A Current Compensated Transformer for Measurement of Large AC Currents in Power Networks

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Keywords: Transformer, AC current, Measurement linearity, Power networks, Magnetic flux, Magnetic field, Power dissipation, Thermal loading.

Abstract. Article presents preliminary results of development and experimental research in the field of measuring large AC currents in industrial applications in fluid power systems and energy networks. It presents the possibility of using current-compensated transformer for measuring purposes and results. The magnetic induction in the ferromagnetic core is in current-compensated transformer is practically zero. The transformer can therefore be designed as a broadband with the possibility to measure the AC current of arbitrary shape, with high short-term overload capacity without affecting the measurement accuracy.

Introduction

Measuring large AC currents in a wide band of frequencies is always a challenging technical problem that can be solved in several standardized ways - and in the current transformer short-circuit wiring, a four-point shunt resistor, Rogowski coil or Hall sensor. Based resin developed its own magnetic workers Electro Technical Laboratory of the Department of Technical Subjects Faculty of Education University of Hradec Kralove special toroidal sensor for measuring large AC currents in order of frequency of 100 kHz [1-3]. Using the knowledge gained during the development and construction of transformer compensators for interference voltage DC power sources [4, 5] for measuring large AC currents of current-compensated transformer is designed with direct measurement of the current passing through without any negative impact on his return waveform.

The standard direct measurements of large currents are directly pointing meters with an electromagnetic measuring device. Usually, however, they produced for currents up to 100 A. Another possibility is to use a four-point shunt resistor. Usually they manufactured with a rated output voltage of 60, 100, 150 and 300 mV for currents up to 15 kA. They are frequency independent, but for the direct measurement of AC currents are not very useful, because they usually are not available sufficiently sensitive measuring instrument. When measuring currents in the order of thousands of amperes resistive shunts have a heat loss of up to several kilowatts. Depending on the installation, then require either a large cooling surface shunt or intense forced cooling.

Indirect measurement of large currents is done usually measuring current transformers with toroidal core, through which lead to the measured current. The advantage is the galvanic isolation of the measured and the measuring circuit. Of ferric core around the conductor, however, it increases the inductance and creates undesirable reactor. This may negatively affect in particular the higher frequency components and form factor. For high frequencies may then constitute an inductive resistance, which can limit the current in the circuit. Coreless type sensor Rogowski coil (coil on glass or plastic collar), Hall sensor and a sensor with a core of magnetic resin [2] are other possibilities for indirect measurement of current.

Their common advantage is the wide frequency band, and their common drawback is the low output voltage, output current, and little if any susceptibility to interference fields in the vicinity of the sensor. Since in these cases it is a shunt transformer \((U_{\text{out}} \sim \text{dI/dt})\) is required for the signal processing
to use the integrating amplifier that eliminates frequency dependence of the sensor output voltage, and converts the signal to a desired voltage or current level suitable for measuring or transmission to a larger distance.

**Measurement of Current with Compensation Transformer**

Current-compensated current transformer is structurally different from the normal type or core type transformer Schell. It can also obtain toroidal core transformers. Like the classical transformer has a current-compensated current transformer on a closed ferromagnetic core wound two working winding. The sensing winding having number of turns $n_1$, through which the measured AC current and the compensating winding turns number $n_2$, which measures the current in the sensing coil. The prototype we developed a compensation transformer still has control winding with the number of turns $n_3$ that are used to check the effectiveness of compensation and detection of magnetization of the core (Figure 1).

![Figure 1. Current-compensated winding transformer.](image)

Measuring AC current $I_1$ flowing through the sensing winding $n_1$ transformer creates a magnetic voltage $F_{m1}$

$$F_{m1} = n_1 I_1$$

which in a closed core magnetic resistance $R_m$

$$R_m = \frac{l_{Fe}}{\mu_0 \mu_r S_{Fe}}$$

Where $l_{Fe}$ is the length of the central power-line and $S_{Fe}$ is clean cross-section of the core, excites magnetic flux $\Phi_1$

$$\frac{\Phi_1}{R_m} = n_1 I_1 \frac{\mu_0 \mu_r S_{Fe}}{l_{Fe}}$$

and magnetic induction $B_1$

$$B_1 = \frac{\Phi_1}{S_{Fe}} = n_1 I_1 \frac{\mu_0 \mu_r}{l_{Fe}}$$

Compensating winding $n_2$ is supplied with power from the regulated source $I_2$, which is dimensionally the same, but opposite phase as the measured current $I_1$. $I_2$ current creates a magnetic voltage $F_{m2}$

$$F_{m2} = -n_2 I_2$$

which in a closed core with magnetic resistance $R_m$ (Eq.2) excited magnetic flux $\Phi_2$

$$\frac{\Phi_2}{R_m} = -n_2 I_2 \frac{\mu_0 \mu_r S_{Fe}}{l_{Fe}}$$

and magnetic induction $B_2$

$$B_2 = \frac{\Phi_2}{S_{Fe}} = -n_2 I_2 \frac{\mu_0 \mu_r}{l_{Fe}}$$
To the resulting magnetic flux $\Phi$ in the transformer core, as the sum of magnetic fluxes $\Phi_1$ and $\Phi_2$ is valid using eq. (3) and eq. (6)

$$\Phi = n_1 I_1 \frac{\mu_0 \mu_r S_{Fe}}{l_{Fe}} - n_2 I_2 \frac{\mu_0 \mu_r S_{Fe}}{l_{Fe}} = \frac{\mu_0 \mu_r S_{Fe}}{l_{Fe}} \cdot (n_1 I_1 - n_2 I_2)$$

and the resulting magnetic induction $B$ is

$$B = \frac{\Phi}{S_{Fe}} = n_1 I_1 \frac{\mu_0 \mu_r}{l_{Fe}} - n_2 I_2 \frac{\mu_0 \mu_r}{l_{Fe}} = \frac{\mu_0 \mu_r}{l_{Fe}} \cdot (n_1 I_1 - n_2 I_2)$$

When applied to the size of the magneto motive tension that

$$|F_{m1}| = |F_{m2}|$$

while their phase shift applies the input assumption that

$$|\phi_{m1} - \phi_{m2}| = \pi$$

the resultant magnetic voltage $F_m$ that gives the core

$$F_m = F_{m1} + F_{m2} = n_1 I_1 - n_2 I_2 = 0$$

and after substituting from equation (13) into equations (9) and (10) will be $\Phi = 0$, $B = 0$ and the voltage in the control winding will be $U_{n3}$ according to Faraday’s law of induction

$$U_{n3} = -n_3 \frac{d\Phi}{dt} = -n_3 S_{Fe} \frac{dB}{dt} = 0$$

From equation (13) can be at a known turns ratio

$$p = \frac{n_2}{n_1}$$

If $U_{m3} = 0$ and the known size of the compensation current $I_2$ determine the size of the measured current $I_1$

$$I_1 = \frac{n_3}{n_1} \cdot I_2 = p \cdot I_2$$

When considering the static inductance of the winding of the measuring transformer according to the general equation (17)

$$L = n \frac{\Phi}{I}$$

they have compensated at magnetic voltages $F_{m1}$ and $F_{m2}$ coil impedance only real resistance and resistive measuring transformer (without considering skin effect at higher frequencies), frequency-independent.

**A Validation Test of Current-Compensated Transformer**

To verify the theoretical assumptions principle of measuring large AC currents of current-compensated transformer was assembled test sample at two columnar core UI 32 × 40 mm. Verification measurement was carried out in connection according to Figure 2.
Compensation current $I_{\text{comp}}$ was through resistor $R$ drawn from the supply current $I_{\text{sum}}$. The measured current flows $I_{\text{meas}}$ winding $n_1$, the voltage in the control winding $n_3$ is used to calculate the residual magnetic induction in the core $B_{\text{res}}$ according to the transformer equation

$$B_{\text{res}} = \frac{10000 \cdot U_3}{4.44 \cdot S_{Fe} \cdot n_3 \cdot f} \quad \text{[mT; mV, cm}^2, \text{-, Hz]}$$

(18)

Results of test measurements are given in the graph of Figure 3. The dependence of the measured current and the compensation is linear over the entire measurement range, the ratio of the two currents were steadily 9.14:1. The residual magnetic induction caused much wider range of dual-colum core does not exceed 80 mT at magnetic voltages $\pm 3$ 400 Az.

Summary

The results achieved validation measurements confirm the linearity of measuring large AC currents using a current-compensated transformer. Given that the magnetic circuit is not transmitted with 100% compensation no power (in contrast to conventional current transformers) are established, the iron losses. This allows the design of a measuring transformer subordinate only to the minimum winding resistance and the necessary cooling surface to dissipate power dissipation (copper losses).

To calculate and design the transformer core thus can be considered with enabled induction of up to 5 T, since according to the type of core and winding structure, the residual magnetic induction in the core should be at least two orders of magnitude lower. Heat losses are at least an order of magnitude smaller than the thermal losses shunt resistor. Current-compensated transformer for measurement of AC currents can be used in industrial and school laboratories, light and heavy rehearsal, as a measuring device in the power industry, or in industrial applications, such as automatic wireless charging system for electric vehicles.
After successful testing personnel of Electro Technical Laboratory of the Department of Technical Subjects Faculty of Education University of Hradec Kralove developed in cooperation with technology department BV Elektronik Holice prototype of current-compensated transformer for measurement of AC currents to 1 500 A in the energy networks of 50 and 60 Hz, while the frequency range of the transformer should be a minimum of 15 to 2 000 Hz. Estimated power loss compensation transformer is about 42 W or about 5 times smaller than a resistive shunt. The principle of current-compensated transformer for measuring large AC currents is protected by a patent application.

Acknowledgement

The article was created with the support of specific research project SV PdF 2127/2016 Analysis of the functionality of current-compensated transformer for measuring large AC currents in power networks.

References


