical instrument transformers from NXTPHASE [1].

6. CONCLUSIONS

The optical instrument transformers pushed the measuring limits beyond the possibilities of the classical technology. The interfacing of the optical sensors with the existing measuring devices and relays is one of the essential differences. In order to become accepted the optical sensors, a simple method for connecting the old and new technologies is a necessary step. If this step is successful, the transition to new systems within the electric stations will be easily accepted. The optic sensors are inherently, different by the conventional iron transformers. They measure the primary current based on the optical effect of the electric current and so, offer a numeric image of the current. This signal must be then converted in the continuous form, possible to be amplified. When the users decide to use optical sensors, they must be prevented on the implications. They can note slight performances of the measuring devices, especially at small primary currents. The slight performances and their dependency on the sensor's design is due to, on one hand the noise contained by the output signal and on the other hand, to the method used by the different numeric devices to compute certain parameters. It is important that the signal/noise ratio to be as high as possible, because the measuring devices could indicate wrong measurements or high harmonic distortion factor. In what concerns the positive economic benefits of the using of the new optic instrument transformers, they can be quantified in time, taking into account the low costs for installation and minimal maintenance costs. Practically, they are maintenance-free, if we not take into account the maintenance of the composite material insulator.

References

[1] J. Blake, W. Williams, *Optical Current Transducers for High Voltage Applications*, NxtPhase Corporation, July 10-th 2000;

[2] M. Brojboiu, *Privind noile tipuri de materiale dedicate dezvoltării noilor tipuri de transductoare electrooptice de măsură a curentului şi tensiunii*, Conferinta Nationala a Energiei FOREN 2004, 13 -17iunie 2002, Neptun Olimp, Romania, CD-S2_P14.

[3] Păduraru, N. - *Utilizarea senzorilor de curent şi de tensiune în echipamentele energetice specifice stațiilor electrice de înaltă tensiune în scopul preluării rolului transformatoarelor de măsură clasice*- Energetica, 46, 1998, nr.II, pag. 536 -539;

[4] D. Chartrefou, *Pockels Cell Electrooptic Sensor Coupled to Solid Voltage Divider*, United States Patent No. 6127817, Oct. 03, 2000;
[5] A. Kevorkian, D. Persegol, A. Danel, *Electrooptic Voltage Sensor With Optic Fiber*, United States Patent No. 5936395, Aug. 10, 1999;
[6] S. Kobayashi, A. Horide, I. Takagi, M. Higaki, G. Takahashi, E. Mori, T. Yamagiwa, *Development and Field Test Evaluation of Optical Current and Voltage Transformers for Gas Insulated Switchgear*, IEEE Transactions on Power Delivery, vol.7, No.2, April, 1992, pp. 815;
[7] A.J. Rogers, *Optical Technique for Measurement of Current at High Voltage*, Proceedings IEEE, vol.120, No.2, February, 1973, pp. 261;
[8] K. Terai, M. Takahashi, S. Ikuta, *Optical Current Transformer*, United States Patent No.6281672, Aug. 28, 2001[18]
[9] ***, NxtPhase, *Technical Specifications, NXVT Optical Voltage Sensor*, www. nxtphase.com
[10]***, GEC Alsthom, *Technical Specifications*, www.gecalsthom.com
[11]*** - www.trenchgroup.com;
[12]*** - www.abb.com;