



## INDUCTIVE CONVERTERS FOR MEASURING HIGH ALTERNATING CURRENTS

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**Annotation:** *This article analyzes the significance of current transformers (CTs) and power transformers (PTs) in the electrical power system, their operating principles, and the key differences between them. The focus is placed on the operational modes, structural features, and functional purposes of CTs and PTs. The issue of accurately measuring high currents and the various current measuring converters (CMCs) used for this purpose including both contact and non-contact types, such as magnetomodulation converters, current comparators, and transformer-based converters are described. The advantages and disadvantages of each converter type are discussed, along with the requirements that should be considered when selecting them. In conclusion, it highlights the importance of current transformers as electromagnetic measuring elements in traction power supply systems and advocates for the use of wide-range CTs to ensure operational flexibility and universality.*

**Keywords:** *resistive, electromagnetic, induction converter, magneto-modulation, current comparator, current transformer, transformer type converter, transistor, current bus, primary winding, secondary winding.*

Current transformers (CTs) and power transformers (PTs) are important components of the electric power system. Current transformers are used to reduce large currents to smaller values for measurement and protection purposes, while power transformers are used in the transmission and distribution of electrical energy by increasing or decreasing voltage.

The operating modes of current transformers differ significantly from those of power transformers in the following ways:

1. A current transformer (CT) operates under conditions close to a short-circuit mode, which is considered its normal operating condition, whereas for power transformers (PTs) this mode is considered an авария (fault/emergency) condition.
2. The primary windings of power transformers can be connected to high-voltage networks even when the secondary winding is open-circuited (no load). In contrast, connecting a current transformer to a high-voltage network with an open (no-load) secondary is considered an emergency condition.
3. In a current transformer, the value of magnetic flux density (induction) in the core is not constant, whereas in a power transformer it remains constant if the supply voltage does not change.
4. In power transformers, the magnetic core flux density operates around a certain nominal value, while in current transformers this value varies around a different operating point.
5. In a current transformer, the secondary current within a certain range does not depend on the load of the secondary circuit and mainly varies according to the primary current. In power transformers, however, the secondary current changes with the load, i.e., it fully depends on the load resistance. In CTs, the primary current is absolutely independent of the secondary circuit mode: the secondary current changes according to the primary current. In PTs, on the contrary, the primary current changes depending on the variation of the secondary current.
6. In current transformers, the load and error are interrelated. The allowable load of a CT may vary depending on different permissible error values.
7. A current transformer is прежде всего a measuring device. As in any transformer, a certain amount of power is transferred through it. However, the main function of a CT is not to transfer power from the primary winding (busbar) to the secondary winding, but to transmit measurement information. Therefore, like all measuring

devices, its main characteristic is accuracy — that is, its ability to convert the primary current into the secondary current with high precision, maintain a constant transformation ratio (sensitivity) under different operating conditions, ensure minimal phase shift of the transformed current, preserve the waveform, and possess satisfactory dynamic characteristics [5].

At present, the demand for alternating current (AC) energy is steadily increasing. This, in turn, is leading to the expansion of fields where large currents are used. The accurate measurement of these large currents (especially in industrial applications) has become one of the most important tasks in electric power engineering and electrical measurement technology. Today, the measurement range of large AC currents at industrial frequency is quite wide, reaching from 10 A to 70 kA. Even higher currents are measured using special measuring devices—intermediate converters for large AC currents. The main function of these converters is to transform a large current value into a secondary physical quantity, which is usually electrical in nature and proportional to the magnitude of the large current. Currently, there are many different types of such converters, available in various forms (Fig. 1). The most widely used type is the current measuring transformer. However, this type of transformer is considered morally outdated and limits the development of modern power systems. Therefore, it is an urgent task to develop new current conversion methods that ensure low measurement error for large AC currents, allow installation and removal without disconnecting the current-carrying conductor, require minimal material resources, are simple to maintain, reliable, contactless, and capable of operating over an ultra-wide range of high currents [4].

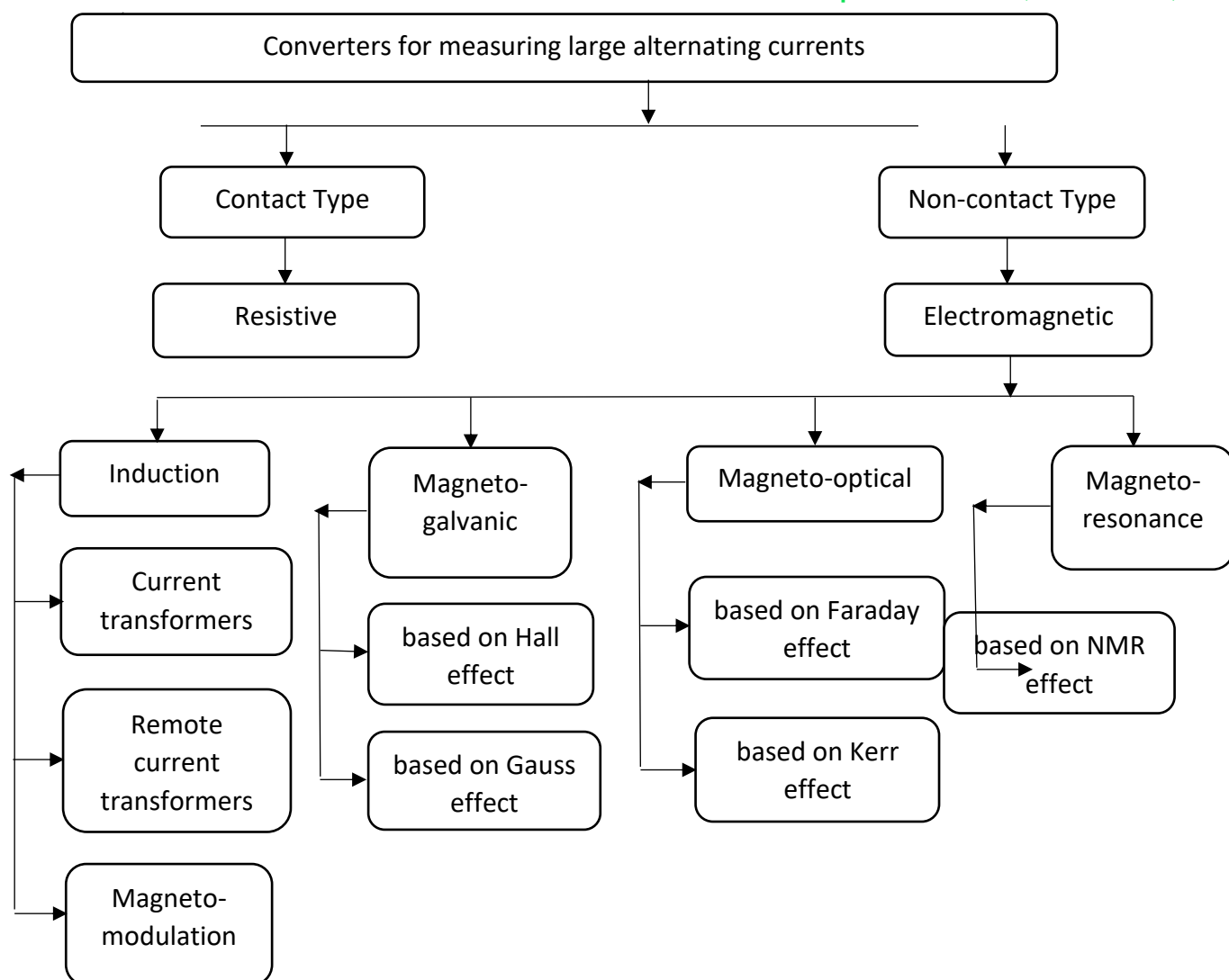


Figure 1. Classification of converters for measuring large alternating currents.

According to the classification, current measuring converters are divided into contact and contactless types [2, pp. 11–47]. Among contact converters, only resistive types are used in practice. Contactless converters include electrometric, electromechanical, autogenerator (quantum), galvanomagnetic, magneto-optical, and inductive types [3].

Magnetomodulation converters are widely used for accurate measurement of large alternating currents. Among them, magnetic comparators provide high accuracy and are used in calibration systems; however, their structure is complex.

The most commonly used are transformer-type converters, which are reliable, simple, and operate across all current ranges. However, their accuracy may be

affected by external factors. Therefore, considering the advantages and disadvantages of both types of converters, their application should be selected based on specific requirements and needs.

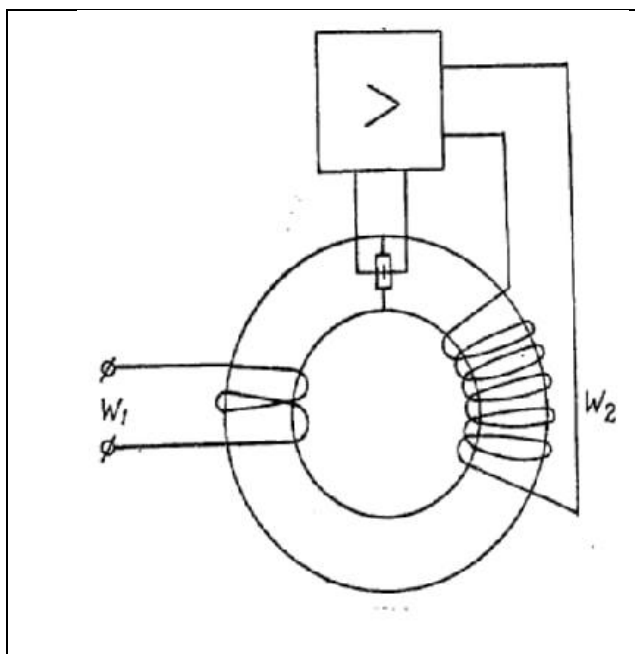


Figure 2. A structural diagram of a current transformer showing the main elements involved in the current transformation process [7].

A current transformer (CT) operates on the following principle. When an alternating current flows through the primary winding (busbar), it creates an alternating magnetic flux in the magnetic core. This flux passes through the turns of the secondary winding and, according to the law of electromagnetic induction, induces an electromotive force (EMF) in it.

Since the secondary winding of a CT is always connected to a low-value load, a current  $I_2$  is generated in the winding under the influence of the induced EMF. The current  $I_2$  produces a magnetic flux  $\Phi_2$  in the core, which is nearly equal in magnitude to the primary flux  $\Phi_1$  but opposite in direction.

As a result, the resultant magnetic flux in the core is the vector sum of  $\Phi_1$  and  $\Phi_2$ , forming a flux  $\Phi_0$ , whose value составляет only a small fraction (about 5–7%) of  $\Phi_1$ . It is this flux  $\Phi_0$  that transfers energy (information) from the primary busbar to the secondary winding during the current transformation process.

For an ideal current transformer (CT), the following equation holds [1, pp. 13–17]:

$$F_1 = -F_2 \text{ or, when } w_1 = 1 \quad I_1 = I_2 w_2 = \frac{I_2}{k}$$

Here,  $F_1$  and  $F_2$  are the magnetomotive forces (MMF) produced in the magnetic core by currents  $I_1$  and  $I_2$  respectively;  $w_1$  and  $w_2$  are the number of turns of the primary (busbar) and secondary windings; and  $k = \frac{1}{w_2}$  is the transformation ratio of the ideal CT.

In electrical measurement technology, particularly in transformer-based measuring bridges, a current comparator device is used. It consists of a magnetic core made of a high-permeability material, two adjustable coil windings arranged in a loop, an indicator winding, and other components. The operating principle of the current comparator is as follows: the indicator winding measures the magnetic flux in the core, while the current in the amplifier compensation winding is controlled to ensure that the magnetic flux in the core is approximately zero [8].

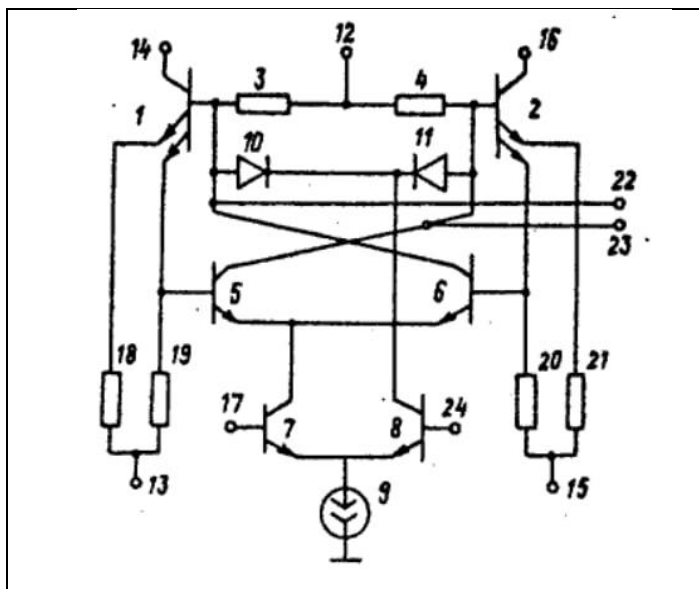


Figure 3. Current comparator:  
 1, 2 – transistors, 18 – 21 – resistors, 13 – 16 – current buses, 24 – control bus, 17, 12 – sliding voltage terminals, 22, 23 – output terminals.

The sensitivity of the comparator is increased by selecting the optimal operating mode for the transistors through their primary emitter circuits. The optimal operating region is determined by the maximum gradient of the base–emitter voltage, which

corresponds to an interval where a small change in current leads to a noticeable change in voltage.

The main drawbacks of current comparators are the complexity of the measurement process and their use in continuous measurements [6]. Therefore, highly accurate and sensitive advanced current comparators are used only for verifying other types of measuring transformers.

Another type of induction converter is the transformer-type converter. It consists of a measuring winding and a movable exciting winding relative to it, and has the following drawbacks:

- the supply voltage phase does not match the output voltage phase;
- the output voltage phase depends on the state of the capacitor;
- the operating current of the exciting winding requires precise adjustment.

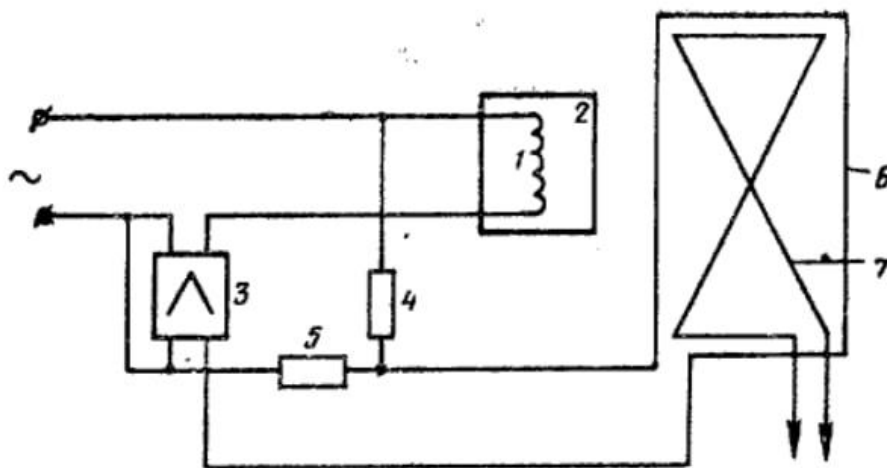


Figure 4. Transformer converters.

A transformer converter consists of the following components:

- Exciting winding (1) — placed on a movable capacitor (2) and supplied with voltage from the power source.
- The exciting winding (1) is connected in series with the output of the amplifier (3).
- At the input of the amplifier (3), the voltage difference is calculated using the voltage from a bridge of resistances (4 and 5) and an additional winding (6). This additional

winding is wound together with the measuring winding (7), so that even when the capacitor moves, the induced voltage remains constant [9].

Ideally, in a transformer converter, the supply voltage and the voltages in windings 6 and 7 are completely in phase. If the resistances (4 and 5) are correctly selected, the voltage at the input and output of the amplifier (3) equals zero. In this case, the movement of the capacitor has no effect, because winding 6 is always encompassed by the same magnetic flux, and a constant voltage is induced.

In practice, however, due to a phase shift between the supply voltage and the voltage in winding 6, a differential voltage appears at the input of the amplifier (3). Since windings 6 and 7 are wound together, their voltages are in phase. This differential voltage is then amplified by the amplifier (3).

Based on the above descriptions and characteristics of current transformers (CTs), it can be concluded that CTs are electromagnetic measuring elements that play a crucial role in traction power supply systems and are evaluated through their static, dynamic, and metrological characteristics. These transformers are mainly used in control systems for current ranges from 25 A to 3000 A. Therefore, to ensure operation at various current levels and achieve versatility, it is appropriate to use wide-range current transformers.

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