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Frequency response and harmonic distortion testing of inductive voltage transformer used for power quality measurements

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Abstract

International standards related to power quality measurements define methods and accuracies for the measuring instruments, but do not specify the accuracy of instrument transformers. Therefore, it is not possible to specify an overall accuracy for such measurements. Inductive voltage transformers (IVTs) which are used for power quality measurements should be tested to determine the ratio correction factors (RCFs) and phase angle errors at higher frequencies. In this paper, harmonic distortion and frequency response tests are performed to determine the level of harmonics generated by IVT and its ability to transform harmonics from high voltage (HV) to low voltage (LV) side. Complex voltages consisting of fundamental voltage and certain amount of superimposed harmonic are used to check the frequency response of IVT. RCFs and phase angle errors of the IVT are determined and can be applied to power quality monitors for compensation of errors that occur at high harmonic frequencies. Different test circuits are proposed for generation of HV consisting of fundamental voltage and harmonic voltages with amplitudes in range 5-15 % of the applied fundamental voltage. In order to improve the testing capabilities at higher voltage levels (for equipment with $123 \text{ kV} \leq U_m \leq 420 \text{ kV}$), a compensation for both fundamental and harmonic voltages is proposed with a special connection through blocking and pass filters.

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Keywords: Inductive voltage transformer; frequency response; harmonic distortion; power quality; high voltage testing.

1. Introduction

Voltage harmonic distortion level is one of the significant parameters of power quality in the power system. Higher harmonics cause the following effects in electrical networks: additional heating and losses on power system elements (such as transmission lines, transformers, compensation devices, etc.), unwanted voltage distortion, increased flow of circulating currents through grounding wire, decrease of transformer rated power and interference with conventional telecommunication lines. Numerous problems related to voltage and current harmonic effects in power systems are commonly observed nowadays due to growth of large industrial consumers with non-linear loads and power electronic equipment [1]. Voltage harmonics may disturb sensitive loads connected to the grid and therefore they should be limited. Levels and spectral content of voltage distortions injected into electric grids are tending to increase even though the acceptable levels are determined by numerous regulations. IEC standards

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[2]-[4] define compatibility levels or planning levels for voltage harmonics in LV, MV and HV networks. Furthermore, European standard [5] defines, describes and specifies the main characteristics of the voltage at a network user's supply terminals in public LV, MV and HV networks under normal operating conditions.

According to [6], power quality and voltage distortion measurements are carried out by high accuracy measuring equipment of class A. In MV and HV grids this measuring equipment is commonly connected to secondary side of IVTs installed within the substations. So, an overall accuracy of the measurement depends on the accuracy of IVTs. The accuracy requirements in [6] are defined only for the measuring equipment but not for IVTs. The standard for IVTs [7] defines the accuracy limits at rated frequency, but it doesn't define the accuracy limits at higher frequencies. The accuracy of IVTs for frequencies higher than the nominal frequency is usually not known. It is therefore difficult to specify an overall accuracy not only for harmonic voltage measurements but also for measurement of any kind of transient containing a wide harmonic spectrum. Literature survey [8]-[17] showed that conventional IVTs may have significant difference between the accuracy at rated frequency and the accuracies at higher frequencies. Therefore, a frequency response of IVTs in the concerned range of frequency should be known to use them for harmonic measurements in power system.

Different measuring setups and calculation procedures for frequency response of IVTs are presented in [18]-[21]. Significant differences between IVT ratio at rated frequency and at higher frequencies can be observed, caused by resonances within the IVT. Also, a little research has been conducted concerning the phase angle characteristics of IVTs operating with non-sinusoidal waveforms. To determine the behaviour of the IVT's ratio and phase angle at higher frequencies two separate tests should be performed: frequency response test and harmonic distortion test. Although different circuit setups for testing the harmonic responses of IVTs are described in literature, only a few of them could achieve the voltage level above 200 kV. Besides, the equipment used in the test circuit setups and test methods are also largely unspecified and differ from each other.

In [22], a test circuit is proposed for determining the harmonic responses of IVTs. The frequency response assessment of a single phase 400 kV IVT and a single phase 275 kV capacitor voltage transformer in a range of frequency from 50 Hz up to 5 kHz is presented. However, at 400 kV level the test circuit has a limitation regarding the harmonic injection ability. The maximum amplitudes of generated voltage harmonics are 1 % with respect to the amplitude of the fundamental voltage up to 1 kHz, while the harmonic amplitudes from 1 kHz up to 5 kHz are lower than 0.2 %. The harmonic injection ability of the test circuit is limited by maximum power capacity of the amplifier which was used as a harmonic power source.

In this paper, three different test circuits are proposed for generation of HV which consists of fundamental voltage and harmonic voltages with amplitudes in range 5-15 % of the applied fundamental voltage. This is of great importance since high signal to noise ratios reduce measurement uncertainty. The selection of appropriate test circuit depends on highest voltage U_m for equipment under test and its required active and reactive power. In order to improve the testing capabilities at voltage levels $123 \text{ kV} \leq U_m \leq 420 \text{ kV}$, a compensation for both fundamental and harmonic voltages is proposed with a special connection through blocking and pass filters. A test method is presented for frequency response and harmonic distortion testing of IVTs used for power quality measurements. Experimental verification is demonstrated in case of medium voltage IVT. RCFs and phase angle errors of the IVT are determined at fundamental frequency and at each harmonic frequency from 2nd to 50th harmonic. These correction factors can be applied to power quality monitors connected to the secondary terminals of the IVT.

2. Test circuits for generation of high voltages containing higher harmonics

2.1. Test circuit with a single source and without compensation

The first test setup shown in Fig. 1 is in most cases suitable for testing of medium voltage equipment. In this test circuit, both fundamental and harmonic voltages are generated from the same source which consists of arbitrary waveform generator (AWG), low frequency amplifier and test transformer. In this case a single source is generating both active and reactive power required by test object and capacitor voltage divider which is used as a reference measuring system.

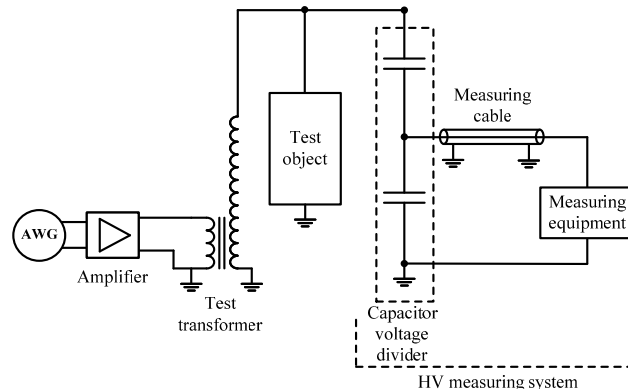


Fig. 1. Test circuit with single source without compensation.

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