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Classification of Transformers

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Abstract *— This paper provides information on the principle, history and classification of Transformers performance.*

Keywords — Transformer equipment; electric energy; operations of transformers;

Introduction

The main electrical equipment of power plants, substations, power transmission lines and other electrical devices are transformers. A transformer is not an electrical machine, since its operation is not related to the conversion of electrical energy into mechanical energy, and Vice versa; it converts only the voltage of electrical energy. In addition, the transformer is a static device, and there are no moving parts in it. However, the electromagnetic processes occurring in transformers are similar to those occurring in electrical machines. Moreover, electric machines and transformers are characterized by the unified nature of electromagnetic and energy processes that occur when a magnetic field and conductor interact with a current. Transformer equipment largely determines the quality and reliability of power supply. Therefore, the production of transformer equipment is assigned a significant role.

Great merits in the creation of transformers and their practical application belong to the remarkable Russian inventor P. N. Yablochkov. In 1876, N. p. Yablochkov built the first transformer and used alternating current for lighting. About ten years later, the transformer received its modern form (brothers D. and E. Hopkinson and D. Mary). Domestic transformer engineering begins its history with 1928, when the Kuibyshev Moscow electric plant came into operation.

Many research organizations take part in solving all the most important problems of transformer engineering, including the all-Union Institute of transformers – VIT (Zaporozhye), the all – Union electrotechnical Institute named after V. I. Lenin-VEI (Moscow), educational, branch and academic institutes.

At present, the domestic engineering industry has achieved significant success. If at the beginning of the last century in Russia there was actually no electric machine building as an independent industry, then over the past 50-70 years a branch of the electrical industry was created-electric machine building, able to meet the needs of our developing national economy in electric machines and transformers.

AC generators at power plants generate electrical energy at a voltage of 6-30 kV, and long-distance transmission of electricity is carried out at significantly higher voltages – 110,150,220,330,400,500,750,1150 kV, which ensures minimal electrical losses in power transmission lines. It is impossible to get such a high voltage in the generator, so electricity after the generator is supplied to the step-up transformer, in which the voltage increases to the required value. This voltage should be the higher, the longer the length of the power line, and the more power transmitted along this line. Therefore, each power plant is equipped with transformers that increase the voltage.

Distribution of electric energy between industrial enterprises, cities and rural areas, as well as within industrial enterprises is made by air and cable lines at a voltage of 220,110,35,20,10,6 kV. Therefore, all nodes of the distribution networks should be equipped with transformers that reduce the voltage to the required value. Such transformers also need to be installed directly at electricity consumers, since most AC consumers work at 220,380,660 V.

Thus, electric energy is subjected to multiple transformations (3 times or more) during transmission from power plants to consumers.

Transformer – a static electromagnetic device having two (or more) inductively coupled winding and intended for conversion by electromagnetic induction of one (primary) AC system to another (secondary) system AC power (from the Latin word transformo – transform).

Transformers used for converting electrical energy in power grid networks, distribution networks, and installations intended for receiving and using electricity are called *power transformers*. Power transformers have a capacity of up to 1250 MV*A in a three-phase version, and up to 2000 MV in a group of three single-phase transformers*A; the mass of such transformers reaches 500 tons. Power transformers, by changing the value of AC voltage and current, leave unchanged the number of phases, the shape of the voltage (current) curve and frequency.

Transformers are classified according to several criteria:

According to their purpose, transformers are divided into *General-purpose power transformers* and *special-purpose transformers.*

Special-purpose transformers are characterized by a variety of operating properties and structural design. These transformers include transformers used in circuits with semiconductor devices (diodes, thyristors, transistors) in which AC rectification or DC inversion is performed. Such transformers with a capacity of up to hundreds of megavolts-amperes are used in electrical installations of industrial enterprises.

In addition to these transformers, other special transformers are produced for powering ore-thermal furnaces (electric furnace transformers), electric welding, electric traction, powering electronic devices, as well as voltage and current measuring transformers.

In gate converters that perform rectification or inversion, the main purpose of transformers is to provide the necessary circuit for switching on the valves and matching the voltage at the input and output of the Converter. Since the ratio of input and output voltages of the valve converters depends on the circuit of switching on the valves, when the standard voltage is applied to the input of the Converter, the output voltage will be non-standard. Therefore, each Converter transformer is designed for a specific circuit for switching on the valves, which determine the specifics of calculating and designing the circuit windings to which the valve Converter is connected.

Significant technical achievements in the field of creating Converter transformers are the construction of unique transformers for DC power lines, when at the beginning of the line, an ultra-high voltage alternating current is rectified to obtain a constant voltage of 1500 kV, and then inverted at the end of the line.

The peculiarity of transformers used for various technological processes (electric welding, steel smelting, etc.) is a relatively small output voltage-about 100-200 V. In this regard, electrical transformers, especially at a power of 50 * 100 MV*A, are designed for large currents of secondary windings, reaching hundreds of kiloampere.

A special feature of the construction of transformers used to power electronic devices, radio equipment, television equipment, communication devices, automation, computers, is their implementation with a large number of secondary windings, often 10, with relatively low power. These transformers are produced in tens of millions per year. They are an integral part of everyday household equipment – radios, televisions, tape recorders.

Measuring transformers are used to include electrical measuring devices and protection devices in high-voltage or high-current circuits, to extend the measurement limits and ensure electrical safety. As a rule, they have a small power, determined by the power consumed by electrical measuring devices, relays, and information systems. These transformers are characterized by high accuracy of execution when implementing special designs that provide for minimizing measurement errors.

General purpose power transformers are used in power transmission and distribution lines, as well as in various electrical installations to obtain the required voltage.

According to the type of cooling – with air (dry transformers) and oil (oil transformers are immersed in a metal tank filled with transformer oil) cooling.

By the number of transformed phases – single-phase and three-phase.

According to the shape of the magnetic core – rod, armor, armor-bearing, toroidal.

According to the number of windings per phase of the voltage being transformed – two-winding, multi-winding.

The simplest power transformer consists of several coils (windings) wound on a frame with an insulated wire, which are placed on a magnetic wire made of thin plates (a core made of ferromagnetic material (usually sheet electrical steel).

Alternating electric current flowing through one of the windings, called the primary, creates an alternating magnetic field around it and in the magnetic conductor, crossing the turns of the other - the secondary-winding of the transformer, exciting a variable electromotive force in it. It is enough to connect an incandescent lamp to the terminals of the secondary winding, as the resulting closed circuit will flow alternating current. In this way, electrical energy is transferred from one transformer winding to another without directly connecting them, only due to the alternating magnetic field binding the windings.

If both windings have an equal number of turns, then the same voltage will be induced in the secondary winding as it is applied to the primary. For example, if you apply an alternating current of 220 V to the primary winding of a transformer, then a current of 220 V will also occur in the secondary winding. If the windings are different, then the voltage in the secondary winding will not be equal to the voltage applied to the primary winding. In a step-up transformer, i.e., a transformer that increases the voltage of an electric current, the secondary winding contains more turns than the primary, so the voltage on it is greater than on the primary. In a step-down transformer, on the contrary, the secondary winding contains fewer turns than the primary, so the voltage on it is less.

The operation of transformers is based on the phenomenon of electromagnetic induction. When connecting the primary winding to an alternating current source, an alternating current flows through the coils of the winding, which creates an alternating magnetic flux in the core. Closing in the magnetic circuit, this flow binds to both windings and induces EMF in them: in the primary winding, EMF self-induction, in the secondary winding, EMF mutual induction.

The transformer winding connected to the network with a higher voltage is called the high voltage winding; the winding connected to the network with a lower voltage is called the low voltage winding.

Transformers have the property of reversibility: the same transformer can be used as a step-up and step-down. But usually the transformer has a certain purpose: either it is a step – up, or it is a step-down.

A transformer is an alternating current device. If its primary winding is connected to a DC eye source, then the magnetic flux in the transformer's magnetic core will also be constant both in magnitude and direction, so EMF will not be induced in the transformer windings, and therefore electricity from the primary circuit will not be transmitted to the secondary.

A modern transformer consists of various structural elements: a magnetic core, windings, inputs, tank, etc. A magnetic conductor with windings mounted on its rods constitutes the active part of the transformer. The rest of the transformer elements are called inactive (auxiliary) parts.

The magnetic core consists of rods and yoke. The windings are located on the strazhniakh, and the yoke serves to connect the magnetic circuit to a closed system. Thin-sheet electrical steel is used for the manufacture of transformer magnetic conductors. At an alternating current frequency of 50 Hz, sheets (strips) with a thickness of 0.5 or 0.35 mm are used. At frequencies of 400 Hz and more, sheets with a thickness of 0.2 – 0.08 mm are used. At frequencies of 1000 Hz and higher, magnetic pipelines are made of permalloy iron-Nickel alloys, which are characterized by improved properties compared to electrical steels: higher magnetic permeability and less coercive force.

Depending on the method of manufacturing magnetic cores of transformers are laminated and tape. Magnetic lines of single-phase transformers are of three types: rod, armor and toroidal.

Plate-type magnetic lines (a-b) they are assembled from individual plates obtained by stamping or cutting sheet electrical steel. To reduce eddy currents, the plates are insulated from each other with a layer of insulating varnish or oxide film.

Rod-shaped plate magnetic pipelines *(*a*)* are assembled from rectangular plates (strips). Core plates are bonded to the package, or through pins are electrically isolated from plates of special bushings and washers, or by a bandage of glass non-woven tape or thread.

Armored plate magnetic *lines (b)* collect from the W-shaped form. They have only one rod, on which all the windings of the transformer are located.

Toroidal magnetic cores of the plate *(in)* they are assembled from separate stamped rings.

Split tape cores core *(g)* and armor *(d)* types consist of separate horseshoe-shaped parts. After installing pre-made windings, these horseshoe-shaped parts are butt-joined and fastened with ties.

Toroidal belt magnetic *lines (e)* it is made by winding the tape. The advantages of such magnetic conduits are the absence of joints, i.e. places with increased magnetic resistance.

Armored-type magnetic conductors provide transformers with the following advantages: better filling of the window of the magnetic conductor with winding wire; partial protection of the winding with yoke from mechanical damage. However, with an armored magnetic core, the cooling conditions of the windings deteriorate.

Windings of transformers of medium and high power are made of winding wires of round or rectangular cross-section, insulated with cotton yarn or cable paper. The basis of the winding in most cases is a paper-bakelite cylinder, on which elements (rails, angle washers, etc.) are attached, providing the winding with mechanical and electrical strength.

According to the mutual arrangement on the rod, the windings are divided into concentric and alternating. *Concentric windings* are made in the form of cylinders placed on the rod concentrically: closer to the rod is usually placed the LV winding (requiring less insulation from the rod), and outside – the HV winding.

Alternating (disk) windings are made in the form of separate sections (disks) of NN and VN and are arranged on the rod in alternating order. Alternating windings are used very rarely, only in some special-purpose transformers.

Concentric windings are divided into several types:

1. *Cylindrical* single-layer and double-layer windings made of rectangular cross-section wire *(a)* they are mainly used as LV windings for rated current up to 800 A.

2. *Screw* single-and multi-pass windings are made of several parallel wires of rectangular cross-section. In this case, the coils are laid along a helical line that has one or more moves *(b)*. To ensure that all parallel conductors are equally loaded with current, perform a transposition (transfer) of these conductors. When transposing, they strive to ensure that within one turn each conductor occupies all positions. Transposition can be a group, when parallel wires are divided into two groups and permutation is performed in groups, or a General one, when the mutual arrangement of all parallel wires changes.

3. *Continuous windings (V)* they consist of separate disk windings (sections) wound in a spiral and connected to each other without soldering, i.e. made "continuously". If the winding is made by several parallel wires, then it applies wire transposition. Continuous windings, despite some complexity of manufacture, have received the greatest use in power windings of NN. This is due to their high mechanical strength and reliability.

In addition to the windings and the magnetic *core, low voltage transformers* have a casing, terminal block and fasteners. The metal casing is connected to the magnetic conductor and grounded – a measure necessary for safety conditions.

High-voltage transformers are made oil - proof-the magnetic wire is placed in a metal tank filled with transformer oil. Transformer oil, washing the windings *2* and *3* and the magnetic *conductor 1*, takes heat from them and, having a higher thermal conductivity than air, through the walls of the tank *4* and the radiator pipe *5* gives it to the environment. The presence of transformer oil provides more reliable operation of high-voltage transformers, since the electrical strength of oil is much higher than that of air. Oil cooling is more intensive than air, so the dimensions and weight of oil transformers are less than those of dry transformers of the same power.

In transformers with a capacity of up to 20-30 kV*And tanks with smooth walls are used. For more powerful transformers, the tank walls are made ribbed to increase the cooling surface, or tubular tanks are used. The oil, heating up, rises up, and cooling down, goes down. At the same time, the oil circulates in the pipes, which contributes to its faster cooling.

To compensate for the volume of oil when the temperature changes, as well as to protect the oil from oxidation and humidification in contact with air in transformers , the expander *9*is used, which is a cylindrical vessel mounted on the tank lid and communicating with it. Fluctuations in the oil level with changes in its temperature occur not in the tank, which is always filled with oil, but in the expander, communicating with the atmosphere.

During the operation of transformers, gases can be released, which leads to a significant increase in the pressure inside the tank, so in order to avoid damage to the tanks, transformers with a capacity of 1000 kV*A and above are provided with an exhaust pipe, which is installed on the tank lid. The lower end of the pipe communicates with the tank, and the upper end ends with a flange on which a glass disk is fixed. When the pressure exceeds the safe pressure for the tank, the glass disk bursts and gases escape.

A gas relay is placed in the pipeline connecting the oil transformer tank to the expander. If there is a significant damage in the transformer, accompanied by an abundant release of gas (for example, when a short circuit occurs between the windings), the gas relay activates and closes the contacts of the control circuit of the switch, which disconnects the transformer from the mains. The transformer windings are connected to the external network with inputs *7* and *8*. in oil transformers, pass-through porcelain insulators are usually used for inputs. Such an inlet is provided with a metal flange, through which it is attached to the tank lid. A trolley is attached to the bottom of the tank, which allows moving the transformer within the substation. On the lid of the tank is located the handle of the voltage switch *6*.

Each transformer is designed for inclusion in the AC network of a certain frequency. In Russia, General purpose transformers are designed for a frequency of f = 50 Hz (in some countries f = 60 Hz), in automation and communication devices, transformers are used for frequencies of 50, 400 or 1000 Hz.

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CONCLUSION

The solution of new challenges facing the transformer industry is connected with the further transition of the industry to an intensive development path, the introduction of resource-and energy-saving technologies, modern research methods, design and testing of transformers, the use of more advanced insulation and conductor materials.

The following trends should be noted in the development of transformer engineering:

increasing the unit capacity of transformers, which is one of the main directions of reducing the cost of manufacturing and operating equipment, along with increasing the reliability of limit capacity transformers by creating monoblock transportable structures and mandatory testing for dynamic stability. Scientific and research work is underway to create autotransformers with a maximum voltage of 1800 kV with a capacity of 3x2000 MV*A;

development of cast transformers and transformers with spatial magnetic cores to improve the technical level while reducing the metal and labor intensity of the capacity up to 1000 kV*A;

improving the characteristics of electrical steels, the technical parameters of which and the level of automation of magnetic wire production are crucial in assessing the competitiveness and technical level of transformers, with a reduction in the thickness of steel to 0.23, and possibly to 0.15 mm;

complete technical re-equipment of magnetic wire production facilities with the introduction of automatic charge of flat magnetic lines and automatic winding of spatial magnetic lines;

improving the quality of conductor materials with the introduction of glued trasponded wires with the expansion of the range of reinforced wires;

creation of automated transformer testing and process control systems;

extensive implementation of automation, design of complex transformer nodes in the graphical dialog mode using software and hardware complexes;

wide application of standardization in accordance with COMECON standards and recommendations of the International electrotechnical Commission;

In solving problems the leading role belongs to the workers of the factories and industrial scientific-research and design-engineering institutions.

A multifunctional device" Energomonitor 3.3. "was developed and manufactured at NPP Mars-Energo in St. Petersburg for verification of voltage measuring transformers at the site of their operation.

In 2003, OJSC "Electrosila" at an air temperature$^{\text{of 28 degrees Fahrenheit}}$C on the open site, verification of nine voltage transformers 35i kV, TN, voltage class 35 kV, accuracy class 0.5 and four – TN 6 kV, accuracy class 0.5 was performed. in the closed RU, verification of two TN 10 kV, accuracy class 0.5 was performed.

In 2004, at JSC Izhorskiye Zavody in a closed unheated RU -7^{o}Six 110 kV HV units were verified with accuracy class 0.5.

The test results showed the following:

1. the Actual load of the measuring windings of all voltage transformers tested is within the range of 0.5 – 1.0 rated power, which meets the established requirements.

2. Despite long-term operation in the conditions of closed RU, transformers of type NTMI-6 of 1949, 1960-1968 years of release, type NTMI-10 of 1968 year of release and type NKF-110 of 1968 year of release, are recognized as suitable for further operation in the accuracy class of 0.5.

3. Transformers of the NOM-35 type (9 PCs.) manufactured in 1977-1986, operated in the conditions of open RU, are recognized as not meeting the accuracy class of 0.5. This is probably due to the influence of atmospheric conditions, the use of phase-to-phase transformers in phase mode, and the reduction of the operating voltage from phase-to-phase to the 35 kV line voltage (verification was also carried out at phase voltage).

Energomonitor 3.3 operates reliably in both high (28^{o}° C) and low (-7 ° C^{o}With temperature. The time of setting the readings does not exceed 1-5 seconds. The actual sensitivity of the device is not worse than 0.01% in voltage and 0.1 min. for the angular error. the information is clearly displayed on the display and can be output to a computer for registration of the test report.

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