



## Fiber Optic 110-150 kV Current Transformers

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## FIBER OPTIC 110 – 150 KV CURRENT TRANSFORMERS

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The current state of high-voltage equipment parks has been studied. Based on this, the analysis of high-voltage measuring current transformers is carried out and the use of optoelectronic current measurement methods is justified. A fundamentally different promising approach based on the use of the magneto-optical Faraday effect has been studied. The external insulation of new generation transformers and its resistance to natural phenomena are considered. An analysis of the main elements of the optical system is given. The further introduction of fiber optic current transformers into the power industry is justified.

**Key words:** fiber optic transformer, Faraday's effect, insulation.

**Introduction.** At the present stage of the development of high-voltage technology, classical methods of measurement based on the electromagnetic principles have reached the limit of their capabilities and cannot satisfy new requirements. They have arisen due to technological revolution of the last several decades. As noted in their work Zubia, Casado, Aldabaldetrek and others, "Unimaginable technological advances in the area of information and communications technology (ICT), the electrical sector had turned into an anachronism using the technology of last century" [2]. Therefore, the modern development of electrical complexes and systems require the introduction of the latest designs of instruments and equipment [1]. As a result, the so-called optical-electronic (OE) measurement methods make it possible to realize the requirements of consumers. They are based on the use of optical communication between the primary and secondary transducers of the measuring system. Such methods use a completely different, more promising approach, based on the use of the magneto-optical Faraday's effect. Most often, this effect realized in fiber optic current transformers (FOCT) used in combination with modern digital signal processing and data transmission technologies.

Currently, the development of the FOCT is produced by leading companies around the world. Such transformers are considered to be the next generation of transformers, because they eliminate defects of the analog transformers and perform all the necessary requirements.

Except sensors, special attention in the FOCT is given to the insulation. The issue of insulation is still of current interest, since only due to the choice of high-quality material, the correct shape of the ribs, the FOCT acquires such features as flexibility, not sensitivity to external influences and easily of mounted.

**Aim of the work.** Comparison of materials and shapes used for external insulation, in terms of optimal protection of optical sensors from natural phenomena and breakdowns.

**Faraday's effect.** Nowadays, FOCT use the magneto-optical Faraday's effect, which is a fundamentally different promising approach.

Khairullin, Giniyatullin and Pashali, speaking of the magneto-optical effect, write that "In 1845, Faraday

discovered a phenomenon that became one of the main steps in the development of optical current converters — the phenomenon of rotation of the plane of polarization of linearly polarized light in a constant magnetic field" [1], as in Fig. 1.

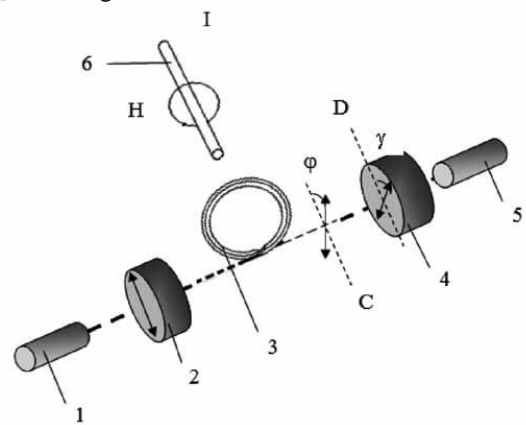


Figure 1 - Schematic diagram of the Faraday's effect  
1 - laser diode; 2 - polarizer; 3 - Faraday's element (twisted optical fiber); 4 - analyzer; 5 - photodiode; 6 - electric current conductor.

Oscillations of the light wave at the output of the polarizer occur in the plane C. At the output of the analyzer the oscillations of the plane-polarized light wave occur in the plane D (taking into account the additional rotation of the plane of polarization in the Faraday element (FE) by the angle  $\varphi$  and the transmission angle of the pair of polarizers  $\gamma$ ).

Making a ring from many turns of optical fiber and wrap a wire around this ring, then by passing an electric current, you can get a magnetic field transducer with high sensitivity. In this case, the angle of rotation of the plane of polarization (1).

$$\varphi = VNfNiI, \quad (1)$$

where V is Verdet constant; I is the electric current; Nf is the number of turns of the optical fiber ring; Ni is the number of intersections electric current with turns of fiber [1].

**Design of FOCT.** The Canadian company NXT Phase is one of the first creators of this type of device. Since 2002, the devices of this company have been tested on existing high-voltage power lines in different countries. In Russia, the best practical results on the

creation of domestic devices of this type were obtained at the company Profotek CJSC [4].

It's a pity, in Ukraine there is no manufacturer of this kind of transformer but there is researchers in this area. Let us consider each type of the FOCT manufactured by Profotek as in Fig. 2 and NXTPhas, as in Fig. 3. A current sensor locates on the support insulator, and it consists of a measuring element, a sensitive optical fiber in a quartz tube and current-carrying bus.

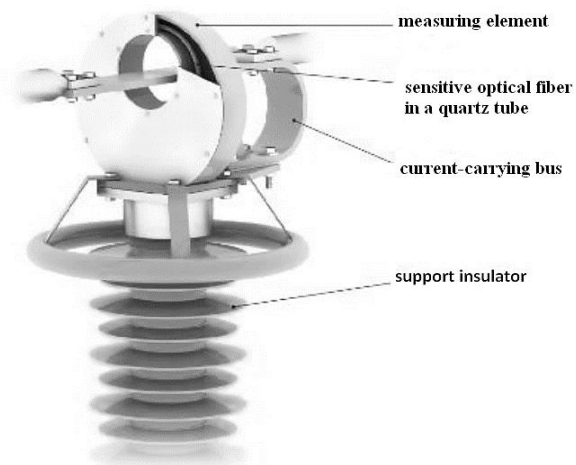


Figure 2 – FOCT manufactured by Profotek

A linearly polarized light signal is supplied from the electro-optical unit, which enters the electron-optical unit through the optical fiber.

The operating principle of the FOCT of the Canadian manufacturer NXT Phase is the same as the Russian one. It is worth noting that NXT Phase offer a new design of the FOCT with a breakable optical loop NXCT-F3, as in Fig. 3b. Optical current transformers can be used in information-measuring systems of technical and commercial metering and quality control of electrical energy. The transformer has a measuring sensor made in the form of several turns fiber optic loop covering a high voltage input, a generator bus, or a current conductor. Design features allow you to install the transformer in those places where the installation of traditional copper transformers is extremely difficult or simply impossible. The measuring loop of the sensor is a polarization-preserving optical fiber connected to a standard NXCT, as in Fig. 3a electronics kit with a standard set of output interfaces. This is an ideal solution that allows, in a short time and with a minimum amount of preparatory work, to organize the deployment of a measuring or verification complex.

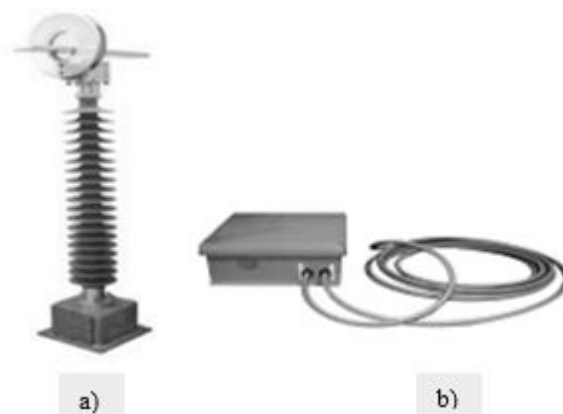


Figure 3 – FOCT manufactured by NXTPHase  
a – NXCT Measuring Fiber Optic Current Transformer  
b – NXCT-F3 Current Transformer with Openable Optical Loop

**Insulation comparison.** As noted in their work, Zhornyak, Afanasiev, Leonov, and Karpuk, “Insulation is an essential element in the design of electrical appliances and has a significant impact on both its design and operational reliability, especially in ultra-high voltage devices” [5]. It is known that the trouble proof operation of networks, the service life of high-voltage equipment, the safety of maintenance directly depends on the quality of the insulators, and especially on their material, reliability, type and number of ribs. If to analyze the current state of the high-voltage equipment parks, it can be sure that they are in poor condition, as in Fig. 4.

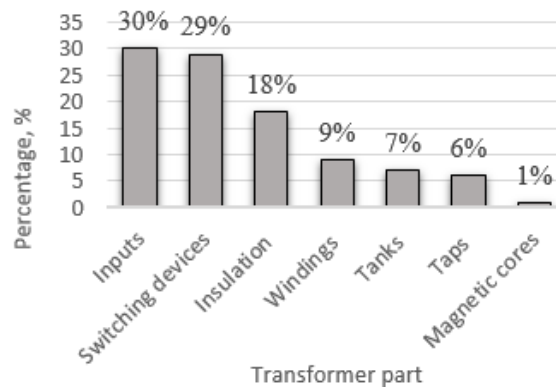


Figure 4 – Estimated damage of the analog transformers 110-150 kV in percent

Due to long-term operation and the lack of necessary service conditions, the external insulation has lost its quality, has stopped to perform its functions, therefore, all these give a large measurement error. Thus, we can conclude that the parks of high-voltage equipment require urgent repair or replacement with completely new promising devices. But as practice shows, a complete replacement of old equipment is much more profitable than its repair.

As mentioned above, fiber optic current transformers are gaining more popularity today. Canadian, Russian, and American FOCT are rapidly replacing analog transformers worldwide. One of the main requirements

for the operation of new generation transformers is reliable operation at voltages reaching many hundreds of kilovolts. Therefore, special attention is paid to external insulation and the calculation of electrical strength.

The high-voltage equipment market offers a wide selection of insulators with completely different characteristics. The most used insulators for FOCT are made of porcelain and polymer. Since the insulating structure during operation must withstand the long-term (tens of years) effect of the highest operating voltage, as well as short-term repeated effects arising in the network of atmospheric (lightning) and internal (switching) overvoltages. The question is, what material is the best to use for insulators?

Porcelain insulators account for a large proportion of FOCT manufactured. Porcelain is a product of inorganic chemistry. The chemical and physical properties of the material remain unchanged over time. Throughout the life cycle the mechanical strength does not change. The material of the insulator is resistant to ultraviolet radiation and solar radiation, as well as to aggressive chemical emissions from industrial enterprises. It has zero permeability and incombustibility. But in addition, there are significant disadvantages that overlap almost all advantages: significant weight, which is important during installation, and high fragility, which complicates the transportation process.

Outdoor porcelain insulators most often have umbrella-shaped ribs with droppers or recesses that prevent water from entering the surface below. In addition, the reliable operation of insulating structures under prolonged exposure to operating voltage is ensured by the selection of the appropriate leakage path, which depends on the number of ribs on the insulator. Leakage path means the smallest distance along the surface of an insulating part between metal parts of different potentials. The leakage path of insulators for different degrees of pollution is determined by the formula (2):

$$L_{l,p} = \lambda_{l,p} \times U_{ph}, \quad (2)$$

where  $U_{ph}$  is the largest phase voltage of the electrical installation;  $\lambda_{l,p}$  is specific leakage path along the insulator [9].

However, in modern apparatus engineering, the use of polymer insulation is increasing. And this is due to the high level of electrical and mechanical strength (achieved by reinforcing them with fiberglass). Polymer insulators in outdoor FOCT are made from epoxy compounds based on cycloaliphatic resins, from silicone rubber, from polyester resins with mineral filler and fluoroplastic additive. Outside, they are coated with a protective coating, for resisting an ultraviolet radiation and chemical influences, as well as waterproof varnishes for reducing hygroscopicity. The use of polymer insulators on power lines can significantly reduce the mass of insulators, and accordingly mass of the entire transformer. They allow to replace whole garlands of porcelain insulators, since they are much lighter.

The advantages of polymer insulators is a higher electrical resistance during pollution, compared with similar porcelain insulators with an equal leakage path, this advantage is even more evident due to the use of the hydrophobicity of the material. The other important advantages of polymer insulators are: flexibility, allows to install optical transformers in vertical, horizontal and tilted positions, and it does not affect the accuracy of measurements; compactness allows them to be installed in conditions that are unacceptable for analog transformers; insensitivity to external electromagnetic fields does not require analysis of the relative position of the tires; light weight allows installation without using of cranes.

Having given a ribbed shape to the polymeric insulator, we will reduce the leakage current (by 1-2 orders of magnitude lower than that of porcelain insulators) to the required level over the surface of the insulator at dirty and moisture conditions. The profile of the ribs is an important component of the polymer insulator because it's a type of self-cleaning insulator.

Depending on the growth of pollution, insulators with the same protrusion of ribs, as in Fig. 5a, require the length increasing (construction height), in order to obtain an increased length of the current leakage path. This solution cannot be used constantly, it is not economical and requires the development of new electrical equipment, especially for increased environmental pollution. The solution of the given problem is the new design of insulators with variable protrusion of ribs, as in Fig. 5b.

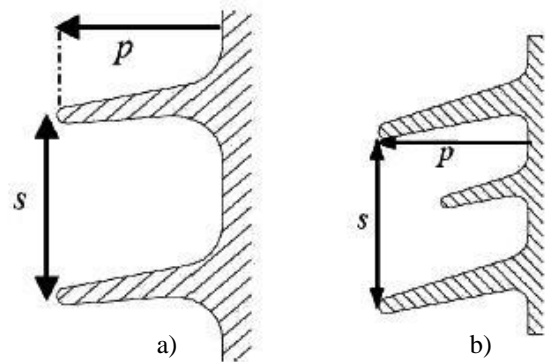


Figure 5 – Profile of ribs

- a – Insulator with the same protrusion of ribs
- b – Insulators with variable protrusion of ribs

An insulator with a variable protrusion of ribs at the same construction height allows an increased length of the leakage path. In addition, due to the variable overhang of the ribs, the dirt resistance is increased. If you look at Fig. 6, you can see the insulators of the outdoor installation with the same protrusion of the ribs, it is obvious that these insulators are not usable for areas with a cold climate, since all the ribs are covered with precipitation. Consequently, it prevents the insulator from fulfilling the protection functions of optical sensors [12].

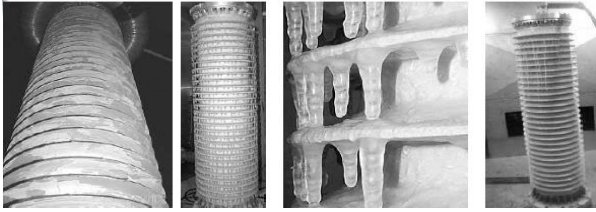


Figure 6 – External insulation with the same protrusion of ribs

**Conclusion.** Based on the analysis of different materials of insulators, it can be concluded that it is rational and profitable to produce FOCT with polymer insulators. Because today polymer insulators are economical and easy to install, due to they have high vandal resistance and much lower weight compared to porcelain one. As indicated above, FOCT with polymer insulators can be used under any environmental conditions. The insulators for categories A, B and C were analyzed. And it should be noted that the material of the insulators, regardless of environmental pollution conditions, does not change, but the number of ribs increases and the distance between them decreases, as in Fig. 7, and accordingly it will help to increase the leakage path, as in Fig. 8 [6].

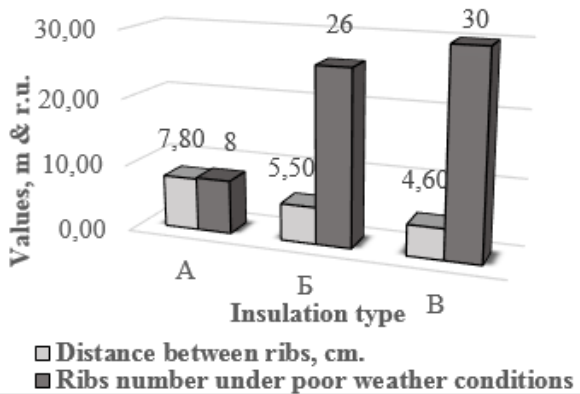


Figure 7 - Change in the number of ribs and the distance between them, depending on environmental conditions

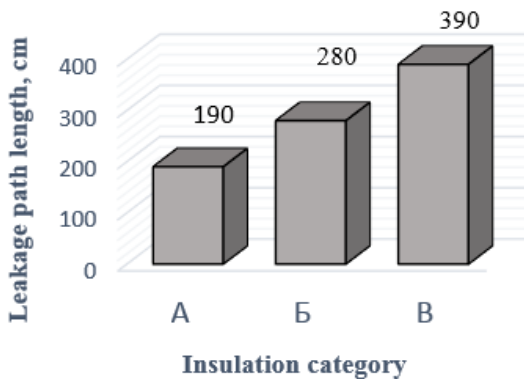


Figure 8 – Change in leakage path along the insulator depending on environmental conditions

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## ОПТОЕЛЕКТРОННІ ТРАНСФОРМАТОРИ СТРУМУ 110-150 кВ

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Було вивчено сучасний стан парків високовольтного обладнання. На підставі цього проведено аналіз високовольтних вимірювальних трансформаторів струму і обґрунтовано застосування оптоелектронних методів вимірювання струмів. Досліджено принципово інший перспективний підхід, заснований на використанні магнітооптичного ефекту Фарадея. Розглянуто зовнішню ізоляцію трансформаторів нового покоління та її стійкість до природних явищ. Наведено аналіз основних елементів оптичної системи. Обґрунтовано подальше впровадження в енергетичну галузь оптоелектронних трансформаторів струму.

**Ключові слова:** оптоелектронний трансформатор, ефект Фарадея, ізоляція.

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