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Inductive current transformer accuracy of transformation for the PQ measurements

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ABSTRACT

Inductive current transformer made of magnetic cores with high permeability are used for accurate wideband transformation of distorted current required by the power quality (PQ) measurements. However, such solutions are often characterized by not acceptable additional secondary current distortion in condition of variation of primary current rms value. The problem presented in this paper concerns determination and analysis of mutually exclusive magnetic requirements on inductive current transformer accuracy for transformation of current in both mentioned conditions. To show relevant considerations and support drawn conclusions about source of deterioration of inductive current transformers accuracy of transformation simple and effective procedure for designing inductive current transformer is discussed. The usage of the composited axially magnetic core from the magnetic cores made of permalloy and transformer steel ensured acceptable composite error for transformation of a given harmonic of distorted current and high accuracy in condition of variation of primary current rms value. Obtained resultant magnetization curve, regardless the rms value of primary current and its distortion level, provides proper magnetic permeability to prevent decrease of transformation accuracy for distorted current. The novelty of the paper concerns presentation of designing process and requirement that ensure such operation of inductive current transformer not obtainable without usage of the composited axially magnetic core.

1. Introduction

In accordance with the standard IEC 60050-617 power quality (PQ) is characteristic of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters [1–3]. It concerns designation of deviations of voltage and current from the ideal sine wave of rated magnitude and frequency [4]. Therefore, the aim of instrument transformer is to accurately convert, without any additional distortion, directly unmeasurable by PQ measurement instruments, voltage and current to provide a suitable signal for their input channel. In accordance with the standard IEC 61000-4-30, considered parameters are: power frequency, magnitude of the supply voltage, flicker, supply voltage dips and swells, voltage interruptions, transient voltages, supply voltage unbalance, voltage and current harmonics and interharmonics, mains signalling on the supply voltage and rapid voltage changes [2,3,5]. Depending on the purpose of the measurement, all or a subset of the phenomena may be measured. In evolution of the PQ accurate transformation of current is required for measurements of harmonics and variations of customer's load current. The impact of current transformer (CT) on the PQ measurements is tied to technology adopted, its design and manufacturing details [2]. Moreover, the standard IEC 61000-3-12 for a given possible to occur in public low-voltage system level of current total harmonic distortion (THD_I) determines the highest limits for 2nd–13th harmonics [6]. Therefore, for measurements of harmonics accurate transformation of distorted current regardless of the impact of high values of low order harmonics is required [7,8]. Simultaneously, to accurately transform current variations additional inductive CT's secondary current distortion in such condition must be eliminated [9]. The aim of this paper is to provided information about inductive CT's magnetic properties required to ensure accuracy of transformation for the PQ measurements.

Toroidal permalloy cores used in inductive CT have the initial magnetic permeability values from 50 000 to 150 000 and the maximum permeability values from 100 000 to 300 000. Properly high values are required to obtain low current ratio error and phase displacement respectively at low and rated values of primary current.

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Unfortunately, this causes less accurate transformation in condition of variation of primary current rms value or rise of overvoltage. This phenomena is a result of a rapid increase of induced electromotive force in inductive CT' s windings [9]. Permalloy cores are characterized by good thermal stability and low power losses but also low saturation polarization, not higher than 0.8 T [10]. This cause a problem with a decrease of magnetic core's permeability at high rms value of primary current with increase of current distortion level [8]. Derating of inductive CT's secondary winding load prevents increase of current ratio error and phase displacement for main harmonic of distorted current but results in decrease of the instrument security factor (FS) of measuring current transformers [11,12]. To improve inductive CT's transformation accuracy in these conditions its magnetic core is composited axially from two the same size magnetic cores made of permalloy Ni80Fe20 and transformer steel SiFe combined in parallel, so that its cross section is doubled [13]. This provided high saturation polarization and required decrease of resultant magnetic core's maximum permeability with increase of its cross-section that enabled possible reduction of used number of turns in CT's windings.

In the paper inductive CT's designing process is presented. Analysis starts with determination of the required magnetic properties of the core to be used and ends with the final tests of inductive CT's accuracy of transformation for the PQ measurements. Currents waveforms on primary and secondary sides of designed CT are recorded in condition of variation of primary current rms value in order to verify required accuracy of transformation. Current ratio error and phase displacement for main harmonic of distorted current are measured to confirm that resultant magnetization curves of the composited axially magnetic core from the magnetic cores made of permalloy and transformer steel ensured proper magnetic permeability. The composite error is measured for transformation of distorted current and from FFT analysis the rms values of its harmonic components are calculated [7,8,11,12,14]. Corresponding harmonic of measured composite error always indicates the highest possible value of current error/phase displacement for harmonic transformation. Magnetic constraints on accuracy of inductive CT for transformation of distorted current and in condition of variation of primary current rms value are discussed. The reasons that the requirements for each condition are mutually exclusive are addressed. This enables the possibility to more consciously select cross-section and maximum magnetic permeability of used magnetic core in inductive CT.

2. Methodology of measurements

The laboratory studies were made for two wound type inductive CTs with the same low voltage insulation system designed for secondary winding rated active load power of 5 W (power factor 1) with rated transformation ratio 5 A/5 A. CT with the toroidal magnetic core made of Ni80Fe20 tape has rated turns ratio 45\45 and accuracy class 0.2 [12]. Second CT with the toroidal magnetic core composited axially from the magnetic cores made of permalloy and transformer steel has rated turns ratio 15\15 and accuracy class 0.5. Used measuring circuit is presented in Fig. 1.

In Fig. 1 the following notations are use:

IVM/ICM – voltage\current inputs of the first digital power meter module,

ICSM – voltage input of the first digital power meter module designed to connect current probe,

IIVM/IICM – voltage\current inputs of the second digital power meter module,

Comparator – resistive bridge circuit designed for determination of CT, VT transformation accuracy for sinusoidal signals of frequency 50 Hz (60 Hz). Due to the build in low pass filter, for distorted current the main harmonic current error and phase displacement are measured.

CTN – current input for the reference CT in the comparator,

CTX – current input for the tested CT in the comparator,

Load – voltage input for secondary terminals of tested CT in the comparator.

To determine hysteresis loops of tested CTs' magnetic cores in measuring circuit from Fig. 1 load resistor in secondary winding was disconnected. In this condition primary current supplied by programmable power source is equal to magnetizing current of the magnetic core. This current and secondary voltage are measured by the digital power meter. The maximum value of magnetic

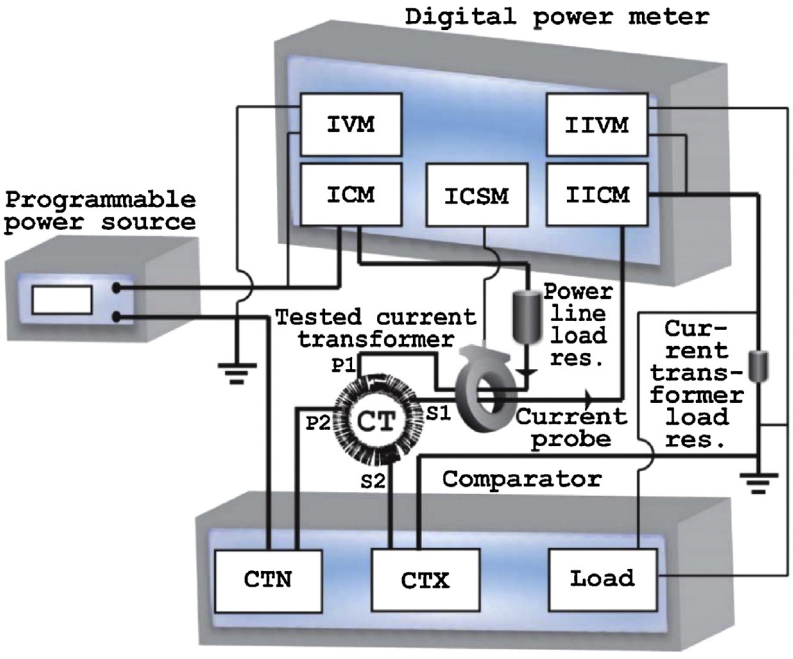

Fig. 1. Block diagram of the measuring system.