A Virtual Instrument for Harmonic Characterization of Instrument Transformers

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A virtual instrument that can be used for performance measurements of Instrument Transformers (IT) under harmonic excitation is developed. Experimental results are shown to validate the proposed method.

Keywords: network harmonics, instrument transformers, virtual instrument

1. Introduction

The performances of instrument transformers are specified in Standards such as IEC 60185 and IEC 60186. These specifications seek conformance of ratio (RE) and phase errors (PE) at various values of primary excitation and burdens. Typically, the performance is sought at a single frequency, viz, the power frequency. With the proliferation of networks that contain significant voltage and current harmonics it would be instructive to analyze the performance of the ITs with non-sinusoidal excitation and to measure the errors.

2. A Virtual Instrument for the Performance Analysis of ITs

Conventional transformer bridges [(1)(2)] evaluate the performance of an IT (Current Transformer (CT) or Voltage Transformer (VT)) at a single frequency. We propose an extension of this instrument to characterize the performance at harmonic excitations. A virtual instrument for evaluating the errors of an IT is designed on the following basis: The comparison method [(3)] is the principle of error measurement. It involves the comparison of the test transformer with a standard transformer of the same ratio. The schematic of the setup for the Comparison method is shown in Fig. 1 for the case of error measurement of CTs. A similar arrangement can also be made for VTs but is not shown. For VTs the expressions are the same, one has to only replace current (I) by voltage (V). The primaries of the test current transformer X and the standard current transformer S are connected in series, so that the same current flows through them.

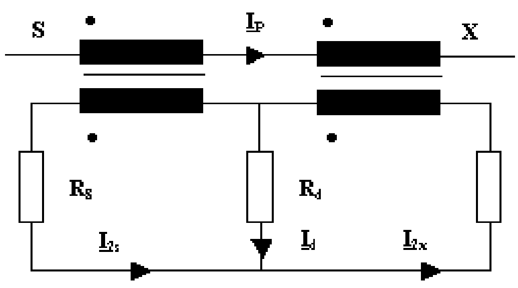

Fig. 1. The comparison method of testing a CT

The secondaries are so connected that the difference between the current in the secondary of S, $\underline{I}_{2S}$ and that of X, $\underline{I}_{2X}$ flows through a standard resistance, R_d. The input section of the test setup has isolating transformers to help to derive voltages proportional to $\underline{I}_{2S}$ and $\underline{I}_d$ and compatible with the Data Acquisition System (DAS). A 12-bit Data Acquisition Card—(PCI 6024 E) from National Instruments [(4)] forms the heart of the Data Acquisition System. The two channels are simultaneously sampled at 10 kHz, which is sufficient for a system with about 40 harmonics of a 50 Hz power frequency. If I_{2sj} and I_{dj} represent the acquired samples of $\underline{I}_{2S}$ and $\underline{I}_d$ respectively, then sampling based methods are used to evaluate the errors of the CT as follows [(3)].

$$\%RE = \frac{\sum_{j=0}^{N-1} I_{2sj} I_{dj}}{\sum_{j=0}^{N-1} I_{2sj} I_{2sj}} \times 100 \quad (1)$$

$$PE = \frac{\sum_{j=0}^{N-1} I_{2s(j+N/4)} I_{dj}}{\sum_{j=0}^{N-1} I_{2sj} I_{2sj}} \times 3438\,\text{min} \quad (2)$$

This method is being extended to the case with harmonic excitation. Here we consider that

$$I_p = \sum_{i=0}^{N-1} A_i \left(\sin\left(\omega_i t + \phi_i\right)\right) \quad (3)$$

$$I_{2s} = \sum_{i=0}^{N-1} a_i \cos\left(\omega_i t + \phi_j\right) \quad (4)$$

where I_p is the primary current and I_{2s} is the secondary current of the standard CT. We use a Fourier based method to

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define and measure errors of ITs. It can be seen that the conventional methods of error measurement Ref. (1) and (2) are special cases of the generalized method proposed here. For example, if the fundamental and first two odd harmonics are known to exist, a Low Pass Filter (LPF) and two Band Pass Filters (BPF) are used to extract the fundamental, third and fifth harmonics. The LPF cut-off frequency is just above the fundamental frequency whereas the BPFs are centered at each harmonic. These filters are implemented digitally in the virtual instrument.

The error components of the individual harmonics (i^{th} harmonic) are evaluated using Eqs. (5) and (6).

$$\%RE|\omega_i = \frac{\sum_{j=0}^{N-1} I_{2sj} I_{dj}}{\sum_{j=0}^{N-1} I_{2sj} I_{2sj}} \times 100 \cdots\cdots (5)$$

$$PE|\omega_i = \frac{\sum_{j=0}^{N-1} I_{2s(j+N/4)} I_{dj}}{\sum_{j=0}^{N-1} I_{2sj} I_{2sj}} \times 3438 \text{ min} \cdots\cdots (6)$$

One problem with the measurement of errors of each frequency is the possibility of interharmonics, especially if the core goes into saturation. In order to check for this condition, the composite error is also evaluated as given in Eq. (7).

$$CE = \frac{\sqrt{\sum_{j=0}^{N-1} {I_{dj}}^2}}{\sqrt{\sum_{j=0}^{N-1} {I_{2sj}}^2}} \cdots\cdots (7)$$

If the composite error exceeds the vector error, ie if

$$CE > 1.05 \times \sqrt{(RE)^2 + (PE)^2},$$

the CT is in saturation. The value 1.05 is a conservative value based on the standard definition of composite error exceeding 10% to be indicative of saturation. One of the advantages of this instrument is that even at a single frequency excitation, the composite error will also be measured and displayed. Existing instruments do not have this feature, which makes it difficult to judge if the CT is saturated. Using the ratio and phase errors of the fundamental component, the core would then become non-linear and interharmonics are likely to occur.

3. Experimental Results

A CT is designed with core of size 90 mm × 60 mm × 15 mm of PERMAX from Vacuumschmelze. It has 100 turns in the primary and secondary. An Arbitrary Function Generator Model 33120 A from Hewlett Packard is programmed to give an excitation of the form given below.

$$I_1 \sin(2\pi 50t) + 0.33 I_1 \sin(2\pi 150t) + 0.2 I_1 \sin(2\pi 250t)$$

(These are the first three harmonics of a square wave with I_1 as the fundamental). The errors of the CT under harmonic excitation are measured using the proposed virtual instrument. Table 1 shows the ratio and phase errors for each frequency at different percentages of full primary current rating with a burden of 4.5 Ω. It is to be noted that such a measurement would be useful when the maximum value of each harmonic is known apriori. This would enable one to fix the maximum value of each harmonic current to 100%.

Table 1. Errors of CT with harmonic excitation

% I_{2S}	%RE			PE (min)			%CE
	50Hz	150Hz	250Hz	50Hz	150Hz	250Hz	
20	-1.09	-0.40	-0.29	50.97	42.71	39.10	2.11
50	-0.83	-0.38	-0.25	38.53	30.63	27.59	1.42
80	-0.69	-0.35	-0.19	32.49	22.40	19.34	1.15
90	-0.67	-0.33	-0.18	30.81	20.78	17.57	1.09
100	-0.65	-0.31	-0.17	29.92	19.53	16.25	1.06

4. Conclusion

A convenient virtual instrument has been developed that serves the functions of measuring errors at harmonic frequencies. Experimental results show the utility of the proposed scheme.

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References

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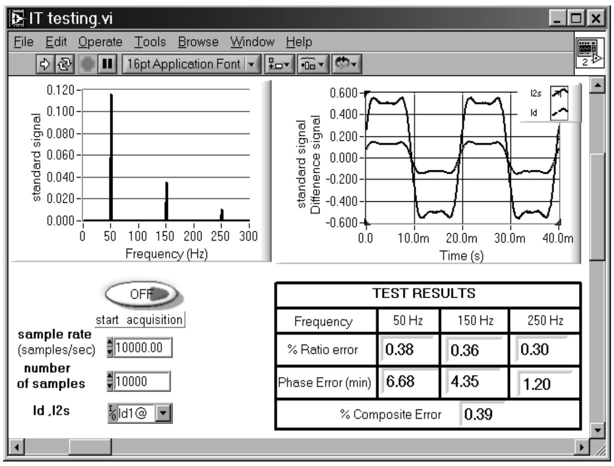
Appendix

The front panel of the developed instrument is shown in app. Fig. 1. It has three sections. The top right portion shows the time domain signal of I_d & I_{2s}. The top left portion shows the frequency domain components of I_{2s}. The parameters that can be set are sampling rate and number of samples. A tabular column in the lower right shows the errors.



app. Fig. 1. Virtual Instrument front panel