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Secondary current distortion of inductive current transformer in conditions of dips and interruptions of voltage in the power line

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ABSTRACT

The aim of this paper is to present results explaining the phenomenon of inductive current transformers (CT) additional secondary current distortion in condition of variation of their primary current rms value caused by dips and interruptions of the power line's voltage. To assess its accuracy of current transformation for such transients, harmonics spectrums' of primary and secondary currents are compared. To ensure repeatability of measurement results with the usage of FFT algorithm, regardless of the beginning of the sampling process, the window of 16 fundamental periods consisting 4 dips/interruptions cycles is used. Additional CT's secondary current distortion caused by repeatable transients results in increased error of indirect measurement of rms values of power line's current higher harmonics and additional inaccuracy of power quality estimation.

1. Introduction

In this paper the conditions when inductive CT secondary current waveform does not accurately reflect primary current are discussed. The issue concerns transients like dips and interruptions of the power line's voltage or other conditions when rms value of CT's primary current is changing. Main source of voltage dips in power supply systems are short circuits or changes of load current. Power line's voltage interruptions are typically associated with switchgear operations related to the occurrence and termination of short circuit in the power system or installations connected to it [1]. Rapid changes of current rms value in power line are a result of a fault in the distribution system and actuation of a circuit breaker or a large load being switching in the immediate vicinity. Commonly analyzed problem is steady state accuracy of transformation of inductive instrument transformers for sinusoidal and distorted signals [2–8] due to detection and classification of power quality disturbances, also important are safety of operation and accuracy of transformation during occurrence of dips and interruptions of inductive instrument transformers' primary winding voltage [9–12]. The issue is important not only because of the reliability of the power grid but also due to financial losses caused by disturbances of supply voltage [13]. Since, magnetic flux entropy is used as another technique to assess electric transformer failures and magnetic behaviour of five-legged wound transformer cores. It may be also used to explain the phenomenon of inductive CT additional secondary current distortion in conditions of dips and interruptions of the power line's voltage [14,15].

Standard [16] defines measurement setup, equipment, requirements and other conditions for testing systems to changes in the AC mains voltage. Standard [17] provides requirements for power quality measurement methods and presents general concerns and procedures for implementation of voltage and current transducers to such systems. In order to obtain reproducible results of harmonic emission analysis, when measuring product with fluctuating power and harmonic current levels, the IEC 61000-4-7 standard for harmonic current measuring equipment specifies the use of 10 cycles, when the input frequency is 50 Hz for the window size of FFT [18]. Due to the fact that dip/interruption occurs in every fourth period of current fundamental frequency, 16 cycles for the window size of FFT is used. It was verified that, regardless of the beginning of the sampling process, if an event is analyzed by comparison of registered harmonics spectrums on primary and secondary sides of tested CT, this ensures repeatability of measurement results with the usage of required by standard IEC 61000-4-7 FFT algorithm. Therefore, measuring system with wavelet transform algorithm was not applied,

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as it is not implemented in power quality measuring apparatus [19,20].

2. Object of research

The object of research is CT with toroidal core made from permalloy tape Ni78Fe22 which cross-section area is 0.0005 m^2 and average magnetic flux path in this core is 0.486 m. Its accuracy class is 0.5 and rated load is equal to 0.6 Ω (power factor equal to 1) [21]. Current ratio of tested CT is equal to 5 A/5 A, while turns ratio is equal to 120/120.

In Fig. 1 the following notations are used:

u_1, u_2—primary and secondary voltages, e_1—applied electromotive force, e_2—induced electromotive force, i_1, i_2—primary and secondary currents, R_1, R_2—resistances of primary and secondary windings, X_1, X_2—leakage reactances of primary and secondary windings, R_O—secondary winding load resistance (power factor equal to 1).

In equivalent circuit from Fig. 1 tested inductive CT is assumed to be ideal transformer. Therefore, the magnetization current is equal to 0, than its current ratio error is equal to 0. The rms values of its primary and secondary currents are equal and current ratio is equal to turns ratio. Such simplification is possible only due to the fact that in considered case magnetization current is not a source of CT's inaccuracy of transformation and secondary current distortion. Moreover, in toroidal core leakage reactances of primary and secondary windings are in practice equal to 0. This is due to the fact that the windings are located directly on the CT's magnetic core and distributed evenly across its surface. Therefore, applied electromotive force is equal to induced electromotive force multiplied by inductive CT's turns ratio.

$$\frac{I_1}{I_2} = \frac{n_2}{n_1} = \frac{e_2}{e_1} \quad (1)$$

where, I_1, I_2—rms values of primary and secondary currents, n_1, n_2—number of turns of primary and secondary windings.

In accordance with Kirchhoff's voltage law applied electromotive force is equal to primary voltage reduced by the voltage drop across CTs primary winding resistance.

$$e_1 = u_1 - i_1R_1 \quad (2)$$

Induced electromotive force reduced by the voltage drop across CT's secondary winding resistance determines its secondary voltage.

$$u_2 = e_2 - i_2R_2 = i_2R_O \quad (3)$$

If CT's secondary winding load power factor is equal to 1, secondary voltage is equal to secondary current multiplied by connected resistance.

3. Measuring system

Laboratory studies were made for transient states which occur during interruptions and dips of supply voltage of measuring circuit presented in Fig. 2.

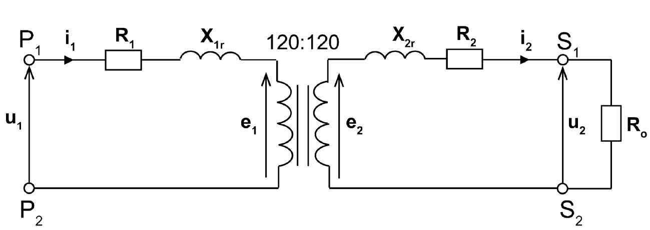

Fig. 1. Equivalent circuit of the system under study.

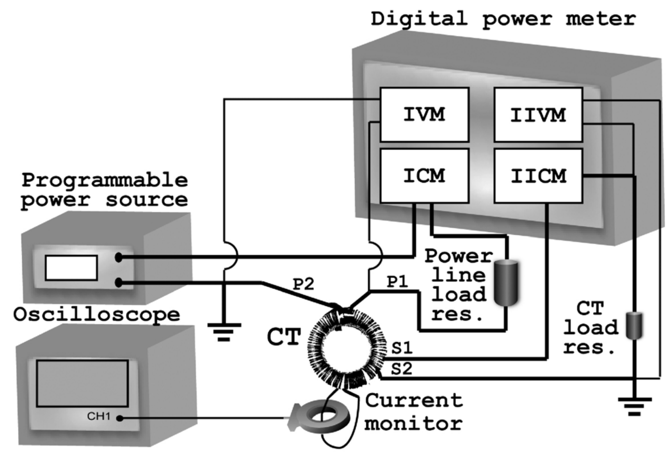

Fig. 2. Block diagram of the measuring system.

Programmable AC source enabled simulation of power line's voltage interruption and dips. A 10 Ω resistor was used to simulate power line's load. To achieve tested CT's rated primary current, rated supply voltage of measuring circuit is equal to 50 V. It was assumed that voltage interruption occurs when supply voltage rms value is reduced to below 90% of rated value, but should not be less than 10% of this value. Voltage dip occurs when the rms value of supply voltage of measuring circuit is not more than 10% of rated value. Voltage that rms value is above 110% of rated voltage in accordance with standard [16] is overvoltage. Laboratory studies consisted of voltages and currents measurements on primary and secondary sides of tested CT to determine their waveforms and harmonics rms values by digital power meter/power quality analyzer. During measurements to tested CT's secondary winding a 0.6 Ω resistor was connected (power factor equal to 1). Additional coil made of 10 turns with shorten terminals is wounded directly on CT toroidal core. It is used to determine the magnetic flux waveform by oscilloscope equipped with current monitor. It is assumed that the magnetic flux in CT's magnetic core is linearly proportional to measured current.

$$\phi(t) = \frac{\mu \cdot a \cdot n \cdot i}{l} \quad (4)$$

where, a—cross-section area of coil (cross-section area of CT magnetic core), n—number of turns, l—average magnetic flux path in the core, i—measured current, μ—initial magnetic permeability of permalloy tape Ni78Fe22 CT toroidal core (40,000 H/m).

4. Results of measurements

Fig. 3 shows voltages and currents waveforms on the primary and secondary sides of tested CT during dips of measuring circuit's supply voltage equal to 30% of its rated rms value.

Analysis of waveforms in Fig. 3 shows that at the time of the dip in measuring circuit's supply voltage there are no additional distortions in tested CT's secondary current. Inaccuracy of primary current transformation occurs if the return of CT's primary winding voltage to its rated value occurs at the time when its waveform is in the minimum. This phenomenon is presented clearly in enlarged part of waveforms in Fig. 4.

Analyzed waveforms were divided into three phases. Stage 1, when waveform of tested CT's primary winding voltage is sinusoidal and increases from 70% of rated value to the nominal voltage. Its secondary voltage also increases to rated value and its waveform is sinusoidal but the magnetic flux is distorted (Fig. 5—stage 1). This is due to the fact that, in accordance with Ampère's law, resultant magnetic flux in inductive CT's magnetic core is equal to magnetic